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DESENVOLVIMENTO DE UM VEÍCULO INOVADOR PARA ARMAZÉNS AUTOMÁTICOS

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DEVELOPMENT OF AN INNOVATIVE SHUTTLE VEHICLE FOR AUTOMATED STORAGE AND RETRIEVAL SYSTEMS

João Augusto da Silva Fernandes

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ISEP – School of Engineering, Polytechnic of Porto
Department of Mechanical Engineering

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KEYWORDS

Automated Storage and Retrieval System, Shuttle Vehicle, Boxes

ABSTRACT

Intralogistics is increasingly a matter of research and development as a form of optimization, automation, integration and management of the flow of materials and information that circulate within a business unit. With a strong connection to material handling equipment and automation solutions, intralogistics has proved to be one of the main factors responsible for something that is already happening: a fourth industrial revolution where it is possible to convert warehouses and manufacturing units into intelligent environments where the entire process can be controlled and supervised through a single system.

It became necessary to develop more and more innovative and efficient solutions to the constant diversity of challenges proposed by the market. In this sense, it was proposed to develop something innovative within the area of Automated Storage and Retrieval Systems (AS/RS), a technology increasingly sought after by today's manufacturing plants. As such, the goal was to improve the most emergent AS/RS in recent years: the Pallet/Box Shuttle AS/RS.

In order to achieve the proposed objective, it was necessary to analyze all the existing solutions in the market and, principally, to find the main points to be improved and the direction to follow in order to innovate an already advanced solution.

The results show a robotized solution where it was possible to increase the automation of the operations in the storage systems and improve the responsiveness of the system, taking this solution to a new level.

PALAVRAS CHAVE

Armazéns Automáticos, Veículo Satélite, Caixas

RESUMO

A intralogística é cada vez mais uma área de investigação e desenvolvimento como uma forma de otimização, automação, integração e gestão do fluxo de materiais e informações que circulam dentro de uma unidade de negócios. Com uma forte ligação com equipamentos de manipulação de materiais e soluções de automação, a intralogística provou ser um dos principais fatores responsáveis por algo que já está a acontecer: uma quarta revolução industrial, onde é possível converter armazéns e unidades fabris em ambientes inteligentes, onde todo o processo pode ser controlado e supervisionado através de um único sistema.

Tornou-se necessário desenvolver soluções cada vez mais inovadoras e eficientes para a constante diversidade de desafios propostos pelo mercado. Nesse sentido, propôs-se desenvolver algo inovador dentro da área dos Armazéns Automáticos, uma solução cada vez mais procurada pelas unidades fabris de hoje. Como tal, estabeleceu-se o objetivo de melhorar o tipo de Armazém Automático mais emergente dos últimos anos: o Armazém Automático com Veículos Satélite para Caixas ou Paletes.

Para alcançar o objetivo proposto, foi necessário analisar todas as soluções existentes no mercado e, principalmente, encontrar os principais pontos a serem aprimorados e definir a direção a seguir para se inovar uma solução já avançada.

Os resultados obtidos apresentam uma solução robotizada onde foi possível aumentar a automatização das operações dos sistemas de armazenamento e melhorar a capacidade de resposta do sistema, levando esta solução para um novo patamar.

LIST OF SYMBOLS AND ABBREVIATIONS

List of Abbreviations

2D	Two Dimensions
3D	Three Dimensions
AC	Alternating Current
AGV	Automated Guided Vehicle
AS/RS	Automated Storage and Retrieval System
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CE	*Conformité Européene*
DC	Direct Current
DCS	Distributed Control Systems
DIN	*Deutsches Institut für Normung*
EN	European
EU	European Union
FEA	Finite Element Analysis
FEM	*Fédération Européene de la Manutention*
FEUP	*Faculdade de Engenharia da Universidade do Porto*
ICS	Industrial Control Systems
IEC	International Electrotechnical Commission
I/O	Input/Output
ISEP	*Instituto Superior de Engenharia do Porto*
ISO	International Organization for Standardization
LED	Light Emitting Diode
N/A	Not Applicable
OEM	Original Equipment Manufacturer
OMV	Overhead Monorail Vehicle
PLC	Programmable Logic Controllers
PU	Polyurethane
PVC	Polyvinyl Chloride
RGV	Rail Guided Vehicle
RSS	Rack-Supported Structure
SCADA	Supervisory Control and Data Acquisition
S/R	Storage and Retrieval
SWOT	Strengths, Weaknesses, Opportunities and Threats
VDI	*Verein Deutscher Ingenieure*
US	United States
WBS	Work Breakdown Structure
WMS	Warehouse Management System

List of Units

bar	Unit of Pressure
ºC	Degree Celsius
GPa	Giga Pascal
h	Hour
kg	Kilogram
kgf	Kilograms Force
kN	Kilonewton
kW	Kilowatt
MPa	Mega Pascal
m	Meter
mm	Milimeter
N	Newton
rad	Radian
rpm	Rotations Per Minute
s	Second
un	Unit
V	Volt
W	Watt

List of Symbols

%	Percentage
α	Angular Acceleration
$\Delta\varphi_{total}$	Total Stroke of the Retractable Finger
$\Delta\varphi_{2}$	Stroke of the Retractable Finger in Section 2
η_{chain}	Chain Efficiency
η_{load}	Load Efficiency
η_{total}	Total Efficiency
μ_{L}	Coefficient of Friction of Bearings
μ_{stat}	Static Coefficient of Friction
ν	Stability Factor
ω_{max}	Maximum Angular Speed
$\sigma_{Von\ Mises,max}$	Maximum Von Mises Stress
σ_{Yield}	Yield Strength
a_{brake}	Brake Acceleration
a_{t1}	Linear Acceleration in Section 1
a_{t3}	Linear Acceleration in Section 3
$a_{travelling}$	Vehicle Acceleration
B	Hub Width
C	Tollok Application Type Factor
C_{1}	Brauer® Factor for the Continuous Running Condition

C_2	Brauer® Factor for the Surface Speed 10-16 km/h Condition
C_3	Brauer® Factor for the Driving Wheels Condition
d_{axle}	Diameter of the Wheels Axle
dg	Fixing Bolts Diameter
DM	Hub Diameter
D_P	Pitch Diameter
d_{TLK}	Locking Assembly Internal Diameter
D_{TLK}	Locking Assembly External Diameter
D_{wheel}	Diameter of the Wheels
e	Retractable Finger Eccentric Distance
E	Young's Modulus
f5	Iwis Lubrication Factor
f	Lever Arm of Rolling Friction
F_{drive}	Driving Force
$F_{friction}$	Friction Force
$F_{friction\ total}$	Total Friction Force
$F_{guiding\ wheel}$	Force on the Guiding Wheel
$F_{inertia}$	Vehicle Inertia Force
f_B	Service Factor
f_M	Mass Acceleration Factor
$F_{rolling}$	Rolling Resistance to Motion Force
F_{tang}	Chain Tangential Pulling Force
$F_{trav\ wheel}$	Force on the Travelling Wheel
F_y	Y-axis Forces
G	Gravitational Acceleration
I_{robot}	Inertia of the Robot
i_v	Gear Ration between Sprockets
$i_{gear\ unit}$	Gear Unit Ratio (calculated)
$I_{vehicle}$	Inertia of the Vehicle
J_{Mot}	Mass Moment of Inertia of the Motor
J_X	External Mass Moment of Inertia
K	Tollok Coefficient K
l	Fixing Bolts Center Distance
L1	Locking Assembly Thickness
M_a	Gearmotor Rated Output Torque
$M_{a,max}$	Gearmotor Maximum Output Torque
$M_{A,stat}$	Moments on Point A
M_{Brake}	Brake Rated Torque
$M_{dynamic}$	Dynamic Driving Torque
m_{finger}	Retractable Finger Mass
M_H	Acceleration Torque

M_L	Load Torque
m_{load}	Boxes Mass
M_N	Motor Rated Torque
M_{RMS}	Root Mean Square Torque
m_{robot}	Robot Mass
M_{stat}	Static Driving Torque
$M_{stat+dyn}$	Maximum Gearmotor Output Torque during operation
M_{t1}	Torsional Torque in Section 1
M_{t2}	Torsional Torque in Section 2
M_{t3}	Torsional Torque in Section 3
$M_{t\_sprocket}$	Maximum Torsional Torque per Driving Sprockets
Mt_{TLK}	Transmissible Torque by One Locking Assembly
Mt_{2TLK}	Transmissible Torque by Two Locking Assembly
m_{total}	Vehicle Total Mass
m_{vehcle}	Vehicle Mass
N	Normal Force
n_a	Gearmotor Output Speed
n_{max}	Maximum Rotation Speed
n_N	Rated Motor Speed
Pa	Fixing Bolts Total Tightening Force
$P_{dynamic}$	Dynamic Power
P_{max}	Maximum Load Supported by the Wheel
$P_{max\ corr}$	Maximum Load Supported by the Wheel (corrected)
pn	Locking Assembly Surface Pressure on Hub
P_N	Motor Rated Power
P_{robot}	Weight of the Robot
P_{static}	Static Power
Pt	Locking Assembly Pre-Load Force
Pv	Fixing Bolts Tightening Force
$P_{vehicle}$	Weight of the Vehicle
R1	Reaction in the First Support
R2	Reaction in the Second Support
r	Distance between the Two Support Points
$R_{A,dyn}$	Dynamic Reaction Force on Point A
$R_{A,stat}$	Static Reaction Force on Point A
$R_{B,dyn}$	Dynamic Reaction Force on Point B
$R_{B,stat}$	Static Reaction Force on Point B
Rm	Tensile Strength
R_{stat}	Static Reaction Force of the Vehicle
$R_{stat,min}$	Minimum Static Reaction Force between the Two Support Points
Sf	Flange Thickness

SF	Safety Factor
$t_{\varphi total}$	Time for Total Stroke of the Retractable Finger
t_1	Cycle Time in Section 1
t_2	Cycle Time in Section 2
t_3	Cycle Time in Section 3
t_a	Acceleration Time
$t_{a,brake}$	Brake Deceleration Time
t_{cycle}	Total Cycle Time
$t_{stopped}$	Stopped Time in each Cycle
$v_{travelling}$	Vehicle Speed
Y	Iwis Shock Factor

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INTRODUCTION

1 INTRODUCTION

1.1 OVERVIEW

Today, intralogistics has played an increasingly important role in the industrial world as a vehicle for optimizing processes, automating operations, and facilitating the flow of information and materials within business units. It is a process that seeks to design specific and highly complex technological solutions for the integration and management of the flow of information and material from warehouses, manufacturing units or distribution centers.

Covering diverse areas of knowledge, such as project management, mechanical engineering, electrical engineering or software engineering, intralogistics enables to increase resource productivity and reduce operational costs by properly controlling and processing the flow of information, and efficiently move materials and warehouse products through sophisticated material handling equipment.

Through material handling equipment, intralogistics serves the warehouses in diverse operations from the receiving of the product until it is properly ready to be delivered to the customer. However, it is in the storage operation that intralogistics produces a special impact on warehouses through Automated Storage and Retrieval Systems (AS/RS), a solution increasingly developed in warehouses around the world.

AS/RS are storage systems that perform the storage and retrieval operations of the products, usually pallets or boxes in rack structures, automatically through machines specifically developed for this purpose. These machines are called Storage/Retrieval machines and can be stacker cranes, mini loads or satellite vehicles, depending on the type of AS/RS.

The Pallet/Box Shuttle AS/RS is one of the newly developed AS/RS types, and the most emergent in the past few years. An innovative solution that has as principle of operation the storage of boxes or pallets through several vehicles that move inside the rack structure, carrying out the whole operation automatically.

The present work was based on the principle of operation of the Box Shuttle AS/RS, in other words, its Storage/Retrieval Machine: the Shuttle Vehicle.

1.2 MAIN GOALS

The main objective of this work was to innovate the shuttle vehicle for the Box Shuttle AS/RS, in other words, take an existing solution and develop something different to what already exists on the market, taking this type of AS/RS to a new level.

In addition to the main objective, the following objectives were established:

1) Develop a shuttle vehicle capable of handling boxes with mass and defined dimensions;
2) Mechanically design a travelling system incorporated in the shuttle vehicle capable of moving it along the rack structure automatically and accurately;
3) Mechanically design an extraction system incorporated in the shuttle vehicle capable of extracting and placing the boxes in the rack structure automatically and accurately;
4) Mechanically design a picking system incorporated in the shuttle vehicle that allows to carry out the picking operations directly on the rack structure automatically and accurately;
5) Develop the parts and systems of the shuttle vehicle, ensuring easy assembly and removal, and minimizing the risk of accidents;
6) Define the sensors and electrical components to be applied in the shuttle vehicle to automate it and provide the necessary safety for its operation;
7) Study the operation of the shuttle vehicle when inserted in a rack structure;
8) Produce the necessary technical documentation to manufacture the shuttle vehicle.

1.3 METHODOLOGY

The methodology adopted to achieve the proposed objectives was the following:

1) Define concretely what problem is the basis of this work;
2) Analyze the main solutions in the market in order to obtain the strengths and weaknesses of each one;
3) Define how to improve existing weaknesses, and especially how to innovate the shuttle vehicle;
4) Define the main requirements to be considered for the development of the equipment;
5) Make initial sketches of previous ideas for mechanical design, for communication and validation of preliminary decisions;
6) Begin by designing the main structure of the shuttle vehicle;
7) Mechanically develop the shuttle vehicle travelling system with incorporation in the main structure, validating the critical parts with adequate calculations;
8) Mechanically develop the extraction system of the shuttle vehicle with incorporation in the main structure, validating the critical parts with adequate calculations;
9) Mechanically develop the picking system of the shuttle vehicle with incorporation in the main structure, validating the critical parts with adequate calculations;
10) Select the electrical equipment to be applied in the shuttle vehicle;
11) Design covers and transport points;

12) Study the interfaces of the shuttle vehicle with a hypothetical system with a rack structure;
13) List the technical specifications of the equipment developed;
14) Produce the detail drawings needed to fabricate the parts and assemble all the equipment.

1.4 THESIS' STRUCTURE

The present work, entitled "Development of an Innovative Shuttle Vehicle for Automated Storage and Retrieval Systems", is divided into four main sections.

The first section corresponds to the introduction, where it is intended to integrate the reader into the theme of this work, present the proposed objectives and define the methodology to achieve these objectives.

The second section is the background and corresponds to an intensive work of collecting theoretical information necessary to understand the development of the dissertation. It is subdivided into four sections: the role of logistics in supply chain management, AS/RS and all of its components, the mechanical design process of a machine, and the most relevant standards for mechanical equipment.

The third section corresponds to the thesis development, where it starts by describing the problem to be solved, presenting the benchmarking, and establishing the definition of the product with the requirements for its development. Then the whole mechanical design is presented, this being the main section of the work, from the initial sketches, through the design and calculations of each shuttle vehicle system, to the detailed drawings.

The fourth section corresponds to the conclusions and proposal of future works, describing what objectives have been achieved, what are the main limitations of the equipment developed and what works can be done in the future from this one.

1.5 TUTORING COMPANY

Consoveyo, S.A. (Figure 1) is a company specialized in automated material handling and storage systems. It is a business partner responsible for designing and building turnkey solutions for customers' intralogistics applications, by integrating all the systems involved.

This company was created in 1984 within one of the divisions of the group Efacec with the name *Automação e Robótica*. In 2015, it was acquired by the Körber group, a technology group with a strong market position, present worldwide and represented by around 12000 employees. Since then, Consoveyo, S.A. is an integral part of the Logistics

Systems Business Area of the Körber group and has officially changed its name in 2017 [1].

Figure 1 - Company logo Consoveyo, S.A [1].

BACKGROUND

2 BACKGROUND

2.1 LOGISTICS IN SUPPLY CHAIN MANAGEMENT

Nowadays, products and services are delivered to the market every minute around the world. Behind this pace of demand and supply are millions of operations and activities between organizations that happen simultaneously so that every product and service is delivered on time. To achieve this, there must be maximum optimization of the flow of materials and information across all businesses, where high cadences and responsiveness are prime conditions to follow the evolution of the market.

The set of all parts involved in the actions necessary to put a product in the market from design to delivery to the customer is known as supply chain. Like Michael Hugos has said in his book Essentials of Supply Chain Management: “Supply chains refer to networks of companies that work together and coordinate their actions to deliver a product to market” [2].

To achieve maximum optimization of a supply chain there is another concept called supply chain management. This term appeared to define and classify the attitudes that are taken to improve the results of the supply chain. According to Michael Hugos in his book Essentials of Supply Chain Management: “Supply chain management is the coordination of production, inventory, location, and transportation among the participants in a supply chain to achieve the best mix of responsiveness and efficiency for the market being served” [2].

Sometimes the concept of supply chain management is confused with the concept of logistics. The difference is that the first one deals with suppliers, the organization itself, and customers as an individual association, networking all of them (Figure 2). The second one manages the actions and activities of a single organization, creating a single strategy for the flow of product and information through a business. For this reason, supply chain management is much more encompassing than logistics (Figure 3) [2],[3],[4].

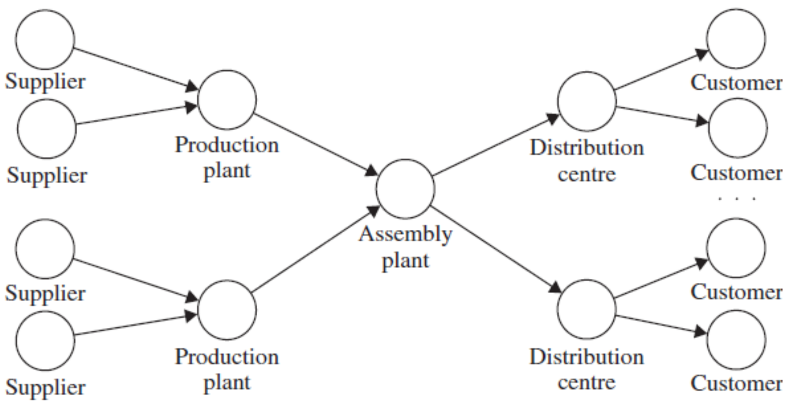


Figure 2 - The idea of a network of suppliers and customers in a supply chain [3].

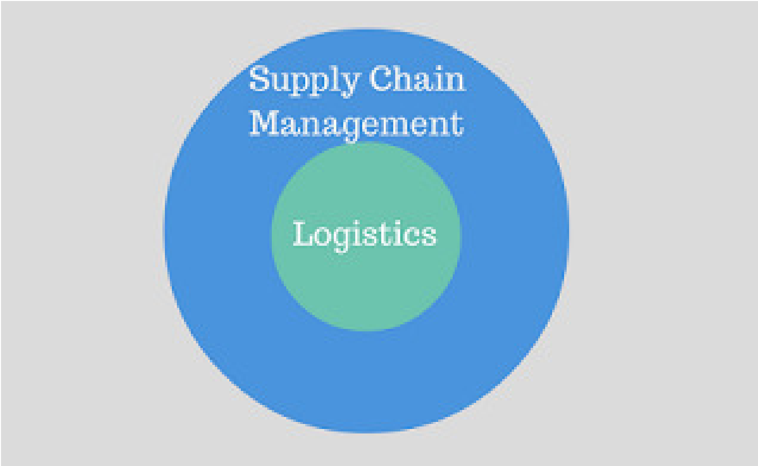


Figure 3 - Supply Chain Management is more encompassing than Logistics [4].

A definition of logistics was told by D. Bowersox, D. Closs and M. Cooper in their book Supply Chain Logistics Management: "Logistics is the process that creates value by timing and positioning inventory; it is the combination of a firm's order management, inventory, transportation, warehousing, materials handling, and packaging as integrated throughout a facility network". In other words, logistics networks five major areas of a company are: customer service, purchasing, production planning, warehouse, and transport (Figure 4) [4],[5].

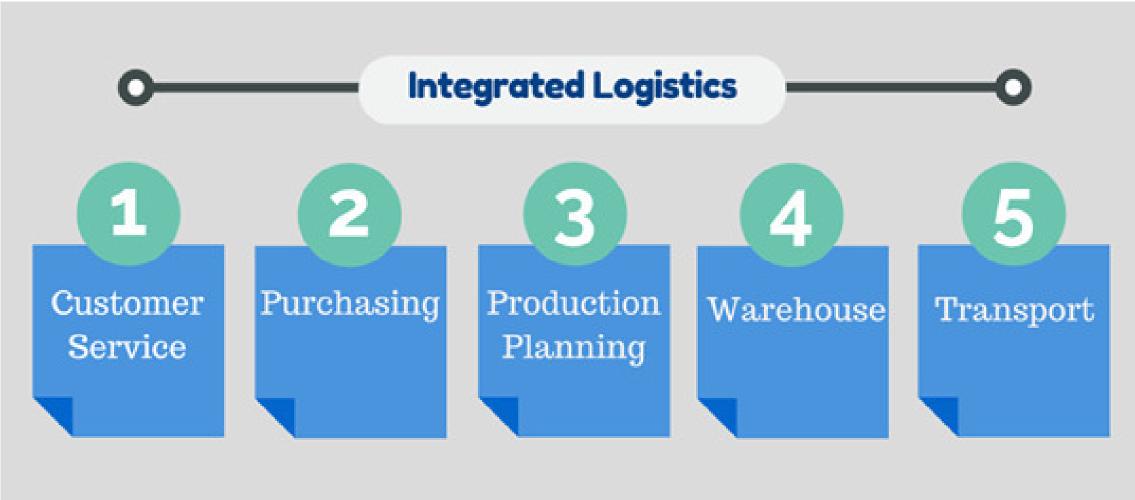


Figure 4 - Company's areas managed by logistics [4].

The present work focuses on the subjects warehousing, materials handling and packaging. From the perspective of logistics and supply chain management, these issues are usually managed by suppliers of intralogistics solutions and Systems Integrators, topics that are described in the next sections.

2.1.1 INTRALOGISTICS AND WAREHOUSE OPERATIONS

The term intralogistics is relatively recent and has been increasingly used with the evolution of logistics in recent years. However, there is still no official meaning in the dictionary, and the existing definitions are those that are presented by companies dedicated to this type of business. So, what is intralogistics?

Many people relate the term intralogistics only to material handling technology, however there is much more to know about the subject. Intralogistics is the process of optimizing, automating, integrating and managing the flow of materials and information that circulates within a business unit and sometimes within a supply chain. It can be found within warehouses, manufacturing units, and distribution centers, but it is so specific that solutions are designed exclusively for each company (Figure 5). It is impossible to copy a system implemented in a single company, apply it to another and obtain the same results. In addition, it requires high knowledge in several subjects and very specific technical skills in the following areas [6],[7],[8]:

1) Project Management;
2) Industrial, Mechanical, Electrical and Software Engineering;
3) Systems Design, Integration, and Implementation;
4) Remote Monitoring and Technical Support.

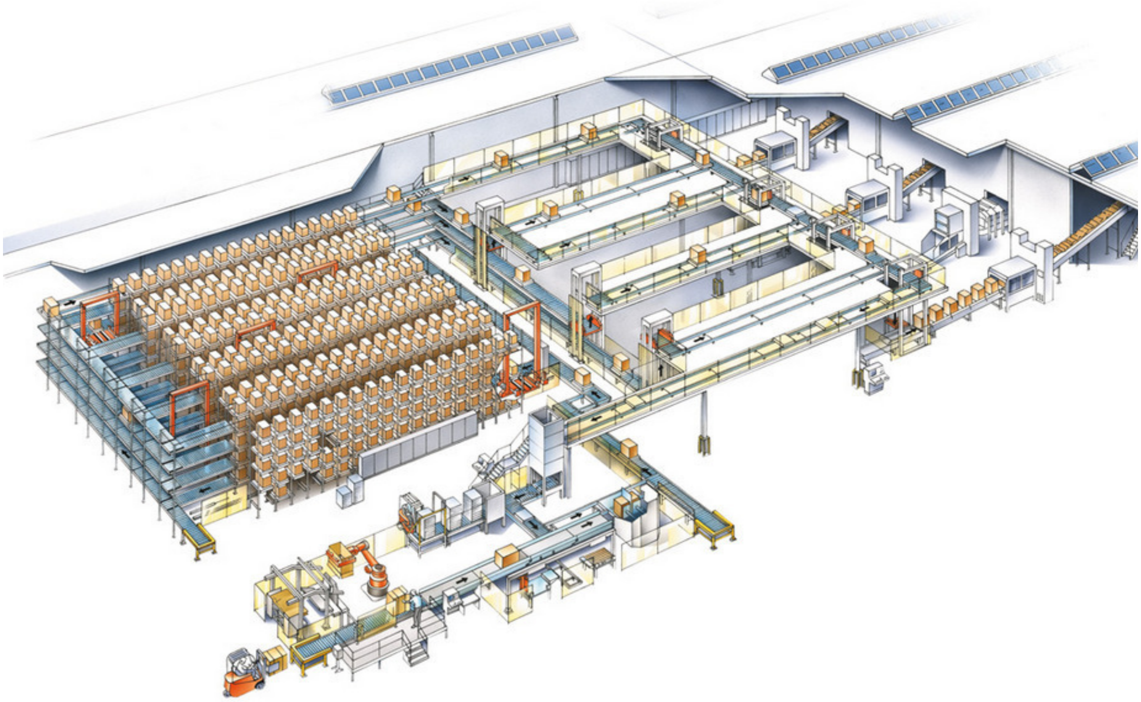


Figure 5 - Example of an Intralogistics System [8].

Building on very sophisticated databases and warehouse management software, intralogistics enables increased resource productivity while reducing operational costs through control and processing of information along with a variety of material handling technologies. But more important than all this, intralogistics increases the competitiveness of companies [6].

Using advanced material handling equipment, intralogistics serves warehouses in various operations. A warehouse reorganizes and repackages product, passing it through a series of operations until it is effectively ready to be delivered to the customer. Generally, the material flow is composed by a single sequence of steps from receipt of bulk shipments to final delivery of products to the customer. Those steps are divided into two major groups (Figure 6) [9]:

1) Inbound Processes (happen from the suppliers to the storage locations):
    a. Receiving;
    b. Put-away.
2) Outbound Processes (happen from the storage locations to the customers site):
    a. Order-picking;
    b. Packing and Shipping

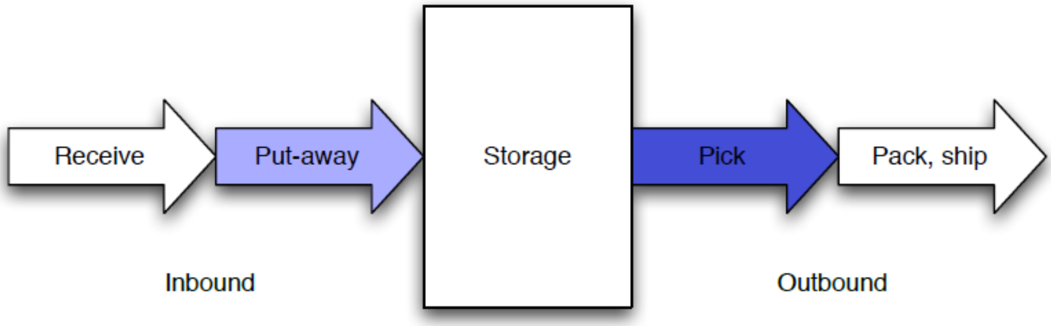


Figure 6 - Physical processes that constitute the material flow in a warehouse [9].

The first stage of the sequence is called the Receiving process and it is where the warehouse receives goods from other suppliers. It begins with the arrival of a prior notification that makes it possible to prepare the reception and coordinate with other activities that take place inside the warehouse. After that, the product arrives (in larger units like pallets or cases) and is unloaded, inspected and registered in the computer system. The complete process ends when everything is staged for Put-away [9].

The second stage is the Put-away process. It is the transfer of the products from the Receiving area to the warehouse so, as such, its efficiency highly depends on the warehouse layout and storage disposition (see section 2.2 for more detailed information). The storage location and the distance from the Receiving area have major influence on the speed of subsequent retrieval of products, increasing the cost of the operation. Besides that, it is also essential to know all the time what is the current availability of the warehouse as well as its real capacity, being necessary an inventory of storage locations and a constant scanning to record where the products have been placed, which increases the complexity of the warehouse management system (WMS), a large software system that comprises all data and information of a warehouse [9].

Intralogistics helps the Put-away process because the flow of goods throughout the warehouse and the subsequent storage can be fully automated, using advanced technologies and sophisticated material handling equipment to perform specific tasks in a faster and cleaner way. A detailed description of the storage operations and respective process automation solutions was provided in section 2.2.

The third stage represents about 55% of warehouse operating costs, so it is the most important process in the sequence. This process is called Order-picking and, as the name indicates, begins with a customer order that is something like a list with specific items and quantities. To fulfill the list, it is necessary to verify the inventory available for each item and reorganize the sequence to achieve great efficiency by reducing the travel in the warehouse around the storage locations. All of this is done by the WMS, which makes a major difference in companies because there's a lot of unproductive time in the travelling part of the picking actions. Therefore, there is a constant search to optimize Order-picking processes and increase warehouse cadences and responsiveness for the company to become increasingly competitive, because the more customer orders a company can respond to, the more it will be able to sell [9].

Generally, there are two types of picking: the carton-picking and the broken-case picking. The difference is in the size and geometry of the component to pick. The first one is all about picking full cartons or cases, the second one is the picking of less-than-carton quantities, requiring much more labor due to handling of smallest units of measure in the warehouse. With the evolution of intralogistics, it is now possible to fully automate both with solutions like stacker cranes or pick and packing robots (see section 2.2.2 for more detailed information), increasing the competitiveness of a warehouse [9].

The last stage is the Packing and Shipping operation. By this time, all customer orders are fulfilled and checked so they must be packed in containers to send to the customer. This operation is labor-intensive but there is almost none unproductive time. The only difficulty here is that customers prefer to receive all products in as few containers as possible to facilitate the unloading process, so there must be a huge use of the volume of the containers so that this need can be satisfied, being essential to take care so that all orders arrive to packing together [9].

Since the Packing process has put together all items in a larger container, the Shipping operation deals with larger units than the Order-picking, so this is not an arduous task. This the time that the trailer leaves the warehouse to make the delivery to the customer site, so the operator needs to register in the WMS all the individual containers that leave the warehouse and enter the system of the shipper and the subsequent departure of the trailer, giving as finished the sequence of the material flow inside a warehouse [9].

Nowadays, what they say is the fourth revolution of intralogistics is happening. Major changes are happening, and distribution centers and warehouses will have to adapt to this rate of evolution. Innovative solutions and new equipment appear every day and the main change is going through an even greater cooperation between the man and the machine, where the robots deserve a special highlight (Figure 7) [10],[11].

So far, robots were only found in manufacturing units and assembly lines where they performed tasks such as the manufacture of parts by welding processes or the assembly of specific sets. From the point of view of intralogistics, robots are now used in conjunction with the automated equipment existing in the warehouses to perform operations such as Receiving, Put-away, Picking, Packing, and Shipping. Because of their ability to operate non-stop, these devices make warehouses less dependent on human labor and increase responsiveness by optimizing the material handling operations. Humans are already working side by side with robots and that is the great step for intralogistics [10].

Figure 7 - Robots and humans are now working together in warehouses and distribution centers [11].

2.1.2 SYSTEMS INTEGRATORS

In a logistics system, there are many material handling equipment working together to create a complete handling process. A system like this incorporates manual and automated mechanical devices to handle the products, while managing all the information that is processed during the materials flow in operations like storage, receiving or picking. Besides that, the linkage between all mechanical devices with a network of communications allows a continuous materials flow throughout the entire warehouse, minimizing delays and unnecessary storage activities [12].

Given its role in providing current logistics solutions, it is important to describe what System Integrators are and how they influence business benefits. A System Integrator is an individual or an organization that has the knowledge and the tools to combine subsystems, making them work together to create a single system that performs a set of operations in the most efficient way possible. In the optic of intralogistics, it is a company that is responsible for the implementation of a logistics system performing the design, installation and commissioning of an entire project that guarantees the combination and communication between all the equipment so that the flow of materials is the most efficient (Figure 8). The subsystems that are integrated are the equipment, controls and information software (see section 2.2.2 for more information about typical systems) [13],[14].

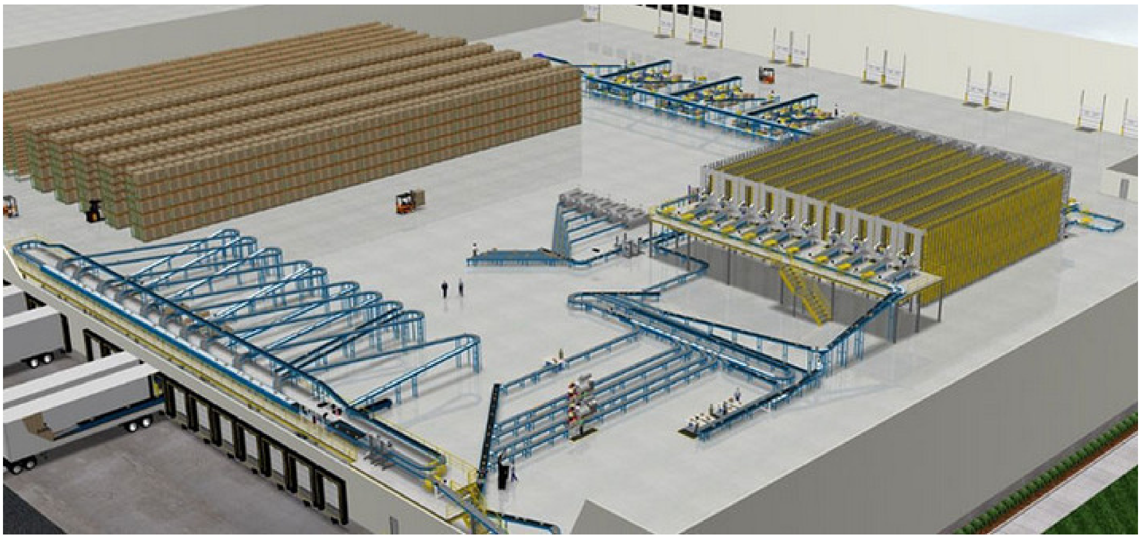


Figure 8 - System Integrators can integrate several equipment for a single materials flow in a logistic system [14].

To be a truly competitive Systems Integrator in the intralogistics and automated warehouses market, there must be total control and cohesion of the following technical areas [15]:

1) Information Technology:
    a. Automation Engineering;
    b. Software Engineering.
2) Electrical Engineering;
3) Mechanical Engineering.

The implementation of a complete logistics system requires an interdisciplinary way of working with universal development methods and processes for each individual discipline that has its own aspects and technical details. However, even with each discipline working individually there must be constant communication between the entire team to ensure an effective response to the customer's request [15].

There are some models that have been designed to define the process of designing an integrated system from the customer's requirements to the final delivery of the product. In VDI Guideline 2206, a process model in a V shape is presented for the development of mechatronic systems - systems that intersect the knowledge of three main technical disciplines: information technology; mechanical engineering; electrical engineering. By analyzing the model in Figure 9, this can be interpreted as an iterative sequence until the best solution is reached. It all starts with the requirements of the customer, which are analyzed by the systems designer who compiles them and begins by defining a first approximation of the desired solution and the way forward. The engineering, divided by different disciplines, seeks to detail the different subsystems so that the systems integration team can connect them and create the final system, which will be provided to the client, according to the characteristics initially defined by the system designer. Only with constant communication between the different areas of development it is possible to achieve the best solution, which is the main objective of a Systems Integrator [15].

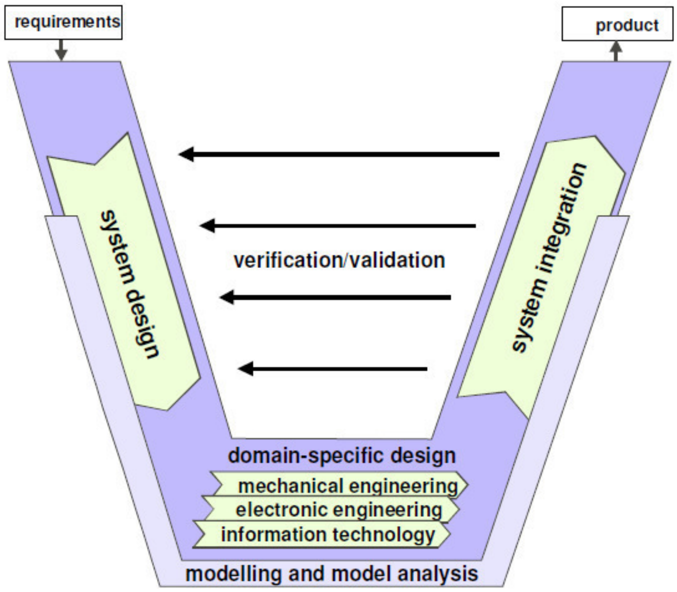


Figure 9 - V model for development of mechatronic systems integrated. Adapted from [15].

Although there are some similarities between both, a Systems Integrator cannot be confused with an Original Equipment Manufacturer (OEM). In the intralogistics industry, an OEM is a person or company that produces specific types of logistics equipment and sells these to clients. These equipment, such as conveyors, Automated Guided Vehicles (AGV) or robots, are sold as individual products and then inserted into a logistics system by a System Integrator [13].

There are some significant differences between a System Integrator and an OEM. The most important one is that a System Integrator seeks to deliver the best solution possible for the client requirements and create a long-term relation for the supply of spare parts and maintenance services, even if there is the need to look for solutions in other suppliers. On the other hand, OEM's only sell the products that exist in the company's catalogue so, to have spare parts available, they try to sell products that are not in a declining phase. Since they are limited to their product range, the risk in the OEM's strategy is that the solution provided can make system processing difficult [13].

Another major difference is, as one would expect, in product integration. If Systems Integrators are experts in integrating products, whether theirs or from of other manufacturers, and always try to find the best combination possible to meet end-user needs, OEMs do not have the ability to integrate their products with others, and they always try to sell products that generate greater profit even if it is not the most appropriate solution for the customer's system [13].

Briefly, a Systems Integrator is someone who can optimize the entire logistics system of a company. In addition to providing the entire system of equipment, controls, software and installation services, a Systems Integrator can analyze a complex material handling project and optimize it to the maximum to increase its efficiency. For the customer, it is enough to define the initial parameters and the rest is done by the System Integrator who delivers a turnkey solution [14].

2.2 AUTOMATED STORAGE AND RETRIEVAL SYSTEMS

In logistics, storage operations are one of the processes with the greatest source of income for the warehouse. Due to the lack of measures to implement optimization solutions for these processes, many warehouses do not run at maximum efficiency, which increases operating costs unnecessarily. Problems like bad occupation of storeplaces and underutilization of storage devices are easily solved with specific storage techniques [16].

The task of storing can be separated in the two operations that are performed with the storage unit [16]:

1) storing of the storage unit by a device specifically designed to stock the storage system;
2) retrieving of the storage unit into the storage system by the same device or a similar one.

Having these two operations as a starting point, the two most important components of a storage system are the unit loads to handle and the storage equipment used to hold or buffer them over a period [17].

A unit load is the set of one or more products and the structure that supports them (such as pallets or boxes) maintaining their integrity when they are handled. The fact of handling the products/materials through unit loads brings some advantages to the logistics system of a company. These include the possibility of using standard material handling equipment which, in turn, reduces material flow times and handling costs [17].

The main structures used in warehouses and in-process storages to support the materials and form a unit load are described in Table 1 [17],[18],[19],[20],[21].

Table 1 - Types of structures used to form unit loads [17],[18],[19],[20],[21].

Designation	Definition	Materials
Pallets 	Rigid structure with openings at its base for attachment of a forklift to lift and transport. The products are placed on top of it.	Wood (most common), pressed wood fiber, corrugated fiberboard, rubber, plastic, or metal.
Skids 	Like pallets, but with a continuous plate at the top that allows the transport of heavier loads. It also lets the attachment of forklifts. The products are also placed on top of it.	Metal (most common), wood, or plastic.
Slip Sheets 	Thick piece of paper or plastic that lies on the floor and the load is placed on top of it. Tabs on the end of the sheet are grabbed by a special push/pull lift truck attachment. The products are placed on top of it.	Thick paper (most common), corrugated fiber, or plastic.
Tote Pans 	Medium/small dimensions container that is used to protect and unitize loose discrete items. Due to their high rigidity, they can be reused.	Plastic (most common), or metal.

Designation	Definition	Materials
Pallet and Skid Boxes 	Medium/high dimensions container that is also used to protect and unitize loose discrete items. It is also reusable, but the openings at its base allows the fork/platform handling.	Plastic (most common), wood, cardboard, or metal.
Bins, Baskets, and Racks 	Small dimensions container that is also used to protect and unitize loose discrete items. Due to their high rigidity, they can be reused.	Plastic (most common), or metal.
Cartons 	Cardboard disposable container that is used to package and transport loose items. Less reusable than tote pans due to its lower rigidity.	Cardboard (most common), or plastic.

Although there are many types of storage equipment used to stock unit loads, this dissertation only focuses in the Automated Storage and Retrieval Systems (AS/RS).

AS/RS are warehousing systems that are used for the operations of storage and retrieval of products in distribution centers and in-process storages. It is an integrated computer-controlled system that achieves fast and accurate random storage of products and materials through various levels of automation. The first systems appeared in the 1950's and 1960's in Europe, the United States and Japan, however, since then, there was a very significant evolution in computer systems, electrical controls and material handling equipment that contributed to the increase in the number of companies acquiring this kind of solutions for their warehouses [22].

A basic AS/RS normally consists of Storage and Retrieval (S/R) machines running on one or more rails between fixed aisles of storage racks (Figure 10). Despite the low human intervention in its operation, there are several advantages in the use of this type of solutions. As this is an automatic system, it reduces the labor costs, floor space, and error rates, increasing reliability and material control (including security). On the other side, the disadvantages are the high investment and maintenance costs, and the low flexibility to modify the system design [5],[17].

A complete AS/RS is composed by the following components [5],[17]:

1) Rack Structures;
2) Storage/Retrieval (S/R) Machines;
3) Input/Output Points (I/O-points);
4) Peripheral Equipment;
5) AS/RS Control Systems.

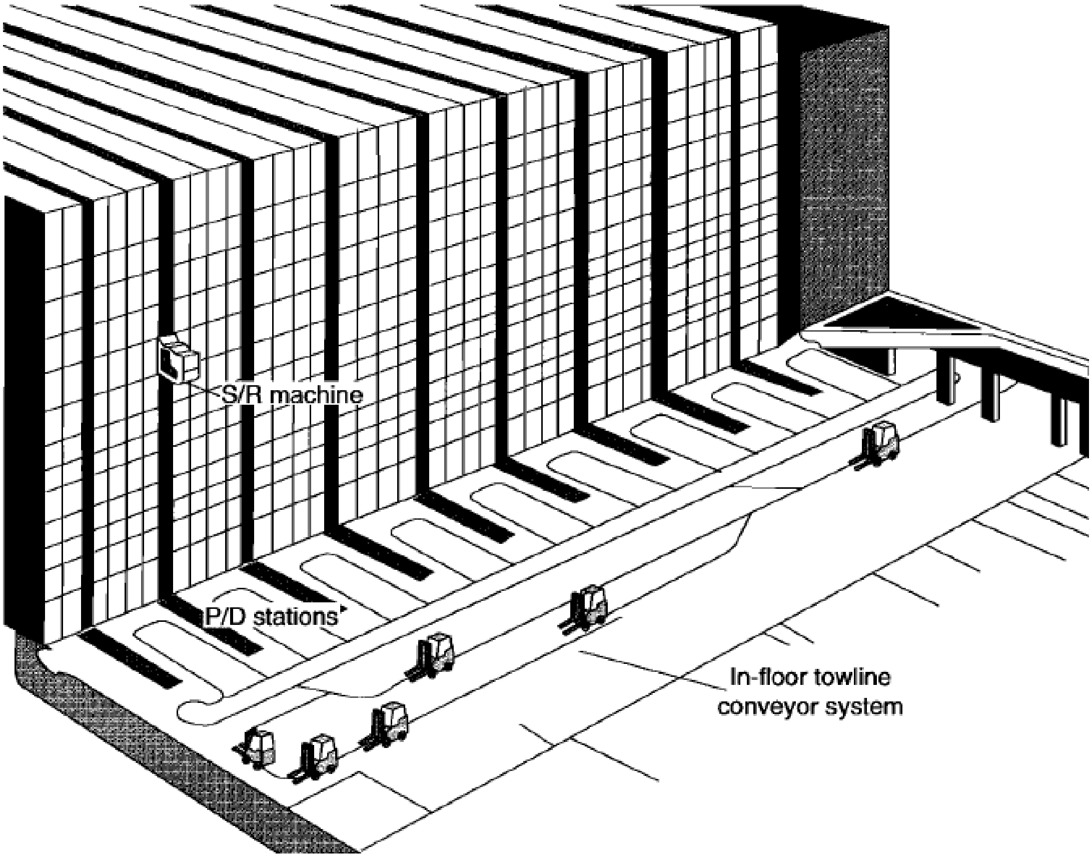


Figure 10 - Representation of an AS/RS [5].

2.2.1 RACK STRUCTURES

The rack structure is a fixed steel structure used to store the inventory, where pallets or bins are supported between load-supporting beams. Normally, a typical AS/RS uses high-rise stationary storage racks that can be freestanding or used to support the building (RSS – rack-supported structure), however there are other types of racks divided by two main groups (Figure 11): stationary racks and movable racks [17],[22].

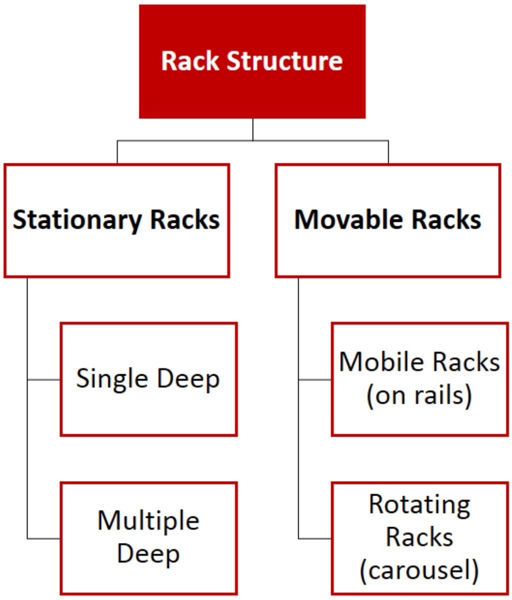


Figure 11 - Classification of racks [22].

Stationary Racks

Stationary racks are fixed on the floor and there is low flexibility to modifications, however there is the possibility to increase rack capacity by increasing the size of the steel structure. This type of rack can be single deep or multiple deep (Figure 12), depending on the number of unit loads stored per position (single or multiple unit load per position, respectively) [17],[22].

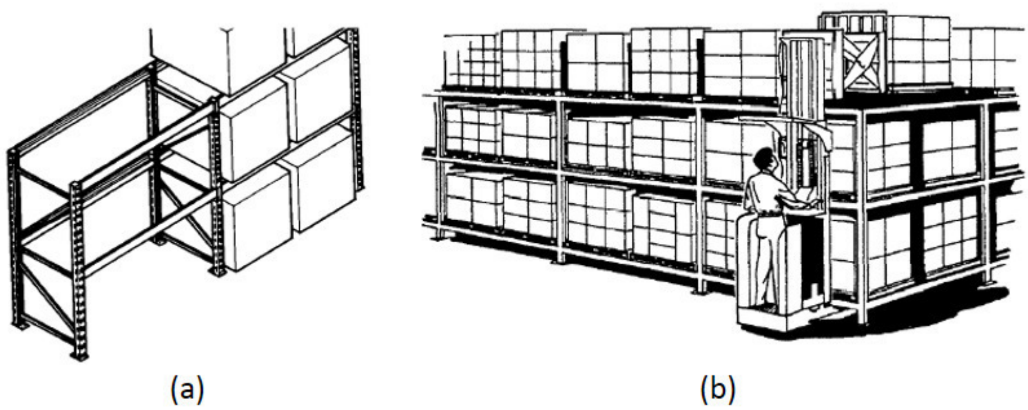


Figure 12 - Single Deep Rack (a) and Multiple Deep Rack (b). Adapted from [17].

Movable Racks

Movable racks take up less floor space and allow greater flexibility for changes, however they are not very common in AS/RS since they are more expensive to implement. The movement can be linear or rotary, depending if it is a mobile rack (on rails) or a rotating rack (carousel) (Figure 13). Mobile or sliding racks are characterized by the movement of racks along guide rails in floor that changes the location of the aisles. They are used when only single deep storage is possible and the space is limited. Rotating racks are carousels that consist of horizontally or vertically revolving storage levels (normally used for baskets or bins). Each level can rotate individually which makes this system achieve great efficiency of storing and retrieving [17],[22].

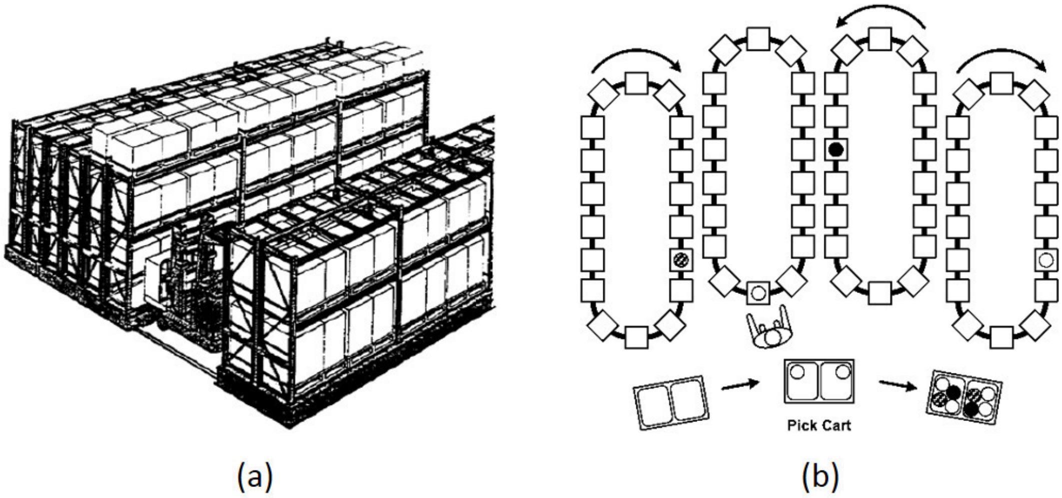


Figure 13 - Mobile Rack (a) and Rotating Rack (b). Adapted from [17].

2.2.2 STORAGE/RETRIEVAL MACHINES

The S/R machine is the device that run along aisles (horizontally and vertically) to serve rack slots on both sides of the aisles, executing the operations of storing and retrieving. In an AS/RS, this machine is what characterize and classify the several types of AS/RS existing. Figure 14 represents the types of AS/RS and their S/R machines [17],[23].

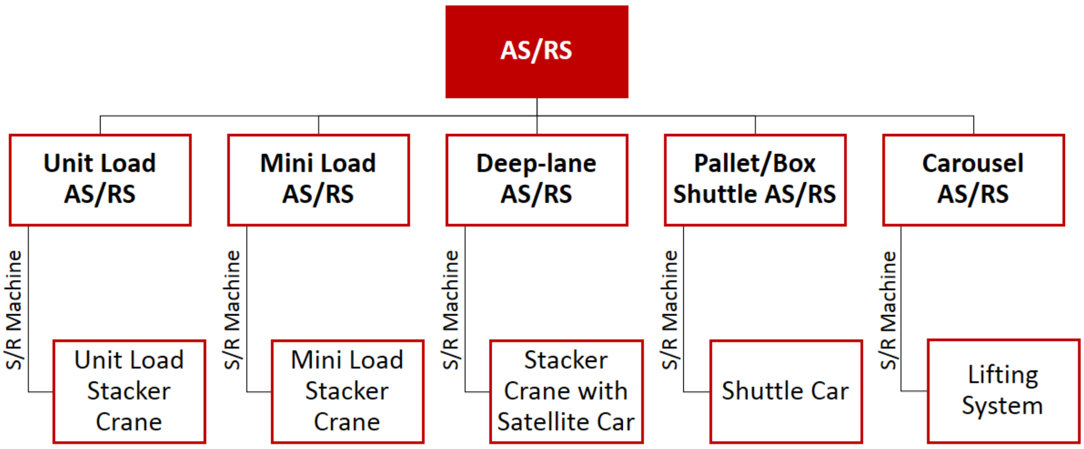


Figure 14 - Types of AS/RS and their S/R machines [17],[23].

Unit Load AS/RS

The unit load AS/RS is normally used to store/retrieve unitized and palletized heavy loads in single or double deep stationary racks (Figure 15). This is the most common system found in warehouses and it has several advantages like fast speed, load stability and security of operations [17],[24].

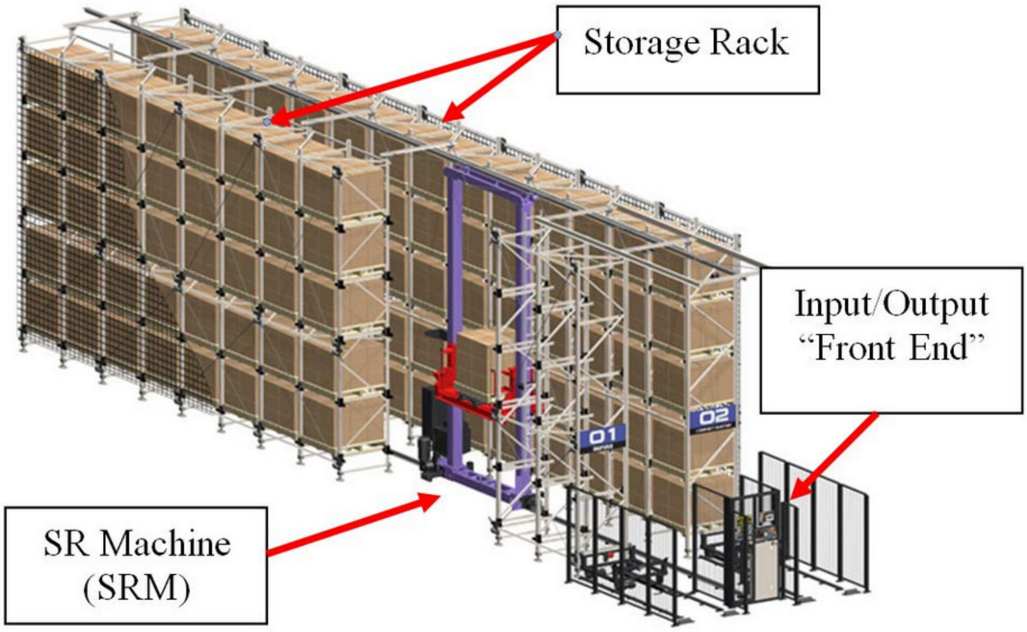


Figure 15 - Unit Load AS/RS [24].

The S/R machine is a unit load stacker crane (Figure 16), a highly developed equipment that can handle up to eight unit loads. It runs horizontally along the aisle guided through rails and vertically through the hoist carriage guided in the mast of the machine structure. In a simplified way, this equipment is composed by the following components: a single or double mast with solid steel structure; a hoisting motor and drum wire to ensure the elevation of the hoist carriage and emergency stops; a top frame used to guide the top of the stacker crane through guide rollers and increase horizontal movement stability; a telescoping fork to store or retrieve the unit loads in or out of the storage rack with maximum security and damage prevention of the unit load; a carriage that moves vertically and supports both the telescopic fork and unit load; a bottom frame assembled on the rail through guide rollers that allows the horizontal movement through the travel machine (a driving wheel); an on-board controller that owns all automation and control systems of the entire equipment [25].

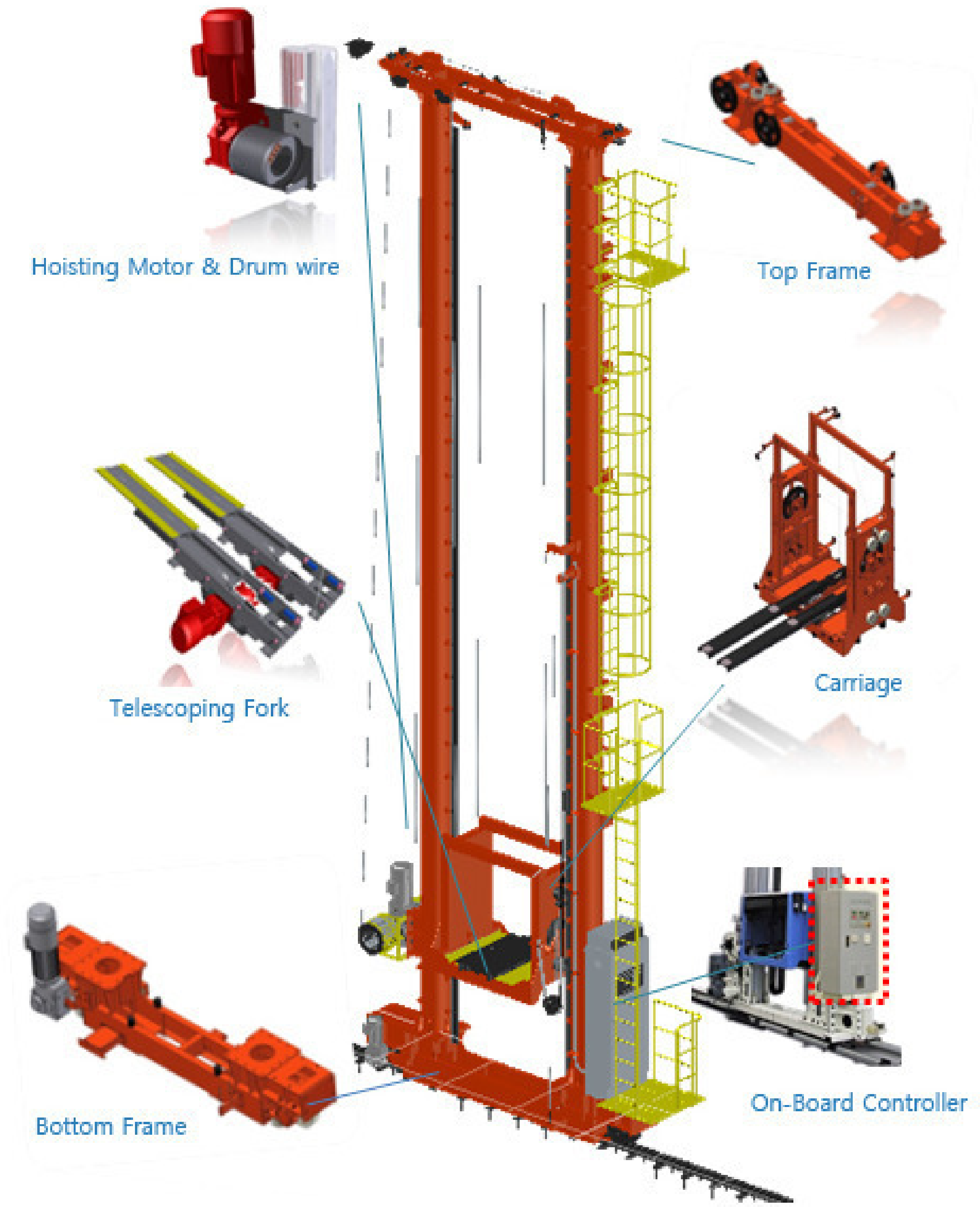


Figure 16 - Unit load stacker crane [25].

Another important characteristic of the unit load stacker crane is that it can operate in more than one aisle through mechanisms that transfer the stacker crane from one aisle to another. One example of these mechanisms is the pivoting wheels option in the bottom frame (Figure 17) [26].

Figure 17 - Pivoting wheels to transfer the stacker crane between aisles [26].

Mini Load AS/RS

The mini load AS/RS is similar to the unit load AS/RS in all aspects, however it is applied to store/retrieve lighter and smaller products that can be unitized in a tote pan or a bin. For that reason, this system has lighter components which makes it less expensive to implement, operate and maintain. On the other hand, it also has the advantages of fast material handling speed, load stability and security of operations. Figure 18 represents an example of a mini load AS/RS [17],[27].

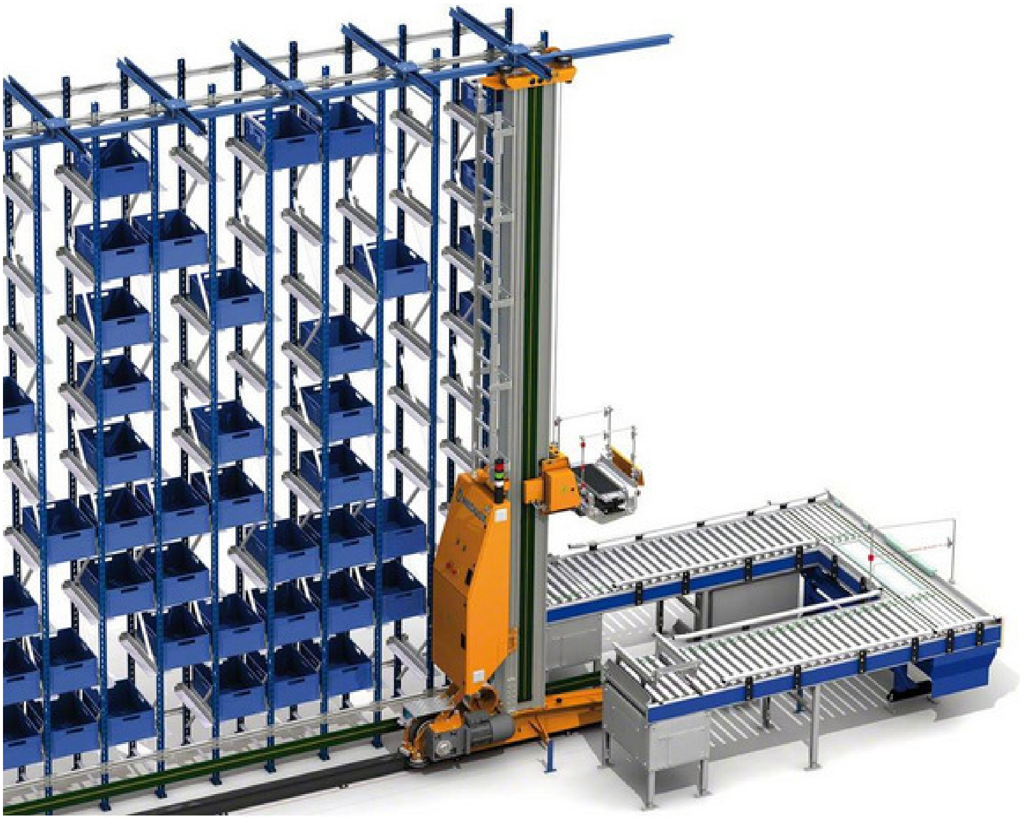


Figure 18 - Mini load AS/RS [27].

The S/R machine is a mini load stacker crane (Figure 19). It is like the unit load stacker crane with the same main components, however, as it is dimensioned to handle lighter loads, it is smaller and has a lighter main structure with a single mast and a carriage that can handle up to four unit loads. This equipment can also operate in more than one aisle [27].

Figure 19 - Mini load stacker crane [27].

Deep-lane AS/RS

Also similar to unit load AS/RS is the deep-lane AS/RS (Figure 20). The main difference is that this system is used to store palletized unit loads to greater depths in the storage rack (in multiple deep racks). In this sense, the space occupied by this system is also smaller, as well as the number of S/R machines needed. However, the main disadvantage of this system is that all the unit loads should be the same in order to achieve maximum efficiency of the system [17].

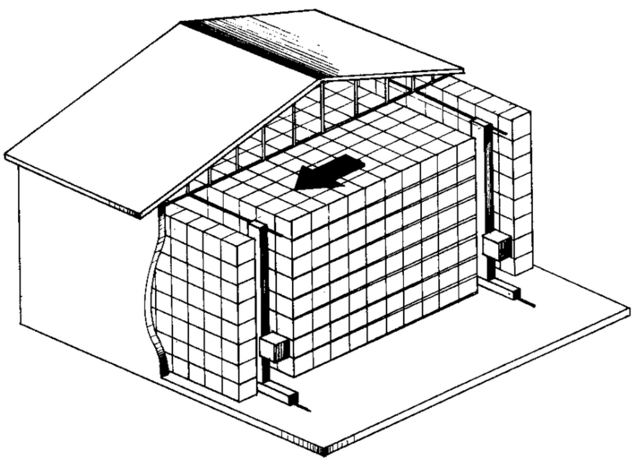


Figure 20 - Deep-lane AS/RS [17].

The stacker crane for this system is very similar to the unit load stacker crane in all components except the telescopic fork that is replaced by a satellite car positioned on the carriage (Figure 21). This component is no more than a cart that has four or more wheels and it moves at high speed under the palletized unit loads along two rails that are part of the racking system (Figure 22). It is capable of store and retrieve unit loads in and out of the racking structure by a lifting mechanism that transports the pallet. The power for this vehicle comes from batteries or supercapacitors that can be charged in the carriage [28],[29].

Figure 21 - Stacker crane with satellite car [29].

Figure 22 - Satellite car that moves under the palletized unit loads along two rails [28].

Pallet/Box Shuttle AS/RS

The most emerging AS/RS in recent years is the pallet/box shuttle AS/RS. This system, characterized by its high storage/retrieve cadences, has been one of the solutions of choice for the goods-to-person technologies. Among all the advantages, it is worth mentioning that it is a more compact storage system, with increased storage capacity and density, reduced handling times, and lower risk of accidents [30].

This solution is used to store/retrieve pallets or boxes (tote pans or bins), and the difference between the two strands lies in the type of rack structure and in the S/R machine. Regarding the rack structure, on the pallet shuttle AS/RS it uses a multiple deep stationary rack similar to the one used in the deep-lane AS/RS but with no aisles and more compact (Figure 23). On the box shuttle AS/RS it uses a single or double deep stationary rack very similar to the mini load AS/RS (Figure 24) [28],[30],[31].

Figure 23 - Pallet shuttle AS/RS [28].

Figure 24 - Box shuttle AS/RS [31].

The S/R machine for this solution is a shuttle vehicle (Figure 25), the great innovation of this system. Although it is very much like the satellite car used in the deep-lane AS/RS, there is no stacker crane in the aisles, which makes it possible to have multiple shuttle vehicles per aisle, one for each storage level. It also consists of a cart that has four or more wheels and moves at high speed along two rails that are part of the racking structure, but the vertical movement from one level of the rack to another is ensured by a second equipment which can be a lifter positioned at one end of the rack or an industrial truck (for pallets) that can remove and place the shuttle vehicles on the rack. However, there is a difference between the shuttle vehicle used to store pallets and the one used to store boxes. The first runs under the pallets inside the rack slots and the storing/retrieving mechanism is a lifting device that is actuated when the vehicle is under the unit load. The box shuttle vehicle runs in the aisles of the rack structure and stores/retrieves on both sides of the aisles. The storing/retrieving mechanism is normally a telescopic load extractor [28],[30],[32].

(a) (b)

Figure 25 - Shuttle vehicle for storing/retrieving of pallets (a) and boxes (b). Adapted from [28],[32].

Carousel AS/RS

The last type of AS/RS is the carousel AS/RS (Figure 26), a system that has the rotating rack as principle of operation. This is simply a series of adjacent storage columns mechanically connected and rotating horizontally around an oval track by an overhead or floor mounted drive mechanism, with no aisles and no machines inside the rack structure. Normally applied to store/retrieve bins or tote pans, this solution gained position in the market because it is a compact system that can achieve a high number of picks per hour [33],[34],[35].

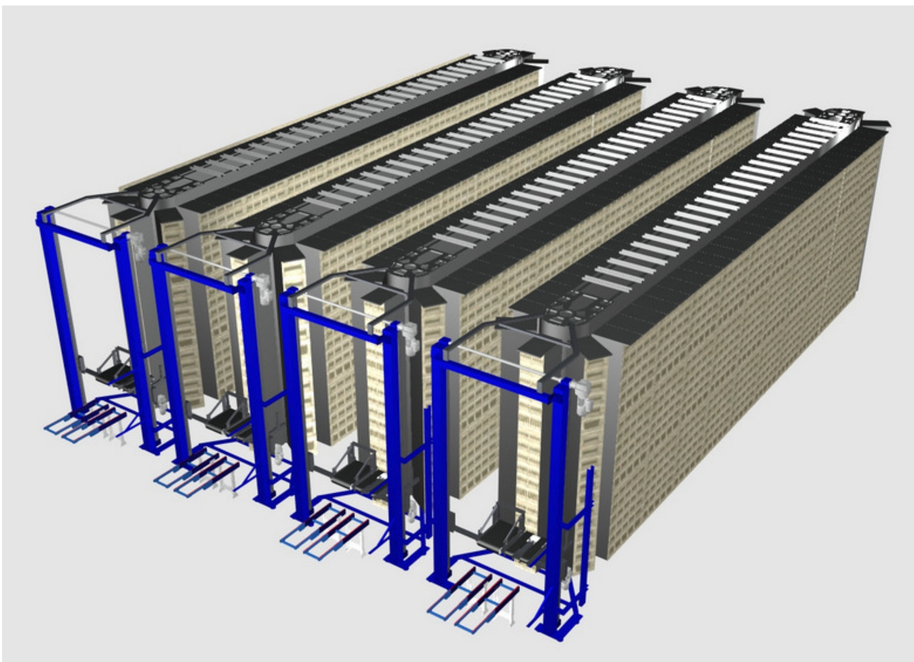
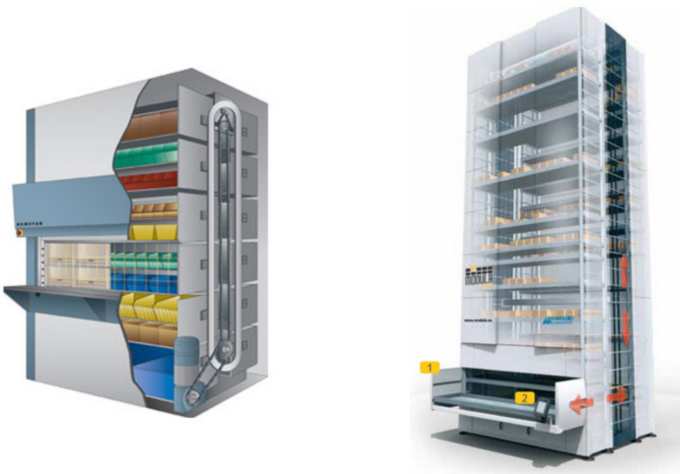


Figure 26 - Carousel AS/RS [35].

The S/R machine works in conjunction with the rotary movement of the rack. It is a lifting system, normally positioned at the end of each storage set, capable of reaching each level of storage, storing/retrieving two or more unit loads simultaneously through a platform with an extraction mechanism (Figure 27) [34].

Figure 27 - Lifting system for the carousel AS/RS. Adapted from [34].

Still within the AS/RS carousel, it is important to mention two other variations with the same operating principle, which, although targeted to other markets and for different applications, are often included in the range of AS/RS solutions. The two variations available are as follows: the vertical carousel (Figure 28 - a), a set of horizontal shelves linked to an oval track which rotates vertically; the vertical lift module (Figure 28 - b), a storage system like the vertical carousel but with two parallel columns separated with fixed shelf locations for containers that are inserted/extracted and travel up and down by a lifting device [36],[37].



(a) (b)

Figure 28 - Vertical carousel (a) and vertical lifting module (b). Adapted from [36],[37].

2.2.3 INPUT/OUTPUT POINTS

The I/O points location of the AS/RS are part of the warehouse layout, having influence in the cost associated with each storage location. For that reason, it is important to study all the options available and decide the one that reduces traveling costs. The I/O points location can be seen as the location of the receiving and shipping zones. These two zones can adopt two possible configurations: located at opposite sides of the rack structure (Figure 29) or located at the same side of the rack structure (Figure 30) [9].

The first option is the most used in AS/RS, being sometimes called the flow-through configuration because all unit loads flow from one side to the other. This configuration brings some advantages to the AS/RS like the possibility to make many storage locations of equal convenience with a conservative design, being appropriate for extremely high volume [9].

The second configuration is called the U-flow configuration because all unit loads flow in and out of the same side of the rack structure. Here, the best storage locations are much more convenient than the previous configuration, however there are more inconvenient storage locations, which is a disadvantage for high volume of storing/retrieving. On the other side, this solution allows expansion along three sides of the rack structure, and a more efficient use of fork lifts [9].

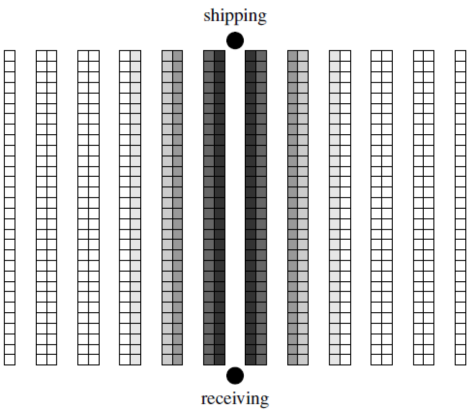


Figure 29 – Flow-through configuration: receiving and shipping located at opposite sides of the rack structure [9].

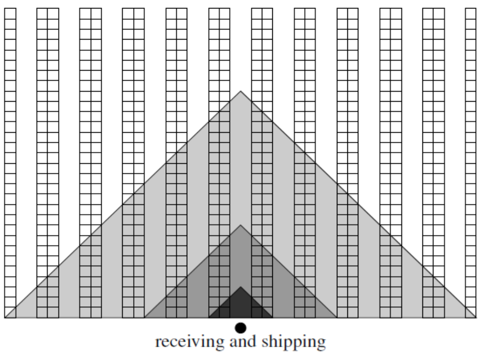


Figure 30 – U-flow configuration: receiving and shipping located at the same side of the rack structure [9].

2.2.4 PERIPHERAL EQUIPMENT SOLUTIONS FOR AUTOMATED STORAGES AND RETRIEVAL SYSTEMS

In an AS/RS, besides the main system with the rack structure and the S/R machines, there are many peripheral equipment to execute different operations and tasks to achieve maximum efficiency in a warehouse. Over the years, different equipment has been developed for certain types of operations and, due to their high applicability to the warehouses, many have become standard equipment for suppliers of intralogistics solutions [17].

Although there are many peripheral equipment for AS/RS, they can be divided into two broad categories: transport equipment and positioning equipment. The first category refers to all equipment that performs tasks of continuous movement of the material from one point to another (for example, from one workplace to another). The second covers all machines and devices designed to manipulate materials within a single workstation, performing tasks such as short positioning movements of parts [17].

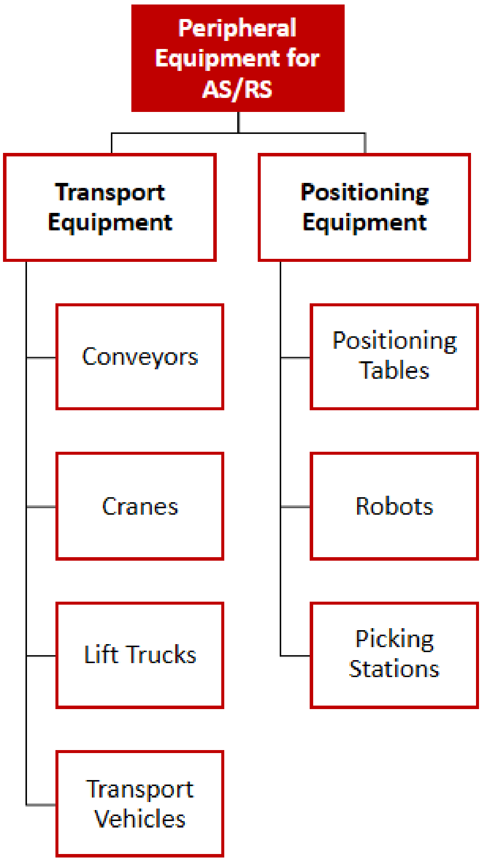


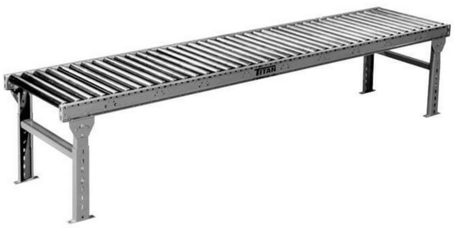
Figure 31 - Types of peripheral equipment for AS/RS [17].

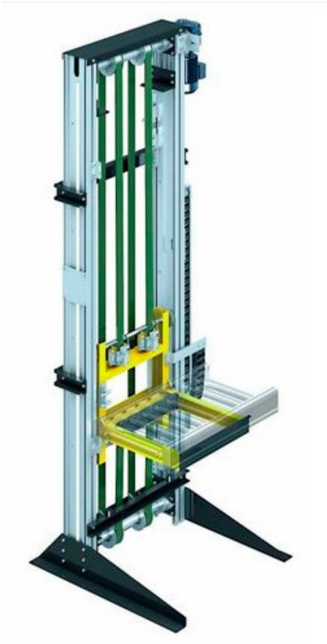
Given the wide variety of equipment, the two main categories can still be divided into sub categories, representing the families of equipment that operate on a similar principle or for the same purpose. This division between each of the categories is represented in Figure 31 [17].

2.2.4.1 CONVEYORS

Conveyors were one of the first equipment to appear in the market and may even be considered the “backbone” of material handling. Known for their simple technology that allows the movement of material between specific points, these devices offer great efficiency to move materials over a fixed path, having great flexibility to handle different types of loads and to be located on the floor or overhead. This is only possible due to a wide range of conveyors that have been developed over the years, each type being able to offer different advantages. The main types of existing conveyors are shown in the Table 2 [17],[38],[39],[40],[41],[42],[43],[44].

Table 2 - Types of conveyors used as peripheral equipment for AS/RS [17],[38],[39],[40],[41],[42],[43],[44].

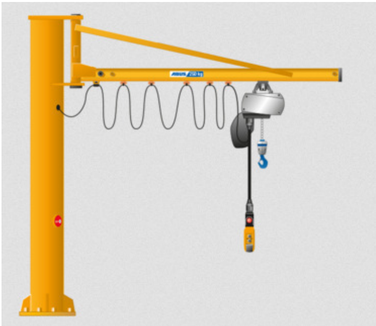
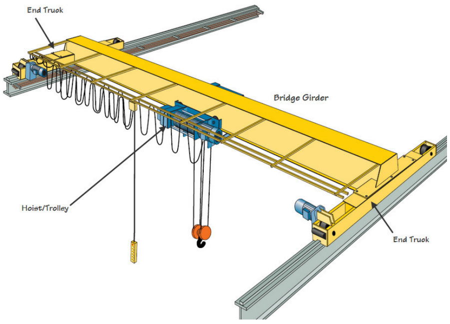
Designation	Definition
Gravity Conveyor 	Since these are non-powered roller conveyors, they are one of the most economical material handling solutions. The loads move due to Earth's gravity, so these conveyors are usually inclined.
Powered Roller Conveyor 	Similar to the gravity conveyor, the load moves over a horizontal set of rollers that rotate due to the action of a gearmotor or drive rollers.
Chain Conveyor 	This is a powered conveyor that moves loads through the movement of roller chain loops divided in two or more stringers to accommodate the load. The friction between the chain and the base of the load prevents slipping between the two.
Belt Conveyor 	For incline/decline applications, the belt conveyor can move loads with great orientation due to the movement of a belt that is actuated by a gearmotor. With a great contact area between the load and the belt, this conveyor is effectively used for elevation changed.

Designation	Definition
Magnetic Belt Conveyor 	The magnetic belt conveyor is like the belt conveyor, the difference is that it has a steel belt that moves over a magnetic slider bed. That magnetic surface is used to transport ferrous materials vertically.
Vertical Conveyor 	The vertical conveyor is an elevator that has the function of lifting/lowering loads between two or more transport levels (for example, the floor level and the mezzanine level). A platform moves vertically guided along a column structure. The load travels on top of a conveyor (normally a roller conveyor or a chain conveyor) that is assembled in the platform and, when the respective levels are reached, the conveyor is driven so that the load is transferred. Generally, the lifting operation is possible due to a gearmotor that drives a chain/belt that pulls the platform.

2.2.4.2 CRANES

When the material flow is not sufficient to justify the use of conveyors to move loads, an alternative and cost-effective solution is the use of cranes. These devices use hoists mechanisms to lift the loads and move them into a restricted area, however they have a few advantages compared to conveyors. With greater flexibility of movement than conveyors and lower than industrial trucks, the main advantage is the ability to handle a greater variety of loads (geometries and weights) using simple technologies and mechanisms. Table 3 represents the main types of cranes used as peripheral equipment of AS/RS [17],[45],[46],[47].

Table 3 - Types of cranes used as peripheral equipment for AS/RS [17],[45],[46],[47].

Designation	Definition
Jib Crane 	The jib crane is normally composed by a vertical stationary column with an arm, mounted on top, that can rotate 360˚. The rotating arm has a hoisting device that moves along and is used to lift loads. This crane can work like a manipulator for positioning operations.
Bridge Crane 	This crane works to the full extent of a warehouse. It is a bridge supported overhead on two rails spaced along the width of the warehouse. This moves longitudinally along the rails and has a heavy load lifting mechanism that moves transversely along the bridge.
Gantry Crane 	Like the bridge crane, except it is mounted on the floor and handles lower loads. If the crane is supported by wheels, it allows handling in three dimensions but in a smaller working area.

2.2.4.3 LIFT TRUCKS

One of the material handling equipment found in virtually all manufacturing plants and warehouses is the lift truck. Being one of the greatest innovations for industrial logistics, this equipment is the most used for moving products at variable distances (usually short) and flexible trajectories. Its operating principle addresses the lifting and transportation of the most varied products, functioning through manual or powered systems (normally hydraulic, electric or combustion systems) [17],[48].

Among all the advantages that a lift truck can offer, stand out the possibility of moving materials horizontally without restrictions of area or of route, being able to still make vertical movements through mechanisms of elevation. In this way, this equipment become more advantageous than conveyors or cranes for providing greater flexibility of movement [17],[48].

Table 4 represents the types of lift trucks that exist in the market. The differences between each type lie in certain operational characteristics of the lift trucks. These characteristics include the type of load to be handled, the type of power source, whether the operator can drive it, or whether it has the capacity to stack loads [17],[48],[49],[50],[51],[52],[53],[54].

Table 4 - Types of lift trucks existing in the market [17],[48],[49],[50],[51],[52],[53],[54].

Designation	**Definition/Characteristics**
Hand Truck 	Hand trucks are used for manual transport of non-palletized loads. It is a trolley that tilts to support the load, moving on two wheels by the operator. Among all lift trucks, this is the most economical solution, since it is not powered. <u>Load Type:</u> Non-Pallet <u>Power Source:</u> Manual <u>Operator can ride it (Yes/No):</u> No <u>Stacking capacity (Yes/No):</u> No
Pallet Jack 	Pallet jacks are the most basic version of a lift truck for pallets. This device has an arm which, when manually balanced, activates a hydraulic cylinder in its base to raise the forks that allow the transport of the load. <u>Load Type:</u> Pallet <u>Power Source:</u> Manual/Hydraulic <u>Operator can ride it (Yes/No):</u> No <u>Stacking capacity (Yes/No):</u> No

Designation	Definition/Characteristics
Walkie Stacker 	The difference between the walkie stacker and the pallet jack is the stacking capacity and the existence of power sources for the lifting and translating mechanisms. For that reason, the operator can handle the vehicle and walk without making any effort (the powered travel speed is limited to a normal walking pace). <u>Load Type:</u> Pallet <u>Power Source:</u> Electric/Hydraulic <u>Operator can ride it (Yes/No):</u> <u>Stacking capacity (Yes/No):</u> Yes
Pallet Truck 	The pallet truck is almost like the walkie stacker. There are only two differences here: it does not have stacking capacity, but the operator can ride the vehicle by leaning on a platform at the rear. <u>Load Type:</u> Pallet <u>Power Source:</u> Electric/Hydraulic <u>Operator can ride it (Yes/No):</u> Yes <u>Stacking capacity (Yes/No):</u> No
Platform Truck 	The most used solution to transport non-palletized loads is the platform truck. With a flat support surface, this vehicle can transport almost any type of load operating with powered lifting/traveling mechanisms. <u>Load Type:</u> Non-Pallet <u>Power Source:</u> Electric/Hydraulic <u>Operator can ride it (Yes/No):</u> No <u>Stacking capacity (Yes/No):</u> No

Designation	Definition/Characteristics
Counterbalanced Lift Truck  	Counterbalanced lift trucks are the most developed lift trucks in the market. Used to handle heavy palletized loads, these vehicles are found in almost any warehouse or facility because of their great flexibility, being able to operate in a variety of surfaces (indoor/outdoor) and handle a wide range of loads. The operator needs to be certified to ride this equipment that functions by balancing weights between the lifting forks and the operator's cabin behind the front wheels. There is a wide range of solutions and additional mechanisms for this type of lifting truck that can perform several movements beyond the traditional lifting and travelling movements, such as turning wheels or mast tilt for loading and unloading pallets. This allows the vehicle to work in restricted areas like narrow aisles. Load Type: Pallet Power Source: Electric/Hydraulic Operator can ride it (Yes/No): Yes Stacking capacity (Yes/No): Yes

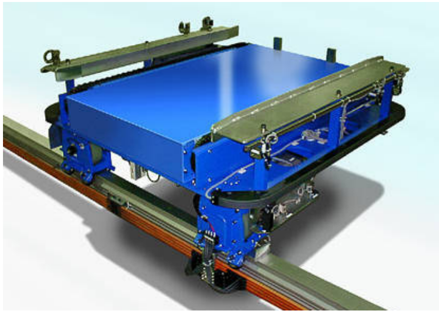
2.2.4.4 DRIVERLESS TRANSPORT VEHICLES

Still within the transport equipment group, the last sub category is the one that puts together the transport vehicles that do not require human interaction. These efficient vehicles are characterized by their high speed, high throughput, great flexibility and great reliability, existing very economical solutions for the amount of advantages that can be obtained [55],[56].

These solutions are used to create complex sorting systems and move loads between very distant points which, in fact, makes it a great alternative for conveyor systems with the added advantage of being able to move on complex routes and perform other operations besides linear transport. Besides that, a wide range of load handling units can fit in a transport vehicle, even if they are not standardized, which allows to solve many problems of transport on certain products [55],[56].

The principle of movement of these vehicles consists on guiding them through rails or laser reflection, depending on the type of transport vehicle. Each solution existing in the market is described in Table 5 [55],[57],[58],[59].

Table 5 - Types of peripheral transport vehicles for AS/RS [55],[57],[58],[59].

Designation	Definition
Rail Guided Vehicle (RGV) 	The RGV is an automatic carrier mounted on the floor and guided through rails. Capable of moving in linear or curvilinear directions, this equipment moves safely and smoothly by carrying one or more load units which, in addition to being transported between two distinct points, are also automatically loaded/unloaded through the conveyor mounted on top of the RGV.
Overhead Monorail Vehicle (OMV) 	The OMV is like the RGV. The difference is that this vehicle is mounted and guided overhead. For that reason, this solution saves more space on the floor while providing the same product transportation and distribution accuracy. Depending on the characteristics of the products and the operations to be carried out, the unit loads can be transported in cages, conveyors or special structures.
Automated Guided Vehicle (AGV) 	The AGV is an innovative robotic vehicle used in the transport of diverse types of materials. Although it is a complex equipment, with the development of electronics and the increasing demand for reliable equipment with high production rates, AGV has become a standard equipment and one of the first choices for material handling. Depending on the type of load to be moved (weight, geometry and dimensions), there are many vehicles developed specifically for each type of unit load (palletized or non-palletized). In the case of palletized unit loads, AGVs are an excellent alternative to lift trucks, as they can run automatically 24/7 without the need of human labor to drive it.

2.2.4.5 POSITIONING EQUIPMENT

The category of positioning equipment, unlike transport equipment, encompasses relatively recent solutions that have gained a prominent place in the market during the last 20/30 years, as a result of a marked evolution in the area of intralogistics that caused the introduction of new operations besides the traditional transport of the unit loads between two different points [17].

Starting with the sub category of the positioning tables, it includes all the equipment that carry out operations of lifting or turning in short working areas. For example, in a conveyor system there may be a need to transfer the unit loads from one line to another in a transverse direction, or in a different height. The main equipment developed to perform this type of tasks are represented in Table 6 [60],[61],[62],[63].

Table 6 - Types of positioning tables used as peripheral equipment for AS/RS [60],[61],[62],[63].

Designation	Definition/Characteristics
Lifting Table 	The lift table is, as the name indicates, used to carry out lifting operations. This equipment is used to hold the vertical conveyor in situations where the drop causes such a low stroke (for example the difference between the conveyor line and the loading / unloading dock) that the use of the vertical conveyor is not justified. Typically, a conveyor is mounted on the top of the lifting table so that it is possible to transfer the unit load to another work station or conveyor. Operation Type: Lifting Power Source: Electric, Hydraulic or Pneumatic
Transfer Table 	The transfer table is an adaptation of the lifting table for the creation of a station for transferring the unit loads from a conveyor line to transverse directions. An example of this device is the assembly constituted by lifting table, roller conveyor and chain conveyor. The chain conveyor is fixed and is mounted transversely relative to the roller conveyor which is on top of the lifting table that goes up and down. It is the passage of the unit load from the rollers to the chains that allows the angle transfer. Operation Type: Angle Transfer Power Source: Electric, Hydraulic or Pneumatic

Designation	Definition/Characteristics
Turning Table 	The turning table performs an operation very similar to the angle transfer of the transfer table. Here, the unit loads are transferred to directions transverse to the conveyor line, however this task is carried out by means of a load rotation mechanism. This allows maintaining the transport width and is very advantageous in cases where the unit loads have different length and width. Another difference is that it is only necessary to mount a conveyor at the top of the turning table to follow the travelling movement of the conveyor line. Operation Type: Turning Power Source: Electric
Tilting Table 	The tilting table is a less commonly used solution when compared to the previous options. It is an equipment used for tipping totes and bins, improving the access to the interior of the boxes or allowing the transfer of the products to another area by sliding them out. In that sense, it is a solution that can be used alone or incorporated into a conveyor line when it has a conveyor coupled at the top. Operation Type: Tilting Power Source: Hydraulic or Pneumatic

2.2.4.6 ROBOTS

The continuous development of advanced robots is changing the world with each passing day, influencing society and its behaviors in a deep and positive way. Today, this technology is present in many places, helping or replacing human actions in medicine, in the environment, in manufacturing plants, or even at home [64].

The wide acceptance and demand for this type of technology is essentially due to the fact that it allows one or more complex operations to be carried out efficiently. Although some initial investment is still needed, there are some advantages that should be highlighted [65]:

1) Quality improvement - robots efficiently perform tasks that require high positioning accuracy, high repeatability, high-precision inspection and sensor measurement, increasing product quality;
2) Improvement of the working environment - robots can perform heavy and repetitive work in contaminated environments, avoiding the risk of injury when these same tasks are performed with human labor;
3) Cost effectiveness - a robot can operate with maximum efficiency for 24 hours without stoppages, something that with human labor would only be possible by creating three shifts, which increases the cost of salaries of operators;
4) Productive flexibility - robots can be reprogrammed and, by changing only the manipulation tool and maintaining the main structure and movement axes, it becomes easily possible to perform new tasks on new products.

Analyzing the different advantages, it makes sense that the robots are applied in logistics, considering the market growth in this area. In fact, such technologies are increasingly being used in warehouses and distribution centers, however, many studies point out that in the future it will be possible to observe operators and robots working side by side, a real industrial revolution that will make services faster, safer and more productive [64].

Numerous robots can already be found in AS/RS peripheral equipment, being able to perform various tasks continuously (24/7). Currently, these logistic robots consist mainly of traditional robots with one or more grippers to pick and move items within a logistics operation, however, these are still solutions developed specifically for each customer (for example, fully automatic picking stations), because the logistics robots have not yet reached a level of intelligence and simplicity of mechanisms that allow them to be a standard and economic solution. Despite this, many have already been developed to perform certain tasks in the warehouses. The main operations that a logistic robot is capable of performing are described in Figure 32 [64],[66],[67].

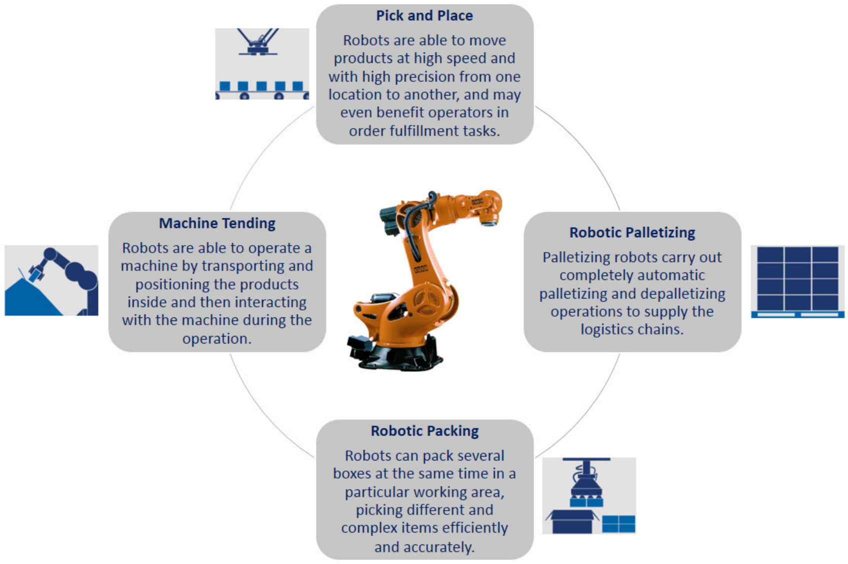


Figure 32 - Tasks and functions of logistics robots. Adapted from [66],[67].

2.2.4.7 PICKING STATIONS

As mentioned in section 2.1.1, one of the most important functions of every distribution center and many warehouses is the order fulfillment process. As such, it is extremely important that this operation is fast, efficient and accurate, as it is here that many companies can differentiate themselves from their competitors, in other words, the ability to respond to customer orders.

There are many engineering order fulfillment systems that depend on several factors related intrinsically with the activity profile and objectives of the warehouse or distribution center. Although there are several order fulfillment configurations, AS/RS normally operates according to the "goods-to-person" configuration which, as the name implies, means that the operator responsible for order picking does not move and the system itself brings the products to the picking station (normally through conveyors). In the picking station, the product is picked and then send back to the storage location [68].

The “goods-to-person” technology is the best when it comes to operator’s productivity and security, since there is no need for walking to perform the picking tasks. Besides, these systems save a lot of space in the warehouses due to the fixed working stations, enabling an easy expansion when needed [68].

When picking tasks are performed manually, there are many solutions directed to the diverse types of picking. Picking stations should be adapted to the desired performance, product characteristics and ergonomics and space requirements. This is where the interface between the AS/RS and the human is located, so some standard solutions were developed for the most common requirements of the warehouses and distribution centers. The main solutions of “goods-to-person” picking stations existing in the market are represented in Table 7 [68],[69],[70].

Table 7 - "Goods-to-person" picking stations for AS/RS [69],[70].

Designation	Definition/Characteristics
Picking Station for Single Orders 	In this solution, the operator works on a single order at a time. There is only one source carton and one order box are moved fully automated around the picking station. The advantages are the lowest failure rates and the high flexibility for different load types and sizes.
Picking Station for Multiple Orders 	In this system, there is one or two source cartons for multiple order boxes. The operator supplies each of the order boxes with the products that are common in different customers’ orders. The main advantage is the maximum throughput rate.

2.2.5 AS/RS CONTROL SYSTEMS

All production systems that perform operations automatically need control systems so that processes can be performed in an accurate and orderly manner. These control systems make up the various existing automation solutions for all other equipment and machines of the manufacturing units [71].

Demand for automation solutions has been steadily increasing over the years. This is fundamentally due to the advantages that automation can provide as higher production speed, higher product quality, higher working safety and lower labor costs. These advantages are much more relevant and evident in repetitive and systematic processes, where high speed and precision are required in the execution of multiple operations, since the initial investment is low compared to the amount of advantages that are obtained. An AS/RS and its peripheral equipment are one of the areas of greater application of automation and control systems because, as can be seen in sections 2.2 and 2.2.2, material handling operations consist of simple and repetitive movements involving the precise positioning of products [71].

Production systems are controlled and executed through industrial control systems (ICS). In automatic processes, with several interconnected equipment, there are three main types of ICS's for different types of applications: programmable logic controllers (PLC), distributed control systems (DCS), and supervisory control and data acquisition (SCADA). In this work, DCS and SCADA systems are not very important since they apply in situations that require the control and supervisory of an entire process with points that can be widely distant at a geographical level, such as the water distribution process or the production process of an oil company. On the other hand, PLC systems are used to control an individual machine or a set of equipment that performs a single process, sending the information to the supervision central. For this reason, taking into account that this is a work directed to the machine design subject, PLC systems were given greater focus [72].

PLC's (Figure 33) are compact, modular and multifunctional controllers based on microprocessors prepared for industrial environments. It consists of a Central Processing Unit (CPU), a programmable memory and input and output ports, three components that together allow the control of operations in machines and automatic processes. The input and output ports provide information about the machines (from the sensors) and thus act on them (via the actuators). On the other hand, in order for the CPU to process all the information and properly send the commands to the machine it is necessary to create a program with a sequence of instructions and logical functions that is then stored in the memory of the PLC. The great advantage of these systems is their versatility, because as the whole architecture is modular, the automation system can always be optimized or even grow with the increase in the number or complexity of the variables to be controlled [65],[73].

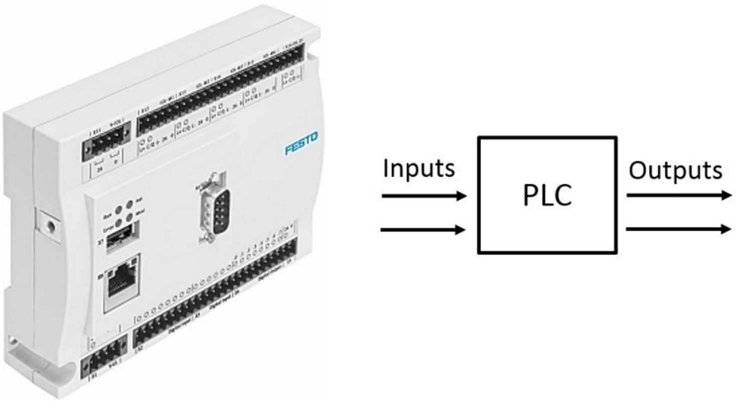


Figure 33 - Example of a PLC and its functioning principle. Adapted from [65],[73].

In a process like an AS/RS, where all equipment is interconnected, there is a constant communication between all automatisms and the central of control and supervision. All of this is possible thanks to the existence of specialized software, communication networks and industrial terminals that ensure the transmission of information, the exploitation, remote control and supervision of the entire process in a compatible way [65].

2.2.5.1 SENSORS

As already mentioned, PLC's receive the information about the machines and their operations through sensors. These devices can convert physical phenomena into electrical signals, functioning as the interface between the physical domain, composed of the operations performed by the machines, and the electrical domain, where all the ICS's operate [73].

Currently, there is a very wide range of sensors capable of performing all kinds of functions. In material handling equipment, sensors are mostly used for positioning products and machine components, for identification of materials, or for accident prevention and safety assurance of the operators. In this work, due to the wide range of sensors, only those that are most used in intralogistics equipment were approached (Figure 34) [74],[75].

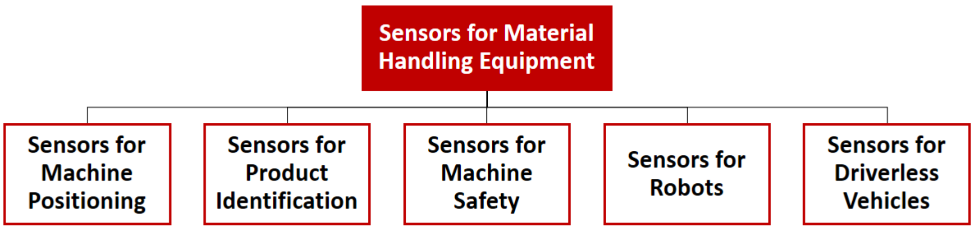


Figure 34 – Main categories of sensors used in intralogistics equipment [74],[75].

Sensors for Machine Positioning

Sensors for machine positioning constitute the group of sensors used in virtually all material handling equipment, since they are simple to install, have a long lifespan and a high detection accuracy. In addition, these sensors can be used in different types of applications, either to position the platform of a stacker crane in the rack, or to detect the end of the stacker crane movement in the aisle. Table 8 represents the main sensors used for machine positioning [75],[76],[77],[78].

Table 8 - Sensors used for machine positioning [75],[76],[77],[78].

Designation	Functioning Principle/Applications
Limit Switch 	This is an electromechanical contact device that has a small actuator connected to a set of contacts. When this actuator is actuated the electrical circuit is interrupted and a signal is sent to the PLC. Its robustness and ease of installation make this sensor to be used in detecting the presence of loads on the machines and, as the name implies, in detecting the limit switches of the machines.
Proximity Sensors (Inductive or Capacitive) 	This type of sensors acts by approaching all types of materials, which vary the capacitance or inductance (depending on the type of proximity sensor) of an electric field, inside the sensor, that sends an electric signal for the PLC. They are widely used to detect the positioning of machine components or the presence of loads on conveyor platforms.
Photoelectric Sensors 	This is a device that detects the presence of any object through the break of a light beam (a modulated LED) that is emitted between a transmitter and a photoelectric receiver. It is mainly used to measure the distance of an object or just to detect its presence.

Designation	Functioning Principle/Applications
Ultrasonic Sensors 	Ultrasonic sensors are used to measure the distance of an object. This is possible through the emission of a sound wave at a certain frequency that is reflected in the object and sent back to the emitter. The time between the emission and reflection of the sound wave allows to determine the distance to which the object is.
Rotary Encoders 	Rotary encoders are sensors that convert the rotational motion of an axis into electrical signals. For this reason, these devices operate by being coupled to rotating elements such as the shaft of a gearmotor. Depending on the purpose, there are two types of rotary encoders: absolute and incremental. Absolute encoders are used to detect the exact angular position of the shafts, incremental encoders are used to measure the speed or distance traveled by the shafts. The technology used to detect the different variables can be mechanical, magnetic, resistive or optical (most common).
Bar Code Positioning Device 	Bar code positioning systems operate, as the name implies, through the principle of data acquisition of a bar code reader. These systems are used to position an equipment that moves over long distances, working for linear or curvilinear motions. They consist of an optical reader head fixed in the equipment that calculates the position by reading a continuous bar code tape that is placed along the path.
Laser Distance Measurement Device 	This sensor is very like the ultrasonic sensor because it is also used to detect the distance of an object. However, its functioning principle consists in the emission of a laser beam that is reflected in the object and sent back to the emitter, which allows to increase the ranges of operation and the precision of measurement. It is widely used in the positioning of equipment that move in long distances under straight lines, simultaneously detecting the end of stroke.

Sensors for Product Identification

In an AS/RS, products move throughout the system independently and without any human intervention. Each product can take different starting and finishing points, and each machine knows what to do with every product, but everything is done autonomously through a constant communication between products and machines, which drives the entire process in an efficient way. When everything is incorporated in a network created through the Internet of Things, it becomes possible to convert warehousing systems and manufacturing units into smart environments where the entire process can be controlled and supervised through a unique system, the vision for the fourth industrial revolution [79].

For the communication between products and machines to be possible, it is very important that each product has its own unique identity, so that there are never two products that are completely alike. In addition, it is also essential that this identity or reference has all the data about the product and is easy to identify or read. Only then will it be possible for each machine to acquire the data of each product and know the operations to be performed.

Product characterization and identification devices are part of the AS/RS automation and control systems. Over the years, innovative ways and tools to identify products appeared in the market, increasing the ease of access and visualization for the operators and machines. Although there are many other forms to do the task, the most used devices for product identification are represented in Figure 35 [75],[80],[81],[82].

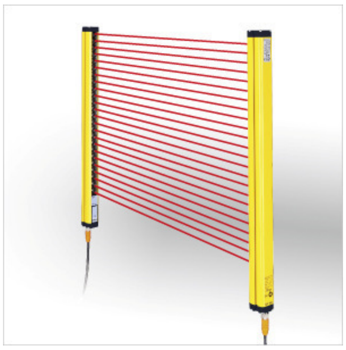
(a) (b) (c)

Figure 35 - Examples of readers for product identification by: bar code (a), data matrix (b) or radio frequency (c). Adapted from [75],[80],[81],[82].

Sensors for Machine Safety

Due to the unpredictability and danger related to the operation of the machines, automation solutions were developed to reduce the risk of accidents and improve the relationship between operators and machines. These solutions include several sensors that are connected to the equipment's PLCs and are triggered when, for example, there is a fault in the machine's operation or when the operator has exceeded safety distances. Some of the main types of sensors used in machine safety are described in Table 9 [83],[75].

Table 9 - Sensors used for machine safety [83],[75].

Designation	Description
Safety Light Curtains 	Safety light curtains protect operators from access to hazardous areas of machinery, usually the mobile components. Its operation is a set of light beams which, when interrupted, immediately stop one or several functions of the machines.
Emergency Stop Button 	An emergency switch is a safety mechanism used to turn off the machinery in an emergency when it is not possible to switch off in the usual manner. Unlike a normal shut-off switch, which shuts off all systems orderly without any damage, an emergency switch is set to shut down all operation as fast as possible (even if it damages the equipment) and to be operated simply and fast.
Stack Lights 	Stack lights are used in equipment to improve process control by providing visual indicators (through the colors) that represent the state of the machine, informing of the occurrence of an unwanted stop or anomaly.

Sensors for robots and driverless vehicles were not approached in such detail since they are sensors too specific for the main subjects of this work.

2.2.5.2 DRIVE SYSTEMS (ACTUATORS)

From the information collected from the sensors, the PLCs act on the machine through drive systems (or actuators) capable of performing the most varied type of operations. In this way, actuators are components that convert signals sent by the controllers into physical parameters. In other words, actuators are devices that convert a type of energy (generated from a source) into mechanical energy (usually in the form of linear or rotational motions) [65].

The types of actuators that exist are directly related to the source of power that makes them operate. In automatic materials handling equipment, the most commonly used types of actuators are those that operate from hydraulic, pneumatic and electric power (Figure 36). In a very brief way, hydraulic actuators are driven by the movement of a hydraulic fluid under pressure, pneumatic actuators are driven by the movement of compressed air, and electric actuators are driven through the electricity that is generated by the power stations. The choice of the type of actuator to be used in a particular equipment depends on several factors such as the type of load, the function to be performed, the desired accuracy, or even the cost [84],[85].

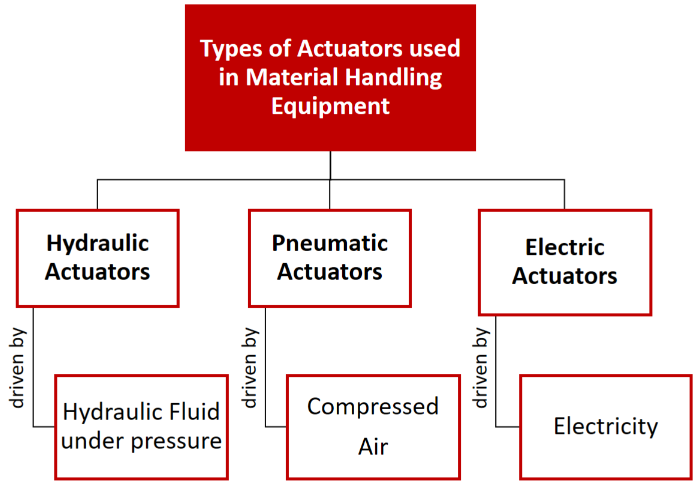


Figure 36 - Types of actuators used in material handling equipment [84],[85].

In the following sections, a more detailed description of each type of actuator was made.

Hydraulic Actuators

As already mentioned, hydraulic actuators are driven by the transport of hydraulic fluids under pressure. As such, these actuators are inserted in a hydraulic circuit, which is composed of a hydraulic pump responsible for pumping the fluid from a reservoir (Figure 37), causing it to reach pressures in the order of 400 bar [85],[86].

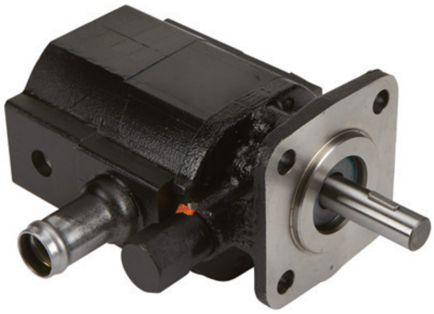


Figure 37 - Example of a hydraulic pump [86].

Hydraulic systems perform energy transmission through Pascal's Law which states that "when there is an increase in pressure at any point in a confined fluid, there is an equal increase at every other point in the container". In Figure 38, this means that when a smaller force (F1) is applied over a smaller area (A1) it can move a much larger load (F2) if it is supported on an area (A2) that is high enough to lower the pressure (P1 = P2). Under this principle, hydraulic systems need lower dimensions and powers to handle the loads, which makes the hydraulic actuators widely used in applications that require the handling of high loads while maintaining high movement accuracy. Within material handling equipment, hydraulic systems are widely used in positioning tables and lift trucks [85].

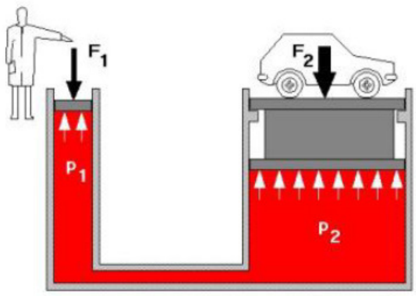


Figure 38 - Example of application of Pascal's Law [85].

In addition to the pumps, hydraulic circuits are also made up of actuators that serve to realize the movements of drive of the machines where they are applied, and valves that serve to control the actuators of the circuits. Although there is a huge diversity of valves and actuators, the most common are, respectively, the hydraulic directional control valve and the hydraulic cylinder (Figure 39) [85],[87],[88].

The directional valve is a device with multiple input and output ports that allow the fluid to be directed to more than one actuator from a single source. In other words, it is a device that controls the flow of hydraulic fluid that is sent to the actuators, however the opening and closing of the doors (functioning positions) is ensured mechanically or electrically through automation and control devices [85].

The hydraulic cylinder is an actuator constituted by a piston that exerts a high unidirectional load, providing linear movement in response to hydraulic pressure [85].

Figure 39 - Example of a hydraulic directional control valve (a) and a hydraulic cylinder (b). Adapted from [87],[88].

Pneumatic Actuators

Pneumatic systems have some similarities with hydraulic systems. In pneumatics, the actuators are driven by compressed air, a safe and inexhaustible source of energy that is obtained after aspiration and accumulation of air from the atmosphere under pressure. The production of compressed air is ensured by compressors (Figure 40) which increase the air pressure of the atmosphere by reducing its volume, retaining it in reservoirs for later use [85],[89].

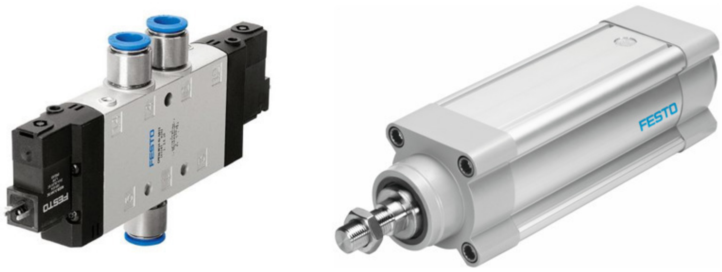
Figure 40 - Example of an air compressor [89].

Compressed air is easy to transport and store, and can achieve high working speeds (1 to 2 m/s), however, the major disadvantage of this energy source is that it is not possible to maintain speeds and forces since there is a limitation of maintaining working pressures between 6 and 12 bar which makes the actuator work forces low (between 20 and 30 kN). For this reason, pneumatic actuators are most commonly used in applications requiring low loads and high operating speeds and are widely used in robot manipulation tools [85].

As in hydraulic circuits, pneumatic circuits are also mainly made up of valves and actuators for the same purpose. However, the difference lies in the operating principle since compressed air and hydraulic fluid under pressure are two completely different energy sources. The most common pneumatic valves and actuators are, respectively, the directional control valve and the pneumatic cylinder (Figure 41), which perform the same function as is performed by these same devices in the hydraulics [65],[85],[90].

The pneumatic directional control valve is used to control the flow of compressed air that is sent to the actuators and is characterized by the number of input/output ports and by the number of configurations it can assume when it is actuated [85].

The pneumatic cylinder consists of a piston that exerts a unidirectional force, and is often characterized by the return of the piston to its initial state after performing the linear movement (if by spring or by compressed air) [65].



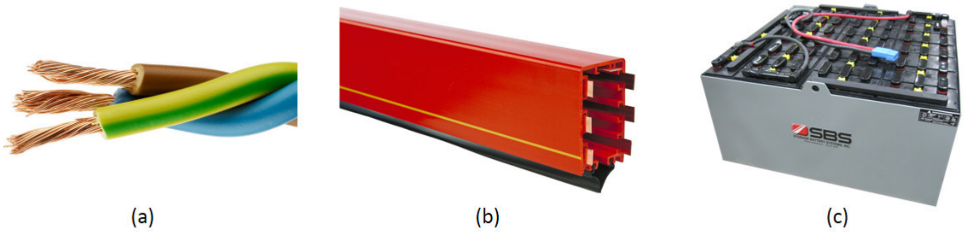
(a) (b)

Figure 41 - Example of a pneumatic directional control valve (a) and a pneumatic cylinder (b). Adapted from [65],[90].

Electric Actuators

Electric actuators operate from the electrical energy which is one of the cleanest, most available and cheapest forms of energy available, which makes these actuators the most used in material handling equipment. Another great advantage of these actuators is that they cover a wide range of speeds and loads at low power, which allows them to be used for all types of applications [65],[84].

The electrical supply of the equipment depends essentially on whether they are fixed or mobile. In the first case, the power is supplied by electrical cables that connect the different machines to the electricity generator (Figure 42 - a). In the second case, there are two possible scenarios: if the machine moves linearly, it is common to use a conductor bar (Figure 42 - b) that accompanies the whole course of the machine and which is no more than a rail with copper wires that are connected to the machine through a contact device that slides along the rail during the movement of the machine; if the movement of the machine is unpredictable and random, it is common to use energy storage forms such as rechargeable batteries (Figure 42 - c) that can be mounted directly on the machines [91],[92],[93].



(a) (b) (c)

Figure 42 - Examples of electrical cables (a), conductor bar (b) and rechargeable batterie (c). Adapted from [91],[92],[93].

The main electric actuators used to drive the machines and equipment are the electric motors that have the function of converting electrical energy into mechanical energy, usually in the form of rotational movement (torque). This type of actuator is characterized by the type of current that operates it, which can be either direct current (DC) or alternating current (AC) motors (Figure 43). DC motors are electromagnetic rotary motors widely used in applications where power is supplied through batteries. However, since they are quite compact and able to fully control the angular displacement of the axis (DC stepper motors), they are widely used in robots [65],[84],[94],[95].

AC motors are electromagnetic rotary motors, more commonly used than DC motors because they are cheaper, simpler in construction, and are more suitable for applications that are powered by electric cable (electricity generator) or by conductor bar system [65],[84].

(a) (b)

Figure 43 - Example of an electric DC motor (a) and an electric AC motor (b). Adapted from [94],[95].

The maximum mechanical efficiency of electric motors generally occurs at high speeds, so it is common to use gear units, thereby reducing speed and hence obtaining an increase in torque available for transmission of mechanical power. The motor and gearbox assembly is called the gearmotor (Figure 44) [96],[97].

(a) (b)

Figure 44 - Example of an electric DC gearmotor (a) and an electric AC gearmotor (b). Adapted from [96],[97].

2.3 MECHANICAL ENGINEERING DESIGN PROCESS OF A MACHINE

Mechanical design is a complex process assured by mechanical engineers, but it requires both mastery and knowledge of many fields beyond mechanical engineering. It is a very variable process that starts from scratch and goes through a series of steps that are dependent on each other, making it also an iterative process [98].

The process starts with the design phase in general and selection of the mechanical components so that the machine can fulfill its intended purpose, and there are several resources to support the engineer such as sources of technical information and computational design tools [98].

The second step is to prevent the failure of the mechanical components through the calculation of stresses and strength, which leads to an optimization of the machine design [98].

The third stage happens when the entire machine is designed and needs to be put into production. For this purpose, detailed drawings with the dimensions and tolerances of each part are produced so that they can be manufactured and assembled in the machine [98].

The process ends with the issuance of all relevant technical documentation such as the technical data sheet of the machine, the maintenance manual, among others [98].

In the sections that follow, it is possible to perceive in more detail each of the stages of the mechanical design of a machine.

2.3.1 THE DESIGN PROCESS

The design of a machine arises after the appearance of a specific need or problem to solve. This problem may be the need to perform a certain task automatically such as handling a material.

Design is a very iterative process supported by constant decision-making that is often made on the basis of little information and then adjusted as the machine is developed. As such, mechanical engineers must have a well-resourced problem-solving ability and, because it is a work that addresses people from different areas, they must also develop high oral and written communication skills [98].

Mechanical engineering is the main building block of machine design, being present in all stages of this process, since it is an extremely comprehensive discipline. In addition, mechanical design covers practically all areas of mechanical engineering, from the production and transmission of energy, the mechanics of materials and solids, manufacturing processes, technical drawings, to the electrical and computer components of machines [98].

The design process can be divided into a series of main steps that are linked together, constituting a sequence that is represented in Figure 45. The complete process begins with the identification of a need in a still very vague way. Next, the specification of the need is set out in more detail by defining the problem. With the problem defined, a synthesis of possible solutions is made and the hypotheses that do not fulfill the requirements are discarded through a deep analysis and optimization. In the end, the best solution is evaluated, and a final presentation is made to the main receiver, where the engineer must defend his work and the solution he has defined. It is important to mention that throughout the process several iterations are performed between the stages of the sequence so that it is possible to answer the various questions that arise [98].

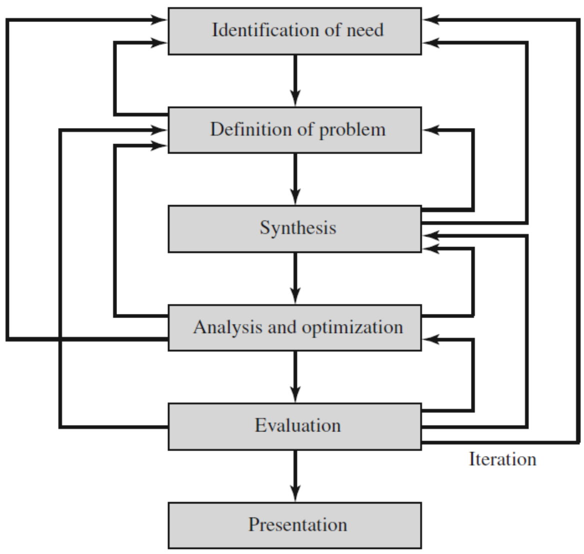


Figure 45 - The phases of the design process [98].

Currently, there is a wide variety of resources available to assist the mechanical engineer when designing a machine. These resources are basically made up of published technical information and computational tools. Sources of technical information are no more than engineering books, government sources, legal standards, or catalogs of manufacturers of mechanical components [98].

The computational tools are essentially the computer-aided design (CAD) and computer-aided engineering (CAE) software. CAD software allows the modeling of the machine in three dimensions (3D), and it is possible to perform the two-dimensional (2D) detail drawings from the modeling. Some examples of CAD software are AutoCAD, Inventor or Unigraphics [98].

CAE software allows to simulate some engineering applications, such as resistance calculations or fluid dynamics. An example of this type of software are the finite element analysis (FEA) programs such as ANSYS or Algor [98].

The mechanical engineer must then combine the design process with the tools that are available to create machines that are essentially functional, secure, reliable, competitive, usable, manufacturable, and marketable.

2.3.2 STRESS AND STRENGTH CALCULATIONS

The calculation of stress and strength of materials is one of the most important steps in the design of a machine. At this stage the mechanical engineer must ensure that the loads exerted on the parts do not cause stresses that exceed the tensile strengths of the materials, creating irreversible displacements in the geometry [98].

This calculation is usually performed on the most critical parts of the machine, such as bolts, beams or shafts, and can be made in two different ways depending on the type of load to which the part is subjected. If the load is static then the calculation is performed considering a static behavior in the part, where the existing stresses cannot exceed the yield stress of the material. If the load is cyclic, then the calculation is performed considering a dynamic behavior in the part, where the existing stress cannot exceed the fatigue limit of the material [98].

It is thus possible to optimize the machines so that they are not oversized for the loads to which they are subjected, however, one should always consider a margin of error when performing the calculations, since there are several external factors that can condition the behavior of the machines, parts and material properties, such as the manufacturing processes or the working temperature of the machine. Through the safety factor, a dimensionless value defined by the mechanical engineer or by tables of standards that increases the loads considered in the calculations above their actual values (generally doubling the actual values), there is always a margin for the possible unexpected variations of the behavior of machines [98].

The calculations of stress and strength of the parts of this work were carried out by the FEA, which is based on the integral or differential equations of mechanics of the materials, through a CAE software.

Solving problems of mechanics of materials analytically through differential equations is only possible for simple geometries where all constraints are well defined and controlled. The reality of machine design is that the problems to be analyzed are much more complex than theoretical ones, and it is here that the FEA plays a fundamental role in the optimization of the products, since it allows to divide the model to analyze in many small parts of simple geometry denominated finite elements, creating a mesh (Figure 46). The vertices of each finite element are designated nodes and, in a general way, the FEA establishes a numerical estimation of algebraic equations that return approximate solutions of the stresses and displacements in each one of the nodes, straining them to the complete model [99].

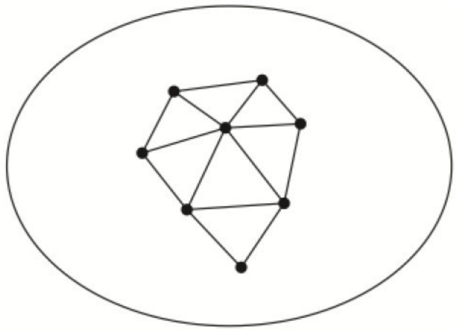


Figure 46 - Creation of a mesh with elements of simple geometry [99].

The FEA can be used in many other applications besides the analysis of stresses and displacements of mechanical components, such as the seismic analysis of civil constructions, however, all of them are based on a procedure consisting of three stages [99]:

1) Preprocessing;
2) Solution;
3) Postprocessing.

In preprocessing, the finite element mesh is defined, choosing the type and size of the element and the refinement of the mesh to guarantee precision of the results. Then it is necessary to define the material and mechanical properties of the model. At the end, the loads are applied, and the physical constraints are established in the form of reaction forces (called boundary conditions), simulating the balance of forces of the real body (Figure 47) [99],[100].

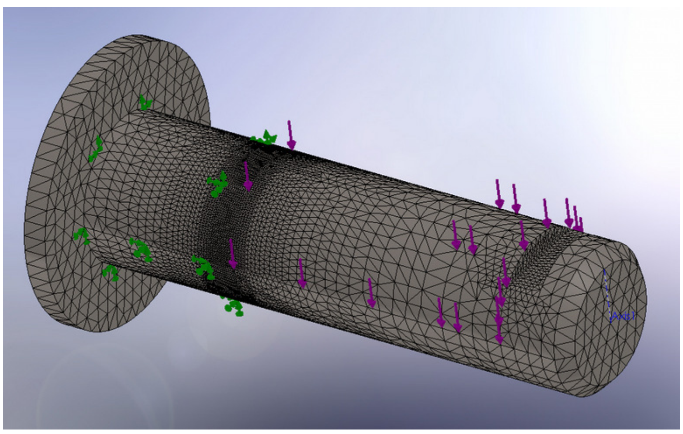


Figure 47 - Mesh creation and boundary conditions in FEA [100].

In the phase of obtaining the solution, the FEA software calculates the algebraic equations for each finite element, forming a system of global equations. In this step the numerical values of the stresses and displacements are obtained [99].

Post-processing is the analysis phase of the simulation results. The software orders the stresses of the elements by magnitude, creating an animation of the model with a color scale of stresses and displacements (Figure 48). At this stage, it is still possible to verify the static equilibrium of the body and to calculate safety coefficients and reaction forces [99],[101].

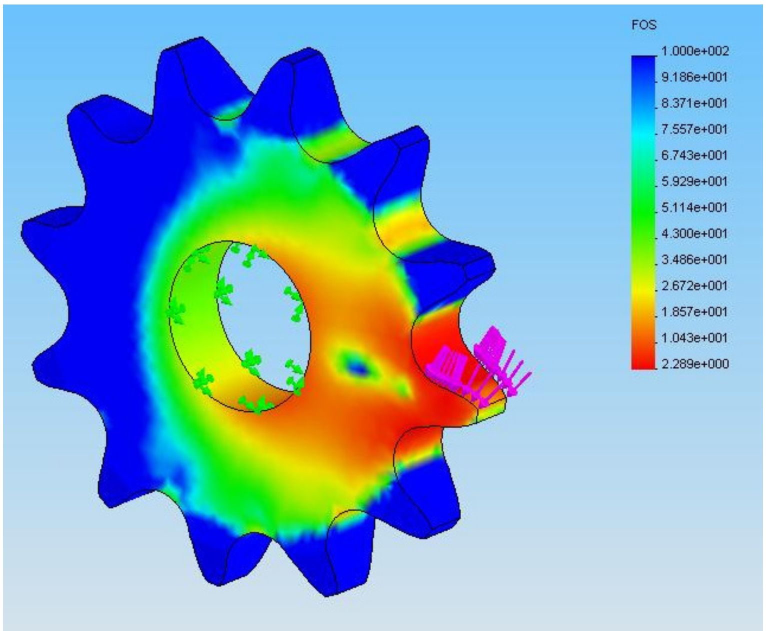


Figure 48 - Animation with color scale of stresses and displacements in FEA [101].

2.3.3 DETAIL DRAWINGS

After realizing the complete design of the machine, it is necessary to manufacture the different parts that constitute it and carry out the assembly operations. For this, the drawings of the parts and the assemblies are made using a universal representation language with rules and symbols established by legal standards of technical drawing, being therefore a means of expression and communication [102].

The drawings of the parts represent a single component of a set and provide, by means of an orthographic representation, their general dimensions and acceptable manufacturing tolerances (Figure 49 - a). It is therefore all the technical information necessary to produce the parts, with a graphic presentation established according to ISO standardization that makes it universal [102],[103].

The assembly drawings give the parts lists and the details of the arrangement of the assembled components (Figure 49 - b). These drawings may be in orthographic or isometric representation, with views of the assembled set of parts or exploded views [102],[103].

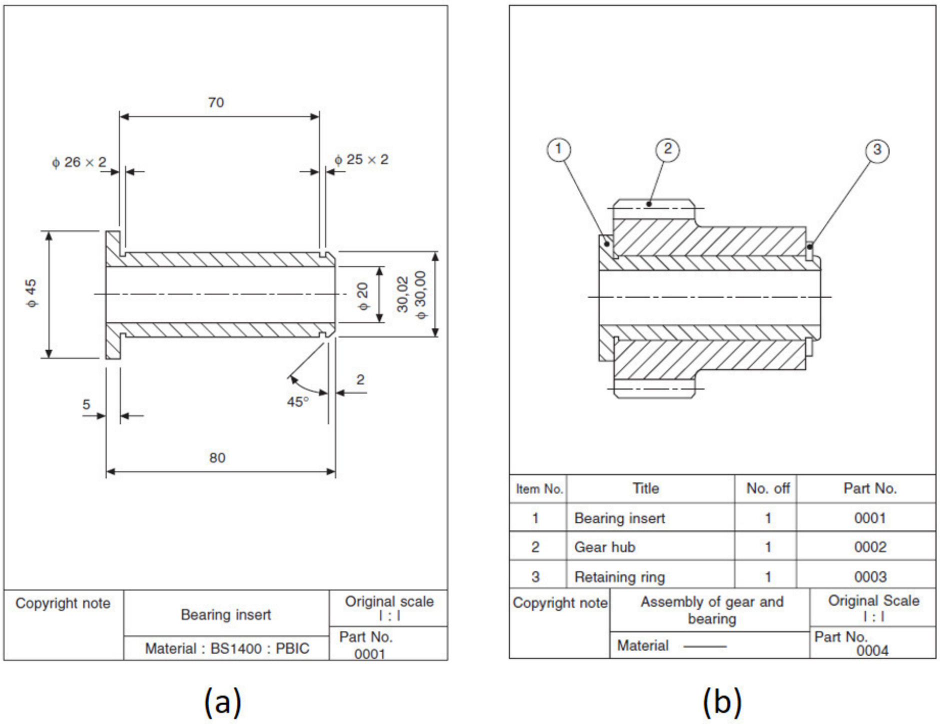


Figure 49 - Examples of part drawing (a) and assembly drawing (b). Adapted from [103].

2.3.4 TECHNICAL DOCUMENTATION

In addition to ensuring and monitoring all stages of the design of a machine, including the manufacturing and assembly operations, the mechanical engineer may also be responsible for ensuring the issuance of the following technical documentation related to the machine [104]:

1) Spare parts list - list of parts critical to the operation of the machine and which suffer greater wear over the lifecycle of the machine. These parts must be purchased for stock in the event of a breakdown, so that the machine can be repaired immediately;
2) User manual - technical communication document designed to assist persons in using the machine. Generally, it is performed by automation engineers, although it can also be written by mechanical engineers;
3) Maintenance manual - Technical communication document designed to assist people in maintaining the machine. This document contains the operations required to repair the machine during a preventive or corrective maintenance task, such as replacing an end-of-life component.

2.4 MECHANICAL EQUIPMENT STANDARDS

Before the creation of the European Union (EU), the commercial exchange of products between the different countries of Europe was largely conditioned by the different technical specifications required for each state. After the creation of the EU, it was necessary to eliminate all obstacles to the free movement of products, creating a single homogeneous market. As such, a set of directives was created to ensure that the safety conditions of the products were met by approaching the design, manufacture and marketing of the products [104].

Currently, machine safety throughout the EU is legally secured by a set of directives and standards. The directives are mandatory and establish the essential safety requirements, being divided between the economic aspect, which establishes the set of requirements for the placing on the market and entry into service in the area of health, people, goods and animals, and the social aspect, which establishes the rules for accident prevention and improving the safety of workers in the workplace. On the other hand, the standards are optional and function as guides that provide more technical specifications for compliance with the requirements of the directives [104].

The main directive that is currently used to regulate the safety of machines and equipment is the Machinery Directive (Directive 2006/42/EC) which establishes the rules and procedures for the legal marketing of machines, and is addressed to the respective manufacturers and merchants. A manufacturer is any natural or legal person responsible for the design and/or manufacture of a machine [104].

If the machines are used by workers in the workplace, it is necessary to add the Machinery Directive to the Use of Work Equipment Directive (Directive 2009/104/EC) to ensure the safety of workers. As such, the aim of this directive is to promote the improvement of working conditions, ensuring a higher level of protection of the health and safety of workers [104].

In terms of material handling equipment, it is important to highlight the standards created by the European Materials Handling Federation (*Fédération Européenne de la Manutention*, FEM), which provide a set of technical specifications that focus on integrating safety into design, supporting European manufacturers of equipment of this scope [105].

In the following ssections a more detailed description of the directives presented here was made.

2.4.1 MACHINERY DIRECTIVE

The Machinery Directive (Directive 2006/42/EC) applies to all machines placed on the market or in service since the date on which it became official. As such, all machinery, whether new or used from inside or outside the EU, whose destination is the internal market are covered by this Directive and must comply with all safety and health requirements [104].

According to the Directive, the concept machine may be defined as "an assembly, fitted with or intended to be fitted with a drive system other than directly applied human or animal effort, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application". The equipment presented in this work are considered machines so only the procedures covered by the Machinery Directive for this type of equipment were addressed [106].

Compliance with the requirements of the Directive must be considered at all stages of the design and manufacture of a machine because, if all safety and health requirements are not met, the machine cannot be used and marketed. As such, the Directive can be fulfilled through the following main steps [104]:

1) Ensure that the machine meets the essential safety, health and environmental protection requirements;
2) Produce a technical file of the machine with relevant technical documentation;
3) Issue the EU/EC declaration of conformity and affix the CE marking to the machine.

The safety, health and environmental protection requirements applicable to each machine shall be adopted at the design stage by implementing necessary protective measures and / or informing users of the existing hazards and the need to use protective devices [104].

In the first instance, one of the ways of ensuring the key essential safety requirements of the Directive can be to consult harmonized standards at the design stage. Harmonized standards, which are not compulsory, serve as methodological guides made up of technical specifications which are designed as aid to designers and manufacturers who need to integrate the technical rules defined by the European directives in the design and manufacture of machines. Often these standards can still be adopted as evaluation methods used by recognized standards bodies.

The Machinery Directive relies on the technical specifications of a hierarchy of European standards (ISO, EN and IEC standards). This hierarchy is composed of three levels and is represented in Figure 50 [104],[107].

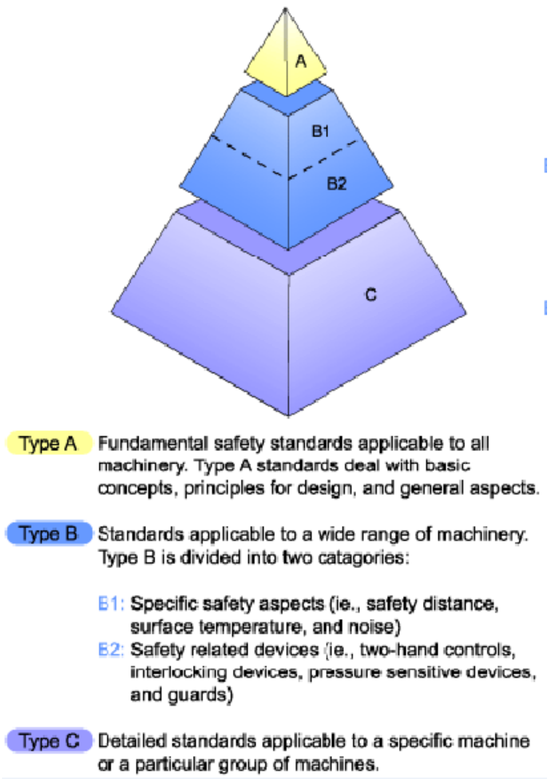


Figure 50 - Hierarchy of European Standards [107].

Another way of ensuring the viability of a machine in terms of safety for people and the environment using the least resources is to carry out a risk assessment. This is a way of determining the level of risk by defining the limits of the machine's use to identify the safety mechanisms to be implemented [104].

Risk assessment plays a key role in the manufacture of a machine because it is this assessment that allows determining the technological solutions to be implemented to make the equipment safe. There are standards that serve as guidelines for the preparation of a risk assessment such as ISO EN 12100-1: 2003 and ISO EN 12100-2: 2003 [104].

The flow diagram in Figure 51 represents the risk assessment process that begins with a hazard identification, an estimation of the associated risks and ends with an analysis of the existing safety levels, repeating the procedure until these levels are acceptable after implementation of security measures [108].

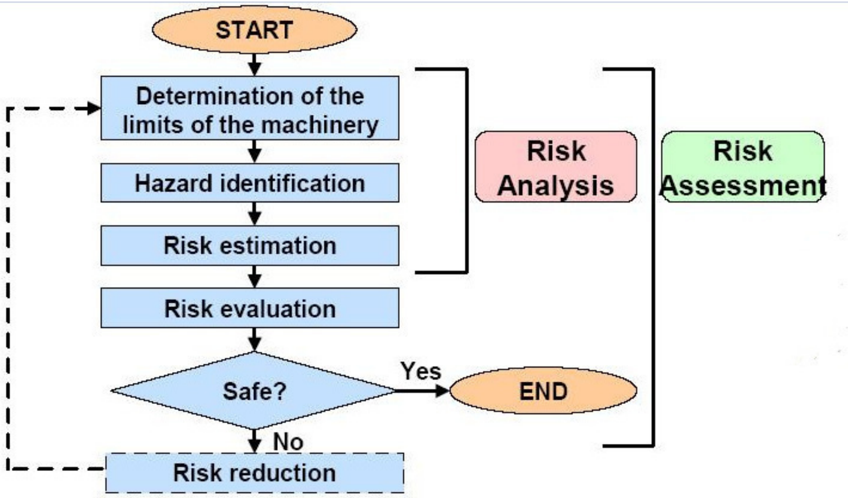


Figure 51 - Flow diagram of Risk Assessment [108].

There are a variety of risks associated with a machine depending on its function and operation. These hazards can be caused mechanically, electrically, thermally, by noise, by vibrations, by radiation, by hazardous materials and substances, or by disrespect of the ergonomic principles of machinery. As discussed in section 2.2.2, one way of minimizing the risks present in the machine may be protection devices which are nothing more than components that interact with the machine, preventing operator access to danger (Figure 52) [104].

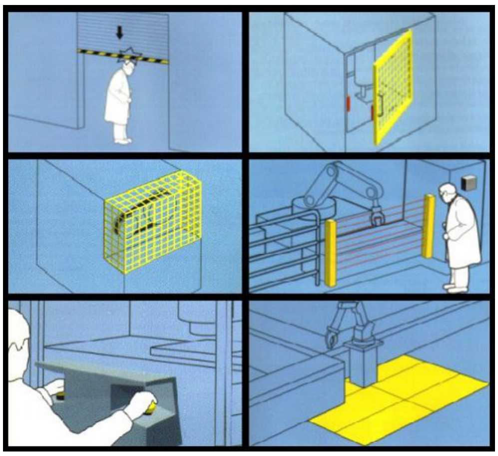


Figure 52 - Different types of risks and protective devices [104].

The second step of the Machinery Directive procedures for a machine to be marketed and used is to constitute a technical file with all relevant technical documentation. This file acts as a register that proves that the machine has been designed and manufactured in accordance with the required safety requirements. As such, it must be produced in accordance with Annex VII of the Directive and must contain all relevant technical documentation such as assembly drawings, control and power circuits, certificates, calculation notes, operating instructions, technical description of the machine, among others [104].

The EC declaration of conformity is the document attesting that the machine meets the essential requirements of the Machinery Directive. When designing and signing the EC declaration of conformity, the manufacturer shall assume responsibility for the conformity of the machinery and shall issue it prior to placing the product on the market. According to Annex II of the Directive, the declaration must contain elements such as the name and address of the manufacturer, machine identification (type, model and serial number), place and date of declaration, among others [104].

The CE marking of a machine is a declaration by the manufacturer that the product is in conformity with the essential requirements of the relevant European legislation on health, safety and environmental protection. The letters "CE" are the initials of French phrase "*Conformité Européene*" which means "European Conformity". All machines covered by the Machinery Directive must bear the acronyms "CE" and the identification number of the notified body involved in the production control phase recorded on its surface, so that they can be marketed and used. This marking shall be carried out in accordance with Annex III of the Directive and the dimensions and shapes laid down shall be respected (Figure 53) [104].

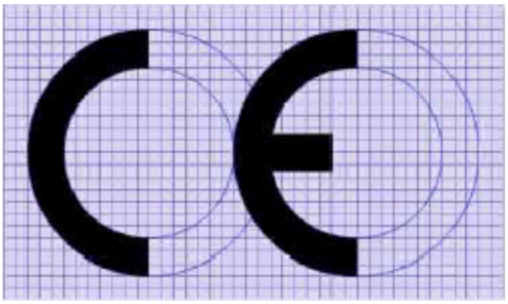


Figure 53 - CE marking [104].

2.4.2 USE OF WORK EQUIPMENT DIRECTIVE

The Use of Work Equipment Directive (Directive 2009/104/EC) establishes the minimum safety and health requirements for the use of work equipment by workers at work and is therefore often added to the Machinery Directive as a way of ensuring the safety and health of workers. It is applicable to all branches of activity of the private, cooperative and social sectors, central public administration, regional and local, public institutes and self-employed [104].

According to the Directive, a work equipment is "any machine, apparatus, tool or installation used at work" and, in turn, the use of work equipment is defined as "any activity involving work equipment such as starting or stopping the equipment, its use, transport, repair, modification, maintenance and servicing, including, in particular, cleaning" [109].

Safety and health requirements must be guaranteed at the design and manufacturing stage of the work equipment, however periodic checks and tests must also be carried out to ensure the proper functioning of the equipment, thus avoiding accidents and consequences to the workers safety [104].

Material handling equipment, such as stacker cranes, are often used by workers in a variety of ways, either by starting or stopping machines or through maintenance activities over their lifetime (Figure 54). For this reason, the Use of Work Equipment Directive is therefore applicable to this type of equipment [110].

Figure 54 - Maintenance of the gearmotor of a stacker crane [110].

2.4.3 FEM STANDARDS

As already mentioned, the European Federation of Material Handling (FEM) is an association representing European manufacturers of material handling, lifting and storage equipment (Figure 55). Founded in 1953, this association was created with the purpose of supporting these manufacturers through the publication of legal standards with technical recommendations for the machine designers in Europe [105].

Figure 55 – FEM logo [105].

The FEM standards are no more than technical guides with very specific rules for the design of this type of equipment, providing recommendations on structural calculation, safety coefficients, periodicity of inspections, among others. The FEM technical documentation is divided by the types of equipment covered (Figure 56) [111].

Heavy lifting and Handling Equipment
Continuous Handling Equipment
Industrial Trucks
Mobile Cranes
Series Lifting Equipment
Storage and retrieval machines
Elevating Equipment
Mobile Elevating Work Platforms

Figure 56 - Types of equipment covered by FEM standards [111].

THESIS DEVELOPMENT

3.1 DESCRIBING THE PROBLEM

3.2 BENCHMARKING

3.3 PRODUCT DEFINITION

3.4 MECHANICAL DESIGN

3 THESIS DEVELOPMENT

3.1 DESCRIBING THE PROBLEM

One of the first steps of the work was to define concretely what problem to solve. From there, the desired objectives were established and the way forward was traced.

The challenge proposed was to develop a shuttle vehicle for the box shuttle AS/RS. As already mentioned (see section 2.2.2), this is the great innovation of this type of AS/RS, having the function of storage and retrieval the products. As such, the major goal of this work was to design a shuttle vehicle that fulfilled its basic function but which at the same time could be innovative when compared to what already exists in the market.

As already mentioned (see section 2.2.2), the shuttle vehicle is like a cart that has four or more wheels and it moves along two rails that are part of the racking structure (Figure 57). When applied on a box shuttle AS/RS, it is capable of transferring packages (cartons, totes or trays) in and out of the layered stacked racks and transport them in a package carrying area [68].

Figure 57 - Example of a shuttle vehicle for cartons, totes or trays [68].

Its main characteristic is the ability of running along the racking structure at high speeds, increasing system cadences and warehouse productivity. However, there are some differences between all the shuttle vehicles existing in the market. The major differences are in the mechanism that is used to store and retrieve packages, and in the source of power that feeds the system. Those differences were described and analyzed in the next section.

3.2 BENCHMARKING

3.2.1 ANALYSIS OF EXISTING SOLUTIONS IN THE MARKET

Having defined the problem to solve, it was necessary to make a complete analysis of the existing solutions in the market and, from there, to study the advantages and disadvantages of each one. The tool that was used to organize ideas and filter distinct aspects was the SWOT analysis.

The first solution encountered is a shuttle vehicle equipped with a telescopic load extractor that expands and contracts to adjust the carrying area for varied sizes of boxes. The power comes from busbars existing in the railway and the vehicle is only capable of moving in one direction. The Dematic Multishuttle® is an example of this solution (Figure 58 and Figure 59) [30].

Figure 58 - Dematic Multishuttle® equipped with a telescopic load extractor [30].

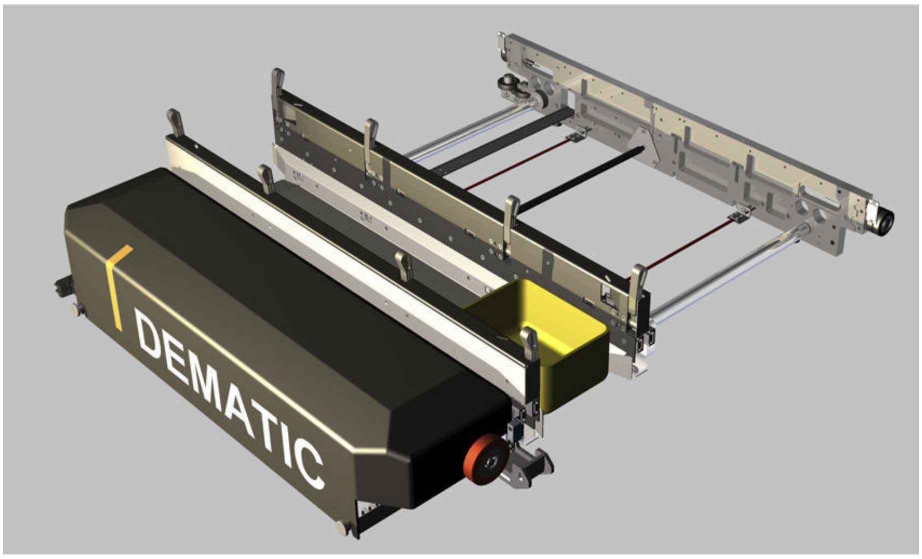


Figure 59 - Dematic Multishuttle®: expansion and contraction of the carrying area [30].

The SWOT analysis for this type of shuttle vehicle is represented in Figure 60.

Strengths • The telescopic load extractor expands and contracts to adjust the carrying area for varied sizes of boxes; • The power comes from busbars so there's no lost time in battery charging.	S	W	**Weaknesses** • The shuttle vehicle is only capable of moving in one direction; • Conductor bars are a source of energy very expensive; • The packages have to travel longer distances from the racking system to the picking stations.
Opportunities • Highly recommended to warehouses that have varied types and sizes of boxes; • High responsiveness to large volumes of customer orders.	O	T	**Threats** • High initial investment dependent on the number of vehicles installed; • High complexity of automation and programming, and in the electrical design process.

Figure 60 - SWOT Analysis for the Dematic Multishuttle®.

The second solution is quite different from the first one. It is a shuttle vehicle that comes with a load deck plate that moves over a belt conveyor, however the carrying area has a fixed length, width and height. On the other hand, it is capable of rotating 360°, thanks to its pivoting wheels, which allows the vehicle to move crosswise and longitudinally, something that is only possible with the use of batteries to feed the system. This solution belongs to KNAPP AG with his YLOG-shuttle (Figure 61 and Figure 62) [112].

Figure 61 - YLOG-shuttle-system (from KNAPP AG) with an extractor plate that moves over a belt conveyor [112].

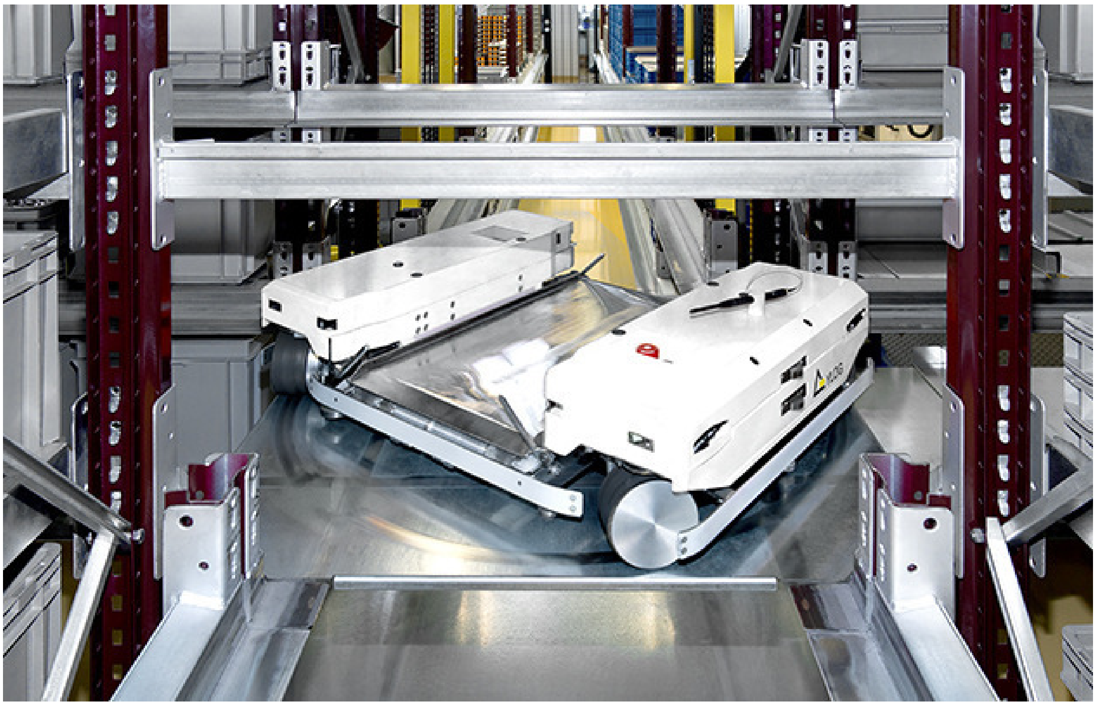


Figure 62 - YLOG-shuttle-system (from KNAPP AG): pivoting wheels that allows the vehicle to move transversely and longitudinally [112].

The SWOT analysis for this type of shuttle vehicle is represented in Figure 63.

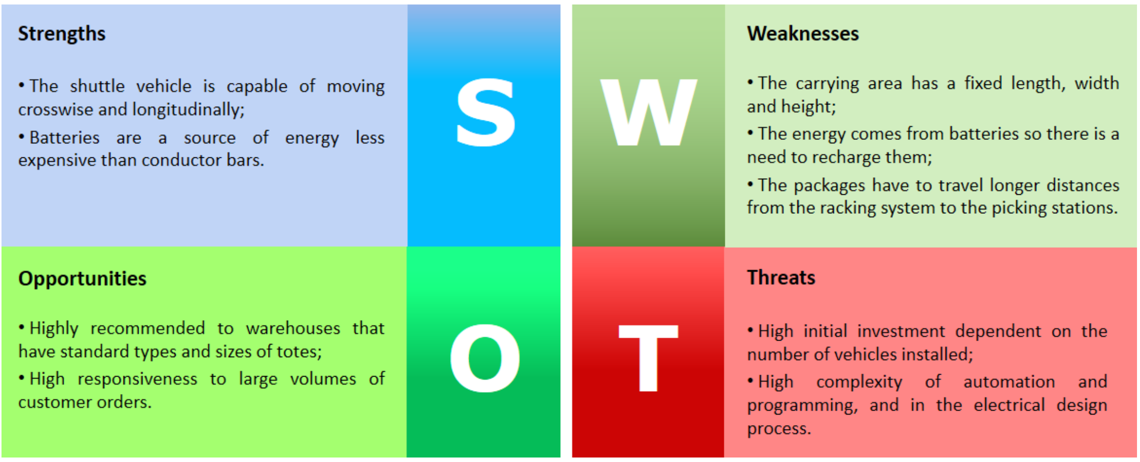


Figure 63 - SWOT Analysis for the YLOG-shuttle-system (from KNAPP AG).

The next solution is very much like the previous one. It also works with batteries and the vehicle can move crosswise and longitudinally. The difference is in the extraction mechanism and the carrying area. In this case, it is composed by a belt conveyor and the carrying area has an open base with fixed dimensions. The ADAPTO from Vanderlande is an example of this solution (Figure 64) [113].

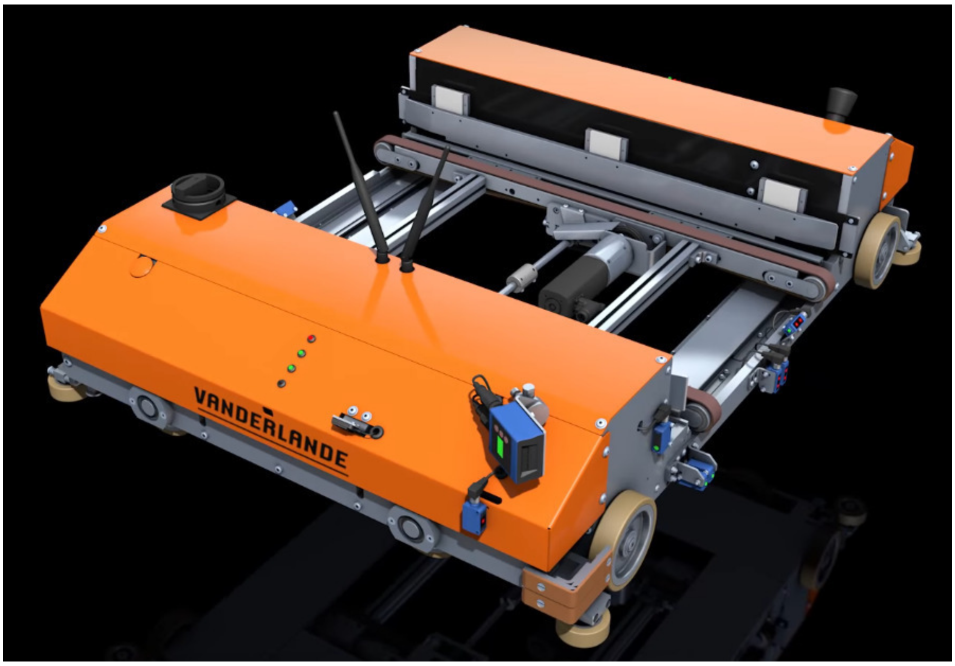


Figure 64 - ADAPTO from Vanderlande with a belt conveyor to extract the packages from the racking system [113].

The SWOT analysis for this type of shuttle vehicle is represented in Figure 65.

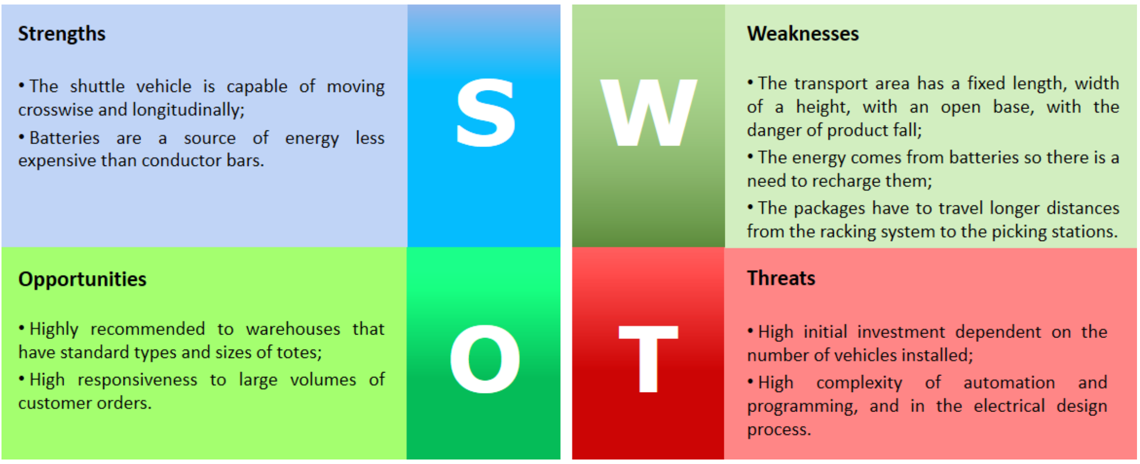


Figure 65 - SWOT Analysis for the ADAPTO from Vanderlande.

The last solution is the Perfect Pick® from OPEX Corporation, an innovative method to make the operations of goods-to-person faster. It is a shuttle system that has the picking stations directly connected to the racking system (composed with only one aisle), in other words, the shuttle vehicles provide the operators without resorting the packages to conveyor systems, working as a single module that encompasses all these components (Figure 66) [114].

The shuttle vehicle in this system walks around a racking structure, going down to the various levels by means of a mechanism actuated by rack and pinion. It is powered by ultracapacitors that capture regenerated energy from a conductor bar, runs along one direction, and the extraction device is a roller conveyor that picks and stores totes and trays on both sides of the aisle (Figure 67) [114].

Figure 66 - Perfect Pick® solution from OPEX Corporation [114].

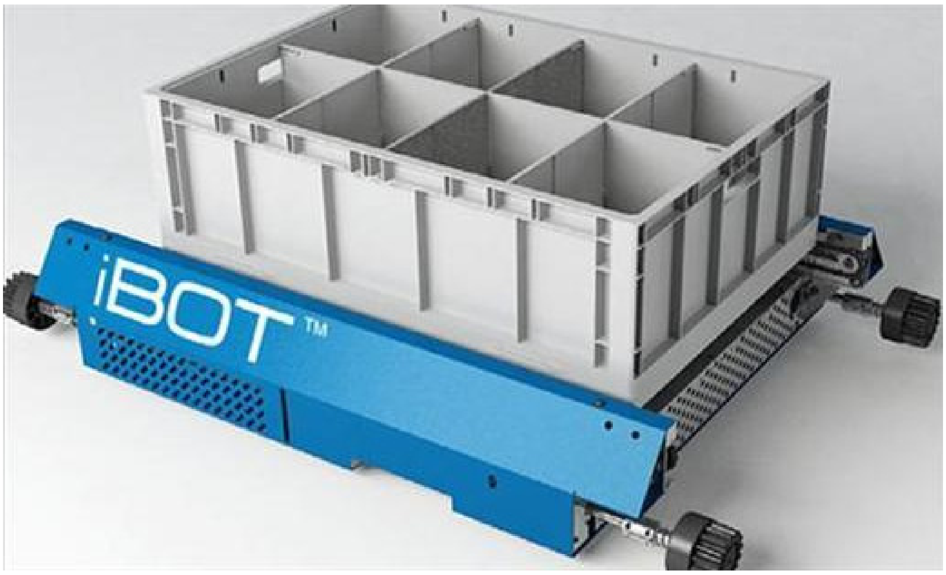


Figure 67 – Perfect Pick® solution from OPEX Corporation: the iBOT® shuttle vehicle [114].

The SWOT analysis for this type of shuttle vehicle is represented in Figure 68.

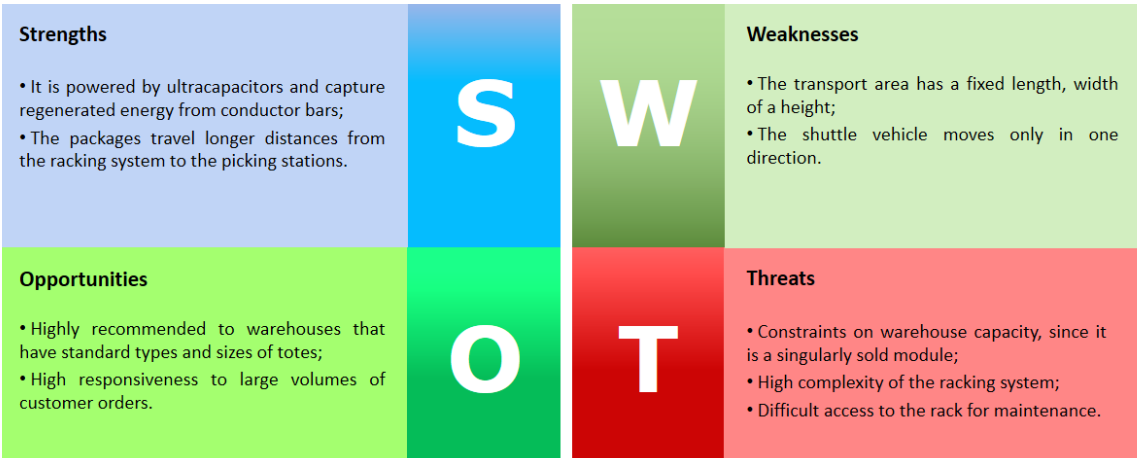


Figure 68 - SWOT Analysis for the Perfect Pick® solution from OPEX Corporation.

In this section, only the main solutions available in the market were analyzed, however there are more similar solutions from other manufacturers.

3.2.2 ANALYSIS OF EXISTING PATENTS

Before starting the mechanical design of the shuttle vehicle, some of the main patents related to this type of equipment were analyzed. In this way, it was possible to know more in detail the technical concepts of the product and to analyze the claims to be avoided during the mechanical design.

Although there are many other patents related to this subject, only two patents published by Dematic GmbH, one of the main manufacturers and drivers of this solution, were analyzed. The publications reviewed were as follows: *U.S. Patent No. 2011/0008138 A1* entitled *Transferring Shuttle for Three Dimensional Automated Warehouse* and *U.S. Patent No. 2012/0099953 A1* entitled *Shuttle for Automated Warehouse* [115],[116].

The first patent claims a shuttle vehicle for storage and retrieval of packages from a racking structure that is part of a three-dimensional automatic warehouse. This vehicle, shown in Figure 69, is composed by a platform that moves horizontally along the racking structure and which includes an article-carrying area of fixed size. For extraction and replacement of the articles, the vehicle has two retractable arms that extend horizontally in a direction perpendicular to the direction of vehicle movement. This is a telescopic mechanism that draws the products into the transport area through several articulated fingers positioned on each of the arms, being actuated over a transmission by means of belt and pulley [115].

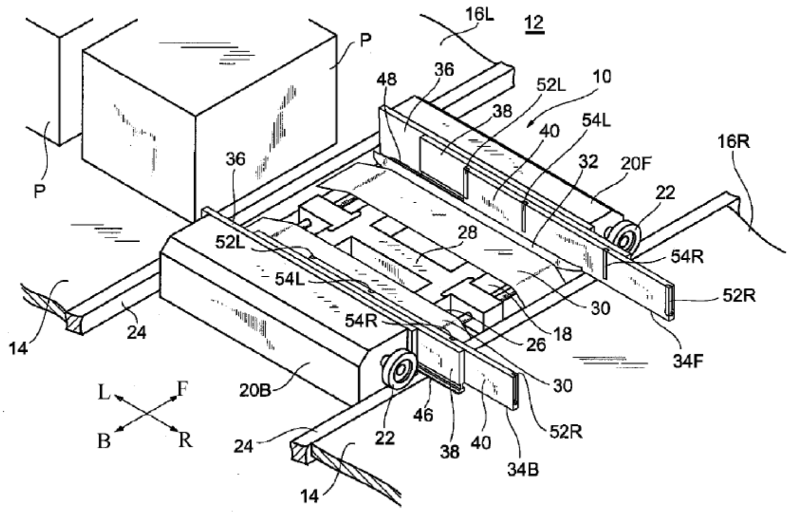


Figure 69 - Transferring shuttle from the U.S. Patent No. 2011/0008138 A1 [115].

The second patent claims a shuttle vehicle very similar to the previous one but with some improvements and variations. This shuttle (Figure 70) is also used in warehouses with several article spaces and a runway for the shuttle to move. It is composed by a structure with two different chassis portions divided by an article-carrying area. Both chassis portions contain a pair of running wheels adapted to travel along the runway, driven by a drive motor connected directly to both wheels through a shaft and a coupling. The products are transferred between an article space and the article-carrying area through two retractable arms similar to the previous patent, containing fingers along the length and a drive mechanism with belt and pulley. However, the great innovation in this patent lies in the connector assembly that links the two chassis portions and is adapted to vary the spacing between, allowing the transport of articles with different widths. This solution is possible through linear actuators or a rack and pinion mechanism, both operated by a drive motor that slides a plurality of overlapping plates along the article support surface [116].

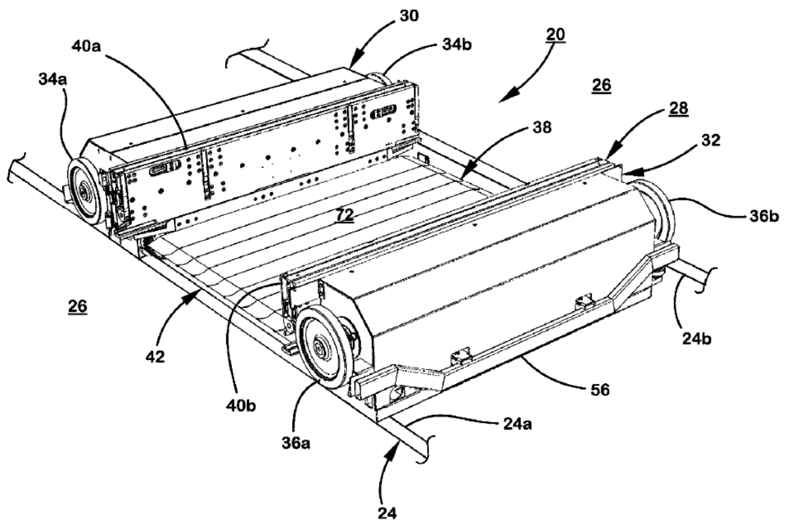


Figure 70 - Shuttle from the U.S. Patent No. 2012/0099953 A1 [116].

3.2.3 PROBLEMS ENCOUNTERED AND HOW TO IMPROVE

According to the analysis performed at the level of existing solutions in the market and some patents related to the subject, it was necessary to identify the problems of the existing solutions in the market, find ways to improve them and create an idea to innovate the shuttle vehicle.

The idea to increase the cadences of the vehicle appeared, in other words, by causing the shuttle vehicle to give the system even more products per minute. The solution found for this problem follows a product introduced by KNAPP AG, the Pick-it-Easy Robot (Figure 71). It is a fully automatic robotic arm capable of performing picking operations for the order-fulfillment process, a task that is normally performed manually by all distribution centers and warehouses. This robotic arm handles small products transporting them from a full box to an empty box that is intended to meet the quantities of a customer order [117].

The idea would be to incorporate a similar solution to the Pick-it-Easy Robot directly in the shuttle vehicle, so that it was able to carry out the picking operations directly on the rack structure, through a material manipulator like a robotic arm of four axes or a system of gantry and gripper. In this way, the shuttle vehicle will increase its cadences because it moves in shorter distances inside the rack structure, and it will create an innovative solution.

Figure 71 - Pick-it-Easy Robot from KNAPP AG [117].

3.3 PRODUCT DEFINITION

3.3.1 MAIN REQUIREMENTS

The developed shuttle is intended for a target market made up of distribution centers and light product warehouses with small dimensions and well-defined geometries such as the pharmaceutical industry or the consumer goods industry (Figure 72), where the products are stored in boxes and order fulfillment operations are a constant [118].

Figure 72 - Consumer goods with small dimensions and well-defined geometries, stored in boxes [118].

The general requirements, without any technical specification, necessary for the design and development of the shuttle vehicle are identified in Table 10, according to the degree of importance to the operation of the equipment and fulfillment of its main function that is to store and retrieve boxes from a rack of an automatic warehouse.

Table 10 - Main requirements for the shuttle vehicle and respective degrees of importance (from 1 (little important) to 5 (very important)).

General Requirement	Degree of Importance
1) The equipment must be able to remove the boxes in both sides of the railway from a single deep stationary rack structure, position them on the transport platform and put them back on the rack structure properly positioned.	5
2) The equipment must have a transport platform with a fixed size for the transport of two boxes.	5
3) The equipment should only move in a straight line, always on a single level of the rack structure.	5

General Requirement	Degree of Importance
4) The equipment must be able to perform the picking operations automatically and directly on the rack structure.	5
5) The equipment must be able to position itself accurately in the different storage positions of the boxes.	5
6) All actuators must be electric.	4
7) The equipment must be kept guided in all directions along the course.	4
8) The electric power supply must allow the movement of the shuttle vehicle over the several meters in length that the rack structure can possess and still be able to operate 24/7.	4
9) The equipment should be as light as possible (supporting all associated loads), as fast as possible, and be produced at low cost.	4
10) The equipment must have all kinds of safety devices, ensuring all EHS protection requirements.	4
11) The maintenance of the equipment shall be facilitated in terms of accessibility to the different components of the vehicle.	3

3.3.2 SELECTION OF SOLUTIONS FOUND FOR THE MAIN REQUIREMENTS

This section describes the phase of prior definition of the solutions found for each of the main requirements of the shuttle vehicle. This definition, although still without any detailed technical specification, allowed to trace the way to go during the phase of the mechanical design and to facilitate the decision making.

Table 11 describes the solution found for each of the requirements and the respective justification for such selection.

Table 11 – Found solution for each main requirement of the shuttle vehicle.

General Requirement	Found Solution
1) Store and Retrieve Boxes	Fixed Stroke Load Extractor
2) Fixed Size Transport Platform	Load Extractor Non-Expandable
3) Vehicle Movement in Straight Line	Non-Pivoting Wheels
4) Perform Picking Operations Automatically	Four-Axis Robot

General Requirement	Found Solution
5) Vehicle Guided on the Route	Side Rollers
6) Accurate Positioning in Box Storage Positions	Bar Code Positioning Device
7) Electric Actuators	AC Gearmotors
8) Electric Power Supply for Movable Equipment	Conductor Bar
9) Lightweight, Fast and Inexpensive Equipment	Optimized Steel Structure and AC Gearmotors
10) Ensure all EHS Protection Requirements	Covers and Safety Devices
11) Good Accessibility for Maintenance Tasks	Transport Points and Easy Removal of Components

All decisions were considering the benchmarking that was made and the solutions that are used for the various material handling equipment. Therefore, the justifications for the solutions selected for each of the main requirements of Table 11 are described below.

1) Store and Retrieve Boxes: The telescopic load extractor has been chosen because it allows easier access to the storage positions of the boxes on the rack structure, correcting them to a possible misalignment of the same. In addition, it is a system that can be used in double deep rack structures;

2) Fixed Size Transport Platform: To ensure that the transport platform maintains its fixed size, it is sufficient that the telescopic loader is not expandable;

3) Vehicle Movement in Straight Line: To ensure that the vehicle only moves in a straight line, it is enough that the wheels are not pivoting;

4) Perform Picking Operations Automatically: The four-axis robot was selected as a portico system due to its smaller space of occupancy, greater precision of movement and greater combination of movements. In addition, this system can be developed and provided externally, since there are many robot manufacturers with very competitive cost;

5) Vehicle Guided on the Route: The use of side rollers ensures that the vehicle remains guided transversely along the rail, compensating for possible deflections of the structure;

6) Precise Positioning in Box Storage Positions: The barcode positioning sensor was selected because of its high accuracy and low cost;

7) Electric Actuators: The AC gearmotors were selected for the travelling system and the extraction system because of its high efficiencies and low drive powers;

8) Electric Power Supply for Movable Equipment: The conductor bar has been chosen to power the vehicle because, although it is more expensive than batteries, there is no need for power charging, maintenance operations are simpler, and it is a very suitable solution for vehicles moving in straight line;

9) Lightweight, Fast and Inexpensive Equipment: An optimization of the main steel structures of the vehicle for the loads to which it is subjected allows to lower the final weight of the assembly and, at the same time, reduce the manufacturing cost of these parts. On the other hand, the use of AC geared motors allows to achieve high speeds of rotation with low power of operation;

10) Ensure all EHS Protection Requirements: At the level of the equipment mechanics, the use of shields was defined to protect the access to components with dangerous movement. At the automation level, it was defined the use of safety devices that made the equipment stop its operation immediately whenever there were situations of danger of accident;

11) Good Accessibility for Maintenance Tasks: To facilitate the tasks of maintenance of the equipment, during the mechanical design, solutions were studied to remove the equipment from the rack structure, such as the points of transport, and, on the other hand, all the conditions were guaranteed for a quick and simple replacement of all parts.

3.3.3 PRELIMINARY TECHNICAL SPECIFICATIONS

Table 12 represents the detailed technical specifications at a stage prior to the mechanical design. During the design of the equipment, other technical specifications were defined, such as the power of the gearmotors, which are not listed in this section. Some of these values were changed during the mechanical design process, so section 3.4.10 shows the final technical specifications of the shuttle vehicle.

Table 12 – Preliminary technical specifications for the shuttle vehicle.

Technical Specification	SI Unit	Value/Description
Load Type	-	Plastic Tote Box
Load Dimensions	mm	600 x 400 x 200
Maximum Payload	kg	100 (50 kg/box)
Robot Maximum Payload	kg	1
Load Extraction System	-	Telescopic Load Extractor
Maximum Vehicle Speed Loaded (Unloaded)	m/s	3,0 (3,0)
Maximum Vehicle Acceleration Loaded (Unloaded)	m/s^2	1,5 (1,5)
Extraction System Speed Loaded (Unloaded)	m/s	0,25 (0,5)
Extraction System Acceleration Loaded (Unloaded)	m/s^2	1,0 (2,0)
Number of Wheels	u	4
Expandable Transport Platform (Yes/No)	-	No
Pivoting Wheels (Yes/No)	-	No
Temperature Range	ºC	0 – 40
Position Control	-	Bar Code Positioning Device
Power Supply	-	Conductor Rail
Power Supply Voltage	V	230

All values were selected considering the technical specifications collected during the benchmarking phase and some standard values existing in the market. Therefore, the reasons for the values selected for each of the technical specifications of Table 12 are described below.

- Load Type: The plastic tote box was selected due to its ergonomics, high rigidity and low weight;

- Load Dimensions: Standard dimensions were selected from the range of values collected during the benchmarking phase;

- Maximum Payload: This value was set having in mind the fact that the shuttle will transport two different boxes at the same time (so, 50 kg for each box), having the possibility to increase the weight range of the products to store;

- Robot Maximum Payload: This value was established considering a storage capacity of fifty products within each box;

- Maximum Vehicle Speed and Acceleration: These values reflect what is currently used by other shuttle vehicle manufacturers, however as the maximum payload has increased, the vehicle dynamics were reduced to ensure greater load transport stability;

- Load Extraction System Speed and Acceleration: These values were defined considering an extraction stroke of 500 mm (for a box with 400 mm width) covered in 1,0 s without load and 2,0 s with load to guarantee stability of the products. On the other hand, it is intended that the speed be reached in 0,25 s, so the acceleration values are four times higher than the speeds;

- Number of Wheels: The number of wheels was selected considering the values from the benchmarking, however it is important to highlight that this characteristic directly affects the stability of the vehicle and the difficulty to remove the equipment from the rack structure;

- Temperature Range: These values reflect what is currently used by other shuttle vehicle manufacturers;

- Power Supply Voltage: This value was set according to the residential voltage used in most of the countries from Europe.

3.4 MECHANICAL DESIGN

Having defined the main problem to be solved, analyzed similar solutions in the market, and established the main requirements and technical specifications, the starting point for the mechanical design of the shuttle vehicle was given.

As can be seen from section 2.3, the design process of a machine is a complex process involving a series of steps, often iterative, depending on each other. Given the high number of small steps involved in the development of the shuttle vehicle, only the main phases are reflected in this work, being described in a very synthesized and concise way so that the reader can easily understand the linkage of the work and, at the same time, evaluate the main decisions that have been taken until the final version of the equipment was reached.

The main development phases of the equipment range from the initial sketches and calculations, which allowed to obtain the first images and an approximation of what could be the equipment, the design and validation of the main components and machine systems (both mechanical and electrical), the most important part of all the work and that has allowed to obtain the final result, until the production of the detailed drawings, which allow to manufacture the different parts and assemble the entire machine..

One thing that helped to sequence the mechanical design was the Work Breakdown Structure (WBS) of the shuttle vehicle (Figure 73). This tool allowed dividing the main system into sub-systems and, in this way, directing the efforts to each of the subsystems in isolation. Since these are dependent on each other, the design process had to be often iterative so that in the end the vehicle would be compact and without interferences between the different subsystems.

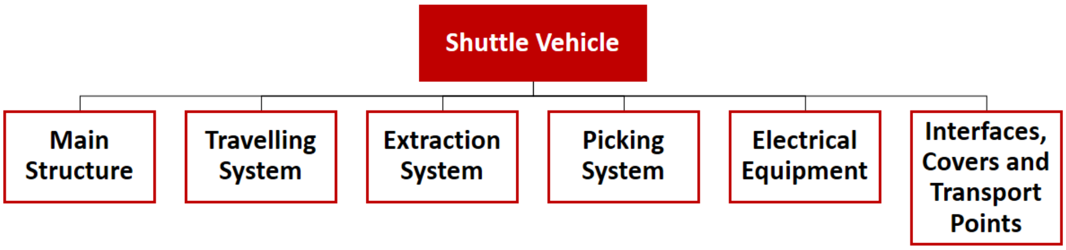


Figure 73 - WBS of the shuttle vehicle.

The final version of the equipment is shown in Figure 74 and Figure 75, where it is possible to analyze which are the subsystems of the vehicle.

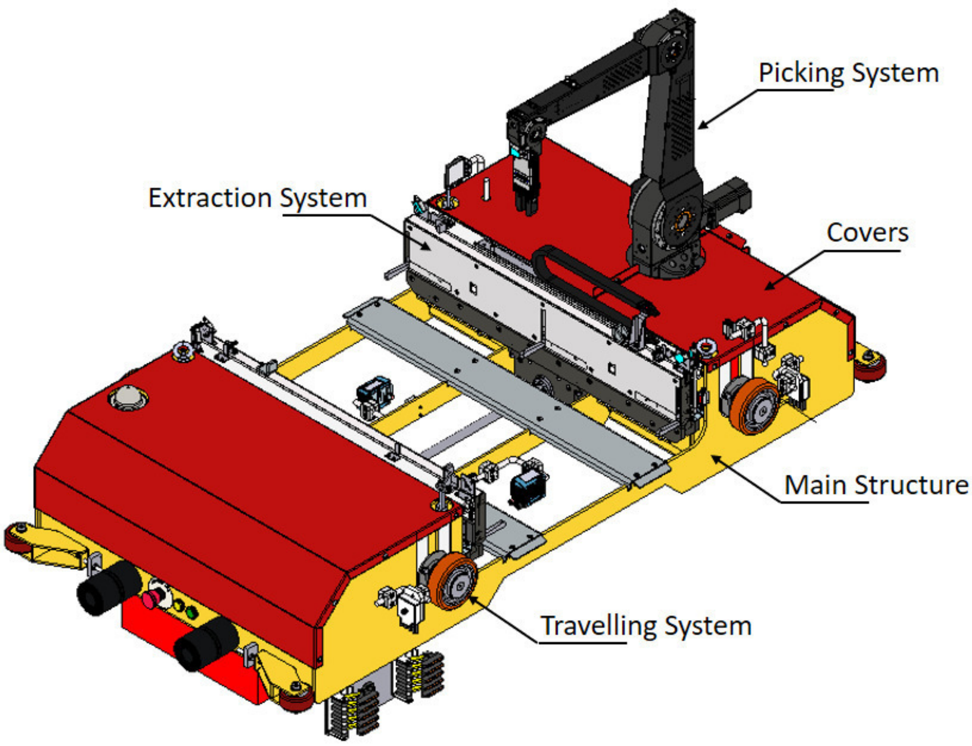


Figure 74 - Final version of the shuttle vehicle with identification of the main systems and components.

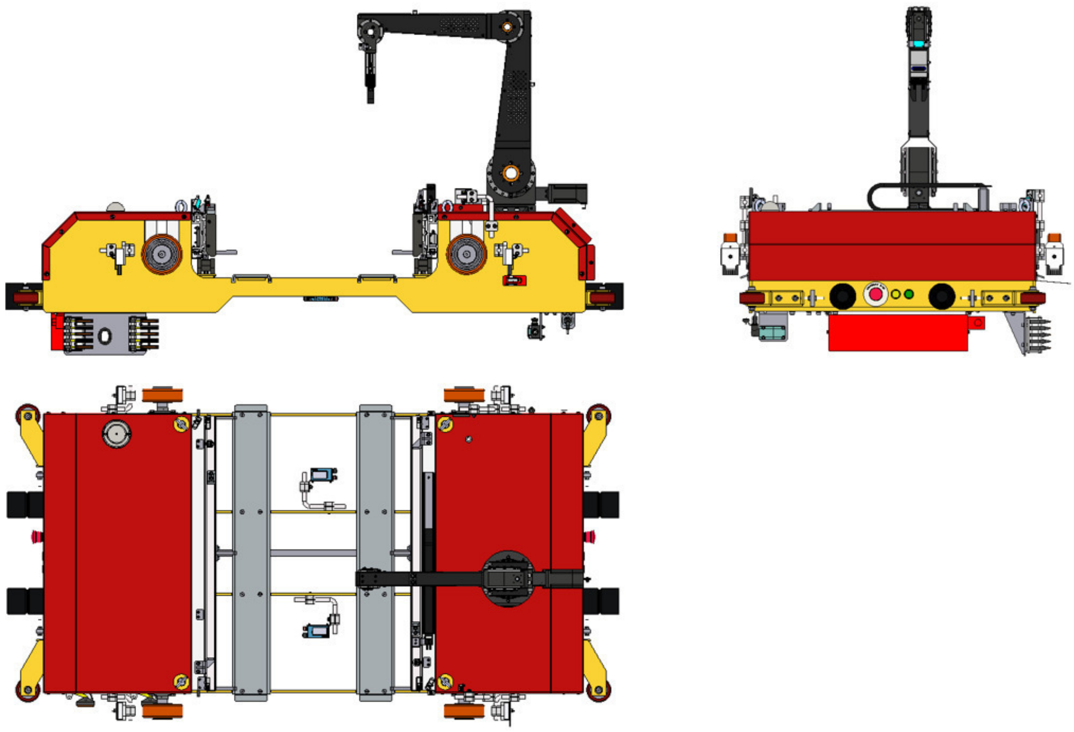


Figure 75 - Right, front and top views of the shuttle vehicle.

In order to better understand the purpose of each of the subsystems of the shuttle, it is necessary to analyze the principle of operation and the different tasks that it is able to perform when inserted in an AS/RS. In Figure 76 it is possible to observe the shuttle vehicle in operation, being inserted in a rack structure that supports it through rails and that has one shuttle for each level. This rack also has the purpose of storing products that are handled by the shuttle vehicle systems.

It is important to note that the purpose of this work was only the shuttle vehicle, so only the vehicle was part of the mechanical design scope, but there are other essential equipment for the shuttle operation within an AS/RS, such as the rack or conveyor lines, that were not the subject of study for this work. The rack used in this work is merely representative and serves only to help understand the operating principle of the shuttle vehicle. On the other hand, it is not shown here how the vehicle is placed inside the rack and interfaces with the outside of the rack so that it can send/receive the boxes of products that are being handled throughout the AS/RS. The shuttle vehicle can be placed on the rack by lift trucks or vertical conveyors (see section 2.2.4) placed on the top of the rack and allow interface with conveyor lines that move the boxes throughout the AS/RS.

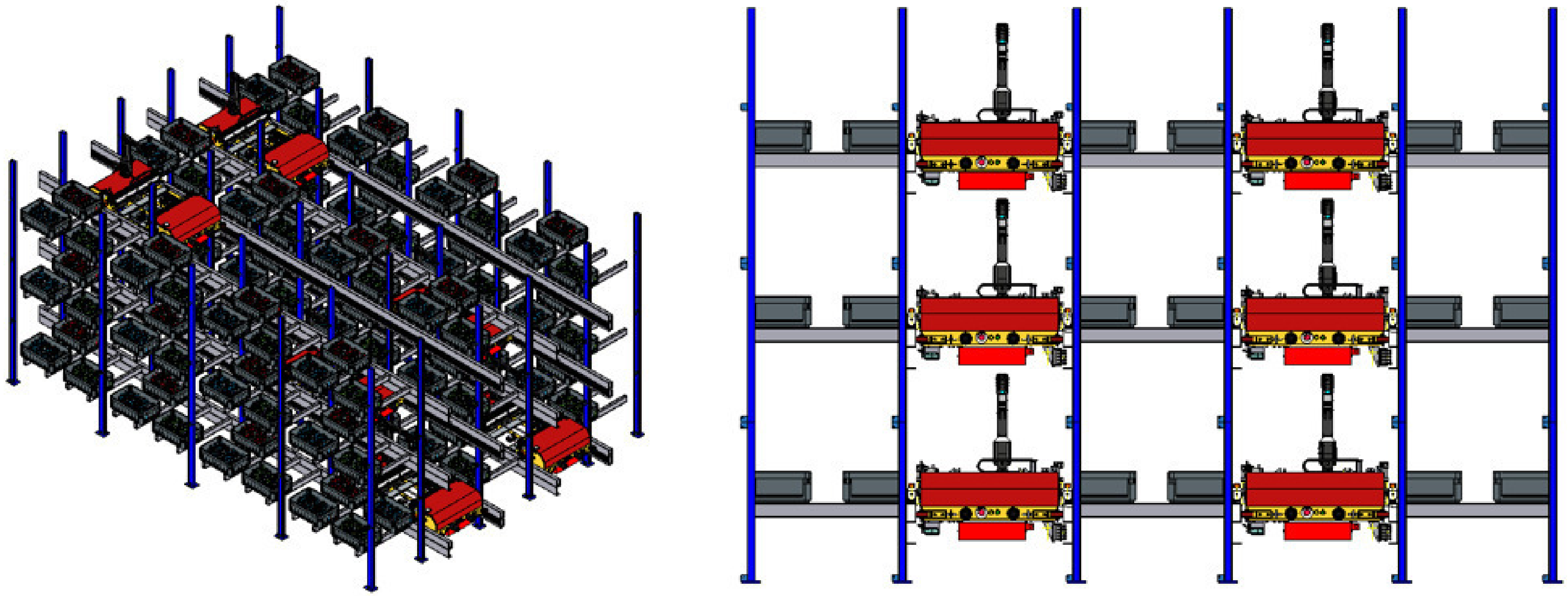


Figure 76 - Shuttle vehicle in operation.

To explain the principle of operation of the shuttle, a hypothetical example of a warehouse is considered to have three different products: blue, green and red bottles stored in the dark grey boxes that stay in the rack. The system then receives customer orders where the number of bottles of each color is indicated. Fully automatically, the shuttle vehicle satisfies each order by placing the respective bottles in the light grey boxes (the customer boxes), directly in the rack, avoiding the need to travel long distances. All the boxes handled by the system have the dimensions initially considered in the technical specifications (600 mm x 400 mm x 200 mm), storing a maximum of fifty bottles positioned in the wells of a matrix sized for this type of product (Figure 77).

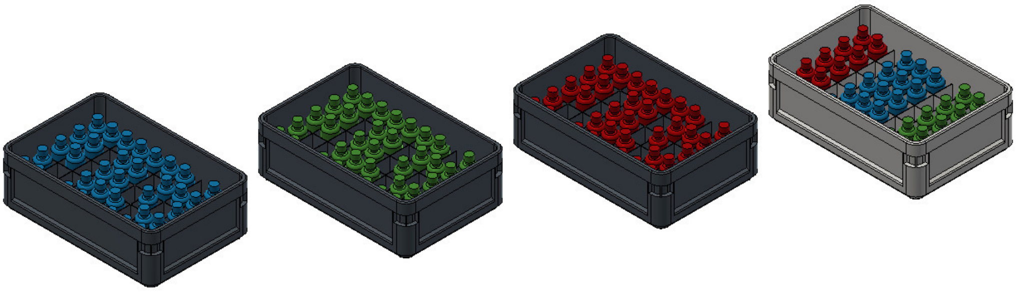


Figure 77 - Plastic boxes (600 mm x 400 mm x 200 mm) with tree different products: blue, green and red bottles.

The shuttle vehicle can carry two boxes at the same time (each 50 kg maximum) that may be dark grey boxes or light grey boxes. The light grey boxes are never stored in the rack since they are the boxes to send to the customer.

The vehicle has three fundamental systems for the operations it can perform. These three systems are as follows: the travelling system, the extraction system and the picking system. It is important to note that each of the systems works independently of the others, it means that when one of the systems is in motion, the other two remain locked.

The travelling system, as the name implies, is responsible for the travelling movement of the vehicle along the rack structure rails (Figure 78), ensuring straight line movement and correct positioning of the vehicle in relation to the boxes it is loading or removing from the rack.

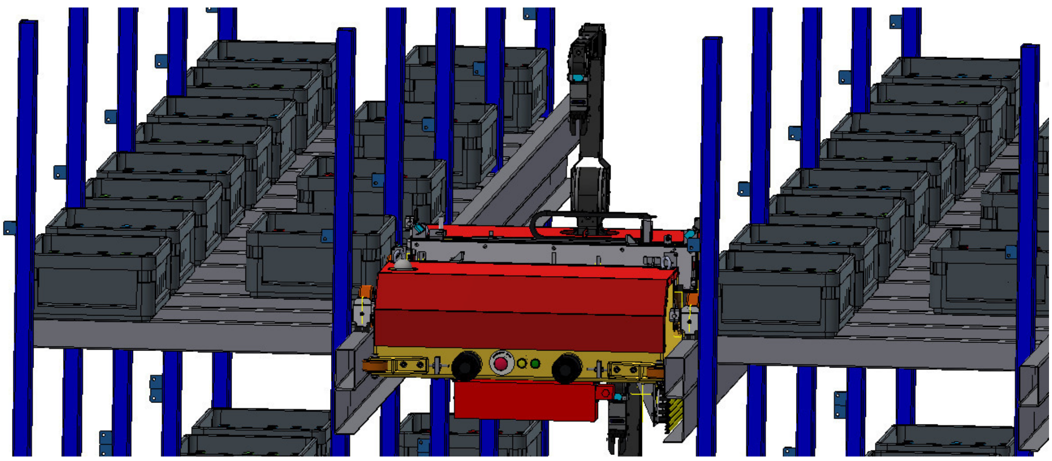


Figure 78 - The shuttle vehicle travels along the racking structure rails through the travelling system.

The extraction system is responsible for extracting or storing the boxes on the rack through two retractable arms that cause the box to move in or out of the vehicle (Figure 79). The shuttle vehicle can extract or store boxes on both sides of the rails, keeping them properly positioned both on the rack and inside the vehicle when they are being handled.

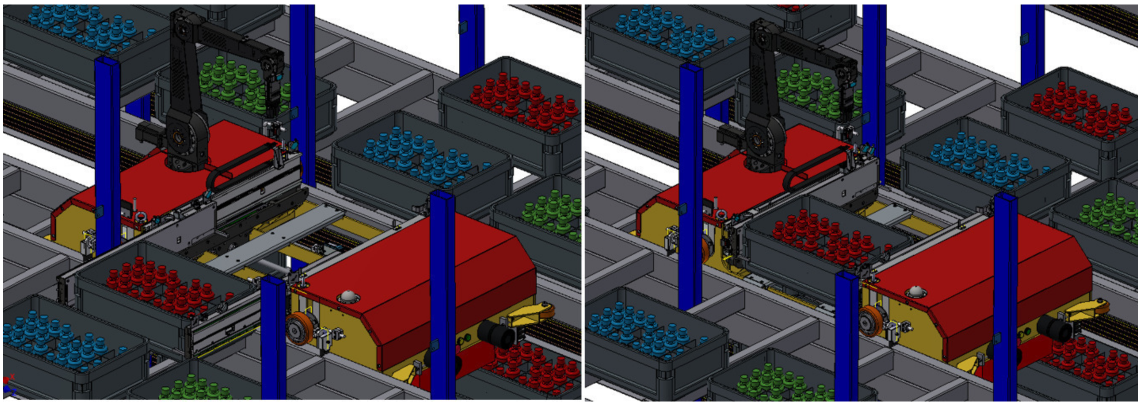


Figure 79 - The shuttle vehicle extracts/sores the boxes on the rack through the extraction system.

The picking system is the system that allows the picking operations to be performed directly in the rack in a completely automatic way, this being the great innovation of the shuttle vehicle when compared to what exists in the market. It is a robot with four axes that transfers the bottles of each color between the dark grey boxes and the light grey box (Figure 80), satisfying the customer's order.

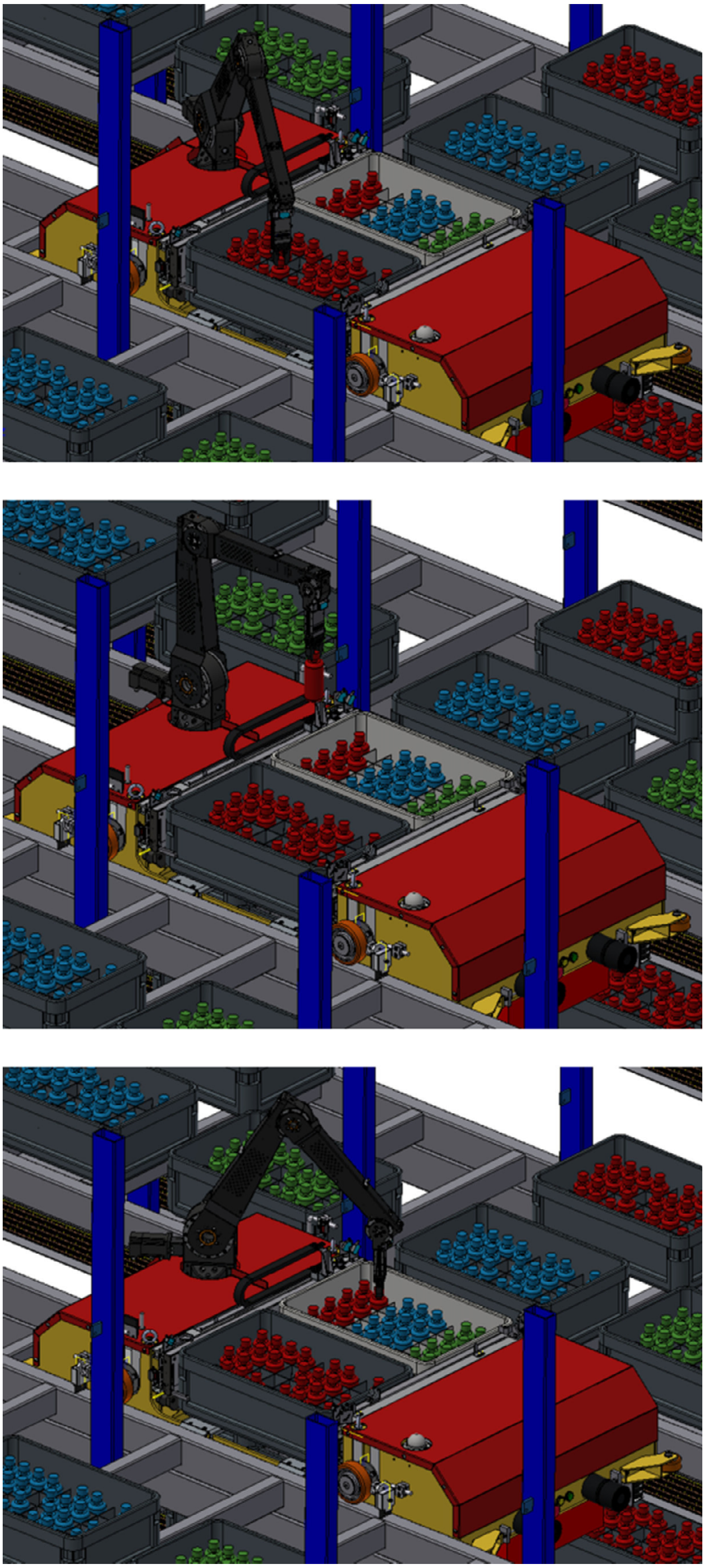


Figure 80 - The shuttle vehicle performs the picking operations directly in the rack.

The following sections address the main steps that were taken throughout the mechanical design until the final version of the shuttle vehicle was reached.

3.4.1 INITIAL SKETCHES

Like any mechanical design of a machine, it always begins with some hand-drawn sketches with paper and pencil. This allows to get the first images of what could be the machine and, more importantly, it facilitates communication between the people involved in the equipment development process.

Two sketches were made for the shuttle vehicle. The first one (Figure 81), handmade and without any software resources, allowed to explain the concept of the equipment and convey the main ideas to the stakeholders in this project. The second one (Figure 82), made using a software with capability for 2D drawing (Autodesk® AutoCAD®), served to estimate the dimensions of the equipment.

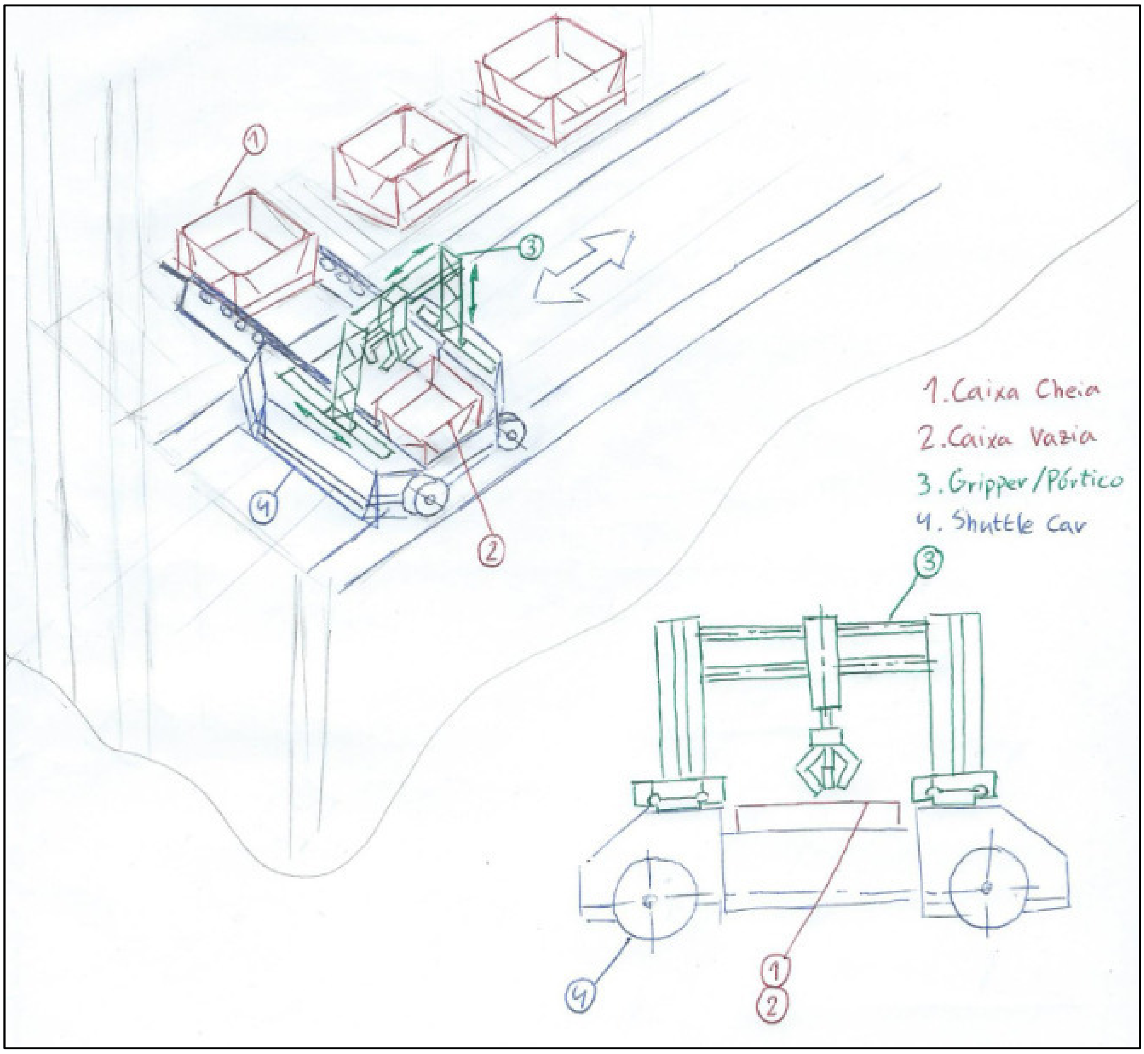


Figure 81 - Handmade sketch.

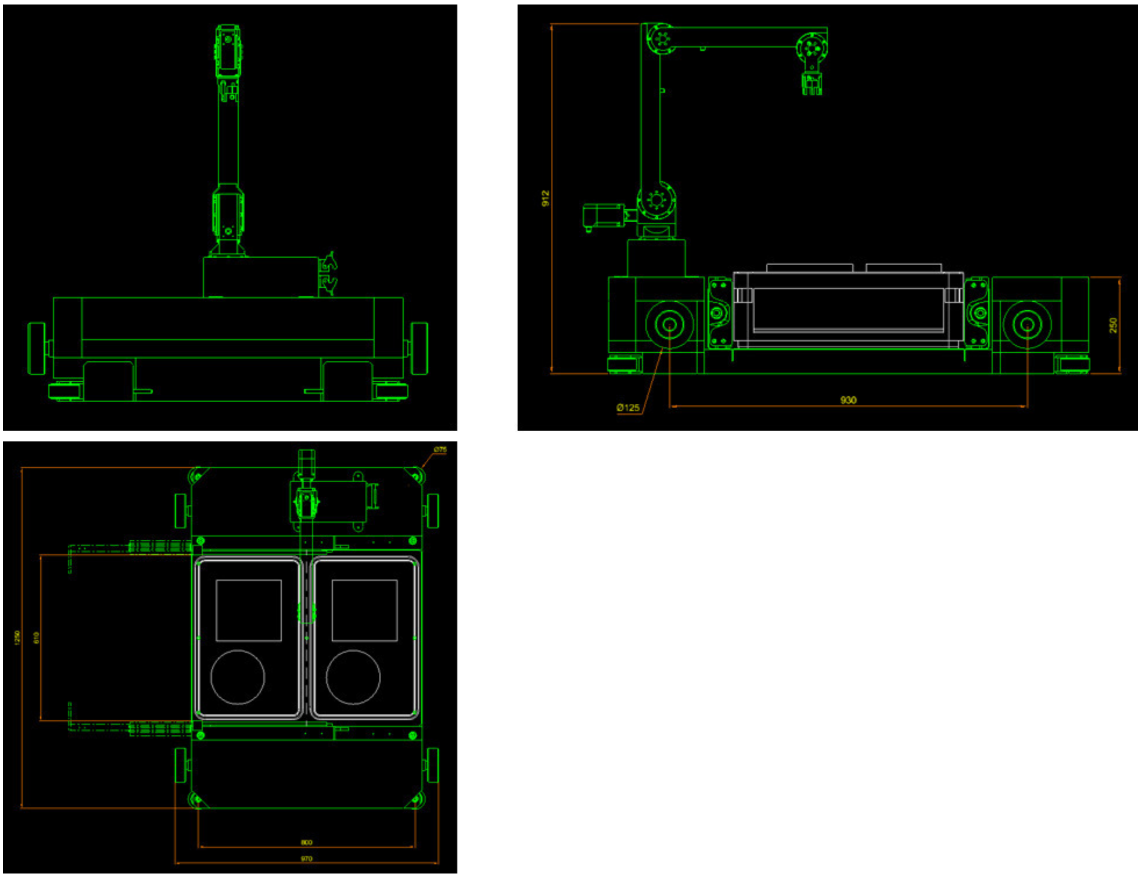


Figure 82 - Sketch made using software with ability to draw 2D (Autodesk® AutoCAD®).

3.4.2 PRELIMINARY CALCULATIONS

Three preliminary calculations were made for the shuttle vehicle:

1) Calculation of reactions in the vehicle supports (wheels) and stability check;
2) Calculation of the travelling wheels and the guiding wheels;
3) Calculation of the travelling gearmotor.

Due to the lack of information that existed at this stage of the mechanical design, it was necessary to estimate some parameters to perform the calculations, namely the mass of the vehicle and the centers of mass of the mechanisms since it has great influence on the stability of the vehicle and the selection of the gearmotor. These calculations have therefore only allowed an initial estimate of the dimensions of some components of the equipment, such as the wheels diameters and widths and the size of the travelling gearmotor. It was therefore necessary to repeat all the calculations in an advanced phase of the process.

All the preliminary calculations presented here can be seen in more detail in Annex 1.

It is important to note that to understand the calculations made here, it is necessary to have some knowledge of static and dynamic mechanics at the level of the equilibrium equations of the static body and Newton's 2nd Law of Motion.

3.4.2.1 PRELIMINARY CALCULATION OF REACTIONS IN THE VEHICLE SUPPORTS AND STABILITY CHECK

In order to calculate the vehicle reactions, the parameters described in Table 13 were considered. The brake acceleration was determined in the preliminary calculation of the travelling gearmotor (see section 3.4.2.2).

Table 13 - Parameters considered to calculate the reactions of the vehicle.

Parameter	Value
Vehicle Mass (estimated) ($m_{vehicle}$)	150 kg
Boxes Mass (m_{load})	100 kg (50 kg/box)
Robot Mass (estimated) (m_{robot})	30 kg
Vehicle Acceleration (estimated) ($a_{travelling}$)	1,5 m/s^2
Brake Acceleration (a_{brake})	1,65 m/s^2
Gravitational Acceleration (g)	9,81 m/s^2

The reactions were determined when the vehicle is stationary (static reactions) and when the vehicle is accelerating (dynamic reactions), in both cases first without the mass of the boxes and then adding that value to the mass of the vehicle. In the case where the vehicle is starting the movement, the reaction forces vary according to the direction of the acceleration, however only the most severe scenario for the vehicle stability was analyzed here, where one of the supports is more overloaded than the other.

The scenario in which the vehicle has an emergency stop is like when the vehicle is accelerating, diverging only in the value of the acceleration. This scenario was also analyzed, not to obtain the reactions, but to study the stability of the vehicle against emergency stops, so in this case only the dynamic reactions with the vehicle unloaded were calculated, because it is the worst condition for the vehicle stability.

The process started by drawing the free-body diagrams for both cases (Figure 83), positioning the different loads to which the vehicle would be subject. In addition, the masses of the robot and the vehicle were separated because of the lack of information about the center of mass of the system and, although the vehicle has two wheels at point A and two wheels at point B, it was assumed that the loads of each reaction are equitably distributed by each of the wheels of the pair. Besides that, it was also considered that the robot remains fixed (no oscillation) and that the floor is perfectly horizontal (no inclination).

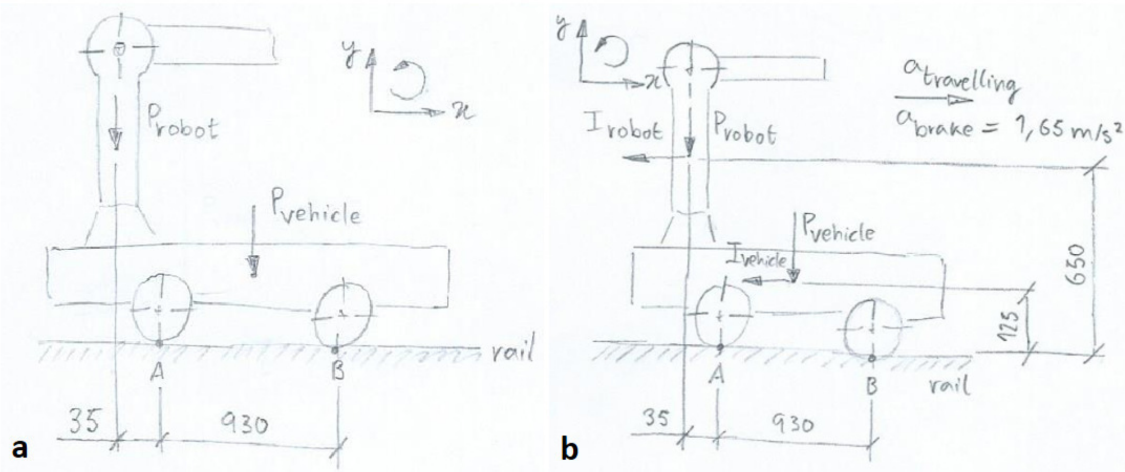


Figure 83 - Shuttle vehicle free-body diagrams when the vehicle is stationary (a) and when the vehicle is starting the movement (b).

With the two free-body diagrams finalized, it was necessary to write the respective equilibrium equations, with at least two equations being required for the two variables corresponding to the reactions on each of the points of support of the vehicle, points A and B. As such, to calculate the static reactions (Figure 83 - a), Equation 1 and Equation 2 were used which relate to the equilibrium of the forces in the Y axis and the moments on the point A, respectively.

$$\sum F_y = 0 \Rightarrow$$
$$\Rightarrow R_{A,stat} + R_{B,stat} - P_{robot} - P_{vehicle} = 0 \Leftrightarrow$$
$$\Leftrightarrow R_{A,stat} + R_{B,stat} - m_{robot} \cdot g - m_{vehicle} \cdot g = 0$$

Equation 1

Where:

F_y – Y-axis forces (N);

$R_{A,stat}$ – Static reaction force on point A (N);

$R_{B,stat}$ – Static reaction force on point B (N);

P_{robot} – Weight of the robot (N);

$P_{vehicle}$ – Weight of the vehicle (N).

$$\sum M_A = 0 \Longrightarrow$$

$$\Longrightarrow R_{B,stat} \cdot 930 + P_{robot} \cdot 35 - P_{vehicle} \cdot (930/2) = 0 \Leftrightarrow$$

$$\Leftrightarrow R_{B,stat} \cdot 930 + m_{robot} \cdot g \cdot 35 - m_{vehicle} \cdot g \cdot 465 = 0$$

Equation 2

Where:

M_A – Moments on point A (N·m).

To calculate the dynamic reactions (Figure 83 - b), Equation 3 and Equation 4 were used, which also relate to the equilibrium of forces in the Y axis and moments on the point A, respectively. In this case the sum of moments in the point A remains zero since it is assumed that the vehicle has a purely horizontal movement.

$$\sum F_y = 0 \Rightarrow$$

$$\Rightarrow R_{A,dyn} + R_{B,dyn} - P_{robot} - P_{vehicle} = 0 \Leftrightarrow$$

$$\Leftrightarrow R_{A,dyn} + R_{B,dyn} - m_{robot} \cdot g - m_{vehicle} \cdot g = 0$$

Equation 3

Where:

$R_{A,dyn}$ – Dynamic reaction force on point A (N);

$R_{B,dyn}$ – Dynamic reaction force on point B (N).

$$\sum M_A = 0 \Rightarrow$$

$$\Rightarrow R_{B,dyn} \cdot 930 + P_{robot} \cdot 35 + I_{robot} \cdot 650 - P_{vehicle} \cdot (930/2) + I_{vehicle} \cdot 125 = 0 \Leftrightarrow$$

$$\Leftrightarrow R_{B,dyn} \cdot 930 + m_{robot} \cdot g \cdot 35 + m_{robot} \cdot a \cdot 650 - m_{vehicle} \cdot g \cdot 465 + m_{vehicle} \cdot a_{travelling} \cdot 125 = 0$$

Equation 4

Where:

I_{robot} – Inertia of the robot (N);

$I_{vehicle}$ – Inertia of the vehicle (N);

$a_{travelling}$ – Vehicle acceleration (m/s^2).

The results of the reaction forces for each case are shown in Table 14.

Table 14 - Results of the reaction forces of the vehicle.

	Without the Mass of the Boxes	With the Mass of the Boxes
Stationary Vehicle	$R_{A,stat}$ = 1041 N $R_{B,stat}$ = 725 N	$R_{A,stat}$ = 1532 N $R_{B,stat}$ = 1215 N
Vehicle Accelerating	$R_{A,dyn}$ = 1103 N $R_{B,dyn}$ = 663 N	$R_{A,dyn}$ = 1613 N $R_{B,dyn}$ = 1133 N
Vehicle Braking	$R_{A,dyn}$ = 1109 N $R_{B,dyn}$ = 657 N	N/A

With these results it can be concluded that the wheels of the vehicle always remain in contact with the ground, since there was no negative value for the reaction forces. Although it is a good indication of the stability of the vehicle, the FEM 9.311 standard suggests a direct calculation of the stability for S/R machines through Equation 5, Equation 6 and Equation 7, where the variables must be replaced by the previously determined values. This is a dimensionless factor which, according to the standard, must be equal to or greater than 1,5 under service conditions [119].

$$\sum stabilising\ moments = R_{stat,min} \times r$$

Equation 5

Where:

$R_{stat,min}$ – Minimum static reaction force between the two support points (N);

r – Distance between the two support points (m).

$$\sum_{i=1}^{n} overturning\ moments = F_1 \cdot h_1 + F_2 \cdot h_2 + (\dots) + F_n \cdot h_n$$

Equation 6

Where:

F_1, F_2, (…), F_n – Inertia forces due to the weight of the bodies (N);

h_1, h_2, (…), h_n – Vertical distance between the inertia forces and the floor (m).

$$\nu = \frac{\sum stabilising\ moments}{\sum overturning\ moments}$$

Equation 7

Where:

ν – Stability factor (-).

The stability factor (ν) was determined for two scenarios - with and without the mass of the boxes - and the results are represented in Table 15.

Table 15 - Results of the stability factor.

	Without the Mass of the Boxes	With the Mass of the Boxes
Vehicle Accelerating	ν = 11,8	ν = 14,8
Vehicle Braking	ν = 10,7	N/A

As expected, the vehicle exhibits greater instability when moving without the boxes since the center of mass rises slightly due to the mass reduction. However, all values are well above the minimum value indicated in the standard, which represents a good indication that there will be no problems with the equipment operation, since the value of the vehicle mass was intentionally estimated below.

3.4.2.2 PRELIMINARY CALCULATION OF THE TRAVELLING GEARMOTOR

To calculate the travelling gearmotor, the parameters presented in Table 16 were considered.

Table 16 - Parameters considered to calculate the travelling gearmotor.

Parameter	Value
Vehicle Total Mass (estimated) ($m_{vehicle}$)	180 kg (estimated)
Boxes Mass (m_{load})	100 kg (50 kg/box)
Vehicle Speed ($v_{travelling}$)	3 m/s
Vehicle Acceleration (estimated) ($a_{travelling}$)	1,5 m/s^2 (estimated)
Gravitational Acceleration (g)	9,81 m/s^2
Diameter of the Wheels (D_{wheel})	125 mm

Parameter	Value
Diameter of the Wheels Axle (d_{axle})	45 mm
Gear Ratio between Sprockets (i_v)	1,0
Lever Arm of Rolling Friction (polyurethane/steel) (f)	0,9 mm
Coefficient of Friction (polyurethane/steel) ($\mu_{stat\ (PU/steel)}$)	0,55
Coefficient of Friction of the Bearings (anti-friction bearings) (μ_L)	0,005
Chain Efficiency (η_{chain})	0,9
Load Efficiency (η_{load})	0,9
Gearmotor Type	Helical Gearmotor (Type R)
Operation Type	16 h/day; 100 cycles/h
Load Classification	Non-uniform
Static Reaction Force on Wheels A (vehicle unloaded) ($R_{A,stat}$)	1041 N
Static Reaction Force on Wheels B (vehicle unloaded) ($R_{B,stat}$)	725 N

To pre-select the gearmotor, it was decided to choose an AC gearmotor from SEW's standard range due to the low cost, durability and wide range of solutions for all types of assemblies. Although the type of assembly for the travelling gearmotor of the shuttle vehicle was still unknown, it was known that the torque would be transmitted to the drive wheels by means of a roller chain and a pair of sprockets. For this reason, the type of gearmotor selected was the type R (Figure 84), considering a gear ratio of 1 between the pair of sprockets [120].

Figure 84 - SEW helical gearmotor (type R) [120].

The gearmotor was calculated according to SEW's Project Planning of Drives calculation procedure for travel drives. As such, it begun with the calculation of the driving force required to move the vehicle (Equation 8), which depends on the force of inertia and the force of resistance to movement. When this value was reached, it became possible to determine the static power (Equation 10), which corresponds to the power output by the motor when the vehicle moves at constant speed, and the dynamic power (Equation 11), which corresponds to the power output by the motor when the vehicle accelerates. Both values had to be affected by the system total efficiency (Equation 9) [121].

$$F_{drive} = F_{inertia} + F_{rolling}$$

$$F_{drive} = m_{total} \cdot a_{travelling} + m_{total} \cdot g \cdot \left(\mu_L \cdot \frac{d_{axle}}{D_{wheel}} \cdot \frac{2f}{D_{wheel}}\right)$$

Equation 8

Where:

F_{drive} – Driving force (N);

$F_{inertia}$ – Vehicle inertia force (N);

$F_{rollling}$ – Rolling resistance to motion force (N).

$$\eta_{total} = \eta_{chain} \cdot \eta_{load}$$

Equation 9

Where:

η_{total} – Gearmotor total efficiency (-).

$$P_{static} = \frac{F_{rolling} \cdot v_{travelling}}{\eta_{total}}$$

Equation 10

Where:

P_{static} – Static power (W).

$$P_{dynamic} = \frac{F_{drive} \cdot v_{travelling}}{\eta_{total}}$$

Equation 11

Where:

$P_{dynamic}$ – Dynamic power (W).

The motor could then be selected via the calculated value of the dynamic power, choosing a motor from SEW's 4-pole motor range. Motor selection can go through several iterations, varying the motor frequency between 50 and 87 Hz, using a frequency inverter that allows adjusting the speed of rotation of the motor without losing torque to the output of the gearmotor, so that it is possible to select a lower power motor.

Between each iteration it was necessary to verify the choice of the motor through the quotient between the motor acceleration torque, the value that the motor must provide to the application when the vehicle is starting, and the motor nominal torque, a catalog value. This quotient must be less than 1,30 (130%) so that the motor selection is valid, which means that the manufacturer of the gearmotors admits that the acceleration torque of the application is 1,30 times higher than the motor nominal torque for travel drives.

To determine the value of the acceleration torque (Equation 15), it was necessary to calculate the external moment of inertia (Equation 12), the motor load torque (Equation 13) and the acceleration time of the shuttle vehicle (Equation 14).

$$J_X = 91{,}2 \cdot m_{total} \cdot \left(\frac{v_{travelling}}{n_N}\right)$$

Equation 12

Where:

J_X – External mass moment of inertia (kg.m^2);

n_N – Rated motor speed (rpm).

$$M_L = \frac{F_{rolling} \cdot v_{travelling} \cdot 9{,}55}{n_N}$$

Equation 13

Where:

M_L – Load torque (N·m).

$$t_a = \frac{v_{travelling}}{a_{travelling}}$$

Equation 14

Where:

t_a – Acceleration time (s).

$$M_H = \frac{\left(J_{Mot} + \frac{1}{\eta_{total}} \times J_X\right) \times n_N}{9{,}55 \times t_a} + \frac{M_L}{\eta_{total}}$$

Equation 15

Where:

M_H – Acceleration torque (N·m);

J_{Mot} – Mass moment of inertia of the motor (kg.m^2).

The results for the selected motors are shown in Table 17.

Table 17 - Results for the selected motor.

Variable	Result
Driving Force (F_{drive})	464,5 N
Gearmotor Total Efficiency (η_{total})	0,81
Static Power (P_{static})	164,8 W
Dynamic Power ($P_{dynamic}$)	1720 W
Selected Motor (1st Selection)	SEW Motors – 4-pole Motors – DRN90L4 P_N = 1,5 kW n_N = 1461 rpm (50 Hz) J_{Mot} = 67,2 x 10^4 kg·m^2 M_N = 9,8 N·m
External Mass Moment of Inertia (1st Selection) (J_X)	0,1077 kg·m^2
Load Torque (1st Selection) (M_L)	0,87 N·m
Acceleration Time (1st Selection) (t_a)	2 s
Acceleration Torque (1st Selection) (M_H)	11,76 N·m
Motor Start-Up Torque/Motor Rated Torque (1st Selection) (M_H/M_N)	120%
Selected Motor (2nd Selection)	SEW Motors – 4-pole Motors – DRN90S4 P_N = 1,1 kW n_N = 2400 rpm (87 Hz) J_{Mot} = 54 x 10^4 kg·m^2 M_N = 7,2 N·m
External Mass Moment of Inertia (2nd Selection) (J_X)	0,0399 kg·m^2
Load Torque (2nd Selection) (M_L)	0,53 N·m
Acceleration Torque (2nd Selection) (M_H)	7,52 N·m
Motor Start-Up Torque/Motor Rated Torque (2nd Selection) (M_H/M_N)	104%
Standard Motor Brake	BE2 M_{Brake} = 5,0 N·m

Both selections would be valid since in both cases the acceleration torque is less than 1,50 times the nominal torque of the motor, however the motor form the 2nd selection was chosen because it has less power. The selected motor (2nd selection) has a lower power than the 1st selection, however it requires that a frequency inverter is used to adjust the speed of rotation of the motor (for a frequency of 87 Hz) without losing torque at the output of the gearmotor.

The selection of the gear unit was a simpler process since this depends only on the following parameters:

1) Output speed of the gearmotor (Equation 16), directly related to the desired linear speed for the shuttle vehicle;
2) Gear ratio between the motor and the gear unit (Equation 17), which depends on the speed of the motor and the output speed of the gearmotor;
3) Mass acceleration factor (Equation 18), a SEW factor calculated through the quotient between the external mass moment of inertia and the mass moment of inertia of the motor, which must be less than 10 for a non-uniform load classification of the shuttle vehicle application;
4) Minimum service factor, a factor that provides an estimate of the maximum torque supported by the gear unit, being determined by querying a graph on SEW's catalog through the operation type and the load classification of the shuttle vehicle application.

$$n_a = 19{,}1 \times 10^3 \times \frac{v_{travelling}}{D_{wheel}} \times i_v$$

Equation 16

Where:

n_a – Gearmotor output speed (rpm).

$$i_{gear\ unit} = \frac{n_N}{n_a}$$

Equation 17

Where:

$i_{gear\ unit}$ – Gear unit ratio (-).

$$f_M = \frac{J_X}{J_{Mot}}$$

Equation 18

Where:

f_M – Mass acceleration factor (-).

After selecting the gear unit, it was necessary to validate the selection by comparing the static and dynamic driving torques, required to move the shuttle vehicle, with the rated output torque of the gearmotor. As such, Equation 19 and Equation 22 were used to determine, respectively, the static driving torque and the dynamic driving torque.

$$M_{static} = \frac{F_{rolling} \cdot \frac{D_{wheel}}{2}}{\eta_{total}}$$

Equation 19

Where:

M_{static} – Static driving torque (N·m).

$$M_{dynamic} = \frac{F_{drive} \cdot \frac{D_{wheel}}{2}}{\eta_{total}}$$

Equation 20

Where:

$M_{dynamic}$ – Dynamic driving torque (N·m).

The results for the selected gear unit are shown in Table 18.

Table 18 - Results for the selected gear unit.

Variable	Result
Gearmotor Output Speed (calculated) (n_a)	458,4 rpm
Gear Unit Ratio (calculated) ($i_{gear\ unit}$)	5,24
Mass Acceleration Factor (f_M)	7,39
Minimum Service Factor (f_B)	1,6
Selected Gear Unit	SEW Gear Units – Helical Gearmotors – R27 i = 5,00 n_a = 480 rpm (with the motor rotating at 2400 rpm) $M_{a\ max}$ = 95 N·m M_a = 36 N·m f_B = 2,6
Static Driving Torque (M_{static})	3,4 N·m
Dynamic Driving Torque ($M_{dynamic}$)	35,8 N·m

Variable	Result
Dynamic Driving Torque/Gearmotor Rated Output Torque ($M_{dynamic}$/Ma)	99,6%
Selected Gearmotor	R27 DRN90S4 BE2

The selected gear unit complies with the required rotational speed requirements, having a service factor of 2,6 (greater than the minimum value calculated), which means that it is structurally capable of supporting a maximum torque of about 2,6 times the rated torque. Besides this, the static and dynamic driving torques are above the rated gearmotor rated output torque (36 N·m), so the selected gear unit is validated.

The selected gearmotor is the final combination between the selected gear unit and the selected engine, along with the respective standard motor brake.

Finally, it was necessary to check the maximum allowable acceleration for each of the wheel pairs of the shuttle vehicle to ensure that the wheels will not slip when accelerating or braking. As such, it was necessary to calculate the friction force in each of the pairs of wheels (Figure 85) that depends on the previously calculated static reactions and the coefficient of static friction between the wheel and the rails (Equation 21). It was considered the scenario where the vehicle is unloaded because it is the worst-case scenario for wheel slippage.

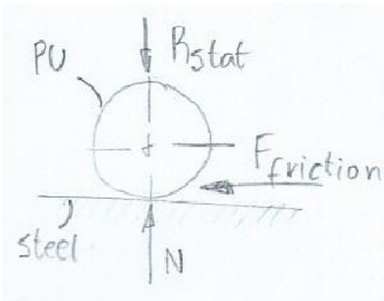


Figure 85 - Friction force applied on the travelling wheels.

$$F_{friction} = N \cdot \mu_{stat} \Leftrightarrow F_{friction} = R_{stat} \cdot \mu_{stat}$$

Equation 21

Where:

$F_{friction}$ – Friction force (N);

N – Normal force (N);

μ_{stat} – Static coefficient of friction between the wheel and the floor (-);

R_{stat} – Static reaction force of the vehicle (N).

For the wheels to not slip, the driving force of the gearmotor should be equal to or less than the friction force. As such, through Equation 22 it was possible to determine the maximum permissible acceleration.

$$F_{drive} \leq F_{friction} \Leftrightarrow$$

$$\Leftrightarrow m_{total} \cdot a_{travelling} + m_{total} \cdot g \cdot \left(\mu_L \cdot \frac{d_{axle}}{D_{wheel}} \cdot \frac{2f}{D_{wheel}}\right) \leq F_{friction}$$

Equation 22

The results for the maximum permissible acceleration on each wheel pair are shown in Table 19.

Table 19 - Results for the maximum permissible acceleration on each wheel pair.

	Wheels A	**Wheels B**
Friction Force ($F_{friction}$)	572,6 N	398,8 N
Maximum Vehicle Acceleration ($a_{travelling}$)	3,0 m/s²	2,1 m/s²

By analysis of the results it is easily concluded that the wheels A should be the driving wheels since they allow a greater acceleration, although this value is strongly related to the center of mass of the shuttle vehicle, which was unknown at this stage. However, wheels B can also be the driving wheels because the maximum acceleration is also above the estimated value for the travelling acceleration.

With the maximum permissible values for the travelling acceleration, it was necessary to check whether the deceleration caused by an emergency braking would cause the travelling wheels to slip. As such, to determine the deceleration caused by the rated braking torque of the motor brake, Equation 23 and Equation 24 were used, which correspond to the emergency deceleration time and the emergency deceleration, respectively.

$$t_{a,brake} = \frac{(J_{Mot} + J_X \cdot \eta_{total}) \cdot n_N}{9{,}55 \cdot (M_{Brake} + M_L \cdot \eta_{total})}$$

Equation 23

Where:

$t_{a,brake}$ – Emergency deceleration time (s).

$$a_{brake} = \frac{v_{travelling}}{t_{a,brake}}$$

Equation 24

Where:

a_{brake} – Emergency deceleration (m/s²).

The result for the emergency deceleration is shown in Table 20.

Table 20 - Results for the emergency deceleration.

Variable	Result
Emergency Deceleration (a_{brake})	1,65 m/s^2

The emergency deceleration caused by the motor brake is less than the maximum permissible accelerations for each travelling wheels pair. As such, the rated braking torque is not enough to cause the wheels to slip, ensuring a good estimate that there will be no problems during the operation of the shuttle vehicle.

3.4.2.3 PRELIMINARY CALCULATION OF THE GUIDING WHEELS AND THE TRAVELLING WHEELS

To calculate the loads on the wheels, the parameters described in Table 21 were considered. The vehicle driving force was determined in the preliminary calculation of the travelling gearmotor (see section 3.4.2.2).

Table 21 - Parameters considered to calculate the loads on the wheels.

Parameter	Value
Vehicle Total Mass (estimated) ($m_{vehicle}$)	150 kg
Boxes Mass (m_{load})	100 kg (50 kg/box)
Vehicle Speed ($v_{travelling}$)	3 m/s
Gravitational Acceleration (g)	9,81 m/s^2
Vehicle Driving Force (F_{drive})	464,5 N
Maximum Dynamic Reaction Force on the Wheels (vehicle accelerating) ($R_{max,dyn}$)	1613 N
Vehicle Deflection when Accelerating (β)	1º
Coefficient of Friction (polyurethane/steel)	$\mu_{stat\ (PU/steel)}$ = 0,55
Brauer® factor for the continuous running condition (C_1)	0,75
Brauer® factor for the surface speed 10-16 km/h condition (C_2)	0,7
Brauer® factor for the driving wheels condition (C_3)	0,7

It was decided that both the guiding wheels and the travelling wheels would be polyurethane because of the high load capacity and the great ability to adapt to the unevenness of the floor when in service conditions. As such, the wheels were selected considering Brauer® load factors associated with specific service conditions for this type of wheels [122].

For the selection of the guiding wheels it was difficult to determine the worst-case scenario for the wheels due to the unpredictability of movements that may occur, however it was considered a scenario where the vehicle accelerates deflected, with one of the guiding wheels causing the vehicle to align. This guiding wheel must be able to support the Y axis component of the driving force and the force of dragging approximately half of the vehicle to align it, according to free body diagram (Figure 86).

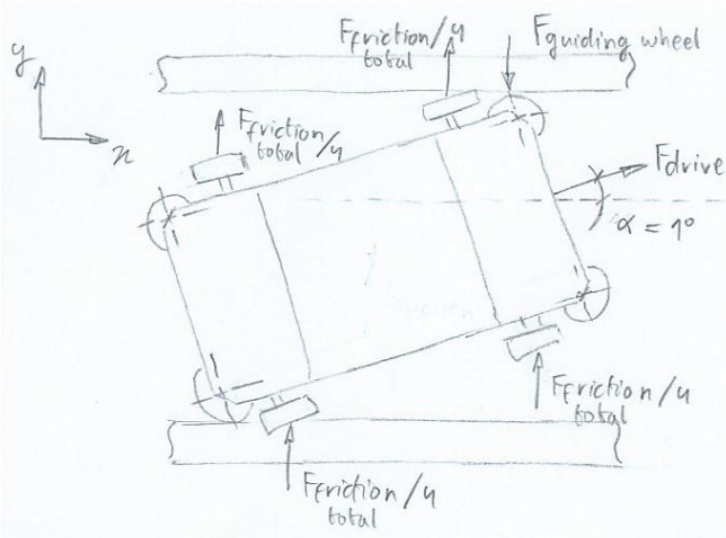


Figure 86 - Shuttle vehicle free-body diagram with the forces on the guiding wheel when the vehicle is accelerating.

To determine the force on the guiding wheel, Equation 25 was used, which relate to the equilibrium of forces in the Y axis.

$$\sum F_y = 0 \Rightarrow \frac{F_{friction\ total}}{2} + F_{drive} \cdot \sin(\beta) - F_{guiding\ wheel} = 0 \Leftrightarrow$$

$$\Leftrightarrow \frac{m_{total} \cdot g \cdot \mu_{stat}\left(\frac{PU}{steel}\right)}{2} + F_{drive} \cdot \sin(\beta) - F_{guiding\ wheel} = 0$$

Equation 25

Where:

F_y – Y axis forces (N);

$F_{friction\ total}$ – Total friction force (N);

$F_{guiding\ wheel}$ – Force on the guiding wheel (N).

m_{total} – Vehicle total mass (kg).

With the load on each of the guiding wheels, it was possible to select a wheel from the catalog. The second step was to correct the permissible load of the selected wheel using the Brauer® factors (Equation 26) and validate the selection by calculating the safety factor between the actual load and the permissible wheel load (Equation 27). The guiding wheels are subject only to factors relating to rolling bearing condition and surface speed 10-16 km/h condition.

$$P_{max\ corr} = P_{max} \cdot C_1 \cdot C_2$$

Equation 26

Where:

$P_{max\ corr}$ – Maximum load supported by the wheel (corrected) (N);

P_{max} – Maximum load supported by the wheel (N);

$$SF = \frac{P_{max\ corr}}{F_{guiding\ wheel}}$$

Equation 27

Where:

SF – Safety factor.

The results are shown in Table 22.

Table 22 - Results of the guiding wheels.

Variable	Result
Force on the Guiding Wheel ($F_{guiding\ wheel}$)	$F_{impacto}$ = 840 N
Selected Wheel	Brauer® Wheels – Polyurethane Tyred Wheels – Wheel Type H75/35
Maximum Load supported by the Wheel (P_{max})	300 kgf = 2943 N
Maximum Load supported by the Wheel (Corrected) ($P_{max\ corr}$)	1545 N
Safety Factor (SF)	2,0

A coefficient of safety of 2,0 is a very acceptable value for a pre-selection of the guiding wheels as it provides some room for maneuver in the event of significant and unexpected variations due to the mechanical design of the machine.

For the travelling wheels, the calculation procedure was very similar to that of the guiding wheels. The difference is that in this case the loads to which the wheels are subjected correspond to the reaction forces of the vehicle, values already determined previously (Table 14). As the worst-case scenario for the travelling wheels, it was considered the maximum dynamic reaction when the vehicle accelerates, which occurs on wheels A (Figure 87).

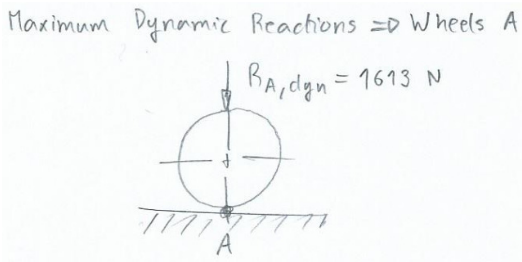


Figure 87 - Force on the travelling wheels.

As such, the force per traveling wheel was calculated through Equation 28.

$$F_{trav.wheel} = \frac{R_{max,dyn}}{2} \Leftrightarrow F_{trav.wheel} = \frac{R_{A,dyn}}{2}$$

Equation 28

Where:

$F_{trav.\ wheel}$ – Force per travelling wheel (N).

After selecting a catalog wheel, it was necessary to affect the permissible load with the Brauer® factors (Equation 29) and, again, validate the selection through the safety coefficient (Equation 30). In this case, the travelling wheels are subject to the factors related to the conditions of continuous rolling, surface speed of 10-16 km/h and driving wheels. Although it is known that only two of the four wheels will be driving, as always, it is considered the worst-case scenario for the wheels selection.

$$P_{max\ corr} = P_{max} \cdot C_1 \cdot C_2 \cdot C_3$$

Equation 29

$$SF = \frac{P_{max\ corr}}{F_{trav.\ wheel}}$$

Equation 30

The results are shown in Table 23.

Table 23 - Results of the travelling wheels.

Variable	Result
Selected Wheel	Brauer® Wheels – Polyurethane Tyred Wheels – Wheel Type H125/40
Maximum Load supported by the Wheel (P_{max})	530 kgf = 5199 N
Maximum Load supported by the Wheel (Corrected) ($P_{max\ corr}$)	1911 N
Safety Factor (SF)	2,4

As with the guiding wheels, a coefficient of safety of 2,4 guarantees some room for maneuver to compensate for possible variations due to the mechanical design of the machine.

3.4.3 DESIGN OF THE MAIN STRUCTURE

With the first sketches made and the preliminary calculations finalized, the 3D design of the equipment was started. It started with the main structure, although it is a component that depends on all the other systems of the machine.

Being one of the main parts of the vehicle, it was necessary to have some care in the design of it, trying to simplify its manufacture to try to reduce the production costs of the machine. Given its complexity, it is natural that there are many alternatives to what is presented in this work, so it is important to note that the solution presented here is only a possible solution and may not even be the optimal solution.

In making the first sketches (Figure 88), the main questions that arose were whether the structure was to be made in structural tube or sheet and whether the material to be used would be aluminum or steel. As it was known at the outset that this structure would undergo welding processes, the material selected was steel because it is easier to weld than aluminum and for having a considerably lower cost. It was decided to design a steel sheet structure to reduce weight, although it is more difficult to have as much mechanical strength as would have been the case if using the structural tube.

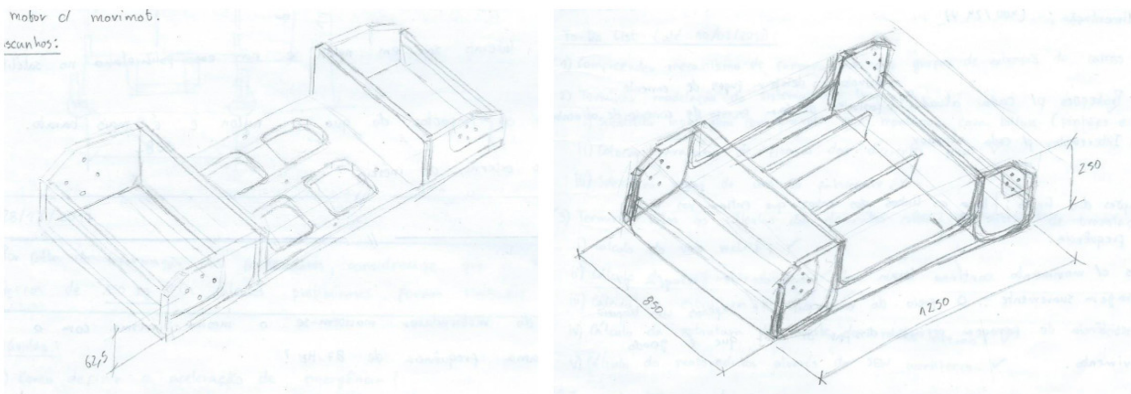


Figure 88 - Sketches of the main structure.

This structure has evolved over time, as different systems of the shuttle vehicle have been developed, so to understand the purpose of each of the elements that constitute this part, it is necessary to read the sections for each of these systems (sections 3.4.4 to 3.4.8). In Figure 89 it is possible to notice the evolution of the structure from the first version to the final version, proving to be an iterative work.

As the main features, the structure is visually symmetrical and consists of two longitudinal plates which are transversely separated by two other U-shaped bent plates

(Figure 90). It then has small bars, bent sheets and reinforcing plates which support the different vehicle systems (see sections 3.4.4 to 3.4.8).

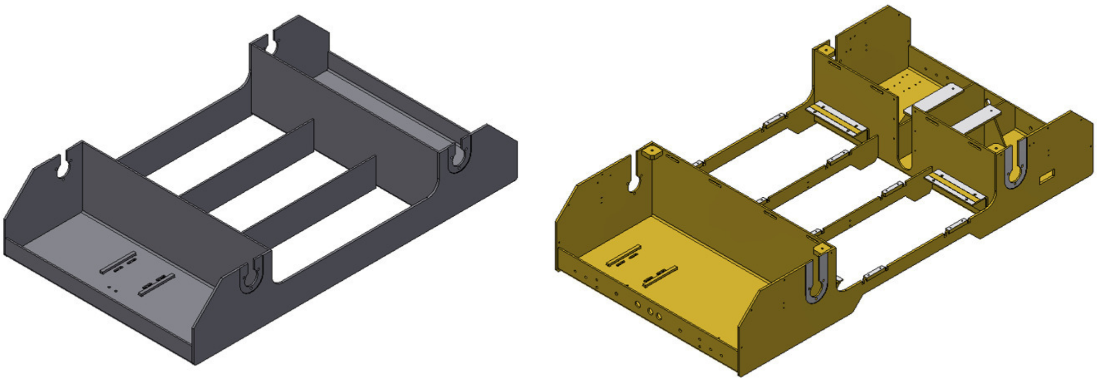


Figure 89 - First and last version of the main structure.

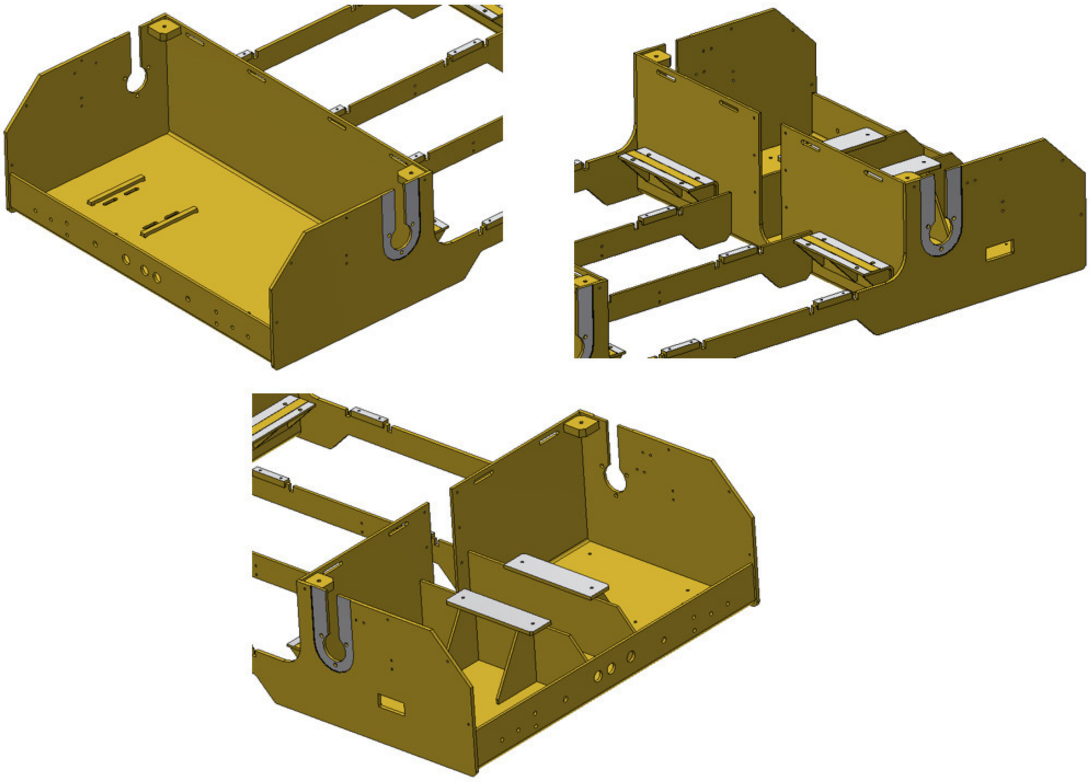


Figure 90 - Some details of the main structure.

The detail drawing of the main structure can be visualized in more detail in Annexes 2 and 3.

3.4.4 DESIGN OF THE TRAVELLING SYSTEM

The travelling system (Figure 91) was the first system to be developed for the shuttle vehicle. It is a system with the main purpose of moving the vehicle along the aisle of the rack automatically at a defined speed and acceleration, stopping accurately in the storage positions of the boxes.

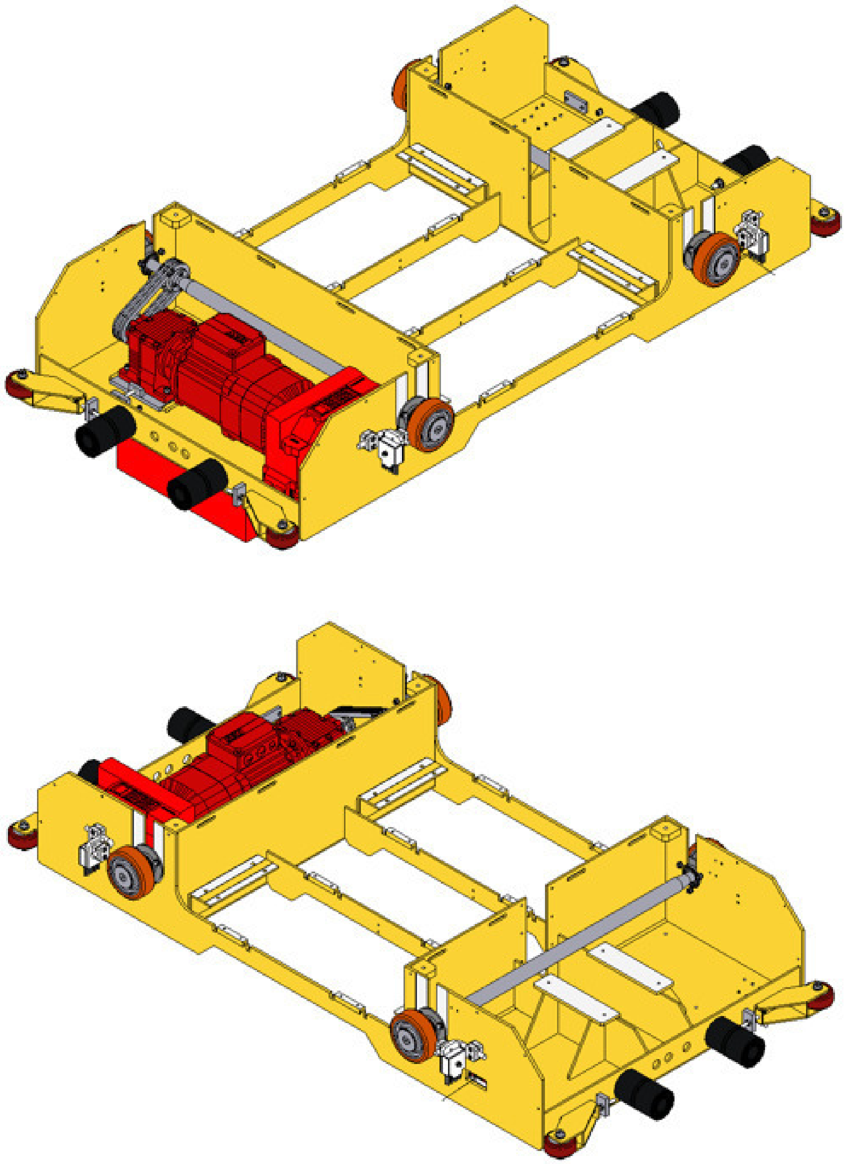


Figure 91 – Travelling system for the shuttle vehicle.

In addition to its main purpose, some requirements were defined from the outset to facilitate decision making throughout the design process of the final solution. These requirements are indicated below:

1) It shall be possible to assemble the travelling system in the main structure of the shuttle vehicle based on the geometry pre-designed for it, trying to put most of the components inside so there is no component visible;
2) The movement of the vehicle is only rectilinear along the aisle, and must remain guided transversely on the rails;
3) The vehicle must be composed of four wheels, two driving and two driven;

4) The gearmotor must be of alternating current and type helical gearmotor of SEW's range of gearmotors;
5) There should be a waste removal system along the rail to extend wheel life;
6) The travelling system shall have shock absorbers at the ends to absorb the impact of the vehicle on the aisle end stoppers in the event of any failure of the controls;
7) The travelling system must have the necessary sensors and controllers to operate automatically and accurately.

The different components that constitute the travelling system were selected or developed in such a way that the mentioned requirements were satisfied. In Figure 92 it is possible to observe the WBS of the travelling system and to see how these components are organized.

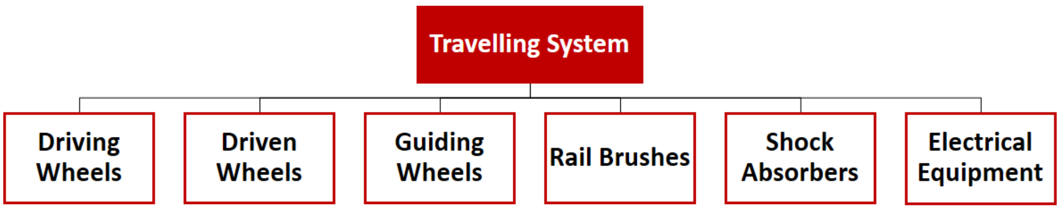


Figure 92 - WBS of the travelling system.

To better understand the description and operation of each of the components from the travelling system, it is necessary to visualize and interpret the respective detail drawings of the parts and assemblies (Annexes 2 and 3), and the standard components data sheets (Annexes 4 and 5).

For the driving wheels assembly (Figure 93), the following components were selected:

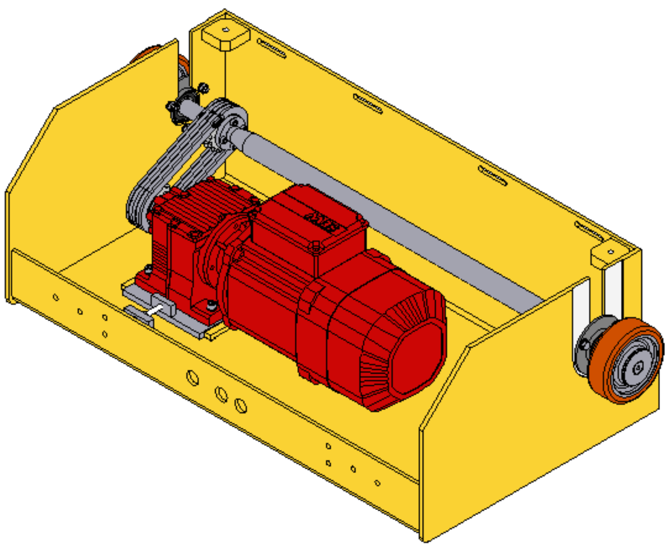


Figure 93 - Driving wheels assembly for the travelling system.

1) A driving shaft that rotates supported by two bearings and where the two driving wheels are assembled;
    a. Notes about the design:
        i. The driving shaft was designed according to the maximum permissible stress and displacement, where it was tried to avoid the creation of zones of stresses concentration, for example softening the transitions of diameter;
        ii. The wheels were selected according to the calculations made initially;
        iii. It was decided to place two driving wheels, instead of one, to ensure greater vehicle stability at start/stop;
        iv. Sheet steel housing units with ball bearing have been selected because of their compactness, ease of assembly, shaft diameter and load capacity.
    b. Notes about the assembly:
        i. This assembly is mounted on the main structure of the shuttle vehicle entering through the slots placed for that purpose;
        ii. The connection is made in the housing units by means of bolts, nuts and Nord-Lock washers, special washers that are used in situations of great vibration because they guarantee a greater safety of the bolted connections due to the interlocking teeth that they have in their support surfaces. These washers were selected for this bolted connection due to the vibration caused by the gearmotor and the rotation of the wheels;
        iii. The shaft is locked axially through bushes placed between the wheels and the bearings, and on the tops through the wheels covers.
2) A gearmotor that transmits the motion to the driving shaft by means of a pair of sprockets and chain;
    a. Notes about the design:
        i. The gearmotor was selected according to the calculations made initially. A helical gearmotor of the SEW range was selected because they have great durability and a wide range of solutions for all types of assemblies.;
        ii. It was decided to transmit the torque of the gearmotor instead of mounting it directly on the driving shaft, so that the displacement of the driving shaft does not affect the gear unit, thus being independent;
        iii. The use of chain and sprockets, instead of belt and pulleys, is due to the great load capacity of the chains and to the fact that they allow some transverse adjustment between the sprockets, being very difficult to disengage;
        iv. A maintenance-free roller chain DIN 8187 08B-2 has been selected. Double chain to increase the load capacity, and

maintenance-free for having a longer life span and for being cleaner;

v. The sprockets were selected considering the following factors: chain type, available space within the main structure of the vehicle, a transmission ratio of 1, pitch diameters high enough to reduce radial loads on the axles, and number of teeth odd and equal to or greater than 17 to reduce tooth wear (chain supplier suggestion).

b. Notes about the assembly:

i. The gearmotor is connected to a support plate using bolts and Nord-Lock washers. The support plate and the gearmotor are then mounted in the main structure between two welded bars, that guide the support plate, and fixed by bolted connection;

ii. The chain loop is placed around the two sprockets, engaging the links in the teeth, and closed with a connecting link;

iii. The support plate of the gearmotor guided on the two welded bars serves to tension the chain. To do this, the plate fixing bolts are relieved in the structure slots and through an adjustment bar the bolt is moved by untightening/tightening two nuts, causing the gearmotor shaft to move away from the driving shaft, which causes the chain tensioning.

3) Locking assemblies and a taper lock bushing that transmit motion to the wheels and sprockets.

a. Notes about the design:

i. It was decided to use locking assemblies to transmit the torque of the driving shaft to the wheels and the driven sprocket, and a taper lock bushing to transmit torque from the output shaft of the gearmotor to the driving sprocket. The keys have not been used because for this type of applications they are advised against due to the constant start/stop cycles and inversions of the movement;

ii. The locking assemblies and the tapper lock bushing are standard components that transmit the movement between shafts and hubs through the friction caused by the tightening between the two existing conical surfaces;

iii. According to the diameters of the shafts and the holes, the following types of locking assemblies and taper lock bushing were selected:

- For the transmission of the movement between the gearmotor output shaft and the driving sprocket the taper lock bushing 1210 D25 was selected due to the existence of the gearmotor key. In this situation the bushing is composed of only one part that has the tolerance hole and a conical surface on the outer diameter. This outer conical surface fits into a conical bore in the driving sprocket;

- For the transmission of the movement between the driving shaft and the driven sprocket, the locking assembly TLK300 25x30 was selected due to the small space between the outside diameters of the driving shaft and the driven sprocket. Two locking assemblies were placed to increase the contact surface area and consequently the torque transmission capacity between the parts;
- For the transmission of the movement between the driving shaft and the travelling wheels, the locking assembly TLK200 25x50 has been selected because it guarantees great torque transmission capacity, and there is enough space for its assembly.

b. Notes about the assembly:

   i. The friction between the contact surfaces is caused by the tightening of the conical surfaces against each other which, in turn, is created by tightening one of the parts against the other. This sliding movement of the conical surfaces causes the outer diameter to expand and the inner diameter contracts, engaging the bushing between the hub and the shaft so that the entire assembly is joined and there may be transmission of movement;

   ii. For proper positioning of the wheels and the sprockets, spacer washers were placed to abut the components before the final tightening of the locking assemblies and the taper lock bushing.

For the driven wheels assembly (Figure 94), the following components were selected:

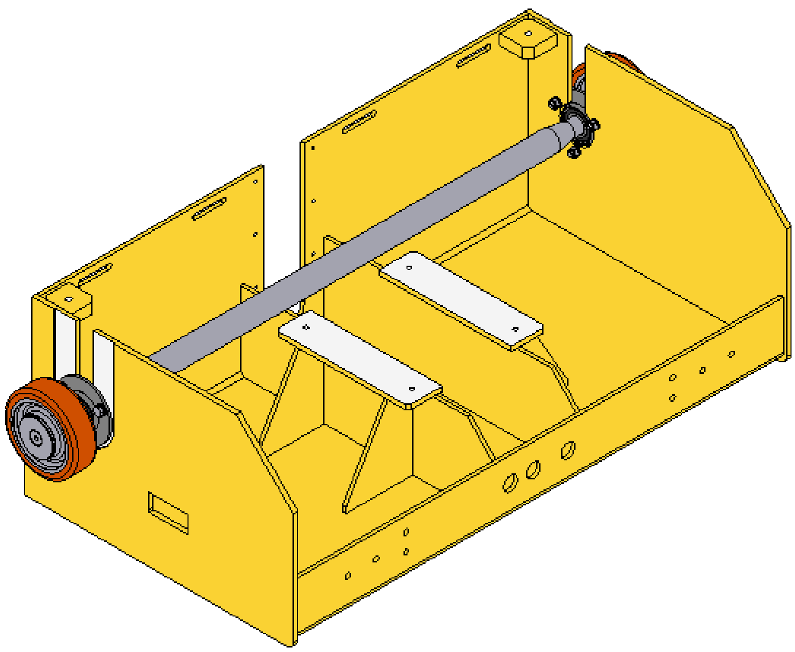


Figure 94 - Driven wheels assembly for the travelling system.

1) A driven shaft that rotates supported by two bearings and where the two driven wheels are mounted;
    a. Notes about the design:
        i. The driven shaft was designed in accordance with the same principles used for the driving shaft, so they are very similar in terms of dimensions and geometry;
        ii. The selected driven wheels were the same as the driving wheels so that all the travelling wheels are the same and so the processes of purchasing the articles and assembling the assemblies are easier;
        iii. The selected housing units were the same ones selected for the driving wheels assembly.
    b. Notes about the assembly:
        i. The mounting of this assembly in the main structure is like the assembly of the driving wheels, in other words, it enters through the slots of the main structure and is bolted through the housing units, all being locked axially through bushes and the wheel covers.
2) Locking assemblies that transmit motion between the driven shaft and the wheels.
    a. Notes about the design:
        i. In this case it was not necessary to use the locking assemblies because there is no torque transmission between the driven shaft and the wheels, however, as it was decided to place driven wheels equal to the driving wheels, it was necessary to use the same locking assemblies to attach the driven wheels to the driven shaft so that there was rotation of the assembly.

For the guiding wheels assembly (Figure 95), the following components were selected:

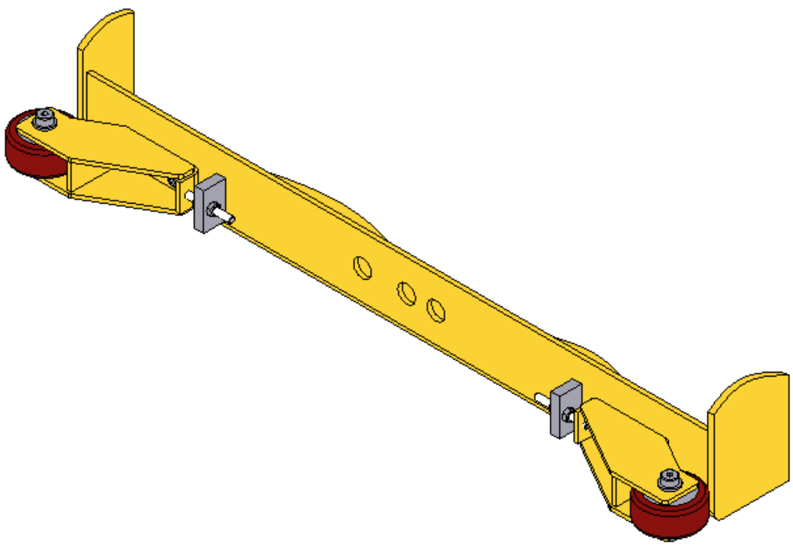


Figure 95 - Guiding wheels for the travelling system.

1) Fork-shaped supports, each with an axle where the guiding wheel is assembled.
    a. Notes about the design:
        i. The guiding wheels supports were designed so that the wheels could be mounted on the main structure with the axis perpendicular to the axis of the travelling wheels, with the guiding rolling laterally between the two rails;
        ii. The wheels were selected according to the calculations made initially;
        iii. For the axles, standardized bolts were selected (ISO 7379) with a smooth and tolerance zone for fitting the wheel with adjustment, and a threaded tip for fixing.
    b. Notes about the assembly:
        i. Each guiding wheel is assembled on its support entering with interference on the axle, and then locked axially through compensation washers and a nylon insert lock nut that is tightened at the threaded end of the axle;
        ii. The supports are fixed to the main structure by bolted connection, where the final tightening should only be given after positioning the wheels on the rail. This adjustment is made through the adjustment bar, by tightening or loosening the nuts on the threaded rod, which causes the wheels to approach or move away from the rail.

The rail brushes (Figure 96), used to remove the waste along the rail, have the following components:

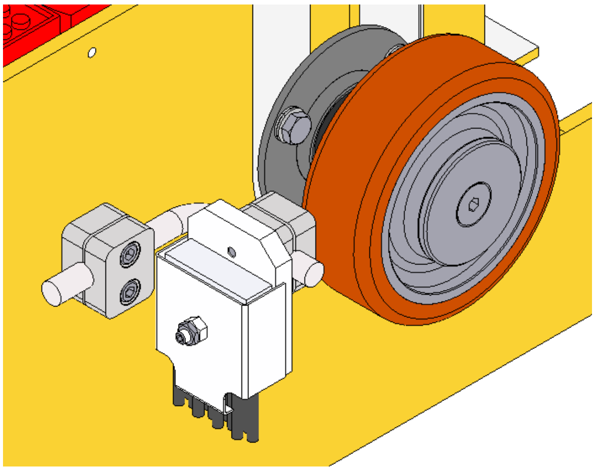


Figure 96 - Rail brush for the travelling system.

1) Brushes and the supports to assemble the set.
    a. Notes about the design:
        i. The brushes consist of a Polyvinyl Chloride (PVC) body in which sixteen blocks of forty-six bristles are embedded, with a width greater than the width of the wheel for cleaning to be effective;

ii. The brackets are welded construction parts that hug the entire body of the brushes to give them greater strength and protection.

b. Notes about the assembly:

i. The brushes are fixed to the respective supports by means of a threaded rod that engages the brush against the base of the support. This rod allows adjusting the brush in height so that it is always in contact with the rails;

ii. The brushes and their supports are mounted on the main structure in front of the travelling wheels by means of clamps and bolted connection, being attached to L-shaped rods;

iii. The L-shaped rods allow the brushes to be adjusted in two directions by sliding over the clamps.

The shock absorbers (Figure 97), used to absorb the impact of the vehicle on the aisle end stoppers, have the following components:

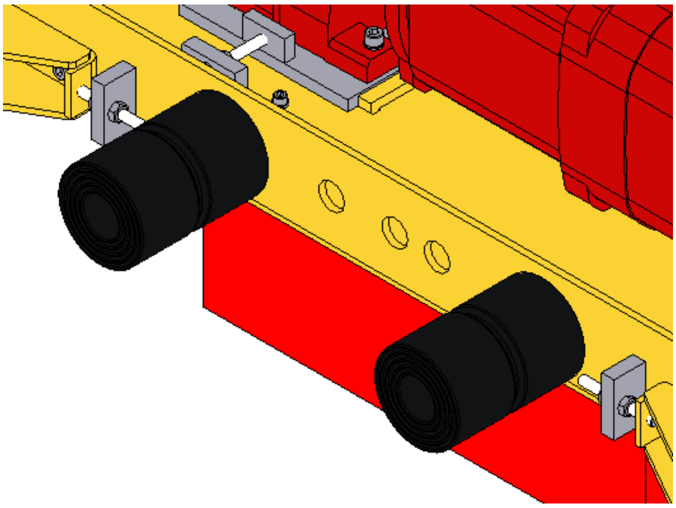


Figure 97 - Shock absorbers for the travelling system.

1) Polyurethane buffers.

a. Notes about the design:

i. The selected shock absorbers were the polyurethane buffers with 80 mm of diameter and 120 mm of height, because they have sufficient load capacity to absorb the impact of the vehicle and because the height allows them to be the most prominent components of the vehicle so that the remaining components remain intact upon impact;

ii. Two buffers were placed on each side of the vehicle to provide greater impact stability and, at the same time, to distribute the load across the two buffers.

b. Notes about the assembly:

i. The shock absorbers are assembled on the main structure by bolted connection, using the threaded bolt they have, and nylon insert lock nut to ensure greater safety in the connection.

The electrical equipment was described in the section 3.4.7.

3.4.5 DESIGN OF THE EXTRACTION SYSTEM

The extraction system (Figure 98) was the second system to be developed for the shuttle vehicle. It is a system with the main purpose of extracting and storing the boxes on the rack at a defined speed and acceleration, ensuring alignment in the final positioning. The entire operation must be performed automatically, accurately and smoothly.

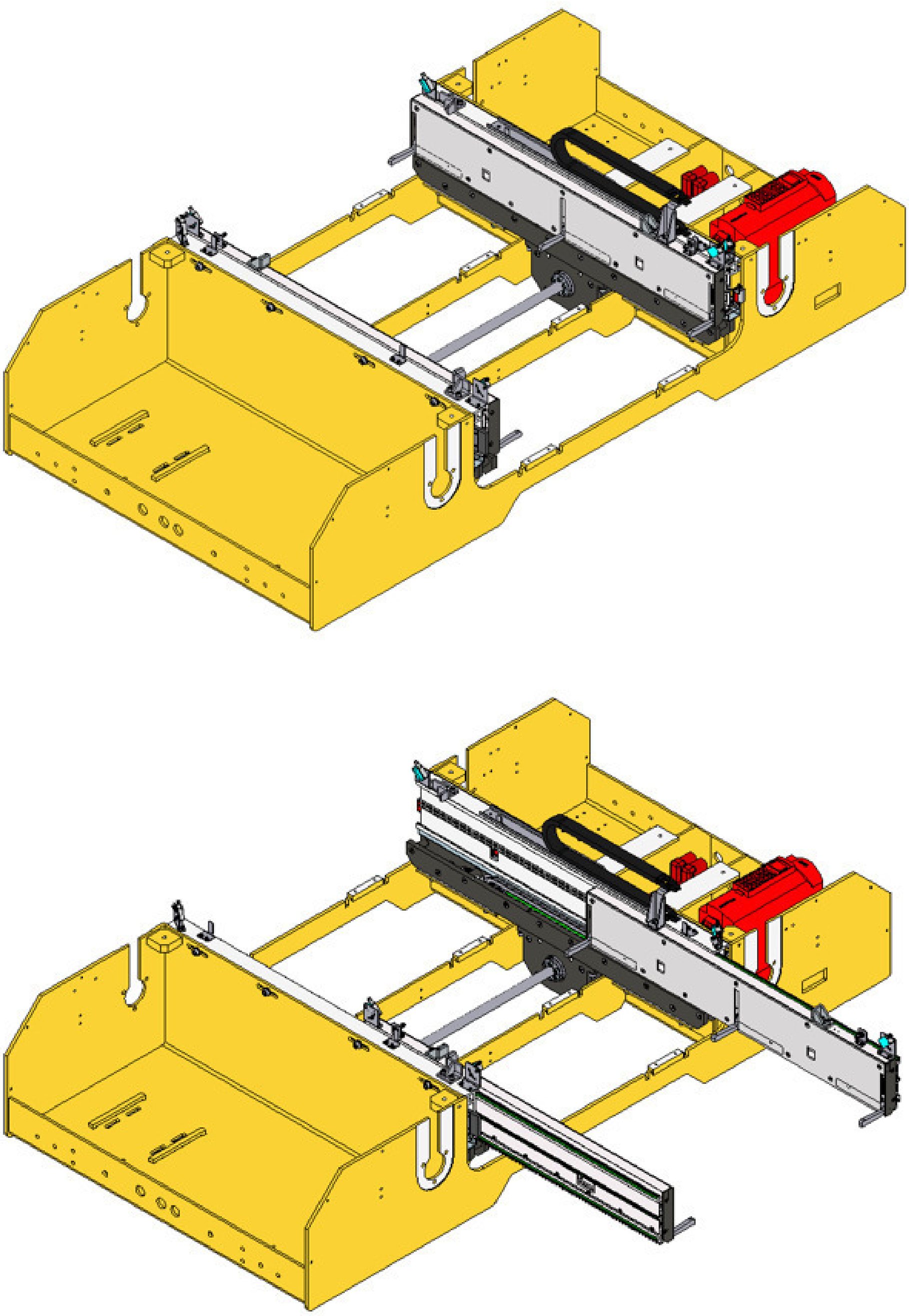


Figure 98 - Extraction system for the shuttle vehicle.

In addition to its main purpose, some requirements were defined from the outset to facilitate decision making throughout the design process of the final solution. These requirements are indicated below:

1) It shall be possible to assemble the extraction system in the main structure of the shuttle vehicle based on the geometry pre-designed for it;
2) Only one box at a time should be removed or stored, even if the vehicle can carry two boxes;
3) The extraction mechanism shall be a retractable mechanism composed of two fixed arms and two movable arms;
4) The extraction or storage movement of the boxes must be linear in the direction of pulling or pushing the boxes, with a maximum stroke of 540 mm;
5) The boxes must be guided along the movement to ensure correct alignment in the final positioning both on the vehicle and on the rack;
6) The boxes must remain locked on all faces when the vehicle is in motion;
7) The fixed and movable arms shall be manufactured from extruded profiles;
8) The parts that make up the system should be made of aluminum, preferably, to reduce the weight of the vehicle;
9) The system must be driven by an electric servo gearmotor to increase the positioning accuracy;
10) The linear movement of the arms must be carried out by means of chain and rack;
11) There shall be mechanical end stoppers for the movable arms;
12) The extraction system must have the necessary sensors and controllers to operate automatically and accurately.

The different components that constitute the extraction system were selected or developed in such a way that the mentioned requirements were satisfied. In Figure 99 it is possible to observe the WBS of the extraction system and to see how these components are organized.

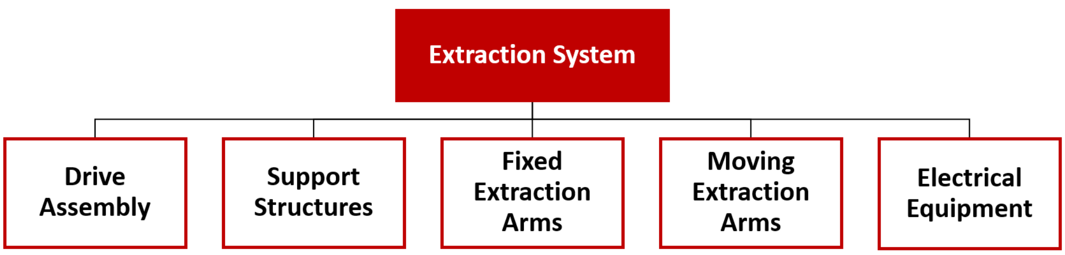


Figure 99 - WBS of the extraction system.

To better understand the description and operation of each of the components from the extraction system, it is necessary to visualize and interpret the respective detail drawings of the parts and assemblies (Annexes 2 and 3), and the standard components data sheets (Annexes 4 and 5).

The drive assembly (Figure 100), used to operate the system, consists of the following components:

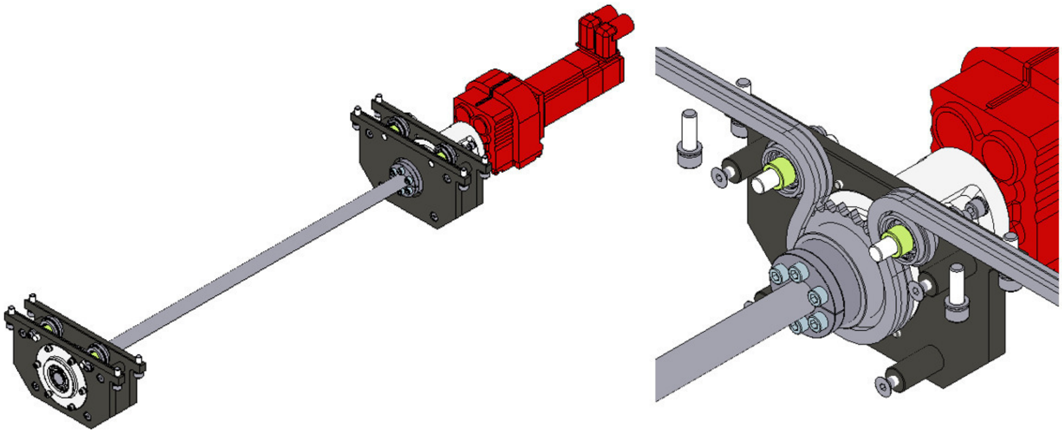


Figure 100 - Drive assembly for the extraction system.

1) Two pairs of support plates to secure the drive assembly and connect it to the support structures of the extraction system;
    a. Notes about the design:
        i. The support plates are aluminum parts divided by two pairs, one for each movable/fixed extraction arm. Each of these pairs has a main bore that is traversed by the driving shaft, with the sprockets and chains being inside each pair;
        ii. Each plate has a small shoulder on the contact surface with the support structures to ensure correct positioning and alignment of the entire drive assembly.
    b. Notes about the assembly:
        i. The support plates are fixed to the support structure of the extraction system by means of bolted connection, using Nord-Lock washers to ensure safety in the attachment since the whole assembly is subject to the vibration coming from the servo gearmotor;
        ii. Each of the pairs of support plates is joined and locked together by pins which are placed inside the plates and fixed with countersunk head bolts.
2) A servo gearmotor that drives a shaft that rotates supported on two bearings, the first mounted on the fixing flange of the servo gearmotor and the second mounted on a customized bearing housing;
    a. Notes about the design:
        i. A servo gearmotor was selected to drive the system because it is suitable for applications that require high positioning accuracy and have low space available (the main reason for this application). A servo gearmotor of the SEW range was selected because, as for the travelling gearmotor, these have great durability and a wide range of solutions for all types of assemblies.

The type of servo gearmotor chosen was the helical type due to the type of assembly that was thought and because the gear unit belongs to the standard range from SEW, which reduces considerably the cost of the machine;

ii. The driving shaft, made of carbon steel, has a diameter that allows it to withstand all the associated loads and guarantee a maximum displacement of less than 0,5 mm. At one end it has a blind hole with keyway for coupling the servo gearmotor and at the other end has a groove for a retaining ring;
iii. In this case the transmission of motion between the gearmotor and the driving shaft had to be keyed because the output shaft of the servo gearmotor is very short and the available space was reduced for mounting a locking assembly between the two parts;
iv. To support the driving shaft rotation, self-aligning ball bearings were selected because they have high axial and radial load capacity and compensate slight angular shaft misalignments without affecting rotation;
v. By supporting the driving shaft on two bearings, all radial loads are absorbed by them and never pass to the output shaft of the servo gearmotor;
vi. The fixing flange of the servo gearmotor, as the name implies, serves to secure the servo gearmotor to the support plates when coupled to the driving shaft. In addition, it has a space for housing one of the self-aligning ball bearings, thus one end of the driving shaft attached to the support plates. This part was designed to be possible to assemble/disassemble the bolts without interference;
vii. The customized bearing housing serves to accommodate the second self-aligning ball bearing and, consequently, securing the other end of the driving shaft to the support plates.

b. Notes about the assembly:
   i. The servo gearmotor is fixed by bolted connection in the respective fixing flange. Nord-Lock washers were used because it is a connection subjected to vibration of the servo gearmotor;
   ii. The servo gearmotor, together with the driving shaft, is mounted on the support plates through the main bore and are then connected by bolted connection at the ends of the driving shaft, through the customized bearing housing and the servo gearmotor fixing flange. Nord-Lock washers were used because these are connections subjected to vibration of the servo gearmotor;
   iii. The driving shaft is locked axially through bushings and retaining rings.

3) Two sprockets, that are used to drive the roller chains, coupled to the driving shaft through locking assemblies;
   a. Notes about the design:

i. The use of chain and sprockets, instead of belt and pulleys, is due to the great load capacity of the chains and to the fact that they allow some transverse adjustment between the sprockets, being very difficult to disengage;
ii. The sprockets were selected considering the following factors: chain type, available space within the extraction system, pitch diameters high enough to reduce radial loads on the axles, and number of teeth odd and equal to or greater than 17 to reduce tooth wear (chain supplier suggestion);
iii. Sprockets are standard steel parts that are purchased to produce the desired hole;
iv. A maintenance-free roller chain DIN 8187 06B-1 has been selected. Maintenance-free for having a longer life span and for being cleaner;
iii. It was decided to use locking assemblies to transmit the movement of the driving shaft to the sprockets because there is enough space available. The keys have not been used because, as previously mentioned, for this type of applications they are not advised due to the constant start/stop cycles and inversions of the movement;
iv. The locking assembly TLK110 20x58 was selected because it guarantees great torque transmission capacity, and there is enough space for its assembly.

b. Notes about the assembly:
   i. For proper positioning of the sprockets, spacer washers were placed to abut the components before the final tightening of the locking assemblies.

4) Chain deviation rollers, so that the chain contacts more than half of the sprocket teeth;
   a. Notes about the design:
      i. The deviation rollers are small steel rings that have a ball bearing housed inside that allows the roller to rotate freely;
      ii. Each roller rotates on a steel axle that is locked in all directions through a small groove where a locking washer is attached.
   b. Notes about the assembly:
      i. The rollers are mounted between the support plates through the axle that passes through the holes of the plates;
      ii. The rollers are locked and positioned axially through bushings and the locking washers that are tightened onto the support plates.

Each of the two support structures (Figure 101), used to support the entire extraction system and to fix it to the main structure of the shuttle vehicle, consists of the following components:

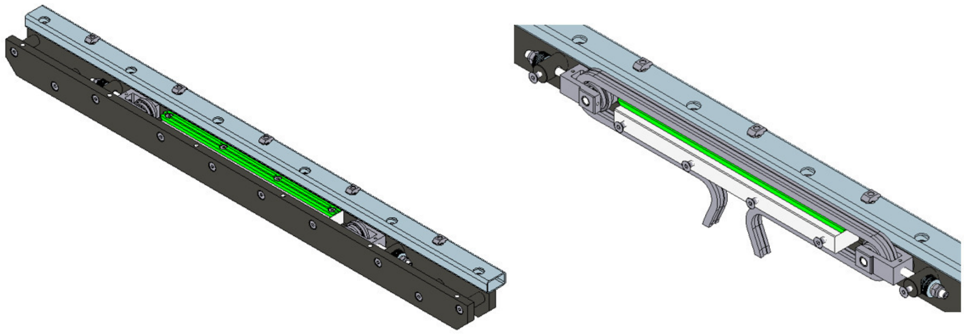


Figure 101 – Support structures for the extraction system.

1) Two longitudinal bars and a structural tube to support the fixed and movable extraction arms and to connect the extraction system to the main structure of the vehicle;
    a. Notes about the design:
        i. The longitudinal bars are parts made of aluminum and are the basis of the entire extraction system, so they have a length equal to the extraction arms. The notches on one side serve to position the parts that are assembled inside the support structure;
        ii. The structural tube is a commercial rectangular profile made of steel that serves to increase the support surface for the fixed extraction arm. It has several slots along the length for access to the fixing bolts.
    b. Notes about the assembly:
        i. The longitudinal bars are joined and locked together by pins that are placed inside the bars and fixed with countersunk head bolts;
        ii. The structural tube is fixed to the longitudinal bar by bolted connection with Nord-Lock washers because it is subject to vibration caused by the movement of the extraction arms.
2) An intermediate block with a plastic profile on top for supporting and sliding the chain;
    a. Notes about the design:
        i. The plastic profile serves to slide the chain avoiding it from being suspended in that zone. It is a part made of plastic to reduce the coefficient of friction between the two surfaces and, at the same time, cause the plastic to wear out instead of being the chain;
        ii. The intermediate block serves only to support and reinforce the plastic profile. It is a part made of aluminum.
    b. Notes about the assembly:
        i. The intermediate block is fixed between the longitudinal bars with countersunk head bolts;
        ii. The plastic profile is fixed on top of the intermediate block with countersunk head bolts.
3) Tensioning systems actuated by spring washers to tension the roller chains.

a. Notes about the design:
   i. The tensioning systems are constituted by a roller, where the chain passes, which is mounted on a steel fork that slides along the two longitudinal bars of the support structure causing the chain to be tensioned;
   ii. To move the fork, a threaded bolt and a nut are used which when tightened/loosened against the spring washers and the fixed adjusting pin causes the fork to approach or move away;
   iii. Spring washers are flexible washers which, when mounted in pairs and in parallel, form a compression spring capable of deforming as much as the sum of the maximum permissible displacements of each washer;
   iv. The spring washers ensure absorption of the impact caused by the starting or stopping of the chain, which is very beneficial for the wear of all the associated components.

b. Notes about the assembly:
   i. The roller is mounted on the fork by being supported on an axle and locked through bushings;
   ii. The fork is mounted between the longitudinal bars, being guided in the notches of each bar;
   iii. The threaded rod passes through the adjusting pin, which is mounted between the longitudinal bars by bolted connection and threaded into the base of the fork. The nylon insert nut ensures locking the entire assembly and crushing the spring washers;
   iv. The number of washers to be placed depends on the maximum deflection desired.

Each of the fixed extraction arms (Figure 102), used to support and guide the movable extraction arms, consists of the following components:

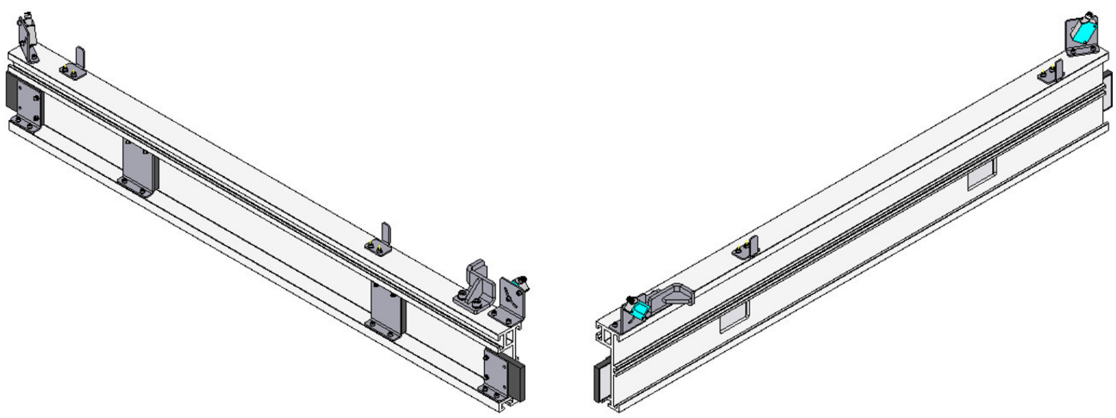


Figure 102 - Fixed extraction arm for the extraction system.

1) A stringer made by an extruded aluminum profile to support all the components and work as the main structure of the fixed extraction arm;
   a. Notes about the design:

   i. The use of a stringer produced from a customized aluminum profile allows the design of a customized part according to the required interfaces and the necessary fixing points. Although it is an expensive manufacturing process, it can be very profitable if several meters of profile are produced.
   ii. The profile has protrusions to support and guide the stringer of the movable arm, and openings in the base and side top for attachment of the stringer to other parts using hammer nuts;
   iii. In the design of the profile, it was tried to optimize the aluminum extrusion process, trying to reduce the volume of extruded material, by placing cavities in the areas with the largest filled area, and surrounding the sharp edges of the profile in the various corners. In this way, in addition to optimizing the manufacturing process, it was also possible to reduce the weight of the stringer.
  b. Notes about the assembly:
   i. The stringer is assembled on top of the structural tube from the support structure by bolted connection using hammer nuts. The hammer nuts can run along the openings that the stringer has for this purpose, ensuring great adjustment, being nailed to the clamping surfaces through the tooth of the contact surface.

2) A mechanical end stopper used to limit the stroke of the retractable mechanism, preventing the movable arm from projecting from the extraction system in the event of a failure of the controls.
  a. Notes about the design:
   i. The mechanical stopper is a small steel plate with two bends, one to create the support face and another to create the face that supports the impact. To increase the strength of the part, two reinforcements were placed in the zone of the two bends in the direction opposite to the force of impact;
   ii. This stopper acts as a fixed stopper since it is attached to the fixed extraction arm. To work properly, it must be aligned with the movable stopper, which is attached to the movable extraction arm.
  b. Notes about the assembly:
   i. The connection between the mechanical stopper and the stringer is made by bolted connection, using blind rivet nuts that allow to increase the depth of the threaded hole since the thickness of the stringer for opening the threaded hole is very reduced. The blind rivet nuts are interlocked between their outer surface and the hole surface.

Each of the movable extraction arms (Figure 103), used to create the retractable mechanism and perform the linear movement, consists of the following components:

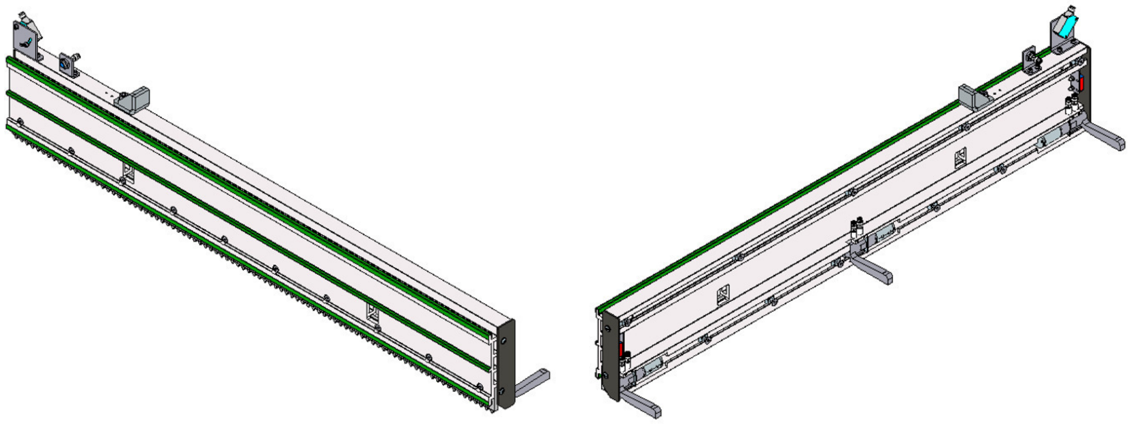


Figure 103 - Movable extraction arm for the extraction system.

1) A stringer, made from an extruded aluminum profile, with the purpose of fixing all the remaining components of the assembly and increasing the strength. Between the contact surfaces of the movable and fixed extraction arms, the stringer has sliders, made from extruded plastic profiles, that facilitate the sliding between the two parts;
   a. Notes about the design:
      i. The use of a stringer produced from a customized aluminum profile has the same advantages already mentioned before;
      ii. This profile of the fixed stringer, such as the profile of the movable stringer, has protrusions so that it can be fitted and guided along the movable stringer. It also has an upper opening and a lower opening for attachment of the longitudinal cover, wherein one of the openings further has a cavity for housing the DC drives and the retractable fingers. There is also a lower rip to attach the rack;
      iii. In the design of the profile, it was also tried to optimize the aluminum extrusion process, as already mentioned before;
      iv. The plastic sliders are made of high density polyethylene in the form of an extruded profile that embraces the protrusions of the movable stringer, reducing the coefficient of friction between the two stringers and functioning as a sacrifice part that wears out over time.
   b. Notes about the assembly:
      i. The movable stringer is mounted on the fixed stringer entering from the top in the direction in which it moves. As it is a movable component, the movable stringer only remains engaged and properly guided through the protrusions that are separated by the sliders.
2) A rack that is driven by the roller chain so that the arm can move;
   a. Notes about the design:
      i. The rack is a part made of steel that, through the driving chain, allows to turn the rotary movement of the servo gearmotor in linear motion. This mechanism is fundamental for the movement

of extracting the boxes to be carried out, because it creates the driving force transmitted to the movable arm through the attachment between the rack and the movable stringer;

ii. The rack has several large holes along its length for weight reduction, since it is a steel part and the mechanical strength must be mostly needed on the teeth.

b. Notes about the assembly:

i. The assembly of the rack is carried out at the bottom of the movable stringer in the existing space for that purpose. The connection is made by bolted connection using countersunk head bolts because there is not enough space for the bolt head.

3) Three retractable fingers, driven by DC drives, that perform the operations of pushing or pulling the boxes, besides serving to keep them locked inside the vehicle;

a. Notes about the design:

i. The retractable fingers are parts made of steel composed of a rod attached to a cylindrical body that allows to perform a rotating movement of 90 degrees on its axis, carrying out the operations of pushing or pulling the boxes. For the movement to be properly done, each of the fingers is housed inside the movable stringer being locked axially and radially. The tangential movement is guided by a support that engages the cylindrical body of the retractable finger, having small stoppers positioned so that the retractable finger stroke never exceeds 90 degrees;

ii. To drive each of the retractable fingers it was decided to use DC drives because it is an application that requires low torque and where the available space is reduced. In addition, the use of a DC drive for each retractable finger guarantees independent control, which is fundamental for the extraction system to function without failures;

iii. As a reaction arm for the DC drive, a plate was developed that fixes to the movable stringer and locks the DC drive body so that it can transmit the movement to the retractable finger;

iv. The transmission of motion between the DC drive and the retractable fingers is carried out directly by mounting the output shaft of the DC drive in the hole of the cylindrical body of the retractable finger through a set screw which is bolted onto the retractable finger and tightened against the output shaft of the DC drive.

b. Notes about the assembly:

i. The DC drive is mounted on the reaction plate by bolted connection on the surface of the output shaft, using countersunk head bolts that allow the output shaft to be released;

ii. The retractable finger is mounted on the output shaft of the DC drive, practically leaning against the reaction plate. Further, as already mentioned, the connection between the output shaft of the motor and the retractable finger axis is made through a set screw which engages against a flat face of the output shaft of the motor;

iii. Each subassembly, together with the retractable finger guiding support, is engaged in the movable stringer laterally in the respective housings, being locked axially through the reaction plate which is fixed in small slots of the stringer that lock it.

4) A mechanical end stopper used to limit the stroke of the retractable mechanism, preventing the movable arm from projecting from the extraction system in the event of a failure of the controls;

   a. Notes about the design:

      i. The mechanical stopper is a small steel plate with one bend to create the face that supports the impact. To increase the strength of the part, two reinforcements were placed in the zone of the bend in the direction opposite to the force of impact;

      ii. This stopper acts as a movable stopper since it is attached to the movable extraction arm. To work properly, it must be aligned with the fixed stopper, which is attached to the fixed extraction arm.

   b. Notes about the assembly:

      i. The connection between the mechanical stopper and the stringer is made by bolted connection, using blind rivet nuts that allow to increase the depth of the threaded hole since the thickness of the stringer for opening the threaded hole is very reduced. The blind rivet nuts are interlocked between their outer surface and the hole surface.

5) A longitudinal cover for guiding and locking the boxes inside the vehicle, and two top covers so that the components inside the stringer are not visible.

   a. Notes about the design:

      i. The longitudinal cover is a plate made of aluminum having a length equal to the length of the movable stringer and cuts in the stroke regions of the retractable fingers. The main function of this part is guiding and transversely locking the boxes between the two extraction arms by creating a contact surface along the entire movable stringer;

      ii. The two top covers are two bars made of aluminum that occupy the whole area of the top faces of the movable stringer, hiding the components that lie inside.

   b. Notes about the assembly:

      i. The longitudinal cover is assembled laterally on the movable stringer by bolted connection using hammer nuts that ensure great adjustment, as already mentioned before;

ii. The top covers are assembled on the top faces of the movable stringer by bolted connection.

The electrical equipment was described in the section 3.4.7.

3.4.6 DESIGN OF THE PICKING SYSTEM

The picking system (Figure 104) was the third system to be developed for the shuttle vehicle. It is a system with the main purpose of performing the picking operations automatically directly on the rack, in other words, transferring the products between the warehouse boxes and the boxes where customer orders are met. In this case, the products must be handled with high precision and flexibility.

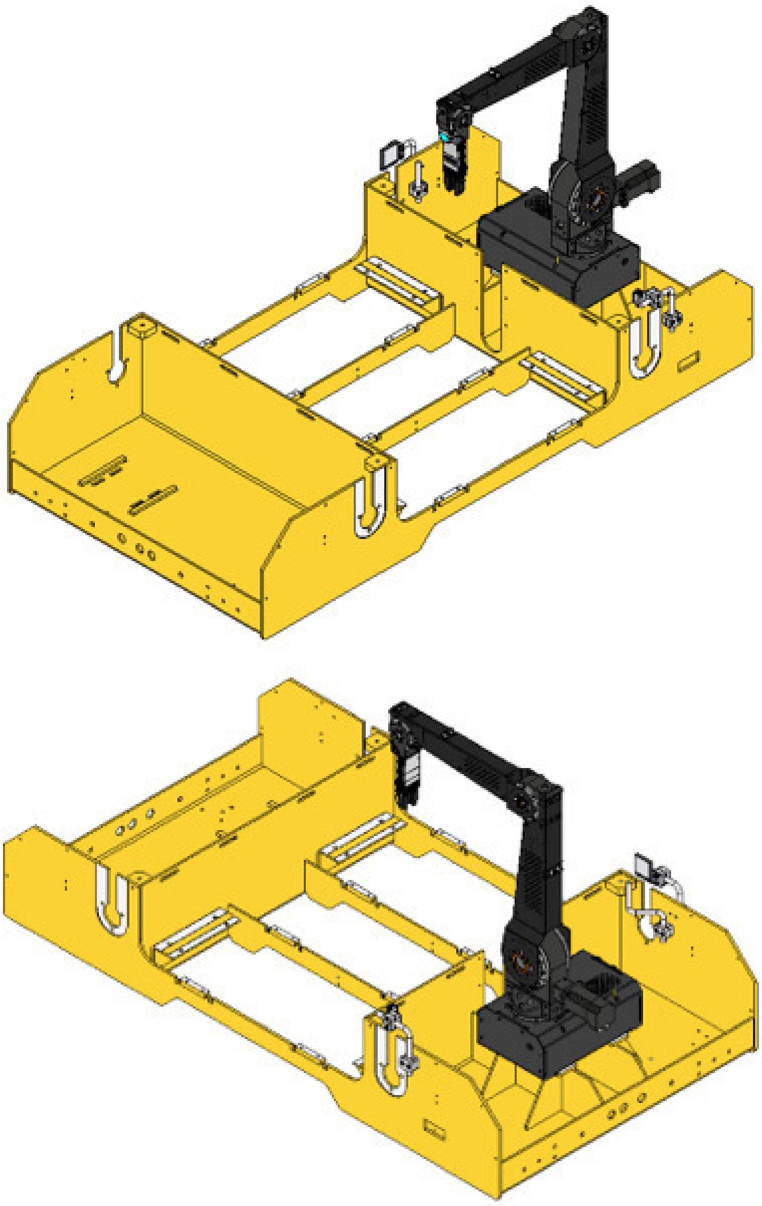


Figure 104 - Picking system for the shuttle vehicle.

In addition to its main purpose, some requirements were defined from the outset to facilitate decision making throughout the design process of the final solution. These requirements are indicated below:

1) It shall be possible to assemble the picking system in the main structure of the shuttle vehicle based on the geometry pre-designed for it;
2) Only one product at a time should be transferred between the two boxes, with high precision and flexibility;
3) The pick and place operations shall be carried out by a robotic arm with an electromechanical gripper at the end to grab the products;
4) The robot must be able to reach the entire occupying area of the two boxes inside the vehicle;
5) The system must have a resting point, in the form of a rod or a block, for the robot to grasp when it is not in operation;
6) The picking system must have the necessary sensors and controllers to operate automatically and accurately.

The different components that constitute the picking system were selected or developed in such a way that the mentioned requirements were satisfied. In Figure 105 it is possible to observe the WBS of the picking system and to see how these components are organized.

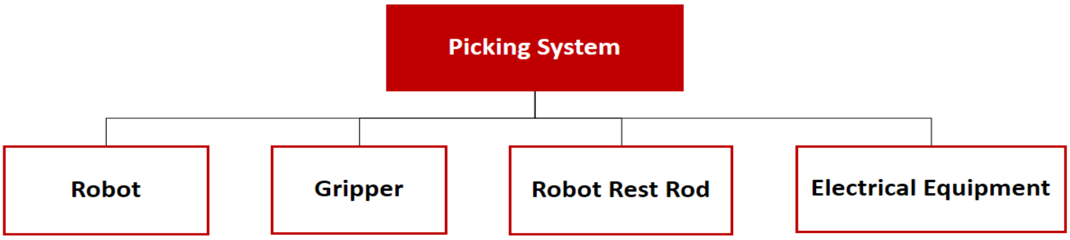


Figure 105 - WBS of the picking system.

To better understand the description and operation of each of the components from the picking system, it is necessary to visualize and interpret the respective detail drawings of the parts and assemblies (Annexes 2 and 3), and the standard components data sheets (Annexes 4 and 5).

The robot, used to transfer products between boxes, consists of the following components:

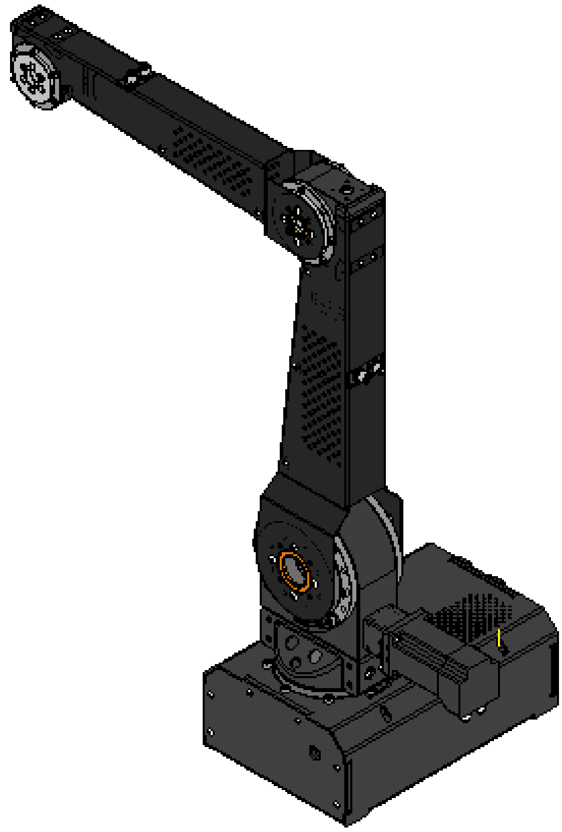


Figure 106 – Robot for the picking system.

1) A four-axis robot responsible for moving the products between boxes in a flexible way.
   a. Notes about the design:
      i. A four-axis robot was selected because it allows to move the products in a very flexible way, maintaining great speed and positioning precision. The number of axes required was determined according to the robot's reach between the two boxes and how to position the gripper to grab the products;
      ii. The robot selected was a robotic modular system of the robolink®-type D range, a low-cost solution patented by IGUS where it is possible to quickly configure the entire robotic arm according to the needs (using an online configurator from IGUS), creating a kit that can be supplied ready to use (including a programmable controller for the robot movement);
      iii. The robot was configured to reach the farthest point between the two boxes, covering the entire area occupied by them, without reducing the desired load capacity (see calculations section).
   b. Notes about the assembly:
      i. The robolink® robotic arm has a support structure at its base where the connection is performed. The robot is assembled on

the main structure of the vehicle through its support structure, resting on two welded bars reinforced with ribs;

ii. The connection is made by bolted connection.

The gripper (Figure 107), used to grab the products inside the boxes, consists of the following components:

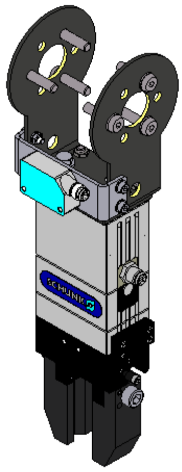


Figure 107 – Gripper for the picking system.

1) An electromechanical gripper with two jaws to grab the products.
   a. Notes about the design:
      i. It was decided to use an electric gripper to facilitate the type of power supply. Although most grippers are pneumatic, this would require placing additional components into the system as a compressor, something that would not be advantageous given the limited space available inside the vehicle;
      ii. The gripper was selected from Schunk's EGP range. This is a two-finger parallel gripper with smooth-running base jaws guided on roller bearings, used to handle small and low weight products. The number of fingers depends on the complexity of the products to be handled. For this work, it was considered that bottles would be handled, so two fingers are enough to carry out the operation;
      iii. The jaws are parts made of aluminum designed to grip cylindrical surfaces (bottle caps) and to fit the fingers of the gripper, according to the maximum permissible finger length predicted on the gripper technical datasheet. Each of the jaws has a V-shaped full length cut so that the contact with the cylindrical surface of the bottle is made in four points.
   b. Notes about the assembly:
      i. The connection between the jaws and the fingers of the gripper is made by bolted connection. To increase the safety of the connection, two elastic pins are attached to each jaw to withstand all kinds of radial stresses, relieving the load on the bolt;

ii. The gripper is attached to the end axis of the robotic arm and is bolted to an existing adapter.

The robot resting rod (Figure 108) is used so that the robotic arm remains in charge when grabbing the rod, preventing it from being loose whenever it is not in operation, namely during the travelling movement of the vehicle. It consists of the following components:

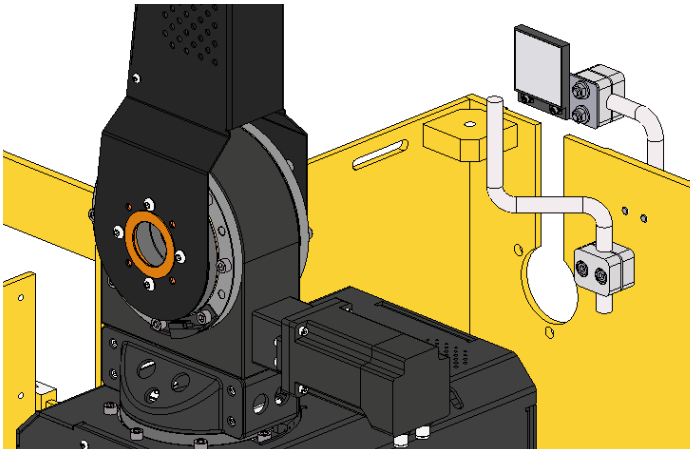


Figure 108 - Robot resting rod for the extraction system.

1) A rod that is gripped by the robotic arm, keeping it loaded and locked.
   a. Notes about the design:
      i. The rod is a part made of steel with two bends, which protrudes from the vehicle so that the robotic arm can grip it;
      ii. It is positioned in a zone outside the product handling zone so that it reduces the risk of collisions between the robotic arm and the rod.
   b. Notes about the assembly:
      i. The rod is assembled inside the main structure next to the base structure of the robot. The connection is made by bolted connection through a clamp that allows adjusting the rod in the axial and tangential direction.

The electrical equipment was described in section 3.4.7.

3.4.7 SELECTION OF ELECTRICAL EQUIPMENT

The selection of the electrical equipment to be applied in the machines is a competence of the automation project engineer and is not therefore the responsibility of the mechanical design engineer. The responsibility of the mechanical design engineer is to develop the supports to assemble the electrical components in the machine. However, this is a very important step in the process of developing a machine because it is what guarantees the automatism and control of the equipment, requiring a lot of communication between the automation project engineer and the mechanical design engineer.

Although the present work is included in the scope of the mechanical design of a machine, a selection of electrical components was made. Even though it is not the best solution, it is a possible solution to automate and control all operations of the shuttle vehicle.

The different electrical components selected are described in Table 24, with all the information necessary to understand the operation of each component and its application in the shuttle vehicle. The communication system selected was the PROFINET, a network based on an Industrial Ethernet communication standard.

To better understand the description and operation of each of the electrical equipment, it is necessary to visualize and interpret the shuttle vehicle assembly drawings (Annexes 2 and 3), and the electrical components data sheets (Annex 6).

Table 24 - Selection of electrical equipment to be applied to the shuttle vehicle.

Shuttle vehicle subsystem	Problem to solve	Type of device selected	Reference (Manufacturer)	Operation and application on the shuttle vehicle
Travelling System	Measure the position of the shuttle vehicle along the rail.	Bar Code Positioning Sensor	BPS-8-SM (Leuze)	The barcode positioning sensor measures the position of the shuttle vehicle along the rail through a bar code strip placed along the entire length of the rail.
Travelling System	Detect the shuttle vehicle's maximum travel at the end of the aisle.	Electromechanical Switch	3SE5112-0CH01 (Siemens)	The limit switch of the shuttle vehicle is driven through ramps at the ends of the aisle.
Travelling System	Restore initial vehicle position for program control purposes (reset).	Inductive Sensor	IME18-05BPS-ZC0S (Sick)	The initial position of the vehicle is restored whenever the limit switch is activated, which means that the inductive sensor is also actuated via the limit ramp.
Travelling System	Possibility of manual emergency stop if the vehicle is being manually controlled.	Emergency Stop Mushroom Pushbutton, Illuminable	3SU1001-1HB20-0AA0 (Siemens)	The shuttle vehicle has one emergency button at each end.

Shuttle vehicle subsystem	Problem to solve	Type of device selected	Reference (Manufacturer)	Operation and application on the shuttle vehicle
Travelling System	By colored light signals, inform the operators of the state of operation of the vehicle.	Indicator Lights	3SU1001-6AA40-0AA0 3SU1001-6AA30-0AA0 (Siemens)	The vehicle moves three light signals at each end (green - means the vehicle is in correct operation, yellow - the vehicle has an anomaly, red - emergency stop, light signal embedded in the emergency button).
Travelling System	Adjust the speed and acceleration of the travelling gearmotor.	Frequency Inverter	MDX61B0022-5A3-4-00 (SEW-Eurodrive)	Frequency inverter located next to the travelling gearmotor, allows to control the motor speed and torque by varying motor input frequency and voltage.
Travelling System	Decelerate the travelling gearmotor by dynamic braking.	Braking Resistor	BW100-006 (SEW-Eurodrive)	Resistors consume heat. A braking resistor can be used to decelerate an electric motor by transforming kinetic energy (generated during normal motor operation) into electrical energy. The braking resistor was placed on the exterior of the shuttle vehicle to facilitate the dissipation of the heat that is consumed.

Shuttle vehicle subsystem	Problem to solve	Type of device selected	Reference (Manufacturer)	Operation and application on the shuttle vehicle
Extraction System	Guide/protect the electrical cables of the different electrical devices embedded in the movable arms, so that they do not become loose during the retractable movement of the arms.	Energy Chain	0.702m 045.20.038.0 + 0450.20.12PZ.A2 (Igus)	Energy chain with a section sufficient to store the cables of the DC drives and sensors on the movable extraction arms, and a stroke equal to the stroke of the extraction system.
Extraction System	Detect the presence of a box between the extraction arms.	Photoelectric Sensor + Mirror	GL6-P3211 + P250 (Sick)	A photoelectric sensor and a mirror were placed for each of the two positions of the boxes between the extraction arms. The presence of a box in one of these positions interrupts the light beam between the sensor and the mirror.
Extraction System	Detect the opening of the movable extraction arms so that the vehicle does not start with them open.	Photoelectric Sensor + Mirror	GL6-P3211 + P250 (Sick)	A sensor and a mirror were placed at each end of the fixed extraction arms. When the movable extraction arms move, they interrupt the light beam between the sensor and the mirror.

Shuttle vehicle subsystem	Problem to solve	Type of device selected	Reference (Manufacturer)	Operation and application on the shuttle vehicle
Extraction System	Detect the end of the box along the width (extraction stroke) to begin closing the extraction arms.	Photoelectric Sensor + Mirror	WL2SG-2F3235 + P45A (Sick)	A sensor and a mirror were placed at each end of the movable extraction arms. When the movable extraction arms move along the width of the carton, the light beam between the sensor and the mirror is interrupted until reaching the end of the box, at which point the arms can stop. This sensor only exists for safety because all the positioning of the extraction system is performed by programming and measuring the rotation of the servomotors.
Extraction System	Detect the maximum positions of the extraction arms (open or closed).	Inductive Sensor	IM08-1B5PS-ZTK (Sick)	There is an inductive sensor in each of the movable extraction arms, one for each direction of the retractable movement. The sensors are actuated by targets placed on the fixed extraction arms whenever the maximum extraction stroke is exceeded or whenever the extraction arms are collapsed.

Shuttle vehicle subsystem	Problem to solve	Type of device selected	Reference (Manufacturer)	Operation and application on the shuttle vehicle
Extraction System	Detect the maximum positions of the retractable fingers (open or closed).	Inductive Sensor	IM08-1B5PS-ZTK (Sick)	There are a pair of inductive sensors for each of the retractable fingers, one for each finger position. They are actuated by the cylindrical body of the retractable finger and whenever one of the sensors is actuated, the other remains unactuated.
Extraction System	Detect whether the storage position on the rack is occupied or not.	Laser Photoelectric Proximity Sensor	WTB8L-P2231 (Sick)	The laser photoelectric proximity sensor is actuated by the boxes (up to a distance detectable by the laser beam of the sensor) whenever they are occupying a rack storage position, preventing the extraction system from storing or removing a box incorrectly. There is one sensor for each side of the aisle.
Extraction System	Detect if there is any obstacle in front of the extraction arms that prevents the opening of them.	Laser Photoelectric Proximity Sensor	WTB8L-P2231 (Sick)	A laser photoelectric proximity sensor was placed on each of the tops of the movable extraction arms. These are actuated whenever an obstacle is encountered in front of the moving arms (up to a distance detectable by the laser beam of the sensor).

Shuttle vehicle subsystem	Problem to solve	Type of device selected	Reference (Manufacturer)	Operation and application on the shuttle vehicle
Extraction System	Adjust the speed and acceleration of the extraction servo gearmotor.	Frequency Inverter	MDX61B0011-5A3-4-00 (SEW-Eurodrive)	Frequency inverter located next to the extraction servo gearmotor, allows to control the motor speed and torque by varying motor input frequency and voltage.
Picking System	Confirm product presence inside the box.	Laser Photoelectric Proximity Sensor	WTB8L-P2231 (Sick)	Laser photoelectric proximity sensor placed next to the gripper, with the laser beam properly aligned so that the robot confirms the presence of product in the different positions of the matrix of the box. The product is what triggers the sensor since it is below the maximum distance detectable by the sensor.
Picking System	Detect that the robot is in the rest position, so the vehicle can start the movement.	Photoelectric Sensor + Mirror	GL6-P3211 + P250 (Sick)	A sensor and a mirror were placed aligned with the robot's resting rod, and the light beam is interrupted by the gripper of the robot whenever it grabs the rod.
Generic	Identify the reference of the boxes being handled by the system.	Barcode Reader	CLV621-1120 (Sick)	Two barcode readers were placed, one for each of the box handling positions inside the vehicle, which read the barcode at the bottom of the boxes.

Shuttle vehicle subsystem	Problem to solve	Type of device selected	Reference (Manufacturer)	Operation and application on the shuttle vehicle
Generic	House all control components (power supply, PLC, etc.).	Terminal Box	KL 1503.510 (Rittal)	Terminal box placed inside the vehicle for storage of control components such as PLC, power supply, safety devices, etc.
Generic	Communicate with the PLC of the shuttle vehicle.	IWLAN antennas	6GK5795-6MN10-0AA6 (Siemens)	Wireless communication device so that there is a connection between the main control PLC of the entire AS / RS and the shuttle vehicle PLC.
Generic	Power the entire system electrically.	Conductor Rail + Collector	081106-5303 + 081106-5301 (Conductix-Wampfler)	Power rail powered shuttle, recommended for systems that move in a straight line and over long distances. The collector that serves as the interface between the vehicle and the power rail is double so that the vehicle never loses power when leaving the rack.

3.4.8 INTERFACES, COVERS AND TRANSPORTATION POINTS

The last components to be developed solved problems related to the shuttle vehicle interfaces inside the rack structure, the transport and handling of the equipment, and the covers/protections of the vehicle. These components do not belong to any of the major subsystems described in previous sections but have the same importance because the mechanical design would be unfinished without them.

To better understand the description and operation of each of these components, it is necessary to visualize and interpret the respective detail drawings of the parts and assemblies (Annexes 2 and 3), and the standard components data sheets (Annexes 4 and 5).

The interface of the shuttle vehicle with the rack structure is related to the passage of the boxes to the interior of the vehicle because there is a natural gap caused by the separation of the two surfaces. As such, two flat steel plates were developed to support the boxes inside the vehicle, between the extraction arms (Figure 109). These plates are fixed to the main frame by bolted connection, using countersunk head bolts to allow the sliding of the boxes on the support surface.

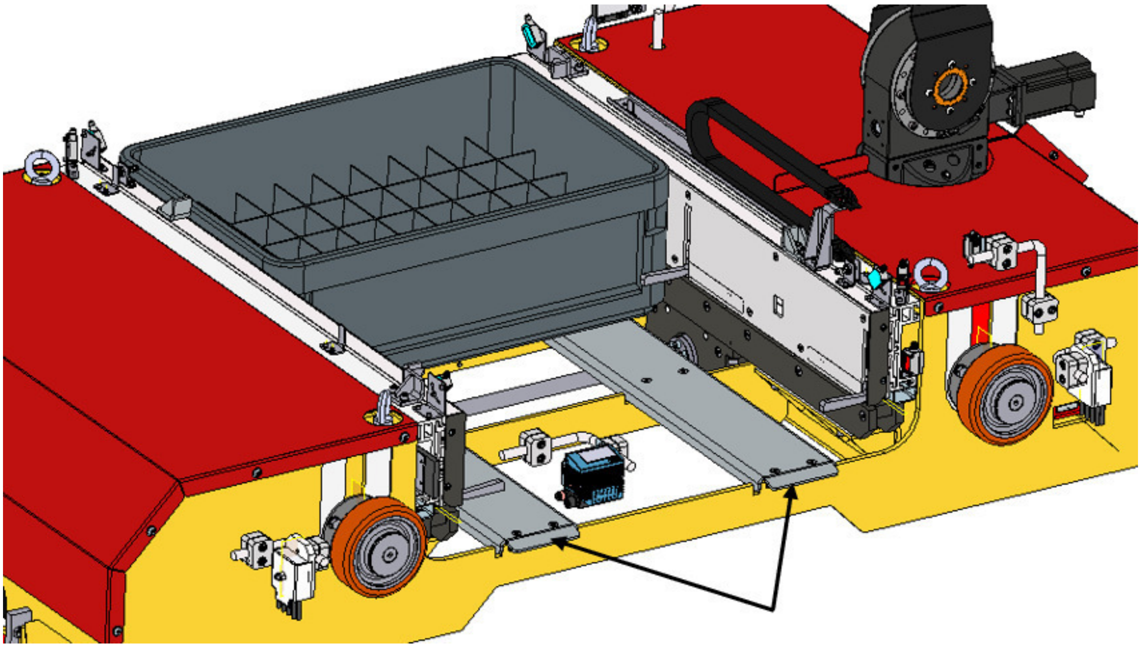


Figure 109 - Boxes support plates.

The plates have four bends all around, two at 90 degrees for reinforcement and two at 20 degrees to smooth the passage of the boxes between the rack structure and the interior of the vehicle (Figure 110).

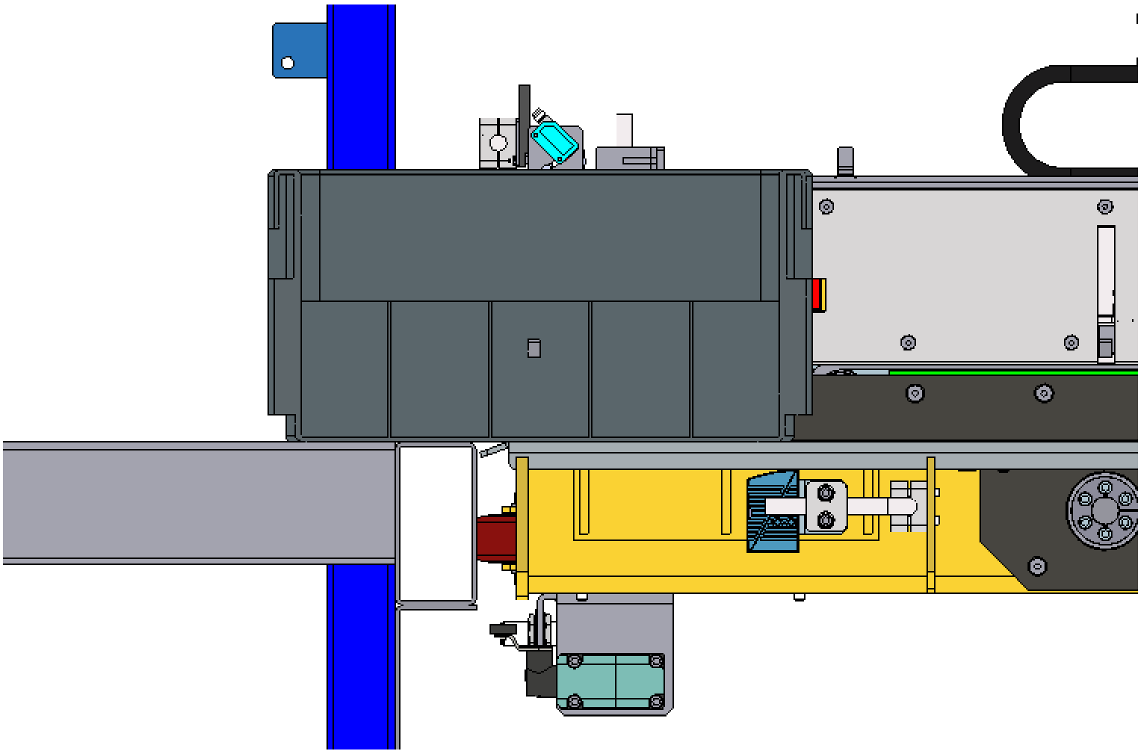


Figure 110 - Passage of the boxes between the shuttle vehicle and the rack.

The transport and handling of the shuttle vehicle during the assembly, installation or maintenance process is carried out by means of four lifting eyes placed at the top of the main structure (Figure 111), allowing the vehicle to be lifted with the use of industrial cranes.

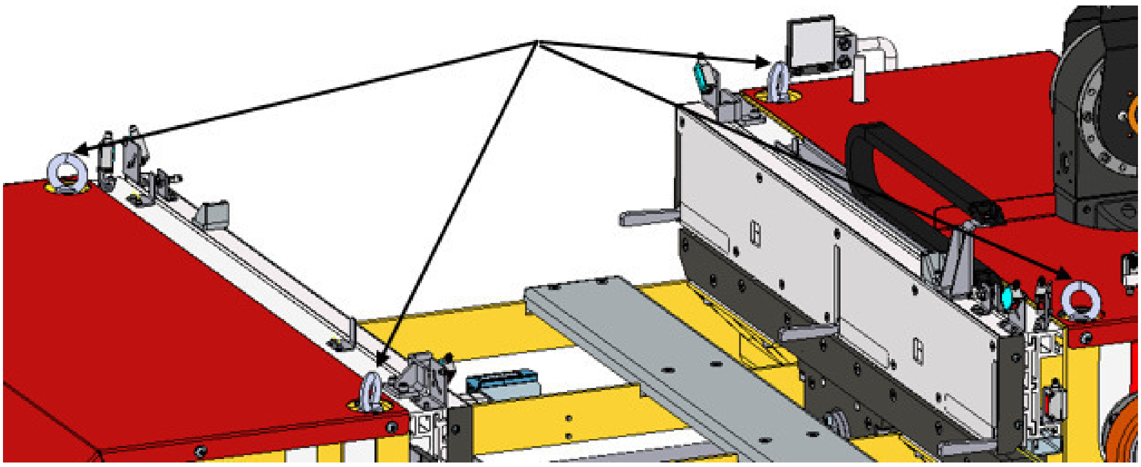


Figure 111 - Four lifting eye bolts on top of the main structure.

The lifting eye was selected according to the total mass of the equipment (300 kg) divided by the four lifting eyes, which gives a load of about 750 N on each one, assuming a bolted connection with the main structure of the vehicle. As such, the lifting eye bolt DIN 580 M10 was selected because it has a load capacity of 1700 N (see Annex 5), more than double the 750 N. The load capacity of the lifting eyes varies according to the direction of the lifting rope (Figure 112). The shuttle vehicle will always be lifted according to scenario 2 of Figure 112 because it has four lifting eyes assembled on top.

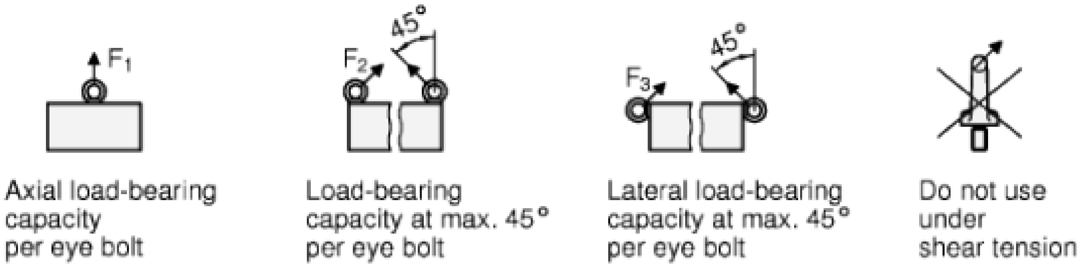


Figure 112 - Types of loads on lifting eyes.

The covers are used to close the two cavities that exist in the main structure of the shuttle vehicle where the travelling and extraction gearmotors are housed. They have been developed to protect the components from external waste, to prevent the risk of manually accessing the components during the testing phases of the equipment off the rack, and to aesthetically improve all equipment.

They were the last components to be developed, being designed in such a way that they could be assembled/disassembled without interfering with any of the other parts. As such, the cover on the side of the travelling gearmotor is a single part that protects the whole area, with cuts close to the components that must stay outside, being fixed to the main structure by bolted connection (Figure 113).

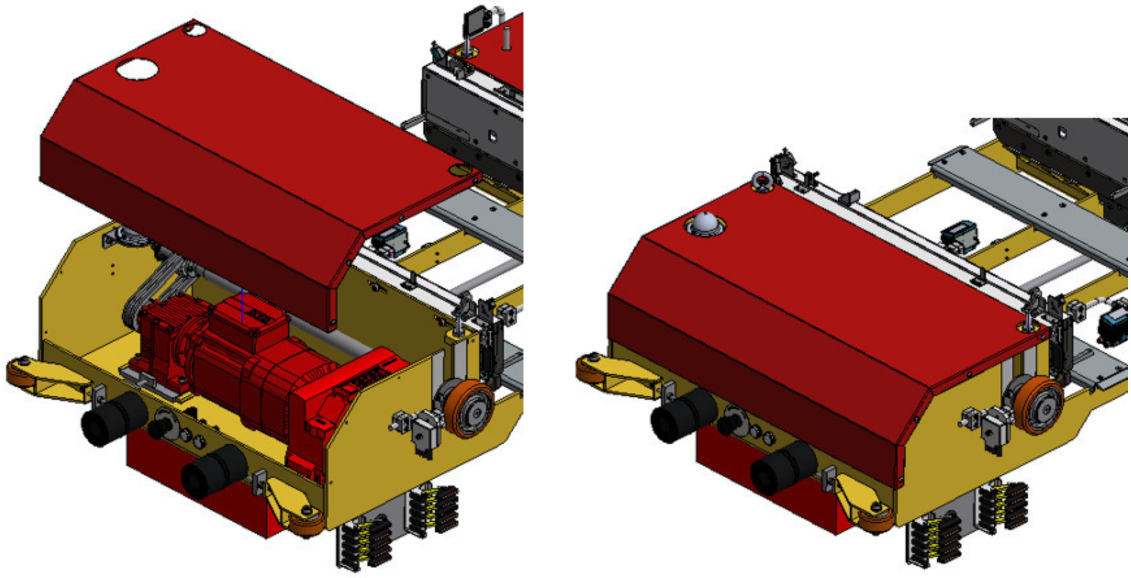


Figure 113 - Cover assembly on the travelling gearmotor side.

The cover on the side of the extraction gearmotor has the same principle as the previous one but is divided into two parts so that the assembly can be carried out without interfering with the robotic arm. The connection is also made laterally in the main frame by bolted connection and the two half covers are further tightened against one another.

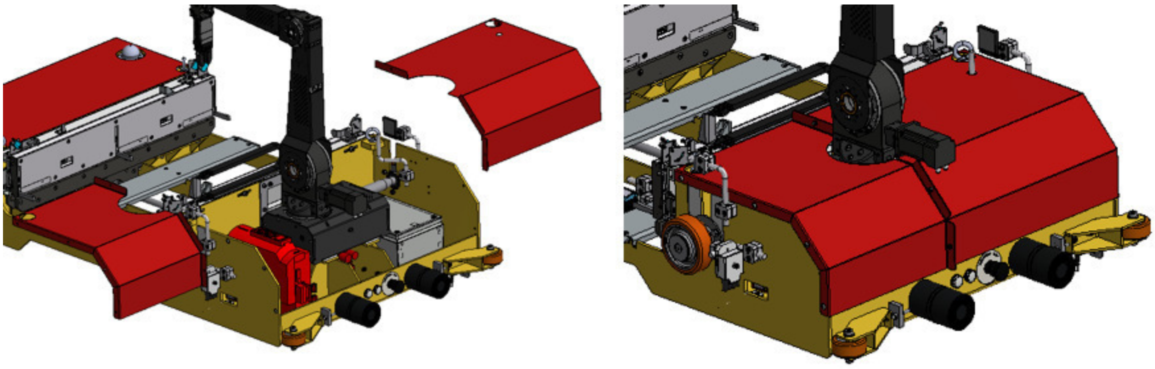


Figure 114 - Cover assembly on the extraction gearmotor side.

3.4.9 FINAL CALCULATIONS

During the development of the three main systems that constitute the shuttle vehicle, several calculations were made as a way of validating the selection of some components and the design of certain parts. As such, these calculations were made to predict whether the parts and components will support the loads to which they will be subjected during the operation of the equipment, allowing to adjust the design of the machine so that it is not undersized, avoiding the risk of the parts failing with the time, nor oversized, avoiding the risk of developing a more expensive machine to produce.

The loads on the different components and parts are strongly related to the mass of each of the subsystems, a variable that has remained open throughout the design process. For this reason, the calculations performed underwent several revisions throughout an iterative process until the systems were perfectly defined and the values of the applied loads were the final ones. The masses of each of the main shuttle vehicle subsystems are listed in Table 25.

Table 25 - Masses of each of the shuttle vehicle systems.

Shuttle Vehicle Subsystem	Value
Total Mass of the Shuttle Vehicle	300 kg
Mass of the Travelling System (with the Shuttle Vehicle Main Structure)	192 kg
Mass of the Extraction System	46 kg
Mass of the Picking System	22 kg

Other information that was also very important to carry out the different calculations is related to the mechanical properties of the materials of the parts studied, since the results of certain equations depend on these values, for example the calculation of the coefficient of safety coefficient after the simulation of the parts by FEA, which depends on the yield stress of the material. The mechanical properties of the materials of the parts that have been studied are listed in Table 26 [123],[124],[125],[126].

Table 26 - Mechanical properties of the materials of the parts studied [123],[124],[125],[126].

Material	Yield Strength (σ_{Yield})	Tensile Strength (Rm)	Young's Modulus (E)
Steel EN S235 JR	235 MPa	435 MPa	210 GPa
Steel EN C45	310 MPa	590 MPa	210 GPa
Aluminum 5052	193 MPa	228 MPa	70,3 GPa
Aluminum 6060	120 MPa	160 MPa	69,5 GPa

The calculations performed on each of the main shuttle vehicle subsystems are described in the following sections. However, all calculations described here, with the exception of FEA calculations, can be seen in more detail in Annex 7.

3.4.9.1 CALCULATIONS IN THE TRAVELLING SYSTEM

For the travelling system, the following calculations were performed:

1) Final calculation of reactions in the vehicle supports and stability check;
2) Final calculation of the travelling gearmotor;
3) Final calculation of the guiding wheels and the travelling wheels;
4) Calculation of the driving shaft;
5) Calculation of the housing units;
6) Calculation of the driving chain;
7) Calculation of the locking assemblies;
8) Calculation of the guiding wheel axle;
9) Calculation of the polyurethane buffer;
10) Calculation of the fork for the guiding wheel (using FEA);
11) Calculation of the main structure (using FEA).

Final Calculation of Reactions in the Vehicle Supports and Stability Check

A preliminary calculation of the vehicle's reactions and stability was done to give an idea of what loads would be on the travelling wheels and what would be the behavior of the vehicle in operation according to the dimensions estimated in the initial sketches and the estimated values for some parameters of the vehicle.

After finishing the mechanical design of the machine, it was necessary to validate these calculations for the dimensions and final parameters of the shuttle vehicle. As such, the parameters used to perform these calculations are indicated in Table 27, where it was chosen to reduce the travelling acceleration to compensate for the mass increase of the shuttle vehicle compared to the values initially estimated. The brake acceleration was determined in the final calculation of the travelling gearmotor.

Table 27 - Parameters considered to calculate the reactions of the vehicle.

Parameter	Value
Vehicle Mass (unloaded and without the robot) ($m_{vehicle}$)	278 kg
Boxes Mass (m_{load})	100 kg
Robot Mass (m_{robot})	22 kg
Vehicle Acceleration ($a_{travelling}$)	1,25 m/s^2
Brake Acceleration (a_{brake})	1,34 m/s^2
Gravitational Acceleration (g)	9,81 m/s^2

The calculation procedure adopted was exactly the same as the preliminary calculation, and the same assumptions and equations were used, adjusting only the dimensions according to the new free-body diagrams for the two scenarios studied: stationary vehicle (Figure 115 - a) and vehicle accelerating/braking (Figure 115 - b). The centers of gravity were determined using the 3D modeling software used in the mechanical design phase (Autodesk® Inventor®) [119].

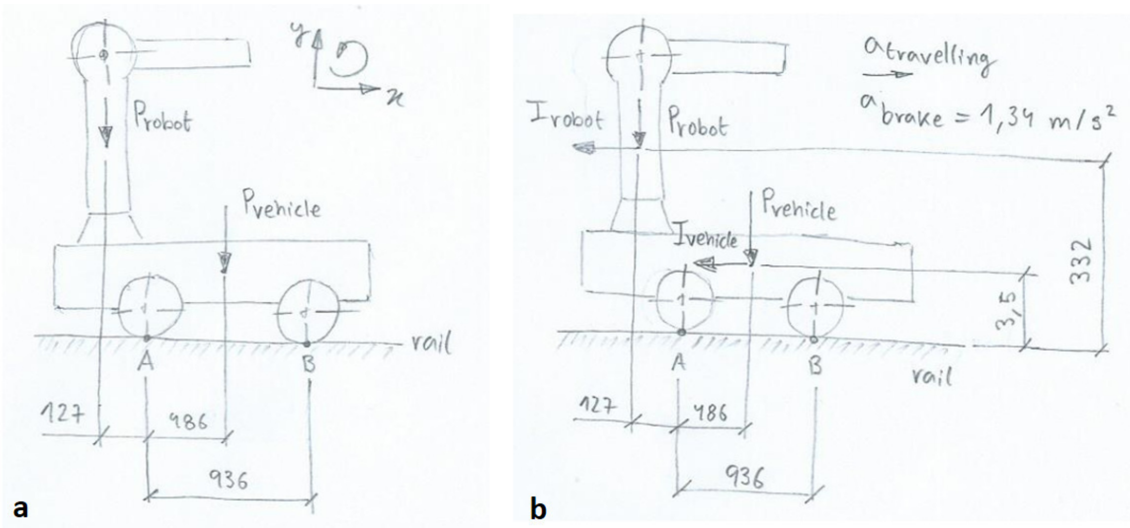


Figure 115 - Shuttle vehicle free-body diagrams when the vehicle is stationary (a) and when the vehicle is starting the movement (b).

In this section, only the results of the equations are represented, without any description of how they were obtained (see section 3.4.2.1 to know which assumptions and equations were considered). These results of the reactions and stability of the vehicle are represented in Table 28 and Table 29, respectively, for each of the scenarios studied.

Table 28 - Results of the reaction forces of the vehicle.

	Without the Mass of the Boxes	With the Mass of the Boxes
Stationary Vehicle	$R_{A,stat}$ = 1556 N $R_{B,stat}$ = 1387 N	$R_{A,stat}$ = 2028 N $R_{B,stat}$ = 1896 N
Vehicle Accelerating	$R_{A,dyn}$ = 1567 N $R_{B,dyn}$ = 1376 N	$R_{A,dyn}$ = 2039 N $R_{B,dyn}$ = 1896 N
Vehicle Braking	$R_{A,dyn}$ = 1568 N $R_{B,dyn}$ = 1375 N	N/A

Table 29 - Results of the stability factor.

	Without the Mass of the Boxes	With the Mass of the Boxes
Vehicle Accelerating	ν = 125,5	ν = 164,6
Vehicle Braking	ν = 117,0	N/A

As expected, due to the increase in mass and reduction of acceleration, the shuttle vehicle presents greater stability in this final calculation than in the preliminary calculation, as evidenced by the fact that the values of the reaction forces are all positive and the stability factor is above of 1,5. However, this calculation had to be performed to determine the final loads on the wheels and to ensure that the final dimensions, namely the mass centers of the vehicle and the robot, would not hamper the stability of the shuttle vehicle.

Final Calculation of the Travelling Gearmotor

The travelling gearmotor was previously calculated before any design of the machine (see section 3.4.2.2) as a way of estimating which would be the gearmotor to use and thus advance with the design of the parts that interface with this component. However, for this preliminary calculation some parameters were estimated, namely the mass of the shuttle vehicle and the travelling acceleration.

After finalizing the design of the shuttle vehicle, it was necessary to validate the preliminary calculation of the travelling gearmotor according to the final values of the parameters that had been initially estimated. As such, the parameters required for the final calculation of the travelling gearmotor are shown in Table 30 , where it was chosen to reduce the travelling acceleration to compensate for the mass increase of the shuttle vehicle compared to the values initially estimated.

Table 30 - Parameters used for the final calculation of the travelling gearmotor.

Parameter	Value
Shuttle Vehicle Mass (unloaded)	300 kg
Shuttle Vehicle Mass (loaded)	400 kg (50 kg/box)
Vehicle Speed	3 m/s
Vehicle Acceleration	1,25 m/s^2
Wheel Diameter	125 mm
Wheel Axle Diameter	25 mm
Lever Arm of the Rolling Friction (polyurethane/steel)	0,9 mm
Wheel Flange Coefficient (vehicle with lateral guiding wheels)	0,002
Bearing Coefficient (vehicle with anti-friction bearings)	0,005
Gear Ratio	1
Load Efficiency	0,9
Pitch Diameter of the Driving Sprocket	69,11 mm
Number of Teeth of the Driving Sprocket	17
Mass Moment of Inertia of the Driving Sprocket	223,207 kgm^2
Mass Moment of Inertia of the Driven Sprocket	223,207 kgm^2
Chain Mass	0,72 kg
Axial Position of the Driving Sprocket Center on the Gearmotor Output Shaft in relation to the Gear Unit Surface	25,5 mm
Gearmotor Type	Helical Gearmotor (Type R) – Foot Mounted
Gearmotor Mounting Position	M1

Unlike the preliminary calculation of the travelling gearmotor, this final calculation was made using the SEW Workbench calculation software because it enabled the selection of the gearmotor more quickly and automatically by simply entering the parameters that characterize the motion of the shuttle vehicle and the respective loads [127].

The steps given in the software until reaching the final solution are indicated below:

1) Select the type of motion, the type of application and the type of power transmission. In this case, it is a travelling movement for a vehicle supported by four wheels, with a power transmission by means of a pair of sprockets and chain (Figure 116);

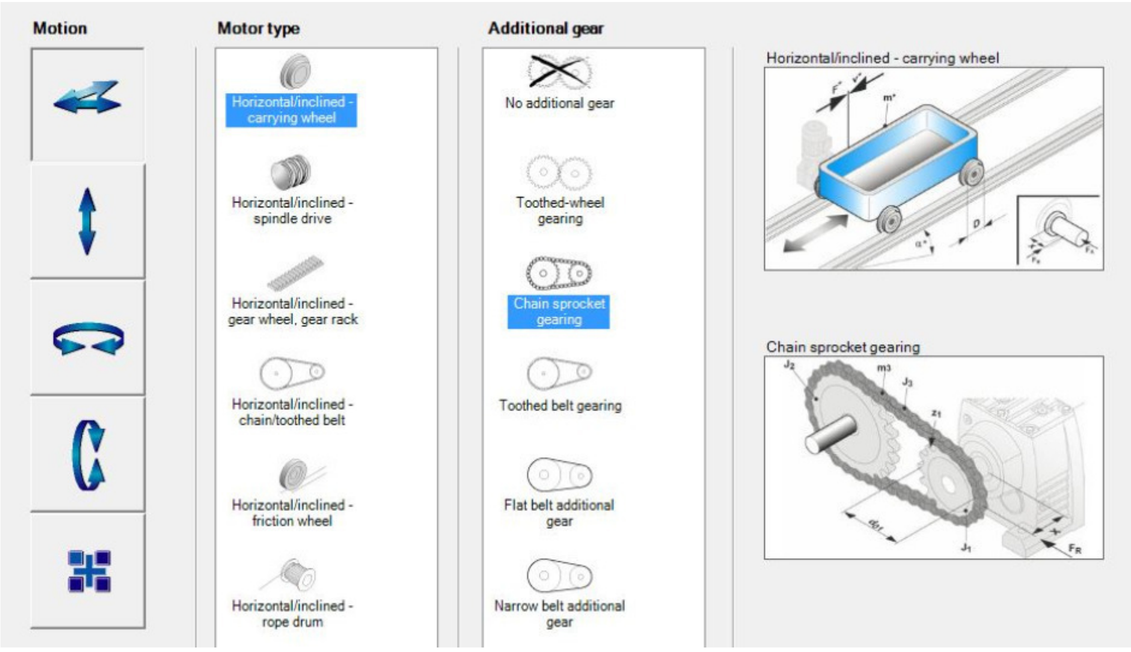


Figure 116 – SEW Workbench – Calculation of the Travelling Gearmotor - Selection of the type of application.

2) Introduction of the parameters that characterize the application, namely related to the calculation of the rolling friction (Figure 117);

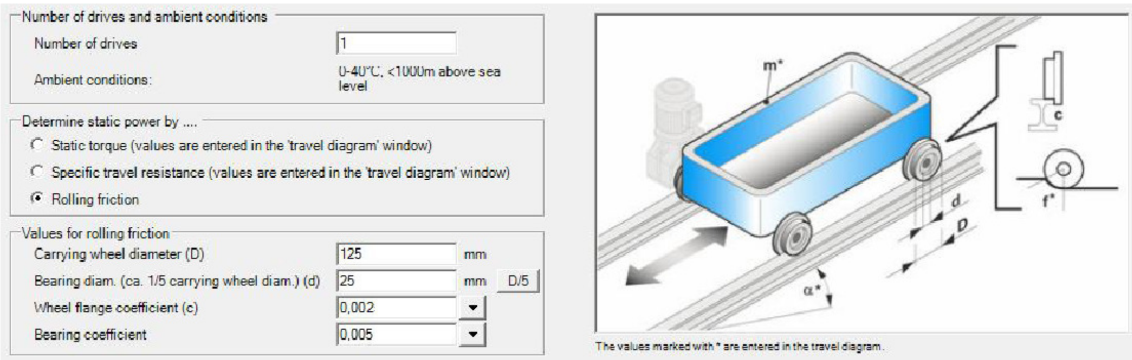


Figure 117 - SEW Workbench – Calculation of the Travelling Gearmotor – Introduction of the parameters to calculate the rolling friction.

3) Introduction of the parameters that characterize the transmission by chain and sprockets (Figure 118). It is important to note that this type of transmission creates a radial load on the gearmotor output shaft caused by the tangential force of the chain. As such, it was necessary to indicate some data for the software to carry out the overhung load calculation;

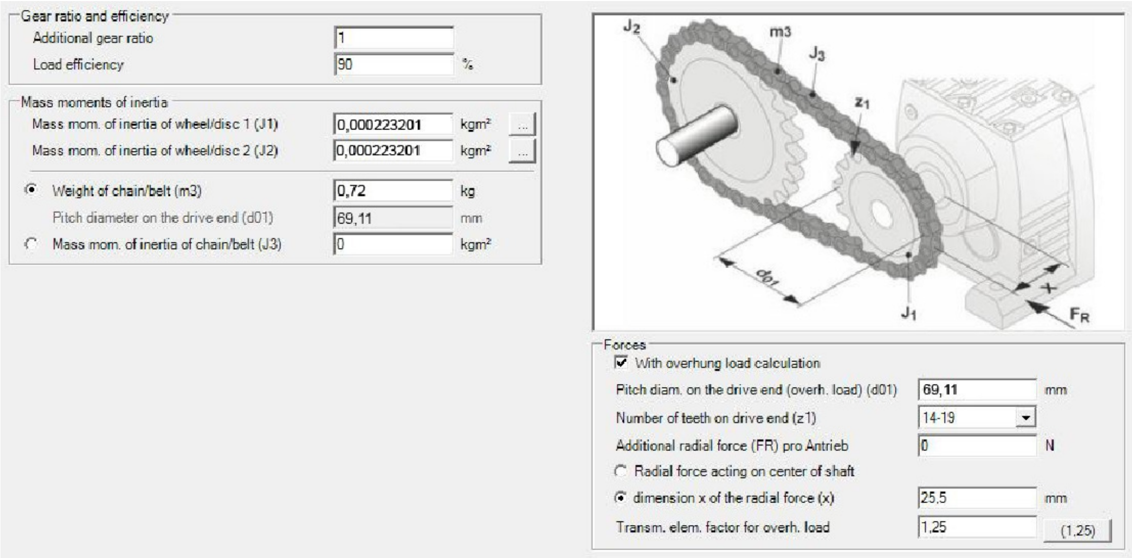
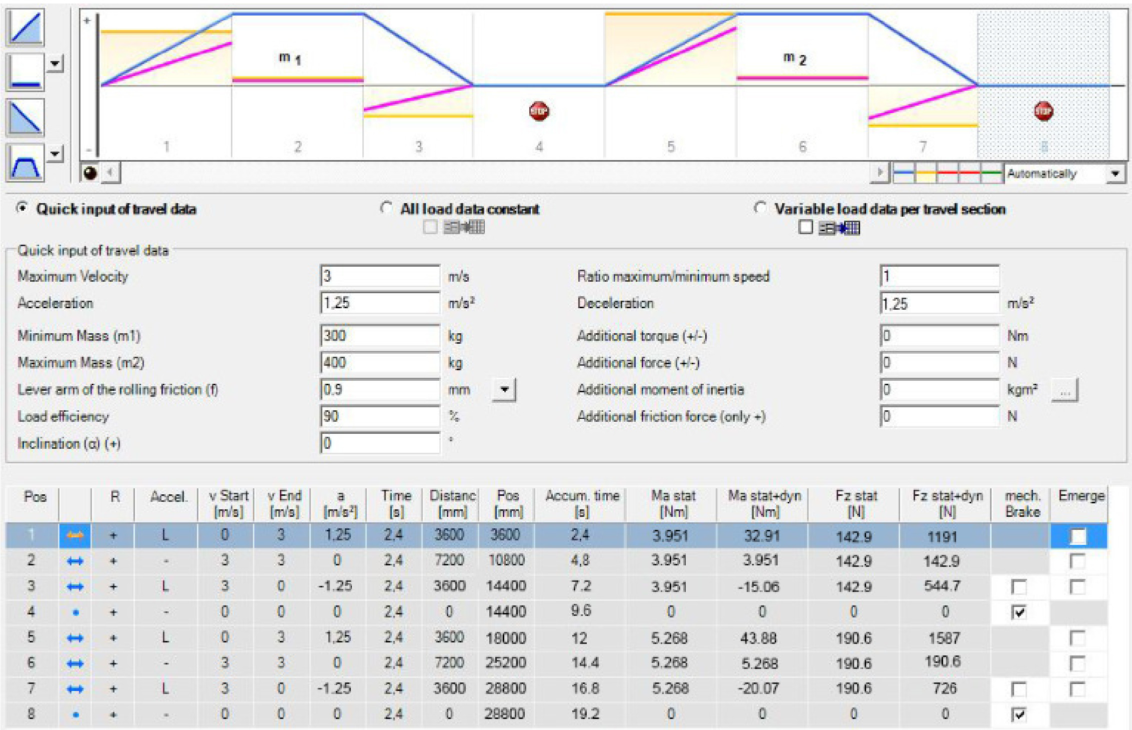


Figure 118 - SEW Workbench – Calculation of the Travelling Gearmotor – Introduction of the parameters that characterize the transmission by chain and sprockets.

4) Definition of the travel diagram of the shuttle vehicle with indication of the respective distances and times of acceleration, and calculation of the driving torques and forces for the gearmotor (Figure 119). In this step it is important to highlight the maximum value of the static and dynamic torques (43,88 N·m) since it was used for many of the calculations performed on the travelling system;



Pos		R	Accel.	v Start [m/s]	v End [m/s]	a [m/s²]	Time [s]	Distanc [mm]	Pos [mm]	Accum. time [s]	Ma stat [Nm]	Ma stat+dyn [Nm]	Fz stat [N]	Fz stat+dyn [N]	mech. Brake	Emerge
1	↔	+	L	0	3	1,25	2,4	3600	3600	2,4	3.951	32.91	142.9	1191		☐
2	↔	+	-	3	3	0	2,4	7200	10800	4,8	3.951	3.951	142.9	142.9		☐
3	↔	+	L	3	0	-1.25	2,4	3600	14400	7.2	3.951	-15.06	142.9	544.7	☐	☐
4	•	+	-	0	0	0	2,4	0	14400	9.6	0	0	0	0	☑	
5	↔	+	L	0	3	1,25	2,4	3600	18000	12	5.268	43.88	190.6	1587		☐
6	↔	+	-	3	3	0	2,4	7200	25200	14.4	5.268	5.268	190.6	190.6		☐
7	↔	+	L	3	0	-1.25	2,4	3600	28800	16.8	5.268	-20.07	190.6	726	☐	☐
8	•	+	-	0	0	0	2,4	0	28800	19.2	0	0	0	0	☑	

Figure 119 - SEW Workbench – Calculation of the Travelling Gearmotor – Definition of the travel diagram.

5) Selection of the best gearmotor for this application, according to the type desired (Figure 120). It is important to note that, as already mentioned, the shuttle vehicle has a frequency inverter to control the speed and acceleration of

the gearmotor, so a base frequency of 87 Hz was considered for selecting a smaller gearmotor.

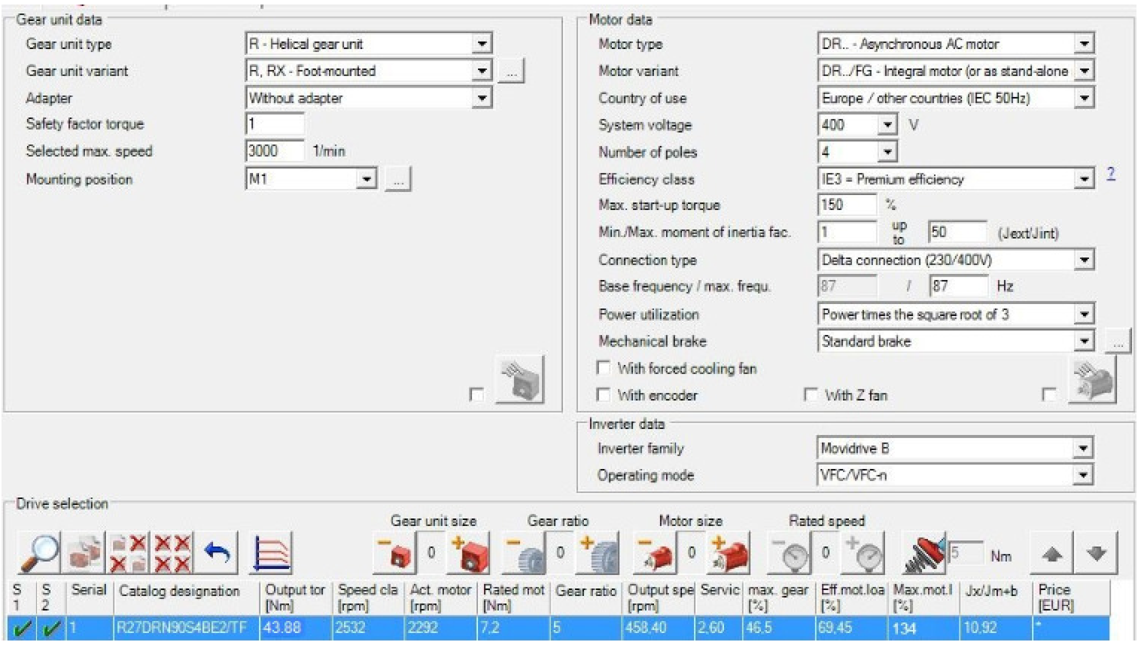


Figure 120 - SEW Workbench – Calculation of the Travelling Gearmotor – Selection of the gearmotor.

The main parameters of the selected gearmotor are shown in Table 31.

Table 31 - Parameters of the selected travelling gearmotor.

Variable	Result
Reference of the Selected Gearmotor	R27 DRN90S4/BE2/TF
Maximum Gearmotor Output Torque during operation ($M_{stat+dyn}$)	43,88 N·m
Gearmotor Rated Output Torque	36 N·m
Motor Speed	2292 rpm (87 Hz)
Motor Rated Torque	7,2 N·m
Gear Unit Ratio	5,00
Gearmotor Output Speed (n_a)	458,4 rpm
Service Factor	2,6
Motor Start-Up Torque/Motor Rated Torque	134,9%
Brake Rated Torque	5,0 N·m
Brake Acceleration (a_{brake})	1,34 m/s^2

Although the mass of the shuttle vehicle increased from the initially estimated value, the gearmotor chosen in the final calculation remained the same as that chosen in the preliminary calculation. This was possible because it was decided to reduce the travelling acceleration to 1,25 m/s^2, a reduction with little impact on the travelling cycle, that compensated for the mass increase, reducing the necessary acceleration torque in the gearmotor and maintaining it less than 1,5 times the rated torque.

In this case, it was not necessary to check whether the wheels will slip, by calculating the maximum permissible travelling acceleration, because the travelling acceleration and the braking acceleration were reduced from the initially estimated values. In addition, the mass of the shuttle vehicle has also increased, which increases the reactions on the wheels and the friction between the travelling wheels and the rails, ensuring that the wheels will not slip in any of the cases.

Final Calculation of the Guiding Wheels and the Travelling Wheels

A preliminary calculation was made of the guiding wheels and the travelling wheels to pre-select the wheels that would be used in the travelling system of the shuttle vehicle. However, this calculation was performed before the mechanical design, based on estimated values for the mass of the vehicle and the travelling acceleration. As such, due to the increased mass of the shuttle vehicle and consequent increase of the loads on the wheels, it was necessary to recalculate the wheels and validate the selection that was made initially.

The parameters required for the final calculation of the guiding wheels and the travelling wheels are shown in Table 32. Note that the calculation was made using the maximum gearmotor output torque during operation to consider the worst scenario for the wheels.

Table 32 - Parameters needed to calculate the loads on the wheels.

Parameter	Value
Shuttle Vehicle Mass ($m_{vehicle}$)	300 kg
Boxes Mass (m_{load})	100 kg
Vehicle Speed ($v_{travelling}$)	3 m/s
Acceleration of the Vehicle ($a_{travelling}$)	1,25 m/s^2
Gravitational Acceleration (g)	9,81 m/s^2
Coefficient of Friction (polyurethane/steel) ($\mu_{stat\ (PU/steel)}$)	0,55
Maximum Gearmotor Output Torque during operation ($M_{stat+dyn}$)	43,88 N·m

Parameter	Value
Maximum Dynamic Reaction Force on the Wheels (vehicle accelerating) ($R_{A,dyn}$)	2039 N
Travelling Wheel Diameter (D_{wheel})	125 mm
Brauer® factor for the continuous running condition (C_1)	0,75
Brauer® factor for the surface speed 10-16 km/h condition (C_2)	0,7
Brauer® factor for the driving wheels condition (C_3)	0,7

The procedure for calculating the guiding wheels was very similar to the one adopted in the preliminary calculation, except for the way of determining the driving force of the shuttle vehicle. In this case, the driving force was calculated by Equation 31, transforming the maximum gearmotor output torque (known value) into the driving force that is applied to the drive wheel. Moreover, the same assumptions were considered, and the same equations were used to determine the loads on the guiding wheels and consequent checking of the chosen wheel [122].

$$M_{stat+dyn} = F_{drive} \cdot \frac{D_{wheel}}{2}$$

Equation 31

The results of the loads and subsequent validation of the chosen guiding wheel are indicated in Table 33.

Table 33 - Results of the guiding wheels.

Variable	Result
Drive Force (F_{drive})	707 N
Load on the Guiding Wheel ($F_{guiding\ wheel}$)	1091 N
Selected Wheel	Brauer® Wheels – Polyurethane Tyred Wheels – Wheel Type H75/35
Maximum Load supported by the Wheel (P_{max})	300 kgf = 2943 N
Maximum Load supported by the Wheel (Corrected) ($P_{max\ corr}$)	1545 N
Safety Factor (SF)	1,4

Even with the increased mass of the shuttle vehicle and consequent increase of the load on the guiding wheels, it was not necessary to choose a wheel with greater load capacity. As such, the safety factor dropped, but remained above 1, validating the selected wheel.

For the calculation of the travelling wheels, the same procedure of the preliminary calculation was adopted, considering the same assumptions and using the same equations. Therefore, in this section only the results of the loads and subsequent validation of the chosen travelling wheel are represented (Table 34) [122].

Table 34 - Results of the travelling wheels.

Variable	Result
Load on the Travelling Wheel ($F_{travelling\ wheel}$)	1020 N
Selected Wheel	Brauer® Wheels – Polyurethane Tyred Wheels – Wheel Type H125/40
Maximum Load supported by the Wheel (P_{max})	530 kgf = 5199 N
Maximum Load supported by the Wheel (Corrected) ($P_{max\ corr}$)	1911 N
Safety Factor (SF)	1,9

Again, the increase in mass of the shuttle vehicle and consequent increase of the load on the travelling wheels was not sufficient to cause a change of the initially selected wheel. The safety factor dropped, as expected, but remained above 1, validating the chosen wheel.

Calculation of the Driving Shaft

The driving shaft was calculated to predict its behavior relative to bending and torsional stresses during the operation of the shuttle vehicle. The driving and driven shafts bear the full weight of the shuttle vehicle, with the driving shaft being more loaded because it receives the torque from the gearmotor. As such, only the driving shaft has been calculated because the driven shaft is geometrically equal and not so loaded, so if the driving shaft is able to withstand the loads to which it is subjected, the driven shaft will also be.

During operation of the shuttle vehicle, the driving shaft is supported on the two drive wheels, being subjected to radial loads caused by the total mass of the shuttle vehicle (the same reaction forces on the travelling wheels) through the housing units, and to an intermediate radial load aligned with the chain and caused by its tangential pulling force (Figure 121). In addition, it is further subjected to torsional stresses, because of the maximum gearmotor output torque which is divided by the two drive wheels to move them.

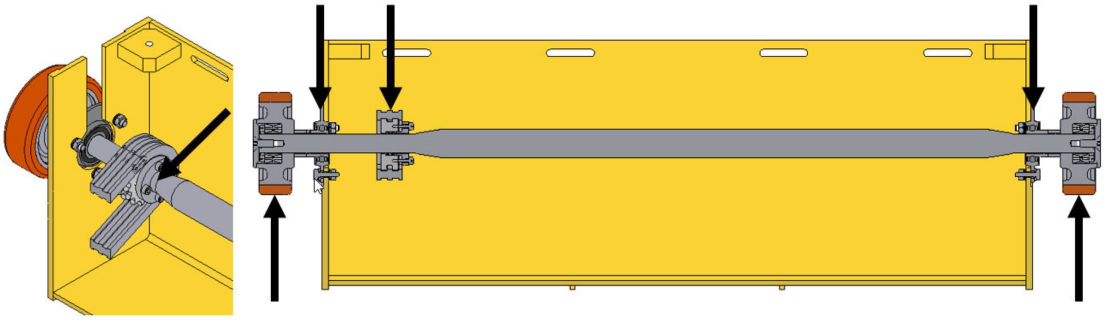


Figure 121 - Loads on the driving shaft from the travelling system.

The parameters required to perform the calculation are indicated in Table 35. Note that the calculation was made using the maximum gearmotor output torque during operation and the maximum dynamic reaction force on the wheels, to consider the worst scenario for the driving shaft.

Table 35 - Parameters used to calculate the driving shaft.

Parameter	Value
Driving Shaft Material	Steel EN C45
Maximum Torsional Torque per Driving Sprockets (equal to the Maximum Gearmotor Output Torque during operation ($M_{stat+dyn}$)) ($M_{t\_sprocket}$)	43,88 N·m
Maximum Dynamic Reaction Force on the Wheels (vehicle accelerating) ($R_{A,dyn}$)	2039 N
Load on the Travelling Wheel ($F_{travelling\ wheel}$)	1020 N
Pitch Diameter of the Driven Sprocket (D_P)	69,11 mm
Shaft Rotation Speed (equal to the Gearmotor Output Speed (n_a))	58,4 rpm

The first step of the calculation was the determination of the radial force of the chain on the driving shaft caused by the tangential force of the chain when being pulled by the vehicle acceleration. This force was determined by Equation 32 which converts the maximum torque on the driving shaft (which in this case is equal to the maximum gearmotor output torque because the transmission ratio is equal to 1) in the tangential force of the chain.

$$M_{t\_sprocket} = F_{tang} \cdot \frac{D_P}{2}$$

Equation 32

Where:

F_{tang} – Chain tangential pulling force (N).

The second step of the calculation was the determination of the maximum stresses and deflections on the shaft. This was made through the shaft calculation module of the software MITCalc, a software for the mechanical calculation of machinery parts. The steps given in the software until reaching the results are indicated below [128]:

1) Representation of the geometry and dimensions of the shaft, with positioning of the two supports (Figure 122). In this case, the supports could be the two wheels or the two housing units, however it was decided to place the housing units because the loads on the wheels are known and theoretically the two supports of the calculation must be rigid, so the housing units represent better this scenario than the wheels that allow some flexibility for deflection of the shaft;

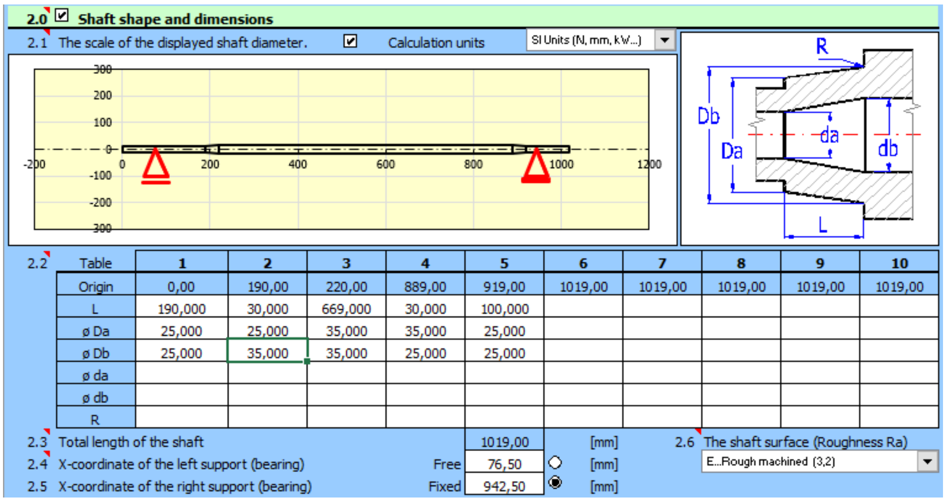
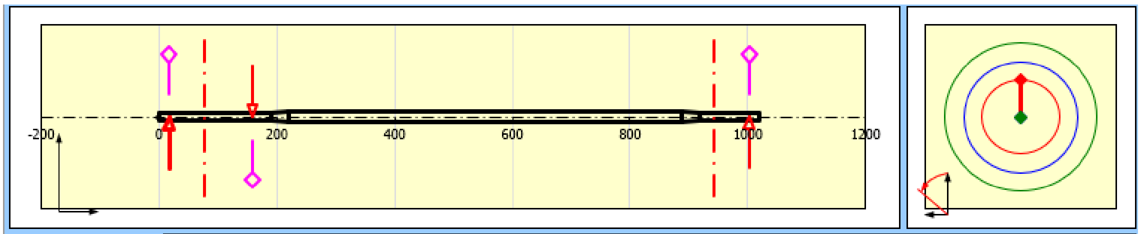


Figure 122 - MITCalc – Calculation of the Driving Shaft from the Travelling System – Geometry and dimensions of the shaft.

2) Representation of the loads to which the driving shaft is subjected (Figure 123). The forces and torque shown in Figure 123 correspond to the following loads:
   - **F1**: Load on the first drive wheel ($F_{travelling\ wheel}$);
   - **Mt1**: Torsional moment of reaction in the first drive wheel ($M_{stat+dyn}/2$);
   - **F2**: Chain tangential pulling force (F_{tang});
   - **Mt2**: Maximum gearmotor output torque ($M_{stat+dyn}$);
   - **F3**: Load on the second drive wheel ($F_{travelling\ wheel}$);
   - **Mt3**: Torsional moment of reaction in the second drive wheel ($M_{stat+dyn}/2$).



4.1 Loading	X	Fx	F	alfa	Mt	Mb	alfa	Q	b	alfa
	[mm]	[N]		[°]	[Nm]		[°]	[N/mm]	[mm]	[°]
1	17,00		1019,5		-21,94					
2	159,00		-1270,0	65	43,88					
3	1002,00		1019,5		-21,94					

Figure 123 - MITCalc – Calculation of the Driving Shaft from the Travelling System – Loads on the shaft.

3) Characterization of the mechanical properties of the shaft material and indication of the load conditions (Figure 124). The material of the shaft is the steel EN C45, a steel found in the MITCalc database. The types of loads on the shaft are mainly repeated radial loads, due to constant accelerations/decelerations and loading/unloading of the shuttle vehicle, and torsional loads reversed because the shaft rotates in both directions.

6.0 ☑ Material and the type of loading

6.1	Shaft material (Ultimate tensile strength min-max)			
	A...Structural steel (350 - 700)		595	[MPa]
6.2	Ultimate tensile strength	Su/Rm	590	[MPa] ☐
6.3	Yield strength in tension	S_y/Re	310	[MPa]
6.4	Yield strength in bending	S_{Yb}/Re_b	449	[MPa]
6.5	Yield strength in shear	S_{Ys}/Re_s	242	[MPa]
6.6	**For reversed loading**			
6.7	Fatigue limit - tension-pressu	σ_C	226	[MPa]
6.8	Fatigue limit - bending	σ_{oC}	292	[MPa]
6.9	Fatigue limit - torsion	τ_C	208	[MPa]
6.10	**For cyclic loading**			
6.11	Fatigue limit - tension-pressu	σ_{hC}	339	[MPa]
6.12	Fatigue limit - bending	σ_{ohC}	437	[MPa]
6.13	Fatigue limit - torsion	τ_{hC}	239	[MPa]
6.14	Specific mass	Ro	7850,0	[kg/m^3]
6.15	Modulus of elasticity in tensic	E	210000	[MPa]
6.16	Modulus of elasticity in shear	G	80000	[MPa]

6.17	Dead load	Yes
6.18	Max. displayed coefficient of safety	20
6.19	Stress ratio factor α_0	1,15 ☑
6.20	**Coefficient of maximum loading**	
6.21	Bending	1,00
6.22	Radial load	1,00
6.23	Torsion	1,00
6.24	Tension/Compression	1,00
6.25	**Loading conditions**	
6.26	Loading from bending moment	B...Repeated
6.27	Loading from radial force	B...Repeated
6.28	Load from torsional moment	C...Reversed
6.29	Loading from tension/pressure force	A...Static
6.30	**Dynamic strength check**	
6.31	Impact from shaft surface	Yes
6.32	Impact from shaft size	Yes
6.33	Impact from stress concentration (notcl	Yes

Figure 124 - MITCalc – Calculation of the Driving Shaft from the Travelling System – Material and type of loading.

4) According to the loads and conditions described so far, determination of the following results:
   - Determination of reaction forces on the supports;
   - Determination of maximum stresses and deflections on the shaft;
   - Graphical representation of the deflection distribution and equivalent stress along the shaft length.

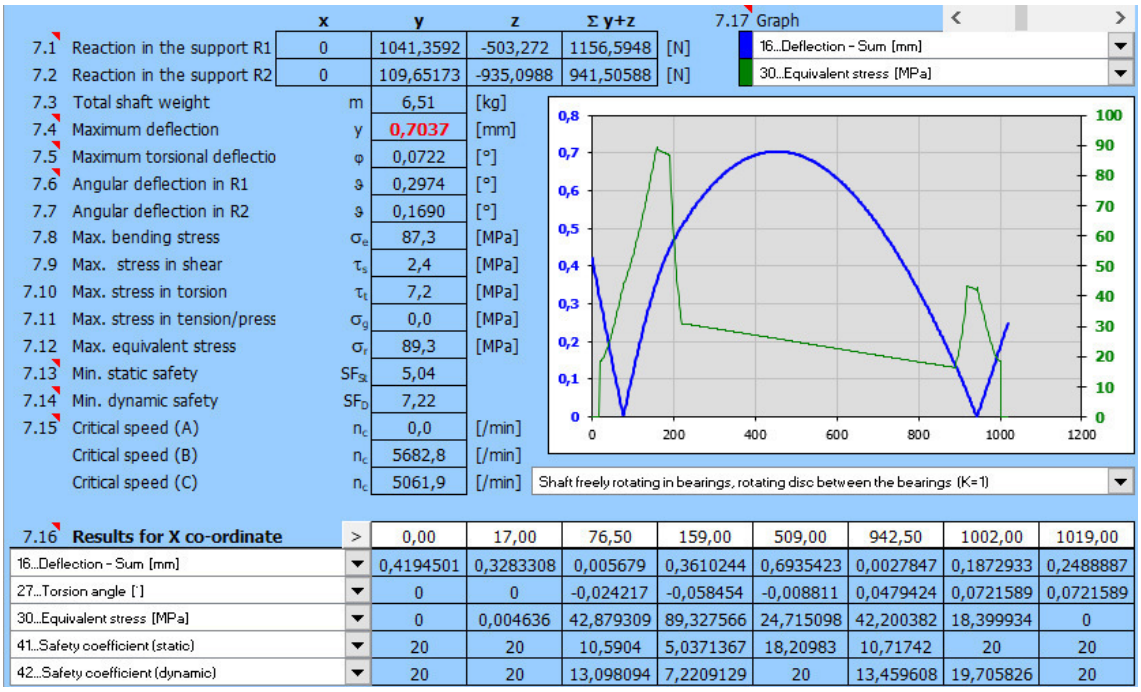


Figure 125 - MITCalc – Calculation of the Driving Shaft from the Travelling System – Final results.

The main results of the calculation of the driving shaft are shown in Table 36.

Table 36 - Results of the calculation of the driving shaft.

Variable	Result
Reaction in the First Support (R1)	1157 N
Reaction in the Second Support (R2)	942 N
Maximum Deflection	0,70 mm
Maximum Torsional Deflection	0,07°
Maximum Equivalent Stress	89 MPa
Minimum Static Safety Factor	5,0
Minimum Dynamic Safety Factor	7,2
Maximum Critical Speed	5062 rpm

The results of the driving shaft calculation are acceptable. The maximum deflection is below 1 mm in a portion of the shaft length where no functional component (such as wheels or sprockets) is mounted and the torsional deflection is below 0,25°, which is the maximum recommended value for such applications. It can be concluded from the analysis of the deflection distribution curve that the deflection values do not exceed 0.3 mm in the wheel or carriage mounting zones, which is accepted since these deflections are all elastic and their maximum value only occurs at the time of acceleration of the shuttle vehicle.

For the equivalent maximum stress, static and dynamic safety factors above 2 ensure that the shaft material withstands the most severe load conditions.

Regarding the critical speed of the shaft, this value is well above the shaft rotation speed of 458,4 rpm.

Finally, note that the values of the reaction forces in the supports are very important for the calculation of the housing units that support the shaft.

Calculation of the Housing Units

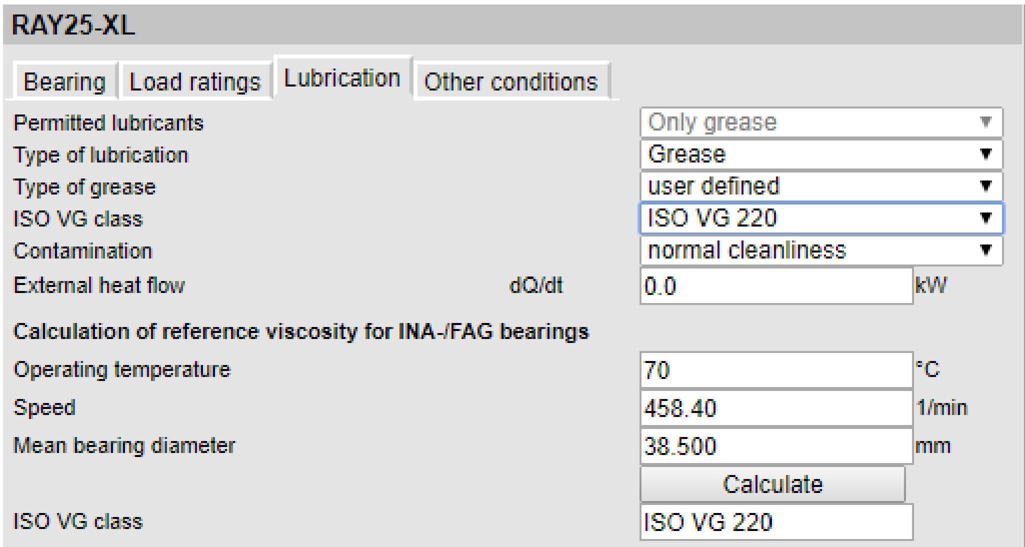
The housing units were calculated to determine their durability and load safety factors in relation to the load conditions to which they are subjected. As they support the driving and driven shafts, they react to the radial loads to which they are subjected, in other words, the loads falling on the housing units are equal to the reaction forces required to balance the shaft radially, allowing it to rotate freely and without oscillations. As such, the parameters required to calculate the housing units are indicated in Table 37. Note that the four housing units of the shuttle vehicle are subjected to different loads, however, the calculation was only made for the largest of the loads between the four housing units (worst scenario), in other words, the largest of the reaction forces determined in the calculation of the driving shaft.

Table 37 - Parameters used to calculate the housing units.

Parameter	Value
Selected Housing Unit	RAY25-XL
Shaft Rotation Speed (equal to the Gearmotor Output Speed (n_a))	458,4 rpm
Radial Load (equal to Reaction in the First Support (R1))	1157 N

The calculation was made using the bearings calculation module from Schaeffler website. The steps taken to perform the calculation are indicated below [129]:

1) Determination of the recommended lubricant to be used according to the speed of rotation (Figure 126);



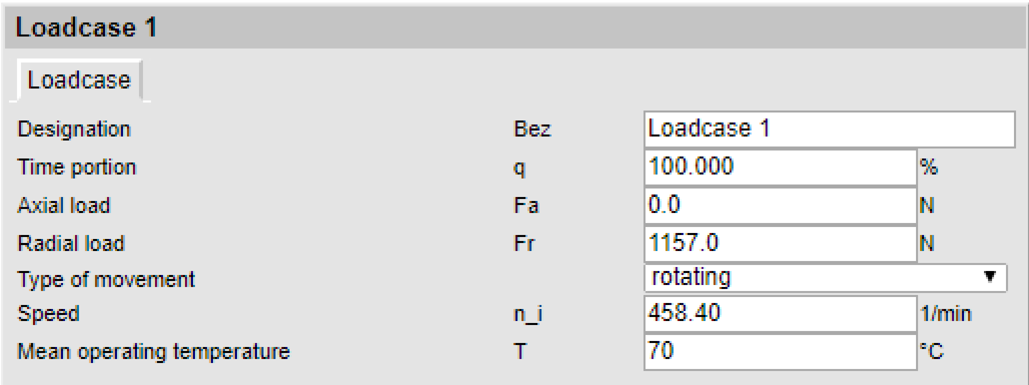
RAY25-XL

Bearing | Load ratings | Lubrication | Other conditions

Permitted lubricants		Only grease	
Type of lubrication		Grease	
Type of grease		user defined	
ISO VG class		ISO VG 220	
Contamination		normal cleanliness	
External heat flow	dQ/dt	0.0	kW
Calculation of reference viscosity for INA-/FAG bearings			
Operating temperature		70	°C
Speed		458.40	1/min
Mean bearing diameter		38.500	mm
		Calculate	
ISO VG class		ISO VG 220	

Figure 126 - Schaeffler website - Calculation of the housing units – Calculation of the recommended lubricant.

2) Indication of the loads on the housing unit (Figure 127), which in this case are only radial loads;



Loadcase 1

Loadcase

Designation	Bez	Loadcase 1	
Time portion	q	100.000	%
Axial load	Fa	0.0	N
Radial load	Fr	1157.0	N
Type of movement		rotating	
Speed	n_i	458.40	1/min
Mean operating temperature	T	70	°C

Figure 127 - Schaeffler website - Calculation of the housing units – Loads on the housing unit.

3) According to the load conditions, determination of the rating life and the safety factors for the housing unit (Figure 128).

Description	Name	Value	Unit
Total rating life in hours (nominal)	Lh10	77651	h
Modified rating life in hours	Lh_nm	559631	h
Static load safety factor	S0_min	6.742	
Dynamic load safety factor	SD	12.878	

Figure 128 - Schaeffler website - Calculation of the housing units – Rating life and safety factors for the housing unit.

The main results of the calculation of the housing unit are shown in Table 38.

Table 38 - Results of the calculation of the housing unit.

Variable	Result
Total Rating Life	77651 h
Static Load Safety Factor	6,7
Dynamic Load Safety Factor	12,9

According to the results, the housing unit is oversized because it has a total rating life above 60000 h and load safety factors above 6. As such, the housing unit will not have problems during operation, but it would be possible to have chosen another one with less load capacity.

Calculation of the Driving Chain

The driving chain was calculated to determine their durability and load safety factors in relation to the load conditions to which it is subjected. As it is used to transmit power and torque between the gearmotor and the wheels through two sprockets, it is subjected to the gearmotor output torque that moves the shuttle vehicle (Figure 129). This torque creates a pulling force on the chain, so it is necessary to verify if the chain can withstand that force without breaking or stretching too early.

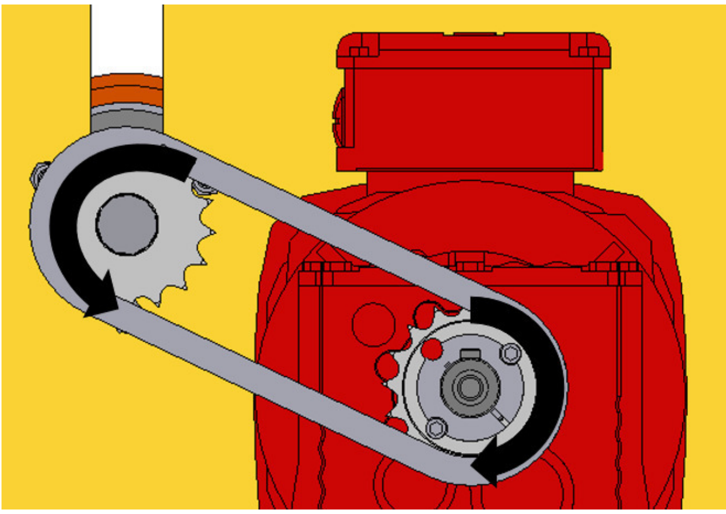


Figure 129 - Torque transmitted between the driving sprocket and the driven sprocket through the chain to drive the travelling system.

The parameters required to calculate the driving chain are indicated in Table 39. Note that the calculation was made using the maximum gearmotor output torque during operation to consider the worst scenario for the driving chain.

Table 39 - Parameters used to calculate the driving chain from the travelling system.

Parameter	Value
Selected Roller Chain	DIN 8187 08B-2 Maintenance Free (equivalent to Iwis D 85 ML)
Pitch Diameter of the Driving Sprocket	69,11 mm
Number of Teeth of the Driving Sprocket	17
Pitch Diameter of the Driven Sprocket	69,11 mm
Number of Teeth of the Driven Sprocket	17
Distance between the Two Sprockets	157 mm
Maximum Gearmotor Output Torque	43,88 N·m
Driving Sprocket Rotation Speed (equal to the Gearmotor Output Speed (n_a))	458,4 rpm
Lubrication Factor (f5)	1
Shock Factor (Y)	2

The chain was calculated using Iwis Chain Engineering software, a chain-dedicated calculation software, with the full range of chains produced by Iwis. The steps given in the software to reach the result are indicated below [130]:

1) Characterization of the chain loop according to the chain type, and the dimensions and positioning of the sprockets. Indication of the operating conditions, in other words, indication of the torque on the driven sprocket, rotation speed of the driving sprocket, lubrication factor and shock factor (Figure 130);

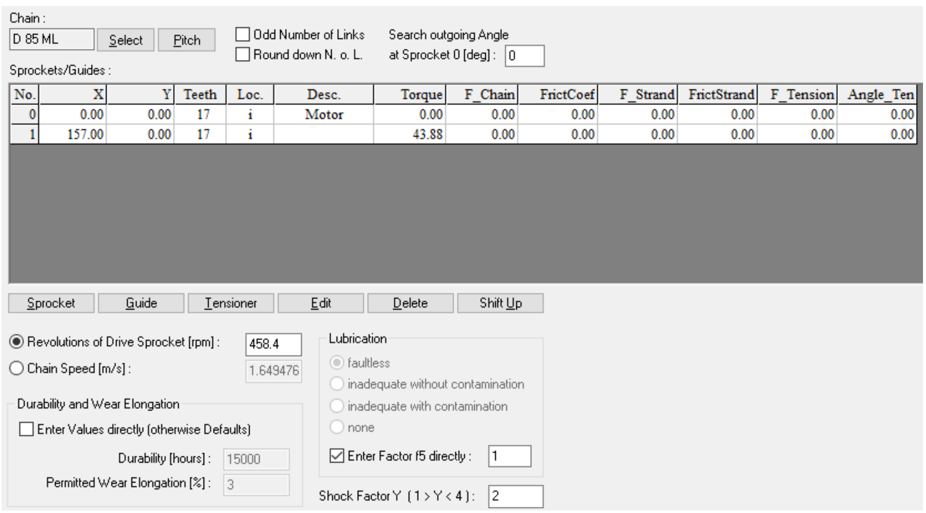


Figure 130 – Iwis Chain Engineering - Calculation of the Driving Chain for the Travelling System – Characterization of the chain loop and indication of the operating conditions.

2) Graphical representation of the chain loop (Figure 131);

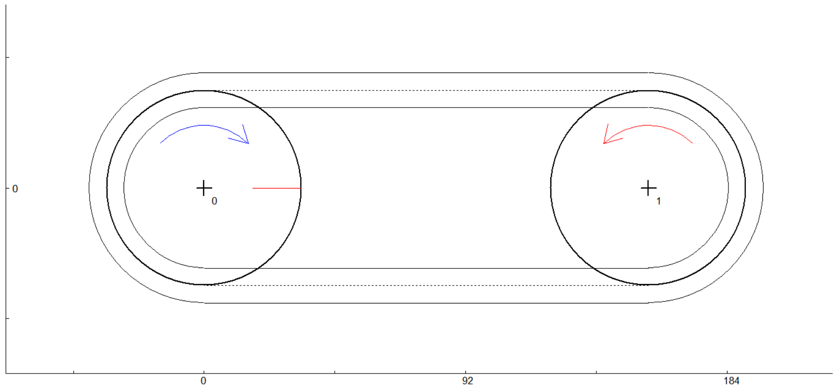


Figure 131 – Iwis Chain Engineering - Calculation of the Driving Chain for the Travelling System – Graphical representation of the chain loop.

3) According to the load conditions, determination of the rating life and the safety factors for the driving chain (Figure 132).

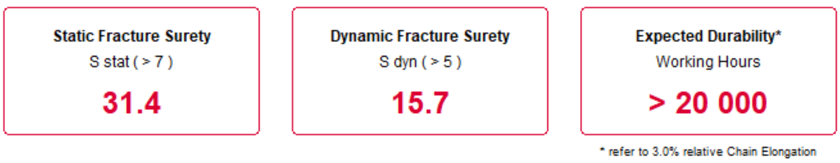


Figure 132 - Iwis Chain Engineering - Calculation of the Driving Chain for the Travelling System – Rating life and safety factors for the driving chain.

The main results of the calculation of the driving chain are shown in Table 40.

Table 40 - Results of the calculation of the driving chain.

Variable	Result
Static Fracture Surety	31,4
Dynamic Fracture Surety	15,7
Expected Durability	> 20000

According to the results, the current is oversized because it has a nominal service life above 20000 h, and at this time only the time in which the current remains in operation is counted. In addition, the static and dynamic safety factors are well above the recommended minimum values, which ensures that the chain is far from being broke by the loads it is subjected to. As such, the chain will have no problems during the operation, but it would be possible to choose a smaller one.

Calculation of the Locking Assemblies

The locking assemblies used to transmit the torque between the driven sprocket and the driving shaft and between the driving shaft and the travelling wheels had to be calculated to verify that the chosen models will be able to transmit the torque between the component pairs and to ensure that the travelling wheels and the driven sprocket will be able to withstand the pressure that is exerted by the locking assemblies on the contact surface.

As already mentioned, the driven sprocket receives the torsional torque of the gearmotor dividing it equally by the two drive wheels. As such, the locking assembly of the driven sprocket must be capable of transmitting the maximum output torque of the gearmotor while the locking assembly of each driving wheel must be able to transmit only half of that torque. Since there are two different locking assemblies and subject to different conditions, two separate calculations were made for each one. These calculations were made according to the procedures, equations and values indicated in the Tollok locking assemblies catalog [131].

The locking assembly for the driven sprocket is represented in Figure 133 and the parameters required to perform the verification calculations are indicated in Table 41.

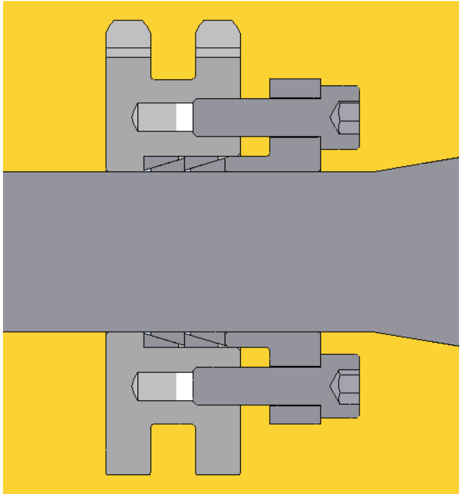


Figure 133 - Locking assembly for the driven sprocket.

Table 41 – Parameters used to calculate the locking assembly for the driven sprocket.

Parameter	Value
Selected Locking Assembly	(2x) TLK300 25x30
Locking Assembly Internal Diameter (d_{TLK})	25 mm
Locking Assembly External Diameter (D_{TLK})	30 mm
Locking Assembly Thickness (L1)	10,6 mm (5,3 mm/locking assembly)
Locking Assembly Pre-Load Force (Pt)	10000 N

Parameter	Value
Locking Assembly Surface Pressure on Hub (pn)	95 MPa
Flange Thickness (Sf)	8 mm
Fixing Bolts Diameter (dg)	M6
Fixing Bolts Tightening Force (Pv)	9000 N
Fixing Bolts Center Distance (l)	42 mm
Hub Material (Driven Sprocket Material)	EN Steel C45
Hub Diameter (Driven Sprocket Minimum Outer Diameter) (DM)	54 mm
Hub Width (Driven Sprocket Width) (B)	21 mm
Application Type Factor (C)	0,8
Tollok Coefficient K	1,25
Maximum Torsional Torque in the Driven Sprocket (equal to the Maximum Gearmotor Output Torque ($M_{stat+dyn}$))	43,88 N·m

To determine the torque transmissible by two locking assemblies TLK300, Equation 33, Equation 34 and Equation 35 were used. Equation 33 was used to determine the total tightening force of the locking assembly fastening screws; Equation 34 was used to determine the torque transmissible by a locking assembly; Equation 35 was used to determine the torque transmissible by two locking assemblies.

$$Pa = Nº\ of\ bolts \cdot Pv$$

Equation 33

Where:

Pa – Fixing Bolts Total Tightening Force (N).

$$Mt_{TLK} = \frac{Pa - Pt}{0{,}54} \cdot 0{,}12 \cdot \frac{d}{2000}$$

Equation 34

Where:

Mt_{TLK} – Transmissible torque by one locking assembly (N·m).

$$Mt_{2TLK} = Mt_{TLK} \cdot 1{,}55$$

Equation 35

Where:

Mt_{2TLK} – Transmissible torque by two locking assemblies (N·m).

Since this type of locking assembly does not have a tightening flange, it was necessary to check the dimensions of the flange designed for this purpose. To determine the minimum flange thickness and the recommended fixing bolts center distance, Equation 36 and the Equation 37, respectively, were used.

$$Sf \geq dg \cdot 1{,}3$$

Equation 36

$$l = D + 12 + dg$$

Equation 37

Finally, to calculate the minimum values for the diameter and width of the hub where the locking assembly is inserted, Equation 38 and Equation 39, respectively, were used.

$$DM \geq D \cdot K$$

Equation 38

$$B \geq 2 \cdot L1$$

Equation 39

The calculations results for the locking assembly for the driven sprocket are showed in Table 42.

Table 42 - Results of the calculation of the locking assembly for the driven sprocket.

Variable	Result
Maximum Transmissible Torque by Two Locking Assemblies (Mt_{2TLK})	112 N·m
Minimum Flange Thickness (Sf)	7,8 mm
Recommended Fixing Bolts Center Distance (l)	48 mm
Minimum Hub Diameter (DM)	37,5 mm
Minimum Hub Width (B)	21,2 mm

By analyzing the values in Table 42 it is concluded that the selected locking assembly is capable of transmitting the torque between the driven sprocket and the driving shaft, since the maximum transmissible torque is well above the application torque of 43,88

N·m. In addition, the minimum dimensions of flange thickness, hub diameter and hub width have been met during the design of the tightening flange and the driven sprocket, ensuring that these components withstand the pressures caused by contact with the locking assembly. Only the recommended fixing bolts center distance could not be guaranteed due to space limitations in the positioning of the threaded holes on the driven gear, but this does not prevent the correct torque transmission.

The locking assembly for the driving wheels is represented in Figure 134 and the parameters required to perform the verification calculations are indicated in Table 43.

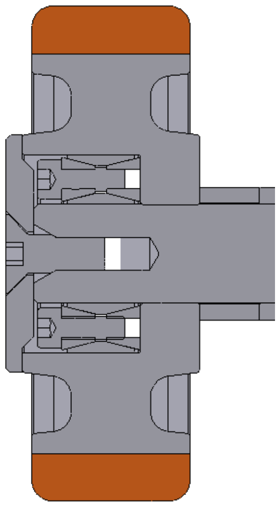


Figure 134 - Locking assembly for the driving wheels.

Table 43 – Parameters used to calculate the locking assembly for the driving wheels.

Parameter	Value
Selected Locking Assembly	(2x) TLK200 25x50
Locking Assembly Internal Diameter (d_{TLK})	25 mm
Locking Assembly External Diameter (D_{TLK})	50 mm
Locking Assembly Transmissible Torque (Mt_{TLK})	400 N·m
Hub Material (Wheel Centre Material)	Cast Iron (σ_{Yield} = 276 MPa)
Hub Diameter (Wheel Center Minimum Outer Diameter) (DM)	70 mm
Hub Width (Wheel Center Width) (B)	45 mm
Application Type Factor (C)	0,8

Parameter	Value
Tollok Coefficient K	1,36
Maximum Torsional Torque per Wheel (half the Maximum Gearmotor Output Torque ($M_{stat+dyn}$))	21,94 N·m

In this case, the torque transmissible by the locking assembly TLK200 is a catalog value so it did not have to be calculated. In addition, this type of locking assembly already has a built-in tightening flange, so it was not necessary to check its dimensions. However, it was necessary to check the contact pressure between the wheel bore and the locking assembly. As such, Equation 38 and Equation 39 were used again to calculate the minimum diameter and width of the hub where the locking assembly is inserted.

The calculations results for the locking assembly for the driving wheels are showed in Table 44.

Table 44 - Results of the calculation of the locking assembly for the driving wheels.

Variable	Result
Maximum Transmissible Torque (Mt_{TLK})	400 N·m
Minimum Hub Diameter (DM)	68 mm
Minimum Hub Width (B)	34 mm

By analyzing the values in Table 44 it is concluded that the selected locking assembly is capable of transmitting the torque between the driving shaft and the driving wheels, since the maximum transmissible torque is well above the application torque of 21,94 N·m. In addition, the minimum dimensions of hub diameter and hub width are guaranteed by the driving wheel dimensions, ensuring the wheel center withstands the pressures caused by contact with the locking assembly. In this case, a greater locking assembly was used than the one used on the driven sprocket, because the space limitations are much smaller, allowing greater freedom of assembly of a more robust locking assembly.

The driving sprocket has a similar assembly on the output shaft of the gearmotor through a taper lock bushing (Figure 135), however this does not need to be calculated since the sprocket and bushing are a direct choice of catalog, in other words, for each sprocket there is a recommended bushing, and may even be supplied as a set. Therefore, the bushing is chosen according to the sprocket.

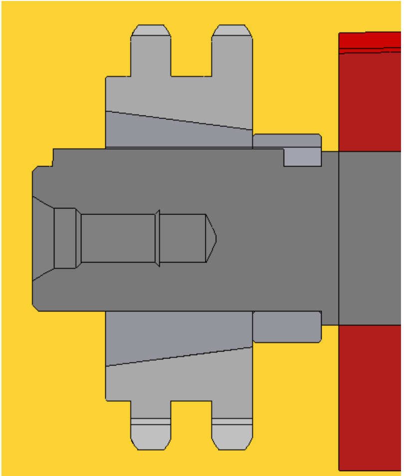


Figure 135 - Taper lock bushing for the driving sprocket.

Calculation of the Guiding Wheels Axle

The support axle of the guiding wheel is subjected to the same radial loads of the guiding wheel (Figure 136), so it was necessary to check whether it can resist such loads.

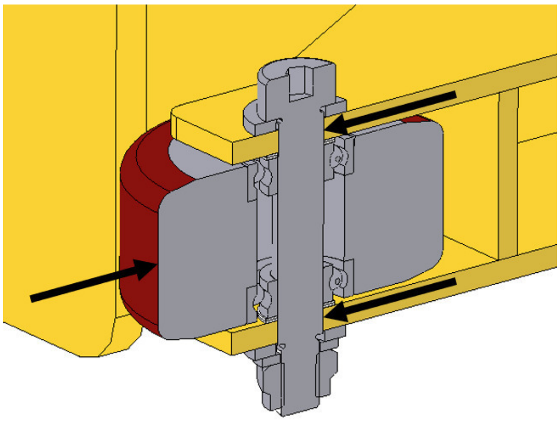


Figure 136 - Loads on the guiding wheel axle.

The parameters necessary to carry out the calculation of the guiding wheels axle are indicated in Table 45. Note that the calculation was made using the maximum load on the guiding wheel, value determined in the calculation process of the wheel.

Table 45 – Parameters used to calculate the guiding wheels axle.

Parameter	Value
Acting Force on the Axle (equal to the Load on the Guiding Wheel ($F_{guiding\ wheel}$))	1091 N
Axle Diameter	12 mm

Parameter	Value
Axle Material	Hexagon Socket Shoulder Head Bolt Class 12.9 (Rm = 1220 MPa)
Material of the Guiding Wheel Support Fork	Steel EN S235 JR
Material of the Guiding Wheel Bearings	High Grade and Alloy Steel (Rm > 700 MPa)

The axle calculation was performed through the pinned coupling calculation module of the MITCalc software. The steps given in the software to get the results are listed below [128]:

1) Characterization of the pinned coupling type, load conditions and mechanical properties of the materials from the clevis and the rod, in other words, the parts bonded by the pin (Figure 137). In this case, the guiding wheel axle is subjected to a unidirectional and repeated loading condition, and the materials of the parts making up the coupling are the steel EN S235 JR for the fork and the high alloy steel for the guiding wheel center (inner rings of ball bearings);

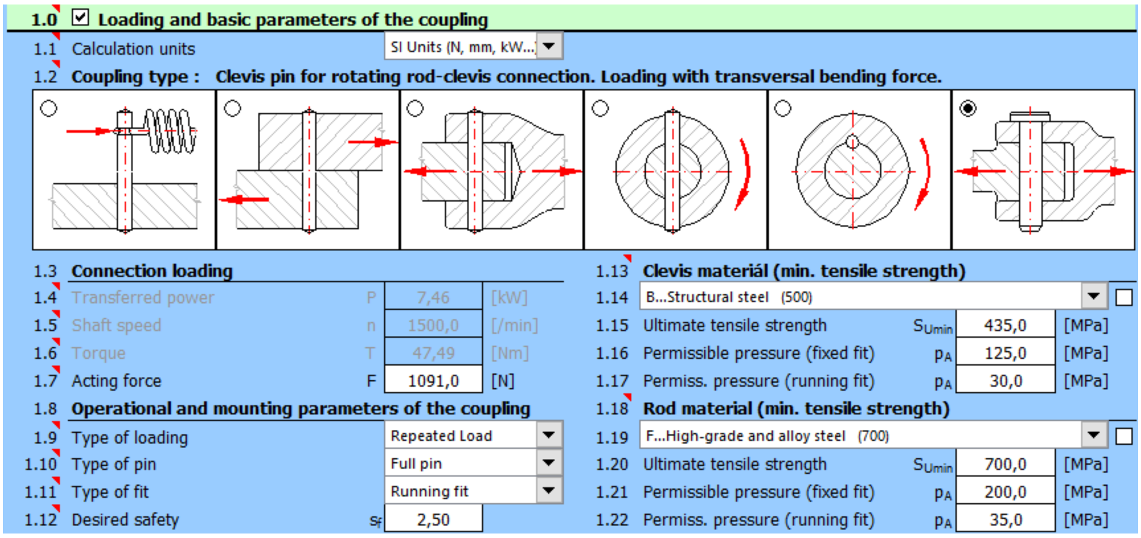
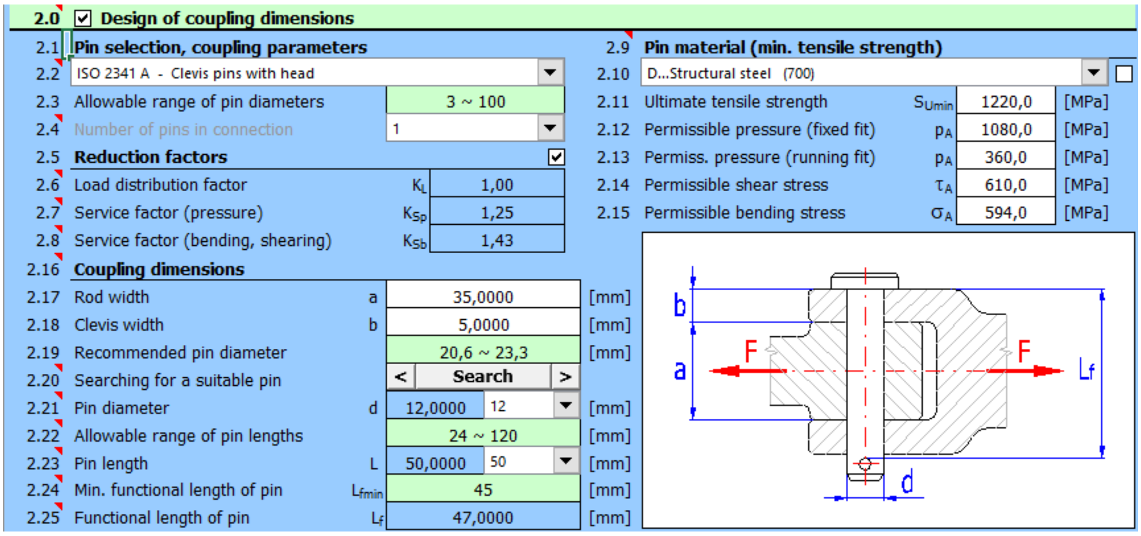


Figure 137 - MITCalc – Calculation of the Guiding Wheel Axle – Loading and basic parameters of the coupling.

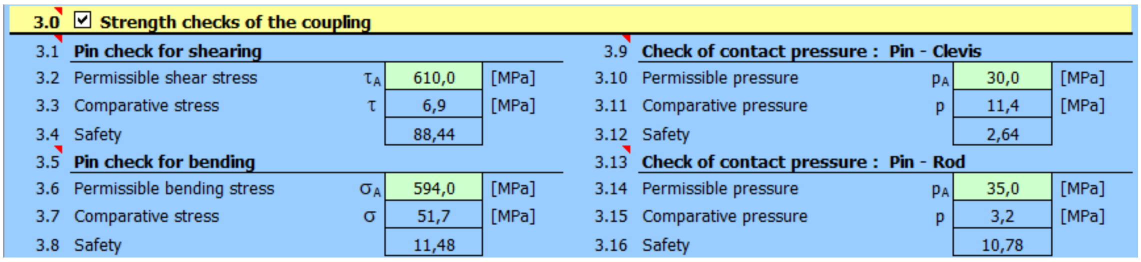
2) Indication of pin type, mechanical properties of pin material, and pin coupling dimensions (Figure 138). In this case, the guiding wheel axle is a standard bolt ISO 7379 (class 12.9) which can be compared, from the point of view of dimensions and geometry, to a standard pin ISO 2341-A;



2.0	☑ Design of coupling dimensions									
2.1	Pin selection, coupling parameters				2.9	Pin material (min. tensile strength)				
2.2	ISO 2341 A - Clevis pins with head				2.10	D...Structural steel (700)				
2.3	Allowable range of pin diameters		3 ~ 100		2.11	Ultimate tensile strength	S_{Umin}	1220,0	[MPa]	
2.4	Number of pins in connection		1		2.12	Permissible pressure (fixed fit)	p_A	1080,0	[MPa]	
2.5	Reduction factors		☑		2.13	Permiss. pressure (running fit)	p_A	360,0	[MPa]	
2.6	Load distribution factor	K_L	1,00		2.14	Permissible shear stress	τ_A	610,0	[MPa]	
2.7	Service factor (pressure)	K_{Sp}	1,25		2.15	Permissible bending stress	σ_A	594,0	[MPa]	
2.8	Service factor (bending, shearing)	K_{Sb}	1,43							
2.16	Coupling dimensions									
2.17	Rod width	a	35,0000	[mm]						
2.18	Clevis width	b	5,0000	[mm]						
2.19	Recommended pin diameter		20,6 ~ 23,3	[mm]						
2.20	Searching for a suitable pin		< Search >							
2.21	Pin diameter	d	12,0000 / 12	[mm]						
2.22	Allowable range of pin lengths		24 ~ 120	[mm]						
2.23	Pin length	L	50,0000 / 50	[mm]						
2.24	Min. functional length of pin	L_{fmin}	45	[mm]						
2.25	Functional length of pin	L_f	47,0000	[mm]						

Figure 138 - MITCalc – Calculation of the Guiding Wheel Axle – Design of coupling dimensions.

3) According to the load conditions and dimensions indicated so far, checking of the pin coupling strength (Figure 139). As such, calculation of the safety factors for the axle strength against shearing and bending stresses and calculation of the safety factors for the surface strength of the fork and guiding wheels holes against the contact pressure caused by the axle.



3.0	☑ Strength checks of the coupling								
3.1	Pin check for shearing				3.9	Check of contact pressure : Pin - Clevis			
3.2	Permissible shear stress	τ_A	610,0	[MPa]	3.10	Permissible pressure	p_A	30,0	[MPa]
3.3	Comparative stress	τ	6,9	[MPa]	3.11	Comparative pressure	p	11,4	[MPa]
3.4	Safety		88,44		3.12	Safety		2,64	
3.5	Pin check for bending				3.13	Check of contact pressure : Pin - Rod			
3.6	Permissible bending stress	σ_A	594,0	[MPa]	3.14	Permissible pressure	p_A	35,0	[MPa]
3.7	Comparative stress	σ	51,7	[MPa]	3.15	Comparative pressure	p	3,2	[MPa]
3.8	Safety		11,48		3.16	Safety		10,78	

Figure 139 - MITCalc – Calculation of the Guiding Wheel Axle – Design of coupling dimensions.

The safety factors for checking the strength of the guiding wheel axle and respective parts that make up the entire pin coupling, are presented in Table 46.

Table 46 - Results of the safety factors from the calculation of the guiding wheel axle.

Variable	Result
Axle Shear Stress Safety Factor	88,4
Axle Bending Stress Safety Factor	11,5
Fork Contact Pressure Safety Factor	2,6
Guiding Wheel Contact Pressure Safety Factor	10,8

As all safety factors are above 2,5, the dimensioning of the guiding wheel axle is validated, ensuring a large safety margin against possible problems that may occur in the coupling during the operation of the shuttle vehicle.

Calculation of the Polyurethane Buffer

The polyurethane buffers are used to stop the shuttle vehicle if it exceeds the maximum travel limit, preventing it from escaping from the rack. It is therefore a mechanical safety component subject to the impact effort caused by the collision of the shuttle vehicle against the end stoppers of the rail.

If the shuttle vehicle exceeds the maximum travel limit, first, the limit switch is actuated and electrically shuts off the system. Then, the emergency brake of the travelling gearmotor is mechanically actuated to brake the vehicle. The polyurethane buffers enter as a third safety component, in case the gearmotor brake is not able to stop the vehicle in the distance between the maximum travel limit and the end stoppers of the rail. Therefore, the worst scenario for the buffers is the shuttle vehicle crashing against the end stoppers of the rail at full speed and loaded with boxes but without any driving force from the gearmotor because the system was electrically switched off. The buffers calculation was made for this scenario.

The parameters required to calculate the polyurethane buffers are listed in Table 47.

Table 47 – Parameters used to calculate the polyurethane buffers.

Parameter	Value
Total Shuttle Vehicle Mass	300 kg
Boxes Mass	100 kg
Vehicle Speed	1,25 m/s^2
Number of Impact Buffers	2 un

The calculation was made using the elastomer buffers calculation module from Weforma website. The steps taken to perform the calculation are indicated below [132]:

1) Indication of the type of application (Figure 140). In this case, the vehicle strikes horizontally against the end stoppers of the rail and without any driving force.

Figure 140 - Weforma website - Calculation of the polyurethane buffers – Indication of the type of application.

2) Indication of the application parameters (Figure 141): vehicle mass, impact speed and number of shock absorbers.

Figure 141 - Weforma website - Calculation of the polyurethane buffers – Indication of the application parameters.

3) Selection of the polyurethane buffer from among the recommended options (Figure 142).

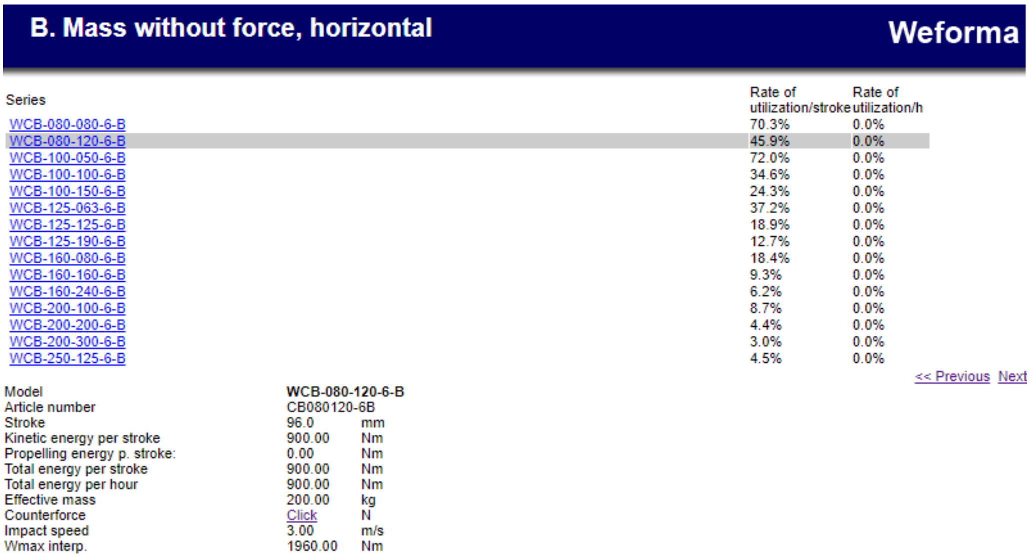


Figure 142 - Weforma website - Calculation of the polyurethane buffers – Selection of the polyurethane buffer.

The polyurethane buffer is a direct choice as a result of the calculation, requiring no checking. As such, the chosen buffer is indicated in Table 48.

Table 48 – Selected polyurethane buffer.

Variable	Result
Selected Polyurethane Buffer	PU Buffer D80x120-M12x35 (Weforma WCB-080-120-6-B)

Calculation of the Fork for the Guiding Wheel (using FEA)

The support fork of the guiding wheel, such as the axle, is subjected to the radial load that is exerted on the guiding wheel. As such, it was necessary to check its behavior against the loading conditions as a way of validating the design that was made for this part.

The parameters required to calculate the fork are given in Table 53.

Table 49 – Parameters used to calculate the fork for the guiding wheel.

Parameter	Value
Acting Force on the Fork (equal to the Load on the Guiding Wheel ($F_{guiding\ wheel}$))	1091 N
Material of the Fork for the Guiding Wheel	Steel EN S235 JR

To determine the maximum stress and displacement of the fork against the load to which it is subject, an FEA simulation was performed through the Simulation module of the CAD software Autodesk® Inventor®. As such, the steps that followed to the results are indicated below:

1) Since this is a model composed of more than one part, the first step was the indication of the types of contact between the parts that make up the model to be simulated. The principles that have been assumed for this first step apply to all simulations of models with more than one part. However, these principles are exposed only in this section to facilitate the reading of the work, avoiding the repetition of information. Therefore, the principles for defining the types of contacts were as follows:
    a. In bolted connections it was defined that the two contact surfaces would be bonded by the area of occupancy of the washer and all the rest would be separated, simulating the actual behavior of a bolted connection;
    b. In welded connections of tee joints or corner joints, it was defined that the two contact surfaces would be bonded throughout the area of contact between both, so there was no need to represent the weld beads in these cases because the bonded contact area between the surfaces would be practically the same;
    c. In welded connections of lap joints, it was defined that the two contact surfaces would be separated from each other, but bonded through the weld beads, so there was a need to represent them to simulate the actual behavior of a welded connection.
2) Definition of the boundary conditions. In this case, a fixed constraint was applied in all directions of the part used to simulate the support and the bolted connection of the fork (Figure 143);

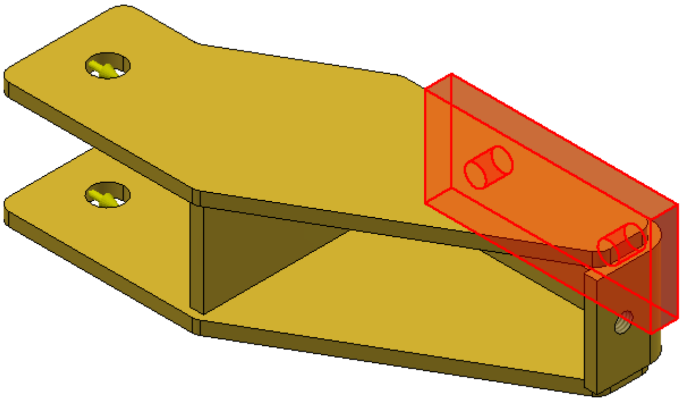


Figure 143 – FEA simulation – Calculation of the Fork for the Guiding Wheel – Definition of the boundary conditions.

3) Definition of the applied loads. In this case, the fork is subjected to the radial load of the guiding wheel, being applied on the support holes of the guiding wheel axle. The weight of the fork is already included in the simulation and is not considered an external force (Figure 144);

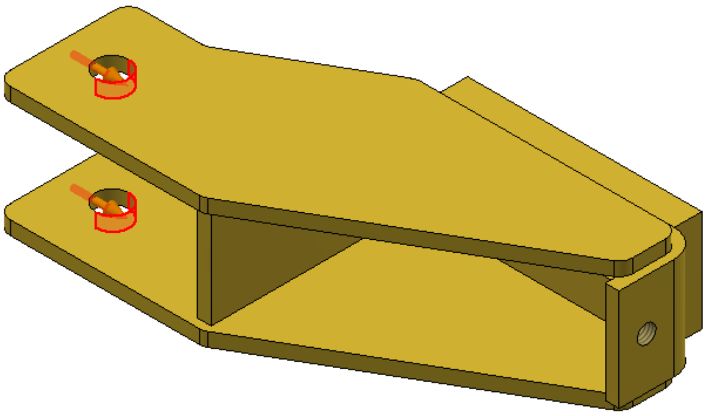


Figure 144 - FEA simulation – Calculation of the Fork for the Guiding Wheel – Definition of the applied loads.

4) Mesh creation. Figure 145 shows the mesh aspect on the fork surface and the number of nodes and elements that characterize it;

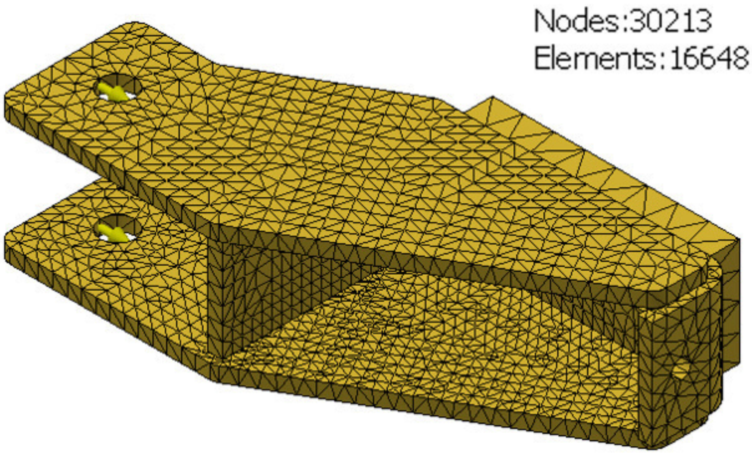


Figure 145 - FEA simulation – Calculation of the Fork for the Guiding Wheel – Mesh creation.

5) Obtaining the results of the simulation. Figure 146 shows the distribution of the Von Mises stresses across the surface of the analyzed part. Figure 147 shows the displacements suffered by the part.

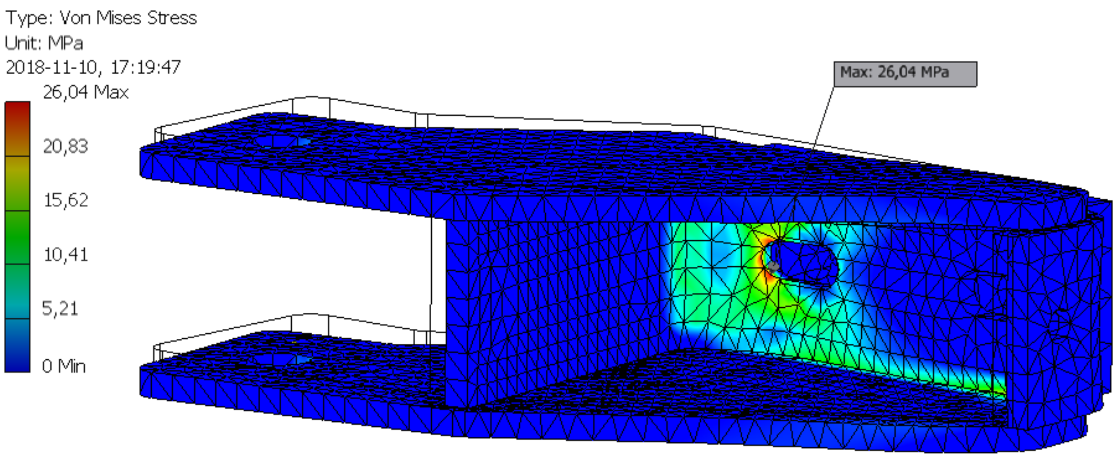


Figure 146 - FEA simulation – Calculation of the Fork for the Guiding Wheel – Distribution of the Von Mises stresses.

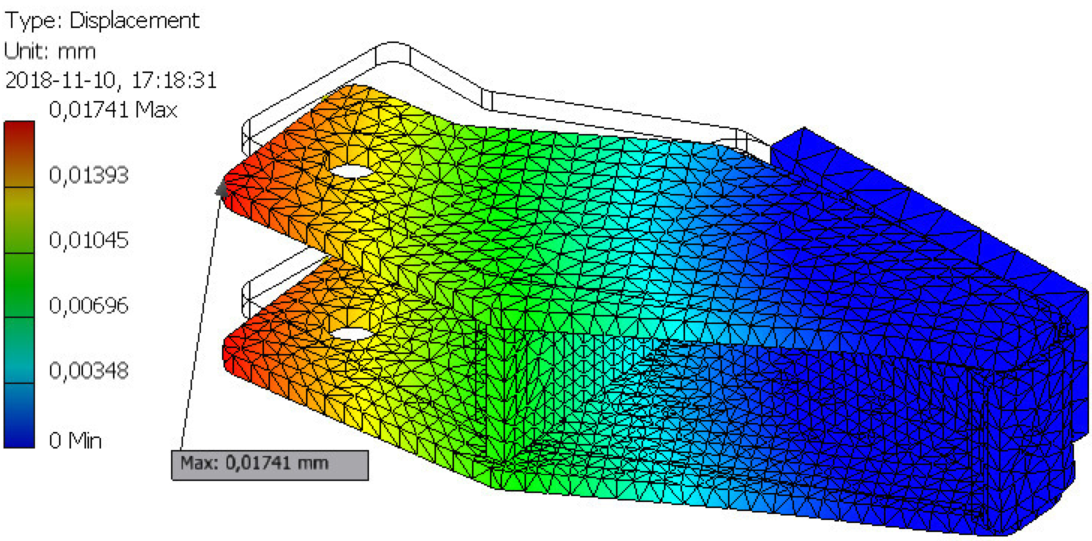


Figure 147 - FEA simulation – Calculation of the Fork for the Guiding Wheel – Displacements on the part.

After obtaining the results, the safety factor between the yield strength of the material and the maximum Von Mises stress was calculated by Equation 40.

$$SF = \frac{\sigma_{Yield}}{\sigma_{Von\ Mises,max}}$$

Equation 40

Where:

σ_{Yield} – Yield strength of the material (MPa);

$\sigma_{Von\ Mises,max}$ – Maximum Von Mises stress (MPa).

All the main results of the FEA simulation are summarized in Table 50.

Table 50 - Results of the FEA simulation of the fork for the guiding wheel.

Variable	Result
Maximum Von Mises Stress ($\sigma_{Von\ Mises,max}$)	26,0 MPa
Maximum Displacement	0,02 mm
Safety Factor (SF)	9,0

A safety factor of the fork of 9,0 ensures that there is no danger of failure of the component for the case studied. In addition, the maximum displacement is very close to 0 mm, ensuring that the part hardly deforms.

Calculation of the Main Structure (using FEA)

All subsystems that make up the shuttle vehicle are mounted on the main structure. As such, it is essential that it is of structurally supporting the weight of all systems and even the drive torques of each of the subsystems, although these occur in isolation from the rest.

To study the behavior of the main structure when subjected to the weight of all subsystems and the output torque of the travelling gearmotor, in other words, when the travelling system is operating, it was necessary to carry out a structural calculation.

The parameters required to calculate the main structure are given in Table 51. Note that the calculation was done using the maximum gearmotor output torque to increase the level of safety of the results. The weights were calculated by multiplying the masses of the respective components by the gravitational acceleration.

Table 51 – Parameters used to calculate the main structure when the travelling system is operating.

Parameter	Value
Maximum Gearmotor Output Torque ($M_{stat+dyn}$)	43,88 N·m
Gearmotor Weight	270 N
Picking System Weight	216 N
Extraction System Weight	457 N
Boxes Weight	981 N
Material of the Main Structure	Steel EN S235 JR

To determine the maximum stress and displacement of the main structure against the load to which it is subject, an FEA simulation was performed through the Simulation module of the CAD software Autodesk® Inventor®. As such, the steps that followed to the results are indicated below:

1) Since this is a model composed of more than one part, the first step was the indication of the types of contact between the parts that make up the model to be simulated. The principles that have been assumed were described before;
2) Definition of the boundary conditions. In this case, pin constraints were applied in the radial directions of the travelling wheel axles and in the holes for the fixing bolts to connect the forks of the guiding wheels (Figure 148), blocking the movement of the main structure in the three possible directions;

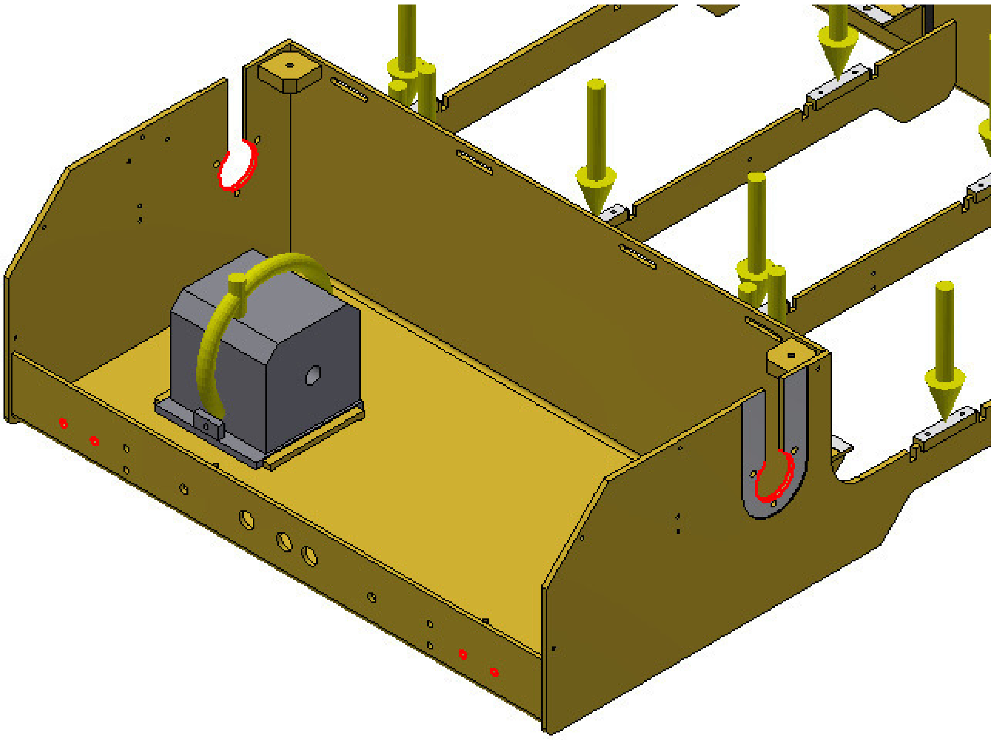


Figure 148 – FEA simulation – Calculation of the Main Structure when the Travelling System is Operating – Definition of the boundary conditions.

3) Definition of the applied loads. In this case, the main structure is subjected to the gearmotor weight and output torque, to the extraction system weight, to the picking system weight and to the boxes weight (Figure 149). The weight of the main structure is already included in the simulation and is not considered an external force;

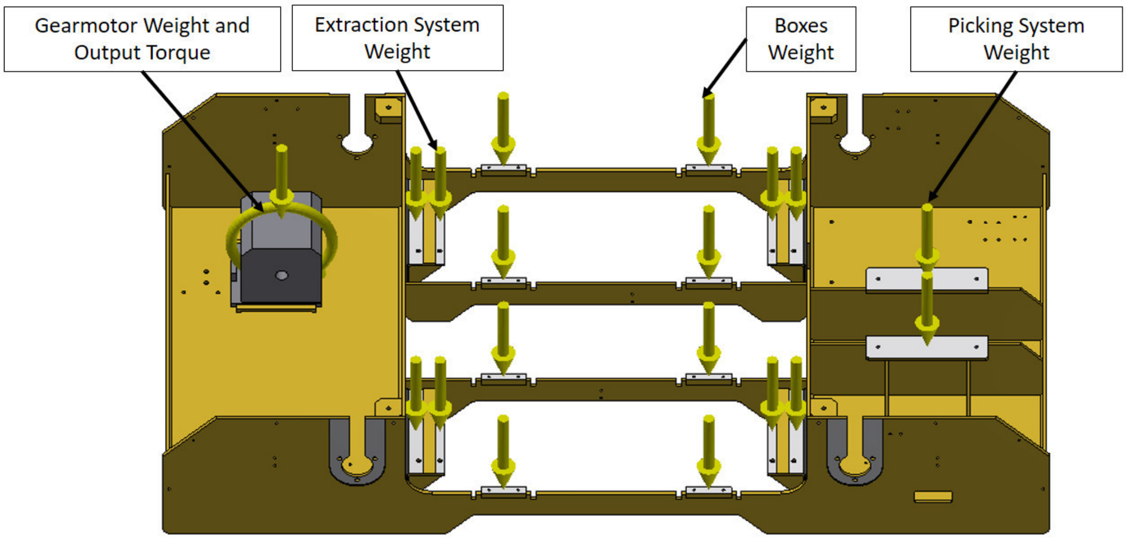


Figure 149 - FEA simulation – Calculation of the Main Structure when the Travelling System is Operating – Definition of the applied loads.

4) Mesh creation. Figure 150 shows the mesh aspect on the main structure surface and the number of nodes and elements that characterize it;

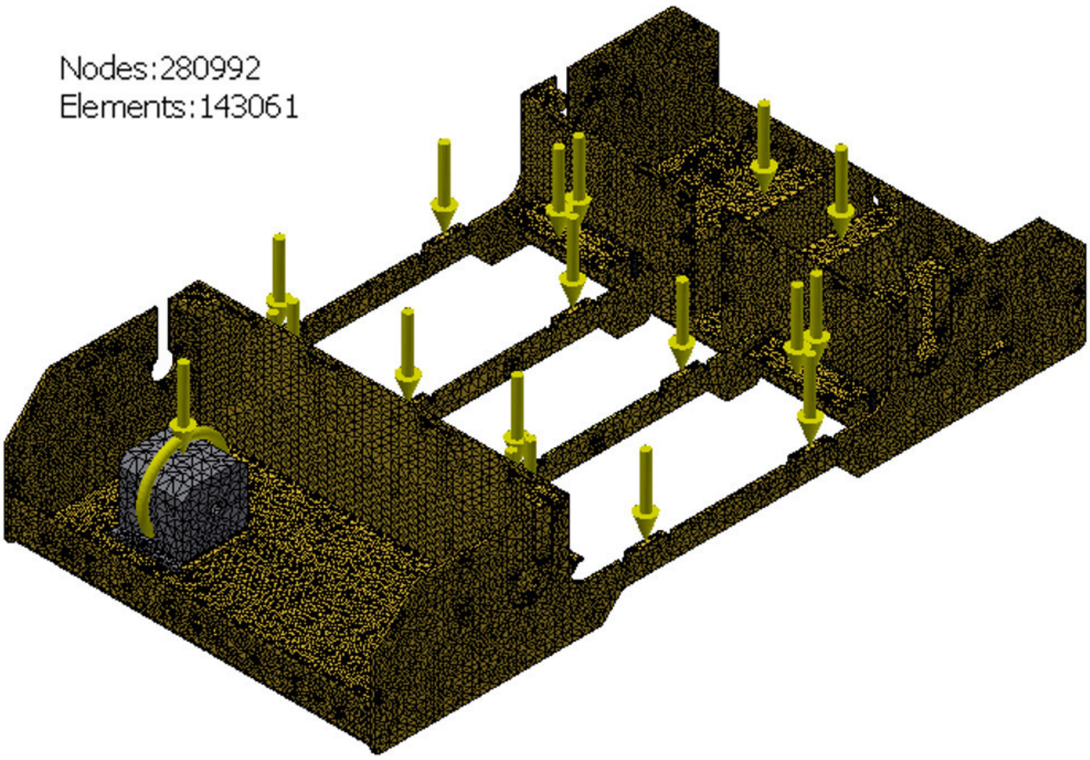


Figure 150 - FEA simulation – Calculation of the Main Structure when the Travelling System is Operating – Mesh creation.

5) Obtaining the results of the simulation. shows the distribution of the Von Mises stresses across the surface of the analyzed part. shows the displacements suffered by the part.

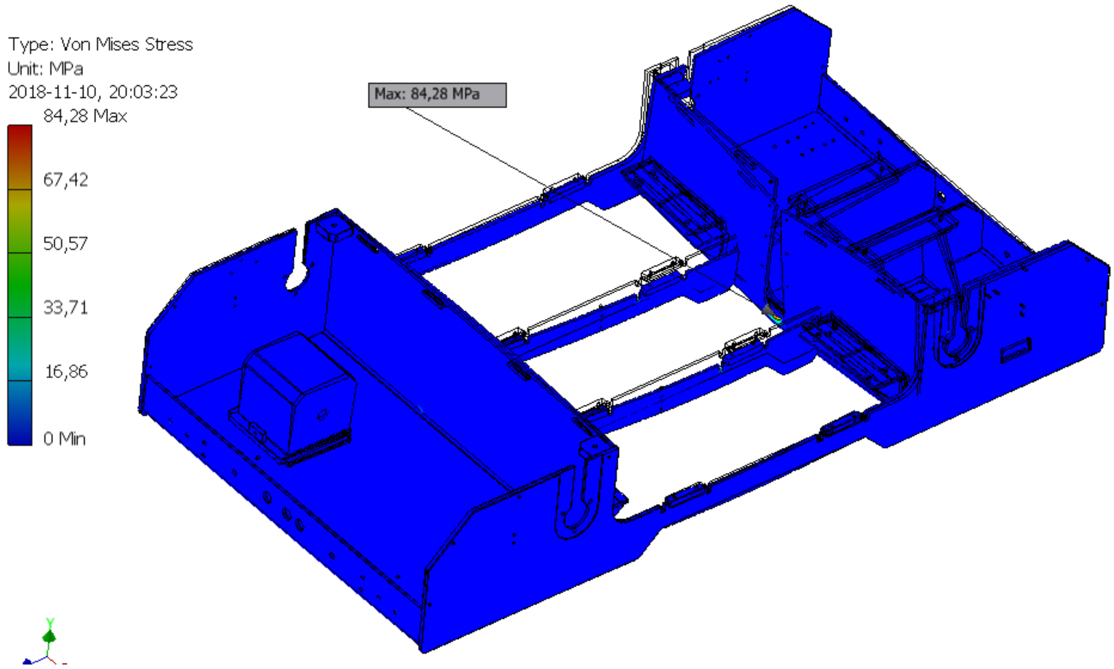


Figure 151 - FEA simulation – Calculation of the Main Structure when the Travelling System is Operating – Distribution of the Von Mises stresses.

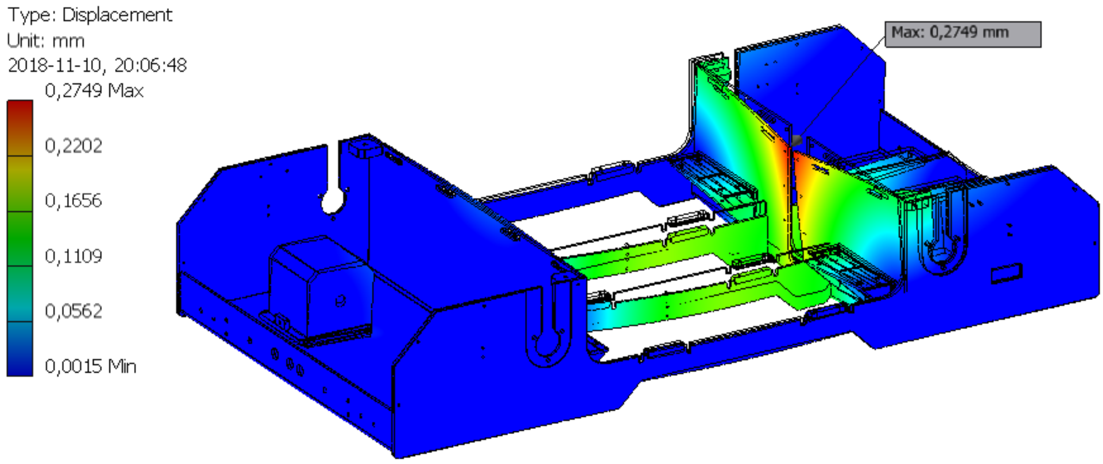


Figure 152 - FEA simulation – Calculation of the Main Structure when the Travelling System is Operating – Displacements on the part.

After obtaining the results, the safety factor between the yield strength of the material and the maximum Von Mises stress was calculated by Equation 40.

All the main results of the FEA simulation are summarized in Table 50.

Table 52 - Results of the FEA simulation of the main structure when the travelling system is operating.

Variable	Result
Maximum Von Mises Stress **($\sigma_{Von\ Mises,max}$)**	84,3 MPa

Variable	Result
Maximum Displacement	0,27 mm
Safety Factor (SF)	2,8

A safety factor of the main structure of 2,8 ensures that there is no risk of failure of the component to the load conditions studied. In addition, the maximum stress occurs only in a small area of the structure not as strong as the rest of the part where the Von Mises stresses are below 20 MPa.

The maximum displacement of the part is very close to 0 mm, ensuring that the part hardly deforms.

3.4.9.2 CALCULATIONS IN THE EXTRACTION SYSTEM

For the extraction system, the following calculations were performed:

1) Calculation of the servo gearmotor;
2) Calculation of the driving shaft;
3) Calculation of the driving shaft bearings;
4) Calculation of the driving chains;
5) Calculation of the locking assemblies for the driving sprockets;
6) Calculation of the DC drive;
7) Calculation of the DC drive fixing plate (using FEA);
8) Calculation of the retractable finger (using FEA);
9) Calculation of the stringers (using FEA);
10) Calculation of the flange for the servo gearmotor (using FEA);
11) Calculation of the main structures (using FEA).

Calculation of the Servo Gearmotor

The servo gearmotor is used to drive the extraction system, in other words, it is used to linearly move the extraction arms to drag the boxes into or out of the shuttle vehicle through a transmission system composed of chains, driving sprockets and racks (Figure 153). As such, it was necessary to perform a calculation to select a servo gearmotor that would be able to drive this system.

The driving force for moving the movable extraction arms and the box is equal to the force required to overcome the friction between the box and its bearing surface and between the movable struts and the fixed struts, in other words, to overcome the friction between polymer and steel caused by the total mass of the movable extraction arms and the box.

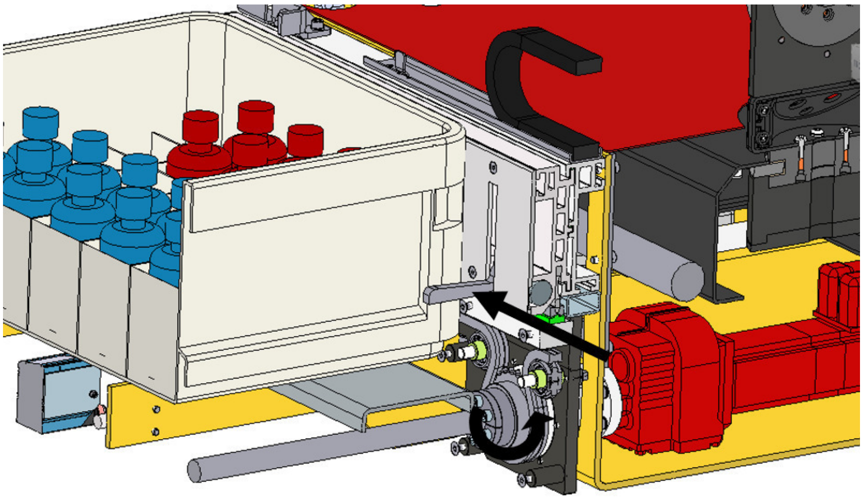


Figure 153 – Servo gearmotor used to produce a driving force for moving the movable extraction arms and the box.

The parameters required to calculate the servo gearmotor are given in Table 53. It should be noted that the speed and acceleration values of the extraction system were altered, with the speed being slightly increased and the acceleration being reduced, keeping the same values whether the system moves with boxes or without boxes.

Table 53 - Parameters used to calculate the servo gearmotor.

Parameter	Value
Mass of the Movable Extraction Arms	17,5 kg (8,75 kg/arm)
Boxes Mass	100 kg (50 kg/box)
Extraction System Speed	0,45 m/s
Extraction System Acceleration	0,9 m/s^2
Static Coefficient of Friction (polymer/steel)	0,45
Pitch Diameter of the Driving Sprockets	76 mm
Number of Teeth of the Driving Sprockets	25
Mass Moment of Inertia of the Driving Sprockets	144,369 kgm^2
Gear Unit Type	Flange-Mounted Helical Gear Unit (Type RF)
Motor Type	Flange-Mounted Synchronous Servomotor (Type CMP)
Servo Gearmotor Mounting Position	M1

This calculation was made using the SEW Workbench calculation software. The steps given in the software until reaching the final solution are indicated below [127]:

1) Selection of the type of motion, the type of application and the type of power transmission. In this case, it is a linear movement created by a mechanism of driving sprocket and rack (Figure 154). There is no additional gear;

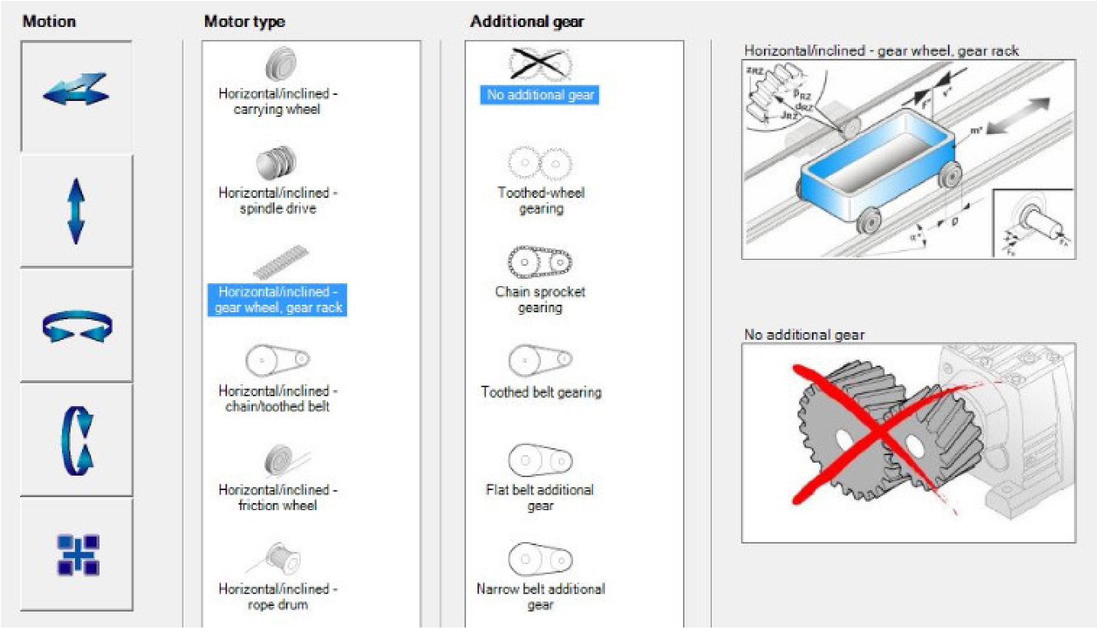


Figure 154 – SEW Workbench – Calculation of the Servo Gearmotor - Selection of the type of application.

2) Introduction of the parameters that characterize the driving sprocket (Figure 155). In this case, there is no need to calculate the overhung load on the gearmotor output shaft because all radial loads are absorbed by the bearings that support the extraction system driving shaft;

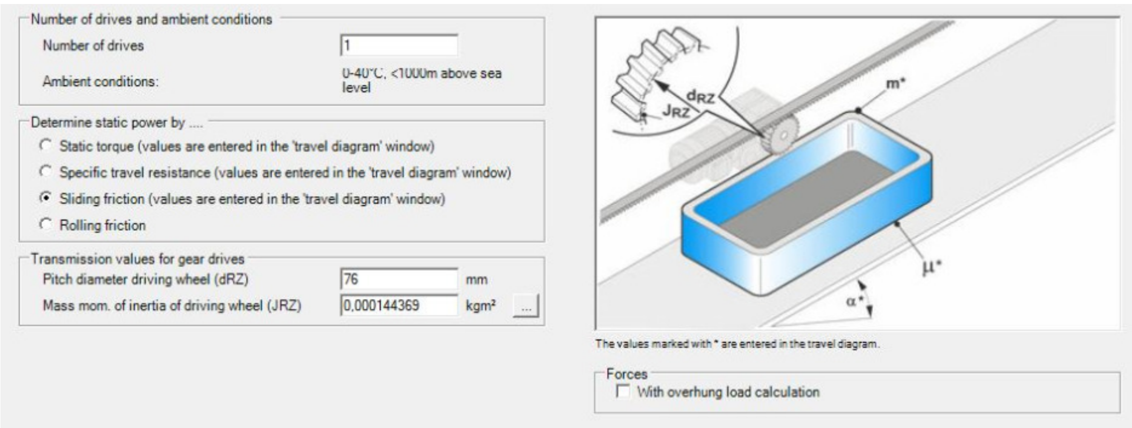


Figure 155 - SEW Workbench – Calculation of the Servo Gearmotor – Introduction of the parameters that characterize the driving sprocket.

3) Definition of the travel diagram for the extraction system movement with indication of the respective distances and times of acceleration, and calculation of the driving torques for the servo gearmotor (Figure 156). In this step it is important to highlight the maximum value of the static and dynamic torques

(15,15 N·m) since it was used for many of the calculations performed on the extraction system;

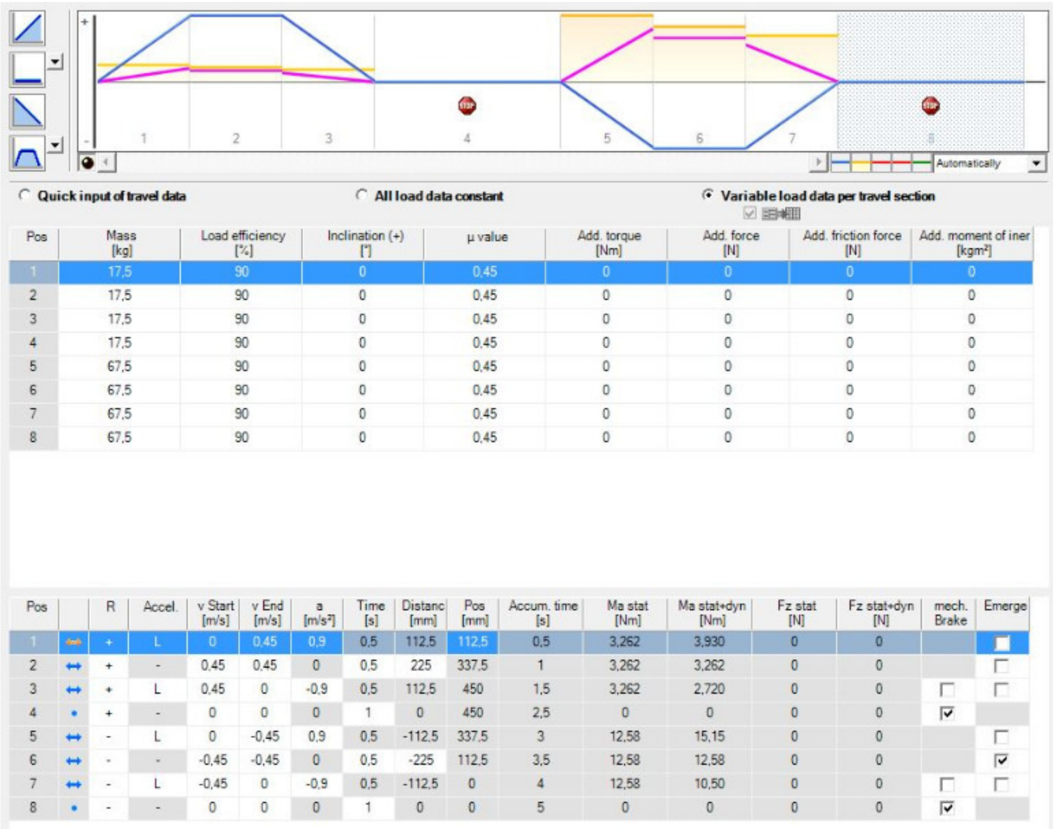


Figure 156 - SEW Workbench – Calculation of the Servo Gearmotor – Definition of the travel diagram.

4) Selection of the best servo gearmotor for this application, according to the type of gear unit and motor desired (Figure 157).

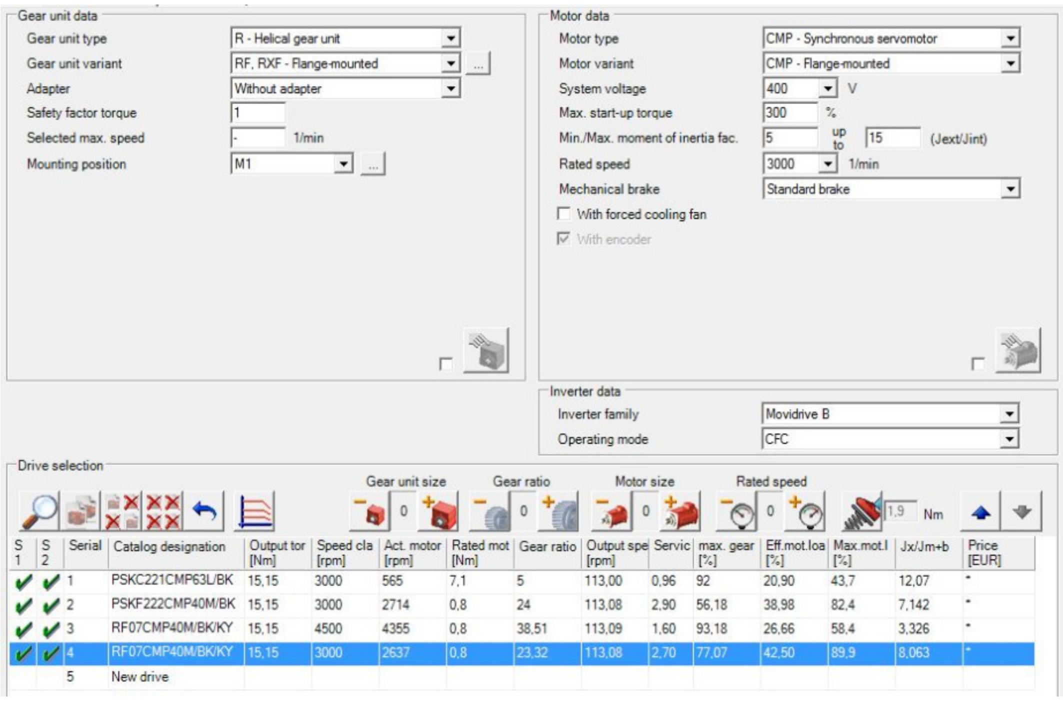


Figure 157 - SEW Workbench – Calculation of the Servo Gearmotor – Selection of the servo gearmotor.

The main parameters of the selected servo gearmotor are shown in Table 54.

Table 54 - Parameters of the selected servo gearmotor.

Variable	Result
Reference of the Selected Gearmotor	RF07 CMP40M/BK/KY
Maximum Gearmotor Output Torque during operation ($M_{stat+dyn}$)	15,15 N·m
Gearmotor Rated Output Torque	18,7 N·m
Motor Speed	2637 rpm
Motor Rated Torque	0,8 N·m
Gear Unit Ratio	23,32
Gearmotor Output Speed (n_a)	113,08 rpm
Service Factor	2,7
Motor Start-Up Torque/Motor Rated Torque	89,9%

By analyzing the values in Table 54, it is concluded that the servo gearmotor is valid to drive the extraction system. It has a service factor above 2, which guarantees high resistance of the gear unit, and a motor start-up torque less than the motor rated torque, which ensures a high safety margin if there are significant variations in the output torque required to drive the system.

Calculation of the Driving Shaft

The driving shaft was calculated to predict its behavior relative to bending and torsional stresses during the operation of the extraction system. The driving shaft is supported on two bearings, being subjected to radial loads caused by tangential pulling forces of the driving chains (Figure 158). In addition, it is further subjected to torsional stresses, because of the maximum gearmotor output torque which is divided by the two driving sprockets to actuate the extraction system.

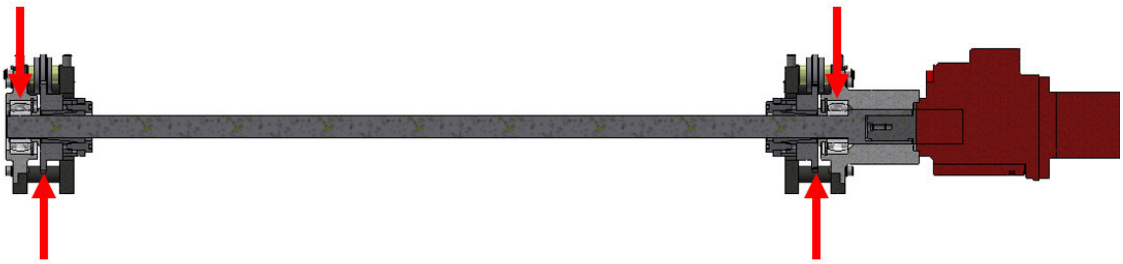


Figure 158 - Loads on the driving shaft from the extraction system.

The parameters required to perform the calculation are indicated in Table 55. Note that the calculation was made using the maximum gearmotor output torque during operation to consider the worst scenario for the driving shaft.

Table 55 - Parameters used to calculate the driving shaft from the extraction system.

Parameter	Value
Driving Shaft Material	Steel EN C45
Maximum Gearmotor Output Torque during operation ($M_{stat+dyn}$)	15,15 N·m
Maximum Torsional Torque per Driving Sprockets (half the Maximum Gearmotor Output Torque during operation ($M_{stat+dyn}$)) ($M_{t\_sprocket}$)	7,6 N·m
Pitch Diameter of the Driving Sprockets (D_P)	76 mm
Shaft Rotation Speed (equal to the Gearmotor Output Speed (n_a))	113 rpm

The first step of the calculation was the determination of the radial forces on the driving shaft caused by the chain tangential pulling force when being pulled by the servo gearmotor acceleration. This force was determined by Equation 32.

The second step of the calculation was the determination of the maximum stresses and deflections on the shaft. This was made through the shaft calculation module of the software MITCalc. The steps given in the software until reaching the results are indicated below [128]:

1) Representation of the geometry and dimensions of the shaft, with positioning of the two supports (Figure 159). In this case, the supports are the two bearings.

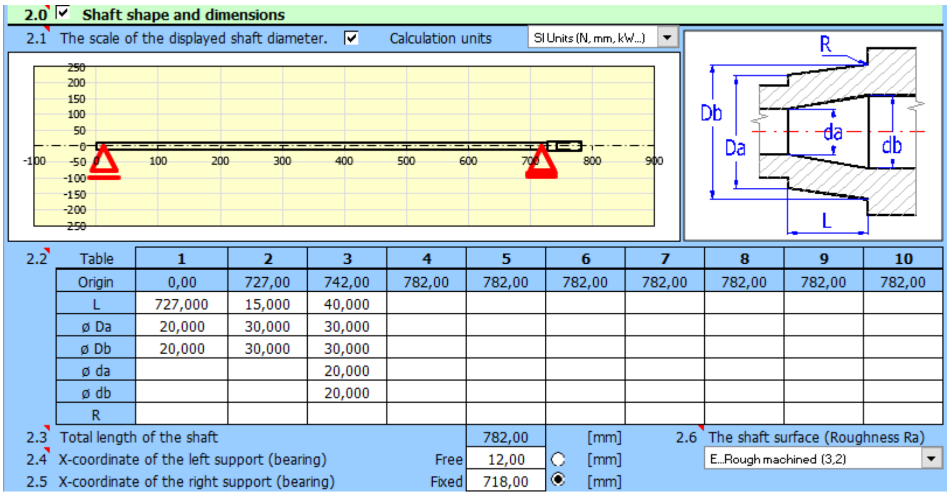
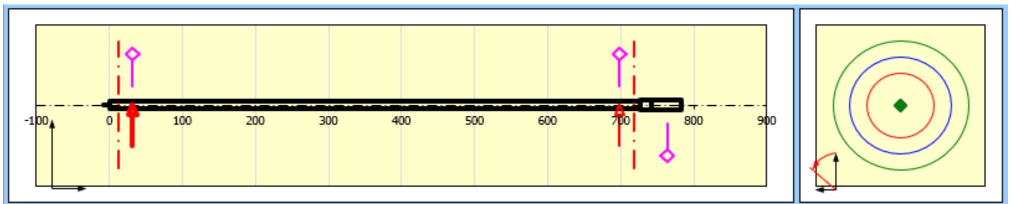


Table	1	2	3	4	5	6	7	8	9	10
Origin	0,00	727,00	742,00	782,00	782,00	782,00	782,00	782,00	782,00	782,00
L	727,000	15,000	40,000							
ø Da	20,000	30,000	30,000							
ø Db	20,000	30,000	30,000							
ø da			20,000							
ø db			20,000							
R										

Figure 159 - MITCalc – Calculation of the Driving Shaft from the Extraction System – Geometry and dimensions of the shaft.

2) Representation of the loads to which the driving shaft is subjected. The forces and torque shown in Figure 213 correspond to the following loads:
   - **F1**: Chain tangential pulling force on the first driving sprocket (F_{tang});
   - **Mt1**: Torsional reaction torque on the first driving sprocket ($Mt_{\_sprocket}$);
   - **F2**: Chain tangential pulling force on the second driving sprocket (F_{tang});
   - **Mt2**: Torsional reaction torque on the second driving sprocket ($Mt_{\_sprocket}$);
   - **Mt3**: Maximum gearmotor output torque ($M_{stat+dyn}$).



4.1 Loading	X	Fx	F	alfa	Mt	Mb	alfa	Q	b	alfa
	[mm]	[N]		[°]	[Nm]		[°]	[N/mm]	[mm]	[°]
1	32,00		200,0		-7,60					
2	698,50		200,0		-7,60					
3	763,50				15,20					
4										
5										
6										
7										
8										
9										
10										

Figure 160 - MITCalc – Calculation of the Driving Shaft from the Extraction System – Loads on the shaft.

3) Characterization of the mechanical properties of the shaft material and indication of the load conditions (Figure 161). The material of the shaft is the steel EN C45. The types of loads on the shaft are mainly repeated radial loads, due to constant accelerations/decelerations of the extraction system, and torsional loads reversed because the shaft rotates in both directions.

6.0 ☑ Material and the type of loading

6.1	Shaft material (Ultimate tensile strength min-max)			
	A..Structural steel (350 - 700)		595	[MPa]
6.2	Ultimate tensile strength	Su/Rm	590	[MPa] ☐
6.3	Yield strength in tension	S_Y/Re	307	[MPa]
6.4	Yield strength in bending	S_{Yb}/Re_b	400	[MPa]
6.5	Yield strength in shear	S_{Ys}/Re_s	215	[MPa]
6.6	**For reversed loading**			
6.7	Fatigue limit - tension-pres	σ_C	201	[MPa]
6.8	Fatigue limit - bending	σ_{oC}	260	[MPa]
6.9	Fatigue limit - torsion	τ_C	186	[MPa]
6.10	**For cyclic loading**			
6.11	Fatigue limit - tension-pres	σ_{hC}	302	[MPa]
6.12	Fatigue limit - bending	σ_{ohC}	390	[MPa]
6.13	Fatigue limit - torsion	τ_{hC}	213	[MPa]
6.14	Specific mass	Ro	7850,0	[kg/m^3]
6.15	Modulus of elasticity in ten	E	210000	[MPa]
6.16	Modulus of elasticity in she	G	80000	[MPa]

6.17	Dead load	Yes
6.18	Max. displayed coefficient of safety	50
6.19	Stress ratio factor α_0	1,15 ☑
6.20	**Coefficient of maximum loading**	
6.21	Bending	1,00
6.22	Radial load	1,00
6.23	Torsion	1,00
6.24	Tension/Compression	1,00
6.25	**Loading conditions**	
6.26	Loading from bending moment	B..Repeated
6.27	Loading from radial force	B..Repeated
6.28	Load from torsional moment	C..Reversed
6.29	Loading from tension/pressure force	A..Static
6.30	**Dynamic strength check**	
6.31	Impact from shaft surface	Yes
6.32	Impact from shaft size	Yes
6.33	Impact from stress concentration (nc	Yes

Figure 161 - MITCalc – Calculation of the Driving Shaft from the Extraction System – Material and type of loading.

4) According to the loads and conditions described so far, determination of the following results (Figure 162):
   - Determination of reaction forces on the supports;

- Determination of maximum stresses and deflections on the shaft;
- Graphical representation of the deflection distribution and equivalent stress along the shaft length.

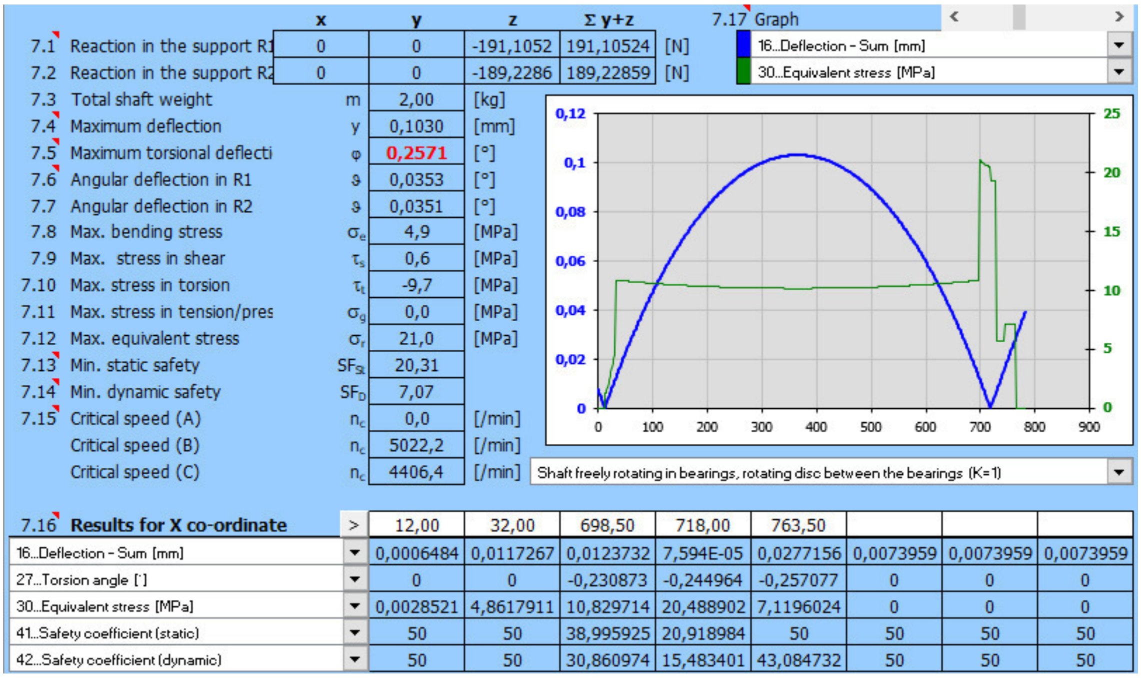


Figure 162 - MITCalc – Calculation of the Driving Shaft from the Extraction System – Final results.

The main results of the calculation of the driving shaft are shown in Table 56.

Table 56 - Results of the calculation of the driving shaft from the extraction system.

Variable	Result
Chain Tangential Pulling Force (F_{tang})	200 N
Reaction in the First Support (R1)	191 N
Reaction in the Second Support (R2)	189 N
Maximum Deflection	0,1 mm
Maximum Torsional Deflection	0,26°
Maximum Equivalent Stress	21 MPa
Minimum Static Safety Factor	20,3
Minimum Dynamic Safety Factor	7,1
Maximum Critical Speed	4406 rpm

The results of the driving shaft calculation are very acceptable. The maximum deflection is approximately 0,1 mm in a portion of the shaft length where no functional component (such as sprockets or bearings) is mounted and the torsional deflection is close to 0,25°, which is the maximum recommended value for such applications.

For the equivalent maximum stress, the static and dynamic safety factors above 2 ensure that the shaft material withstands the most severe load conditions.

Regarding the critical speed of the shaft, this value is well above the shaft rotation speed of 113 rpm.

Finally, note that the values of the reaction forces in the supports are very important for the calculation of the bearings that support the shaft.

Calculation of the Driving Shaft Bearings

The bearings that support the driving shaft were calculated to determine their durability and load safety factors in relation to the load conditions to which they are subjected. As they support the driving shaft, they react to the radial loads to which it is subjected, in other words, the loads falling on the bearings are equal to the reaction forces required to balance the shaft radially, allowing it to rotate freely and without oscillations. As such, the parameters required to calculate the bearings are indicated in Table 57. The calculation was made for the largest of the loads between the two bearings (worst scenario), in other words, the largest of the reaction forces determined in the calculation of the driving shaft.

Table 57 - Parameters used to calculate the housing units.

Parameter	**Value**
Selected Bearing	Self-aligning ball bearing 2204-2RS-TVH
Shaft Rotation Speed (equal to the Gearmotor Output Speed (n_a))	113 rpm
Radial Load on the Bearing (equal to Reaction in the First Support (R1))	191 N

The calculation was made using the bearings calculation module from Schaeffler website. The steps taken to perform the calculation are indicated below [133]:

1) Determination of the recommended lubricant to be used according to the speed of rotation (Figure 163);

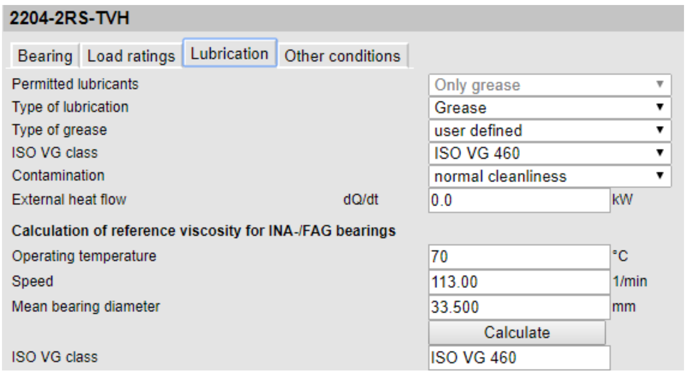
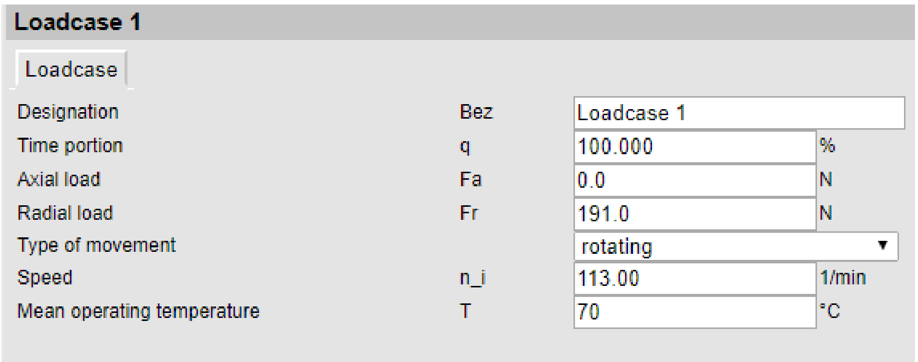


Figure 163 - Schaeffler website - Calculation of the driving shaft bearings from the extraction system – Calculation of the recommended lubricant.

2) Indication of the loads on the bearing (Figure 164), which in this case are only radial loads;


Loadcase 1

Loadcase

Designation	Bez	Loadcase 1	
Time portion	q	100.000	%
Axial load	Fa	0.0	N
Radial load	Fr	191.0	N
Type of movement		rotating	
Speed	n_i	113.00	1/min
Mean operating temperature	T	70	°C

Figure 164 - Schaeffler website - Calculation of the driving shaft bearings from the extraction system – Loads on the bearing.

3) According to the load conditions, determination of the rating life and the safety factors for the bearing (Figure 165).

Description	Name	Value	Unit
Total rating life in hours (nominal)	Lh10	>1000000	h
Modified rating life in hours	Lh_nm	>1000000	h
Static load safety factor	S0_min	13.613	

Figure 165 - Schaeffler website - Calculation of the driving shaft bearings from the extraction system – Rating life and safety factors for the bearing.

The main results of the calculation of the bearing are shown in Table 58.

Table 58 - Results of the calculation of the housing unit.

Variable	Result
Total Rating Life	>1000000 h
Static Load Safety Factor	13,6

According to the results, the bearing is oversized because it has an infinite total rating life and a static load safety factor above 13 for the load conditions described before. As such, the bearing will not have problems during operation, but it would be possible to have chosen another one with less load capacity.

Calculation of the Driving Chains

The driving chains were calculated to determine their durability and load safety factors in relation to the load conditions to which they are subjected. As they are used to convert the rotation movement of the driving sprockets in linear movement of the racks, they are subjected to the torques from the sprockets that drive the extraction system (Figure 166). Those torques create a pulling force on the chains, so it is necessary to verify if the chains can withstand that force without breaking or stretching too early.

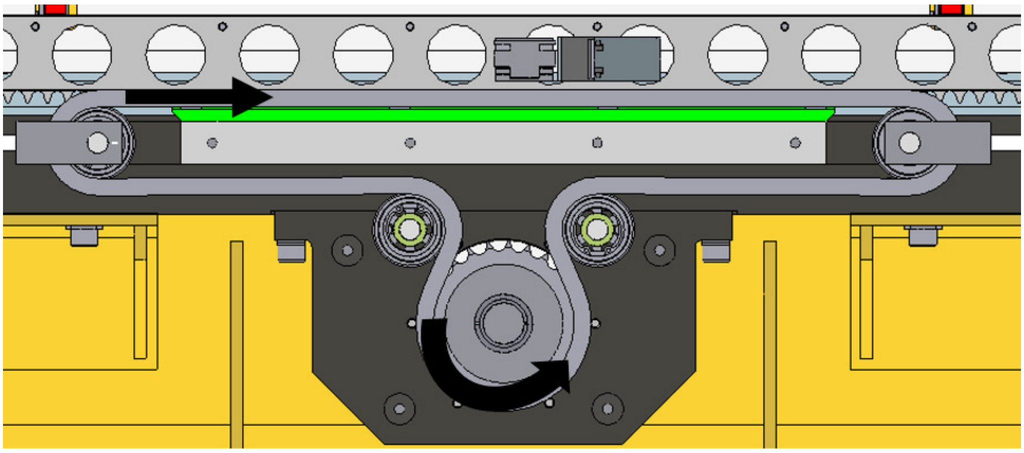


Figure 166 - Torque from the driving sprocket converted in a linear drive force to move the rack and drive the extraction system (opposite directions to visualize the creation of the tangential pulling force in the chain).

The parameters required to perform the calculation are indicated in Table 59. Note that the calculation was made using the maximum torsional torque on the driving sprockets to consider the worst scenario for the driving chain.

Table 59 - Parameters used to calculate the driving chain from the extraction system.

Parameter	Value
Selected Roller Chain	DIN 8187 06B-1 Maintenance Free (equivalent to Iwis G67 ML)
Pitch Diameter of the Driving Sprocket	76 mm
Number of Teeth of the Driving Sprocket	25
Outer Diameter of the Deviation Roller	36 mm
Maximum Torsional Torque per Driving Sprockets (half the Maximum Gearmotor Output Torque during operation ($M_{stat+dyn}$))	7,6 N·m
Chain Tangential Pulling Force (F_{tang})	200 N

Parameter	Value
Driving Sprocket Rotation Speed (equal to the Gearmotor Output Speed (n_a))	113,1 rpm
Iwis Lubrication Factor (f5)	1
Iwis Shock Factor (Y)	2

The chain was calculated using Iwis Chain Engineering software. The steps given in the software to reach the result are indicated below [130]:

1) Characterization of the chain loop according to the chain type, and the dimensions and positioning of the sprockets. The software does not allow a calculation with rack and deviation rollers. As such, the deviation rollers have been replaced by driven sprockets with a similar outside diameter, and the rack has been replaced by the resistive force that opposes the movement of the chain creating the tangential pulling force on the chain that is essential to perform the calculation; Indication of the operating conditions, in other words, indication of the chain tangential pulling force, rotation speed of the driving sprocket, lubrication factor and shock factor (Figure 167);

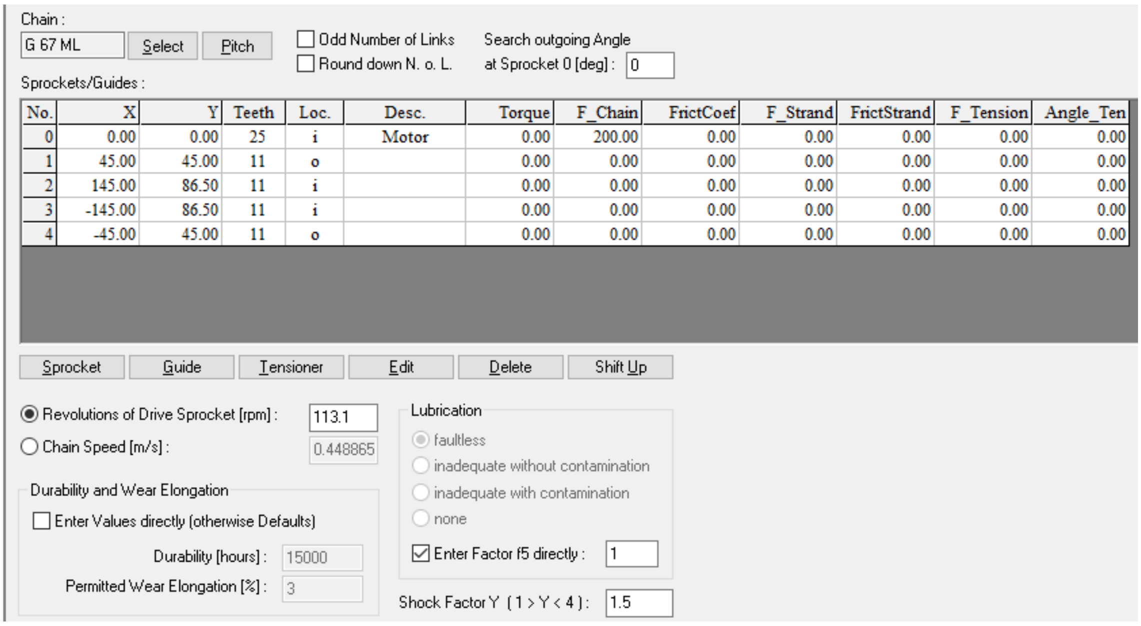


Figure 167 – Iwis Chain Engineering - Calculation of the Driving Chain for the Extraction System – Characterization of the chain loop and indication of the operating conditions.

2) Graphical representation of the chain loop (Figure 168);

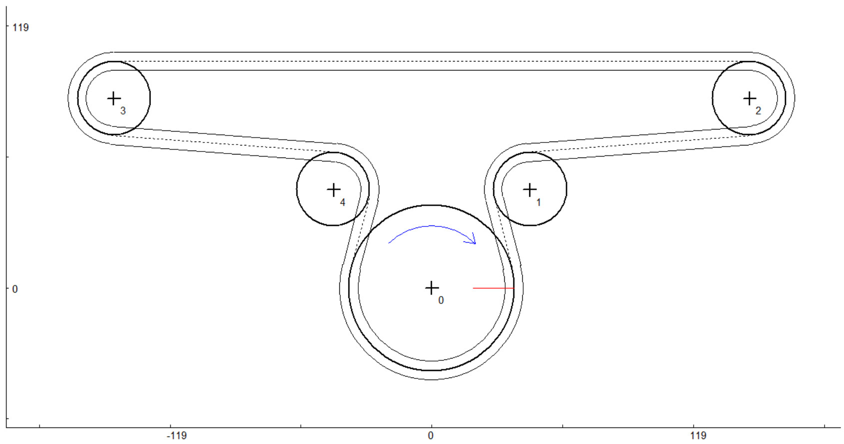


Figure 168 – Iwis Chain Engineering - Calculation of the Driving Chain for the Extraction System – Graphical representation of the chain loop.

3) According to the load conditions, determination of the rating life and the safety factors for the driving chain (Figure 169).

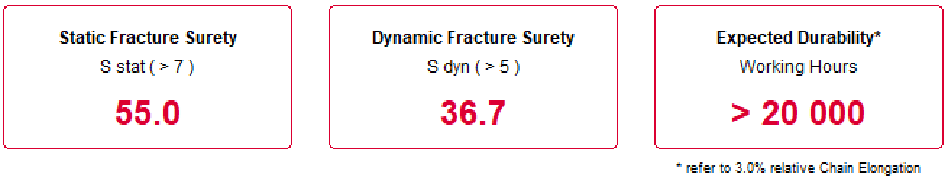


Figure 169 - Iwis Chain Engineering - Calculation of the Driving Chain for the Extraction System – Rating life and safety factors for the driving chain.

The main results of the calculation of the driving chain are shown in Table 60.

Table 60 - Results of the calculation of the driving chain from the extraction system.

Variable	Result
Static Fracture Surety	55,0
Dynamic Fracture Surety	36,7
Expected Durability	> 20000

According to the results, the chain is oversized because it has a nominal service life above 20000 h. In addition, the static and dynamic safety factors are well above the recommended minimum values, which ensures that the chain is far from being broke by the loads it is subjected to. As such, the chain will have no problems during the operation, but it would be possible to choose a smaller one.

Calculation of the Locking Assembly for the Driving Sprockets

The locking assemblies used to transmit the torque between the driving shaft and the driving sprockets had to be calculated to verify that the chosen models can transmit the torque and to ensure that the driving sprockets are able to withstand the pressure that is exerted by the locking assemblies on the contact surface.

As already mentioned, the torsional torque of the gearmotor is divided equally by the two driving sprockets. As such, the locking assemblies for the driving sprockets must be capable of transmitting half of the maximum gearmotor output torque. The calculation of the locking assembly was made according to the procedures, equations and values indicated in the Tollok catalog [131].

The locking assembly for each of the driving sprockets is represented in Figure 170 and the parameters required to perform the verification calculations are indicated in Table 61.

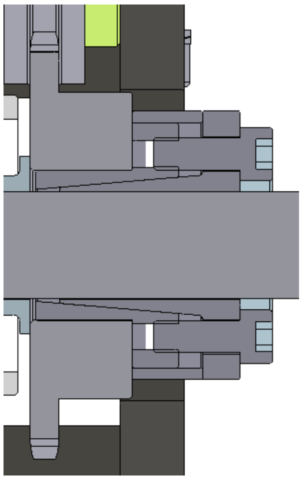


Figure 170 - Locking assembly for the driving sprockets.

Table 61 – Parameters used to calculate the locking assembly for the driving sprockets from the extraction system.

Parameter	Value
Selected Locking Assembly	(2x) TLK110 20x58
Locking Assembly Internal Diameter (d_{TLK})	20 mm
Locking Assembly External Diameter (D_{TLK})	28 mm
Locking Assembly Transmissible Torque (Mt_{TLK})	220 N·m
Hub Material (Driving Sprocket Material)	Steel EN C45
Hub Diameter (Driving Sprocket Minimum Outer Diameter) (DM)	57 mm
Hub Width (Driving Sprocket Width) (B)	19 mm
Application Type Factor (C)	1
Tollok Coefficient K	1,41

Parameter	Value
Maximum Torsional Torque per Driving Sprocket (half the Maximum Gearmotor Output Torque ($M_{stat+dyn}$))	7,6 N·m

The torque transmissible by the locking assembly TLK110 is a catalog value so it did not have to be calculated. It was necessary to check the contact pressure between the driving sprocket bore and the locking assembly. As such, Equation 38 and Equation 39 were used to calculate the minimum diameter and width of the hub where the locking assembly is inserted.

The calculations results are showed in Table 62.

Table 62 - Results of the calculation of the locking assembly for the driving sprockets from the extraction system.

Variable	Result
Maximum Transmissible Torque of the Locking Assembly (Mt_{TLK})	220 N·m
Minimum Hub Diameter (DM)	39,5 mm
Minimum Hub Width (B)	18 mm

By analyzing the values in Table 62, it is concluded that the selected locking assembly can transmit the torque between the driving shaft and the driving sprockets, since the maximum transmissible torque is well above the application torque of 7,6 N·m. In addition, the minimum dimensions of hub diameter and hub width are guaranteed by the driving sprocket dimensions, ensuring that the sprocket bore withstands the pressures caused by the contact with the locking assembly.

Calculation of the DC Drive

As already mentioned, the DC drives of the extraction system are used to perform the rotary motion of the retractable fingers. As such, the retractable finger when rotating around the axis of the DC drive works like the drive of an eccentric because of its geometry, causing the greater load on the DC drive whenever it is in the lower position and it is necessary to put it in the position higher (Figure 171). As such, it was necessary to determine the loads on the DC drive to choose the most suitable one.

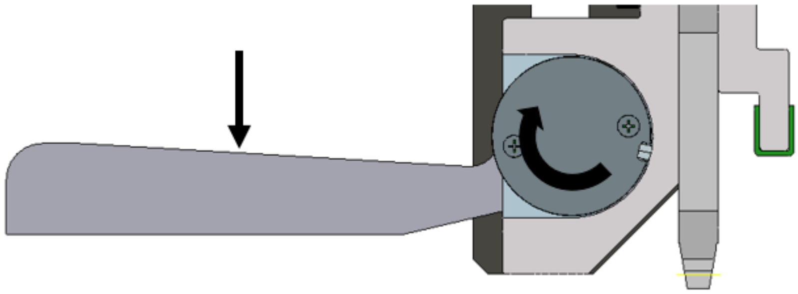


Figure 171 - Representation of the retractable finger drive as the actuation of an eccentric.

The parameters used to determine the loads on the DC drive are represented in Table 63.

Table 63 – Parameters used to calculate the loads on the DC drive for the retractable finger.

Parameter	Value
Total Stroke of the Retractable Finger ($\Delta\varphi_{total}$)	π/2 rad
Retractable Finger Eccentric Distance (e)	0,0225 m
Time for Total Stroke of the Retractable Finger ($t_{\varphi total}$)	1 s
Acceleration Time (t_a)	0,3 s
Deceleration Time	0,3 s
Stopped Time in each Cycle ($t_{stopped}$)	2 s
Retractable Finger Mass (m_{finger})	0,12 kg
Gravitational Acceleration (g)	9,81 m/s^2
Load Efficiency (η_L)	0,9
Maximum DC Drive Diameter for selection	24 mm

Figure 172 represents the positioning of the center of mass of the retractable finger with respect to its axis of rotation, in other words, it represents the positioning of the eccentric load relative to the axis of the DC drive, which is the essential dimension for performing the calculations.

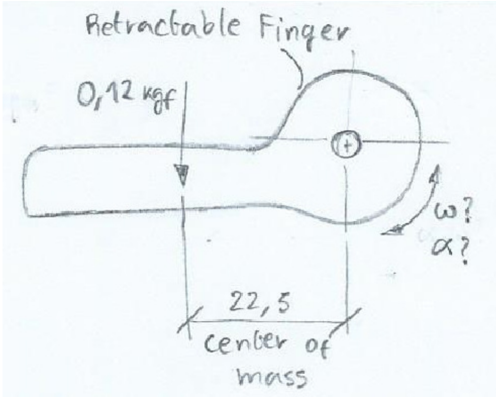


Figure 172 – Positioning of the center of mass of the retractable finger with respect to its axis of rotation.

The first step in determining the DC drive loads was the graphical representation of its operating cycle (Figure 173), in other words, from the time it accelerates to the point where it remains stopped to start a new cycle. Note that one cycle corresponds to the four sections shown in the chart: acceleration (section 1), constant speed (section 2), deceleration (section 3) and stop (section 4).

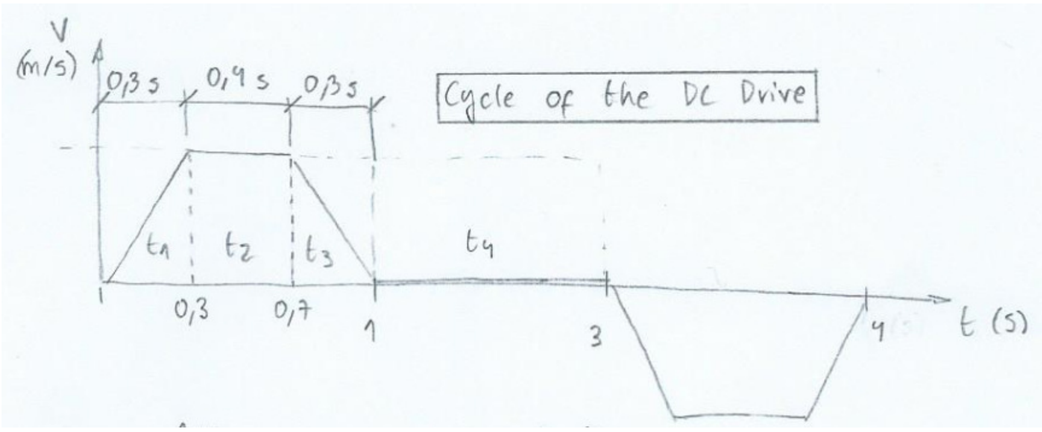


Figure 173 - Graphical representation of the operating cycle of the DC drive.

This calculation was based on the equations and procedures of the "Formulae Handbook" from Maxon Motor, a manufacturer of DC drives [134].

Equation 41, Equation 42 and Equation 43 were used to determine, respectively, the maximum angular velocity, the maximum rotation speed and the angular acceleration, which are essential values for the DC drive selection.

$$\omega_{max} = \frac{\Delta\varphi_2}{t_2}$$

Equation 41

Where:

ω_{max} - Maximum angular speed (rad/s);

$\Delta\varphi_2$ - Stroke of the retractable finger in section 2 (rad);

t_2 – Cycle time in section 2 (s).

$$n_{max} = \frac{30}{\pi} \cdot \omega_{max}$$

Equation 42

Where:

n_{max} – Maximum rotation speed (rpm).

$$\alpha = \frac{\Delta\varphi_2}{\mathrm{t}_a}$$

Equation 43

Where:

α - Angular acceleration (rad/s^2).

The required torque on the DC drive was determined for each of the first three sections of the operating cycle shown in Figure 173 because the values are different for each section.

In section 1, Equation 44 and Equation 45 were used to determine the linear acceleration of the application and the torsional torque required to move the retractable finger (static and dynamic torque).

$$a_{t1} = \alpha \cdot e$$

Equation 44

Where:

a_{t1} – Linear acceleration in section 1 (m/s^2).

$$M_{t1} = M_{stat} + M_{dyn} \Leftrightarrow M_{t1} = m_{finger} \cdot g \cdot \frac{1}{\eta_L} \cdot e + m_{finger} \cdot a_{t1} \cdot \frac{1}{\eta_L} \cdot e$$

Equation 45

Where:

M_{t1} – Torsional torque in section 1 (N·m).

In section 2, the speed is constant, so the acceleration is zero and, consequently, there is no dynamic torque. Equation 46 was used to determine the torsional torque required to move the retractable finger (static torque).

$$M_{t2} = M_{stat} \Leftrightarrow M_{t2} = m_{finger} \cdot g \cdot \frac{1}{\eta_L} \cdot e$$

Equation 46

Where:

M_{t2} – Torsional torque in section 2 (N·m).

In section 3, the linear acceleration is equal to the acceleration in section 1 because the acceleration time is equal to the deceleration time. So, only the Equation 47 was used to determine the torsional torque required to move the retractable finger (static and dynamic torque).

$$M_{t3} = M_{stat} - M_{dyn} \Leftrightarrow M_{t3} = m_{finger} \cdot g \cdot \frac{1}{\eta_L} \cdot e - m_{finger} \cdot a_{t3} \cdot \eta_L \cdot e$$

Equation 47

Where:

M_{t3} – Torsional torque in section 3 (N·m);

a_{t3} – Linear acceleration in section 3 (m/s^2).

The torsional torques of the three sections were calculated using the maximum cam distance as reference of the force acting arm. It was decided to perform the calculations in this way so as not to make them too complex and increase the margin of safety in the DC drive selection.

The DC drive was chosen according to the root mean square torque required for the application, so this variable was calculated through the Equation 48.

$$M_{RMS} = \sqrt{\frac{M_{t1}^2 \cdot t_1 + M_{t2}^2 \cdot t_2 + M_{t3}^2 \cdot t_3}{t_{cycle}}}$$

Equation 48

Where:

M_{RMS} – Root mean square torque (N·m);

t_1 – Cycle time in section 1 (s);

t_3 – Cycle time in section 3 (s);

t_{cycle} – Total cycle time (s).

The main results of the calculations of the DC drive loads for selection of a suitable model are represented in Table 64.

Table 64 - Results of the calculation of the DC drive loads for selection of the model to use.

Variable	Result
Maximum Rotation Speed (n_{max})	15 rpm
RMS Torque (M_{RMS})	0,017 N·m

The DC drive was selected through the selection program from Maxon Motor website. The steps given in the program are indicated below [135]:

1) Indication of the main parameters of the application (Figure 174): maximum rotation speed, RMS torque and maximum drive diameter;

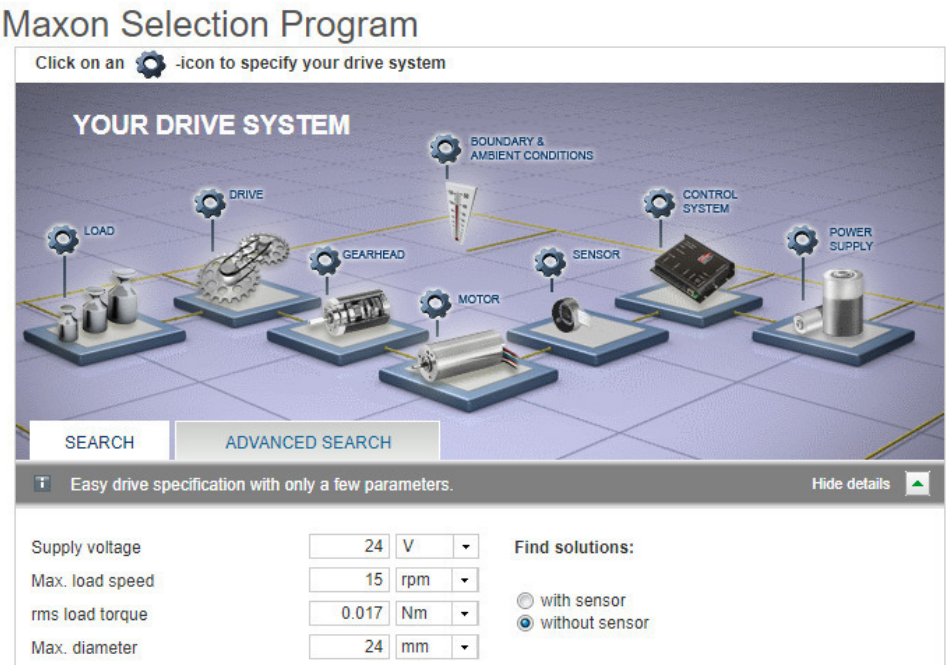


Figure 174 – Maxon Selection Program - Calculation of the DC Drive – Indication of the main parameters of the application.

2) Selection of one DC Drive among the recommended options (Figure 175).

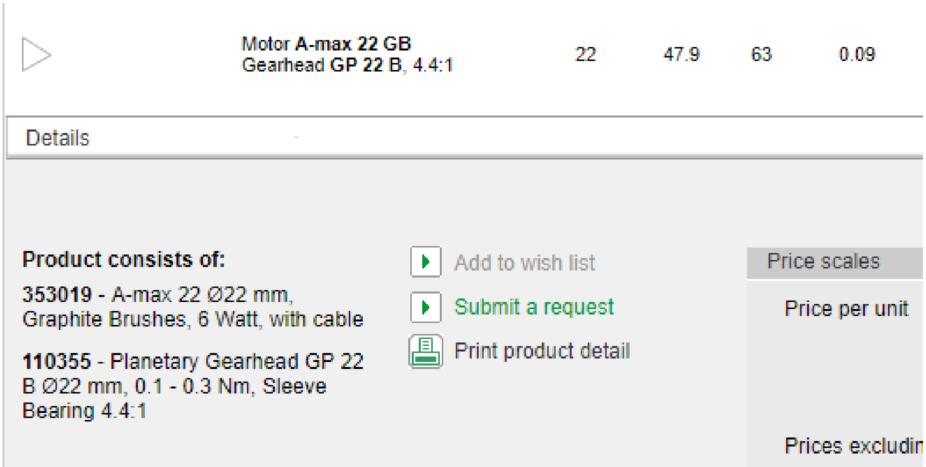


Figure 175 – Maxon Selection Program - Calculation of the DC Drive – Selection of the DC drive.

As a conclusion, the selected DC drive that fits inside the movable extraction arm and can actuate the retractable finger was the Maxon GP 22 B + A-MAX 22 GB.

The DC drive is a direct choice as a result of the calculation, requiring no checking. As such, the chosen DC drive is indicated in Table 65.

Table 65 – Selected DC drive.

Variable	**Result**
Selected DC Drive	Maxon GP 22 B + A-MAX 22 GB

Calculation of the Retractable Finger (using FEA)

The retractable fingers on each of the movable extraction arms are used to push the housings into or out of the shuttle vehicle, so the driving force caused by the servo gearmotor is divided by each of the retractable fingers, creating two reaction forces in the contact surfaces with the carton being moved (Figure 176). As such, it was necessary to perform a calculation to verify that the retractable fingers are able to withstand this reaction force without deforming plastically.

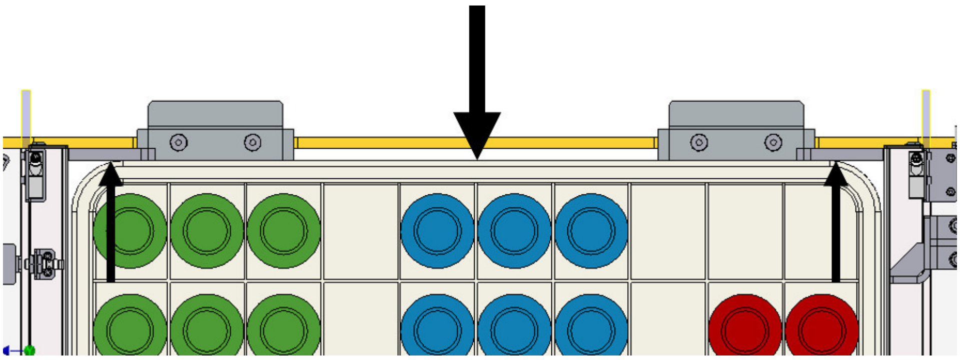


Figure 176 - Reaction forces on the retractable fingers.

The parameters used perform the calculation are indicated in Table 66. Note that the calculation was made using the maximum chain tangential pulling force to consider the worst scenario for the retractable finger.

Table 66 – Parameters used to calculate the retractable finger.

Parameter	**Value**
Actuating Force on the Retractable Finger (equal to the Chain Tangential Pulling Force (F_{tang}))	200 N
Material of the Main Structure	Steel EN S235 JR

To determine the maximum stress and displacement of the retractable finger against the load to which it is subject, an FEA simulation was performed through the Simulation module of the CAD software Autodesk® Inventor®. As such, the steps given in the software until reaching the results are indicated below:

1) In this case, pin constraints were applied in the radial directions of the retractable finger assembly holes (Figure 177), blocking the movement in the three possible directions;

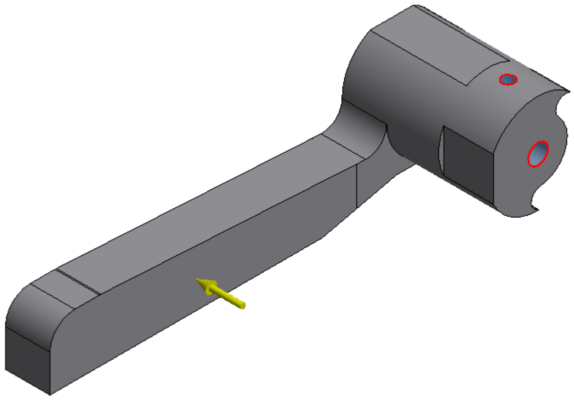


Figure 177 – FEA simulation – Calculation of the Retractable Finger – Definition of the boundary conditions.

2) Definition of the applied loads. In this case, the retractable finger is subjected to the reaction force created when pulling the box into the shuttle vehicle (). The weight of the retractable finger is already included in the simulation and is not considered an external force;

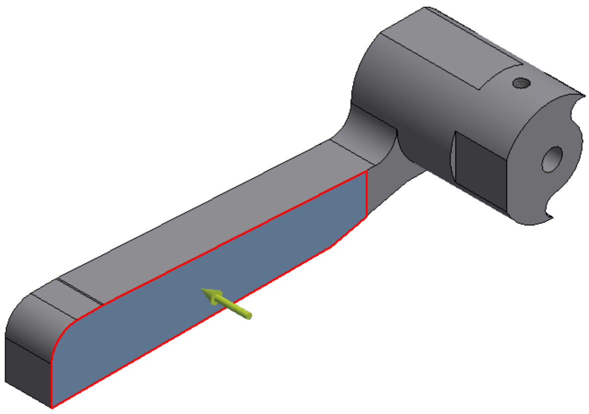


Figure 178 - FEA simulation – Calculation of the Retractable Finger – Definition of the applied loads.

3) Mesh creation. Figure 179 shows the mesh aspect on the retractable finger surface and the number of nodes and elements that characterize it;

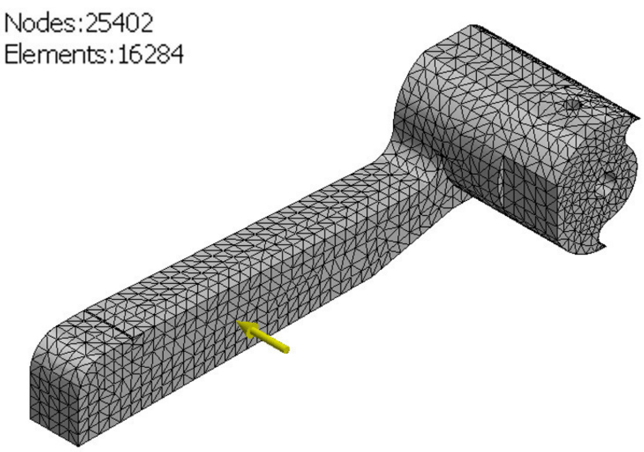


Figure 179 - FEA simulation – Calculation of the Retractable Finger – Mesh creation.

4) Obtaining the results of the simulation. Figure 180 shows the distribution of the Von Mises stresses across the surface of the analyzed part. Figure 181 shows the displacements suffered by the part.

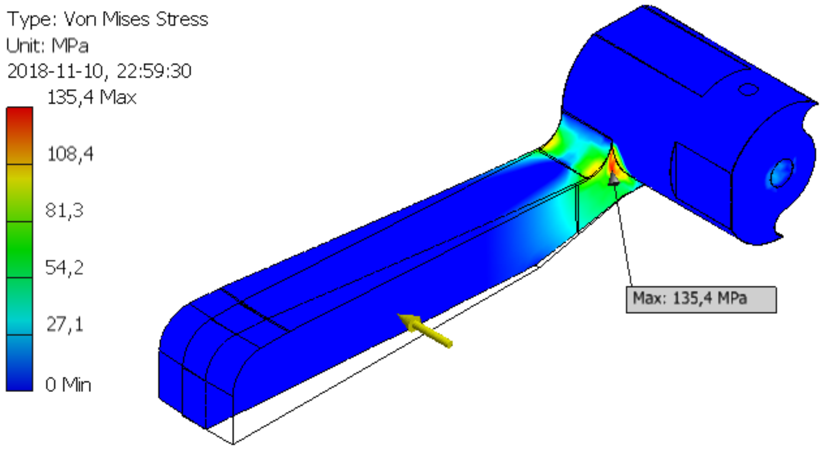


Figure 180 - FEA simulation – Calculation of the Retractable Finger – Distribution of the Von Mises stresses.

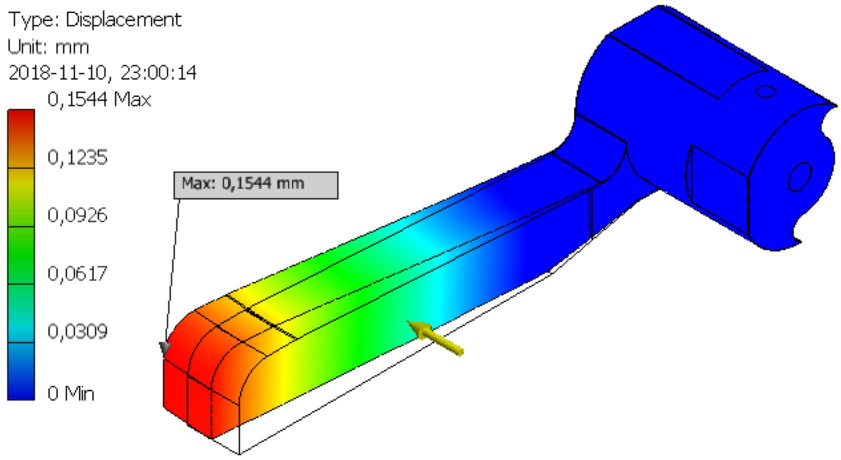


Figure 181 - FEA simulation – Calculation of the Retractable Finger – Displacements on the part.

After obtaining the results, the safety factor between the yield strength of the material and the maximum Von Mises stress was calculated by Equation 40.

All the main results of the FEA simulation are summarized in Table 67.

Table 67 - Results of the FEA simulation of the retractable finger.

Variable	Result
Maximum Von Mises Stress ($\sigma_{Von\ Mises,max}$)	135,4 MPa
Maximum Displacement	0,15 mm
Safety Factor (SF)	1,7

A safety factor of the of 1,7 ensures that there is no risk of failure of the retractable finger to the load conditions studied. In addition, the maximum displacement of the part is very close to 0 mm, ensuring that the part hardly deforms.

Calculation of the DC Drive Fixing Plate (using FEA)

As the retractable fingers are axially attached to the output shaft of the DC drive, when they must pull a box into or out of the shuttle vehicle, they are loaded from a counter-reaction force (force used in the calculation of the retractable finger). The part that ensures that the retractable finger and the DC drive do not move axially is the DC drive fixing plate because it is blocked inside the movable stringer, suffering from that same reaction force through the DC Drive (Figure 182). It was then necessary to study the behavior of the plate when subjected to this type of load, calculating the maximum stress and displacement.

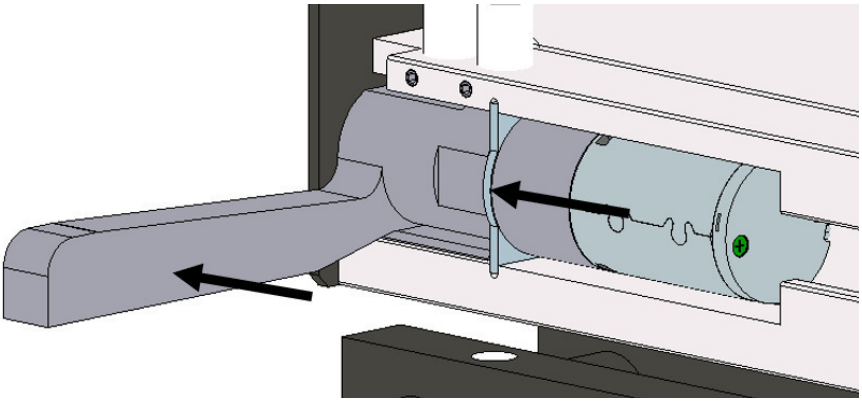


Figure 182 – Actuating force on the DC drive fixing plate.

The parameters used to perform the calculation are indicated in Table 68.

Table 68 – Parameters used to calculate the DC drive fixing plate.

Parameter	Value
Actuating Force on the DC Drive Fixing Plate (equal to the Actuating Force on the Retractable Finger)	200 N
Material of the DC Drive Fixing Plate	Steel EN S235 JR

To determine the maximum stress and displacement of the DC drive fixing plate against the load to which it is subject, an FEA simulation was performed through the Simulation module of the CAD software Autodesk® Inventor®. As such, the steps given in the software until reaching the results are indicated below:

1) Definition of the boundary conditions. In this case, frictionless constraints were applied in the contact surfaces of the fixing plate with the movable stringer preventing the motion in the direction normal to that faces;

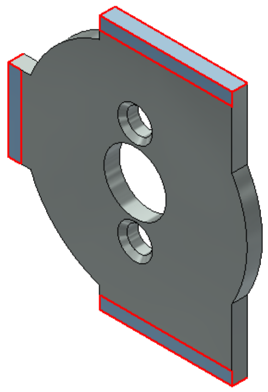


Figure 183 – FEA simulation – Calculation of the DC Drive Fixing Plate – Definition of the boundary conditions.

2) Definition of the applied loads. In this case, the fixing plate is loaded by the DC drive with a force equal to the actuating force on the retractable finger when pulling a box into the shuttle vehicle (Figure 184). The weight of the fixing plate is already included in the simulation and is not considered an external force;

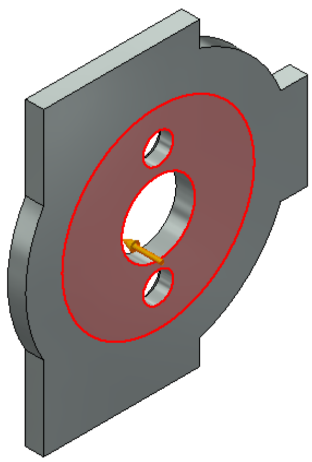


Figure 184 - FEA simulation – Calculation of the DC Drive Fixing Plate – Definition of the applied loads.

3) Mesh creation. Figure 185 shows the mesh aspect on the DC drive fixing plate surface and the number of nodes and elements that characterize it;

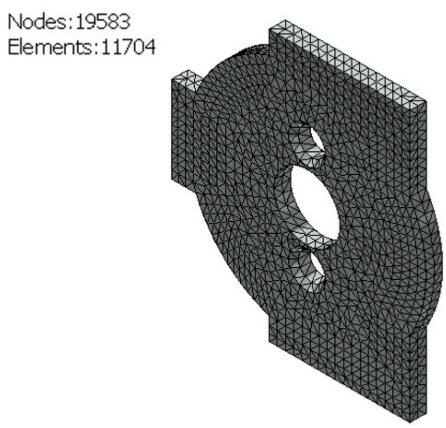


Figure 185 - FEA simulation – Calculation of the DC Drive Fixing Plate – Mesh creation.

4) Obtaining the results of the simulation. Figure 186 shows the distribution of the Von Mises stresses across the surface of the analyzed part. Figure 187 shows the displacements suffered by the part.

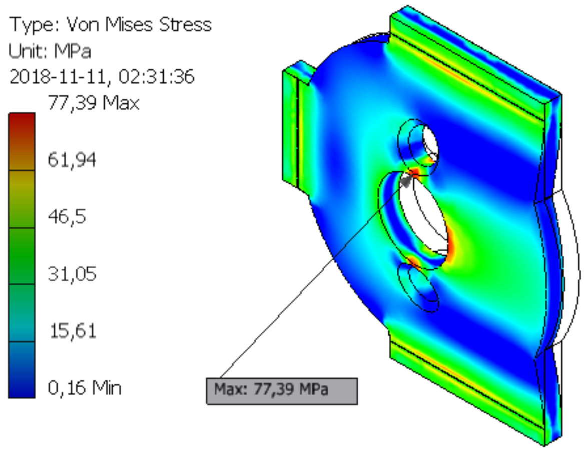


Figure 186 - FEA simulation – Calculation of the DC Drive Fixing Plate – Distribution of the Von Mises stresses.

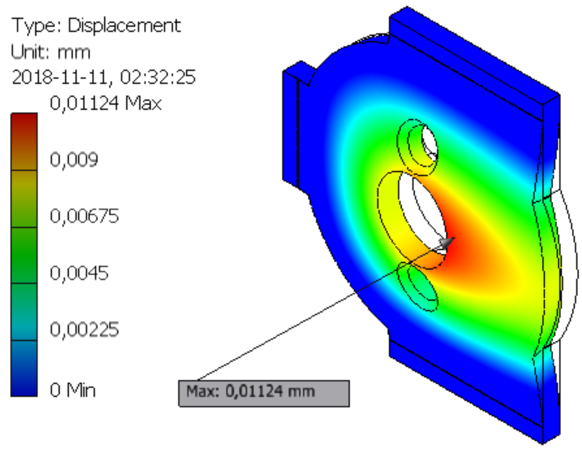


Figure 187 - FEA simulation – Calculation of the DC Drive Fixing Plate – Displacements on the part.

After obtaining the results, the safety factor between the yield strength of the material and the maximum Von Mises stress was calculated by Equation 40.

All the main results of the FEA simulation are summarized in Table 69.

Table 69 - Results of the FEA simulation of the DC drive fixing plate.

Variable	Result
Maximum Von Mises Stress ($\sigma_{Von\ Mises,max}$)	77,4 MPa
Maximum Displacement	0,01 mm
Safety Factor (SF)	3,0

A safety factor of the of 3,0 ensures that there is no risk of failure of the DC drive fixing plate to the load conditions studied. In addition, the maximum displacement of the part is very close to 0 mm, ensuring that the part hardly deforms.

Calculation of the Stringers (using FEA)

The stringers that compose each of the extraction arms are subjected to the stresses caused by the activation of the rack that causes the movable stringer to slide over the fixed stringer. As such, it was necessary to study the behavior of the two stringers together when subjected to such efforts.

Basically, the movable stringer is driven through the rack, sliding on the fixed stringer, and the part that tries to prevent its movement, creating an opposite reaction force, is the DC drive fixing plate, as can be perceived by Figure 188.

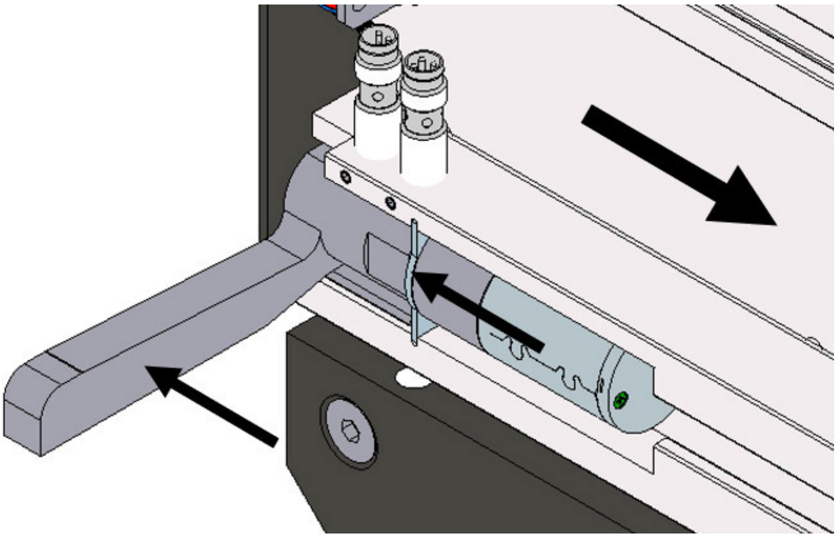


Figure 188 - Actuating forces on the movable stringer.

The parameters used to calculate the stringers are given in Table 70. The weights were calculated by multiplying the masses of the respective components by the gravitational acceleration.

Table 70 – Parameters used to calculate the stringers.

Parameter	Value
Actuating Force on the Retractable Finger (equal to the Chain Tangential Pulling Force (F_{tang}))	200 N
Movable Extraction Arm Weight	80 N
Material of the Stringers	Aluminum 6060

To determine the maximum stress and displacement of the stringers against the loads to which they are subject, an FEA simulation was performed through the Simulation module of the CAD software Autodesk® Inventor®. As such, the steps that followed to the results are indicated below:

1) This is a model composed of more than one part, the first step was the indication of the types of contact between the parts that make up the model to be simulated. However, there is no bonded contacts between the two stringers because they are not fixed to each other. The movable stringer is only guided by the fixed stringer when moving longitudinally;
2) Definition of the boundary conditions (Figure 189). For the fixed stringer, a fixed constraint was applied on the clamping faces of the hammer nuts. For the movable stringer, a frictionless constraint was applied in the contact surface of the DC drive fixing plate with the movable stringer preventing the motion in the direction normal to that face;

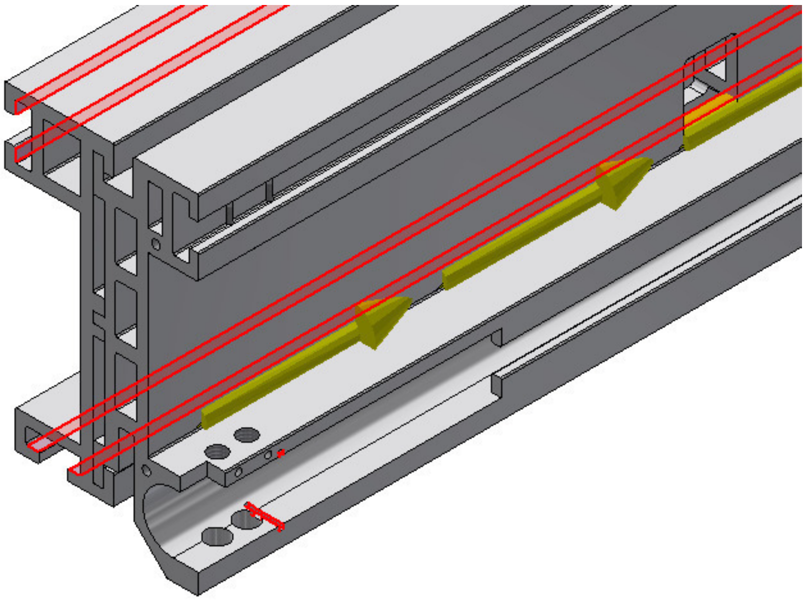


Figure 189 – FEA simulation – Calculation of the Stringers – Definition of the boundary conditions.

3) Definition of the applied loads. In this case, the movable stringer is subjected to the weight of the movable extraction arm on the top face, and to the drive force caused by the connection with the driving rack (Figure 190). The weight of the stringers is already included in the simulation and is not considered an external force;

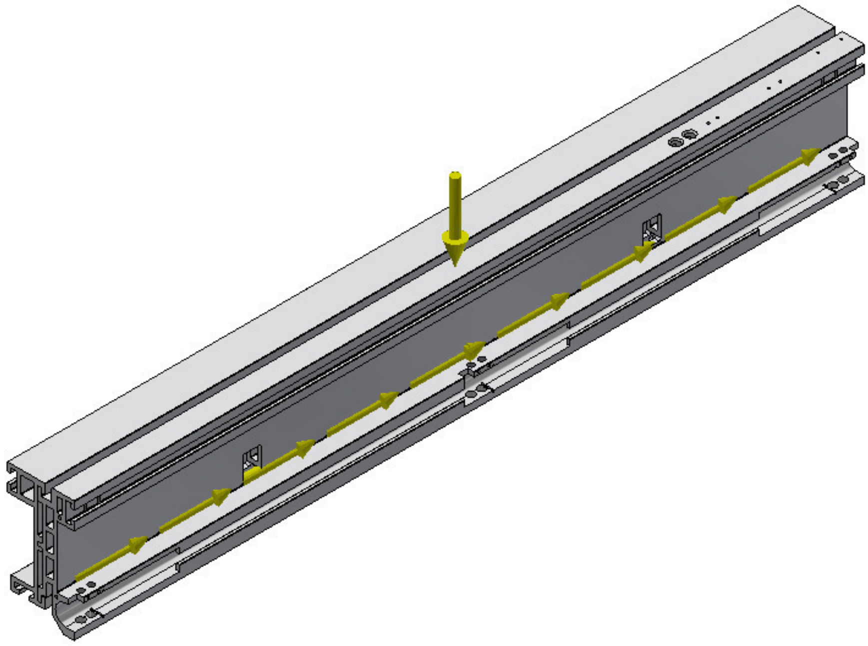


Figure 190 - FEA simulation – Calculation of the Stringers – Definition of the applied loads.

4) Mesh creation. Figure 191 shows the mesh aspect on the main structure surface and the number of nodes and elements that characterize it;

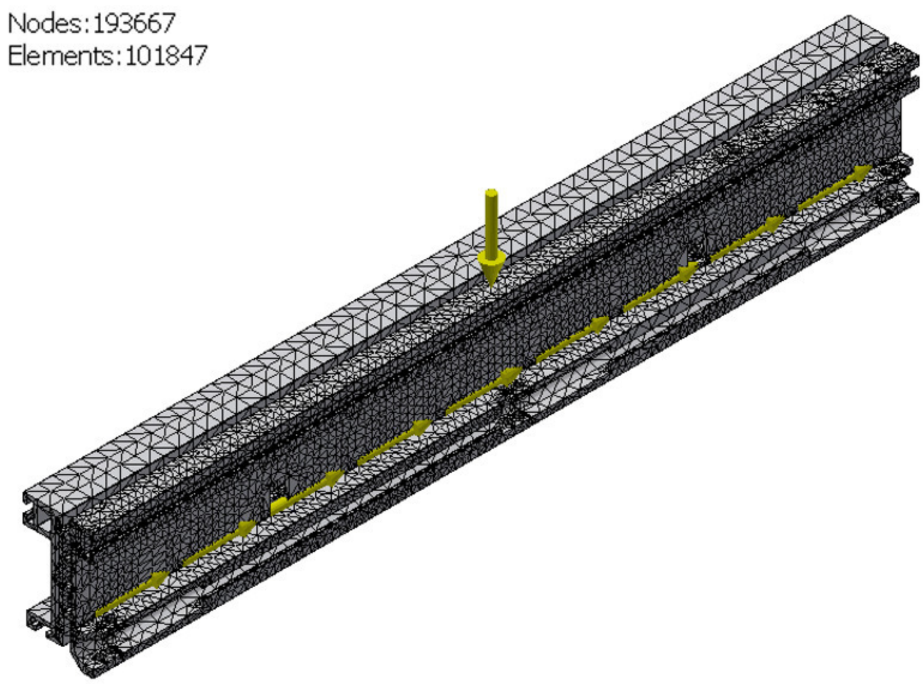


Figure 191 - FEA simulation – Calculation of the Stringers – Mesh creation.

5) Obtaining the results of the simulation. Figure 192 shows the distribution of the Von Mises stresses across the surface of the analyzed part. Figure 193 shows the displacements suffered by the part.

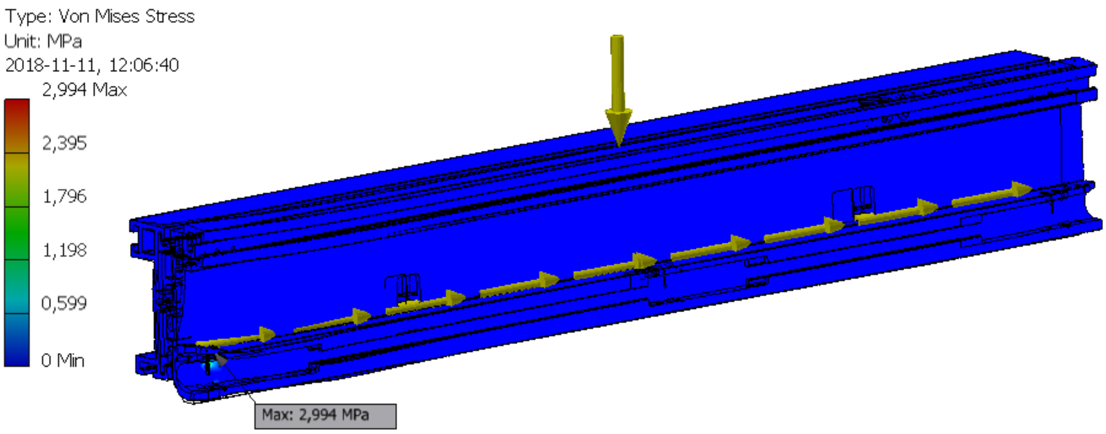


Figure 192 - FEA simulation – Calculation of the Stringers – Distribution of the Von Mises stresses.

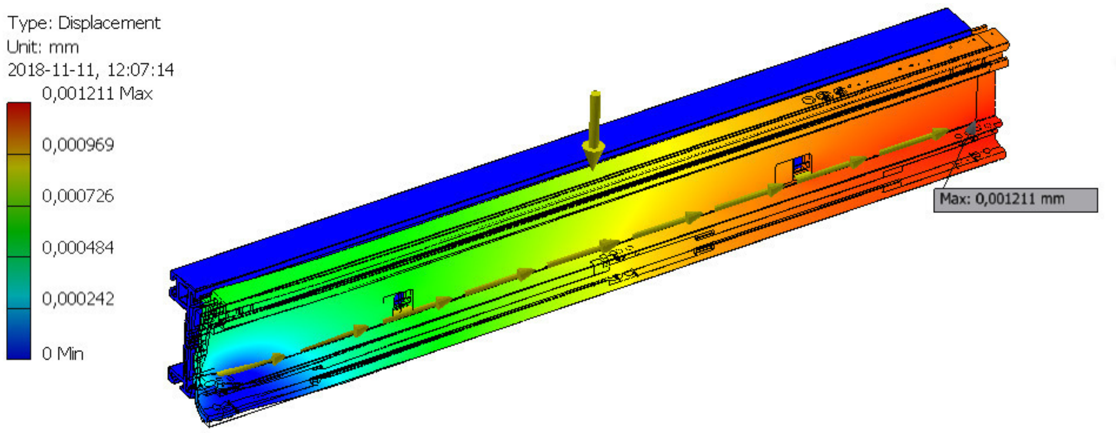


Figure 193 - FEA simulation – Calculation of the Stringers – Displacements on the part.

After obtaining the results, the safety factor between the yield strength of the material and the maximum Von Mises stress was calculated by Equation 40.

All the main results of the FEA simulation are summarized in Table 71.

Table 71 - Results of the FEA simulation of the stringers.

Variable	Result
Maximum Von Mises Stress ($\sigma_{Von\ Mises,max}$)	3,0 MPa
Maximum Displacement	0,001 mm
Safety Factor (SF)	40

A safety factor of the main structure of 40,0 ensures that there is no risk of failure of the component to the load conditions studied, however it shows that the stringers are oversized for this application. The maximum displacement of the part is very close to 0 mm, ensuring that the parts hardly deform.

Calculation of the Flange for the Servo Gearmotor (using FEA)

The flange for the servo gearmotor is one of the most important parts of the extraction system. It is responsible for making the connection between the servo gearmotor and the extraction system and housing one of the support bearings support of the driving shaft. As such, it is fundamentally subject to the output torque of the gearmotor and the radial load applied on the bearing. It was then necessary to check the flange behavior when subjected to these loading conditions.

The parameters used to calculate the flange are given in Table 72. The weights were calculated by multiplying the masses of the respective components by the gravitational acceleration.

Table 72 – Parameters used to calculate the flange for the servo gearmotor.

Parameter	Value
Maximum Servo Gearmotor Output Torque ($M_{stat+dyn}$)	15,15 N·m
Servo Gearmotor Weight	59 N
Radial Load on the Bearing	191 N
Flange Material	Aluminum 5052

To determine the maximum stress and displacement of the flange against the loads to which they are subject, an FEA simulation was performed through the Simulation module of the CAD software Autodesk® Inventor®. As such, the steps given in the software to reach the results are indicated below:

1) Since this is a model composed of more than one part, the first step was the indication of the types of contact between the parts that make up the model to be simulated. The principles that have been assumed were described before;
2) Definition of the boundary conditions (Figure 194). A fixed constraint was applied on the support plate of main structure of the extraction system, preventing the motion in the three possible directions. The rest of the parts are bonded to the support plate;

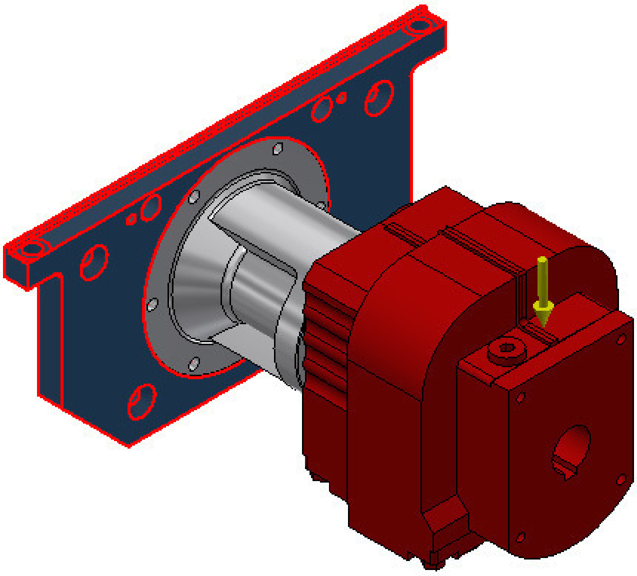


Figure 194 – FEA simulation – Calculation of the Flange for the Servo Gearmotor – Definition of the boundary conditions.

3) Definition of the applied loads (Figure 195). In this case, the flange is subjected to the weight and output torque of the servo gearmotor, and to the radial load on the bearing. The weight of the flange is already included in the simulation and is not considered an external force;

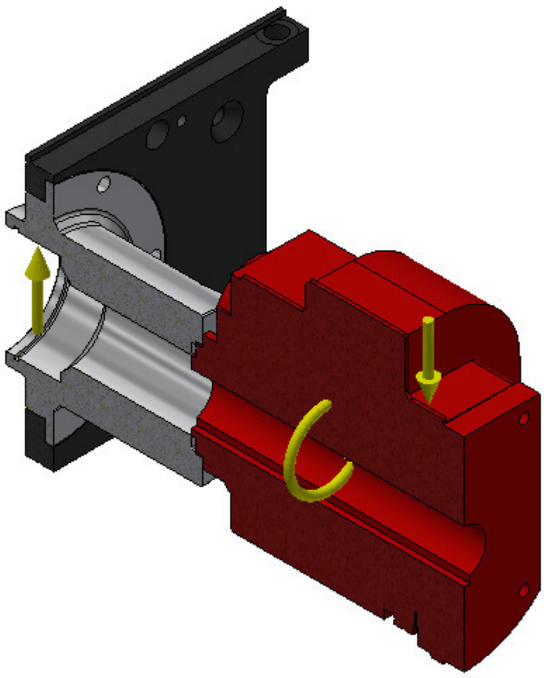


Figure 195 - FEA simulation – Calculation of the Flange for the Servo Gearmotor – Definition of the applied loads.

4) Mesh creation. shows the mesh aspect on the flange surface and the number of nodes and elements that characterize it;

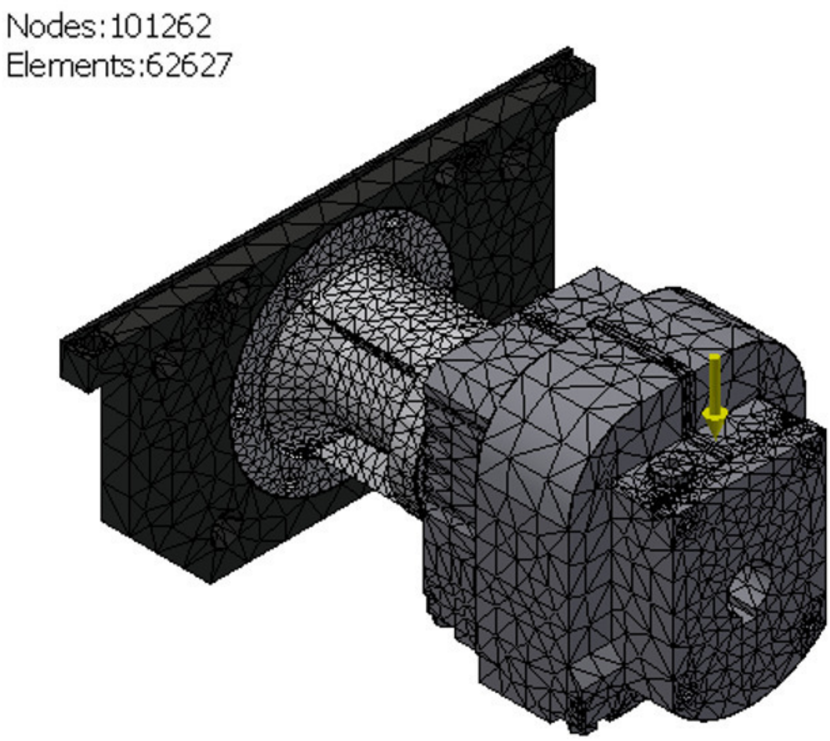


Figure 196 - FEA simulation – Calculation of the Flange for the Servo Gearmotor – Mesh creation.

5) Obtaining the results of the simulation. Figure 197 shows the distribution of the Von Mises stresses across the surface of the analyzed part. Figure 198 shows the displacements suffered by the part.

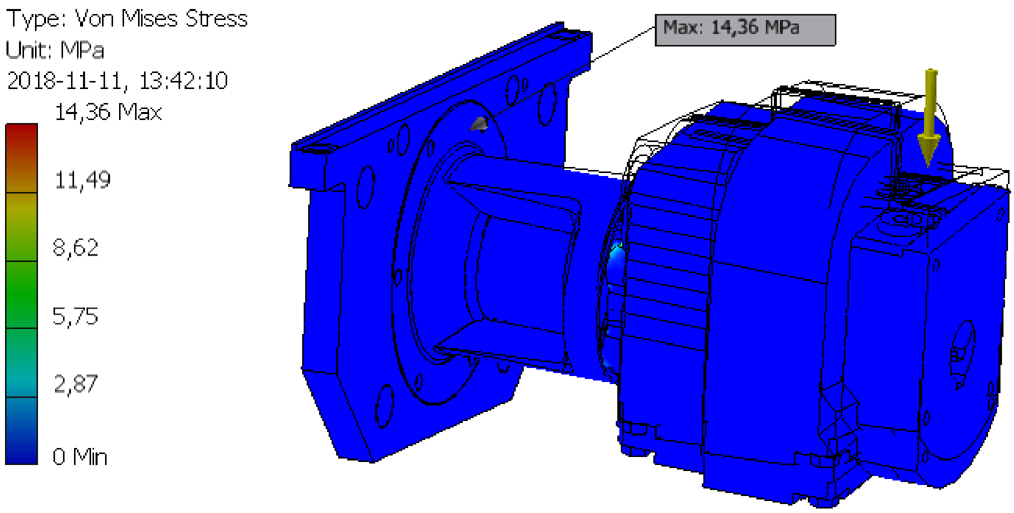


Figure 197 - FEA simulation – Calculation of the Flange for the Servo Gearmotor – Distribution of the Von Mises stresses.

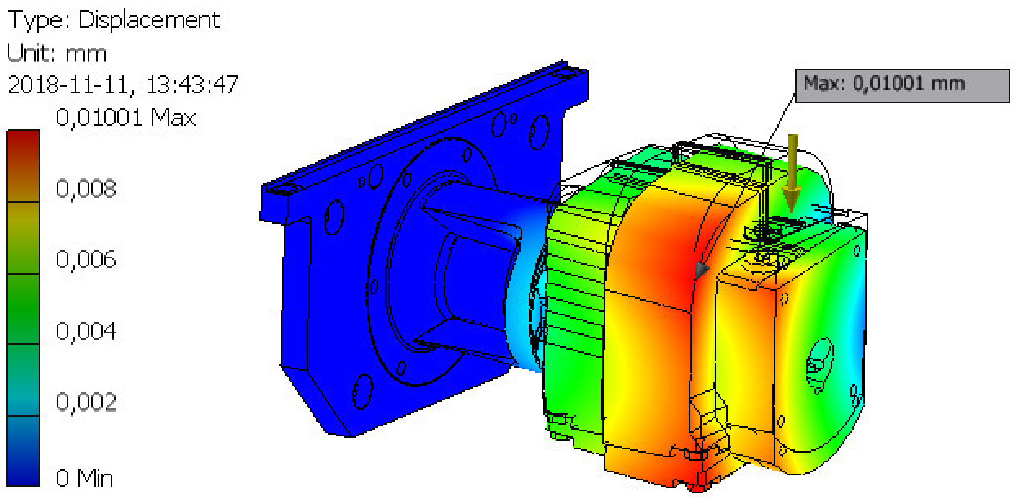


Figure 198 - FEA simulation – Calculation of the Flange for the Servo Gearmotor – Displacements on the part.

After obtaining the results, the safety factor between the yield strength of the material and the maximum Von Mises stress was calculated by Equation 40.

All the main results of the FEA simulation are summarized in Table 73.

Table 73 - Results of the FEA simulation of the flange for the servo gearmotor.

Variable	Result
Maximum Von Mises Stress ($\sigma_{Von\ Mises,max}$)	14,4 MPa
Maximum Displacement	0,01 mm
Safety Factor (SF)	13,4

A safety factor of the flange of 13,4 ensures that there is no risk of failure of the component to the load conditions studied, however it shows that the flange is oversized for this application. In addition, the maximum displacement of the part is very close to 0 mm, ensuring that the part hardly deform.

Calculation of the Main Structure (using FEA)

To study the behavior of the shuttle vehicle main structure when subjected to the weight of all subsystems and the output torque of the servo gearmotor, in other words, when the extraction system is operating, it was necessary to carry out a structural calculation.

The parameters required to calculate the main structure are given in Table 74. Note that the calculation was done using the maximum servo gearmotor output torque to increase the level of safety of the results. The weights were calculated by multiplying the masses of the respective components by the gravitational acceleration.

Table 74 – Parameters used to calculate the main structure when the extraction system is operating.

Parameter	Value
Maximum Servo Gearmotor Output Torque ($M_{stat+dyn}$)	15,15 N·m
Travelling Gearmotor Weight	270 N
Picking System Weight	216 N
Extraction System Weight	457 N
Boxes Weight	981 N
Material of the Main Structure	Steel EN S235 JR

To determine the maximum stress and displacement of the main structure against the load to which it is subject, an FEA simulation was performed through the Simulation module of the CAD software Autodesk® Inventor®. As such, the steps that followed to the results are indicated below:

1) Since this is a model composed of more than one part, the first step was the indication of the types of contact between the parts that make up the model to be simulated. The principles that have been assumed were described before;
2) Definition of the boundary conditions. In this case, pin constraints were applied in the radial directions of the travelling wheel axles and in the holes for the fixing bolts to connect the forks of the guiding wheels (Figure 199), blocking the movement of the main structure in the three possible directions;

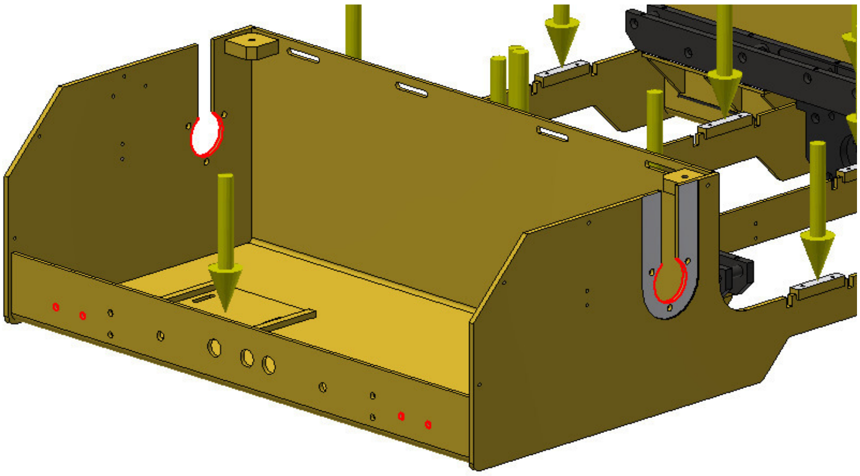


Figure 199 – FEA simulation – Calculation of the Main Structure when the Extraction System is Operating – Definition of the boundary conditions.

3) Definition of the applied loads. In this case, the main structure is subjected to the travelling gearmotor weight, to the extraction system weight, to the servo gearmotor output torque, to the picking system weight and to the boxes weight

(Figure 200). The weight of the main structure is already included in the simulation and is not considered an external force;

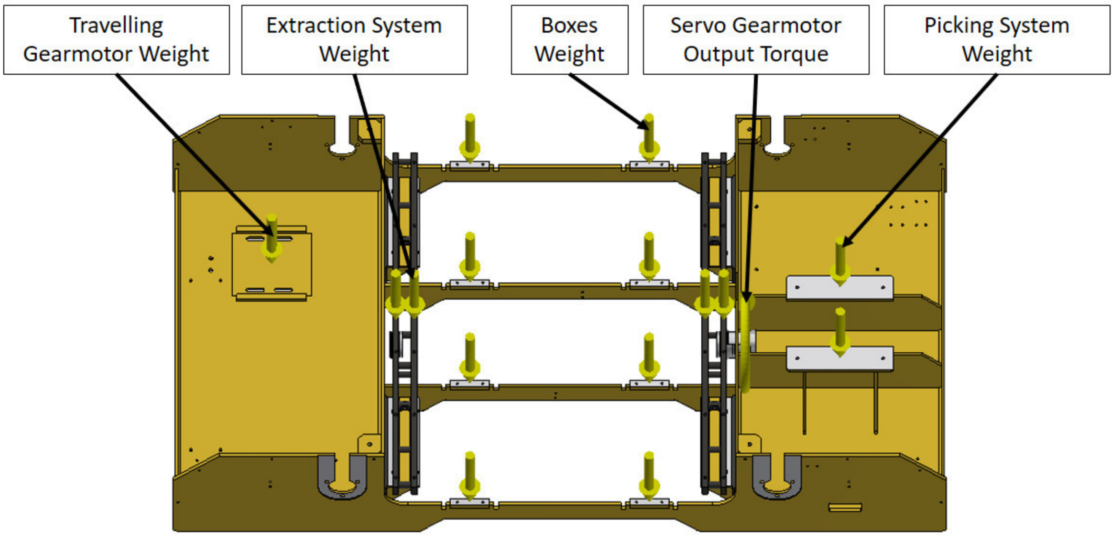


Figure 200 - FEA simulation – Calculation of the Main Structure when the Extraction System is Operating – Definition of the applied loads.

4) Mesh creation. Figure 201 shows the mesh aspect on the main structure surface and the number of nodes and elements that characterize it;

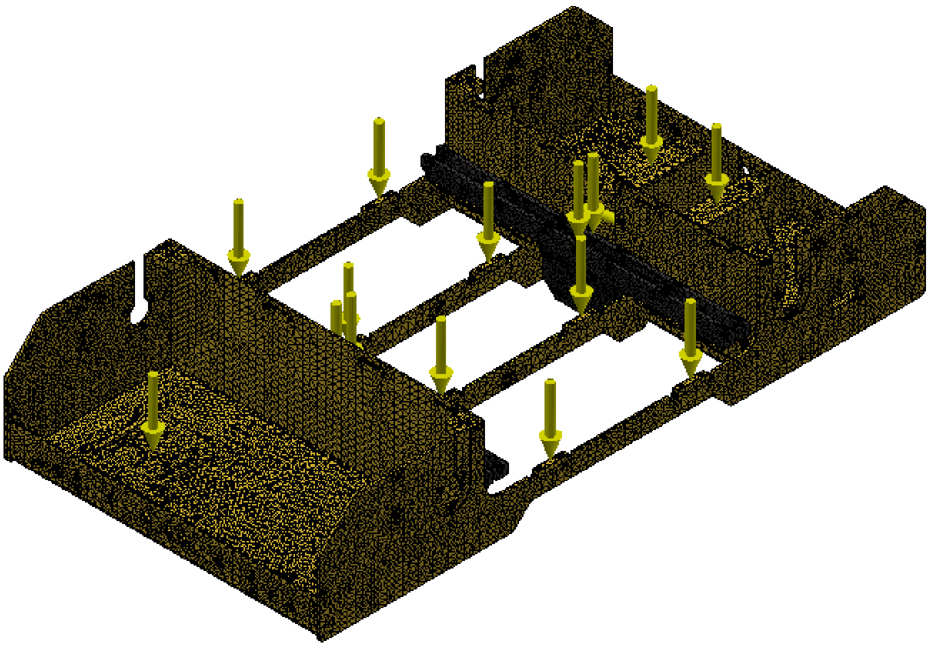


Figure 201 - FEA simulation – Calculation of the Main Structure when the Extraction System is Operating – Mesh creation.

5) Obtaining the results of the simulation. shows the distribution of the Von Mises stresses across the surface of the analyzed part. shows the displacements suffered by the part.

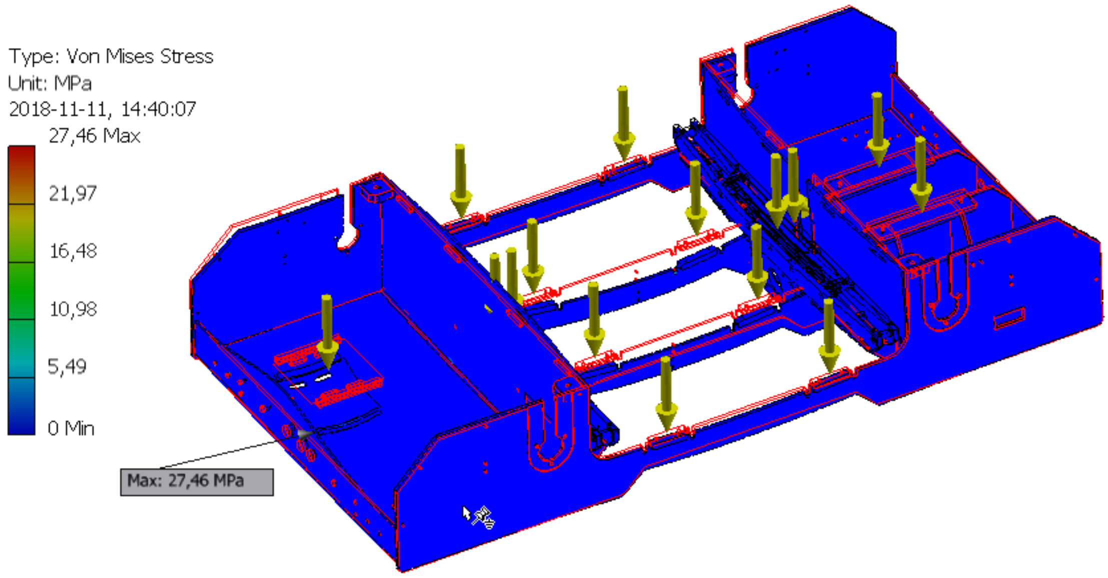


Figure 202 - FEA simulation – Calculation of the Main Structure when the Extraction System is Operating – Distribution of the Von Mises stresses.

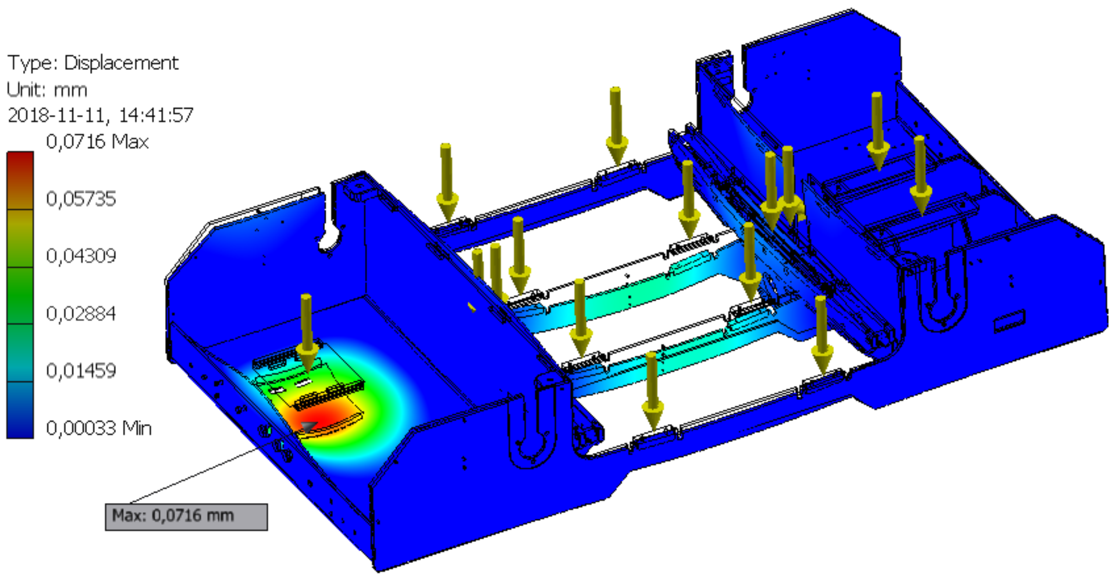


Figure 203 - FEA simulation – Calculation of the Main Structure when the Extraction System is Operating – Displacements on the part.

After obtaining the results, the safety factor between the yield strength of the material and the maximum Von Mises stress was calculated by Equation 40.

All the main results of the FEA simulation are summarized in Table 75.

Table 75 - Results of the FEA simulation of the main structure when the extraction system is operating.g

Variable	Result
Maximum Von Mises Stress ($\sigma_{Von\ Mises,max}$)	27,5 MPa

Variable	Result
Maximum Displacement	0,07 mm
Safety Factor (SF)	8,5

A safety factor of the main structure of 8,5 ensures that there is no risk of failure of the component to the load conditions studied. In addition, the maximum stress occurs only in a small area of the structure not as strong as the rest of the part where the Von Mises stresses are below 10 MPa. This means that the main structure is oversized to the load conditions caused by the extraction system operation.

The maximum displacement of the part is very close to 0 mm, ensuring that the part hardly deforms.

3.4.9.3 CALCULATIONS IN THE PICKING SYSTEM

For the picking system, the following calculations were performed:

1) Configuration of the robot;
2) Selection of the electromechanical gripper;
3) Calculation of the shuttle vehicle main structure (using FEA)

Configuration of the Robot (using FEA)

The robot selected for the picking system was a robot from the robolink-type D range of Igus. As already mentioned, it is a low-cost solution where it is possible to quickly configure the entire robotic arm according to the needs (using an online configurator from Igus).

To configure the robot, the parameters indicated Table 76 were used.

Table 76 – Parameters used to configure the robot.

Parameter	Value
Minimum Reach	1020 mm
Minimum Load Capacity	1 kg
Number of Robot Axes	4

Figure 204 represents the final specifications of the robot after configuration, which highlights the fact that the desired minimum reach has been reached together with the desired load capacity [136].

Figure 204 - Configuration of the robolink-type D from igus [136].

The result of the configuration of the robot produced a robolink of Igus with the following reference: Robolink RL-D-RBT-5532-BC. Figure 205 represents the list of components that make up the configured robolink-type D according to the intended specifications.

Joints

Part No.	Qty	Description
RL-D-50-102-48-01035	1x	Asymmetrical high-end RL-D 50 joint
RL-D-50-101-48-01033	1x	Symmetrical high-end RL-D 50 joint
RL-D-30-101-50-01000	1x	Symmetrical RL-D 30 joint
RL-D-20-101-38-01000	1x	Symmetrical RL-D 20 joint

Motor kits

Part No.	Qty	Description
RL-D-50-MK-C-N23XL-02	2x	NEMA 23XL
RL-D-30-MK-C-N23-02	1x	NEMA 23
RL-D-20-MK-C-N17-02	1x	NEMA 17

INI kits

Part No.	Qty	Description
RL-D-50-IK-001	2x	INI kit for RL-D 50 joint
RL-D-30-IK-001	1x	INI kit for RL-D 30 joint
RL-D-20-IK-001	1x	INI kit for RL-D 20 joint

Other

Part No.	Qty	Description
RL-DC-BL-50-BX-AA-02	1x	Mounting box for RL-D 50 base joint
RL-DC-50-50-T-AB	1x	Connection element 50-50
RL-DC-50-30-AA	1x	Connection element 50-30
RL-DC-30-20-AA	1x	Connection element 30-20
RL-DC-20-GRI-90-01-NA	1x	igus® end effector adapter 20-4

Figure 205 – List of components that make up the configured robolink-type D.

Selection of the Electromechanical Gripper

The gripper was a direct choice in Schunk's product catalog for mounting on the Igus robot and handling small products. The parameters used to make your selection are indicated in Table 77.

Table 77 – Parameters used to select the gripper.

Parameter	Value
Type of Drive	Electromechanical
Number of Jaws	2
Minimum Load Capacity	1 kg

The gripper chosen was Schunk's EGP 50-N-N-B and is shown in Figure 206 [137].

Technical data EGP 50-N-N-B

ID	0310960
Stroke per jaw [mm]	8
Min. gripping force [N]	54
Permanent gripping force (100% continuous duty) [N]	215
Recommended workpiece weight [kg]	1.05

Figure 206 – Selected gripper from Schunk and the main technical data. Adapted from [137].

Calculation of the Main Structure (using FEA)

To study the behavior of the shuttle vehicle main structure when subjected to the weight of all subsystems and the output torque of the robot base joints, in other words, when the picking system is operating, it was necessary to carry out a structural calculation.

The parameters required to calculate the main structure are given in Table 78. Note that the calculation was done using the maximum output torque of the robot base joints to increase the level of safety of the results. The weights were calculated by multiplying the masses of the respective components by the gravitational acceleration.

Table 78 – Parameters used to calculate the main structure when the picking system is operating.

Parameter	Value
Maximum Output Torque of the Robot Base Joints (drive NEMA23XL)	38 N·m
Travelling Gearmotor Weight	270 N
Picking System Weight	216 N
Extraction System Weight	457 N
Boxes Weight	981 N
Material of the Main Structure	Steel EN S235 JR

To determine the maximum stress and displacement of the main structure against the load to which it is subject, an FEA simulation was performed through the Simulation module of the CAD software Autodesk® Inventor®. As such, the steps that followed to the results are indicated below:

1) Since this is a model composed of more than one part, the first step was the indication of the types of contacts between the parts that make up the model to be simulated. The principles that have been assumed were described before;
2) Definition of the boundary conditions. In this case, pin constraints were applied in the radial directions of the travelling wheel axles and in the holes for the fixing bolts to connect the forks of the guiding wheels (Figure 207), blocking the movement of the main structure in the three possible directions;

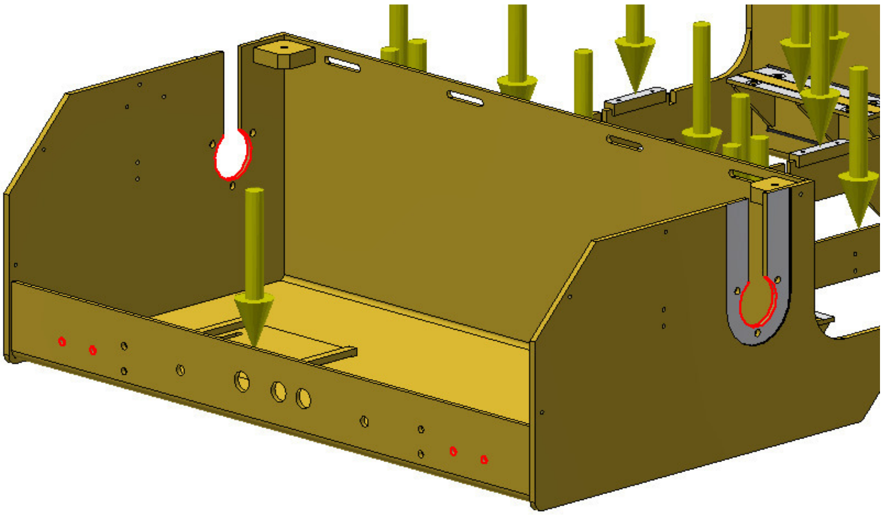


Figure 207 – FEA simulation – Calculation of the Main Structure when the Picking System is Operating – Definition of the boundary conditions.

3) Definition of the applied loads. In this case, the main structure is subjected to the travelling gearmotor weight, the extraction system weight, the boxes weight, the picking system weight and the boxes weight (Figure 208). The weight of the

main structure is already included in the simulation and is not considered an external force;

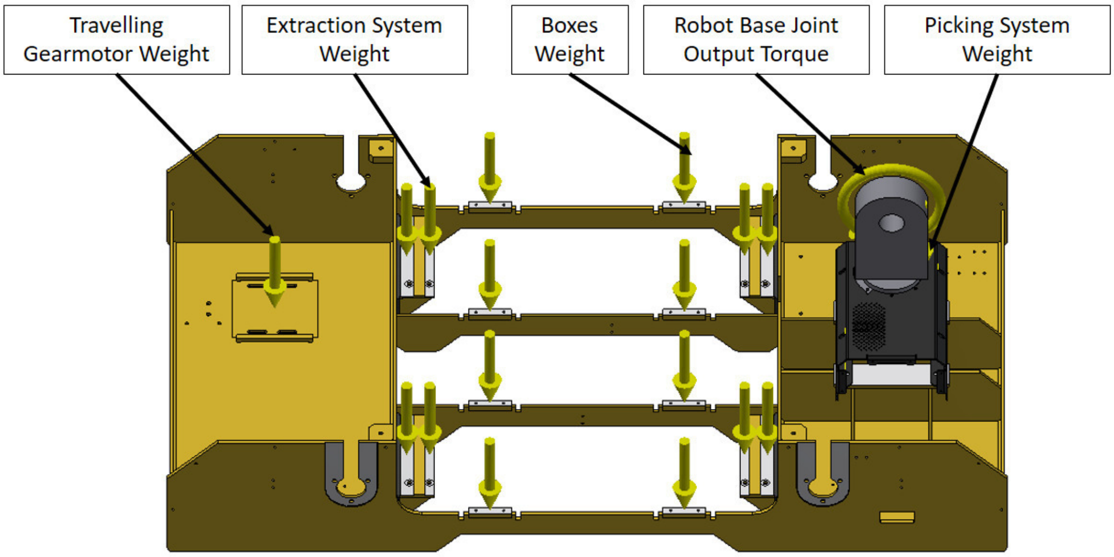


Figure 208 - FEA simulation – Calculation of the Main Structure when the Picking System is Operating – Definition of the applied loads.

4) Mesh creation. Figure 209 shows the mesh aspect on the main structure surface and the number of nodes and elements that characterize it;

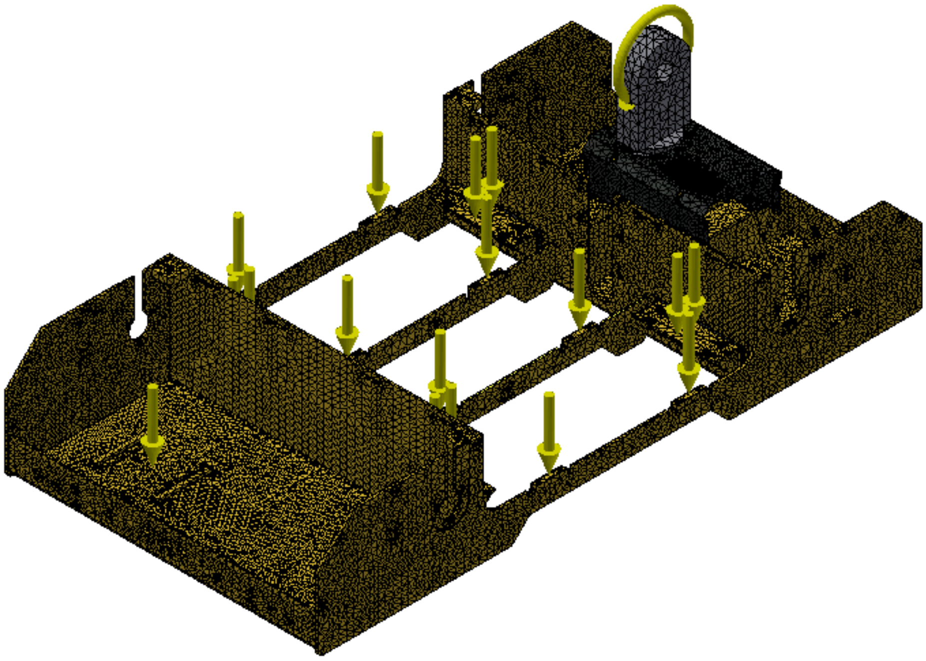


Figure 209 - FEA simulation – Calculation of the Main Structure when the Picking System is Operating – Mesh creation.

5) Obtaining the results of the simulation. shows the distribution of the Von Mises stresses across the surface of the analyzed part. shows the displacements suffered by the part.

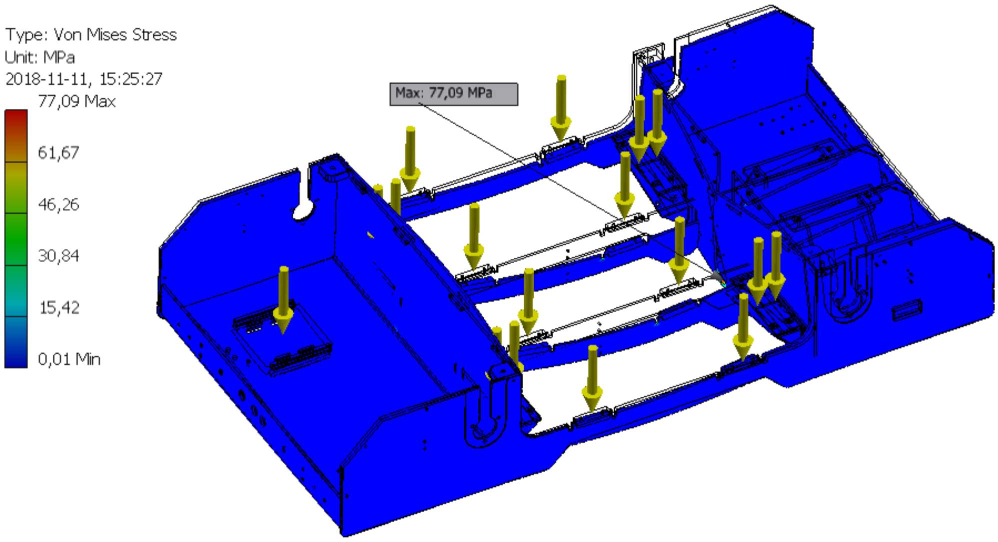


Figure 210 - FEA simulation – Calculation of the Main Structure when the Picking System is Operating – Distribution of the Von Mises stresses.

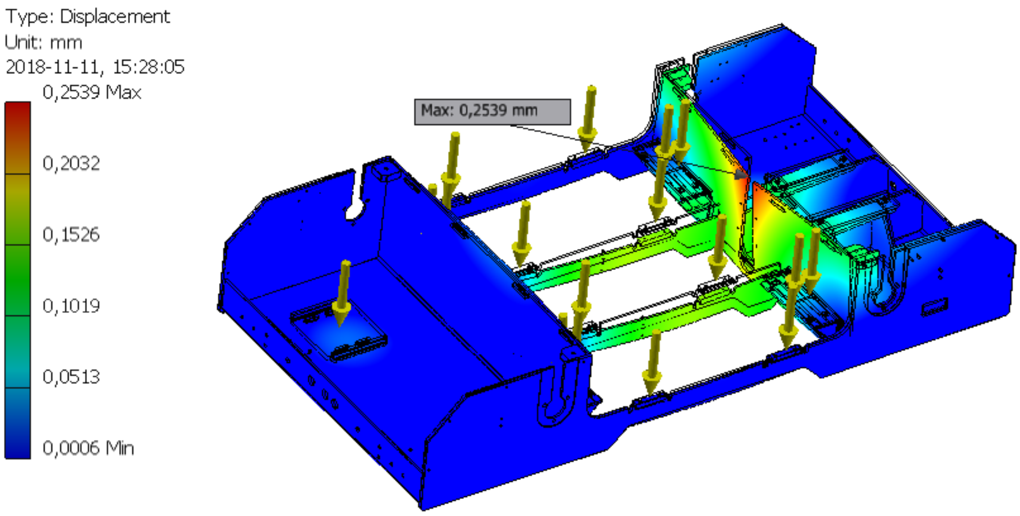


Figure 211 - FEA simulation – Calculation of the Main Structure when the Picking System is Operating - Displacements on the part.

After obtaining the results, the safety factor between the yield strength of the material and the maximum Von Mises stress was calculated by Equation 40.

All of the main results of the FEA simulation are summarized in Table 79.

Table 79 - Results of the FEA simulation of the main structure when the picking system is operating.

Variable	Result
Maximum Von Mises Stress ($\sigma_{Von\ Mises,max}$)	77,1 MPa
Maximum Displacement	0,25 mm
Safety Factor (SF)	3,0

A safety factor of the main structure of 3,0 ensures that there is no risk of failure of the component to the load conditions studied. In addition, the maximum stress occurs only in a small area of the structure not as strong as the rest of the part where the Von Mises stresses are below 15 MPa.

The maximum displacement of the part is very close to 0 mm, ensuring that the part hardly deforms.

3.4.10 FINAL TECHNICAL SPECIFICATIONS

Table 80 represents the final technical specifications after the mechanical design of the shuttle vehicle, where all technical specifications were defined and updated in relation to the preliminary ones. As such, some technical specifications that were not defined previously were added, such as the powers of the gearmotors or the mass of the shuttle vehicle, and some values that were adjusted during the calculations of the equipment such as the travelling acceleration or the extraction acceleration were updated.

Table 80 – Final technical specifications for the shuttle vehicle.

Technical Specification	SI Unit	Value/Description
Shuttle Vehicle Mass	kg	300 kg
Load Type	-	Plastic Tote Box
Load Dimensions	mm	600 x 400 x 200
Maximum Payload	kg	100 (50 kg/box)
Robot Maximum Payload	kg	1
Maximum Vehicle Speed Loaded (Unloaded)	m/s	3,0 (3,0)
Maximum Vehicle Acceleration Loaded (Unloaded)	m/s^2	1,5 (1,5)
Number of Wheels	u	4
Pivoting Wheels (Yes/No)	-	No
Travelling Gearmotor	-	Standard AC Helical Gearmotor (SEW Type R)
Travelling Gearmotor Power	kW	1,1
Load Extraction System	-	Fixed Stroke Load Extractor
Extraction System Maximum Stroke	mm	575
Extraction System Speed Loaded (Unloaded)	m/s	0,45 (0,45)
Extraction System Acceleration Loaded (Unloaded)	m/s^2	0,9 (0,9)

Extraction System Gearmotor	-	Standard AC Helical Servo Gearmotor (SEW Type R)
Expandable Transport Platform (Yes/No)	-	No
Picking System	-	Four-Axis Robot with Electromechanical Gripper
Temperature Range	ºC	0 – 40
Position Control	-	Bar Code Positioning Device
Power Supply	-	Conductor Rail
Power Supply Voltage	V	230

3.4.11 DETAIL DRAWINGS

As already mentioned, the detail drawings are the communication documents that allow to manufacture the parts that constitute the machines and to make the assembly of all the equipment.

As such, all the detailed drawings related to the parts and assemblies of the shuttle vehicle were carried out in accordance with the technical drawing standards, respecting the general principles of representation applicable to technical drawings of mechanical engineering.

In general, the parts drawings have information about the manufacturing dimensions, the material and the finish, but all were made according to the assembly needs, having been placed all the dimensional, geometric and general tolerances that must be respected during the manufacturing process. The general tolerances are defined according to international standards, depend on the manufacturing process and must be applied to all dimensions without individual tolerance. In this work, the following standards were adopted for the general tolerances [138],[139]:

1) ISO 2768-1:1989 – General tolerances – Part 1: Tolerances for linear and angular dimensions without individual tolerance indications;
2) ISO 2768-1:1989 – General tolerances — Part 2: Geometrical tolerances for features without individual tolerance indications.

The assembly drawings have information about assembling the subassemblies that make up the entire shuttle vehicle, namely the parts lists with the quantities and designations of each part. The shuttle vehicle was divided into subassemblies to cause a rapid interpretation of the assembly drawings and assembly operations, avoiding the density of information in the assembly drawings. The main assembly drawing of the shuttle vehicle is shown in Figure 212 and Figure 213, where the general dimensions of the machine were represented, and an exploded view of the whole assembly, respectively.

The assemblies, parts and standard components (or purchase items) were encoded according to Consoveyo, S.A. internal coding process. This coding allows the separation of manufacturing parts from standard components (such as screws and bearings) by accordance with the subsystem in which they are applied. As such, the assembly codes are all those that start with R1, the part codes are all those that start with R2, R3, R4 OR R5, and the codes of the standard components are all those that start with G or O.

Annex 2 lists all the assemblies and manufacturing parts from the shuttle vehicle, together with the respective subsystem where they are applied, the material, the manufacturing process, the finishing and the assembly where they are used.

Annex 4 lists the main standard components (excluding all types of fasteners) with the respective manufacturer and the assembly drawing where they are used.

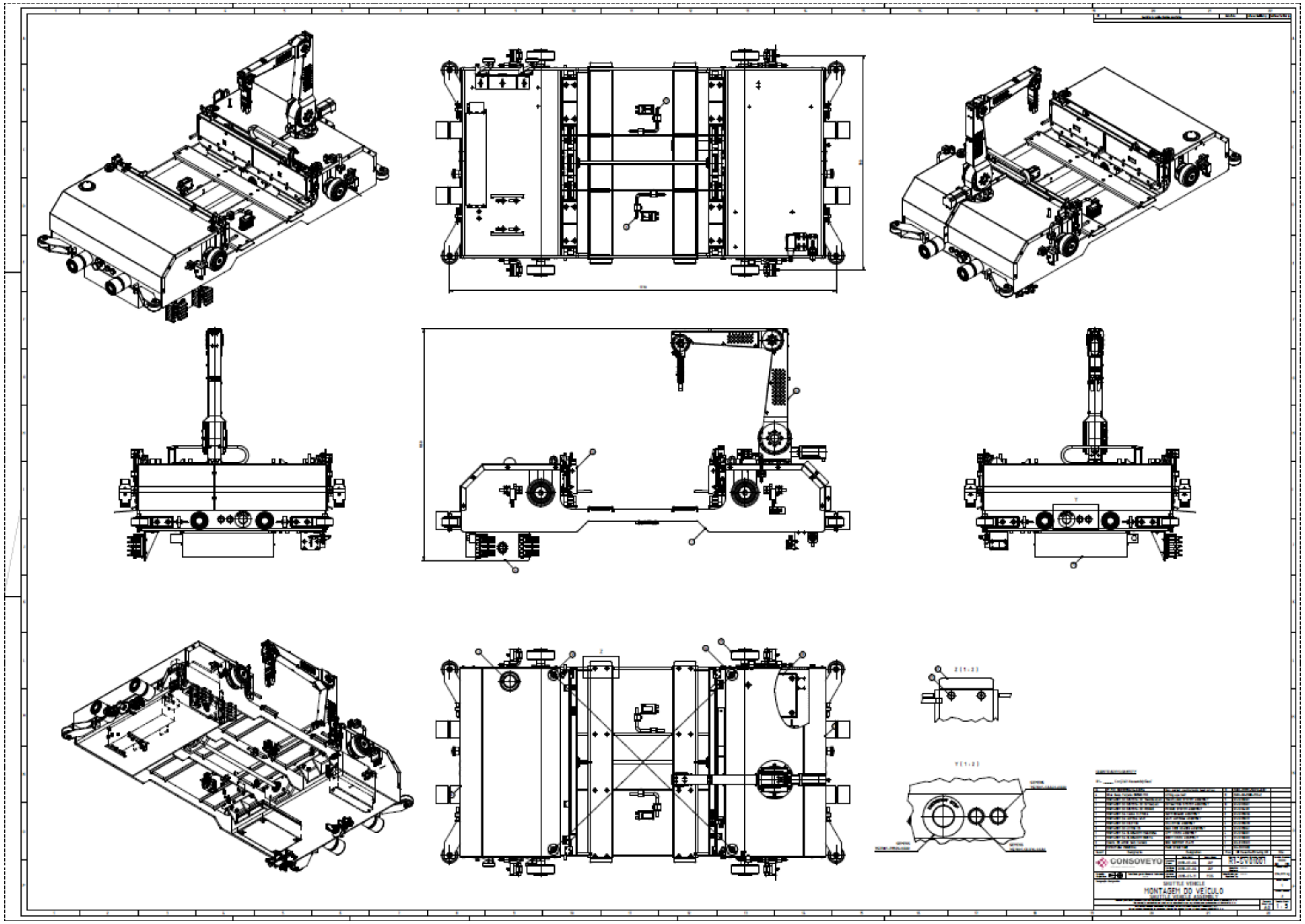


Figure 212 - Main assembly drawing of the shuttle vehicle (sheet 1/2).

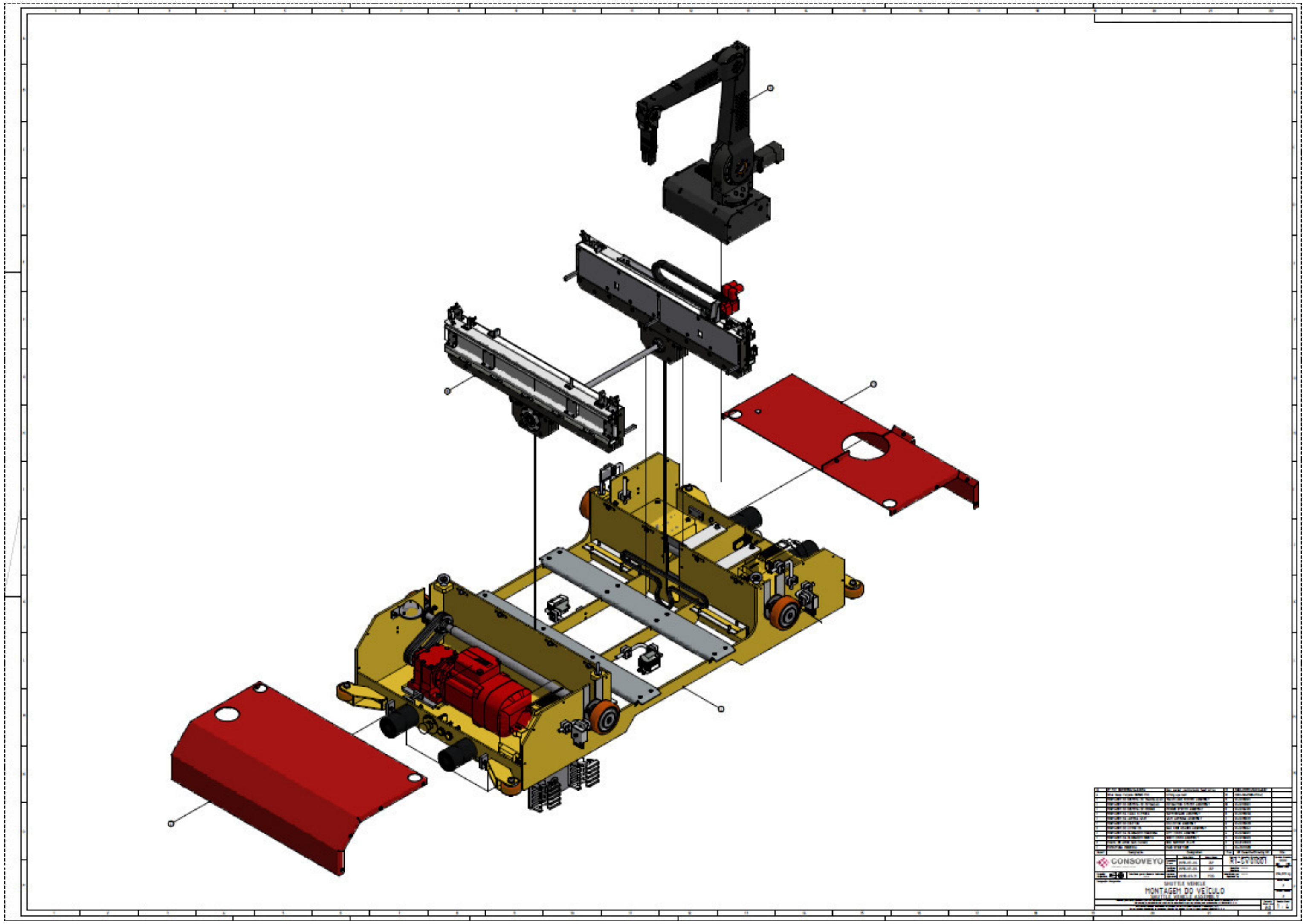


Figure 213 - Main assembly drawing of the shuttle vehicle (sheet 2/2).

CONCLUSIONS

4 CONCLUSIONS AND PROPOSALS OF FUTURE WORKS

4.1 CONCLUSIONS

According to the result of the equipment developed, it is possible to conclude that the main objective of innovating the shuttle vehicle for the shuttle box AS/RS has been completed. The idea of incorporating in the shuttle vehicle a picking system able to carry out the picking operations automatically and directly in the rack structure is, in fact, something innovative with the solutions existing in the market.

The developed shuttle vehicle is functional and capable of handling boxes with mass and defined dimensions, through the contribution of the following main subsystems that make up the equipment:

1) The travelling system allows to move the vehicle automatically along the rack structure;
2) The developed extraction system allows to extract and store the boxes of the rack structure automatically and accurately;
3) The picking system allows to perform the picking operations automatically and directly in the rack structure.

These three main subsystems, together with the defined sensors and control components, guarantee the main operations of the shuttle vehicle and thus the operation of the AS/RS with the appropriate interfaces between the rack structure and the vehicle.

The critical parts and components of the shuttle vehicle were all checked and validated using appropriate calculations. The results of the calculations proved that many of these parts and components are oversized, something to be expected since the boxes to be handled have a relatively low mass. This ensures that the parts will not cause problems during the operation of the vehicle but, on the other hand, there is margin to optimize the developed parts.

At the end of the mechanical design, all the detail drawings necessary for manufacturing the parts and assemble the equipment were made. The drawings produced are an important technical document for understanding the operation of the machine and reading the present work.

After all, and since there is no perfect machine, the shuttle vehicle has some disadvantages. The main disadvantage is the fact that the picking system, despite introducing an innovation in the AS/RS, requires that the space of occupancy of the rack structure is poorly used, since it is necessary to have enough gap between the levels. As such, implementing such system implies having enough space available in the warehouse, being necessary to realize an investment analysis to study if it pays to invest in the shuttle vehicle with the picking system incorporated or not. It will always depend on the type of warehouse and the type of products stored.

The main difficulties experienced during the execution of this work are related to the management of time and the management of all the interested parties. Being a work limited in time, the design of the machine could not be optimized much for lack of available time, so the obtained result can be quite optimized. Also, it was not easy to align everyone involved in the job, from the company to the engineering school.

With this work it was possible to develop mechanical engineering competences strongly related to the field of machine design.

4.2 PROPOSALS OF FUTURE WORKS

As a suggestion for future works that may arise from this dissertation, the following are proposed:

1) Development of an alternative picking system for the four-axis robot. Possibly a gantry system of three axes to reduce the space occupied by the shuttle vehicle inside the rack structure;
2) Development of an elevator to transfer the shuttle vehicle between levels of the rack structure;
3) Calculation of a complete rack structure, with rails incorporated for the shuttle vehicle.

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5 REFERENCES AND OTHER SOURCES OF INFORMATION

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ANNEXES

6 ANNEXES

All the following annexes are available in digital format on a DVD that accompanies this work. The annexes are subdivided into the following sections:

- Annex 1 – Preliminary Calculations;
- Annex 2 – List of Parts and Assemblies;
- Annex 3 – Detail Drawings;
- Annex 4 – List of Standard Components;
- Annex 5 – Standard Components Data Sheets;
- Annex 6 – Electrical Equipment Data Sheets;
- Annex 7 – Final Calculations.

ANNEX 1

Preliminary Calculations

CONSOVEYO KÖRBER SOLUTIONS	Assunto / Subject: Master's Thesis - Preliminary Calculation of Reactions in the Vehicle Supports and Stability Check		
Design calculations			
Referência / Reference	Autor / Author: João Fernandes	Aprovado por / Approved by	Folha / Sheet: 1
	Data / Date: 28/12/2017	Data / Date	Folhas / Sheets: 4

Data:

$m_{vehicle} = 150$ kg (estimated)

$m_{robot} = 30$ kg (estimated)

$m_{load} = 100$ kg (50 kg / box)

$a_{travelling} = 1{,}5$ m/s^2 (estimated)

$g = 9{,}81$ m/s^2

Assumptions:

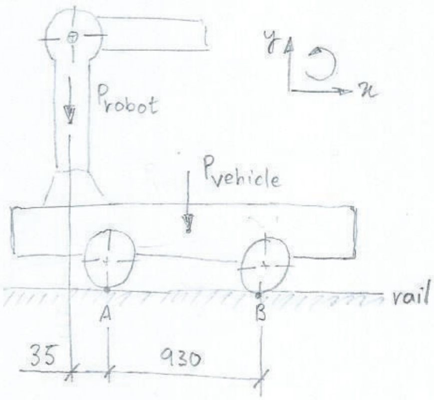
i) Consider that the rail is perfectly horizontal;

ii) The masses from the robot and the vehicle need to be separated because the center of mass of the shuttle vehicle is unknown;

iii) The boxes are properly locked and stabilised inside the vehicle;

iv) According to FEM 9.311, since there is no load lifting, all loads are considered deadloads. Therefore, all loads and reactions remain unaffected by coefficients.

Calculation of the Static Reactions (Vehicle Unloaded):



$$\begin{cases} \Sigma F_y = 0 \\ \Sigma M_A = 0 \end{cases} \Rightarrow \begin{cases} R_{A,stat} + R_{B,stat} - P_{robot} - P_{vehicle} = 0 \\ R_{B,stat} \cdot 930 + P_{robot} \cdot 35 - P_{vehicle} \cdot \frac{930}{2} = 0 \end{cases} \Leftrightarrow$$

$$\Leftrightarrow \begin{cases} R_{A,stat} + R_{B,stat} - m_{robot} \cdot g - m_{vehicle} \cdot g = 0 \\ R_{B,stat} \cdot 930 + m_{robot} \cdot g \cdot 35 - m_{vehicle} \cdot g \cdot \frac{930}{2} = 0 \end{cases} \Leftrightarrow \begin{cases} R_{A,stat} + R_{B,stat} - 30 \cdot 9{,}81 - 150 \cdot 9{,}81 = 0 \\ R_{B,stat} \cdot 930 + 30 \cdot 9{,}81 \cdot 35 - 150 \cdot 9{,}81 \cdot 465 = 0 \end{cases} \Leftrightarrow$$

$$\Leftrightarrow \begin{cases} R_{A,stat} = 1041 \text{ N} > 0 \quad \text{ok!} \\ R_{B,stat} = 725 \text{ N} > 0 \quad \text{ok!} \end{cases}$$

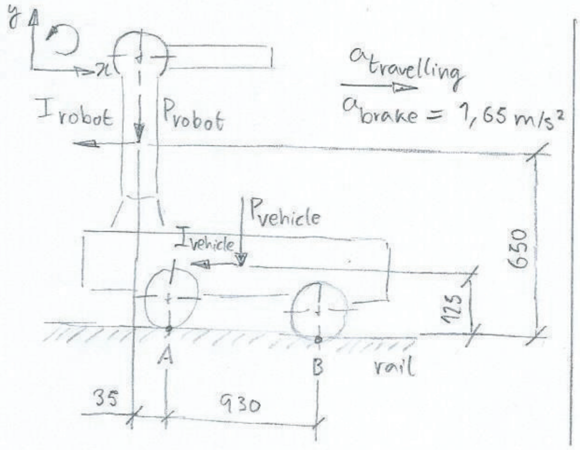
$\Sigma M_{stabilising} = \min(R_{A,stat}; R_{B,stat}) \cdot 930 \Leftrightarrow \Sigma M_{stabilising} = 725 \cdot 930 \Leftrightarrow$

$\Leftrightarrow \Sigma M_{stabilising} = 674\,250 \text{ N} \cdot \text{mm}$

Calculation of the Dynamic Reactions (Vehicle Unloaded):

v) The results of the reactions are different according to the direction of the movement, however, the calculation is made for the worst scenario in terms of the stability of the vehicle, which is when it moves from left to right according to the body diagram of the vehicle.

vi) In this case there is no oscillation effect of the robot, so $S_w = 1$ (FEM 9.311).



vii) Consider the scenario where the vehicle is initiating the movement (travelling acceleration) and the scenario in which the vehicle brakes (emergency brake acceleration). The brake acceleration was determined in the document "Preliminary Calculation of the Travelling Gearmotor".

→ Travelling Acceleration:

$$\begin{cases} \Sigma F_y = 0 \\ \Sigma M_A = 0 \end{cases} \Rightarrow \begin{cases} R_{A,dyn} + R_{B,dyn} - P_{robot} - P_{vehicle} = 0 \\ R_{B,dyn} \cdot 930 + P_{robot} \cdot 35 + I_{robot} \cdot 650 - P_{vehicle} \cdot \frac{930}{2} + I_{vehicle} \cdot 125 = 0 \end{cases} \Leftrightarrow$$

$$\Leftrightarrow \begin{cases} R_{A,dyn} + R_{B,dyn} - m_{robot} \cdot g - m_{vehicle} \cdot g = 0 \\ R_{B,dyn} \cdot 930 + m_{robot} \cdot g \cdot 35 + m_{robot} \cdot a_{travelling} \cdot 650 - m_{vehicle} \cdot g \cdot 465 + m_{vehicle} \cdot a_{travelling} \cdot 125 = 0 \end{cases} \Leftrightarrow$$

$$\Leftrightarrow \begin{cases} R_{A,dyn} + R_{B,dyn} - 30 \cdot 9{,}81 - 150 \cdot 9{,}81 = 0 \\ R_{B,dyn} \cdot 930 + 30 \cdot 9{,}81 \cdot 35 + 30 \cdot 1{,}5 \cdot 650 - 150 \cdot 9{,}81 \cdot 465 + 150 \cdot 1{,}5 \cdot 125 = 0 \end{cases} \Leftrightarrow \begin{cases} R_{A,dyn} = 1103\ N > 0 \text{ ok!} \\ R_{B,dyn} = 663\ N > 0 \text{ ok!} \end{cases}$$

$\sum M_{overturning} = I_{robot} \cdot 650 + I_{vehicle} \cdot 125 \Leftrightarrow$

$\Leftrightarrow \sum M_{overturning} = m_{robot} \cdot a_{travelling} \cdot 650 + m_{vehicle} \cdot a_{travelling} \cdot 125 \Leftrightarrow$

$\Leftrightarrow \sum M_{overturning} = 30 \cdot 1{,}5 \cdot 650 + 150 \cdot 1{,}5 \cdot 125 \Leftrightarrow \sum M_{overturning} = 57\,375 \text{ N} \cdot \text{mm}$

→ Brake Acceleration:

viii) To determine the dynamic reactions of the shuttle vehicle using the emergency brake acceleration, the same equations applied previously are used, replacing the travelling acceleration with the brake acceleration.

$$\begin{cases} \sum F_y = 0 \\ \sum M_A = 0 \end{cases} \Rightarrow \begin{cases} R_{A,dyn} = 1109 \text{ N} > 0 \quad \text{OK!} \\ R_{B,dyn} = 657 \text{ N} > 0 \quad \text{OK!} \end{cases}$$

$\sum M_{overturning} = 63\,112{,}5 \text{ N} \cdot \text{mm}$

Calculation of the Static/Dynamic Reactions (Vehicle Loaded):

ix) To determine the static/dynamic reactions considering that the shuttle vehicle is loaded, the same equations previously applied in each case are used, adding the mass of the boxes to the mass of the vehicle;

→ Static Reactions (Vehicle Loaded):

$$\begin{cases} \sum F_y = 0 \\ \sum M_A = 0 \end{cases} \Rightarrow \begin{cases} R_{A,stat} = 1532 \text{ N} > 0 \quad \text{OK!} \\ R_{B,stat} = 1215 \text{ N} > 0 \quad \text{OK!} \end{cases}$$

$\sum M_{stabilising} = 1\,129\,950 \text{ N} \cdot \text{mm}$

→ Dynamic Reactions (Vehicle Loaded):

x) In this case, it is not necessary to determine the dynamic reactions when the vehicle brakes (emergency brake acceleration) because this is a rare scenario for the wheels and better for the vehicle stability when compared to the scenario where the vehicle is unloaded and preforms an emergency brake.

→ Travelling Acceleration :

$$\begin{cases} \Sigma F_y = 0 \\ \Sigma M_A = 0 \end{cases} \Rightarrow \begin{cases} R_{A,dyn} = 1613 \text{ N} > 0 \text{ ok!} \\ R_{B,dyn} = 1133 \text{ N} > 0 \text{ ok!} \end{cases}$$

$$\Sigma M_{overturning} = 76\,125 \text{ N.mm}$$

Stability Check :

→ Vehicle Unloaded (travelling acceleration) :

$$\nu = \frac{\Sigma M_{stabilising}}{\Sigma M_{overturning}} \Leftrightarrow \nu = \frac{674\,250}{57\,375} \Leftrightarrow \nu = 11{,}8 > 1{,}5 \quad \text{ok!}$$

→ Vehicle Unloaded (brake acceleration) :

$$\nu = \frac{\Sigma M_{stabilising}}{\Sigma M_{overturning}} \Leftrightarrow \nu = \frac{674\,250}{63112{,}5} \Leftrightarrow \nu = 10{,}7 > 1{,}5 \quad \text{ok!}$$

→ Vehicle Loaded (travelling acceleration) :

$$\nu = \frac{\Sigma M_{stabilising}}{\Sigma M_{overturning}} \Leftrightarrow \nu = \frac{1129\,950}{76\,125} \Leftrightarrow \nu = 14{,}8 > 1{,}5 \quad \text{ok!}$$

CONSOVEYO KÖRBER SOLUTIONS	Assunto / *Subject*: Master's Thesis — Preliminary Calculation of the Travelling Gearmotor		
Design calculations			
Referência / *Reference*	Autor / *Author*: João Fernandes	Aprovado por / *Approved by*	Folha / *Sheet*: 1
	Data / *Date*: 02/01/2018	Data / *Date*	Folhas / *Sheets*: 4

Data:

$m_{vehicle} = 180$ kg (estimated)

$m_{load} = 100$ kg (50 kg / box)

$D_{wheel} = 125$ mm ; $d_{axle} = 45$ mm

$i_v = 1{,}0$

$v_{travelling} = 3$ m/s

$a_{travelling} = 1{,}5$ m/s^2 (estimated)

$g = 9{,}81$ m/s^2

$f_{Vulkollan/steel\ (\phi 125\ mm)} = 0{,}9$ mm

$\mu_{L,\ anti\text{-}friction\ bearings} = 0{,}005$

$\mu_{stat\ (PU/steel)} = 0{,}55$

$\eta_{chain} = 0{,}90$

$\eta_{load} = 0{,}90$

Intended Gearmotor → Type R

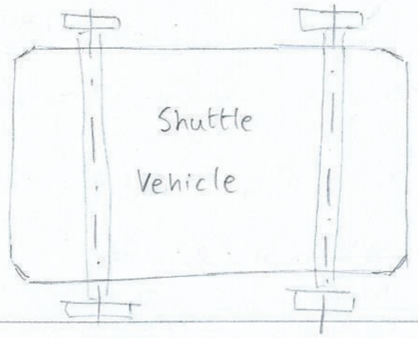
Assumptions:

i) Calculate a gearmotor to drive a vehicle with four wheels with an outer diameter of 125 mm;

ii) The power transmission between the gearmotor and the wheels is made by chain and sprockets (gear ratio of 1);

iii) Consider an operation of 16 h/day and 100 cycles/h;

iv) The motor is controlled by a frequency inverter, to adjust the speed and acceleration.



Motor Calculation:

$$F_{drive} = F_{inertia} + F_{rolling} \Leftrightarrow F_{drive} = m_{total} \cdot a_{travelling} + m_{total} \cdot g \cdot \left(\mu_L \cdot \frac{d_{axle}}{D_{wheel}} + \frac{2 \cdot f}{D_{wheel}}\right) \Leftrightarrow$$

$$\Leftrightarrow F_{drive} = (180+100) \cdot 1{,}5 + \underbrace{(180+100) \cdot 9{,}81 \cdot \left(0{,}005 \cdot \frac{45}{125} + \frac{2 \cdot 0{,}9}{125}\right)}_{= 44{,}5\ N} \Leftrightarrow F_{drive} = 464{,}5\ N$$

$$\eta_{total} = \eta_{chain} \cdot \eta_{load} = 0{,}90 \cdot 0{,}90 = 0{,}81$$

$$P_{static} = \frac{F_{rolling} \cdot v_{travelling}}{\eta_{total}} \Leftrightarrow P_{static} = \frac{44{,}5 \cdot 3}{0{,}81} \Leftrightarrow P_{static} = 164{,}8\ W \simeq 0{,}16\ kW$$

$$P_{dynamic} = \frac{F_{drive} \cdot v_{travelling}}{\eta_{total}} \Leftrightarrow P_{dynamic} = \frac{464{,}5 \cdot 3}{0{,}81} \Leftrightarrow P_{dynamic} = 1720\ W = 1{,}72\ kW$$

Selected Motor (1st selection):

DRN90L4 → $P_N = 1{,}5$ kW ; $n_N = 1461$ rpm (a 50 Hz) ; $J_{Mot} = 67{,}2E{-}4$ kg·m^2 ; $M_N = 9{,}8$ N·m

Motor Check (1st selection):

$$J_X = 91,2 \cdot m_{total} \cdot \left(\frac{v_{travelling}}{n_N}\right)^2 \Leftrightarrow J_X = 91,2 \cdot (180+100) \cdot \left(\frac{3}{1461}\right)^2 \Leftrightarrow J_X = 0,1077 \ kg \cdot m^2$$

$$M_L = \frac{F_{rolling} \cdot v_{travelling} \cdot 9,55}{n_N} \Leftrightarrow M_L = \frac{44,5 \cdot 3 \cdot 9,55}{1461} \Leftrightarrow M_L = 0,87 \ N \cdot m$$

$$t_a = \frac{v_{travelling}}{a_{travelling}} \Leftrightarrow t_a = \frac{3}{1,5} \Leftrightarrow t_a = 2 \ s$$

$$M_H = \frac{\left(J_{Mot} + \frac{1}{\eta_{total}} \cdot J_X\right) \cdot n_N}{9,55 \cdot t_a} + \frac{M_L}{\eta_{total}} \Leftrightarrow M_H = \frac{\left(67,2E-4 + \frac{1}{0,81} \cdot 0,1077\right) \cdot 1461}{9,55 \cdot 2} + \frac{0,87}{0,81} \Leftrightarrow$$

$$\Leftrightarrow M_H = 11,76 \ N \cdot m$$

$$\frac{M_H}{M_N} = \frac{11,76}{9,8} = 120\% < 130\% \quad ok!$$

Motor Selection (2nd selection):

v) In the second selection, a lower power motor was chosen, considering that it runs at a frequency of 87 Hz. This is possible with the use of the frequency inverter, and no torque is lost at the output of the gearmotor.

DRN90S4 → $P_N = 1,1 \ kW$; $n_N = 2400 \ rpm$ (a 87 Hz) ; $J_{Mot} = 54E-4 \ kg \cdot m^2$; $M_N = 7,2 \ N \cdot m$

Motor Check (2nd selection):

$J_X = 0,0399 \ kg \cdot m^2$; $t_a = 2 \ s$

$M_L = 0,53 \ N \cdot m$; $M_H = 7,52 \ N \cdot m \Rightarrow M_H / M_N = 104\% < 130\%$ ok!

Gear Unit Calculation:

$$n_a = 19,1E3 \cdot \frac{v_{travelling}}{D_{wheel}} \cdot i_V \Leftrightarrow n_a = 19,1E3 \cdot \frac{3}{125} \cdot 1,0 \Leftrightarrow n_a = 458,4 \ rpm$$

$$i_{gear\ unit} = \frac{n_N}{n_a} \Leftrightarrow i_{gear\ unit} = \frac{2400}{458,4} \Leftrightarrow i_{gear\ unit} = 5,24$$

$$f_M = \frac{J_X}{J_{Mot}} \Leftrightarrow f_M = \frac{0,0399}{54E-4} \Leftrightarrow f_M = 7,39 < 10 \quad ok!$$

$f_M = 7,39$; operation 16 h/day, 100 cycles/h ⇒ $f_B \geq 1,6$ (according to graph from SEW's catalog)

CONSOVEYO KÖRBER SOLUTIONS	Assunto / Subject: Master's Thesis — Preliminary Calculation of the Travelling Gearmotor		
Design calculations			
Referência / Reference	Autor / Author: João Fernandes	Aprovado por / Approved by	Folha / Sheet: 3
	Data / Date: 02/01/2018	Data / Date	Folhas / Sheets: 4

Gear Unit Selection:

R27 ⟶ $i = 5{,}00$; $n_a = 480$ rpm ($n_N = 2400$ rpm) ; $M_{a,max} = 95$ N.m ; $M_a = 36$ N.m

$f_B = 2{,}6$

Gear Unit Check:

$f_B = 2{,}6 > 1{,}6$ ok!

$$M_{static} = \frac{F_{rolling} \cdot \frac{D_{wheel}}{2}}{\eta_{total}} \Leftrightarrow M_{static} = \frac{44{,}5 \cdot \frac{125E-3}{2}}{0{,}81} \Leftrightarrow M_{static} = 3{,}4 \text{ N·m}$$

$M_{static} = 3{,}4$ N·m $< M_a = 36$ N·m ok!

$$M_{dynamic} = \frac{F_{drive} \cdot \frac{D_{wheel}}{2}}{\eta_{total}} \Leftrightarrow M_{dynamic} = \frac{464{,}5 \cdot \frac{125E-3}{2}}{0{,}81} \Leftrightarrow M_{dynamic} = 35{,}8 \text{ N·m}$$

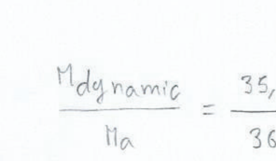
$$\frac{M_{dynamic}}{M_a} = \frac{35{,}8}{36} = 99{,}6\,\% < 130\,\% \quad \text{ok!}$$

Selected Gearmotor: R27 DRN90S4 BE2 with Frequency Inverter

Acceleration Check:

vi) Determine the maximum acceleration so that the drive wheels do not slip. Consider the worst scenario where the shuttle vehicle is unloaded;

vii) This calculation depends on the static reactions on the travelling wheels. These values were determined in the document "Preliminary Calculation of Reactions in the Vehicle Supports and Stability Check".



$R_{A,stat} = 1041$ N, $R_{B,stat} = 725$ N — Shuttle Vehicle Unloaded

$R_{stat} = N \Rightarrow F_{friction} = N \cdot \mu_{stat} \Leftrightarrow F_{friction} = R_{stat} \cdot \mu_{stat}$

If the drive wheels are the wheels A:

$F_{friction} = R_{A,stat} \cdot \mu_{stat(PU/steel)} \Leftrightarrow F_{friction} = 1041 \cdot 0{,}55 \Leftrightarrow F_{friction} = 572{,}6$ N

$$F_{drive} \leq F_{friction} \Leftrightarrow m_{vehicle} \cdot a_{travelling} + m_{vehicle} \cdot g \cdot \left(\mu_L \cdot \frac{d_{axle}}{D_{wheel}} + \frac{2 \cdot f}{D_{wheel}}\right) \leq F_{friction} \Leftrightarrow$$

$$\Leftrightarrow 180 \cdot a_{travelling} + 180 \cdot 9{,}81 \cdot \left(0{,}005 \cdot \frac{45}{125} + \frac{2 \cdot 0{,}9}{125}\right) \leq 572{,}6 \Leftrightarrow a_{travelling} \leq 3{,}0 \text{ m/s}^2$$

$1{,}5 < 3{,}0 \rightarrow$ OK!

If the drive wheels are the wheels B:

$F_{friction} = R_{B,stat} \cdot \mu_{stat\,(PU/steel)} \Leftrightarrow F_{friction} = 725 \cdot 0{,}55 \Leftrightarrow F_{friction} = 398{,}8\ N$

$F_{drive} \leq F_{friction} \Leftrightarrow a_{travelling} \leq 2{,}1\ m/s^2$

viii) The wheels A should be the driving wheels because the probability of slipping is lower when compared with the wheels B.

Motor Brake Check:

Brake BE2 $\rightarrow$ $M_{Brake} = 5{,}0\ N \cdot m$

ix) Consider that the wheels A are the driving wheels;

x) Check if an emergency braking torque causes the wheels to slip, considering the worst scenario where the shuttle vehicle is unloaded.

$F_{drive\ adm.} = F_{friction} \Leftrightarrow F_{drive\ adm.} = 572{,}6\ N$

$$M_{brake\ adm.} = \frac{F_{drive\ adm} \cdot \frac{D_{wheel}}{2}}{i} \Leftrightarrow M_{brake\ adm} = \frac{572{,}6 \cdot \frac{0{,}125}{2}}{5{,}00} \Leftrightarrow$$

$\Leftrightarrow M_{brake\ adm} = 7{,}2\ N \cdot m < M_{brake} = 5{,}0\ N \cdot m$ OK!

$$t_{a,brake} = \frac{(J_M + J_X \cdot \eta_{total}) \cdot n_N}{9{,}55 \cdot (M_{brake} + M_L \cdot \eta_{total})} \Leftrightarrow t_{a,brake} = \frac{(54E{-}4 + 0{,}0399 \cdot 0{,}81) \cdot 2400}{9{,}55 \cdot (5{,}0 + 0{,}53 \cdot 0{,}81)} \Leftrightarrow$$

$\Leftrightarrow t_{a,brake} = 1{,}81\ s$

$$a_{brake} = \frac{V_{travelling}}{t_{a,brake}} \Leftrightarrow a_{brake} = \frac{3}{1{,}81} \Leftrightarrow a_{brake} = 1{,}65\ m/s^2$$

CONSOVEYO KÖRBER SOLUTIONS	Assunto / Subject: Master's Thesis - Preliminary Calculation of the Guiding Wheels and the Travelling Wheels		
Design calculations			
Referência / Reference	Autor / Author: João Fernandes	Aprovado por / Approved by	Folha / Sheet: 1
	Data / Date: 29/12/2017	Data / Date	Folhas / Sheets: 2

Data:

$m_{vehicle} = 180$ kg (estimated)

$m_{load} = 100$ kg (50 kg / box)

$v_{travelling} = 3{,}0$ m/s $= 10{,}8$ km/h

$\mu_{stat(PU/steel)} = 0{,}55$; $g = 9{,}81$ m/s^2

→ Catálogo Brauer:

C_1 (continuous running) $= 0{,}75$

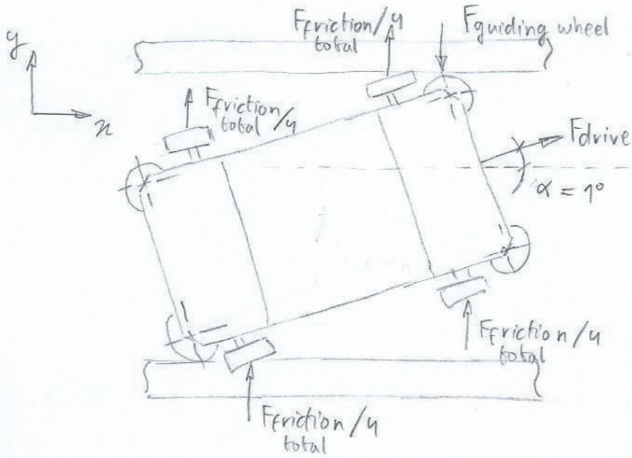
C_2 (surface speed 10 - 16 km/h) $= 0{,}7$

C_3 (driving wheels) $= 0{,}7$

Calculation of the Guiding Wheels (Vehicle Loaded):

i) Consider a scenario where the vehicle accelerates deflected, with one of the guiding wheels causing the vehicle to align. This guide wheel must be able to support the "y" componente of the driving force (see free body diagram) and the friction force of dragging approximately half of the vehicle to align it;

ii) The maximum permissible load on the guiding wheel is affected by the factors C_1 and C_2.



$F_{drive} = 464{,}5$ N, calculated in the document "Preliminary Calculation of the Travelling Gearmotor".

$$\sum F_y = 0 \Rightarrow \frac{F_{friction\ total}}{2} + F_{drive} \cdot \sin\alpha - F_{guiding\ wheel} = 0 \Leftrightarrow$$

$$\Leftrightarrow \frac{m_{total} \cdot g \cdot \mu_{stat(PU/steel)}}{2} + 464{,}5 \cdot \sin(1°) - F_{guiding\ wheel} = 0 \Leftrightarrow$$

$$\Leftrightarrow \frac{(180+100) \cdot 9{,}81 \cdot 0{,}55}{2} + 464{,}5 \cdot \sin(1°) - F_{guiding\ wheel} = 0 \Leftrightarrow F_{guiding\ wheel} = 763{,}4 \text{ N}$$

→ Guiding Wheel Selection:

Brauer → Polyurethane H75/35 → $P_{max} = 300$ kgf $= 2943$ N

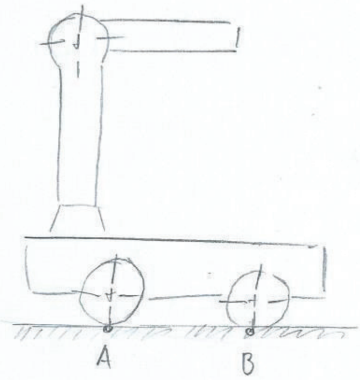
$$P_{max.corr} = P_{max} \cdot C_1 \cdot C_2 \Leftrightarrow P_{max.corr} = 2943 \cdot 0{,}75 \cdot 0{,}7 \Leftrightarrow P_{max.corr} = 1545 \text{ N}$$

$$CS = \frac{P_{max.corr}}{F_{guiding\ wheel}} \Leftrightarrow CS = \frac{1545}{763{,}4} \Leftrightarrow CS = 2 > 1 \quad \text{ok!}$$

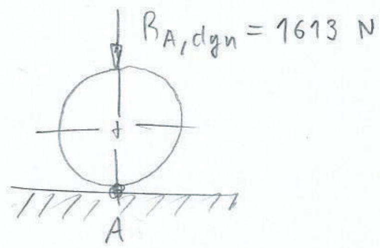
Calculation of the Travelling Wheels (Vehicle Loaded):

i) Consider the highest of the dynamic reactions in the vehicle supports, determined in the document "Preliminary Calculation of Reactions in the Vehicle Supports and stability Check", as the load on the travelling wheels;

ii) The maximum permissible load on the travelling wheels is affected by factors C_1, C_2 and C_3.



Maximum Dynamic Reactions => Wheels A



(2x) wheels => $F_{trav.\ wheel} = \frac{R_{A,dyn}}{2} = \frac{1613}{2} = 806{,}5\ N$

-> Travelling wheel selection:

Brauer -> Polyurethane H125/40 -> $P_{max.} = 530\ kgf = 5199\ N$

$P_{max\ corr} = P_{max} \cdot C_1 \cdot C_2 \cdot C_3 \Leftrightarrow P_{max.\ corr} = 5199 \cdot 0{,}75 \cdot 0{,}7 \cdot 0{,}7 \Leftrightarrow P_{max\text{-}corr} = 1911\ N$

$CS = \frac{P_{max\ corr}}{F_{trav.\ wheel}} \Leftrightarrow CS = \frac{1911}{806{,}5} \Leftrightarrow CS = 2{,}4 > 1$ ok!

ANNEX 2

List of Parts and Assemblies

Drawing Number	Designation	Material	Manufacturing Processes	Surface Finishing	Shuttle Vehicle Subsystem	Where Used
R1-SV01001	Shuttle Vehicle Assembly	-	-	-	Shuttle Vehicle	-
R2-SV01003	Box Support Plate	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Shuttle Vehicle	R1-SV01001
R4-SV01002	Main Structure	Steel EN S235 JR	Cutting, Bending, Welding and Machining	RAL 1018	Shuttle Vehicle	R1-SV01001
R1-SV02001	Travelling System Assembly	-	-	-	Travelling System	R1-SV01001
R1-SV02002	Drive Wheels Assembly	-	-	-	Travelling System	R1-SV02001
R1-SV02003	Driven Wheels Assembly	-	-	-	Travelling System	R1-SV02001
R1-SV02004	Guiding Wheels Assembly	-	-	-	Travelling System	R1-SV02001
R1-SV02005	Assembly of Brush for Rail	-	-	-	Travelling System	R1-SV02001
R2-SV02015	Bar with Two Holes	Steel EN S235 JR	Cutting and Drilling	Zinc Coating	Travelling System	R1-SV02004
R2-SV02018	Rail Brush	Plastic PVC (grey)	Cutting	Natural	Travelling System	R1-SV02005

Drawing Number	Designation	Material	Manufacturing Processes	Surface Finishing	Shuttle Vehicle Subsystem	Where Used
R3-SV02017	Brush Support	Steel EN S235 JR	Cutting, Bending, Welding and Drilling	Zinc Coating	Travelling System	R1-SV02005
R4-SV02010	Support Plate for Gearmotor	Steel EN S235 JR	Cutting, Drilling, Welding and Machining	Zinc Coating	Travelling System	R1-SV02002
R4-SV02016	Fork for Guiding Wheel	Steel EN S235 JR	Cutting, Bending, Drilling and Welding	RAL 1018	Travelling System	R1-SV02004
R5-SV02006	Spacing Washer with Key Slot	Steel EN S235 JR	Machining	Zinc Coating	Travelling System	R1-SV02002
R5-SV02007	Adjuster	Steel EN S235 JR	Machining	Zinc Coating	Travelling System	R1-SV02002 R1-SV02004
R5-SV02008	Tightening Flange for Tollok	Steel EN S235 JR	Machining	Zinc Coating	Travelling System	R1-SV02002
R5-SV02009	Double Sprocket Z17 For Chain 08B-2	Steel EN C45	Machining	Black Oxide	Travelling System	R1-SV02002
R5-SV02011	Cover for Wheel	Steel EN S235 JR	Machining	Zinc Coating	Travelling System	R1-SV02002 R1-SV02003
R5-SV02012	Drive Shaft	Steel EN C45	Machining	Black Oxide	Travelling System	R1-SV02002

Drawing Number	Designation	Material	Manufacturing Processes	Surface Finishing	Shuttle Vehicle Subsystem	Where Used
R5-SV02013-01	Bushing	Steel EN S235 JR	Machining	Zinc Coating	Travelling System	R1-SV02002 R1-SV02003
R5-SV02014	Driven Shaft	Steel EN C45	Machining	Black Oxide	Travelling System	R1-SV02003
R1-SV03001	Extraction System Assembly	-	-	-	Extraction System	R1-SV01001
R1-SV03002	Drive Assembly	-	-	-	Extraction System	R1-SV03001
R1-SV03003	Assembly of The Support Structure	-	-	-	Extraction System	R1-SV03001
R1-SV03004	Assembly of The Fixed Extraction Arm (Left)	-	-	-	Extraction System	R1-SV03001
R1-SV03005	Assembly of The Fixed Extraction Arm (Right)	-	-	-	Extraction System	R1-SV03001
R1-SV03006	Assembly of The Moving Extraction Arm (Left)	-	-	-	Extraction System	R1-SV03001
R1-SV03007	Assembly of The Moving Extraction Arm (Right)	-	-	-	Extraction System	R1-SV03001
R1-SV03010	Assembly of the Chain Deviation Roller	-	-	-	Extraction System	R1-SV03002
R1-SV03021	Chain Tensioner Assembly	-	-	-	Extraction System	R1-SV03003

Drawing Number	Designation	Material	Manufacturing Processes	Surface Finishing	Shuttle Vehicle Subsystem	Where Used
R2-SV03008	Plate With 6 Holes	Steel EN S235 JR	Cutting	Zinc Coating	Extraction System	R1-SV03001
R2-SV03013	Anti-Rotating Washer	Steel EN S235 JR	Cutting	Zinc Coating	Extraction System	R1-SV03010
R2-SV03026	Stringer Support Tube	Steel EN S235 JR	Cutting	Zinc Coating	Extraction System	R1-SV03003
R2-SV03038	Top Cover for Moving Stringers	Steel EN S235 JR	Cutting	Zinc Coating	Extraction System	R1-SV03006 R1-SV03007
R2-SV03041	Stepping Motor Fixing Plate	Steel EN S235 JR	Cutting and Drilling	Zinc Coating	Extraction System	R1-SV03006 R1-SV03007
R3-SV03031	Fixed Stopper	Steel EN S235 JR	Cutting, Bending and Welding	Zinc Coating	Extraction System	R1-SV03004 R1-SV03005
R3-SV03033	Moving Stopper	Steel EN S235 JR	Cutting, Bending and Welding	Zinc Coating	Extraction System	R1-SV03006 R1-SV03007
R5-SV03009	Pin with Two Threaded Holes	Steel EN S235 JR	Machining	Black Oxide	Extraction System	R1-SV03002 R1-SV03003
R5-SV03011	Deviation Roller	Steel EN C45	Machining	Black Oxide	Extraction System	R1-SV03010 R1-SV03021
R5-SV03012	Axle with Groove	Steel EN C45	Machining	Black Oxide	Extraction System	R1-SV03010
R5-SV03014	Bearing Housing	Aluminum 5052	Machining	Natural	Extraction System	R1-SV03002

Drawing Number	Designation	Material	Manufacturing Processes	Surface Finishing	Shuttle Vehicle Subsystem	Where Used
R5-SV03015	Flange for Servo Gearmotor	Aluminum 5052	Machining	Natural	Extraction System	R1-SV03002
R5-SV03016	Support Plate for The Drive Assembly	Aluminum 5052	Machining	RAL 7022	Extraction System	R1-SV03002
R5-SV03017	Support Plate for The Drive Assembly	Aluminum 5052	Machining	RAL 7022	Extraction System	R1-SV03002
R5-SV03018	Drive Shaft	Steel EN C45	Machining	Black Oxide	Extraction System	R1-SV03002
R5-SV03019-01	Bushing with Flange	Steel EN S235 JR	Machining	Zinc Coating	Extraction System	R1-SV03002
R5-SV03019-02	Bushing with Flange	Steel EN S235 JR	Machining	Zinc Coating	Extraction System	R1-SV03021
R5-SV03020	Simple Sprocket Z25 for Chain 06B-1	Steel EN C45	Machining	Black Oxide	Extraction System	R1-SV03002
R5-SV03022-01	Bushing	Steel EN S235 JR	Machining	Zinc Coating	Extraction System	R1-SV03010
R5-SV03022-02	Bushing	Steel EN S235 JR	Machining	Zinc Coating	Extraction System	R1-SV03021
R5-SV03023	Chain Tensioner Fork	Steel EN S235 JR	Machining	Black Oxide	Extraction System	R1-SV03021
R5-SV03024	Chain Tensioner Pin	Steel EN S235 JR	Machining	Black Oxide	Extraction System	R1-SV03021

Drawing Number	Designation	Material	Manufacturing Processes	Surface Finishing	Shuttle Vehicle Subsystem	Where Used
R5-SV03025	Roller Axle	Steel EN C45	Machining	Black Oxide	Extraction System	R1-SV03021
R5-SV03027	Structure of Support of Arms	Aluminum 5052	Machining	RAL 7022	Extraction System	R1-SV03003
R5-SV03028	Support Middle Bock for The Chain	Aluminum 5052	Machining	Natural	Extraction System	R1-SV03003
R5-SV03029	Slider for Chain 06B-1	Plastic PEHD	Machining	Natural	Extraction System	R1-SV03003
R5-SV03030	Fixed Stringer (Right)	Aluminum 6060	Machining	Natural	Extraction System	R1-SV03005
R5-SV03032	Fixed Stringer (Left)	Aluminum 6060	Machining	Natural	Extraction System	R1-SV03004
R5-SV03034	Rack for Chain 06B-1	Steel EN C45	Machining	Black Oxide	Extraction System	R1-SV03004 R1-SV03005
R5-SV03035-01	Slider in PEHD	Plastic PEHD	Extrusion and Cutting	Natural	Extraction System	R1-SV03006 R1-SV03007
R5-SV03035-02	Slider in PEHD	Plastic PEHD	Extrusion and Cutting	Natural	Extraction System	R1-SV03006 R1-SV03007
R5-SV03036	Moving Stringer (Left)	Aluminum 6060	Machining	Natural	Extraction System	R1-SV03006
R5-SV03037-01	Cover for Moving Stringer	Aluminum 5052	Machining	Natural	Extraction System	R1-SV03006

Drawing Number	Designation	Material	Manufacturing Processes	Surface Finishing	Shuttle Vehicle Subsystem	Where Used
R5-SV03037-02	Cover for Moving Stringer	Aluminum 5052	Machining	Natural	Extraction System	R1-SV03007
R5-SV03039-D	Retractable Finger	Steel EN S235 JR	Machining	Black Oxide	Extraction System	R1-SV03006 R1-SV03007
R5-SV03039-E	Retractable Finger	Steel EN S235 JR	Machining	Zinc Coating	Extraction System	R1-SV03006 R1-SV03007
R5-SV03040	Retractable Finger Support	Steel EN S235 JR	Machining	Zinc Coating	Extraction System	R1-SV03006 R1-SV03007
R5-SV03042	Moving Stringer (Right)	Aluminum 6060	Machining	Natural	Extraction System	R1-SV03007
R1-SV04001	Picking System Assembly	-	-	-	Picking System	R1-SV01001
R1-SV04002	Robot Assembly	-	-	-	Picking System	R1-SV04001
R1-SV04003	Gripper Assembly	-	-	-	Picking System	R1-SV04002
R1-SV04007	Robot Rest Rod Assembly	-	-	-	Picking System	R1-SV04001
R2-SV04008	Robot Rest Rod	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Picking System	R1-SV04007

Drawing Number	Designation	Material	Manufacturing Processes	Surface Finishing	Shuttle Vehicle Subsystem	Where Used
R5-SV04004	Gripper Claw	Jaw from SCHUNK ABR-MPG-plus 50	Machining	Natural	Picking System	R1-SV04003
R1-SV05001	Braking Resistor Assembly	-	-	-	Electrical Equipment	R1-SV02001
R1-SV05002	Frequency Inverter Assembly	-	-	-	Electrical Equipment	R1-SV02001
R1-SV05003	Inductive Sensor Assembly	-	-	-	Electrical Equipment	R1-SV02001
R1-SV05004	Limit Switch Assembly	-	-	-	Electrical Equipment	R1-SV02001
R1-SV05005	Bar Code Positioning System Assembly	-	-	-	Electrical Equipment	R1-SV02001
R1-SV05010	Frequency Inverter Assembly	-	-	-	Electrical Equipment	R1-SV03001
R1-SV05011	Energy Chain Assembly	-	-	-	Electrical Equipment	R1-SV03001
R1-SV05012	Photoelectric Sensor Assembly	-	-	-	Electrical Equipment	R1-SV03001
R1-SV05014	Assembly of The Inductive Sensor Target	-	-	-	Electrical Equipment	R1-SV03001

Drawing Number	Designation	Material	Manufacturing Processes	Surface Finishing	Shuttle Vehicle Subsystem	Where Used
R1-SV05016	Laser Sensor Assembly	-	-	-	Electrical Equipment	R1-SV03001
R1-SV05018	Laser Sensor Assembly	-	-	-	Electrical Equipment	R1-SV03001
R1-SV05019	Reflector Mirror Assembly	-	-	-	Electrical Equipment	R1-SV03001
R1-SV05021	Reflector Mirror Assembly	-	-	-	Electrical Equipment	R1-SV03001
R1-SV05023	Reflector Mirror Assembly	-	-	-	Electrical Equipment	R1-SV03001
R1-SV05024	Inductive Sensor Assembly	-	-	-	Electrical Equipment	R1-SV03001
R1-SV05026	Photoelectric Sensor Assembly	-	-	-	Electrical Equipment	R1-SV03001
R1-SV05030	Laser Sensor Assembly	-	-	-	Electrical Equipment	R1-SV03001
R1-SV05032	Photoelectric Sensor Assembly	-	-	-	Electrical Equipment	R1-SV04001
R1-SV05034	Reflector Mirror Assembly	-	-	-	Electrical Equipment	R1-SV04001
R1-SV05036	Switchboard Assembly	-	-	-	Electrical Equipment	R1-SV01001

Drawing Number	Designation	Material	Manufacturing Processes	Surface Finishing	Shuttle Vehicle Subsystem	Where Used
R1-SV05037	Wi-Fi Antenna Assembly	-	-	-	Electrical Equipment	R1-SV01001
R1-SV05039	Collector Assembly	-	-	-	Electrical Equipment	R1-SV01001
R1-SV05041	Bar Code Reader Assembly	-	-	-	Electrical Equipment	R1-SV01001
R2-SV05006-01	L-Shaped Rod D12	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV02005
R2-SV05006-02	L-Shaped Rod D12	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05005 R1-SV05032 R1-SV05034 R1-SV05041
R2-SV05007	Bar Code Positioning System Support	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05005
R2-SV05008	Inductive Sensor Support	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05003
R2-SV05009	Limit Switch Support	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05004
R2-SV05013	Photoelectric Sensor Support	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05012
R2-SV05015	Inductive Sensor Target	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05014

Drawing Number	Designation	Material	Manufacturing Processes	Surface Finishing	Shuttle Vehicle Subsystem	Where Used
R2-SV05017-01	Laser Sensor Support	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05016
R2-SV05017-02	Laser Sensor Support	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05018
R2-SV05020	Reflector Mirror Support	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05019
R2-SV05022	Reflector Mirror Support	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05021
R2-SV05025	Inductive Sensor Support	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05024
R2-SV05027	Photoelectric Sensor Support	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05026
R2-SV05028	Fixed Support for The Energy Chain	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05011
R2-SV05029	Moving Support for The Energy Chain	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05011
R2-SV05031	Laser Sensor Support	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05030
R2-SV05033	Photoelectric Sensor Support	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05032
R2-SV05035	Reflector Mirror Support	Steel EN S235 JR	Cutting	Zinc Coating	Electrical Equipment	R1-SV05034

Drawing Number	Designation	Material	Manufacturing Processes	Surface Finishing	Shuttle Vehicle Subsystem	Where Used
R2-SV05038	Wi-Fi Antenna Support	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05037
R2-SV05040	Collector Locking Plate	Steel EN S235 JR	Cutting, Bending and Welding	Zinc Coating	Electrical Equipment	R1-SV05039
R2-SV05042	Bar Code Reader Support	Steel EN S235 JR	Cutting and Bending	Zinc Coating	Electrical Equipment	R1-SV05041
R1-SV06001	Left Cover Assembly	-	-	-	Covers and Protections	R1-SV01001
R1-SV06002	Right Cover Assembly	-	-	-	Covers and Protections	R1-SV01001
R2-SV06003	Left Cover	Steel EN S235 JR	Cutting and Bending	RAL 3020	Covers and Protections	R1-SV06001
R2-SV06004	Right Cover	Steel EN S235 JR	Cutting and Bending	RAL 3020	Covers and Protections	R1-SV06002
R2-SV06005	Right Cover	Steel EN S235 JR	Cutting and Bending	RAL 3020	Covers and Protections	R1-SV06002

ANNEX 3

Detail Drawings

ANNEX 4

List of Standard Components

Reference	Designation	Manufacturer	Shuttle Vehicle Subsystem	Where Used
G200-2204-2RS	Self-aligning Ball Bearing 2204-2RS	Schaeffler	Extraction System	R1-SV03002
G200-6000-2RS	Deep Groove Ball Bearings 6000-2RS	Schaeffler	Extraction System	R1-SV03010 R1-SV03021
G204-025-48-01	Housing Unit RAY25-XL	Schaeffler	Travelling System	R1-SV02002 R1-SV02003
G212-01-02-125X40-SK1-BR-00	Polyurethane Wheel H125/40	Brauer	Travelling System	R1-SV02002 R1-SV02003
G212-01-02-75x35x12-BR-01	Polyurethane Wheel H75/35/BJM 12	Brauer	Travelling System	R1-SV02004
G603-MAX-GP22A-Amax22-0001	DC Drive GP 22 B (110355)+ A-max 22 GB (353019)	Maxon	Extraction System	R1-SV03006 R1-SV03007
G603-SEW-R27-DRN90S4BE2-0000	Gearmotor R27 DRN90S4BE2/TF	SEW-Eurodrive	Travelling System	R1-SV02002
G603-SEW-RZ07-CMP40MBK-0000	Servo Gearmotor RZ07 CMP40M/BK/KY	SEW-Eurodrive	Extraction System	R1-SV03002
G606-03-01-050	Energy Chain 045.20.038.0 - 54 Links	Igus	Electrical Equipment	R1-SV05011
G607-RE-TL-08B2-17-01	Sprocket 08B-2 Z17 for Taper Lock 1210	Fenner	Travelling System	R1-SV02002

Reference	Designation	Manufacturer	Shuttle Vehicle Subsystem	Where Used
G608-D8187-06B1-20-L=1095,4mm	Maintenance Free Roller Chain DIN 8187 06B-1 (115 Links)	Iwis	Extraction System	R1-SV03001
G608-D8187-06B1-21	Maintenance Free Roller Chain Connecting Link 06B-1	Iwis	Extraction System	R1-SV03001
G608-D8187-08B2-01-L=520,7mm	Maintenance Free Roller Chain DIN 8187 08B-2 (41 Links)	Iwis	Travelling System	R1-SV02002
G608-D8187-08B2-02	Maintenance Free Roller Chain Connecting Link 08B-2	Iwis	Travelling System	R1-SV02002
G609-31-1210-D25-CH8X7	Taper Lock Bushing 1210 D25 – Keyway 8x7	Fenner	Travelling System	R1-SV02002
G610-08-D580-M10-Z	Lifting Eye Bolt DIN 580 M10	Elesa + Ganter	Shuttle Vehicle	R1-SV01001
G612-02-20X28-01	Locking Assembly TLK110 20x28	Rexnord	Extraction System	R1-SV03002
G612-02-25X30-01	Locking Assembly TLK300 25x30	Rexnord	Travelling System	R1-SV02002
G612-02-25X50-02	Locking Assembly TLK200 25x50	Rexnord	Travelling System	R1-SV02002 R1-SV02003
G703-D80x120-M12x35	PU Buffer D80x120-M12x35	Weforma	Travelling System	R1-SV02001
O11-050	Robolink RL-D-RBT-5532-BC	Igus	Picking System	R1-SV04002
O15-050	Gripper EGP 50-N-N-B	Schunk	Picking System	R1-SV04003

ANNEX 5

Standard Components Data Sheets

/medias/en!hp.ec.br.pr//medias/en!hp.pv/2.82.108.2622..-2RSPendelkugellager

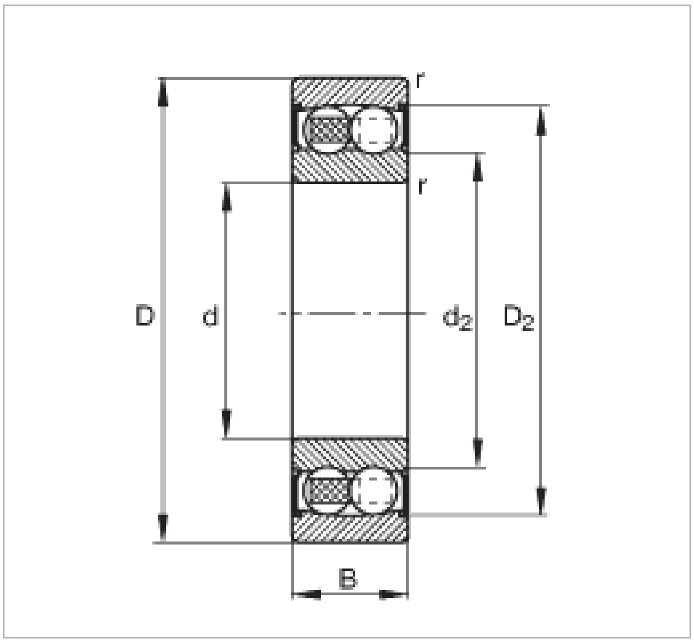
Self-aligning ball bearings

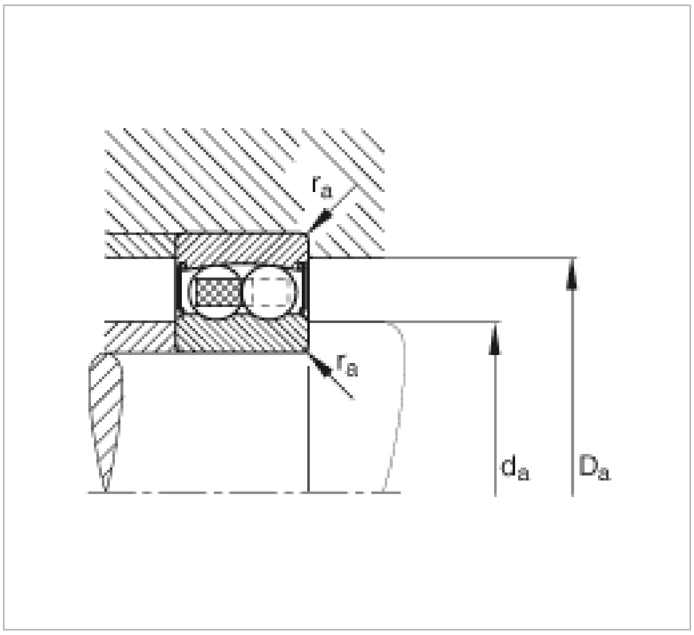
2204-2RS-TVH (Series 22..-2RS)

main dimensions to DIN 630, lip seals on both sides

The datasheet is only an overview of dimensions and basic load ratings of the selected product. Please always observe all the guidelines in these overview pages. Further information is given on many products under the menu item "Description". You can also order comprehensive information via the Catalogue selection system (https://www.schaeffler.de/content.schaeffler.de/en/news_media/index.jsp) or by telephone on +49 (91 32) 82 - 28 97.

d	20	mm	
D	47	mm	
B	18	mm	
D_2	41	mm	
d_2	25,8	mm	
$D_{a\,max}$	41,4	mm	
$d_{a\,min}$	25,6	mm	
$r_{a\,max}$	1	mm	
r_{min}	1	mm	
m	0,151	kg	Mass
C_r	10100	N	Basic dynamic load rating, radial
C_{0r}	2600	N	Basic static load rating, radial
C_{ur}	161	N	Fatigue limit load, radial
n_G	9400	1/min	Limiting speed
e	0,28		
Y_1	2,24		
Y_2	3,46		
Y_0	2,34		


r
r
D
d
d2
D2
B


ra
ra
da
Da

/medias/en!hp.ec.br.pr//medias/en!hp.pv/2.82.108.2660..-2RSRRillenkugellager

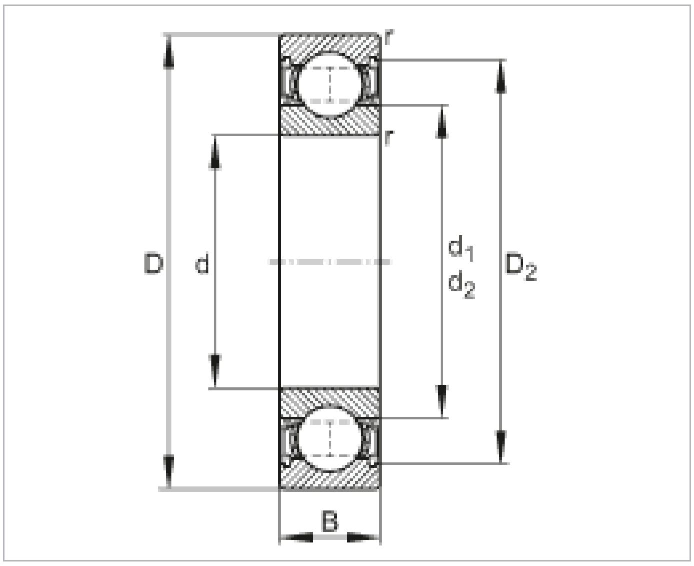
Deep groove ball bearings

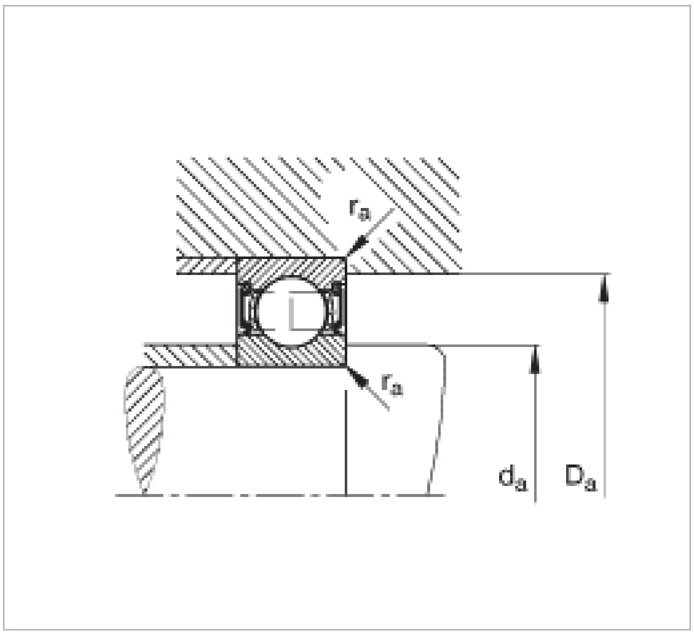
6000-2RSR (Series 60..-2RSR)

main dimensions to DIN 625-1, lip seals on both sides

The datasheet is only an overview of dimensions and basic load ratings of the selected product. Please always observe all the guidelines in these overview pages. Further information is given on many products under the menu item "Description". You can also order comprehensive information via the Catalogue selection system (https://www.schaeffler.de/content.schaeffler.de/en/news_media/index.jsp) or by telephone on +49 (91 32) 82 - 28 97.

d	10	mm	
D	26	mm	
B	8	mm	
d_1	14,7	mm	
D_2	22,5	mm	
D_a max	24	mm	
d_a min	12	mm	
r_a max	0,3	mm	
r_{min}	0,3	mm	
m	0,02	kg	Mass
C_r	4850	N	Basic dynamic load rating, radial
C_{0r}	1970	N	Basic static load rating, radial
C_{ur}	100	N	Fatigue limit load, radial
n_G	18300	1/min	Limiting speed


r
r
D
d
d1
d2
D2
B


ra
ra
da
Da

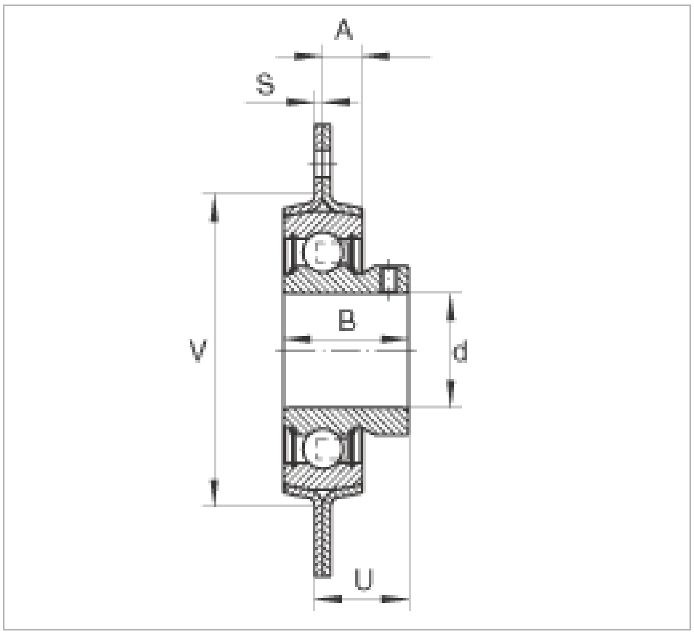
/medias/en!hp.ec.br.pr//medias/en!hp.pv/2.82.108.26RAYGehäuseeinheiten

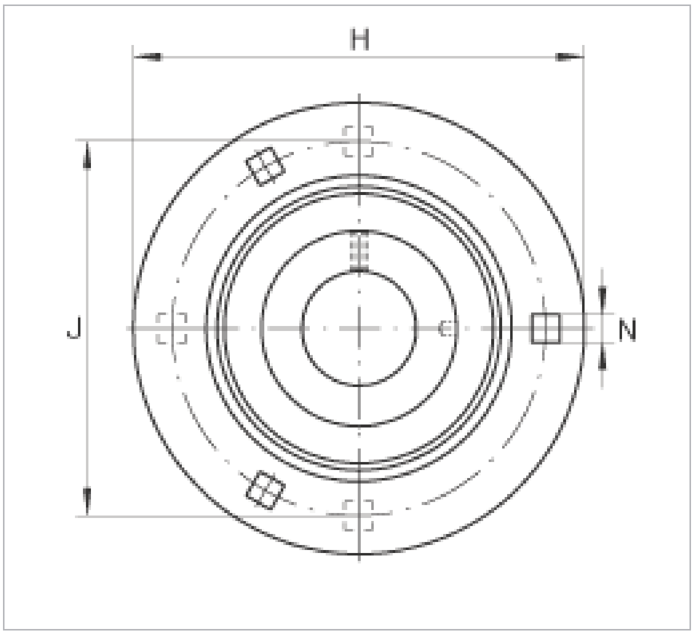
Housing units RAY25-XL (Series RAY)

three/four-bolt flanged housing units, sheet steel, grub screws in inner ring, P seals

The datasheet is only an overview of dimensions and basic load ratings of the selected product. Please always observe all the guidelines in these overview pages. Further information is given on many products under the menu item "Description". You can also order comprehensive information via the Catalogue ordering system (https://www.schaeffler.de/content.schaeffler.de/en/news_media/index.jsp) or by telephone on +49 (91 32) 82 - 28 97.

d	25	mm	
H	95	mm	
B	27	mm	
A	8,7	mm	
J	76	mm	
N	8,7	mm	
n	3		Number of screw holes
S	2	mm	
U	21,5	mm	
V	60	mm	
m	0,34	kg	Mass
C_{0rG}	3650	N	Load carrying capacity of housing, radial
C_r	14900	N	Basic dynamic load rating, radial
C_{0r}	7800	N	Basic static load rating, radial
	FLAN52-MSB (2 X)		Designation of housing
	AY25-XL-NPP-B		Designation of bearing


A
S
V
B
d
U


H
J
N

Polyurethane Tyred Wheels

BRAUER®

Drawings show grease nipple but standard wheels do not come with grease nipple unless specifically requested.

FULL PART NUMBER FOR ORDERING

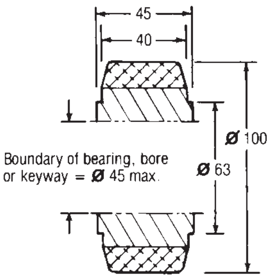
WHEEL TYPE: H100/40

See table for full part number

Maximum load rating: 450Kg

See page 22 for load factors

Approximate weight: 1.5Kg



Axle Ø	Plain Bore	Plain Bore Keywayed	Ball Bearing	Taper Roller Bearing
METRIC AXLE Ø				
12	H100/40/PBM 12	H100/40/KM 12	H100/40/BJM 12	
20	H100/40/PBM 20	H100/40/KM 20	H100/40/BJM 20	
25	H100/40/PBM 25	H100/40/KM 25	H100/40/BJM 25	
30	H100/40/PBM 30	H100/40/KM 30		
35	H100/40/PBM 35	H100/40/KM 35		

Wheels fitted with ball journals are pre-lubricated, double shielded

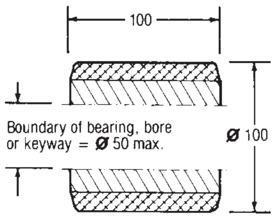
WHEEL TYPE: H100/100

See table for full part number

Maximum load rating: 1100Kg

See page 22 for load factors

Approximate weight: 5Kg



Axle Ø	Plain Bore	Plain Bore Keywayed	Ball Bearing	Taper Roller Bearing
METRIC AXLE Ø			(1)	
20	N/A		H100/100/BJM 20	H100/100/TBM 20
25	N/A		H100/100/BJM 25	H100/100/TBM 25
30	N/A		H100/100/BJM 30	H100/100/TBM 30
35	N/A	H100/100/KM 35		

LOAD LIMITED BY BEARINGS TO: (1) 900Kg

Wheels fitted with ball journals are pre-lubricated, double shielded

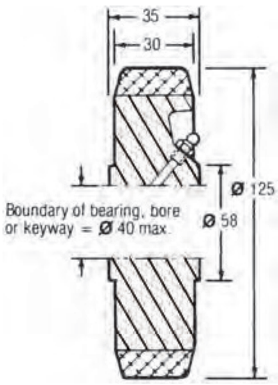
WHEEL TYPE: H125/30

See table for full part number

Maximum load rating: 400Kg

See page 22 for load factors

Approximate weight: 1.5Kg



Axle Ø	Plain Bore	Plain Bore Keywayed	Ball Bearing	Taper Roller Bearing
METRIC AXLE Ø				
20	H125/30/PBM 20	H125/30/KM 20	H125/30/BJM 20	
25	H125/30/PBM 25	H125/30/KM 25	H125/30/BJM 25	
30	H125/30/PBM 30	H125/30/KM 30		
35	H125/30/PBM 35	H125/30/KM 35		

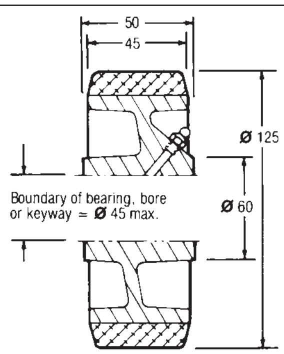
WHEEL TYPE: H125/45

See table for full part number

Maximum load rating: 600Kg

See page 22 for load factors

Approximate weight: 2Kg



Axle Ø	Plain Bore	Plain Bore Keywayed	Ball Bearing	Taper Roller Bearing
METRIC AXLE Ø				
25	H125/45/PBM 25	H125/45/KM 25	H125/45/BJM 25	
30	H125/45/PBM 30	H125/45/KM 30		
35	H125/45/PBM 35	H125/45/KM 35		

BRAUER®

Polyurethane Tyred Wheels

Brauer HEAVITHANE™ Polyurethane is resilient, durable material, resistant to abrasion and to many common chemicals. Polyurethane tyred wheels are capable of carrying heavy loads and of transmitting driving forces.

MATERIAL: Wheel centre – cast iron to BS1452: 1977: Grade 200 or steel to BS970: Part 1: 1983: 080M40.
Tyre – Polyester based polymer of 92°± 3° A Shore hardness.

OPERATING TEMPERATURE RANGE:
-20°C to +60°C (115°C for limited use)

PLEASE SPECIFY IF OPERATING IN HIGH HUMIDITY.
Anti-hydrolysis polyurethane is recommended for use in an operating environment of high humidity.

Polyurethane to the above hardness used on these wheels is Vulkollan, a high quality material that provides superior performance in most applications.

Should the mechanical properties of standard Vulkollan be inappropriate for the application, alternative grades of Polyurethane can be produced to meet the requirements. Polyurethane can be bonded onto most metal centres including aluminium, titanium, stainless steel and various ferrous and non-ferrous alloys.

The ‘maximum load rating’ given for each wheel is for operation under ideal conditions. Load factors must be applied according to the anticipated working conditions – see ‘Design Data’ para. 5.1.

For wheels of larger diameter or greater load capacity see the PH series on pages 78-81. Alternative bore/bearing diameters and alternative bearing types (i.e. bronze bushes, self-lubricating bushes, roller bearings, spherical roller bearings, etc.) are available to order – see page 26-27.

For technical information covering load factors, chemical resistance, inertial and rolling resistance, coefficients of friction between wheel and surface, and keyway dimensions, see “Design Data” Index on page 20.

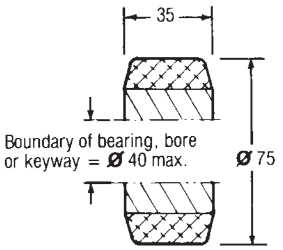
Drawings show grease nipple but standard wheels do not come with grease nipple unless specifically requested.

Tyres can be produced with crown/dome treads to suit specific applications.

ALLOWABLE LOADS @ 6KPH

FULL PART NUMBER FOR ORDERING

WHEEL TYPE:
H75/35
See table for full part number



Maximum load rating:
300Kg

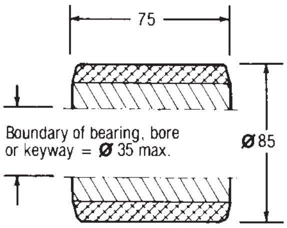
See page 22 for load factors

Approximate weight: 0.5Kg

Axle Ø	Plain Bore	Plain Bore Keywayed	Ball Bearing	Taper Roller Bearing
METRIC AXLE Ø				
12	H75/35/PBM 12	H75/35/KM 12	H75/35/BJM 12	
20	H75/35/PBM 20	H75/35/KM 20	H75/35/BJM 20	
25	H75/35/PBM 25	H75/35/KM 25		
30	H75/35/PBM 30	H75/35/KM 30		

Wheels fitted with ball journals are pre-lubricated, double shielded

WHEEL TYPE:
H85/75
See table for full part number



Maximum load rating:
700Kg

See page 22 for load factors

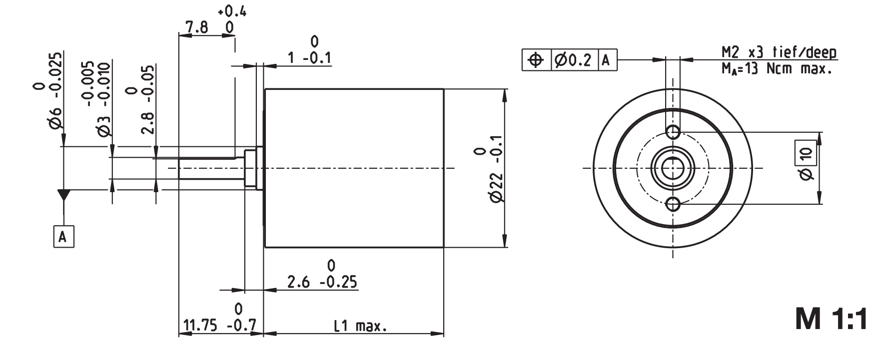
Approximate weight: 0.6Kg

Axle Ø	Plain Bore	Plain Bore Keywayed	Ball Bearing	Taper Roller Bearing
METRIC AXLE Ø				
20	N/A		H85/75/BJM 20	

Wheels fitted with ball journals are pre-lubricated, double shielded

POLYURETHANE TYRED

Planetary Gearhead GP 22 B ∅22 mm, 0.1–0.3 Nm



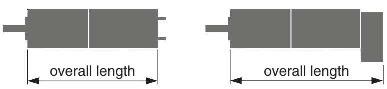
Technical Data

Planetary Gearhead	straight teeth
Housing	steel
Output shaft	stainless steel, hardened
Bearing at output	sleeve bearing
Radial play, 6 mm from flange	max. 0.06 mm
Axial play	0.02–0.10 mm
Max. axial load (dynamic)	8 N
Max. force for press fits	100 N
Direction of rotation, drive to output	=
Max. continuous input speed	8000 rpm
Recommended temperature range	-30…+100°C
Extended range as option	-40…+100°C
Number of stages	1 2 3 4 5
Max. radial load, 6 mm from flange	8 N 12 N 16 N 20 N 20 N

maxon gear

Stock program
Standard program
Special program (on request)

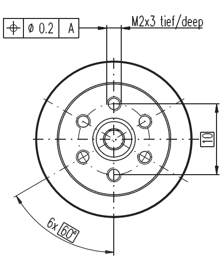
			Part Numbers							
			110355	110356	110357	118653	110358	134772	110359	134775
Gearhead Data										
1	Reduction		4.4 : 1	19 : 1	84 : 1	157 : 1	370 : 1	690 : 1	1621 : 1	3027 : 1
2	Absolute reduction		57/13	3249/169	185193/2197	19683/125	10556001/28561	1121931/1625	601692057/371293	63950067/21125
3	Max. motor shaft diameter	mm	2	2	2	1.5	2	2	2	2
	Part Numbers		118651	134767	134768		134770	118654	134773	134776
1	Reduction		5.4 : 1	24 : 1	104 : 1		455 : 1	850 :1	1996 : 1	3728 : 1
2	Absolute reduction		27/5	1539/65	87723/845		5000211/10985	531441/625	285012027/142805	30292137/8125
3	Max. motor shaft diameter	mm	1.5	2	2		2	1.5	2	2
	Part Numbers			118652	134769		134771		134774	118655
1	Reduction			29 : 1	128 : 1		561 : 1		2458 : 1	4592 : 1
2	Absolute reduction			729/25	41553/325		2368521/4225		135005697/54925	14348907/3125
3	Max. motor shaft diameter	mm		1.5	2		2		2	1.5
4	Number of stages		1	2	3	3	4	4	5	5
5	Max. continuous torque	Nm	0.10	0.15	0.20	0.20	0.25	0.25	0.30	0.30
6	Max. intermittent torque at gear output	Nm	0.150	0.225	0.300	0.300	0.375	0.375	0.450	0.450
7	Max. efficiency	%	90	81	73	73	65	65	59	59
8	Weight	g	39	48	57	57	65	65	73	73
9	Average backlash no load	°	1.4	1.6	2.0	2.0	2.4	2.4	3.0	3.0
10	Mass inertia	gcm²	0.07	0.05	0.05	0.05	0.05	0.05	0.05	0.05
11	Gearhead length L1	mm	15.9	19.5	23.1	23.1	26.7	26.7	30.3	30.3



maxon Modular System

+ Motor	Page	+ Sensor/Brake	Page	Overall length [mm] = Motor length + gearhead length + (sensor/brake) + assembly parts							
A-max 22	147-150			47.9	51.5	55.1	55.1	58.7	58.7	62.3	62.3
A-max 22	148/150	MR	416/417	52.9	56.5	60.1	60.1	63.7	63.7	67.3	67.3
A-max 22	148/150	Enc 22	426	62.3	65.9	69.5	69.5	73.1	73.1	76.7	76.7
A-max 22	148/150	MEnc 13	407	55.0	58.6	62.2	62.2	65.8	65.8	69.4	69.4

Option Ball Bearing



Part Numbers

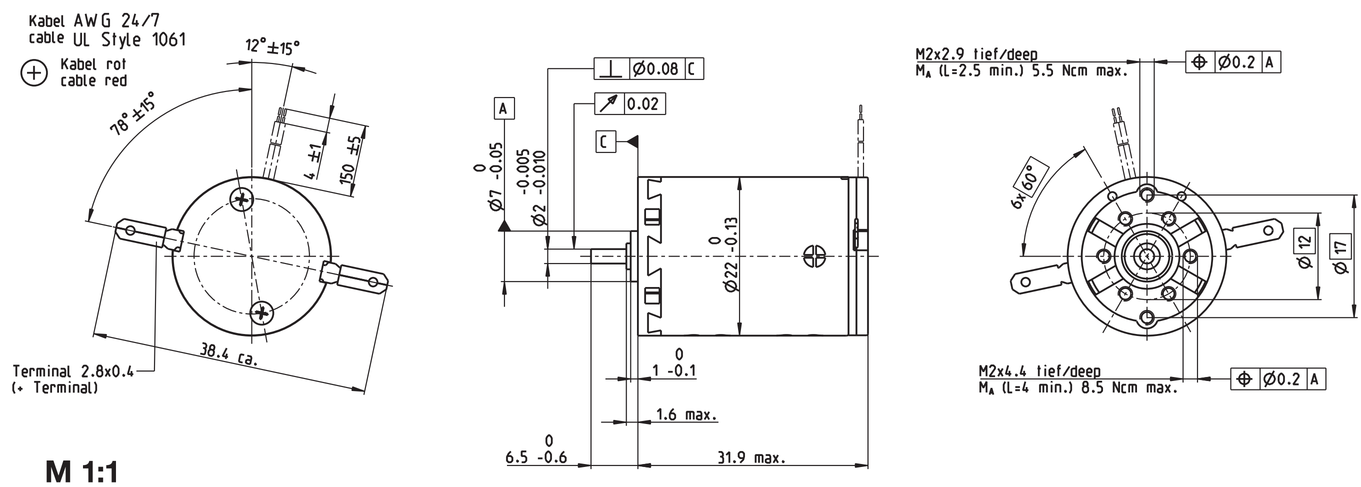
4.4 : 1	144137	455 : 1	144147
5.4 : 1	144138	561 : 1	144148
19 : 1	144139	690 : 1	144149
24 : 1	144140	850 : 1	144150
29 : 1	144141	1621 : 1	144151
84 : 1	144142	1996 : 1	144152
104 : 1	144143	2458 : 1	144153
128 : 1	144144	3027 : 1	144154
157 : 1	144145	3728 : 1	144155
370 : 1	144146	4592 : 1	144156

Technical Data

Planetary Gearhead	straight teeth
Housing	steel
Output shaft	stainless steel, hardened
Bearing at output	preloaded ball bearings
Radial play, 6 mm from flange	max. 0.08 mm
Axial play at axial load < 4 N	0 mm
> 4 N	max. 0.05 mm
Max. axial load (dynamic)	8 N
Max. force for press fits	25 N
Direction of rotation, drive to output	=
Max. continuous input speed	8000 rpm
Recommended temperature range	-40…+100°C
Number of stages	1 2 3 4 5
Max. radial load, 6 mm from flange	10 N 15 N 20 N 20 N 20 N

Gearhead values according to sleeve bearing version

A-max 22 ∅22 mm, Graphite Brushes, 6 Watt



M 1:1

- Stock program
- Standard program
- Special program (on request)

Part Numbers

		1	2	3	4	5	6	7	8	9	10	11	12
with terminals		110143	110145	110146	**110147**	110148	110149	110150	**110151**	110152	110153	110154	110155
with cables		139840	353017	199807	320206	323856	108828	199424	202921	267433	325492	313302	353019
Motor Data													
Values at nominal voltage													
1 Nominal voltage	V	6	9	9	12	12	15	18	24	24	36	48	48
2 No load speed	rpm	9240	9690	8500	10200	9170	10000	9770	10500	8480	9630	9110	8210
3 No load current	mA	83.1	57.9	49.6	45.8	40.5	36	29	23.7	18.4	14.2	9.99	8.84
4 Nominal speed	rpm	6240	6530	5350	7060	6000	6890	6600	7380	5270	6420	5840	4940
5 Nominal torque (max. continuous torque)	mNm	5.91	6.88	7.04	6.96	6.95	6.93	6.92	6.9	6.97	6.86	6.75	6.86
6 Nominal current (max. continuous current)	A	1.08	0.859	0.77	0.681	0.613	0.534	0.432	0.347	0.283	0.21	0.147	0.135
7 Stall torque	mNm	19.4	22.1	19.8	23.7	20.9	22.9	22	23.7	18.9	21.1	19.2	17.6
8 Stall current	A	3.29	2.59	2.04	2.17	1.72	1.65	1.29	1.12	0.721	0.606	0.393	0.325
9 Max. efficiency	%	67	70	69	72	70	72	72	73	70	72	71	70
Characteristics													
10 Terminal resistance	Ω	1.82	3.48	4.42	5.53	6.96	9.09	14	21.5	33.3	59.4	122	148
11 Terminal inductance	mH	0.106	0.223	0.288	0.363	0.445	0.585	0.891	1.37	2.1	3.69	7.3	8.97
12 Torque constant	mNm/A	5.9	8.55	9.73	10.9	12.1	13.9	17.1	21.2	26.2	34.8	48.9	54.3
13 Speed constant	rpm/V	1620	1120	981	875	790	689	558	450	364	274	195	176
14 Speed / torque gradient	rpm/mNm	500	454	446	444	455	452	457	456	461	468	487	479
15 Mechanical time constant	ms	20.9	20.2	20.1	19.9	19.9	19.9	19.7	19.7	19.8	19.7	19.9	19.8
16 Rotor inertia	gcm²	4	4.25	4.3	4.29	4.19	4.2	4.13	4.13	4.09	4.02	3.9	3.94

Specifications

Thermal data

17	Thermal resistance housing-ambient	20 K/W
18	Thermal resistance winding-housing	6.0 K/W
19	Thermal time constant winding	10.2 s
20	Thermal time constant motor	314 s
21	Ambient temperature	-30…+85°C
22	Max. winding temperature	+125°C

Mechanical data (sleeve bearings)

23	Max. speed	9800 rpm
24	Axial play	0.05 - 0.15 mm
25	Radial play	0.012 mm
26	Max. axial load (dynamic)	1 N
27	Max. force for press fits (static)	80 N
28	Max. radial load, 5 mm from flange	2.8 N

Mechanical data (ball bearings)

23	Max. speed	9800 rpm
24	Axial play	0.05 - 0.15 mm
25	Radial play	0.025 mm
26	Max. axial load (dynamic)	3.3 N
27	Max. force for press fits (static)	45 N
28	Max. radial load, 5 mm from flange	12.3 N

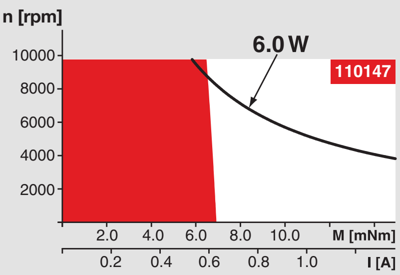
Other specifications

29	Number of pole pairs	1
30	Number of commutator segments	9
31	Weight of motor	54 g

Values listed in the table are nominal.
Explanation of the figures on page 64.

Option
Ball bearings in place of sleeve bearings

Operating Range



Comments

Continuous operation
In observation of above listed thermal resistance (lines 17 and 18) the maximum permissible winding temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit.

Short term operation
The motor may be briefly overloaded (recurring).

Assigned power rating

maxon Modular System

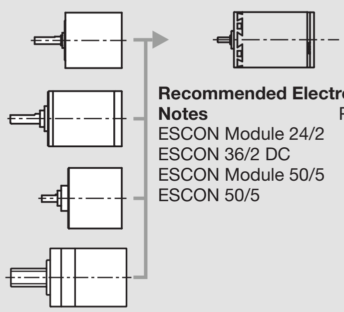
Overview on page 28–36

Planetary Gearhead
∅22 mm
0.1 - 0.6 Nm
Page 331/332

Planetary Gearhead
∅22 mm
0.5 - 2.0 Nm
Page 333/335

Spur Gearhead
∅24 mm
0.1 Nm
Page 339

Screw Drive
∅22 mm
Page 372/373



Recommended Electronics:

Notes	Page 30
ESCON Module 24/2	444
ESCON 36/2 DC	444
ESCON Module 50/5	445
ESCON 50/5	447

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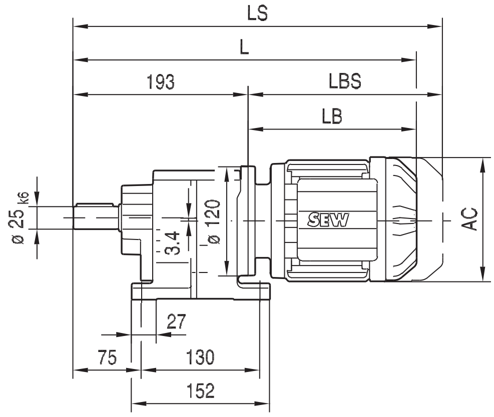
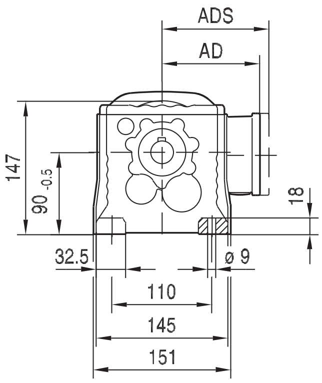
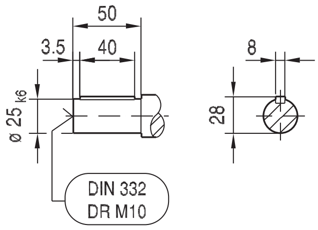
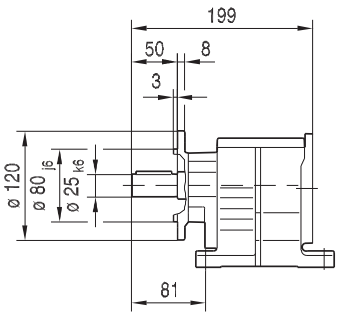
R27..

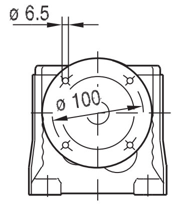






R27F..



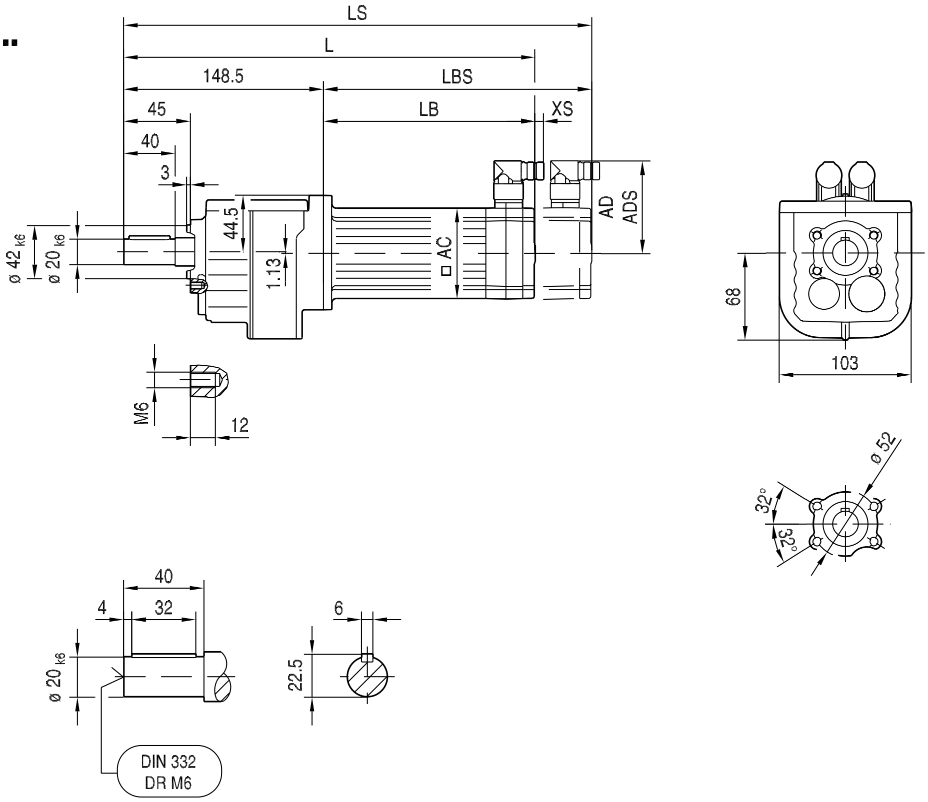


(→ 155)	DR63..	DR71S	DR71M	DRN80M	DRN90S	DRN90L	DRN100LS	DRN100L
AC	132	139	139	156	179	179	197	197
AD	105	119	119	128	140	140	157	157
ADS	105	129	129	139	150	150	158	158
L	384	395	420	475	476	508	507	557
LS	439	463	488	556	570	602	601	651
LB	191	202	227	282	283	315	314	364
LBS	246	270	295	363	377	409	408	458

21933189/EN – 11/2015

01 027 00 07

RZ07..



(→ 194)	CMP..						
	40M						
AC	57						
AD	78						
ADS	78						
L	284						
LS	314						
LB	136						
LBS	166						
XS	19						

22316612/EN – 04/2017

E045 Z045

E-Chain System® E-Z Chain Series E045/Z045

.37 .37

Price Index

Series E045

Special Features / Options

IPA

IPA Qualification Certificate
Air Cleanliness Class ISO Class 2
(at v = 3.28 ft/s) upon request

Flammability Class
VDE 0304 IIC UL94 V2

EX

Special equipment: Electrically conductive ESD/ATEX version upon request

Assembly Tips

Just push the cables into the E-Chain using your thumb

Usage Guidelines

+

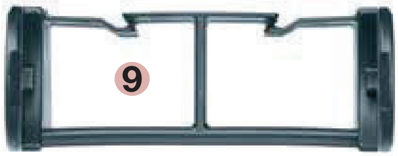
- If filling is required without opening and closing
- If a very small pitch is required

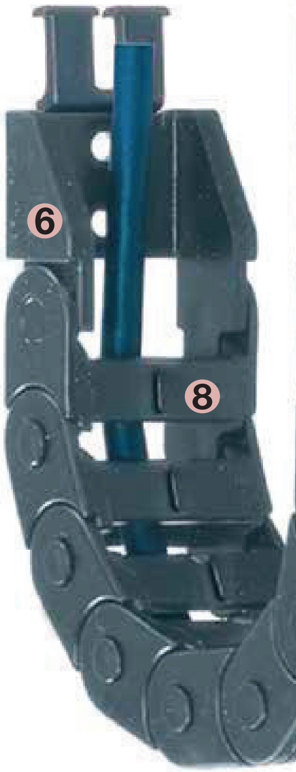
−

- If smooth operation is required
  ➤ **Series 045 E2 Micro**
- If high stability is required
  ➤ **Series 06 E2 Micro**
- If non-opening is required
  ➤ **Series 045 E2 Micro**

Features & Benefits

1. Limited torsion tolerance
2. Small pitch for low-noise and smooth operation
3. Cable friendly interior
4. Patented push button design holds the links together
5. Very easy to fill
6. Mounting brackets available
7. "E" Series features split crossbar along the outer radius
8. "Z" Series features split crossbar along the inner radius
9. 1-, 2-, or 3-chamber system available





Order Example: Complete E-Chain®

Please indicate chain length or number of links. Example:

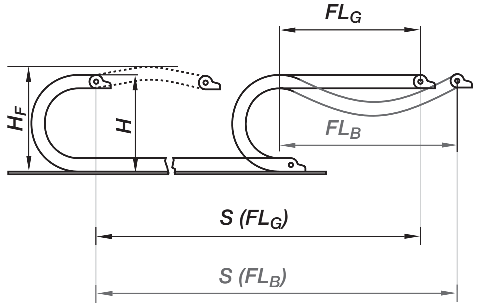
3.28 ft (1 m) **E045-16-038-0**	**E-Chain®**
1 Set **0450-16-12**	**Mounting Bracket**

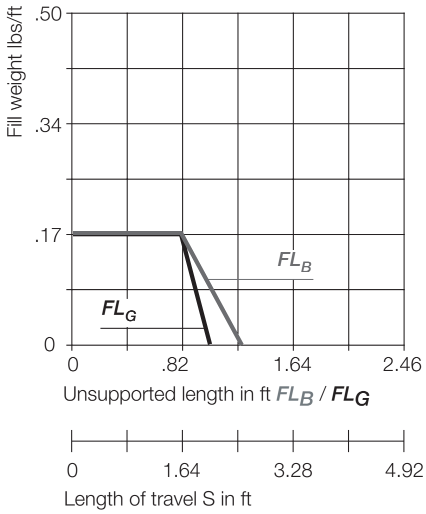
E-Chain System® E-Z Chain Series E045/Z045 Installation Dimensions

Short travel, unsupported length

- FL_B = unsupported with permitted sag
- FL_G = unsupported with straight upper run

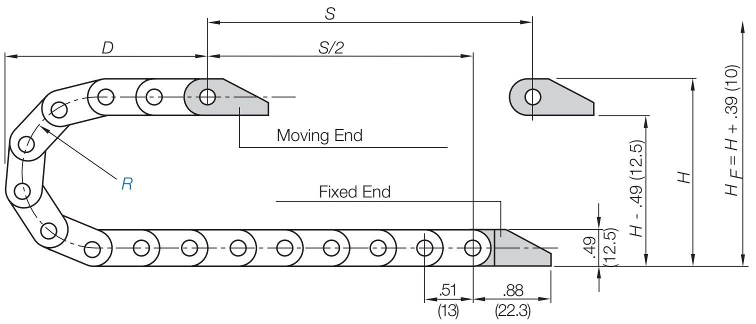
Further information ➤ Design, Chapter 1





Short Travels - Unsupported

Unsupported E-Chains® feature positive camber over short travels. This must be accounted for when specifying the clearance height. Please refer to **Installation dimensions** for further details.



Pitch per link: = .51" (13 mm)
Links per ft (m): = 23.47 (77)
For center mount applications:
Chain length = $S/2 + K$

Legend

- S = Length of travel
- R = Bending radius
- H = Nominal clearance height
- D = Overlength E-Chain® radius in final position
- *K* = π • *R + safety buffer*
- H_F = Required clearance height

The required clearance height: ***H_F = H* + .39 in. (10 mm)** (with .067 lbs/ft (0.1 kg/m) fill weight.
Please consult igus® if space is particularly restricted.

R	.71 (018)	1.10 (028)	1.50 (038)
H	1.91 (48.5)	2.70 (68.5)	3.48 (88.5)
D	1.73 (44)	2.13 (54)	2.52 (64)
K	3.35 (85)	4.53 (115)	5.91 (150)

PDF: www.igus.com/E-Chain-pdfs
Specs/CAD/RFQ: www.igus.com/E-Chains
RoHS info: www.igus.com/RoHS

Technical Data

Speed / acceleration FL_G	max. 65.6 ft/s (20 m/s) / max. 656 ft/s² (200 m/s²)
Speed / acceleration FL_B	max. 9.84 ft/s (3 m/s) / max. 19.69 ft/s² (6 m/s²)
Material (E-Chain®) - permitted temperature	igumid NB / -40°F (-40°C) up to +176°F (+80° C)
Material (mounting brackets)* - permitted temperature	igumid G / -40°F (-40°C) up to +248°F (+120° C)
Flammability Class (E-Chain®), igumid NB	VDE 0304 IIC UL94 V2
Flammability Class (mounting brackets), igumid G	VDE 0304 IIC UL94 HB

Details of material properties
➤ Chapter 1

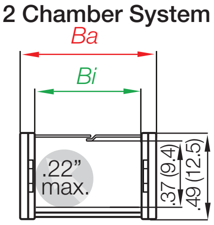
E-Chain System® E-Z Chain Series E045/Z045

Telephone 1-800-521-2747
Fax 1-401-438-7270

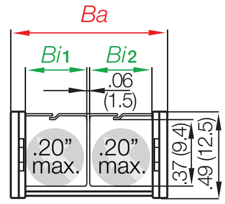
Internet: http://www.igus.com
email: sales@igus.com
QuickSpec: http://www.igus.com/quickspec

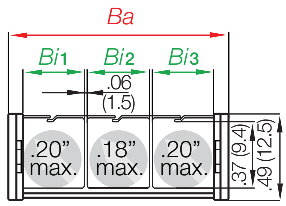
Series E045 - Split crossbar along the outer radius

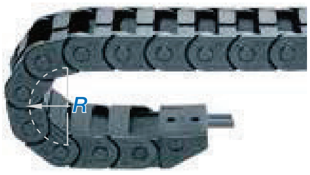
Single Chamber System
2 Chamber System

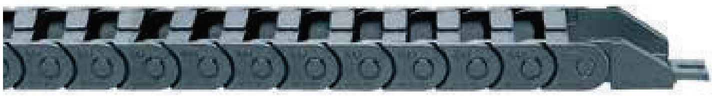


3 Chamber System

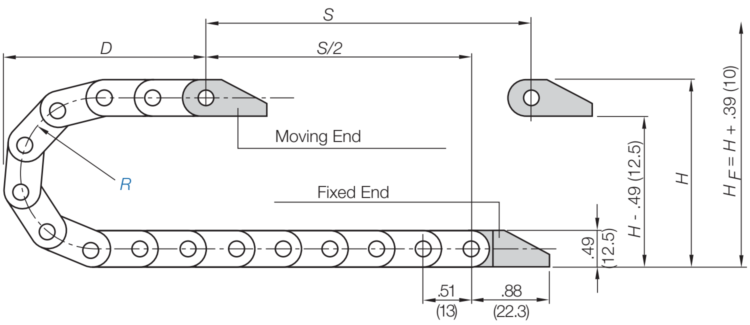




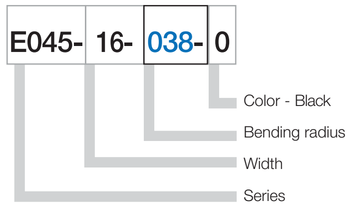




Supplement part number with required radius. Example: E045-16-038-0
Pitch: .51 in. (13 mm) per link links/ft (m) = 23..47 (77)



Part Number Structure



Part Number	Bi in. (mm)	Ba in. (mm)	Weight lbs/ft (kg/m)	Crossbar Gap in. (mm)
Single Chamber System				
E045-10-[ ] -0*	.39 (10)	.63 (16)	≈ 0.06 (0.09)	.08 (2)
E045-16-[ ] -0	.63 (16)	.91 (23)	≈ 0.07 (0.11)	-
2 Chamber System				
E045-2/7-[ ] -0*	.28/.28 (7/7)	.91 (23)	≈ 0.09 (0.13)	.09 (2.25)
E045-2/9-[ ] -0*	.35/.35 (9/9)	1.06 (27)	≈ 0.09 (0.14)	.09 (2.25)
3 Chamber System				
E045-3/9-[ ] -0*	.35/.35/.35 (9/9/9)	1.46 (37)	≈ 0.11 (0.17)	.09 (2.25)

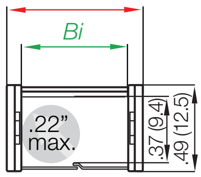
Choose from the radii below for all of the above sizes
Radius (mm) Example: E045-16-038-0

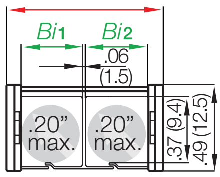
	018	028	038
R	.71 (018)	1.10 (028)	1.50 (038)
H	1.91 (48.5)	2.70 (68.5)	3.48 (88.5)
D	1.73 (44)	2.13 (54)	2.52 (64)
K	3.35 (85)	4.53 (115)	5.91 (150)

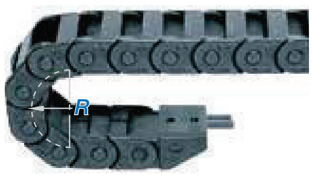
0=Standard color black. For other colors see Chapter 1
*Please note: For this series the crossbars do not overlap. Please see table for gap amount.

Series Z045 - Split crossbar along the inner radius

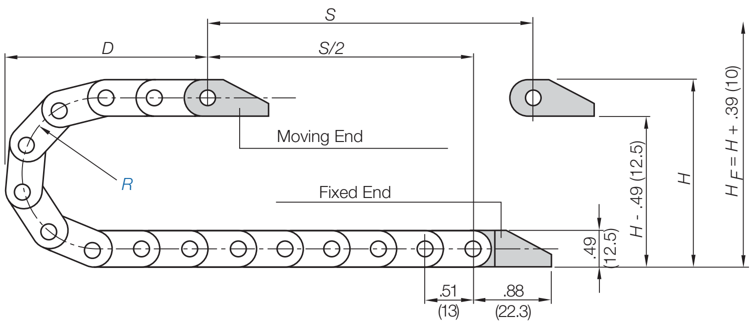
Single Chamber System
2 Chamber System



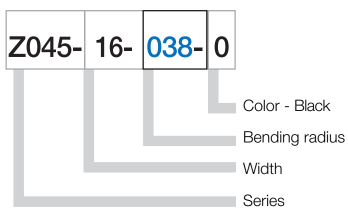




Supplement part number with required radius. Example: Z045-16-038-0
Pitch: .51 in. (13 mm) per link links/ft (m) = 23..47 (77)



Part Number Structure



Part Number Single Chamber System	*Bi* in. (mm)	*Ba* in. (mm)	Weight lbs/ft (kg/m)	Crossbar Gap in. (mm)
Z045-16- [ ] -0*	.63 (16)	.91 (23)	≈ 0.07 (0.11)	.08 (2)
2 Chamber System				
Z045-2/7- [ ] -0*	.28/.28 (7/7)	.91 (23)	≈ 0.09 (0.13)	.09 (2.25)

Choose from the radii below for all of the above sizes
Radius (mm) Example: Z045-16-038-0

	018	028	038
R	.71 (018)	1.10 (028)	1.50 (038)
H	1.91 (48.5)	2.70 (68.5)	3.48 (88.5)
D	1.73 (44)	2.13 (54)	2.52 (64)
K	3.35 (85)	4.53 (115)	5.91 (150)

0=Standard color black. For other colors see Chapter 1
*Please note: For this series the crossbars do not overlap. Please see table for gap amount.

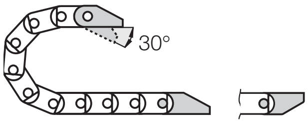
PDF: www.igus.com/E-Chain-pdfs
Specs/CAD/RFQ: www.igus.com/E-Chains
RoHS info: www.igus.com/RoHS

E-Chain System® E-Z Chain Series E045/Z045 Mounting Brackets

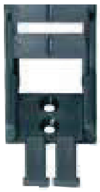
Polymer, one-piece

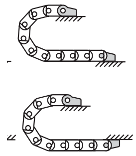
- One-piece mounting bracket
- Corrosion resistant
- Available preassembled

Moving end
0450 ...1(PZ)



Fixed end
0450...2(PZ)





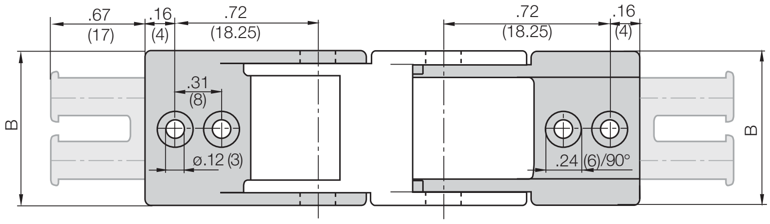
Possible installation configurations -

Part Number Structure

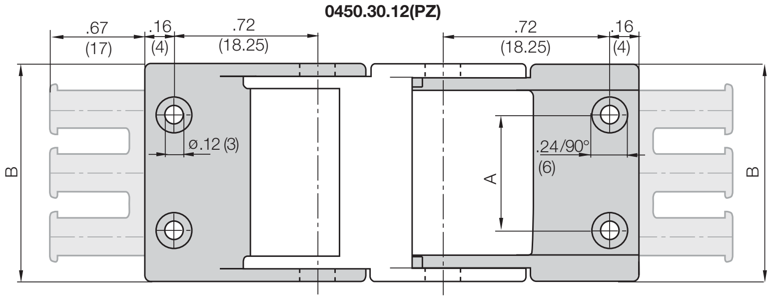
0450- | 10- | 12 | PZ

- PZ: With tiewrap plates
- 12: Complete Set
- 10-: Width
- 0450-: Mounting brackets for selected chain type

0450.10.12(PZ) – 0450.20.12(PZ)



0450.30.12(PZ)



Full set, for both ends:
0450- 10- 12 PZ
Full set, **each part with pin/bore + tiewrap plate**

Single-part order:
0450- 10- 1 PZ
Mounting bracket **with bore + tiewrap plate**
0450- 10- 2 PZ
Mounting bracket **with pin + tiewrap plate**

Chain Type	Part No. Full set with Tiewrap Plate	Part No. Full Set without Tiewrap Plate	Dimension A in.	Dimension A (mm)	Dimensions B in.	Dimensions B (mm)	Number of Teeth
E045/Z045-10	**0450-10-12PZ**	**0450-10-12**	—	—	.63	(16)	1
E045/Z045-16	**0450-16-12PZ**	**0450-16-12**	—	—	.87	(22)	2
E045/Z045-2/7	**0450-16-12PZ**	**0450-16-12**	—	—	.87	(22)	2
E045/Z045-2/9	**0450-20-12PZ**	**0450-20-12**	—	—	1.02	(26)	2
E045/Z045-3/9	**0450-30-12PZ**	**0450-30-12**	.87	(22)	1.42	(36)	3

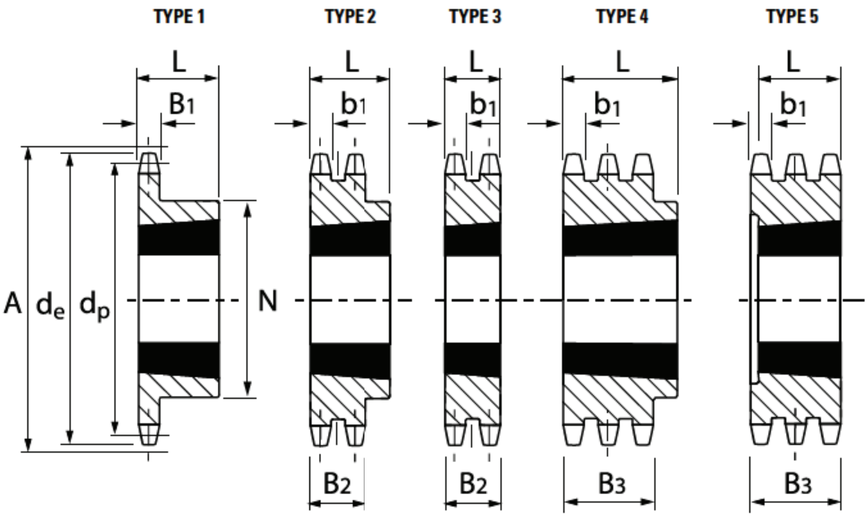
Additional Accessories

Quickfix - mounting bracket
with dowel, upon request
Part No.
0450-16-12Q

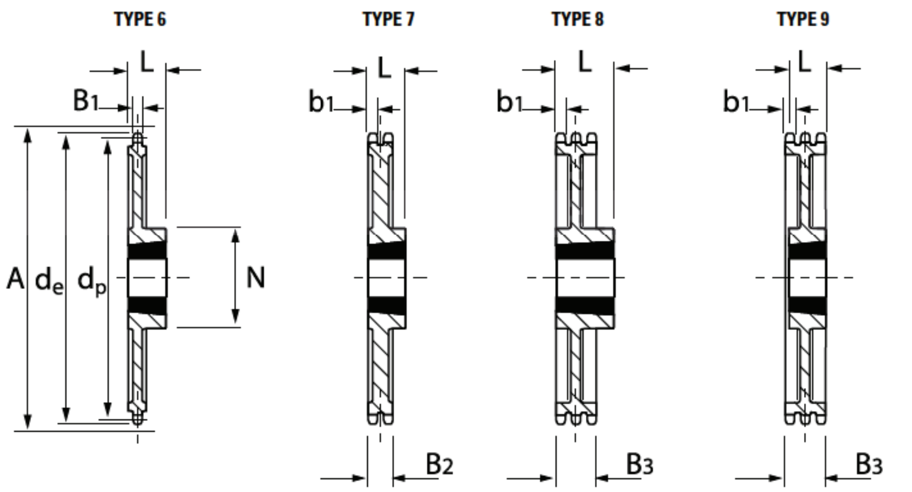
igus® E-Chain System®
Telephone 1-800-521-2747
Fax 1-401-438-7270
Internet: http://www.igus.com
email: sales@igus.com
QuickSpec: http://www.igus.com/quickspec

Taper Lock® Sprockets

STEEL C45



CAST IRON GG22



06B T/L SPROCKET 3/8" (9.5mm) PITCH

Tooth Width

B1	5.3mm
b1	5.2mm
B2	15.4mm
B3	25.6mm

No.of Teeth	Pitch Dia dp (mm)	Outer Dia de (mm)	Dia Over Chain A (mm)	Simplex Taper Lock Product code	Simplex Desig-nation	Simplex Bush No.	Simplex Type	Simplex Length Bore L (mm)	Simplex Hub Dia N (mm)	Duplex Taper Lock Product code	Duplex Desig-nation	Duplex Bush No.	Duplex Type	Duplex Length Bore L (mm)	Duplex Hub Dia N (mm)	Triplex Taper Lock Product code	Triplex Desig-nation	Triplex Bush No.	Triplex Type	Triplex Length Bore L (mm)	Triplex Hub Dia N (mm)
17	51.84	56	60	026A0117	**31–17**	1008	1	22.2	45	026A0217	**32–17**	1008	2	22.2	45	026A0317	**33–17**	1008	5	25.6	
19	57.86	62	66	026A0119	**31–19**	1008	1	22.2	45	026A0219	**32–19**	1008	2	22.2	45	026A0319	**33–19**	1008	5	25.6	
20	60.89	64	68	026A0120	**31–20**	1008	1	22.2	46												
21	63.91	68	72	026A0121	**31–21**	1008	1	22.2	46	026A0221	**32–21**	1008	2	22.2	49	026A0321	**33–21**	1008	5	25.6	
23	69.95	74	78	026A0123	**31–23**	1210	1	25.4	63	026A0223	**32–23**	1210	2	25.4	59	026A0323	**33–23**	1210	5	25.6	
25	76.00	80	84	026A0125	**31–25**	1210	1	25.4	63	026A0225	**32–25**	1210	2	25.4	65	026A0325	**33–25**	1210	5	25.6	
27	82.05	86	90	026A0127	**31–27**	1210	1	25.4	63	026A0227	**32–27**	1210	2	25.4	70	026A0327	**33–27**	1210	5	25.6	
30	91.12	95	99	026A0130	**31–30**	1210	1	25.4	63	026A0230	**32–30**	1210	2	25.4	75	026A0330	**33–30**	1615	4	38.0	79
38	115.34	119	123	026A0138	**31–38**	1210	1	25.4	70	026A0238	**32–38**	1610	2	25.4	80	026A0338	**33–38**	1615	4	38.0	90
45	136.55	141	145	026A0145	**31–45**	1210	1	25.4	70	026A0245	**32–45**	1610	2	25.4	80						
57	172.90	177	181	026A0157	**31–57**	1210	6	25.4	83	026A0257	**32–57**	1610	7	25.4	80						
76	230.48	234	239	026A0176	**31–76**	1210	6	25.4	83	026A0276	**32–76**	1610	7	25.4	92						
95	288.08	292	296	026A0195	**31–95**	1210	6	25.4	83	026A0295	**32–95**	1610	7	25.4	92						

Taper Lock bushes supplied as a separate items

Taper Lock® Sprockets

08B T/L SPROCKET ½" (12.7mm) PITCH

Tooth Width

B_1	7.2mm
b_1	7.0mm
B_2	21.0mm
B_3	34.9mm

No.of Teeth	Pitch Dia.	Outer Dia	Dia Over Chain	Simplex Taper Lock						Duplex Taper Lock						Triplex Taper Lock					
	dp (mm)	de (mm)	A (mm)	Product code	Desig-nation	Bush No.	Type	Length Bore L (mm)	Hub Dia N (mm)	Product code	Desig-nation	Bush No.	Type	Length Bore L (mm)	Hub Dia N (mm)	Product code	Desig-nation	Bush No.	Type	Length Bore L (mm)	Hub Dia N (mm)
15	61.09	66	73	026B0115	**41–15**	1008	1	22.2	45	026B0215	**42–15**	1008	2	22.2	46	026B0315	**43–15**	1008	5	34.9	
17	69.11	74	81	026B0117	**41–17**	1210	1	25.4	60	026B0217	**42–17**	1210	2	25.4	56	026B0317	**43–17**	1210	5	34.9	
19	77.17	82	89	026B0119	**41–19**	1210	1	25.4	63	026B0219	**42–19**	1210	2	25.4	62	026B0319	**43–19**	1210	5	34.9	
20	81.19	86	93	026B0120	**41–20**	1610	1	25.4	65												
21	85.22	90	97	026B0121	**41–21**	1610	1	25.4	71	026B0221	**42–21**	1610	2	25.4	70	026B0321	**43–21**	1610	5	34.9	
23	93.27	99	106	026B0123	**41–23**	1610	1	25.4	76	026B0223	**42–23**	1610	2	25.4	79	026B0323	**43–23**	1610	5	34.9	
25	101.32	106	113	026B0125	**41–25**	1610	1	25.4	76	026B0225	**42–25**	2012	2	32.0	87	026B0325	**43–25**	2012	5	34.9	
27	109.40	114	121	026B0127	**41–27**	1610	1	25.4	76	026B0227	**42–27**	2012	2	32.0	87	026B0327	**43–27**	2012	5	34.9	
30	121.50	126	133	026B0130	**41–30**	2012	1	32.0	90	026B0230	**42–30**	2012	2	32.0	87	026B0330	**43–30**	2012	5	34.9	
38	153.80	159	166	026B0138	**41–38**	2012	1	32.0	90	026B0238	**42–38**	2012	2	32.0	100	026B0338	**43–38**	2012	5	34.9	
45	182.07	188	195	026B0145	**41–45**	2012	1	32.0	100	026B0245	**42–45**	2012	2	32.0	100						
57	230.53	236	243	026B0157	**41–57**	2012	6	32.0	110	026B0257	**42–57**	2012	7	32.0	110						
76	307.31	312	319	026B0176	**41–76**	2012	6	32.0	110	026B0276	**42–76**	2012	7	32.0	110						
95	384.10	389	396	026B0195	**41–95**	2012	6	32.0	110	026B0295	**42–95**	2012	7	32.0	110						

Taper Lock bushes supplied as a separate item

10B T/L SPROCKET ⁵⁄₈" (15.9mm) PITCH

Tooth Width

B_1	9.1mm
b_1	9.0mm
B_2	25.5mm
B_3	42.1mm

No .of Teeth	Pitch	Outer Dia	Dia Over Chain	Simplex Taper Lock						Duplex Taper Lock						Triplex Taper Lock					
	dp (mm)	de (mm)	A (mm)	Product code	Desig-nation	Bush No.	Type	Length Bore L (mm)	Hub Dia N (mm)	Product code	Desig-nation	Bush No.	Type	Length Bore L (mm)	Hub Dia N (mm)	Product code	Desig-nation	Bush No.	Type	Length Bore L (mm)	Hub Dia N (mm)
13	66.34	73	81	026C0113	**51–13**	1008	1	22.2	47												
15	76.35	83	91	026C0115	**51–15**	1210	1	25.4	60	026C0215	**52–15**	1210	3	25.4		026C0315	**53–15**	1210	5	42.1	
17	86.39	93	101	026C0117	**51–17**	1210	1	25.4	71	026C0217	**52–17**	1610	3	25.4		026C0317	**53–17**	1210	5	42.1	
19	96.44	103	111	026C0119	**51–19**	1610	1	25.4	75	026C0219	**52–19**	1610	3	25.4		026C0319	**53–19**	1615	5	42.1	
20	101.49	108	116	026C0120	**51–20**	1610	1	25.4	76												
21	106.50	114	122	026C0121	**51–21**	1610	1	25.4	76	026C0221	**52–21**	1610	3	25.4		026C0321	**53–21**	1615	5	42.1	
23	116.59	124	132	026C0123	**51–23**	1610	1	25.4	76	026C0223	**52–23**	1610	3	25.4		026C0323	**53–23**	2012	5	42.1	
25	126.67	134	142	026C0125	**51–25**	2012	1	32.0	90	026C0225	**52–25**	2012	2	32.0	90	026C0325	**53–25**	2517	4	45.0	105
27	136.75	144	152	026C0127	**51–27**	2012	1	32.0	90	026C0227	**52–27**	2012	2	32.0	90	026C0327	**53–27**	2517	4	45.0	110
30	151.87	159	167	026C0130	**51–30**	2012	1	32.0	90	026C0230	**52–30**	2012	2	32.0	90	026C0330	**53–30**	2517	4	45.0	120
38	192.23	200	208	026C0138	**51–38**	2012	1	32.0	100												
45	227.58	235	243	026C0145	**51–45**	2012	6	32.0	100												
57	288.19	296	304	026C0157	**51–57**	2012	6	32.0	110												
76	384.15	392	400	026C0176	**51–76**	2012	6	32.0	110												

Taper Lock bushes supplied as a separate items

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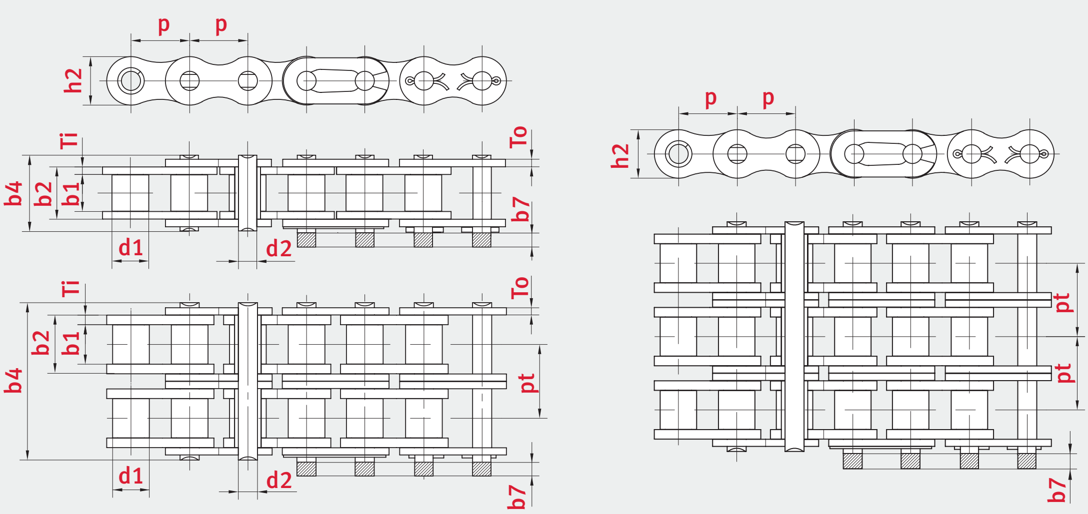
MEGAlife wartungsfreie Rollenketten

MEGAlife maintenance-free roller chains

Kettentyp / Chain type		Teilung / Pitch	Lichte Weite / Width between inner plates	Rollen-Ø / Roller Ø	Bolzen-Ø / Pin Ø	Bolzenlänge / Pin length	Max. zusätzl. Länge für Verschlussglieder / Max. add. length of connecting link	Innengliedbreite / Total width inner link	Laschendicke / Plate thickness	Laschenhöhe / Height inner plate	Querteilung / Traverse pitch	Min. Bruchkraft / Min. tensile strength	Gewicht pro Meter / Weight per meter	Gelenkfläche / Bearing surface
		p mm	b1 min. mm	d1 max. mm	d2 max. mm	b4 max. mm	b7 max. mm	b2 max. mm	Ti/To mm	h2 max. mm	pt mm	FU kN	q kg/m	f cm²
BS - Simplex														
06B-1 ML[1]	G67 ML	9,525	5,72	6,35	3,31	12,9	3,3	8,53	1,30/1,30	8,26	–	8,9	0,41	0,28
08B-1 ML	L85 ML	12,7	7,75	8,51	4,45	16,9	3,9	11,3	1,60/1,60	11,81	–	17,8	0,69	0,5
10B-1 ML	M106 ML	15,875	9,65	10,16	5,08	19,5	4,1	13,28	1,70/1,70	14,73	–	22,2	0,93	0,67
12B-1 ML	M127 ML	19,05	11,68	12,07	5,72	22,7	4,6	15,62	1,85/1,85	16,13	–	28,9	1,15	0,89
16B-1 ML	M161 ML	25,4	17,02	15,88	8,28	36,1	5,4	25,45	4,15/3,10	21,08	–	60	2,71	2,1
20B-1 ML	M2012 ML	31,75	19,56	19,05	10,19	41,6	6,1	29,01	4,50/3,50	26,42	–	95	3,7	2,96
24B-1 ML		38,1	25,4	25,4	14,63	53,4	6,6	37,92	6,00/4,80	33,4	–	160	7,1	5,54
BS - Duplex														
06B-2 ML[1]	D67 ML	9,525	5,72	6,35	3,28	23,4	3,3	8,53	1,30/1,30	8,26	10,24	10,24	0,77	0,56
08B-2 ML	D85 ML	12,7	7,75	8,51	4,45	30,8	3,9	11,3	1,60/1,60	11,81	13,92	13,92	1,34	1,01
10B-2 ML	D106 ML	15,875	9,65	10,16	5,08	36	4,1	13,28	1,70/1,70	14,73	16,59	16,59	1,84	1,34
12B-2 ML	D127 ML	19,05	11,68	12,07	5,72	42,1	4,6	15,62	1,85/1,85	16,13	19,46	19,46	2,31	1,79
16B-2 ML	D1611 ML	25,4	17,02	15,88	8,28	68	5,4	25,45	4,15/3,10	21,08	31,88	31,88	5,42	4,21
20B-2 ML	D2012 ML	31,75	19,56	19,05	10,19	79,7	6,1	29,01	4,50/3,50	26,42	36,45	36,45	7,2	5,91
BS - Triplex														
08B-3 ML	TR85 ML	12,7	7,75	8,51	4,45	44,7	3,9	11,3	1,60/1,60	11,81	13,92	13,92	2,03	1,51
10B-3 ML	TR106ML	15,875	9,65	10,16	5,08	52,5	4,1	13,28	1,70/1,70	14,73	16,59	16,59	2,77	2,02
12B-3 ML	TR127ML	19,05	11,68	12,07	5,72	61,5	4,6	15,62	1,85/1,85	16,13	19,46	19,46	3,46	2,68
16B-3 ML	TR1611 ML	25,4	17,02	15,88	8,28	99,2	5,4	25,45	4,15/3,10	21,08	31,88	31,88	8,13	6,31

[1] Gerade Laschen
[1] Straight side plates



Taper Lock® Metric Bushes

METRIC BORES AND KEYWAYS

Bore Dia	Keyway		Shallow Keyway Depth	Product Code								
	Width	Depth		1008	1108	1210	1610	1615	2012	2517	3020	3030
9	3	1.4	–	029A0009	029B0009							
10	3	1.4	–	029A0010	029B0010							
11	4	1.8	–	029A0011	029B0011	029C0011						
12	4	1.8	–	029A0012	029B0012	029C0012						
14	5	2.3	–	029A0014	029B0014	029C0014	029G0014	029H0014	029K0014			
15	5	2.3	–	029A0015	029B0015	029C0015	029G0015	029H0015	029K0015			
16	5	2.3	–	029A0016	029B0016	029C0016	029G0016	029H0016	029K0016	029M0016		
18	6	2.8	–	029A0018	029B0018	029C0018	029G0018	029H0018	029K0018	029M0018		
19	6	2.8	–	029A0019	029B0019	029C0019	029G0019	029H0019	029K0019	029M0019		
20	6	2.8	–	029A0020	029B0020	029C0020	029G0020	029H0020	029K0020	029M0020		
22	6	2.8	–	029A0022	029B0022	029C0022	029G0022	029H0022	029K0022	029M0022		
24	8	3.3	1.3	029A0024*	029B0024	029C0024	029G0024	029H0024	029K0024	029M0024		
25	8	3.3	1.3	029A0025*	029B0025	029C0025	029G0025	029H0025	029K0025	029M0025	029P0025	
28	8	3.3	1.3		***029B0028****	029C0028	029G0028	029H0028	029K0028	029M0028	029P0028	
30	8	3.3	–			029C0030	029G0030	029H0030	029K0030	029M0030	029P0030	
32	10	3.3	–			029C0032	029G0032	029H0032	029K0032	029M0032	029P0032	
35	10	3.3	–				029G0035	029H0035	029K0035	029M0035	029P0035	029Q0035
38	10	3.3	–				029G0038	029H0038	029K0038	029M0038	029P0038	029Q0038
40	12	3.3	–				***029G0040***	029H0040	029K0040	029M0040	029P0040	029Q0040
42	12	3.3	2.2				***029G0042****	***029H0042****	029K0042	029M0042	029P0042	029Q0042
45	14	3.8	–						029K0045	029M0045	029P0045	029Q0045
48	14	3.8	–						029K0048	029M0048	029P0048	029Q0048
50	14	3.8	–						029K0050	029M0050	029P0050	029Q0050
55	16	4.3	–							029M0055	029P0055	029Q0055
60	18	4.4	–							029M0060	029P0060	029Q0060
65	18	4.4	–								029P0065	029Q0065
70	20	4.9	–								029P0070	029Q0070
75	20	4.9	–								029P0075	029Q0075

METRIC BORES AND KEYWAYS

Bore Dia	Keyway		Shallow Keyway Depth	Product Code							
	Width	Depth		3525	3535	4030	4040	4535	4545	5040	5050
35	10	3.3	–	029J0035	029R0035						
38	10	3.3	–	029J0038	029R0038						
40	12	3.3	–	029J0040	029R0040	029X0040	029S0040				
42	12	3.3	–	029J0042	029R0042	029X0042	029S0042				
45	14	3.8	–	029J0045	029R0045	029X0045	029S0045				
48	14	3.8	–	029J0048	029R0048	029X0048	029S0048				
50	14	3.8	–	029J0050	029R0050	029X0050	029S0050				
55	16	4.3	–	029J0055	029R0055	029X0055	029S0055	029Y0055	029T0055		
60	18	4.4	–	029J0060	029R0060	029X0060	029S0060	029Y0060	029T0060		
65	18	4.4	–	029J0065	029R0065	029X0065	029S0065	029Y0065	029T0065		
70	20	4.9	–	029J0070	029R0070	029X0070	029S0070	029Y0070	029T0070	029Z0070	029U0070
75	20	4.9	–	029J0075	029R0075	029X0075	029S0075	029Y0075	029T0075	029Z0075	029U0075
80	22	5.4	–	029J0080	029R0080	029X0080	029S0080	029Y0080	029T0080	029Z0080	029U0080
85	22	5.4	–	029J0085	029R0085	029X0085	029S0085	029Y0085	029T0085	029Z0085	029U0085
90	25	5.4	–	029J0090	029R0090	029X0090	029S0090	029Y0090	029T0090	029Z0090	029U0090
95	25	5.4	–	***029J0095***		029X0095	029S0095	029Y0095	029T0095	029Z0095	029U0095
100	28	6.4	4.4	***029J0100****		029X0100	029S0100	029Y0100	029T0100	029Z0100	029U0100
105	28	6.4	-			***029X0105***		029Y0105	029T0105	029Z0105	029U0105
110	28	6.4	–			***029X0110***		029Y0110	029T0110	029Z0110	029U0110
115	32	7.4	5.4			***029X0115****		***029Y0115***		029Z0115	029U0115
120	32	7.4	–					***029Y0120***		029Z0120	029U0120
125	32	7.4	–					***029Y0125***		029Z0125	029U0125

Dimensions in millimetres.
Keyways are British Standard Metric BS 4235: Part 1: 1972 DIN 6885 and conform to ISO recommendations with the exception of those marked* which are shallower. Where a key is to be used it should be parallel and side fitting, with top clearance. Depth of keyway is measured at the CENTRE.
Bold italic type indicates bushes made of steel or ductile iron.

Taper Lock® Engineering Data

MINIMUM DIAMETERS OF TAPER BORED HUBS

The following table shows the recommended minimum diameter in mm for bespoke component hubs that are to be drilled, tapped and taper bored for use with Taper Lock bushes. The table differentiates between grey iron and ductile materials of various minimum tensile strength grades (in N/mm² or MN/m² units, which are numerically equal).

All standard Fenner Taper Lock products are tested to ensure that they are capable of safely containing the radial and circumferential hub stresses generated by the wedging mechanism which makes Taper Lock the equivalent of a shrink-on fit. For Taper Lock hub machining details, consult your local Authorised Distributor.

Taper Lock Bush	Minimum Hub Diameters (mm) for Various Materials Tensile Strength N/mm²			
	Cast Iron 180	Cast Iron 250	Steel/Ductile Iron420	Steel 600
1008	62	54	51	47
1108	64	57	54	50
1210	104	86	78	69
1610	109	92	85	78
1615	90	81	77	73
2012	121	106	99	92
2517	130	119	113	108
3020	160	146	140	132
3030	144	136	132	127
3525	211	191	178	167
3535	191	176	168	160
4030	224	207	197	186
4040	209	195	188	180
4535	223	212	205	198
4545	215	205	200	194
5040	240	229	223	216
5050	233	223	219	213

AVERAGE SLIP TORQUES FOR TAPER LOCK FIXING (WITHOUT KEY)

The following table shows empirically derived average slip torque values in Nm for each basic Taper Lock bush size with a variety of common metric bore diameters.

The values assume that the assembly uses a Fenner Taper Lock bush fitted, in accordance with the instructions supplied with every bush, to a hub prepared to the Fenner specification. Slip will tend to occur at the bush/shaft interface, at the prescribed torque, unless a key is fitted. With a key, the slip tendency transfers to the bush/hub interface at a greater torque value related to the ratio of bush outer dia. to bore dia.. Consult your local Authorised Distributor for specific values.

Taper Lock bushes should only be used without a key fitted on smooth, uniformly loaded drives with service factors of 1.0 or less.

Formula to calculate the slip torque if a key is used: $\frac{\text{Large end diameter*}}{\text{Bush bore}}$ **x Average slip torque value Nm (below)**

* from the table on Page 132

Bush	Bore (mm)	Average Slip Torque (Nm)
1008	12	29
	19	51
	24	66
1108	12	28
	19	49
	24	64
	28	79
1210	16	82
	19	105
	24	142
	32	210
1610	19	98
1615	24	135
	38	240
	42	265
2012	24	165
	38	320
	42	340
	48	400
	50	420
2517	24	220
	38	380
	42	430
	48	510
	55	600
	60	670

Bush	Bore (mm)	Average Slip Torque (Nm)
3020	38	520
3030	48	730
	55	890
	60	970
	75	1300
3525*	42	1000
3535	60	1580
	75	2150
	90	2600
	100*	3075
4030*	48	1700
4040	60	2300
	75	3150
	100	4400
	115*	5150
4535*	55	2500
4545	75	3900
	100	5500
	110	6300
	125*	6625
5040	75	3950
5050	100	5650
	125	7370

Large bores marked* are only available in bush sizes marked*

Taper Lock bushes work effectively on shaft diameters with h9 tolerance. If in doubt please consult your local Authorised Distributor.. (Nominally +0.05/-0.125mm)

Taper Lock® Installation Instructions

TO INSTALL

1. After ensuring that the mating tapered surfaces, bore and shaft are completely clean and free from oil or dirt, insert bush in hub so that holes line up.
2. Sparingly oil thread and point of grub screws, or thread and under head of cap screws. Place screws loosely in holes threaded in hub, shown thus ◎ in diagram.
3. If a key is to be fitted place it in the shaft keyway before fitting the bush. It is essential that it is a parallel key and side fitting only and has TOP CLEARANCE.
4. Clean shaft and fit hub to shaft as one unit and locate in position desired, remembering that bush will nip the shaft first and then hub will be slightly drawn on to the brush.
5. Using a hexagon wrench tighten screws gradually and alternately to torque shown in table below.
6. Hammer against large-end of bush, using a block or sleeve to prevent damage. (This will ensure that the bush is seated squarely in the bore.) Screws will now turn a little more. Repeat this alternate hammering and screw tightening once or twice to achieve maximum grip on the shaft.
7. After drive has been running under load for a short time stop and check tightness of screws.
8. Fill empty holes with grease to exclude dirt.

Visit www.fptgroup.com to view the Taper Lock installation video.

INSERT BUSH

INSERT SCREWS AND LOCATE ON SHAFT

TIGHTEN SCREWS FINGER TIGHT

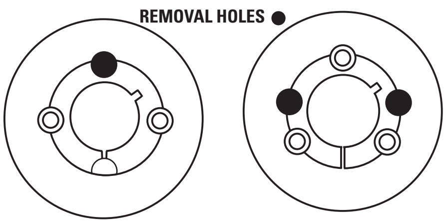
TIGHTEN SCREWS ALTERNATELY

TIGHTEN SCREWS TO THE CORRECT TORQUE SETTING

REMOVAL

TO REMOVE

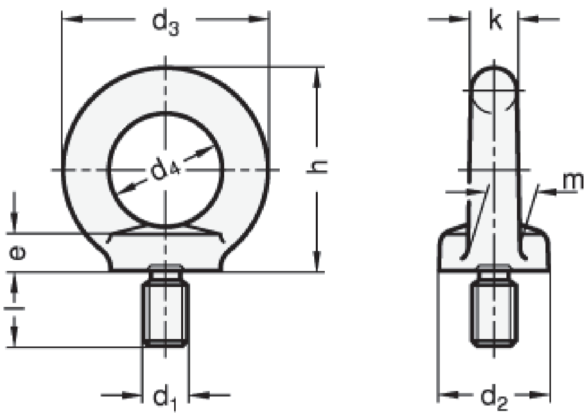
1. Slacken all screws by several turns, remove one or two according to number of removal holes shown thus ● in diagram. Insert screwsinto removal holes after oiling thread and under head of cap screws.
2. Tighten screws alternately until bush is loosened in hub and assembly is free on the shaft.
3. Remove assembly from shaft.

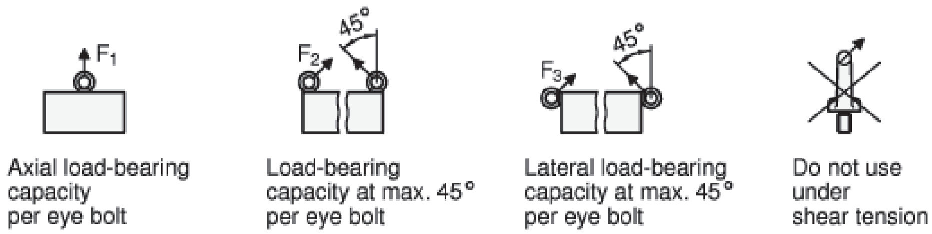


Bush size		1008	1108	1210	1610	1615	2012	2517	3020	3030	3525	3535	4030	4040	4535	4545	5040	5050
Screw tightening Torque (Nm)		5.6	2.6	20	20	20	30	50	90	90	115	115	170	170	190	190	270	270
	Qty	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3
Screw Details	Size (BSW)	1/4"	1/4"	3/8"	3/8"	3/8"	7/16"	1/2"	5/8"	5/8"	1/2"	1/2"	5/8"	5/8"	3/4"	3/4"	7/8"	7/8"
	Hex. Scket Size (mm)	3	3	5	5	5	6	6	8	8	10	10	12	12	14	14	14	14
Large end dia. (mm)		35.0	38.0	47.5	57.0	57.0	70.0	85.5	108.6	108	127	127	146	146	162	162	178	178
Bush length (mm)		22.3	22.3	25.4	25.4	38.1	38.1	44.5	50.8	76.2	63.5	89.0	76.2	102	89.0	114	102	127
Approx mass (kg)		0.1	0.1	0.2	0.3	0.5	0.7	1.5	2.7	3.6	3.8	5.0	5.6	7.7	7.5	10.0	11.1	14.0

DIN 580

Lifting eye bolts





technical informations

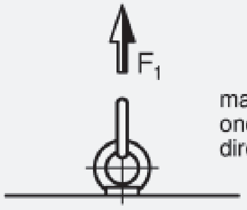
Material

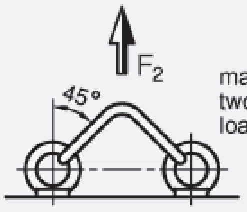
Drop-forged steel annealed body, zinc-plated blue passivated, machined contact face.

Features and applications

These lifting eye bolts correspond to standard sheet DIN 580.
The following guidelines of lifting eye bolts DIN 580 the have to be observed in addition to the load values given in the above table.
The eye bolt must be of fully screwd in to achieve a perfect contact between the two mating faces.
Both threads must be of a equal length and the base material of equal strength to that of the bolt.

For more guidelines, see the enclosed operating instruction.

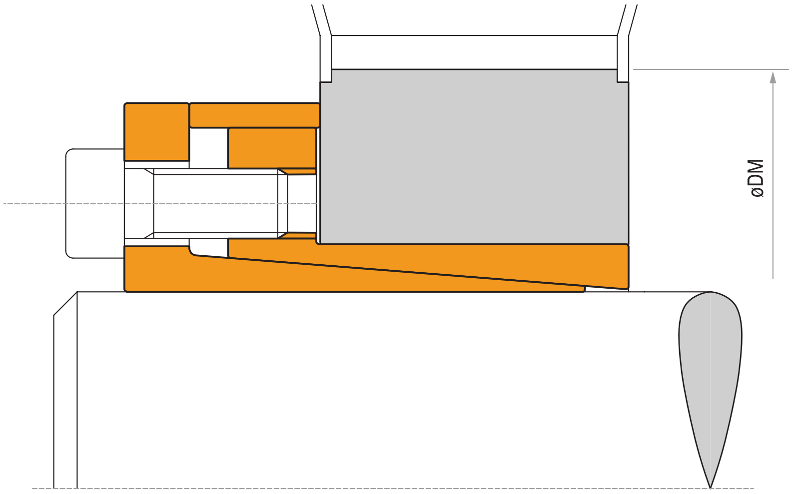




Standard Elements	Main dimensions							Threaded stud		F_1 max. in N	F_2 max. in N	F_3 max. in N	Weigh
Description	d_2	d_3	d_4	e	h	k	m	d_1	l				g
DIN 580-M8-ST	20	36	20	6	36	8	10	M8	13	1400	1000	700	56
DIN 580-M10-ST	25	45	25	8	45	10	12	M10	17	2300	1700	1150	108
DIN 580-M12-ST	30	54	30	10	53	12	14	M12	20.5	3400	2400	1700	174
DIN 580-M16-ST	35	63	35	12	62	14	16	M16	27	7000	5000	3500	280
DIN 580-M20-ST	40	72	40	14	71	16	19	M20	30	12000	8600	6000	450
DIN 580-M24-ST	50	90	50	18	90	230	24	M24	36	18000	12900	9000	880
DIN 580-M30-ST	65	108	60	22	109	24	28	M30	45	32000	23000	16000	1525
DIN 580-M36-ST	75	126	70	26	128	28	32	M36	54	46000	33000	23000	2605

Locking assembly - Self-centering

TLK 110



Characteristics

- Medium-high torque
- Restricted hub diameter
- Limited installation time
- Very low surface pressure

Installation

Carefully clean the hub and shaft contact surfaces and apply a light oil film. Slide the locking assembly into the hub bore, insert the shaft and tighten all screws gradually and regularly in crossed sequence to reach the tightening torque M_s as indicated in the table.

The values M_t and F_{ax} indicated in the table are valid only in case of oil installation. Do not use any oil with **molibdenum bisulphide** or high pressure additives and not grease. Above substances notably reduce the friction coefficient.

Dismantling

Loosen the clamping screws. Insert the screws into the dismantling threading and tighten gradually and regularly in crossed sequence until the bottom cone is released.
If the element is to be reused, relubricate both screws and threadings.

Tolerances, surface finish

A good surface finish by machine tool is sufficient.
Maximum allowable surface finish:
Rt max 16 µm (Ra 3 µm - Rz 13 µm)

Maximum permissible tolerances:
h8 for shaft
H8 for hub

Axial movement

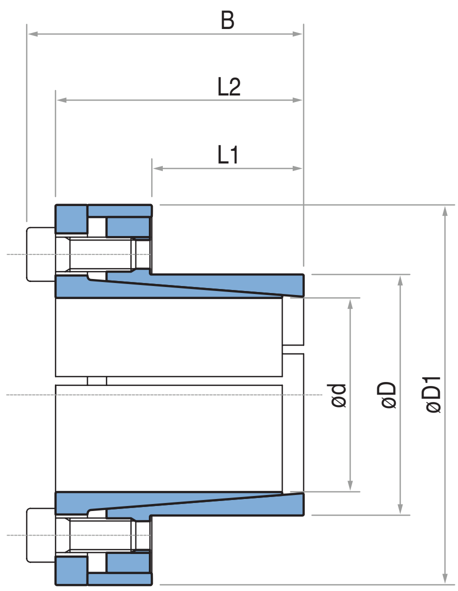
TLK 110: during screws tightening the hub has no axial movement with respect to the shaft.

DM hub calculation

The pressure P_n in the hub can be compared to the inside pressure on a thick hollow cylinder.

For DM calculation see page 46.

TLK 110



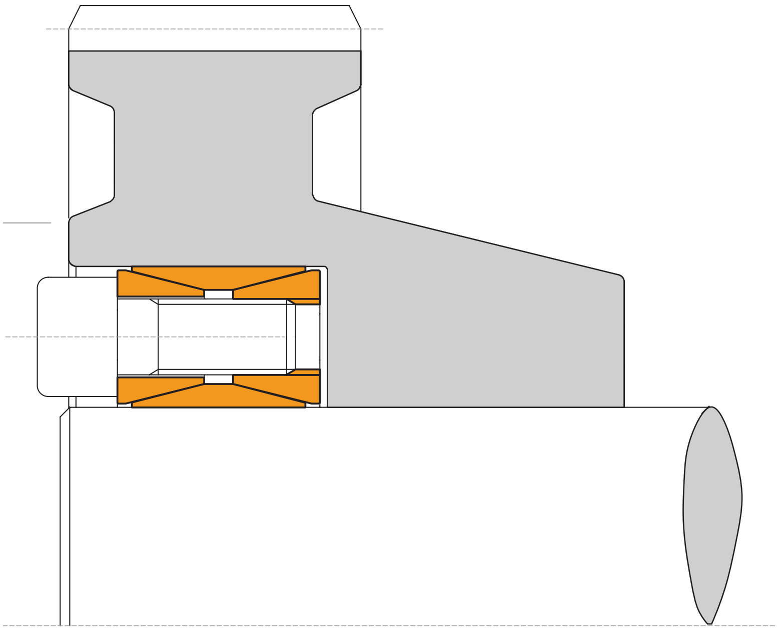
TLK 110 DIMENSIONS

Dimensions					Torque	Axial force	Surface pressures on		Tightening screws		Weight
							Shaft	Hub	DIN912 12.9	Tightening torque	
d x D mm	L1 mm	L2 mm	B mm	D1 mm	M_t Nm	F_{ax} KN	p_w N/mm^2	p_n N/mm^2	N° x Type	M_s Nm	Kg
6 x 14	9	21	24	25	16	6	277	119	4 x M3	2	0,04
7 x 15	12	25	29	27	25	7	234	109	3 x M4	5	0,06
8 x 15	12	25	29	27	29	7	204	109	3 x M4	5	0,05
9 x 16	14	26	30	28	44	10	208	117	4 x M4	5	0,06
10 x 16	14	26	30	28	49	10	187	117	4 x M4	5	0,06
11 x 18	14	26	30	32	53	10	170	104	4 x M4	5	0,07
12 x 18	14	26	30	32	58	10	156	104	4 x M4	5	0,07
13 x 23	14	26	30	38	63	10	144	81	4 x M4	5	0,11
14 x 23	14	26	30	38	68	10	134	81	4 x M4	5	0,1
* 15 x 23	14	30	35	39	120	16	204	133	4 x M5	10	0,14
15 x 24	16	36	42	44	170	23	251	157	4 x M6	17	0,22
16 x 24	16	36	42	44	180	23	236	157	4 x M6	17	0,22
17 x 26	18	38	44	47	190	23	197	129	4 x M6	17	0,25
18 x 26	18	38	44	47	200	23	186	129	4 x M6	17	0,24
19 x 27	18	38	44	49	210	23	176	124	4 x M6	17	0,26
* 19 x 28	18	38	43	49	150	16	125	85	4 x M5	10	0,27
20 x 28	18	38	44	50	220	23	168	120	4 x M6	17	0,27
22 x 32	25	45	51	54	250	23	110	75	4 x M6	17	0,34
24 x 34	25	45	51	56	270	23	101	71	4 x M6	17	0,36
25 x 34	25	45	51	56	280	23	97	71	4 x M6	17	0,35
28 x 39	25	45	51	61	475	34	129	93	6 x M6	17	0,48
30 x 41	25	45	51	62	510	34	121	88	6 x M6	17	0,48
32 x 43	25	45	51	65	720	45	151	112	8 x M6	17	0,47
35 x 47	30	50	56	69	790	45	115	86	8 x M6	17	0,58
38 x 50	30	50	56	72	860	45	106	80	8 x M6	17	0,61
40 x 53	30	50	56	75	900	45	101	76	8 x M6	17	0,68
42 x 55	32	52	60	78	1750	84	166	127	8 x M8	41	0,76
45 x 59	40	65	73	85	1890	84	124	94	8 x M8	41	1,2
48 x 62	45	70	78	87	2010	84	103	80	8 x M8	41	1,2
50 x 65	45	70	78	92	2600	105	124	95	10 x M8	41	1,4
55 x 71	50	75	83	98	2850	105	101	79	10 x M8	41	1,6
60 x 77	50	75	83	104	3150	105	93	72	10 x M8	41	1,8
65 x 84	50	75	83	111	3400	105	86	66	10 x M8	41	2,1
70 x 90	60	91	101	119	5800	167	105	82	10 x M10	83	3
75 x 95	60	91	101	126	6200	167	98	78	10 x M10	83	3
80 x 100	65	96	106	131	8000	200	102	82	12 x M10	83	3,5
85 x 106	65	96	106	137	8500	200	96	77	12 x M10	83	3,6
90 x 112	65	96	106	144	11250	250	113	91	15 x M10	83	3,9
95 x 120	65	96	106	149	11850	250	107	85	15 x M10	83	4,4
100 x 125	65	96	106	154	15000	300	123	98	18 x M10	83	4,6
110 x 140	90	128	140	180	16000	291	78	61	12 x M12	145	8,7
120 x 155	90	128	140	198	17500	291	72	55	12 x M12	145	10,6
130 x 165	90	128	140	208	25000	389	88	69	16 x M12	145	11,3

* Upon request.
For larger diameter please contact us.

Locking assembly - Not self-centering

TLK 200



Characteristics

- Medium-high torque
- Wide tolerances
- Easy availability
- Easy dismantling

Installation

Carefully clean the hub and shaft contact surfaces and apply a light oil film. Slide the locking assembly into the hub bore and insert the shaft. Tighten cadmium plated clamping screws until inner ring grips the shaft and the outer ring grips the hub bore then tighten gradually and regularly in crossed sequence all screws to reach the tightening torque M_s indicated in the table. The values M_t and F_{ax} indicated in the table are valid only in case of oil installation.
Do not use any oil with **molibdenum bisulphide** or high pressure additives and not grease.

Dismantling

By loosening all tightening screws the clamping unit is normally released. In case of difficulties slightly hammer the released screws to push back the rear pressure cone.

Tolerances, surface finish

A good surface finish by machine tool is sufficient.
Maximum allowable surface finish:
Rt max 16 µm (Ra 3 µm - Rz 13 µm)

Maximum permissible tolerances:
h11 for shaft
H11 for hub

Centering

Mod. TLK 200 is not self-centering. The hub concentricity with respect to the shaft depends on the guide surface tolerance and its length.

Axial movement

TLK 200: during screws tightening the hub has no axial movement with respect to the shaft.

DM hub calculation

The pressure P_n in the hub can be compared to the inside pressure on a thick hollow cylinder.

For DM calculation see page 46.

M_t transmissible

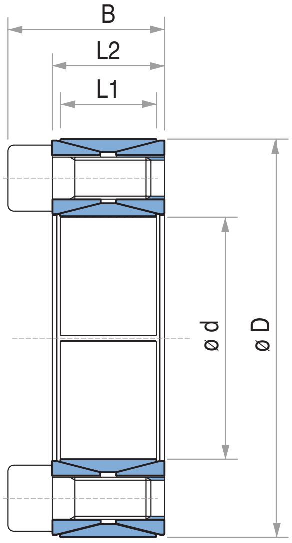
If two or more clamping unit are installed together, as a result of carried tests, the **M_t** transmissible shall be calculated as follow:

Nr. 1 TLK 200	$M_t = M_t$ cat.
Nr. 2 TLK 200	$M_t = M_t$ cat. • 1,9
Nr. 3 TLK 200	$M_t = M_t$ cat. • 2,7

TLK 200 DIMENSIONS

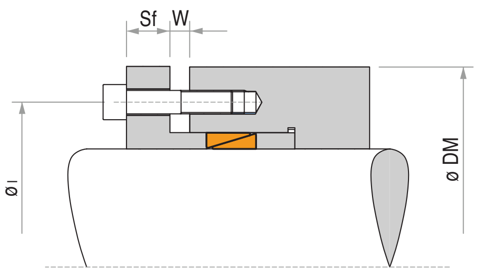
Dimensions				Shaft / Hub tolerances h11 / H11				Shaft / Hub tolerances h7 / H7		Tightening screws		Weight
				Torque	Axial force	Surface pressures on Shaft	Surface pressures on Hub	Torque	Pressure on Hub	DIN912 12.9	Tightening torque	
d x D mm	L1 mm	L2 mm	B mm	M_t Nm	F_{ax} KN	p_w N/mm²	p_n N/mm²	M_t Nm	p_n N/mm²	N° x Type	M_s Nm	Kg
17 x 47	17	20	26	280	33	305	110	310	125	8 x M6	17	0,2
18 x 47	17	20	26	300	33	290	110	330	125	8 x M6	17	0,2
19 x 47	17	20	26	310	33	275	110	350	125	8 x M6	17	0,2
20 x 47	17	20	26	330	33	260	110	370	125	8 x M6	17	0,2
22 x 47	17	20	26	360	33	235	110	410	125	8 x M6	17	0,2
24 x 50	17	20	26	390	33	215	105	440	115	8 x M6	17	0,3
25 x 50	17	20	26	410	33	205	105	460	115	8 x M6	17	0,3
28 x 55	17	20	26	570	41	230	115	650	130	10 x M6	17	0,3
30 x 55	17	20	26	610	41	215	115	690	130	10 x M6	17	0,3
32 x 60	17	20	26	780	49	240	130	890	145	12 x M6	17	0,3
35 x 60	17	20	26	850	49	220	125	970	145	12 x M6	17	0,3
38 x 65	17	20	26	1070	57	235	135	1230	155	14 x M6	17	0,4
40 x 65	17	20	26	1120	56	220	135	1300	155	14 x M6	17	0,3
42 x 75	20	24	32	1860	89	280	155	2170	185	12 x M8	41	0,6
45 x 75	20	24	32	1990	89	260	155	2320	185	12 x M8	41	0,6
48 x 80	20	24	32	2120	88	245	145	2480	170	12 x M8	41	0,6
50 x 80	20	24	32	2200	88	235	145	2580	170	12 x M8	41	0,6
55 x 85	20	24	32	2810	102	245	160	3310	190	14 x M8	41	0,6
60 x 90	20	24	32	3050	102	225	150	3610	180	14 x M8	41	0,7
65 x 95	20	24	32	3770	116	235	160	4470	190	16 x M8	41	0,7
70 x 110	24	28	38	5600	160	255	160	6700	190	14 x M10	83	1,3
75 x 115	24	28	38	5970	159	235	155	7170	185	14 x M10	83	1,3
80 x 120	24	28	38	6330	158	220	145	7650	175	14 x M10	83	1,4
85 x 125	24	28	38	7660	180	235	160	9290	195	16 x M10	83	1,4
90 x 130	24	28	38	8080	180	220	155	9840	185	16 x M10	83	1,5
95 x 135	24	28	38	9560	201	235	165	11600	200	18 x M10	83	1,6
100 x 145	26	33	45	11300	227	230	160	13900	195	14 x M12	145	2,2
110 x 155	26	33	45	12400	226	210	150	15300	185	14 x M12	145	2,5
120 x 165	26	33	45	15400	258	220	160	19100	195	16 x M12	145	2,6
130 x 180	34	38	50	20800	320	190	140	25800	175	20 x M12	145	3,8
140 x 190	34	38	50	24500	351	195	145	30600	180	22 x M12	145	3,9
150 x 200	34	38	50	28500	381	200	150	35800	185	24 x M12	145	4
160 x 210	34	38	50	32900	411	200	155	41400	190	26 x M12	145	4,3
170 x 225	38	44	58	40400	476	195	150	51000	185	22 x M14	230	5,8
180 x 235	38	44	58	46500	518	200	155	59000	195	24 x M14	230	6
190 x 250	46	52	66	57200	602	185	140	72600	175	28 x M14	230	8,5
200 x 260	46	52	66	64200	643	185	145	81900	180	30 x M14	230	8,6
220 x 285	50	56	72	84500	769	185	145	108500	185	26 x M16	355	11
240 x 305	50	56	72	106000	884	195	155	136600	200	30 x M16	355	12
260 x 325	50	56	72	129300	995	205	160	167800	210	34 x M16	355	13
280 x 355	60	66	84	157200	1123	175	140	204600	180	32 x M18	485	19
300 x 375	60	66	84	188200	1255	185	150	246700	195	36 x M18	485	20
320 x 405	72	78	98	259400	1622	185	150	341400	195	36 x M20	690	30
340 x 425	72	78	98	274500	1615	175	140	362700	185	36 x M20	690	30
360 x 455	84	90	112	360300	2002	175	140	478100	185	36 x M22	930	42
380 x 475	84	90	112	378700	1994	165	135	504600	175	36 x M22	930	44
400 x 495	84	90	112	397000	1985	155	125	531200	170	36 x M22	930	46
420 x 515	84	90	112	461800	2199	165	135	619700	180	40 x M22	930	50
440 x 545	96	102	126	557200	2533	160	130	749700	175	40 x M24	1200	65
460 x 565	96	102	126	580800	2526	150	125	783800	165	40 x M24	1200	67
480 x 585	96	102	126	634600	2644	150	125	858800	170	42 x M24	1200	71
500 x 605	96	102	126	690500	2762	155	125	937200	170	44 x M24	1200	73
520 x 630	96	102	126	732400	2817	150	125	996800	170	45 x M24	1200	80
540 x 650	96	102	126	759500	2813	145	120	1035000	165	45 x M24	1200	82
560 x 670	96	102	126	837700	2992	150	125	1145000	170	48 x M24	1200	85
580 x 690	96	102	126	902500	3112	150	125	1235000	170	50 x M24	1200	88
600 x 710	96	102	126	930900	3103	145	120	1278000	165	50 x M24	1200	91
620 x 730	96	102	126	997500	3218	145	120	1373000	170	52 x M24	1200	93
640 x 750	96	102	126	1067000	3337	145	125	1472000	170	54 x M24	1200	96
660 x 770	96	102	126	1140000	3456	145	125	1574000	170	56 x M24	1200	99
680 x 790	96	102	126	1173000	3450	140	120	1622000	165	56 x M24	1200	102
700 x 810	96	102	126	1290000	3686	145	125	1789000	175	60 x M24	1200	104
720 x 830	96	102	126	1325000	3681	140	125	1840000	170	60 x M24	1200	107
740 x 850	96	102	126	1405000	3798	140	125	1954000	170	62 x M24	1200	110
760 x 870	96	102	126	1487000	3915	140	125	2072000	175	64 x M24	1200	113
780 x 890	96	102	126	1548000	3970	140	125	2159000	170	65 x M24	1200	116
800 x 910	96	102	126	1610000	4025	140	120	2249000	170	66 x M24	1200	118

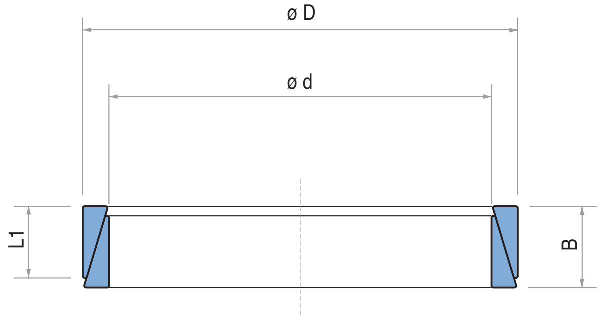
For larger diameter please contact us.



Locking assembly - Not self-centering

TLK 300





TLK 300 DIMENSIONS

dg	DIN912 Pv in N 8.8	DIN912 Pv in N 10.9	DIN912 Pv in N 12.9	C=0,140 M_s in Nm 8.8	C=0,140 M_s in Nm 10.9	C=0,140 M_s in Nm 12.9
M4	3900	5450	6550	2,9	4,1	4,9
M5	6350	8950	10700	6	8,5	10
M6	9000	12600	15100	10	14	17
[M7]	13200	18500	22200	16	23	28
M8	16500	23200	27900	25	35	41
[M9]	22000	30900	37100	36	51	61
M10	26200	36900	44300	49	69	83
M12	38300	54000	64500	86	120	145
M14	52500	74000	88500	135	190	230
M16	73000	102000	123000	210	295	355
M18	88000	124000	148000	290	405	485
M20	114000	160000	192000	410	580	690
M22	141000	199000	239000	550	780	930
M24	164000	230000	276000	710	1000	1200
M27	215000	302000	363000	1050	1500	1800
M30	262000	368000	442000	1450	2000	2400

Pa = N° of screws • Pv

Pt = see page 25

$$M_t \text{ transmissible} = \frac{Pa - Pt}{0{,}54} \bullet 0{,}12 \bullet \frac{d}{2000}$$

Screws center distance I = D + 12 + dg (screws fixed on the hub)
Screws center distance I = d - 12 - dg (screws fixed on the shaft)

Flange thickness Sf = dg • 1,3 (screws quality 8.8)
Flange thickness Sf = dg • 1,8 (screws quality 12.9)

Note: On request the type TLK 300 can be supplied also with split rings: therefore the trasmissible torque M_t increases. Please contact our technical department.

Characteristics

- Medium low torque
- Restricted radial encumbrance
- Limited installation time
- Application economically advantageous

Installation

Carefully clean the hub and shaft contact surfaces and apply a light oil film. Slide the locking elements into the hub bore, insert the shaft and tighten gradually and regularly in crossed sequence all screws to reach the tightening torque M_s as indicated in the table. The values M_t and F_{ax} indicated in the table are valid only in case of oil installation. Do not use any oil with **molybdenum bisulphide** or high pressure additives and not grease. Above substances notably reduce the friction coefficient.

Dismantling

By loosening all tightening screws the locking elements are released and the clamping is free. However in case of difficulties slightly hammer the hub.

Tolerances, surface finish

A good surface finish by the machine tool is sufficient.
Maximum allowable surface finish:
Rt max 6 µm (Ra 1 µm - Rz 5 µm)

Maximum permissible tolerances:
shaft h6 - hub H7 (up to 40mm d. diameter)
shaft h8 - hub H8 (over 42mm d. diameter)

M_t transmissible

Nr. 1 TLK 300 M_t = M_t cat.
Nr. 2 TLK 300 M_t = M_t cat. • 1,55
Nr. 3 TLK 300 M_t = M_t cat. • 1,85
Nr. 4 TLK 300 M_t = M_t cat. • 2,02

DM hub calculation

The pressure P_n in the hub can be compared to the inside pressure on a thick hollow cylinder.

For DM calculation see page 46.

TLK 300 DIMENSIONS

Dimensions			Pre-load force	Total force	Torque	Axial force	Distance W before tightening				Spacer diameter		Surface pressures on		Weight
											Inside	Outside	Shaft	Hub	
d x D mm	B mm	L1 mm	Pt N	Pa N	M_t Nm	F_{ax} KN	1 mm	2 mm	3 mm	4 mm	d1 mm	D1 mm	p_w N/mm²	p_n N/mm²	Kg
6 x 9	4,5	3,7	-	3800	2	0,84	2,5	2,5	3	4	6,1	8,9	115	75	0,002
7 x 10	4,5	3,7	-	3900	3	0,86	2,5	2,5	3	4	7,1	9,9	105	70	0,002
8 x 11	4,5	3,7	-	5300	5	1,17	2,5	2,5	3	4	8,1	10,9	120	90	0,002
9 x 12	4,5	3,7	7650	15600	8	1,76	2,5	2,5	3	4	9,1	11,9	140	105	0,000
10 x 13	4,5	3,7	7000	15600	10	1,91	2,5	2,5	3	4	10,1	12,9	135	105	0,002
12 x 15	4,5	3,7	7000	15600	11	1,91	2,5	2,5	3	4	12,1	14,9	115	90	0,002
13 x 16	4,5	3,7	6500	15600	13	2,02	2,5	2,5	3	4	13,1	15,9	110	90	0,000
14 x 18	6,3	5,3	11000	25400	22	3,18	3,5	3,5	4,5	5,5	14,1	17,9	115	90	0,005
15 x 19	6,3	5,3	10800	25400	24	3,24	3,5	3,5	4,5	5,5	15,1	18,9	110	85	0,005
16 x 20	6,3	5,3	10000	25400	27	3,42	3,5	3,5	4,5	5,5	16,1	19,9	105	85	0,006
17 x 21	6,3	5,3	9600	25400	30	3,51	3,5	3,5	4,5	5,5	17,1	20,9	105	85	0,006
18 x 22	6,3	5,3	9150	25400	32	3,61	3,5	3,5	4,5	5,5	18,1	21,9	100	80	0,007
19 x 24	6,3	5,3	12500	36000	49	5,22	3,5	3,5	4,5	5,5	19,2	23,8	140	110	0,007
20 x 25	6,3	5,3	12000	36000	53	5,33	3,5	3,5	4,5	5,5	20,2	24,8	135	105	0,009
22 x 26	6,3	5,3	9000	36000	66	6	3,5	3,5	4,5	5,5	22,2	25,8	135	115	0,007
24 x 28	6,3	5,3	8400	36000	73	6,13	3,5	3,5	4,5	5,5	24,2	27,8	130	110	0,008
25 x 30	6,3	5,3	10000	36000	72	5,77	3,5	3,5	4,5	5,5	25,2	29,8	115	95	0,009
28 x 32	6,3	5,3	7500	36000	88	6,33	3,5	3,5	4,5	5,5	28,2	31,8	115	100	0,010
30 x 35	6,3	5,3	8600	36000	91	6,08	3,5	3,5	4,5	5,5	30,2	34,8	100	85	0,011
32 x 36	6,3	5,3	7900	45000	131	8,24	3,5	3,5	4,5	5,5	32,2	35,8	130	115	0,011
35 x 40	7	6	10000	54000	171	9,77	3,5	3,5	4,5	5,5	35,2	39,8	125	110	0,016
36 x 42	7	6	11700	54000	169	9,39	3,5	3,5	4,5	5,5	36,2	41,8	115	100	0,019
38 x 44	7	6	11000	54000	181	9,55	3,5	3,5	4,5	5,5	38,2	43,8	110	95	0,021
40 x 45	8	6,6	13900	66000	231	11,57	3,5	4,5	5,5	6,5	40,2	44,8	115	105	0,021
42 x 48	8	6,6	15550	66000	235	11,22	3,5	4,5	5,5	6,5	42,2	47,8	110	95	0,026
45 x 52	10	8,6	28300	99000	353	15,71	3,5	4,5	5,5	6,5	45,2	51,8	105	95	0,045
48 x 55	10	8,6	24700	132000	572	23,84	3,5	4,5	5,5	6,5	48,2	54,8	155	135	0,043
50 x 57	10	8,6	23600	132000	602	24,08	3,5	4,5	5,5	6,5	50,2	56,8	150	130	0,045
55 x 62	10	8,6	21700	132000	670	24,35	3,5	4,5	5,5	6,5	55,2	61,8	140	125	0,049
56 x 64	12	10,4	29500	157200	790	28,2	3,5	4,5	5,5	7	56,2	63,8	130	115	0,070
60 x 68	12	10,4	27500	157200	860	28,6	3,5	4,5	5,5	7	60,2	67,8	125	110	0,070
63 x 71	12	10,4	26500	157200	910	28,8	3,5	4,5	5,5	7	63,2	70,8	120	105	0,080
65 x 73	12	10,4	25500	157200	950	29,2	3,5	4,5	5,5	7	65,2	72,8	115	100	0,090
70 x 79	14	12,2	31000	209600	1380	39,4	3,5	5	6,5	7,5	70,3	78,7	125	110	0,115
71 x 80	14	12,2	31000	209600	1400	39,4	3,5	5	6,5	7,5	71,3	79,7	120	110	0,110
75 x 84	14	12,2	34700	209600	1450	38,6	3,5	5	6,5	7,5	75,3	83,7	115	100	0,120
80 x 91	17	15	48000	290000	2200	55	4	6	6,5	8	80,3	90,7	125	105	0,210
85 x 96	17	15	45500	305000	2400	56,4	4	6	6,5	8	85,3	95,7	120	105	0,210
90 x 101	17	15	43600	320000	2730	60,5	4	6	6,5	8	90,3	100,7	120	105	0,220
95 x 106	17	15	41300	330000	3050	64,2	4	6	6,5	8	95,3	105,7	120	110	0,230
100 x 114	21	18,7	61000	445000	4200	84	5	6	7	9	100,3	113,7	120	105	0,390
110 x 124	21	18,7	66000	485000	5150	93,6	5	6	7	9	110,3	123,7	120	105	0,420
120 x 134	21	18,7	60300	510000	6050	100,8	5	6	7	9	120,2	133,7	120	105	0,460
130 x 148	28	25,3	96300	765000	9600	147,6	5	7	9	11	130,4	147,6	120	105	0,860
140 x 158	28	25,3	89000	800500	11000	158,5	6	7	9	11	140,4	157,6	120	105	0,960
150 x 168	28	25,3	85000	860000	12900	172	6	7	8	11	150,4	167,6	120	105	1,000
160 x 178	28	25,3	78600	900000	14600	182,5	6	7	9	11	160,4	177,6	120	110	1,000
170 x 191	33	30	117400	1160000	19500	229	7	9	10	12	170,5	190,5	120	105	1,540
180 x 201	33	30	111300	1200000	21300	236	7	9	10	12	180,5	200,5	120	105	1,500
190 x 211	33	30	105000	1260000	24200	255	7	9	10	12	190,5	210,5	120	110	1,800
200 x 224	38	34,8	134200	1550000	31000	310	7	8	11	13	200,6	223,4	120	105	2,400
210 x 234	38	34,8	127200	1610000	35000	333	7	9	11	13	210,6	233,4	120	110	2,500
220 x 244	38	34,8	122100	1690000	38000	345	7	9	11	13	220,6	243,4	120	110	2,600
230 x 257	43	39,5	164500	2000000	47000	408	7	10	12	14	230,6	256,4	120	105	3,400
240 x 267	43	39,5	157400	2250000	51000	425	7	10	12	14	240,6	266,4	120	110	3,800
250 x 280	48	44	190000	2060000	52000	415	7	10	13	16	250,8	279,2	100	89	4,800
260 x 290	48	44	182000	2132000	56500	435	7	10	13	16	260,8	289,2	100	89	4,900
270 x 300	48	44	177000	2207000	61000	450	7	10	13	16	270,8	299,2	100	89	5,000
280 x 313	53	49	206000	2536000	72500	520	7	11	14	17	280,8	312,2	100	89	6,400
290 x 323	53	49	222000	2632000	77500	535	7	11	14	17	290,8	322,2	100	89	6,500
300 x 333	53	49	214000	2704000	83000	555	7	11	14	17	300,8	332,2	100	89	6,800
320 x 360	65	59	292000	3492000	114000	710	10	15	20	25	321,0	359,0	100	89	11,000
340 x 380	65	59	272000	3672000	128500	755	10	15	20	25	341,0	379,0	100	89	11,500
360 x 400	65	59	258000	3858000	144000	800	10	15	20	25	361,0	399,0	100	90	12,300
380 x 420	65	59	269000	4069000	160500	845	10	15	20	25	381,0	419,0	100	90	13,000
400 x 440	65	59	256000	4256000	178000	890	10	15	20	25	401,0	439,0	100	90	13,700
420 x 460	65	59	244000	4444000	196000	935	10	15	20	25	421,0	459,0	100	90	14,100
440 x 480	65	59	234000	4633000	215000	980	10	15	20	25	441,0	479,0	100	90	14,800
460 x 500	65	59	224000	4824000	235000	1020	10	15	20	25	461,0	499,0	100	91	15,500
480 x 520	65	59	239000	5039000	256000	1070	10	15	20	25	481,0	519,0	100	91	16,000
500 x 540	65	59	229000	5229000	278000	1110	10	15	20	25	501,0	539,0	100	91	16,700
520 x 570	80	73	338000	6788000	372000	1430	12	18	24	30	521,0	569,0	100	91	27,000
540 x 590	80	73	326000	7026000	400000	1480	12	18	24	30	541,0	589,0	100	91	28,000

For larger diameter or inch series please contact us.

Kranpuffer · Crane Buffers

Butée de Grue · Respingenti per Gru · Amortiguadores de Gruas

D

Material	Mikrozelliges Polyurethan-Elastomer
Befestigung	Gewindebolzen oder Grundplatte
Temperaturbereich	-35°C - +80°C (kurzzeitig bis ca. +100°C)
Lange Lebensdauer	Beständig gegen Öle, Fette, Ozon, UV-Strahlung und Alterung
Einsatzbereich	Krananlagen, Maschinenbau, Fördertechnik

GB

Material	Microcellular polyurethane elastomer
Mounting	Threaded bolt or base plate
Temperature	-35°C - +80°C (limited duration +100°C)
Long service life	Resistant to oil, grease, ozone, UV radiation and weathering
Applications	Crane systems, machine building, conveyor technology

F

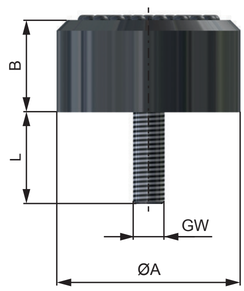
Matière	Élastomère de polyuréthane micro-cellulaire
Fixation	Boulon fileté ou plaque de base
Température	-35°C - +80°C (durée limitée +100°C)
Longue durée de vie	Résistant à l'huile, aux graisses, à l'ozone, aux rayons UV et au vieillissement
Applications	Grues, ingénierie, manutention

I

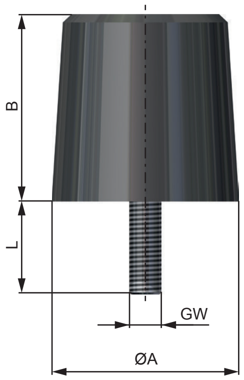
Materiale	Elastomero al poliuretano con struttura a microcellule
Fissaggio	Spinotto filettato oppure piastra di supporto
Temperatura	-35°C - +80°C (tempo limitato +100°C)
Lunga durata	Resistente a oli, grasso, ozono, raggi ultravioletti e invecchiamento
Applicazioni	Impianti di sollevamento, ingegneria meccanica, tecnica dei trasporti industriali

E

Material	Elastómero de poliuretano microcelular
Fijación	Perno roscado o placa base
Temperatura	-35°C - +80°C (tiempo limitado +100°C)
Larga vida útil	Resistente a aceites, grasas, ozono, radiación UV y envejecimiento
Aplicaciones	Instalaciones de grúas, ingeniería mecánica, técnica de movimiento de materiales



Typ 1 x*



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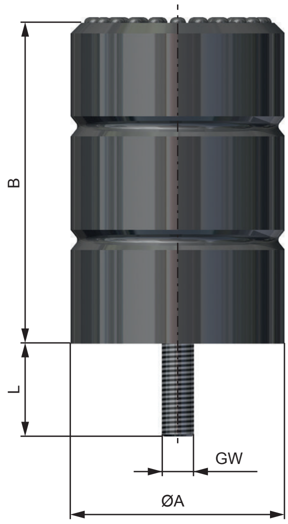

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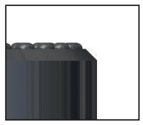
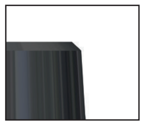


*x: mit Noppen,
with nubs



*y: ohne Noppen,
without nubs

ABMESSUNGEN ▪ DIMENSIONS ▪ DIMENSIONI ▪ DIMENSIONES

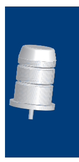
	Typ*		A mm	B mm	L mm	GW	Gewicht Weight
WCB-070-070-6-B	2	y	70	70	35	M 12	0,25
WCB-080-040-6-B	1	x	80	40	35	M 12	0,21
WCB-080-080-6-B	2	y	80	80	35	M 12	0,31
WCB-080-120-6-B	3	x	80	120	35	M 12	0,42
WCB-100-050-6-B	1	x	100	50	35	M 12	0,31
WCB-100-100-6-B	2	y	100	100	35	M 12	0,52
WCB-100-150-6-B	3	x	100	150	35	M 12	0,73
WCB-125-063-6-B	1	x	125	63	35	M 12	0,51
WCB-125-125-6-B	2	y	125	125	35	M 12	0,92
WCB-125-190-6-B	3	x	125	190	35	M 12	1,32
WCB-160-080-6-B	1	x	160	80	35	M 12	0,95
WCB-160-160-6-B	2	y	160	160	35	M 12	1,80
WCB-160-240-6-B	3	x	160	240	35	M 12	2,66

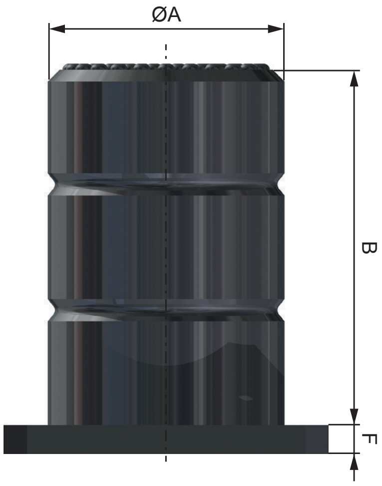
	Typ*		A mm	B mm	L mm	GW	Gewicht Weight
WCB-200-100-6-B	1	x	200	100	35	M 12	1,76
WCB-200-200-6-B	2	y	200	200	35	M 12	3,43
WCB-200-300-6-B	3	x	200	300	35	M 12	5,10
WCB-250-125-6-B	1	x	250	125	80	M 24	5,40
WCB-250-250-6-B	2	x	250	250	80	M 24	8,50
WCB-250-375-6-B	3	x	250	375	80	M 24	11,50
WCB-315-158-6-B	1	x	315	158	80	M 24	8,50
WCB-315-315-6-B	2	x	315	315	80	M 24	14,65
WCB-315-475-6-B	3	x	315	475	80	M 24	20,80
WCB-400-200-6-B	1	x	400	200	80	M 30	16,50
WCB-400-400-6-B	2	x	400	400	80	M 30	29,10
WCB-400-600-6-B	3	x	400	600	80	M 30	41,60

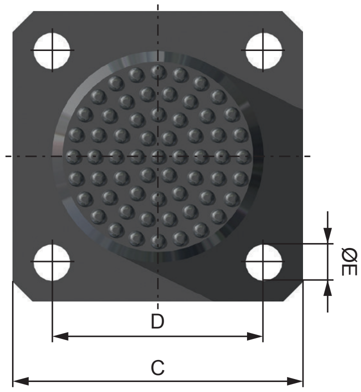
LEISTUNGEN ▪ PERFORMANCE ▪ CARATTERISTICHE TECNICHE ▪ CARACTERÍSTICAS TÉCNICAS

	Federweg max. ▪ max. Deflection max. Écrasement ▪ max. Deformazione máx. Aplastante	V statisch ▪ static statique ▪ statico ▪ estática		V 1 m/s		V 2 m/s		V 3 m/s		V 4 m/s	
	mm	kNm*	kN**	kNm*	kN**	kNm*	kN**	kNm*	kN**	kNm*	kN**
WCB-070-070-6-B	56	0,46	24	0,59	26	0,67	30	0,84	35	1	38
WCB-080-040-6-B	32	0,37	31	0,47	34	0,54	41	0,67	47	0,8	51
WCB-080-080-6-B	64	0,70	31	0,89	34	1,02	41	1,28	47	1,52	51
WCB-080-120-6-B	96	1,08	31	1,37	34	1,57	41	1,96	47	2,33	51
WCB-100-050-6-B	40	0,69	50	0,88	55	1	65	1,25	75	1,5	80
WCB-100-100-6-B	80	1,42	50	1,81	55	2,1	65	2,6	75	3,1	80
WCB-100-150-6-B	120	2,10	50	2,6	55	3	65	3,7	75	4,5	80
WCB-125-063-6-B	50	1,33	65	1,7	80	2,06	95	2,42	110	2,9	120
WCB-125-125-6-B	100	2,61	65	3,33	80	4,04	95	4,75	110	5,7	120
WCB-125-190-6-B	150	3,94	65	5	80	6	95	7,1	110	8,6	120
WCB-160-080-6-B	64	2,30	123	3,1	147	3,9	172	4,9	186	6	200
WCB-160-160-6-B	128	4,70	123	6,1	147	7,8	172	9,7	186	11,4	200
WCB-160-240-6-B	192	7,10	123	9,14	147	11,8	172	14,55	186	18	200
WCB-200-100-6-B	80	5,50	190	7,2	230	8,8	270	10,4	300	12,2	315
WCB-200-200-6-B	160	10,80	190	14,2	230	17,4	270	20,5	300	24	315
WCB-200-300-6-B	240	15,80	190	20,7	230	25,3	270	30	300	35	315
WCB-250-125-6-B	100	10,54	275	13,64	300	16,74	350	19,84	400	23	490
WCB-250-250-6-B	200	21,13	275	27,35	300	33,56	350	39,79	400	46	490
WCB-250-375-6-B	300	31,71	275	41,03	300	50,36	350	59,68	400	69	490
WCB-315-158-6-B	126	13,30	650	17,5	717	22,5	728	35	750	47	780
WCB-315-315-6-B	252	26,60	650	35,28	717	45,36	728	70,56	750	93	780
WCB-315-475-6-B	380	39,84	650	54,67	717	69,58	728	109,34	750	140	780
WCB-400-200-6-B	160	31,13	1000	39,5	1100	49,22	1150	72	1200	94	1250
WCB-400-400-6-B	320	50,00	1000	80	1100	90	1150	140	1200	190	1250
WCB-400-600-6-B	480	80	1000	120	1100	140	1150	220	1200	282	1250

* Energieaufnahme - Energy absorption - Energie d'absorption - Assorbimento d'energia - Absorción de energia
** Endkraft max. - Force max. - Forces finales - Forza finale - Fuerza final





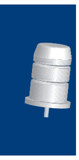


ABMESSUNGEN ▪ DIMENSIONS ▪ DIMENSIONI ▪ DIMENSIONES

Kunststoffflansch Plastic Flange Bride en plastique Flangia in plastica Brida de plástico	Aluminiumflansch Aluminum Flange Bride en aluminium Flangia in alluminio Brida de aluminio	A	B	C	D	ØE	F	Gewicht - Weight Poids - Peso - Peso	
		mm	mm	mm	mm	mm	mm	FK kg	FA kg
WCB-080-040-6-FK	WCB-080-040-6-FA	80	40	110	80	14 (13,8*)	10	0,2	0,4
WCB-080-080-6-FK	WCB-080-080-6-FA	80	80	110	80	14 (13,8*)	10	0,3	0,5
WCB-080-120-6-FK	WCB-080-120-6-FA	80	120	110	80	14 (13,8*)	10	0,4	0,6
WCB-100-050-6-FK	WCB-100-050-6-FA	100	50	125	100	14	10	0,3	0,6
WCB-100-100-6-FK	WCB-100-100-6-FA	100	100	125	100	14	10	0,5	0,8
WCB-100-150-6-FK	WCB-100-150-6-FA	100	150	125	100	14	10	0,7	1,0
WCB-125-063-6-FK	WCB-125-063-6-FA	125	63	160	125	18	12	0,6	1,2
WCB-125-125-6-FK	WCB-125-125-6-FA	125	125	160	125	18	12	1,0	1,5
WCB-125-190-6-FK	WCB-125-190-6-FA	125	190	160	125	18	12	1,4	2,0
WCB-160-080-6-FK	WCB-160-080-6-FA	160	80	200	160	18	12	1,1	1,6
WCB-160-160-6-FK	WCB-160-160-6-FA	160	160	200	160	18	12	2,0	2,8
WCB-160-240-6-FK	WCB-160-240-6-FA	160	240	200	160	18	12	2,8	3,7
WCB-200-100-6-FK	WCB-200-100-6-FA	200	100	250	200	22	14	2,15	3,6
WCB-200-200-6-FK	WCB-200-200-6-FA	200	200	250	200	22	14	3,8	5,5
WCB-200-300-6-FK	WCB-200-300-6-FA	200	300	250	200	22	14	5,5	7,2

* für Flansche aus Aluminium / for aluminum flange

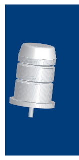
Stahlflansch - Steel Flange Bride en acier - Flangia in acciaio Brida de acero	A	B	C	D	ØE	F	Gewicht - Weight Poids - Peso - Peso
	mm	mm	mm	mm	mm	mm	FS kg
WCB-250-125-6-FS	250	125	315	250	22	15	4,2
WCB-250-250-6-FS	250	250	315	250	22	15	7,8
WCB-250-375-6-FS	250	375	315	250	22	15	11,0
WCB-315-158-6-FS	315	158	400	315	22	15	22,0
WCB-315-315-6-FS	315	315	400	315	22	15	29,0
WCB-315-475-6-FS	315	475	400	315	22	15	36,0
WCB-400-200-6-FS	400	200	500	400	26	20	47,0
WCB-400-400-6-FS	400	400	500	400	26	20	59,0
WCB-400-600-6-FS	400	600	500	400	26	20	71,0
WCB-500-250-6-FS	500	250	630	500	26	20	83,0
WCB-500-500-6-FS	500	500	630	500	26	20	105,0
WCB-500-750-6-FS	500	750	630	500	26	20	129,0
WCB-600-300-6-FS	600	300	730	600	26	20	116,0
WCB-600-600-6-FS	600	600	730	600	26	20	167,0
WCB-600-900-6-FS	600	900	730	600	26	20	198,0



LEISTUNGEN ▪ PERFORMANCE ▪ CARATTERISTICHE TECNICHE ▪ CARACTERÍSTICAS TÉCNICAS

	Federweg max. ▪ max. Deflection max. Écrasement ▪ max. Deformazione máx. Aplastante	V statisch ▪ static statique ▪ statico ▪ estática		V 1 m/s		V 2 m/s		V 3 m/s		V 4 m/s	
	mm	kNm*	kN**	kNm*	kN**	kNm*	kN**	kNm*	kN**	kNm*	kN**
WCB-080-040-6	32	0,37	31	0,47	34	0,54	41	0,67	47	0,8	51
WCB-080-080-6	64	0,70	31	0,89	34	1,02	41	1,28	47	1,52	51
WCB-080-120-6	96	1,08	31	1,37	34	1,57	41	1,96	47	2,33	51
WCB-100-050-6	40	0,69	50	0,88	55	1	65	1,25	75	1,5	80
WCB-100-100-6	80	1,42	50	1,81	55	2,1	65	2,6	75	3,1	80
WCB-100-150-6	120	2,10	50	2,6	55	3	65	3,7	75	4,5	80
WCB-125-063-6	50	1,33	65	1,7	80	2,06	95	2,42	110	2,9	120
WCB-125-125-6	100	2,61	65	3,33	80	4,04	95	4,75	110	5,7	120
WCB-125-190-6	150	3,94	65	5	80	6	95	7,1	110	8,6	120
WCB-160-080-6	64	2,30	123	3,1	147	3,9	172	4,9	186	6	200
WCB-160-160-6	128	4,70	123	6,1	147	7,8	172	9,7	186	11,4	200
WCB-160-240-6	192	7,10	123	9,14	147	11,8	172	14,55	186	18	200
WCB-200-100-6	80	5,50	190	7,2	230	8,8	270	10,4	300	12,2	315
WCB-200-200-6	160	10,80	190	14,2	230	17,4	270	20,5	300	24	315
WCB-200-300-6	240	15,80	190	20,7	230	25,3	270	30	300	35	315
WCB-250-125-6	100	10,54	275	13,64	300	16,74	350	19,84	400	23	490
WCB-250-250-6	200	21,13	275	27,35	300	33,56	350	39,79	400	46	490
WCB-250-375-6	300	31,71	275	41,03	300	50,36	350	59,68	400	69	490
WCB-315-158-6	126	13,30	650	17,5	717	22,5	728	35	750	47	780
WCB-315-315-6	252	26,60	650	35,28	717	45,36	728	70,56	750	93	780
WCB-315-475-6	380	39,84	650	54,67	717	69,58	728	109,34	750	140	780
WCB-400-200-6	160	31,13	1000	39,5	1100	49,22	1150	72	1200	94	1250
WCB-400-400-6	320	50,00	1000	80	1100	90	1150	140	1200	190	1250
WCB-400-600-6	480	80,00	1000	120	1100	140	1150	220	1200	282	1250
WCB-500-250-6	200	50,00	1500	70	1700	90	1800	140	1900	185	1950
WCB-500-500-6	400	100,00	1500	154	1700	178	1800	275	1900	370	1950
WCB-500-750-6	600	150,00	1500	225	1700	275	1800	425	1900	555	1950
WCB-600-300-6	240	87,50	2500	125	2650	150	2700	250	2750	317	2800
WCB-600-600-6	480	175,00	2500	250	2650	300	2700	500	2750	633	2800
WCB-600-900-6	720	250,00	2500	400	2650	500	2700	750	2750	950	2800

* Energieaufnahme - Energy absorption - Energie d'absorption - Assorbimento d'energia - Absorción de energia
** Endkraft max. - Force max. - Forces finales - Forza finale - Fuerza final



robolink®...

igus.eu ...Components for low-cost robots...03.2018...

modular system

robolink® D components | Modular system

robolink® modular system | Low-cost robots

Robotic joints and components made from igus® tribo-polymers.

Our basic idea is to give developers, labs, and automation integrators access to a joint modular system to construct customised robots which can be used in the most different applications. Always at the lowest possible costs, with the appropriate technology. The required number of joint axes in the appropriate geometric constellation is often decisive for the correct solution.

Our robolink® joints (RL-D worm gear and RL-S strain wave gear) can be combined with each other and powered with different motors. In the framework of the modular system concept, our customers can select either joints, joints with our igus® motors or predefined articulated arm configurations and receive them within short delivery times.

Central characteristics of our joints are lubrication-free plastic gears (worm, strain wave and the new cycloidal gear), igus® bearing technology (usually with our PRT polymer slewing ring bearings), and a variety of modular versions.

The main components of the modular system at the moment are:

- RL-D joints with worm gear in 3 installation sizes with currently 8 transmission ratios as standard
- RL-S joints with strain wave gear in 2 sizes
- A large number of motor kits for direct linkage to the above gears
- External incremental encoder kits for angle monitoring and referencing
- RL-C or RL-Q connection system in order to make modular articulated arms from the joints
- Standard articulated arms up to 5 axes from the above-named components

In addition, our axes can also be combined with igus® linear technology and open up another area for customised automation solutions.

The basic idea underlying the igus® draw wire technology RL-W is based on the bionic principle of the decoupling of joints and motors in order to obtain especially light and flexible arms. These products are used in service robotics and in projects with human-machine interaction.

Martin Raak
Product Manager robolink®
e-mail: mraak@igus.de
Phone.: +49 2203 9649-409

blog.igus.eu/category/robolink

Application areas:

- Single joints as driven slewing rings in a horizontal installation position or as positioning units or as rotating axes in linear systems
- Combined joints as rotary-drive units
- Articulated arms with different kinematics, low-cost automation, pick & place, teaching, research, training

igus® – plastics for longer life®

www.igus.eu/robolink
Also visit our igus® website www.igus.eu, explore other products, technical details, novelties, helpful online tools, and benefit from our online product range – any hour of the day.

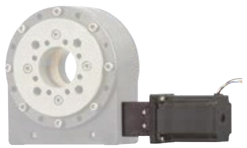
Our offers are exclusively directed to dealers / resellers. The quoted unit prices in Euros are net prices without VAT. All previous price lists become invalid with the publication of this price list.

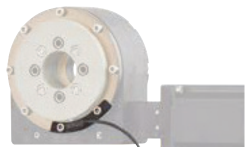
Delivery
free within Germany for orders over EUR 150.00

Payment
2 % discount within 14 days net within 30 days

robolink® D components

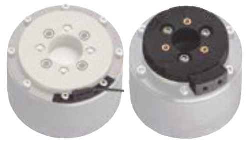

Joint with plastic worm gear
▶ Page 8


Motor kits
▶ Page 12


Accessories
▶ Page 16


Joint with plastic strain wave gear
▶ Page 20


Motor kits
▶ Page 24

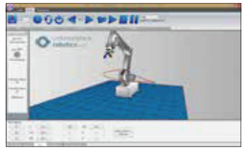

Accessories
▶ Page 25

Electro-mechanical robot arms


robolink® C arms
▶ Page 28


robolink® Q arms
▶ Page 30

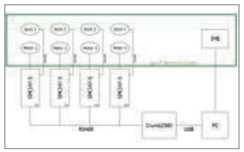

robolink® online designer
▶ Page 33


CPR control
▶ Page 34

robolink® W draw wire technology

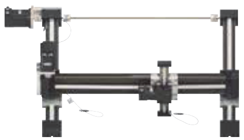

Rope drive for rotating joint
▶ Page 38


Complete 6 DOF unit
▶ Page 44


Open source
▶ Page 48

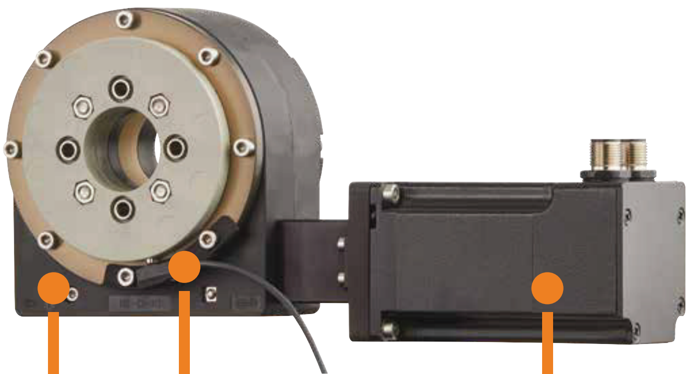

Software for programming articulated joints
▶ Page 49

Linear robots for predefined surfaces and spaces

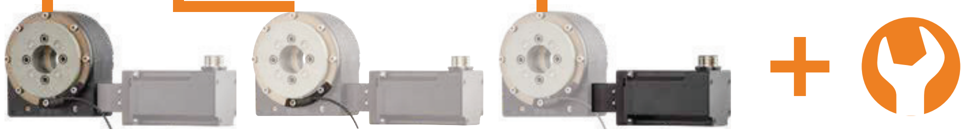

Multi-axis modular system for drylin® linear robots
▶ www.igus.eu/gantry

robolink® components

RL-D joints standard configuration



Configuration example:
RL-D-30-A0100
consisting of
- RL-D-30-102-50-01035
- RL-D-30-MK-C-N23-02
- RL-D-30-IK-001
- RL-D-MONT-MOT-01
- RL-D-MONT-INI-01



RL-D-30-102-50-01035
Asymmetric joint
i = 50:1
Quality: high end
more joints
▶ **from page 8**

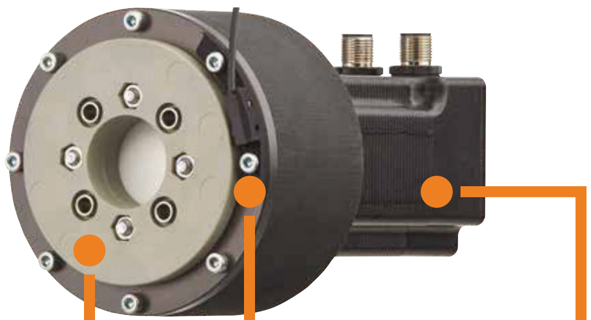
RL-D-30-IK-001
Proximity switch kit
for RL-D-30 joints
more information
▶ **from page 16**

RL-D-30-MK-C-N23-02
Motor kit for RL-D-30
NEMA23 stepper motor
+ encoder
more combinations
▶ **from page 12**

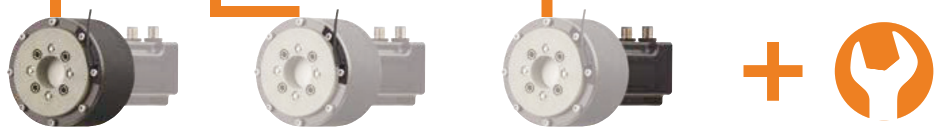
RL-D-MONT-MOT-01
RL-D-MONT-IK-01
Motor and proximity
switch kit assembly
incl. functional check

robolink® components

RL-S joints standard configuration



Configuration example:
RL-S-20-A0100
consisting of
- RL-S-20-N23-00-38-12000
- RL-S-20-MK-N23-02
- RL-S-20-IK-01
- RL-S-MONT-MOT-01
- RL-S-MONT-INI-01



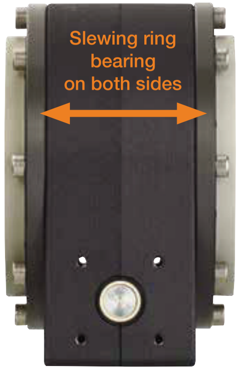
RL-S-20-N23-00-38-12000
Asymmetric joint
i = 38:1
Quality: high end
more joints
▶ **from page 20**

RL-S-20-IK-01
Proximity switch kit
for RL-S-20 joints
more information
▶ **from page 23**

MOT-AN-S-060-020-056-M-A-AAAC
Motor for RL-S-20
NEMA23 stepper motor
+ encoder
more combinations
▶ **from page 22**

RL-S-MONT-MOT-01
RL-S-MONT-INI-01
Motor and proximity
switch kit assembly
incl. functional check

Symmetrical - with two PRT slewing ring bearings



robolink® D robot joint with two PRT slewing ring bearings

Slewing ring bearing (iglidur® PRT) with a plastic housing. The drive component is a worm gear. The centre hole remains free for feeding cables etc. through. The articulated joints can be ordered with or without motor.

- Self-locking drive only for reduction gearing of 1:70
- Standard motor option: stepper motor NEMA17 / 23 / 23XL
- INI kit for zero position optionally adaptable

Order key

Type | Dimensions [mm]

RL - D -20 - 101 -38 - 01000

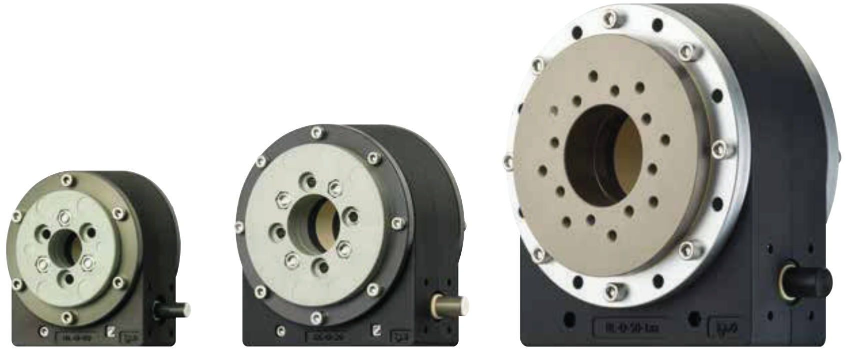
- robolink®
- Type "D"
- Installation size
- Symmetric, 2 PRT
- Reduction gearing
- Options

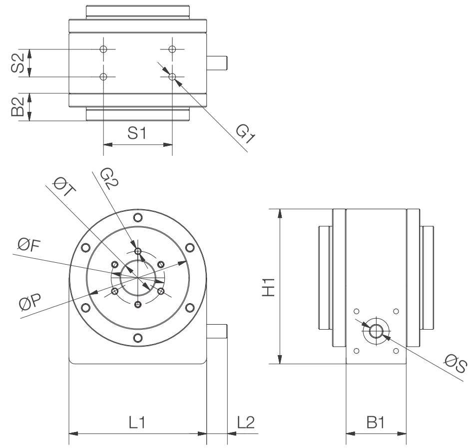
Versions:
Standard: -01000
FULL PLASTIC: -03011
High end: -01033

Technical data

		RL-D-20-101	RL-D-30-101	RL-D-50-101
Size	[mm]	90 x 80 x 67	110 x 100 x 94	170 x 150 x 103
Shaft diameter	[mm]	8	10	15
Reduction gearing	[1:x]	3/5/8/16/38/70	3/5/8/30/50/70	3/5/16/48/70
Axis distance	[mm]	31	40	63
Backlash	[°]	< 0.5	< 0.5	< 0.5
Breakaway torque	[cNm]	< 5	< 7	< 10
Max. axial dyn. load on output	[N]	> 500	> 700	> 1,200

Delivery time
2–3 days





3 versions

- **Standard (-01000):** 2 pcs aluminium PRT (PRT-02-xx-AL), aluminium worm shaft (AL hard-anodised). Application e.g. in our low-cost robot arms as front joints (RL-D-20 and RL-D-30).
- **FULL PLASTIC (-03011):** 2 pcs low-cost PRT (PRT-02-xx-LC), worm shaft made from plastic RN33. Application e.g. for manual adjustments.
- **High end (-01033):** 2 pcs PRT design 01 (PRT-01-xx), aluminium worm shaft (AL hard-anodised), high rigidity. Application e.g. as the first pivoting axis in robolink® articulated arms.

Dimensions [mm] / Prices [€]

Part No.	ØT	ØS	ØP	ØF	L1	L2	B1	B2	H1	G1	G2	S1	S2	1–9 pieces	10–24 pieces	25–49 pieces
Size 20																
RL-D-20-101-38-01000	20	8	60	31	80.5	12	35	10.5	90.5	M4	3 x M5	40	16	202.00	182.93	168.49
RL-D-20-101-38-03011	20	8	60	31	80.5	12	35	10.5	90.5	M4	3 x M5	40	16	186.00	168.30	155.01
RL-D-20-101-38-01033	20	8	60	31	80.5	12	35	16	90.5	M4	6 x M4	40	16	327.00	295.81	272.45
Size 30																
RL-D-30-101-50-01000	30	10	80	42.5	100.5	12	45	12.5	110.5	M4	4 x M5	55	20	233.00	211.20	194.53
RL-D-30-101-50-03011	30	10	80	42.5	100.5	12	45	12.5	110.5	M4	4 x M5	55	20	215.00	194.31	178.97
RL-D-30-101-50-01033	30	10	80	42.5	100.5	12	45	19.5	110.5	M4	8 x M4	55	20	345.00	312.45	287.78
Size 50																
RL-D-50-101-48-01000	50	15	120	65	150.5	13	60	13	170.5	M6	8 x M6	80	30	424.00	361.08	324.45
RL-D-50-101-48-03011	50	15	120	65	150.5	13	60	13	170.5	M6	8 x M6	80	30	390.00	332.19	298.49
RL-D-50-101-48-01033	50	15	120	65	150.5	13	60	21.5	170.5	M6	8 x M6	80	30	538.00	462.02	415.15

Asymmetrical - with one PRT slewing ring bearing and cover plate

Order key

Type			Dimensions [mm]		
RL	- D	-20	-102	-38	-01004
robolink®	Type "D"	Installation size	Asymmetric, 1 PRT	Reduction gearing	Options

Versions:
Standard: -01004
FULL PLASTIC: -03014
High end: -01035

robolink® D robot joint with one PRT slewing ring bearing and cover plate

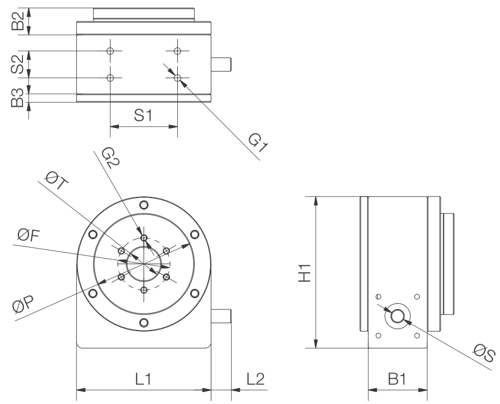
Slewing ring bearing (iglidur® PRT) in a plastic housing. The drive component is a worm gear. The centre hole remains free for feeding cables etc. through. The articulated joints can be ordered with or without motor.

- Self-locking drive only for reduction gearing of 1:70
- Standard motor option: stepper motor NEMA17 / 23 / 23XL
- Application e.g. horizontal on base plate

Technical data

		RL-D-20-102	RL-D-30-102	RL-D-50-102
Size	[mm]	90 x 80 x 67	110 x 100 x 94	170 x 150 x 103
Shaft diameter	[mm]	8	10	15
Reduction gearing	[1:x]	3/5/8/16/38/70	3/5/8/30/50/70	3/5/16/48/70
Axis distance	[mm]	31	40	63
Backlash	[°]	< 0.5	< 0.5	< 0.5
Breakaway torque	[cNm]	< 5	< 7	< 10
Max. axial dyn. load on output	[N]	> 500	> 700	> 1,200

Delivery time
2–3 days



3 versions

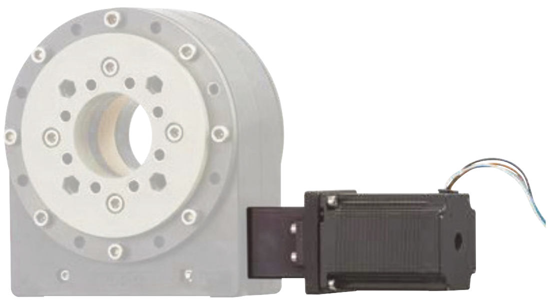
- **Standard (-01004):** 1 pc aluminium PRT (PRT-02-xx-AL), aluminium worm shaft (AL hard-anodised). Application e.g. in our low-cost robot arms as front joints (RL-D-20 and RL-D-30).
- **FULL PLASTIC (-03014):** 1 pc low-cost PRT (PRT-02-xx-LC), worm shaft made from plastic RN33. Application e.g. for manual adjustments.
- **High end (-01035):** 1 pc PRT design 01 (PRT-01-xx), aluminium worm shaft (AL hard-anodised), high rigidity. Application e.g. as first rotating axis in robolink® articulated arms

Dimensions [mm] / Prices [€]

Part No.	ØT	ØS	ØP	ØF	L1	L2	B1	B2	B3	H1	G1	G2	S1	S2	1–9 pieces	10–24 pieces	25–49 pieces
Size 20																	
RL-D-20-102-38-01004	20	8	60	31	80.5	12	35	10.5	5	90.5	M4	3 x M5	40	16	182.00	164.64	151.64
RL-D-20-102-38-03014	20	8	60	31	80.5	12	35	10.5	5	90.5	M4	3 x M5	40	16	167.00	151.47	139.51
RL-D-20-102-38-01035	20	8	60	31	80.5	12	35	16	5	90.5	M4	6 x M4	40	16	272.00	246.51	227.05
Size 30																	
RL-D-30-102-50-01004	30	10	80	42.5	100.5	12	45	12.5	6	110.5	M4	4 x M5	55	20	210.00	190.08	175.08
RL-D-30-102-50-03014	30	10	80	42.5	100.5	12	45	12.5	6	110.5	M4	4 x M5	55	20	193.00	174.88	161.07
RL-D-30-102-50-01035	30	10	82	42.5	100.5	12	45	19.5	6	110.5	M4	8 x M4	55	20	288.00	260.38	239.82
Size 50																	
RL-D-50-102-48-01004	50	15	120	65	150.5	13	60	13	6	170.5	M6	4 x M6	80	30	381.00	324.97	292.00
RL-D-50-102-48-03014	50	15	120	65	150.5	13	60	13	6	170.5	M6	4 x M6	80	30	351.00	298.97	268.64
RL-D-50-102-48-01035	50	15	120	65	150.5	13	60	21.5	6	170.5	M6	8 x M6	80	30	414.00	352.56	316.79

robolink® D | Motor kit | Stepper motor

robolink® D robot joint with direct drive



- Adaptable to various motors, standard option: NEMA17 / 23 / 23XL stepper motor
- INI kit for zero position optionally adaptable ▶ **page 16**

Motor kit

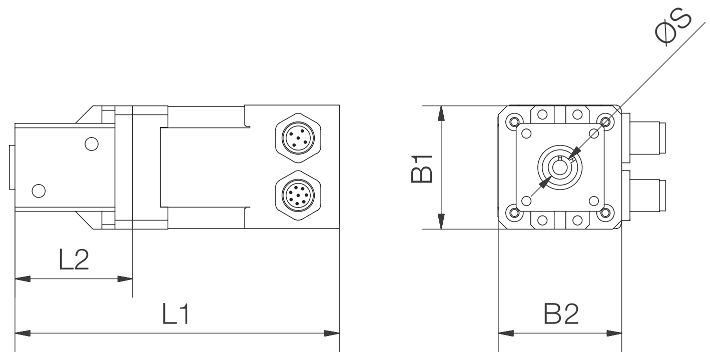
Motor type igus® stepper motor	Distance over hubs [mm]	Versions
NEMA17, NEMA23, NEMA23XL	42, 56, 60	-00: with strand wires -01: with stepper motor without encoder -02: with motor encoder

Technical data – joints with motor

Joint		Size 20 RL-D-20-101-38-XXxx	Size 30 RL-D-30-101-50-XXxx		Size 50 RL-D-50-101-48-XXxx	
Motor		+ NEMA17	+ NEMA17	+ NEMA23	+ NEMA23	+ NEMA23XL
Motor type		Stepper motor				
Weight (with standard joint)	[g]	890	1,140	1,860	2,540	2,970
Max. radial torque strength (short-term)	[Nm]	5	6	12	21	38
Max. radial torque strength (long-term)	[Nm]	4	5	8	18	33
Max. speed (at max. load)	[rpm]	5	4	4	4	4
Max. axial dynamic load (horizontal installation)	[N]	> 500	> 700	> 700	> 1,200	> 1,200

Delivery time
2–3 days

robolink® D | Robot joint | Motor kit



Dimensions [mm]						Prices [€]		
Part No.	ØS	L1	L2	B1	B2	1-9 pieces	10-24 pieces	25-49 pieces
NEMA17								
RL-D-20-MK-C-N17-00	8	99.4	40	42	42	93.90	84.87	77.33
RL-D-20-MK-C-N17-01	8	110.4	40	42	42	153.55	141.54	132.81
RL-D-20-MK-C-N17-02	8	110.4	40	42	42	241.55	225.14	214.65
RL-D-20-MK-C-N17-NM	8	–	40	42	42	56.55	45.83	37.97
RL-D-30-MK-C-N17-00	10	99.4	40	42	42	93.90	84.87	77.33
RL-D-30-MK-C-N17-01	10	110.4	40	42	42	153.55	141.54	132.81
RL-D-30-MK-C-N17-02	10	110.4	40	42	42	241.55	225.14	214.65
RL-D-30-MK-C-N17-NM	10	–	40	42	42	56.55	45.83	37.97
NEMA23								
RL-D-30-MK-C-N23-00	10	118	42	56.4	56.4	159.58	146.07	135.26
RL-D-30-MK-C-N23-01	10	140	42	56.4	56.4	207.76	191.84	180.07
RL-D-30-MK-C-N23-02	10	140	42	56.4	56.4	294.36	274.11	260.61
RL-D-30-MK-C-N23-NM	10	–	42	56.4	56.4	89.78	72.72	60.28
RL-D-50-MK-C-N23-00	15	124	48	60	60	159.58	146.07	135.26
RL-D-50-MK-C-N23-01	15	146	48	60	60	207.76	191.84	180.07
RL-D-50-MK-C-N23-02	15	146	48	60	60	294.36	274.11	260.61
RL-D-50-MK-C-N23-NM	15	–	48	60	60	89.78	72.72	60.28
NEMA23XL								
RL-D-50-MK-C-N23XL-00	15	136.5	48	60	60	186.12	171.28	159.94
RL-D-50-MK-C-N23XL-01	15	158.5	48	60	60	274.12	254.88	241.78
RL-D-50-MK-C-N23XL-02	15	158.5	48	60	60	376.94	352.57	337.42
RL-D-50-MK-C-N23XL-NM	15	–	48	60	60	89.78	72.72	60.28

Assembly costs motor kit	1-9 pieces [€]	10-24 pieces [€]	25-49 pieces [€]
RL-D-MONT-MOT-01	34.80	28.30	18.85

robolink® D | Motor Kit | DC Motor

robolink® D robot joint with direct drive

- Easy rotary movements without control technology
- Only voltage supply needed

Available DC motors:
MOT-AE-B-024-001-037-F-A-AAAA (0.1 Nm)
MOT-AE-B-024-003-037-F-A-AAAA (0.3 Nm)
MOT-AE-B-024-005-036-F-A-AAAA (0.5 Nm)
MOT-AE-B-024-007-037-F-A-AAAA (0.7 Nm)
MOT-AE-B-024-010-042-F-A-AAAA (1.0 Nm)
MOT-AE-B-024-015-037-F-A-AAAA (1.5 Nm)
MOT-AE-B-024-018-042-F-A-AAAA (1.8 Nm)

Motor kits:
RL-D-20-MK-C-DCxx-04
RL-D-30-MK-C-DCxx-04
RL-D-50-MK-C-DCxx-04

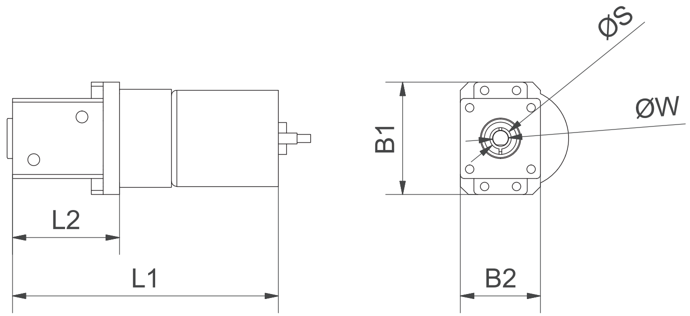
xx = DC motor type

Technical data

	Unit	
Maximum voltage	[VDC]	24
Nominal voltage	[VDC]	24
Nominal torque	[Nm]	0.1–1.8
Start up torque	[Nm]	0.3–6
Idling speed	[rpm]	22–440
Rated speed	[rpm]	17–350
Nominal current	[A]	0.5–2.3

Delivery time
2–3 days

robolink® D | Motor kit | DC Motor



Dimensions [mm]

Part No.	ØS	ØW	L1	L2	B1	B2
Size 20						
RL-D-20-MK-C-DC01-04	8	6	100	40	42	30
RL-D-20-MK-C-DC03-04	8	6	102	40	42	30
RL-D-20-MK-C-DC05-04	8	6	126	40	42	30
RL-D-20-MK-C-DC07-04	8	6	105	40	42	30
RL-D-20-MK-C-DC10-04	8	8	145	40	42	30
Size 30						
RL-D-30-MK-C-DC01-04	10	6	100	40	42	30
RL-D-30-MK-C-DC03-04	10	6	102	40	42	30
RL-D-30-MK-C-DC05-04	10	6	126	40	42	30
RL-D-30-MK-C-DC07-04	10	6	105	40	42	30
RL-D-30-MK-C-DC10-04	10	8	145	40	42	30
RL-D-30-MK-C-DC15-04	10	6	107	40	42	30
RL-D-30-MK-C-DC18-04	10	8	152	40	42	30
Size 50						
RL-D-50-MK-C-DC01-04	15	6	108	48	59	42
RL-D-50-MK-C-DC03-04	15	6	110	48	59	42
RL-D-50-MK-C-DC05-04	15	6	134	48	59	42
RL-D-50-MK-C-DC07-04	15	6	113	48	59	42
RL-D-50-MK-C-DC10-04	15	8	153	48	59	42
RL-D-50-MK-C-DC15-04	15	6	115	48	59	42
RL-D-50-MK-C-DC18-04	15	8	160	48	59	42

Assembly costs motor kit	1-9 pieces [€]	10-24 pieces [€]	25-49 pieces [€]
RL-D-MONT-MOT-01	34.80	28.30	18.55

robolink® D | Robot joint | INI kit

robolink® D robot joint with direct drive

INI kit

Fitting	Switching output	Switching function	Operating voltage	Rated operational current
M8 x 1	PNP	NO (Closer)	10…30 V DC	100mA

INI kit - prices [€]

Part No.	1-9 pieces [€]	10-24 pieces [€]	25-49 pieces [€]
RL-D-20-IK-001	38.00	34.20	32.30
RL-D-30-IK-001	41.00	36.90	34.85
RL-D-50-IK-001	44.00	39.96	37.74
Assembly costs INI kit			
RL-D-MONT-INI-01	18.50	15.50	13.90

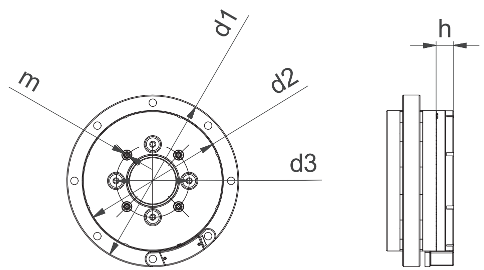
Selection:
Initiator kit, drive encoder or output encoder

Delivery time
2-3 days

robolink® D | Robot joint | Output encoder

Output encoder for RL-D gearboxes

Measurement of the angular position of the joint on the output side by means of an external angle sensor. Hall sensor for the neutral position and incremental A/B signals with a high resolution for the control system. The INI switch and the motor encoder can therefore be dispensed with.



Conductor colours of sensor cable

+5V	GND	Hall sensor	Encoder Index	Encoder A channel	Encoder B channel
red	black	white	green	blue	yellow

Dimensions [mm] / Prices [€]

Part No.	d1	d2	d3	m	h	Pole pairs	for	1-9 pieces	from 10 pieces
RL-D-20-EK-01	80	60	31	3 x M4	10	47	PRT-01	142.00	Upon request
RL-D-20-EK-02	80	60	31	3 x M4	10	47	PRT-02	142.00	Upon request
RL-D-30-EK-01	80	60	31	3 x M4	10	63	PRT-01	154.00	Upon request
RL-D-30-EK-02	80	60	31	3 x M4	10	63	PRT-02	154.00	Upon request
RL-D-50-EK-01	150	120	65	4 x M6	10	94	PRT-01	182.00	Upon request
RL-D-50-EK-02	150	120	65	4 x M6	10	94	PRT-02	182.00	Upon request

Assembly costs encoder kit	1-9 pieces [€]	10-24 pieces [€]	25-49 pieces [€]
RL-D-MONT-INI-01	34.80	28.30	18.55

robolink® D | RL-D-PT

Rotary-drive unit

Rotary-drive unit for highly precise manual adjustment of components

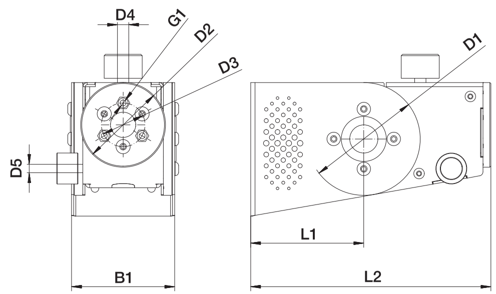
- 2 lubrication-free robolink® gearboxes with a transmission ratio of 1:70, incl. two hand wheels
- Gearboxes are self-locking
- Pivoting: RL-D-30, gearbox set 1:70
- Rotating: RL-D-20, gearbox set 1:70
- Lubrication-free support with igus® plain bearings

Typical application areas:

- Adjustment of satellite dishes
- Manual adjustment of instruments or devices
- Format adjustments

robolink® D | RL-D-PT

Rotary-drive unit



DESIGN AWARD 2018

reddot design award winner 2018

Dimensions [mm]

Part No.	L1	L2	B1	D1	D2	D3	D4	D5	G1	Prices [€]
RL-D-PT-30-20-70-AA	80	170	73	80	60	31	8	6	3 x M5	233.00

Available from stock

robolink® S | Strain wave gear

robolink® S – low clearance strain wave gear made from plastic

Coaxial gearbox added to the gearbox portfolio of igus®. Can be adapted to different motors, like the RL-D worm gear.

Advantages of strain wave gears:

- Low clearance
- Lightweight
- High transmission ratios in one stage
- High static holding strength

Typical application areas:

- 5th axis for igus® articulated arms
- Low-cost robotics

Size

RL-S-17-...

RL-S-20-...

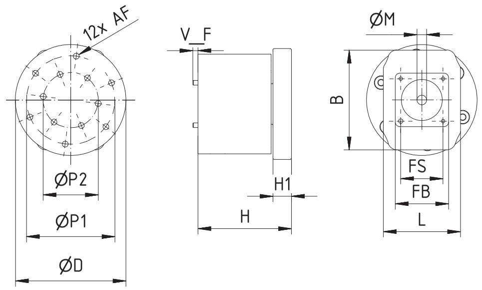
RL-S-30-...

Properties

- Main components : igus® PRT-01/-02, shaft generator, flexible inner ring, outer ring
- RL-S-20: self-locking drive - slewing ring bearing remains in position when powered off
- Lightweight and compact

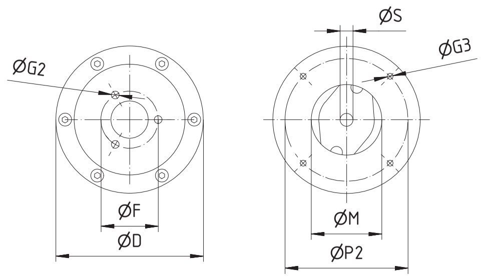
Technical data - standard version

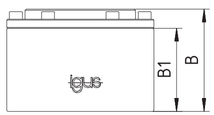
Part No.	Weight [g]	Reduction gearing	Efficiency	Moment of breakage at the output (static) [Nm]	Max. output torque (long-term) [Nm]	Max. output torque (short-term) [Nm]
RL-S-17-N11-00-28-020K0	100	28:1	> 0.2	26	0.5	0.75
RL-S-17-N17-00-28-020K0	100	28:1	> 0.25	26	1.5	3.0
RL-S-20-N23-00-38-12000	290	38:1	> 0.3	50	3.0	5.0
RL-S-30-N23-NM-38-02000	490	38:1	> 0.3	50	8.0	10.0



Dimensions [mm]

Part No.	ØD	ØP1	ØP2	AF	V_F	H	ØM	FS	FB	L	B	H1	Prices [€]
RL-S-17-N11-00-28-020K0	60	48	30	M4x8	M2.5x2.75	50.75	5	23	29	42	54	10	108.00
RL-S-17-N17-00-28-020K0	60	48	30	M4x8	M3x5.4	44	5	31	42	42	42	10	108.00

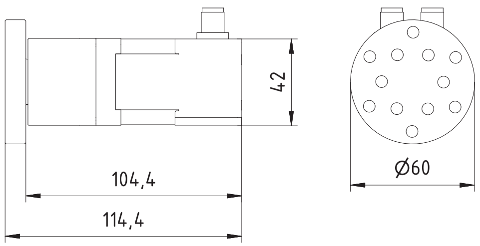


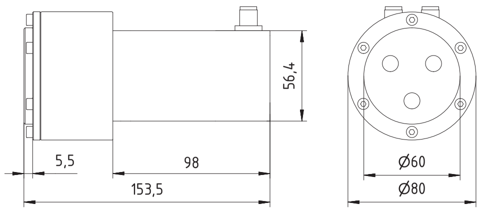


Dimensions [mm]

Part No.	ØD	B	ØM	B1	B2	ØG2	ØG3	ØP1	ØP2	ØS	Prices [€]
RL-S-20-N23-00-38-12000	80	55.5	38	45	10.5	M5 x 15.5	4xM4	31	66.67	6.35mm (1/4")	172.00
RL-S-30-N23-00-38-02000	100	66.5	38	54	12.5	M5 x 15.5	4xM4	42.5	66.67	6.35mm (1/4")	upon request

robolink® S | Strain wave gear with motor





Part No.	Gear	Motor	Specification	Prices [€]
RL-S-17-A0164	RL-S-17-N17-00-28-020K0	MOT-AN-S-060-005-042-M-C-AAAC	NEMA17 stepper motor with encoder and M12 connector	327.88
RL-S-20-A0165	RL-S-20-N23-00-38-12000	MOT-AN-S-060-020-056-M-C-AAAC	NEMA23 stepper motor with encoder and M12 connector	411.46

robolink® S | Strain wave gear | Options

Initiator kit for RL-S gears

- INI kit for zero positions optional
- Can also be retrofitted for sizes RL-S-17, RL-S-20 and RL-S-30

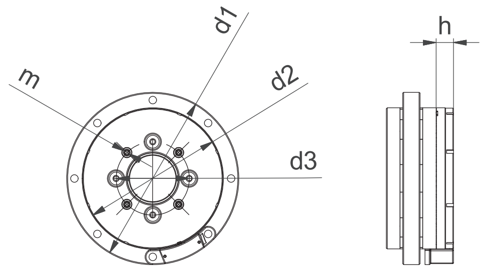
INI kit

Fitting	Switching output	Switching function	Operating voltage	Rated operational current
M8 x 1	PNP	NO (Closer)	10…30 V DC	100 mA

INI kit - prices [€]

Part No.	1-9 pieces	10-24 pieces	25-49 pieces
RL-S-17-IK-01	38.00	34.20	32.30
RL-S-20-IK-01	41.00	36.90	34.85
Assembly costs INI kit			
RL-D-MONT-INI-01	18.50	15.50	13.90

Output encoder for RL-S gearboxes



Dimensions [mm]

Part No.	d1	d2	d3	m	h	Prices [€]
RL-S-17-EK-xx*	–	–	–	–	–	114.00
RL-S-20-EK-xx	80	60	31	3 x M5	10	142.00
RL-S-30-EK-xx	100	82	42.5	4 x M5	10	154.00

* The RL-S-17 output encoder does not change the outer dimensions.

Assembly costs encoder kit	1-9 pieces [€]	10-24 pieces [€]	25-49 pieces [€]
RL-D-MONT-INI-01	18.50	15.50	13.90

robolink®

Standard joints (from stock)

robolink® C – arm
For direct drive
robolink® D

8 base configuration up to 5 DOF

from 2,548,-€

robolink® Q - arm
For direct drive
robolink® S and
robolink® D

8 base configuration up to 5 DOF

from 2,963,-€

robolink® | RL-C 5 DOF

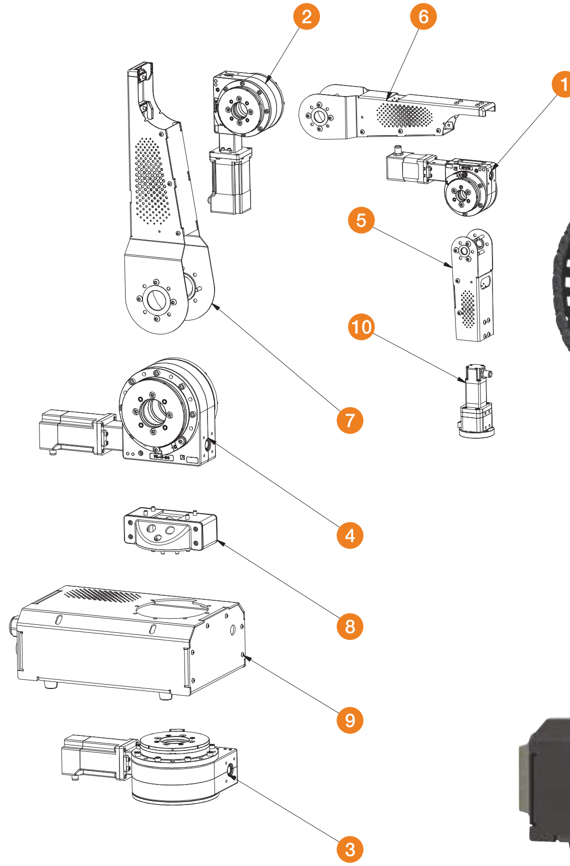


Image exemplary

Configuration example	
1 RL-D-20...01000 / MK-N17-01 / EK	6 270mm connecting part
2 RL-D-30...01000 / MK-N23-01 / EK	7 350mm connecting part
3 RL-D-50...01035 / MK-N23XL-01 / EK	8 50-50 connecting part
4 RL-D-50...01033 / MK-N23XL-01 / EK	9 Base-50 connecting part
5 170mm connecting part	10 RL-S-17

robolink® | RL-DC standard configuration

Milling with a robolink® DC

Typical application areas:
- Low-cost robotics
- Simple handling
- Pick and place

Part No.	Designation	Prices [€]
RL-D-RBT-3322-BC	4 axes robolink® DC, small version, with motor encoder and INI	2,766.00
RL-D-RBT-3322-BC-AE	4 axes robolink® DC, small version, with output encoder	2,548.00
RL-D-RBT-5532-BC	4 axes robolink® DC, large version, with motor encoder and INI	3,437.00
RL-D-RBT-5532-BC-AE	4 axes robolink® DC, large version, with output encoder	3,195.00
RL-D-RBT-3322S-BC	5 axes robolink® DC, small version, with motor encoder and INI	3,174.00
RL-D-RBT-3322S-BC-AE	5 axes robolink® DC, small version, with output encoder	2,932.00
RL-D-RBT-5532S-BC	5 axes robolink® DC, large version, with motor encoder and INI	3,845.00
RL-D-RBT-5532S-BC-AE	5 axes robolink® DC, large version, with output encoder	3,579.00

Order key

Type | Dimensions [mm]

RL - D - RBT - 3322 - 5532 - S - BC - AE

- RL: robolink®
- D: Type
- RBT: Robot arm
- 3322: Joint configuration 30-30-20-20
- 5532: Joint configuration 50-50-30-20
- S: 5th axis with RL-S-17 strain wave gear
- BC: Version designation
- AE: Output encoder

5m cables for each motor, encoder, INI routed out of the base

robolink® | 5th axis for robolink® RL-DC

5th axis for robolink® RL-DC with RL-S-17 strain wave gear adaptable to robolink® RL-D-20

- Axis of rotation with igus® stepper motor NEMA11 and encoder
- Direct screw-connection to the RL-S-17 strain wave gear
- The output disc has an INI switch for zero point definition
- The motor-gearbox unit is directly connected to the robolink® RL-D-20-101-38-01000 standard joint by means of an adapter plate (4th axis in the modular articulated arm, "big" and "small version")
- Cables (motor, encoder and initiator cables are placed in the existing e-chainsystem® of the joint)
- Output encoder optional

More Information about robolink® D modular system
▶ from page 6

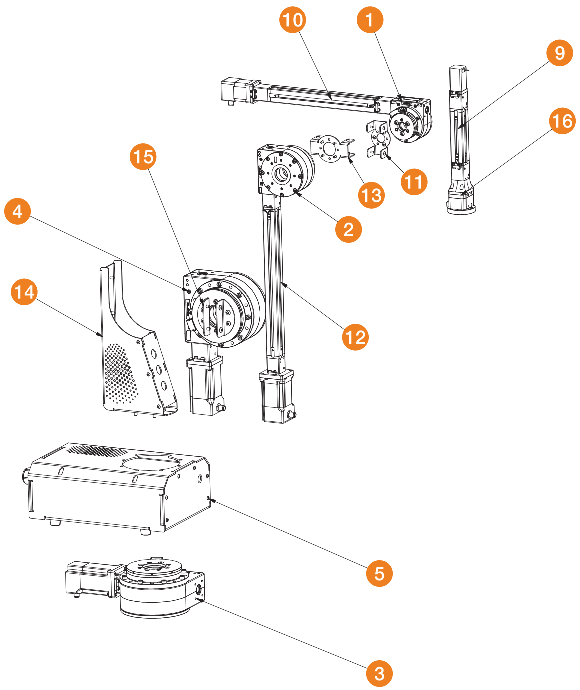
Information about the new robolink® strain wave gears
▶ from page 18

Part No.	Designation	Prices [€]
RL-DC-S17-N11-AA	5th axis for RL-DC with motor encoder and INI	408.00
RL-DC-S17-N11-AA-AE	5th axis for RL-DC with output encoder	384.00

Available upon request

robolink® DQ/SQ

robolink® SQ and DQ with worm and strain wave gears



Combination of different gear types, worm gear and new igus® strain wave gear. With it, the prototype of a 5-axis pivoting robot arm can be configured.

More Information about robolink® D modular system
▶ from page 6

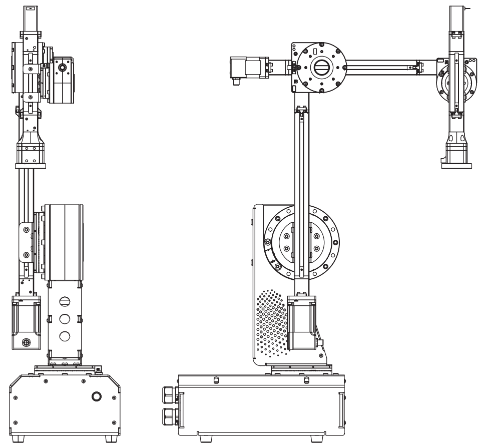
Information about the new robolink® strain wave gears
▶ from page 18

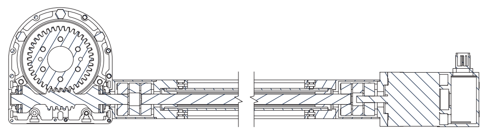
Configuration example	
1 RL-D-20...01035 / MK-N17-01 / EK	11 Connecting part 20-P30
2 RL-D-30...01053 / MK-N23-01 / EK	12 Profile connector 370mm
3 RL-D-50...01035 / MK-N23XL-01 / EK	13 Connecting part 30-P30
4 RL-D-50...01035 / MK-N23XL-01 / EK	14 Connecting part L-50-50
5 Base-50 connecting part	15 Connecting part 50-P30
9 Profile connector 160mm	16 RL-S-17
10 Profile connector 300mm	

Available upon request

robolink® DQ

robolink® DQ with decoupled motors





New concept compared to connection with folded sheet-metal parts. Motor and joint are uncoupled by means of a standard profile. As a result, the operating temperature in the joint is reduced and the motor is used as a counterweight to the joint (optimisation of the payload). The geometry of the articulated arm can be altered within minutes.

Typical application areas:
- Low-cost robotics
- Simple handling
- Pick and place

More Information about robolink® D modular system
▶ from page 6

Information about the new robolink® strain wave gears
▶ from page 18

Part No.	Designation	Prices [€]
RL-DQ-RBT-3322-BC	4 axes robolink® DQ, small version, with motor encoder and INI	3,277.00
RL-DQ-RBT-3322-BC-AE	4 axes robolink® DQ, small version, with output encoder	2,963.00
RL-DQ-RBT-5532-BC	4 axes robolink® DQ, large version, with motor encoder and INI	3,565.00
RL-DQ-RBT-5532-BC-AE	4 axes robolink® DQ, large version, with output encoder	3,324.00
RL-DQ-RBT-3322S-BC	5 axes robolink® DQ, small version, with motor encoder and INI	3,752.00
RL-DQ-RBT-3322S-BC-AE	5 axes robolink® DQ, small version, with output encoder	3,414.00
RL-DQ-RBT-5532S-BC	5 axes robolink® DQ, large version, with motor encoder and INI	3,987.00
RL-DQ-RBT-5532S-BC-AE	5 axes robolink® DQ, large version, with output encoder	3,775.00

Available upon request

robolink® | 5th axis for robolink® RL-DQ

5th axis for robolink® RL-DQ with RL-S-17 strain wave gear

- Axis of rotation with igus® stepper motor NEMA11 with encoder
- Connected to the RL-S-17 strain wave gear by means of a standard 30x30 aluminium section
- The output disc has an INI switch for zero point definition
- On the profile, the motor-gearbox unit is connected to the RL-D-20-101-38-01000 standard joint (4th axis in modular articulated arm)
- Cables (motor, encoder and initiator cables) are placed in the existing e-chainsystem® of the 4-axis articulated arm
- Output encoder optional

More Information about robolink® D modular system
▶ from page 6

Information about the new robolink® strain wave gears
▶ from page 18

iF DESIGN AWARD 2018

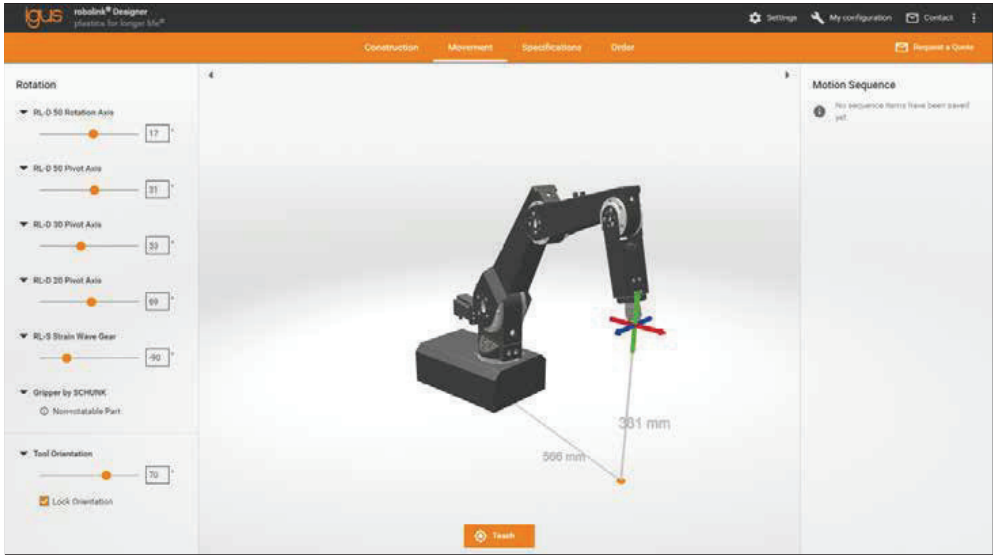
reddot design award winner 2018

Part No.	Designation	Prices [€]
RL-DQ-S17-N11-AA	5th axis for RL-DQ with motor encoder and INI	475.00
RL-DQ-S17-N11-AA-AE	5th axis for RL-DQ with output encoder	451.00

Available upon request

robolink® | Online designer

Digital modular kit configurator for robolink®



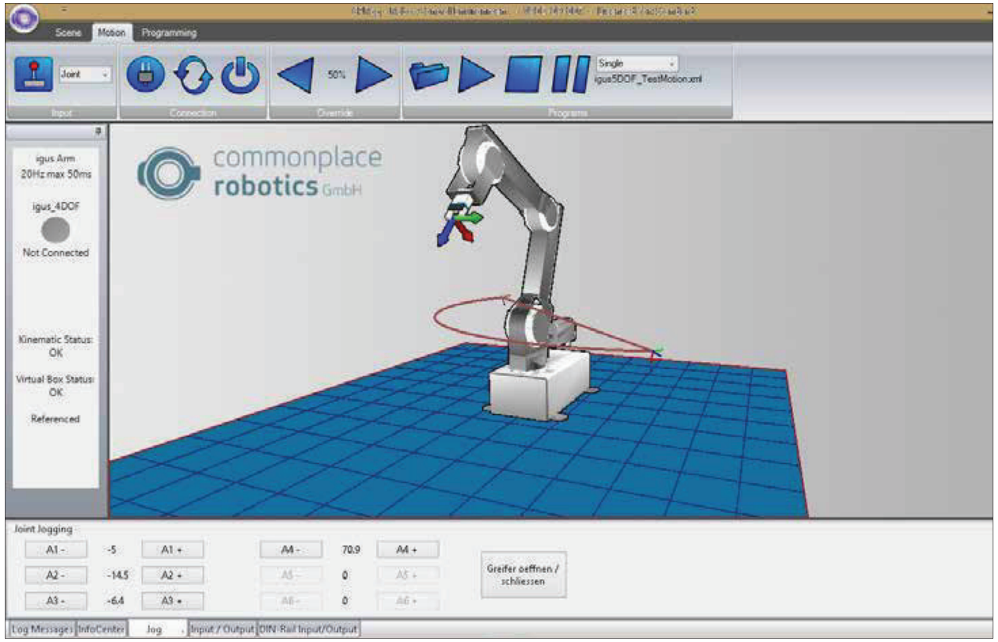
With the new robolink® designer, you can quickly and easily configure your individual robolink® D robot arm online, in an intuitive CAD interface.

- Select robolink® components step by step, individually configure the robotic arms from the first axis up to the tool
- Adapt to your working space with free selection of arm length
- Output the max. payload and the max. range of your individual configuration
- Output the parts list
- Save and download your individual configurations
- Also usable on a tablet/smartphone
- Inverse kinematics: Simulate movement of the entire robot arm by pulling the tool axis
- "Teach" function for learning movement sequences with several intermediate steps
- Simulate robot arm movements by rotating individual joints
- Calculate the work space and output of the tool centre point
- Maximum range and movable weight can be calculated
- Get an indication of the price and delivery time for your configured robot arm
- Direct request option
- Simply transfer to the shopping cart, no minimum order quantity

www.igus.eu/robolink-designer

robolink® | Control

robolink® software for programming articulated joints



- Modular control
- 3D user interface
- Intuitive operator control
- Axis linear movements
- CAN-Bus interface
- Easy-to-maintain DIN rail modules
- Control system for 4, 5, 6-axis robot arms
- Control system for 3, 4-axis linear robots

Scope of supply: control system, CPRog software, 24V power, USB-CAN adapter, connecting cable
Also needed: Windows PC, power supply unit, gripper, safety-relevant components

Special possibilities for a Cartesian control system of robolink® articulated arms
BECKHOFF: controller CX5130, stepper controller, EL7047

Supplier:
Commonplace Robotics GmbH
www.cpr-robots.com
www.cpr-roboter.de
info@commonplacerobotics.de

robolink® | With control

robolink® 4 or 5-axis robot arm with integrated control system

- Integrated motor controller, digital inputs/outputs and control computer
- Touch display for operator control
- Programming via connected laptop with intuitive 3D interface
- Advantage: Very compact design without additional control cabinet
- Modular control
- CAN-Bus interface
- Control system for 4 or 5-axis robot arms

Technical data – robolink® compact

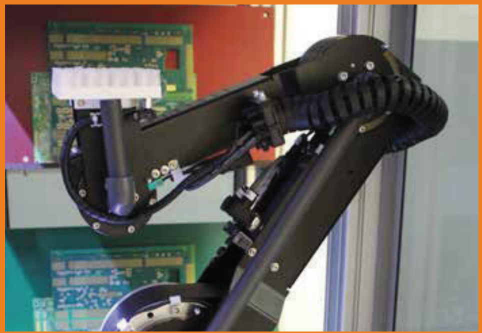
		4 DOF*	5 DOF*
Model name		RL-DCi-4S	RL-DCi-4S
Operating voltage	[VDC]	24	24
Nominal power (at full load)	[W]	120	120
Max. payload (incl. gripper)	[kg]	1	0.5
Weight (without power supply unit, ext. display)	[kg]	11	12
Dimensions (base)	[mm]	360 x 160	
Reach	[mm]	510	
Precision (WDH precision)	[mm]	1	1
Max. speed (TCP)	[m/s]	–0.1	–0.1

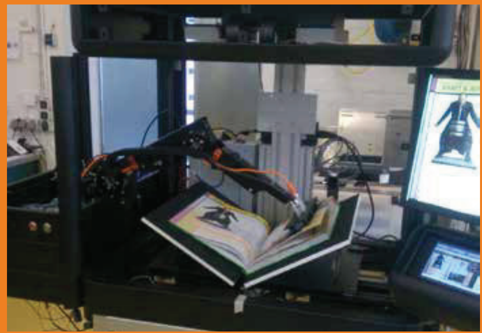
Dimensions [mm]

Part No.	L1	L2	L3	X1	X2	X3	X4
RL-DCi-4S	280	160	360	217.5	270	240	–
RL-DCi-5S	280	160	360	227.5	270	240	170

* DOF: degree of freedom

robolink® RL-D application examples


robolink® D for checking printed circuit boards (4Stars Engineering Systems GmbH)


Automatic book scanner with 2 DOF (EPS GmbH)


Camera-based control of a sensorless RL-D arm with 5 DOF (RoVi Robot Vision, TU Munich, LMT)


Injection-moulding process with automated handling thanks to robolink® D with 4 DOF (Dr. BOY GmbH & Co. KG)


robolink® D – Suction arm in a machine tool (igus®)


Storage and retrieval unit with two RL-D and drylin® linear guides (MATRIUM GmbH)


robolink® D with 4 DOF as manipulator in demo factory (ALBIS PLASTIC GmbH)


Measuring machine with RL-DQ-RBT-5532S and CPR control system for sorting good from bad parts (PROFACTOR GmbH)

Trade fair machine – 5 DOF robot arm with RL-D and RL-S joints. System simulates real use in the igus® factory (igus®)


Manual adjustment of a receiver unit for satellite signals

Trade fair machine RL-DQ-RBT-5532S-AC with 5 DOF and 3-finger gripper (igus®)

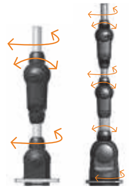
robolink® joints and systems


Rotating joint
▶ from page 38


Pivoting joint
▶ from page 38


Base joint
▶ from page 38


2-axis joint
▶ from page 38


Infinite possibilities
▶ from page 39

robolink® components


Angle sensors
▶ www.igus.eu/robolink


2-jaw gripper
▶ www.igus.eu/robolink


3-jaw gripper
▶ www.igus.eu/robolink


Drive units
▶ www.igus.eu/robolink


Complete
6 DOF unit
▶ from page 40

robolink® accessories


Camera adapter
▶ www.igus.eu/robolink


Drive wheel
▶ www.igus.eu/robolink


Clamping tool
▶ www.igus.eu/robolink


Wire end bottom and wires
▶ www.igus.eu/robolink


Bowden cable
▶ www.igus.eu/robolink

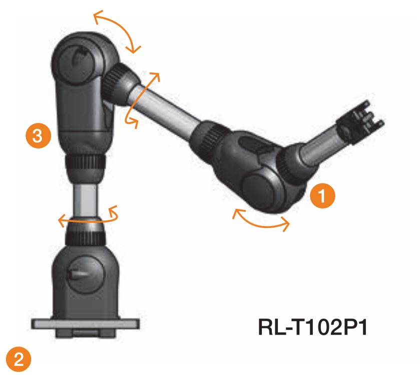

Connecting tubes
▶ www.igus.eu/robolink


Flange shaft support
▶ www.igus.eu/robolink

robolink® software


robolink® software
"open source"
▶ from page 44

robolink® W | Modular system overview

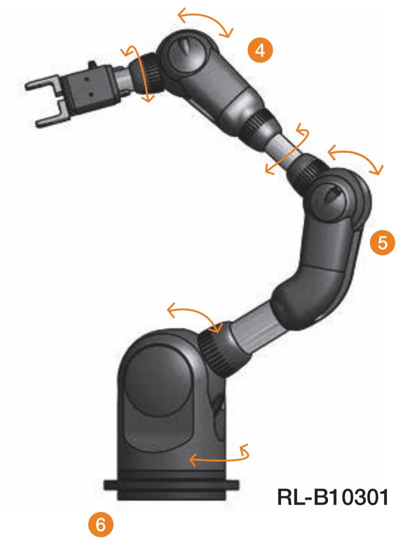


Components kit to make robotic systems

A couple of years ago, we established our objective to develop a modular system of mechanical components for the assembly of robotic systems. The first component in this system was a plastic link with tendon drive.
This element has the following special properties: lightweight, compact and unlimited. Universities and R&D organisations use these components to build customised systems.

The main components of the robolink® W set are:

- Wire driven joints with 1 or 2 degrees of freedom (DOF)
- Electrical grippers
- Direct driven joints "robolink® D"
- Open source software IME (igus® motion editor)
- The main components are made from plastics and produced by laser sintering (SLS), injection-moulded parts made from igus® tribo polymers are planned.



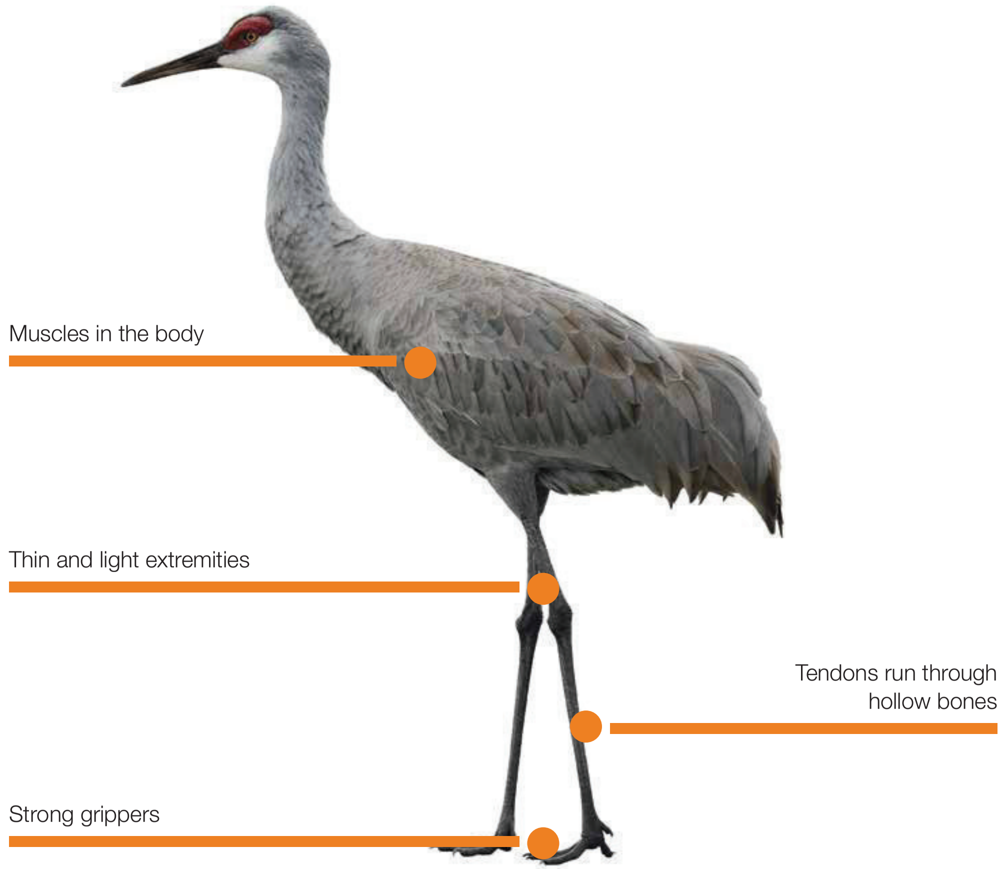
Configuration example RL-T102P1
1 RL-50-PL1 – swivel joint (1 DOF)
2 RL-50-TL1 – rotating joint (1 DOF)
3 RL-50-002 – 2-axis joint (2 DOF)

Configuration example RL-B10301
4 RL-50-001 – 2-axis joint (2 DOF)
5 RL-50-003 – 2-axis joint (2 DOF)
6 RL-90-BL1 – base joint (2 DOF)

robolink® W | The idea

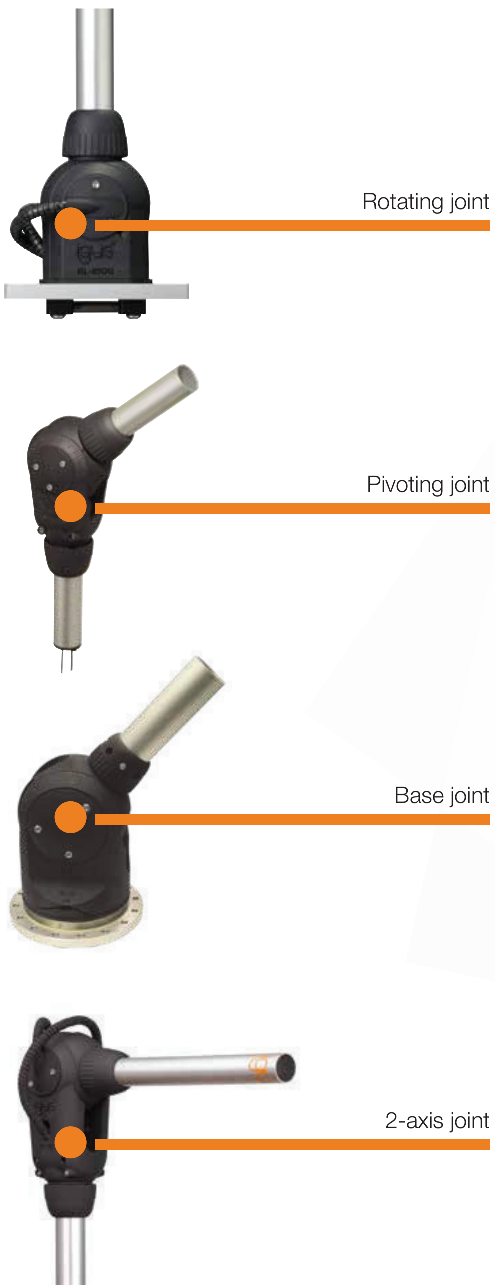
Bionic model of a crane

robolink® joints were patented in 2009 as a "bionic" concept (see pic. below, the crane). The basic RL-50-001 joint can pivot and rotate like a human elbow and is actuated by wires (tendons). This means that the actuators can be placed away from the joint, resulting in a very lightweight arm (one joint with 2 DOF weighs just 350g).



robolink® W | Joints

Different joints



Today, 7 different joint types are available. There are a large number of combination options. The pivoting range can be varied (± 90°, +130/–50°, +180°/0°) and there is a choice of rotating or pivoting joints. For higher load requirements a base joint RL-90-BL1 is available.

More information
▶ www.igus.eu/robolink-joint

igus

robolink® W | System examples

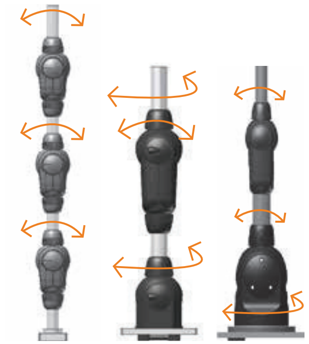
7 joint variants … unlimited possibilities ... several possible combinations …

The plastic joints are linked by aluminium tubes, which can be made to specified lengths for every joint arm. In order to reduce weight further there are also options for carbon fibre or reinforced plastic tubes. The actuation wires are fed through the arms. These are specially developed Bowden cables. This method enables flexibility within the design stage allowing from 1 DOF up to a maximum of 6 DOF.

2 DOF: from 495,-*

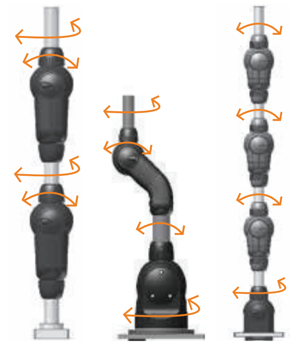
RL-T1P1 -(E)

3 DOF: from 845,-*



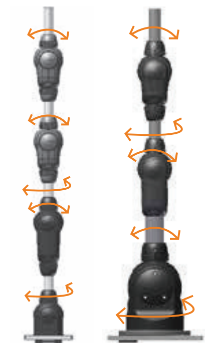
RL-P1P1P1 -(E) | RL-T101 -(E) | RL-B1P1 -(E)

4 DOF: from 1,134,-*



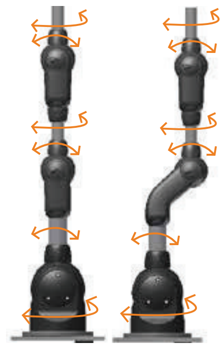
RL-0101 -(E) | RL-B103 -(E) | RL-T1P1P1P1 -(E)

5 DOF: from 1,484,-*



RL-T101P1P1 -(E) | RL-B101P1 -(E)

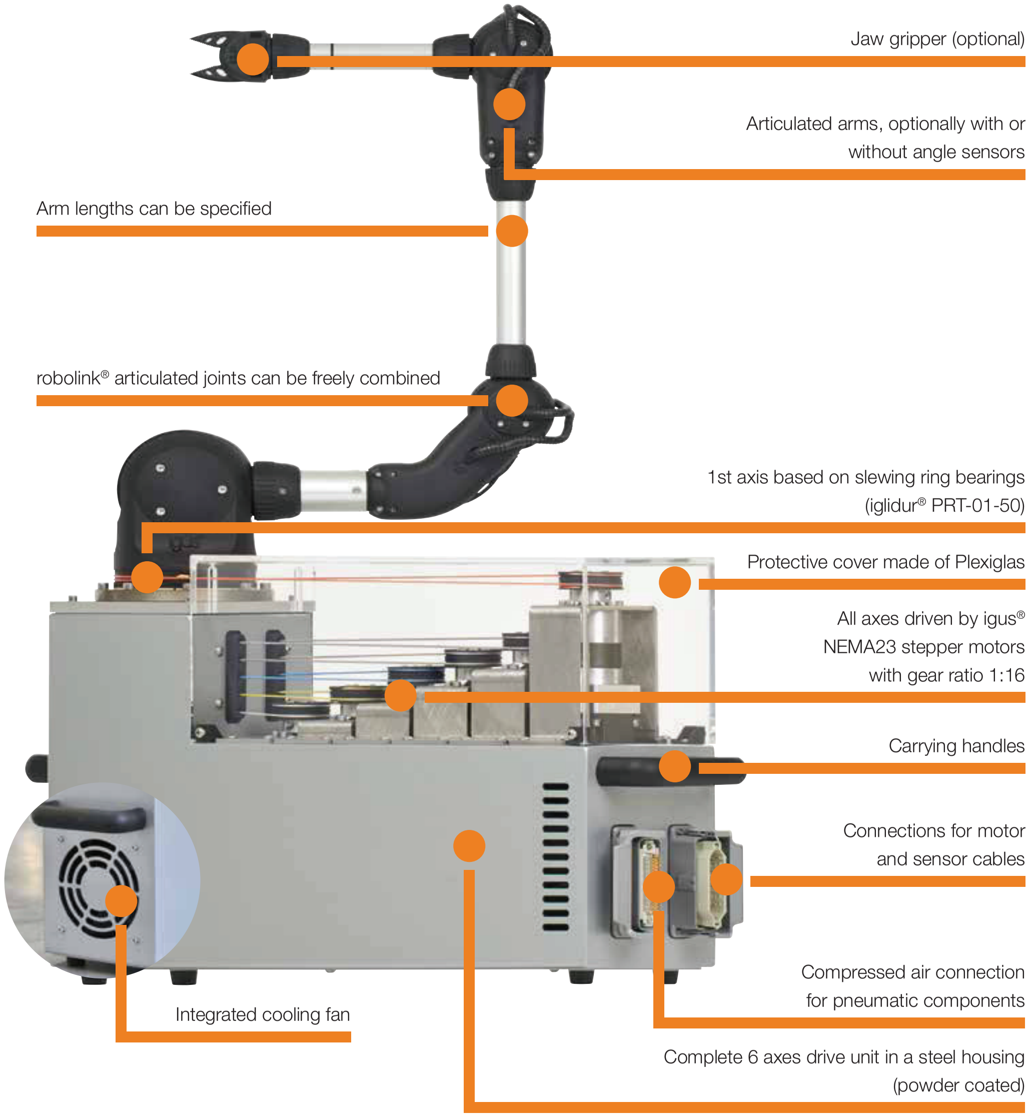
6 DOF: from 2,132,-*



RL-B10101 -(E) | RL-B10301 -(E)

* System price in EUR for 1 unit purchases, incl. aluminium tubes and wires (no sensors)
DOF: degree of freedom

igus

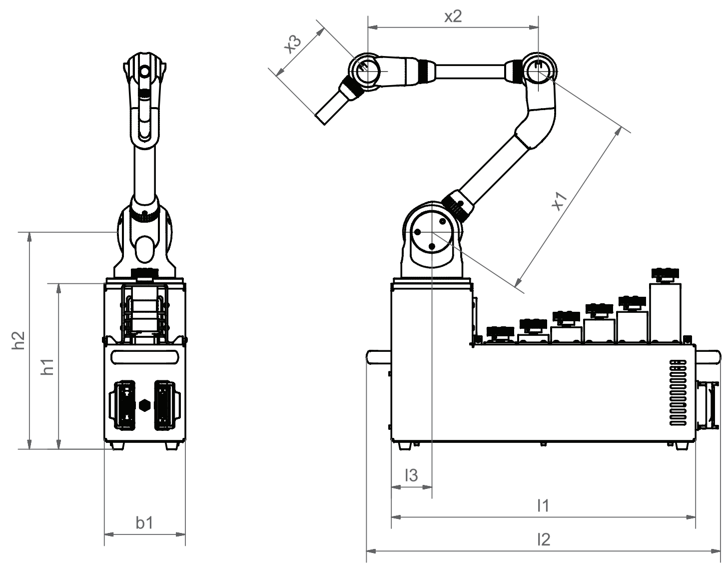


Cables:
Motor and sensor cables available from stock

Connectors:
2 versions available: Socket/plug and socket/open

Cables

	Motor cable Socket/connector	Motor cable Socket/open	Sensor cable Socket/connector	Sensor cable Socket/open
Part No.	RL-CB13-CAB-MOT-01	RL-CB13-CAB-MOT-02	RL-CB13-CAB-SENS-01	RL-CB13-CAB-SENS-02
Length	3 m	3 m	3 m	3 m
Cable type	igus® CF130.05.25.UL	igus® CF130.05.25.UL	igus® CF2.01.48	igus® CF2.01.48
Number of cables / cross section	25 x 0.5 mm²	25 x 0.5 mm²	48 x 0.15 mm²	48 x 0.15 mm²
Connector housing	Harting Han 16 A	Harting Han 16 A	Harting Han 16 A	Harting Han 16 A
Socket	Harting Han 25 D	Harting Han 25 D	D-Sub 50 pol	D-Sub 50 pol
Connectors	Harting Han 25 D	"open" side for individual connection	D-Sub 50 pol	"open" side for individual connection
Price in € / piece	130.31	101.50	202.37	170.91



Dimensions [mm]

Part No.	Specification	b1	h1	h2	l1	l2	l3	Standard arm lengths x1*	x2*	x3*	Prices [€] 1 pieces
RL-B10201-DU3623L	Without angular encoders	160	326	427	600	698	80	280	236	134	from 5,846.40
RL-B10201-E-DU3623L	With angular encoders	160	326	427	600	698	80	280	236	134	from 6,992.40

*** Standard tube length = 100mm; other lengths available**

Delivery time **Cables: from stock**
complete drive unit: 5–10 days

robolink® application examples

robolink® articulated arm with gesture based control. [The Institute for Product Development and Machinery Design at the Leibnitz University, Hannover]

Manual workstation support system with human-machine interface for the production of the Manufacturing Technology Lab (LaFT) at Helmut-Schmidt University in Hamburg

Special design with 4 DOF, 3 joints in series (Fraunhofer IFF Magdeburg)

Submerged camera guidance, articulated arm with 4 DOF (igus®)

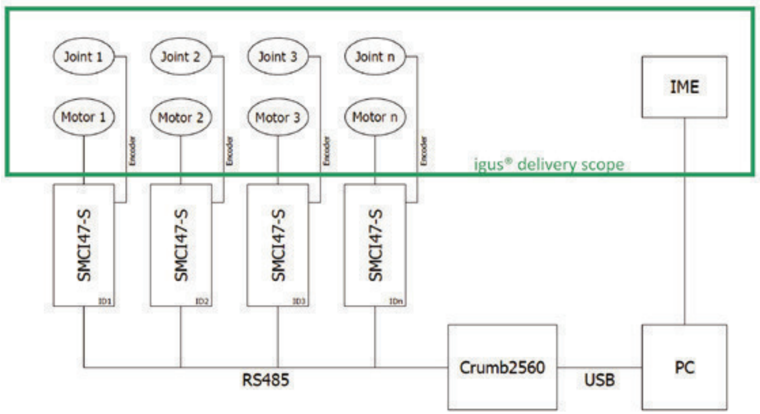
The Technical University at Wroclaw, Poland equipped its autonomous robot FLASH with 2 robolink® articulated arms, each with 4 DOF.

"HOBBIT" service robotics project at TU Vienna. robolink® articulated joints on autonomous systems. (Project partner Hella Automation, Austria) igus® uses its own control system for internal use. It consists of stepper motor controllers by Nanotec® and a Crumb 2560 ATmega Chip. The controllers make use of an RS485 bus which is transferred via USB by the Crumb chip (see picture below). For this hardware configuration, igus® offers an open source software named IME ("igus® motion editor"). The software has been developed by the University of Bonn, Institute for computer science. It is a stand-alone software for easy programming of robolink® systems and can be configured for individual joint arms (1-6 DOF).

Open source software for the robolink® modular system

You can use our robolink® modular kit to easily implement your individual ideas and concepts. No matter if you use 1, 2, 3, 4, 5 or 6 axes.

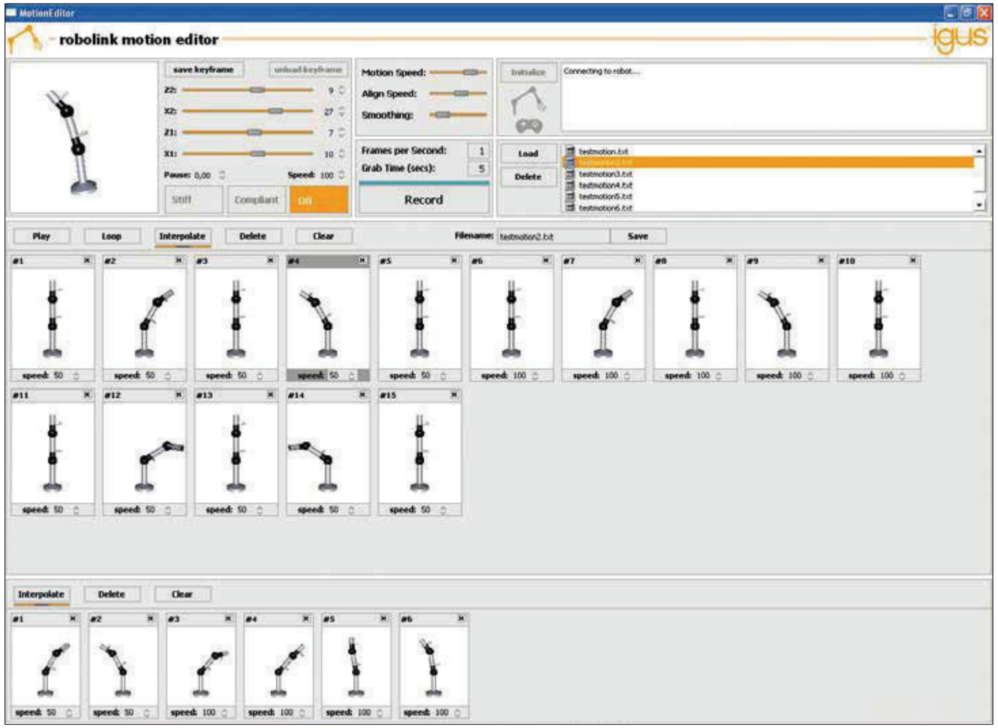
- Free of charge
- Intuitive programming
- For all versions of articulated arms, 1-6 DOF
- Simple control software



Hardware configuration:

Stepper motor control - NANOTEC SMCI47-S2, memory-chip Crumb2560 ATmega USB module.

robolink® | Software



robolink® software for programming articulated arms: IME (igus® motion editor)

A large number of options exist to control robolink® articulated arms. For controlling of igus® stepper motors usually using stepper motor cards. Additionally a higher level control is required to coordinate the axes. igus® has developed a simple, intuitive control software, which allows the programming of articulated arms (1-6 DOF).

Simple control software: free of charge, open source
▶ www.igus.eu/robolink-software

More information about software also online in robolink® blog
▶ www.igus.eu/robolink/blog

Milling with a robolink® DC

robolink® DC (4 DOF*)

		Small versions		Large versions	
		With motor encoder and INI	With output encoder	With motor encoder and INI	With output encoder
Weight	[kg]	12.1	10.9	21.4	20.2
Reach	[mm]	510		620	
Payload	[g]	1,000		3,000	
Precision	[mm]	1		1	
Part No.		RL-D-RBT-3322-BC	...-AE	RL-D-RBT-5532-BC	...-AE
Prices		2,766,- €	2,548,- €	3,437,- €	3,195,- €

robolink® DC (5 DOF*)

		Small versions		Large versions	
		With motor encoder and INI	With output encoder	With motor encoder and INI	With output encoder
Weight	[kg]	13.2	11.7	22.4	21.0
Reach	[mm]	680		790	
Payload	[g]	500		2,500	
Precision	[mm]	1		1	
Part No.		RL-D-RBT-3322S-BC	...-AE	RL-D-RBT-5532S-BC	...-AE
Prices		3,174,- €	2,932,- €	3,845,- €	3,579,- €

* DOF: degree of freedom

Available from stock

robolink® | Electro-mechanical robot arms

Electrical control included (Commonplace Robotics)
Software runs on external Windows PC.

robolink® DCi-4 (4 DOF*)

		With output encoder
Weight	[kg]	12.0
Reach	[mm]	510
Payload	[g]	1,000
Precision	[mm]	1
Part No.		RL-DCi-4S
Prices		4,978,- €

robolink® DCi-5 (5 DOF*)

		With output encoder
Weight	[kg]	13.0
Reach	[mm]	680
Payload	[g]	500
Precision	[mm]	1
Part No.		RL-DCi-5S
Prices		5,492,- €

* DOF: degree of freedom

Available from stock

robolink®

igus®.eu/8pm

Orders can be placed until 8pm local time. Ordering and deliveries weekdays from 7am to 8pm, Saturday from 8am to 12pm.
No minimum order quantities, no surcharges.
Quick delivery.
www.igus.eu Phone: +49-2203-9649-0 Fax -222

igus®.eu/24

Buy online - 24 hrs!

/9001:2016
/16949:2016

igus® is certified in accordance with ISO 9001:2016 and ISO/TS 16949:2016 in the field of energy supply systems, cables and harnessing, as well as plastic bearings.

igus®.eu

igus® GmbH Spicher Str. 1a 51147 Cologne
Phone +49-2203-9649-409 Fax +49-2203-9649-222
info@igus.de www.igus.eu

Subject to technical alterations. MAT0071620.20 Issue 03/2018

Superior Clamping and Gripping

Product Information

Gripper for small components EGP 50

High Performance Density. Fast. Compact.
EGP gripper for small components

Electric 2-finger parallel gripper with smooth-running base jaws guided on roller bearings

Field of application

Gripping and moving of small to medium-sized workpieces with flexible force and high speed in clean environments, such as assembly, testing, laboratory and pharmaceutical industry

Advantages – Your benefits

Highest performance density for the use of smaller grippers sizes

Control via digital I/O for easy commissioning and rapid integration into existing systems

Two to four stage adjustable gripping force for simple adaption to sensitive workpieces

Backlash-free, pre-loaded cross roller guide for precise gripping with nearly constant force for all permissible finger lengths

Very high maximum cycles per minute for highest productivity

Compact dimensions for minimal interfering contours in the application

Proven a thousand times MPG-plus basis for equal gripping forces and strokes with identically high efficiency

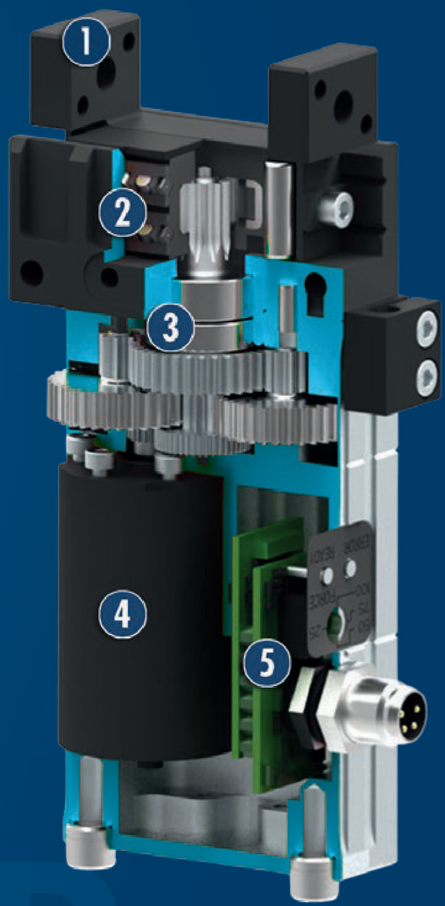
Brushless DC servomotor for almost wear-free use and a long service life

Sizes	Weight	Gripping force	Stroke per jaw	Workpiece weight
Quantity: 4	0.11 .. 0.8 kg	12 .. 300 N	3 .. 10 mm	0.07 .. 1.25 kg

Functional description

The brushless servomotor drives the base jaw via the gear mechanism.

The jaw stroke is synchronized by means of rack and pinion kinematics.



① **Base Jaw**
for the connection of workpiece-specific gripper fingers

② **Cross roller guidance**
precise gripping due to backlash-free base jaw guidance

③ **Gear**
Rack and pinion principle for centric gripping

④ **Drive**
Brushless DC servomotor

⑤ **Control electronics**
Integrated control and power electronics for decentralized control of the servomotor

CAD data, operating manuals and other current product documents can be found online.

General notes about the series

Operating principle: Rack and pinion principle

Housing material: Aluminum alloy, coated

Base jaw material: Steel

Actuation: servo-electric, via brushless DC servomotor

Warranty: 24 months

Scope of delivery: Enclosed pack with centering sleeves, mount for proximity switch, assembly and operating manual with Declaration of Incorporation.

Gripping force: is the arithmetic total of the gripping force applied to each gripper jaw at distance P (see illustration).

Finger length: is measured from the reference surface as the distance P in direction to the main axis.

Repeat accuracy: is defined as the spread of the end position during 100 consecutive strokes.

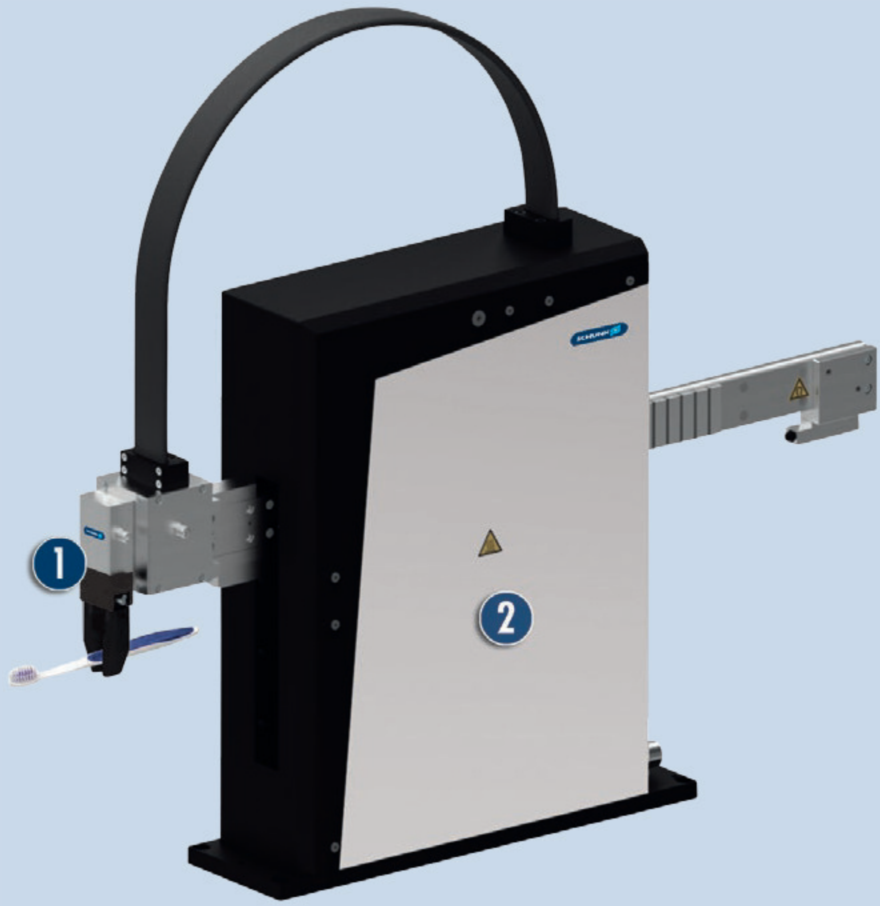
Workpiece weight: is calculated for force-fit gripping with a coefficient of static friction of 0.1 and a safety factor of 2 against workpiece slippage at acceleration due to gravity g. For form-fit or capture gripping, there are significantly higher permissible workpiece weights.

Closing and opening times: are purely the times that the base jaws or fingers are in motion. PLC reaction times are not a part of this and are to be considered when cycle times are calculated.

Application example

Electrically driven, dual-axis pick-and-place machine for small components

1. EGP electric 2-finger parallel gripper
2. PPU-E pick & place unit



SCHUNK offers more ...

The following components make the product EGP even more productive – the suitable addition for the highest functionality, flexibility, reliability, and controlled production.

Linear modules

Rotary modules

Pick & Place modules

Pillar assembly system

Flexible position sensor

Inductive Proximity Switches

Finger blanks

Adapter plates

Optical distance sensor

Connection cables

ⓘ Additional information regarding the products can be found on the following product pages or at www.schunk.com. Please contact us for further information: SCHUNK technical hotline +49-7133-103-2696

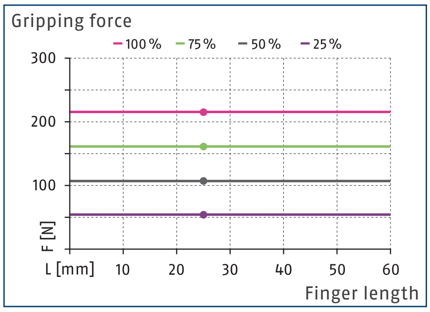
Options and special information

Manually adjustable gripping force: With an integrated rotary switch, the gripping force can be adjusted in two stages for the EGP 25 - 100% and 50%, and in four stages for EGP 40, 50 and 64 - 100%, 75%, 50%, and 25%.
Optional status monitoring via external sensor system: The status of the gripper can be monitored by external senors.
Optional adapter plates: Space-saving frontal mounting of the gripper is enabled by optional adapter plates.
KA connection cable: Connection cables with an angled or a straight female connector can be ordered in various lengths to connect the gripper with the power supply and higher-level control system.
Speed Version S: for faster closing and opening times due to the use of a different gear ratio. The option of a gripping force adjustment is no longer available.

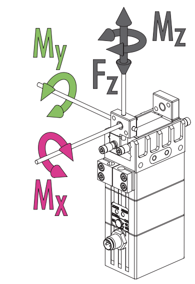
EGP 50

Gripper for small components

Gripping force



Finger load



M_x max. 3 Nm

M_y max. 4 Nm

M_z max. 5 Nm

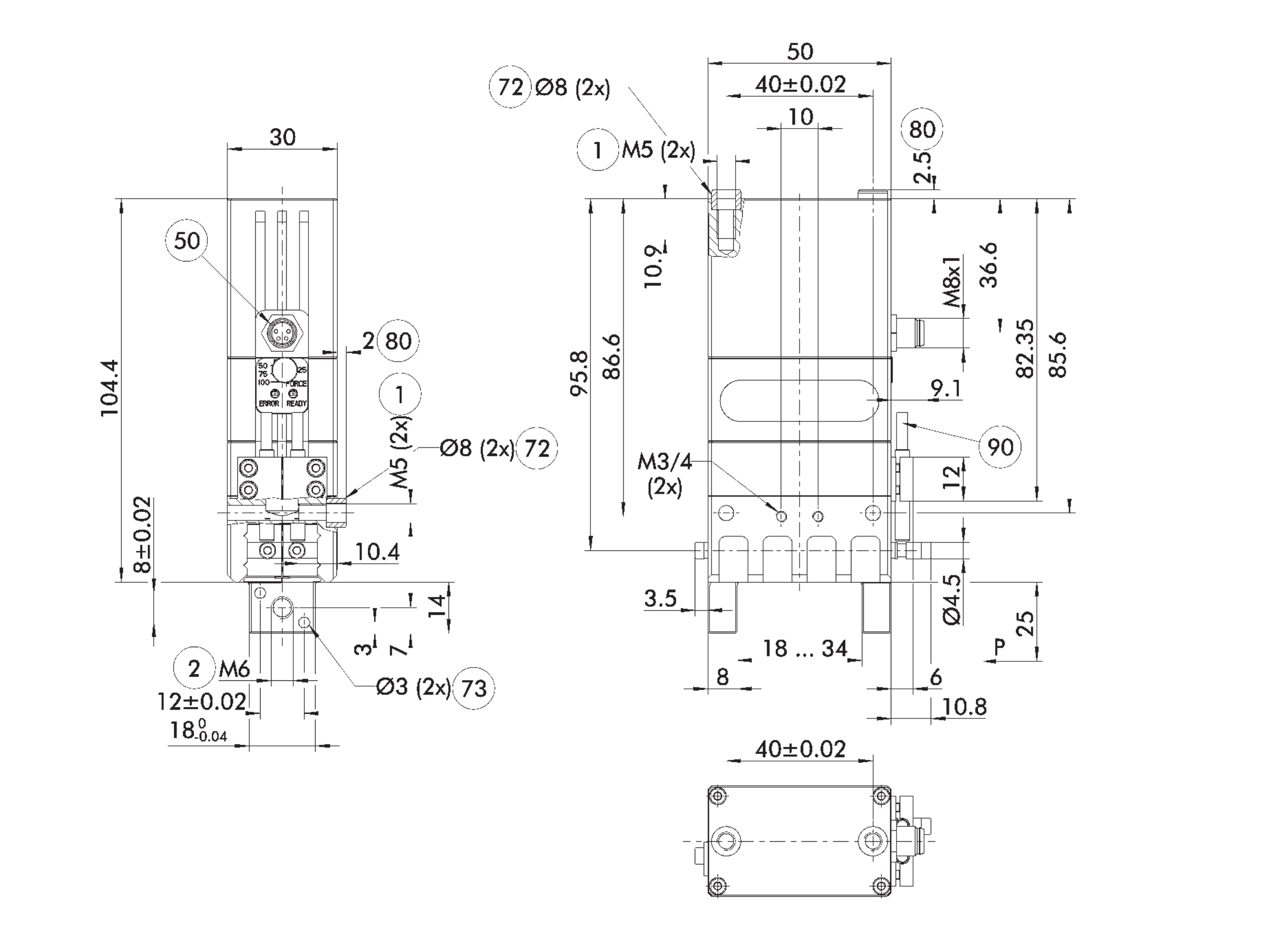
F_z max. 200 N

ⓘ The specified torques and forces are static values, apply for each base jaw, and may occur simultaneously. M_y may arise in addition to the moment generated by the gripping force itself.

Technical data

Description		EGP 50-N-N-B
ID		0310960
General operating data		
Stroke per jaw	[mm]	8
Min./max. gripping force	[N]	54/215
Recommended workpiece weight	[kg]	1.05
Max. permissible finger length	[mm]	64
Max. permissible mass per finger	[kg]	0.14
Repeat accuracy	[mm]	0.02
Closing/opening time	[s]	0.21/0.21
Weight	[kg]	0.51
Min./max. ambient temperature	[°C]	5/55
Protection class IP		30
Noise emission	[dB(A)]	< 70
Electrical operating data		
Nominal voltage	[V DC]	24
Nominal current	[A]	0.3
Max. current	[A]	2
Controller electronics		integrated
Communication interface		Digital Inputs
Number of digital inputs/outputs		2/-

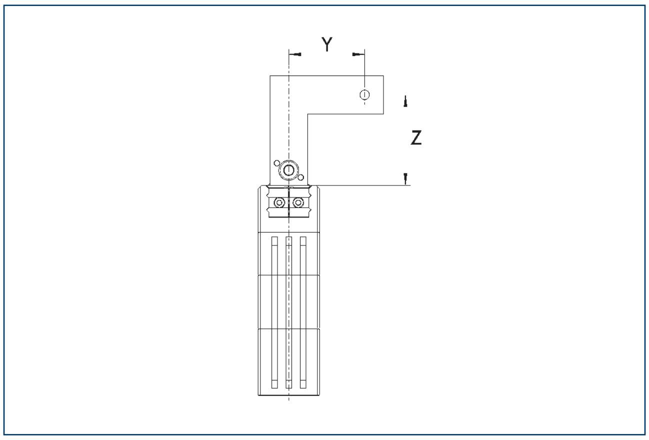
Main view

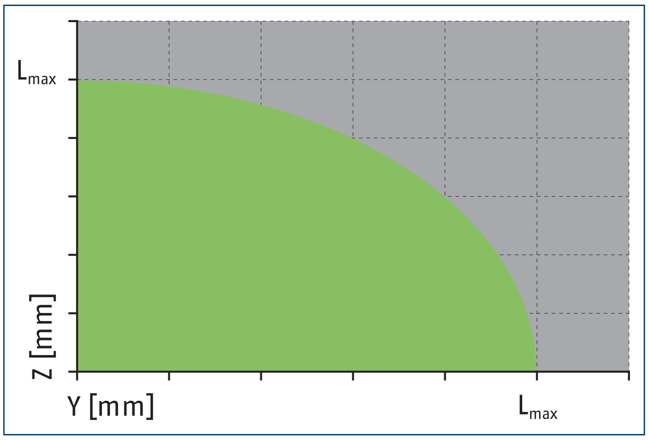


The drawing shows the basic version of the gripper with open jaws, without dimensional consideration of the options described below.

1. Gripper connection
2. Finger connection
50. Electrical connection
72. Fit for centering sleeves
73. Fit for centering pins
80. Depth of the centering sleeve hole in the counter part
90. Sensor IN ...

Maximum permitted finger projection



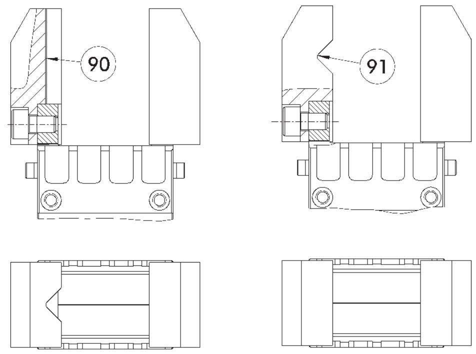


Permitted range

Inadmissible range

L_{max} is equivalent to the maximum permitted finger length, see the technical data table

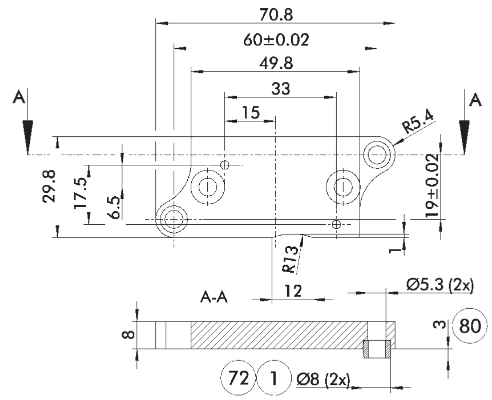
Jaw design



(90) Vertically positioned prism (91) Horizontally positioned prism

A workpiece, which is gripped using three points of contact, can be reliably gripped with high repeatability. A system with more than three points of contact is overdetermined. The drawing shows two alternative gripper finger designs for coaxial and radial gripping of a cylindrical part.

Adapter plate



(1) Gripper connection

(72) Fit for centering sleeves

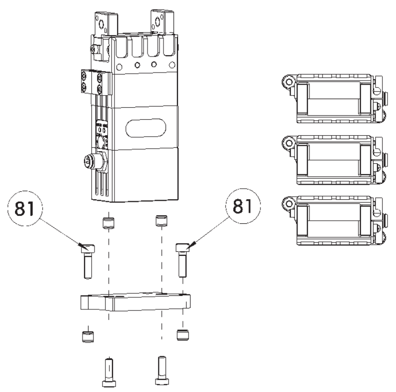
(80) Depth of the centering sleeve hole in the counter part

The adapter plate includes an O-ring* for a direct air connection, additional centering sleeves, and screws for mounting the gripper.
*Optional only with pneumatic actuators

Description	ID	
Adapter plate		
APL-MPG-plus 50	0305537	

ⓘ The adapter plate is a separately ordered, optional accessory.

Adapter plate



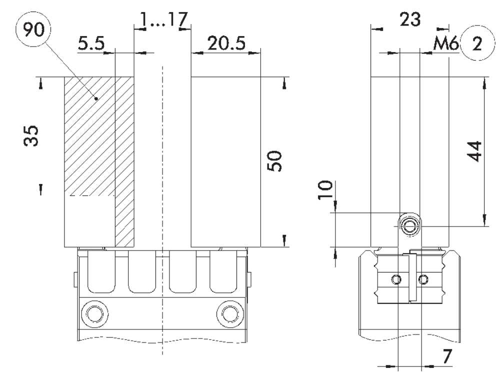
(81) Not included in the scope of delivery

The adapter plate includes an O-ring* for a direct air connection, additional centering sleeves, and screws for mounting the gripper.
*Optional only with pneumatic actuators

Description	ID	
Adapter plate		
APL-MPG-plus 50	0305537	

ⓘ The adapter plate is a separately ordered, optional accessory.

Finger blanks with BSWS ABR-BSWS-MPG-plus 50

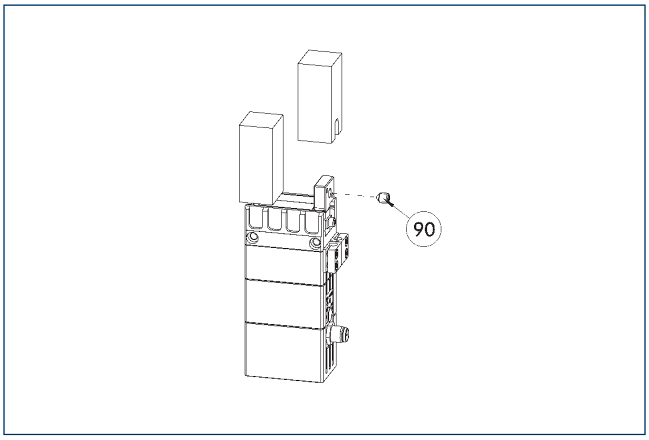


(2) Finger connection (90) Machining volume

Finger blanks for customized subsequent machining with integrated jaw quick-change system for precise and fast finger changes.

Description	ID	Scope of delivery
Finger blanks with quick-change jaw system		
ABR-BSWS-MPG-plus 50	0302897	2

Finger blanks with BSWS

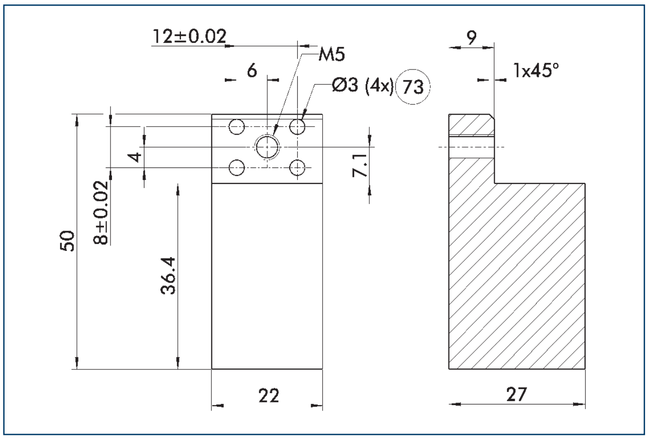


(90) Included in the scope of delivery

The finger blanks with jaw quick-change system allow fast and manual gripper finger changes. The mechanical interface to the gripper is already integrated. Only the specific workpiece geometry needs to be machined into the finger blank.

Description	ID	Scope of delivery
Finger blanks with quick-change jaw system		
ABR-BSWS-MPG-plus 50	0302897	2

Finger blanks ABR-MPG-plus 50

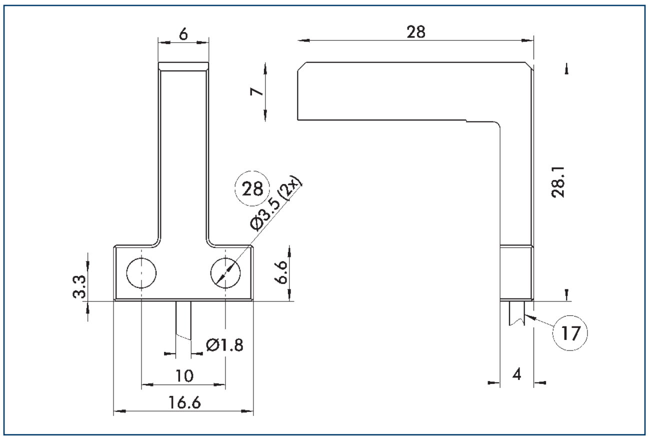


(73) Fit for centering pins

The drawing shows the finger blank which can be reworked by the customer.

Description	ID	Material	Scope of delivery
Finger blanks			
ABR-MPG-plus 50	0340214	Aluminum	2

Object distance sensor OAS-MPG-plus 50

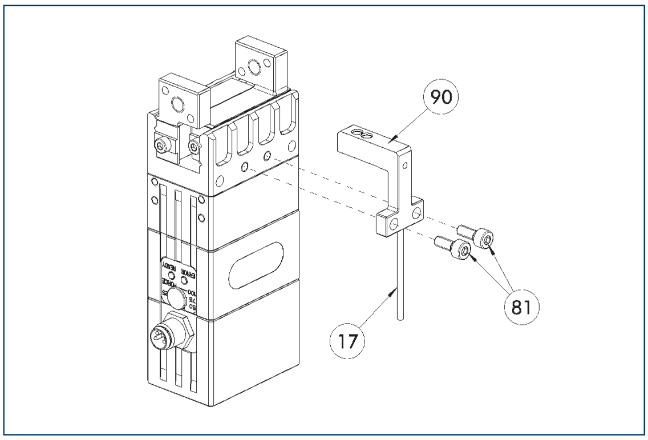


(17) Cable outlet (28) Through-hole

Object distance sensor for detecting a workpiece and for measuring its distance to the gripper.

Description	ID	
Object distance sensor		
OAS-MPG-plus 50	0308894	

Object distance sensor

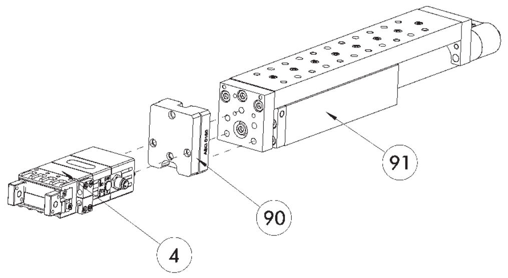


(17) Cable outlet (90) OAS
(81) Not included in the scope of delivery

Optical distance and presence sensor for direct mounting to to the gripper. One OAS sensor can be attached per gripper.

Description	ID	
Object distance sensor		
OAS-MPG-plus 50	0308894	
Evaluation electronics		
OAS-V09-D	0308865	
OAS-V10-A	0308867	
OAS-V10-D	0308866	

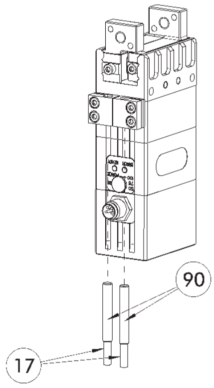
Modular Assembly Automation



(4) Grippers
(90) ASG adapter plate
(91) CLM/KLM/LM/ELP/ELM/ELS/HLM linear modules

Grippers and linear modules can be combined with standard adapter plates from the modular assembly system. For more information see our main catalog "Modular Assembly Automation".

IN 40 inductive proximity switches



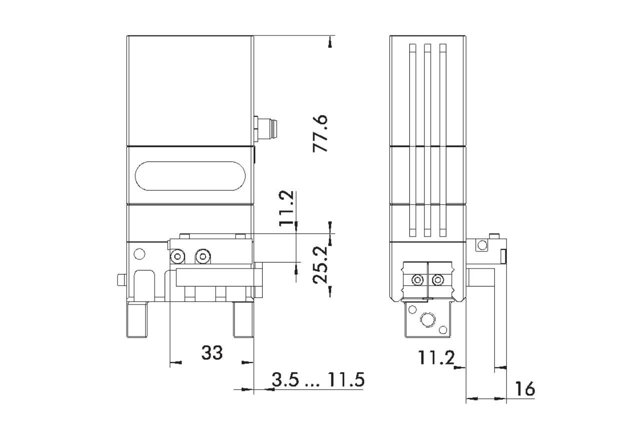
(17) Cable outlet
(90) Inductive Proximity Switches

Directly mounted end position monitoring.

Description	ID	Often combined
Inductive Proximity Switches		
IN 40-S-M12	0301574	
IN 40-S-M8	0301474	●
INK 40-S	0301555	
Cable extension		
KV BG12-SG12 3P-0030-PNP	0301999	
KV BG12-SG12 3P-0060-PNP	0301998	
KV BW08-SG08 3P-0030-PNP	0301495	
KV BW08-SG08 3P-0100-PNP	0301496	
KV BW08-SG08 3P-0200-PNP	0301497	●
KV BW12-SG12 3P-0030-PNP	0301595	
KV BW12-SG12 3P-0100-PNP	0301596	
KV BW12-SG12 3P-0200-PNP	0301597	
clip for plug/socket		
CLI-M12	0301464	
CLI-M8	0301463	
Connection cables		
KA BG08-L 3P-0300-PNP	0301622	●
KA BG08-L 3P-0500-PNP	0301623	
KA BG12-L 3P-0500-PNP	30016369	
KA BW08-L 3P-0300-PNP	0301594	
KA BW08-L 3P-0500-PNP	0301502	
KA BW12-L 3P-0300-PNP	0301503	
KA BW12-L 3P-0500-PNP	0301507	
Sensor distributor		
V2-M12	0301776	●
V2-M8	0301775	●
V4-M12	0301747	
V4-M8	0301746	
V8-M12	0301752	
V8-M8	0301751	

ⓘ Two sensors (closer/S) are required for each unit and extension cables are available as an option. For sensor cables, note the minimum permissible bending radii. These are generally 35 mm.

Attachment kit for FPS

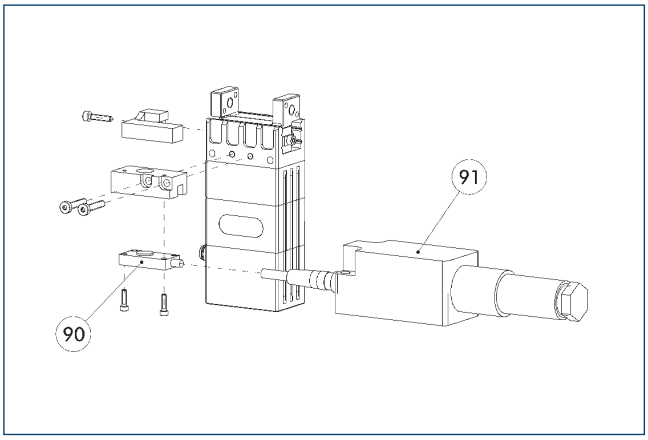


The following FPS position sensor can differentiate between five programmable areas or switching points for the stroke of a gripper, and can be used in connection with a PC as a measuring system.

Description	ID	
Attachment kit for FPS		
AS-FPS-MPG-plus 50	0301763	

ⓘ This attachment kit needs to be ordered optionally as an accessory.

Flexible position sensor



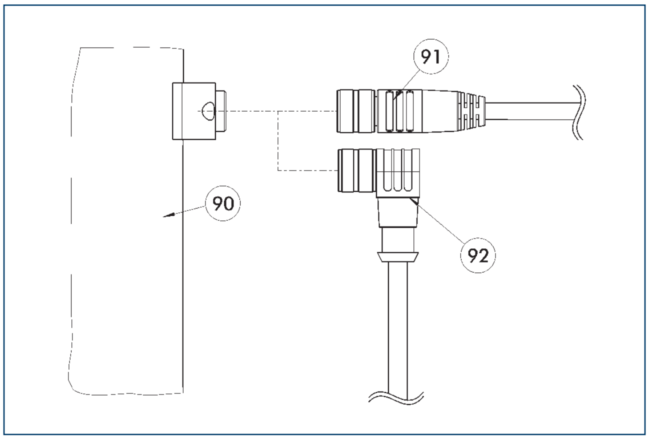
(90) FPS-S sensor (91) FPS-F5 evaluation electronic

Flexible position monitoring of up to five positions.

Description	ID	Often combined
Attachment kit for FPS		
AS-FPS-MPG-plus 50	0301763	
Sensor		
FPS-S 13	0301705	
Cable extension		
KV BG08-SG08 3P-0050	0301598	
KV BG08-SG08 3P-0100	0301599	
Evaluation electronics		
FPS-F5	0301805	●

ⓘ When using an FPS system, an FPS sensor (FPS-S) and an electronic processor (FPS-F5 / F5 T) are required for each gripper as well as an attachment kit (AS), if listed. Cable extensions (KV) are available as options in the "Accessories" catalog chapter.

Connection cables



90 Electrical connection component

91 Cable with straight connector

92 Cable with angled connector

Description	ID	Length	Often combined
		[m]	
Connection cables			
KA BG08-L 4P-0500	0307767	5	●
KA BG08-L 4P-1000	0307768	10	
KA BW08-L 4P-0500	0307765	5	
KA BW08-L 4P-1000	0307766	10	

ⓘ BG stands for a connection cable with a straight female connector and BW for an angled female connector. SG stands for a connection cable with a straight male connector and SW for an angled male connector.

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ANNEX 6

Electrical Equipment Data Sheets

SMART
SENSOR
BUSINESS

Leuze electronic

the sensor people

Figure can vary

Part no.: 50104783
BPS 8 SM 102-01
Bar code positioning system

Contents

Part no.: 50104783 – BPS 8 SM 102-01 – Bar code positioning system

Technical data

Basic data	
Series	BPS 8
Data telegram	Binary protocol 1
Order guide	Bar code tape must be ordered separately

Optical data	
Depth of field	80 ... 140 mm
Light source	Laser, Red
Laser class	2, IEC/EN 60825-1:2007
Light beam exit	Front

Measurement data	
Measurement range	0 ... 10,000,000 mm
Resolution	0.001 ... 100 mm
Measurement value output	3.3 ms
Max. traverse rate	4 m/s

Electrical data	
Protective circuit	Short circuit protected
Performance data	
Supply voltage	4.9 ... 5.4 V, DC
Current consumption, max.	250 mA
Inputs/outputs selectable	
Output current, max.	100 mA
Number of inputs/outputs selectable	1 Piece(s)

Interface	
Type	RS 232
RS 232	
Function	Process
Transmission speed	1,200 ... 187,500 Bd
Data format	Adjustable
Start bit	1
Data bit	8 data bits
Stop bit	1
Parity	Adjustable
Data encoding	Binary

Service interface	
Type	RS 232
RS 232	
Function	Service

Connection	
Number of connections	1 Piece(s)

Part no.: 50104783 – BPS 8 SM 102-01 – Bar code positioning system

Connection 1	
Type of connection	Connector
Function	Connection to device
Thread size	M12
No. of pins	5 -pin

Mechanical data	
Dimension (W x H x L)	15 mm x 48 mm x 40.3 mm
Housing material	Metal, Diecast zinc
Lens cover material	Glass
Net weight	70 g
Housing color	Red Black
Type of fastening	Dovetail grooves Mounting thread Through-hole mounting Via optional mounting device

Operation and display	
Type of display	LED
Number of LEDs	2 Piece(s)

Environmental data	
Ambient temperature, operation	0 ... 40 °C
Ambient temperature, storage	-20 ... 60 °C
Relative humidity (non-condensing)	0 ... 90 %

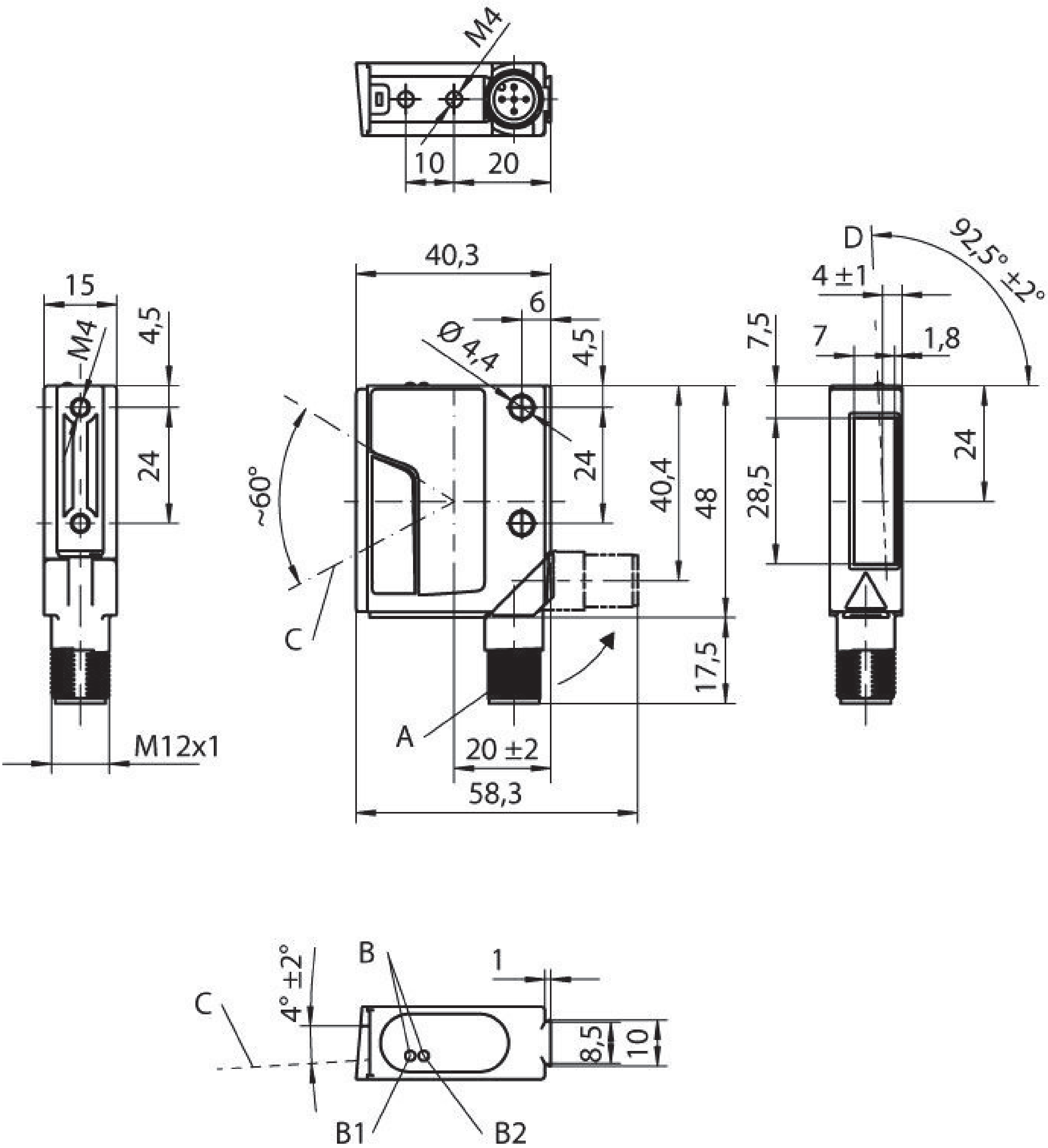
Certifications	
Degree of protection	IP 67, EN 60529 with various connectors or screwed-on caps
Protection class	III
Certifications	c UL US
US patents	US 6,822,774 B

Classification	
eCl@ss 8.0	27280190
eCl@ss 9.0	27280190

Dimensioned drawings

All dimensions in millimeters

Part no.: 50104783 – BPS 8 SM 102-01 – Bar code positioning system



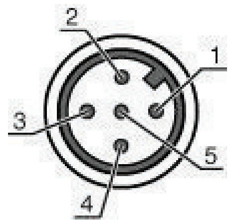
Electrical connection

Connection 1	
Type of connection	Connector
Function	Connection to device
Thread size	M12

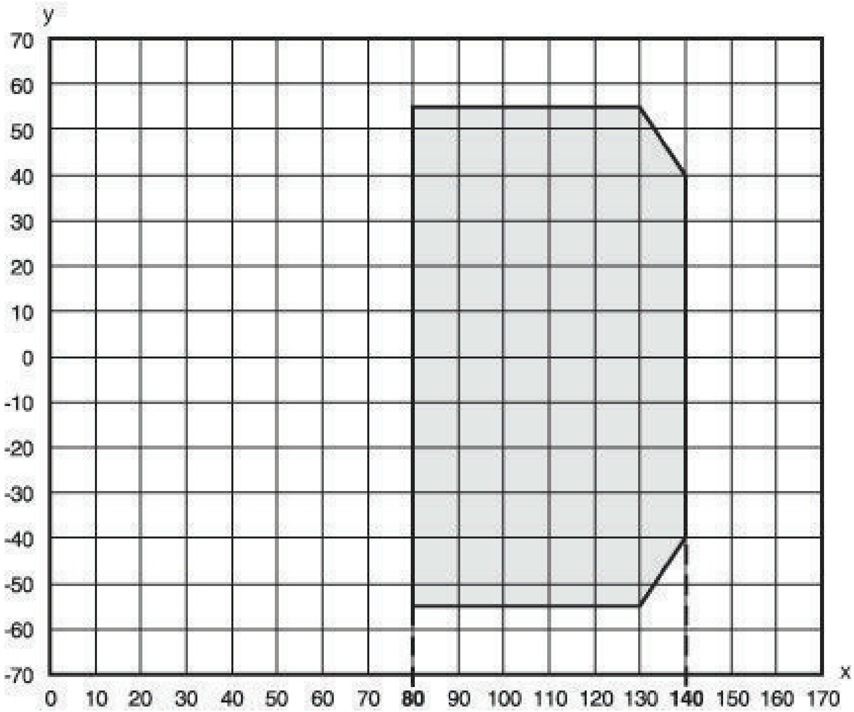
Part no.: 50104783 – BPS 8 SM 102-01 – Bar code positioning system

Connection 1	
Type	Male
Material	Metal
No. of pins	5 -pin
Encoding	A-coded

Pin	Pin assignment
1	+5 V DC
2	RS 232 TxD
3	GND
4	RS 232 RxD
5	SW IN/OUT



Diagrams



Operation and display

LEDs

LED	Display	Meaning
1	Off	No supply voltage
	Green, flashing	Device ok, initialization phase
	Green, continuous light	Operational readiness

LED	Display	Meaning
	Red, flashing	Device OK, warning set
	Red, continuous light	Device error
	Orange, flashing	Service operation active
2	Off	Positioning deactivated
	Green, continuous light	Positioning running (position value valid)
	Red, continuous light	Positioning running (position value invalid)
	Orange, continuous light	Positioning running (marker label detected)

Part number code

Part designation:

-

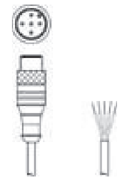
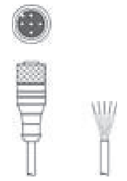
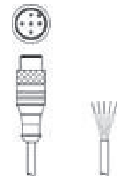
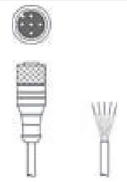
Accessories

Connection technology - Connection unit

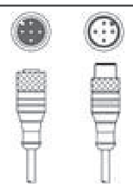
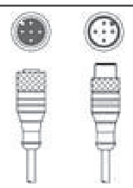
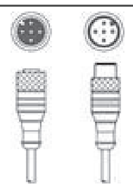
	Part no.	Designation	Article	Description
	50112893	MA 204i Profibus Gateway	Modular connection unit	Supply voltage: 18 ... 30 V Current consumption, max.: 300 mA Interface: PROFIBUS DP, RS 232 Connections: 6 Piece(s) Degree of protection: IP 65
	50112892	MA 208i Ethernet Gateway	Modular connection unit	Supply voltage: 18 ... 30 V Current consumption, max.: 300 mA Interface: Ethernet, RS 232 Connections: 6 Piece(s) Degree of protection: IP 65
	50112891	MA 248i Profinet Gateway	Modular connection unit	Supply voltage: 18 ... 30 V Current consumption, max.: 300 mA Interface: PROFINET, RS 232 Connections: 6 Piece(s) Degree of protection: IP 65
	50104790	MA 8-01	Modular connection unit	Supply voltage: 10 ... 30 V Current consumption, max.: 50 mA Interface: RS 485 Connections: 3 Piece(s) Degree of protection: IP 67
	50104789	MA 8-02	Modular connection unit	Supply voltage: 10 ... 30 V Current consumption, max.: 50 mA Interface: RS 485 Connections: 3 Piece(s) Degree of protection: IP 67

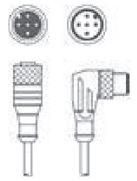
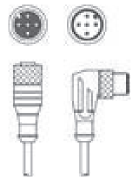
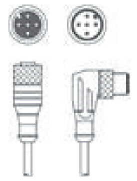
Part no.: 50104783 – BPS 8 SM 102-01 – Bar code positioning system

Connection technology - Connection cables

	Part no.	Designation	Article	Description
	50102971	KB 008-10000 A-S	Connection cable	Connection 1: Connector, M12, Axial, Male, A-coded, 5 -pin Connection 2: Open end Shielded: Yes Cable length: 10,000 mm Sheathing material: PUR
	50040757	KB 008-3000 A	Connection cable	Connection 1: Connector, M12, Axial, Female, A-coded, 5 -pin Connection 2: Open end Shielded: Yes Cable length: 3,000 mm Sheathing material: PUR
	50101941	KB-008-3000 A-S	Connection cable	Connection 1: Connector, M12, Axial, Male, A-coded, 5 -pin Connection 2: Open end Shielded: Yes Cable length: 3,000 mm Sheathing material: PUR
	50133861	KD S-M12-5A-P1-100	Connection cable	Connection 1: Connector, M12, Axial, Female, A-coded, 5 -pin Connection 2: Open end Shielded: Yes Cable length: 10,000 mm Sheathing material: PUR

Connection technology - Interconnection cables

	Part no.	Designation	Article	Description
	50113467	KB JST-M12A-5P-3000	Connection cable	Suitable for interface: RS 232 Connection 1: Connector, M12, Axial, Female, A-coded, 5 -pin Connection 2: JST ZHR, 12 -pin Shielded: Yes Cable length: 3,000 mm Sheathing material: PUR
	50133888	KDS S-M12-5A-M12-5A-P1-010	Interconnection cable	Connection 1: Connector, M12, Axial, Female, A-coded, 5 -pin Connection 2: Connector, M12, Axial, Male, A-coded, 5 -pin Shielded: Yes Cable length: 1,000 mm Sheathing material: PUR
	50133890	KDS S-M12-5A-M12-5A-P1-020	Interconnection cable	Connection 1: Connector, M12, Axial, Female, A-coded, 5 -pin Connection 2: Connector, M12, Axial, Male, A-coded, 5 -pin Shielded: Yes Cable length: 2,000 mm Sheathing material: PUR
	50133891	KDS S-M12-5A-M12-5A-P1-030	Interconnection cable	Connection 1: Connector, M12, Axial, Female, A-coded, 5 -pin Connection 2: Connector, M12, Axial, Male, A-coded, 5 -pin Shielded: Yes Cable length: 3,000 mm Sheathing material: PUR

	Part no.	Designation	Article	Description
	50133882	KDS S-M12-5A-M12-5W-P1-010	Interconnection cable	Connection 1: Connector, M12, Axial, Female, A-coded, 5 -pin Connection 2: Connector, M12, Angled, Male, A-coded, 5 -pin Shielded: Yes Cable length: 1,000 mm Sheathing material: PUR
	50133883	KDS S-M12-5A-M12-5W-P1-020	Interconnection cable	Connection 1: Connector, M12, Axial, Female, A-coded, 5 -pin Connection 2: Connector, M12, Angled, Male, A-coded, 5 -pin Shielded: Yes Cable length: 2,000 mm Sheathing material: PUR
	50133884	KDS S-M12-5A-M12-5W-P1-030	Interconnection cable	Connection 1: Connector, M12, Axial, Female, A-coded, 5 -pin Connection 2: Connector, M12, Angled, Male, A-coded, 5 -pin Shielded: Yes Cable length: 3,000 mm Sheathing material: PUR

Connection technology - Connectors

	Part no.	Designation	Article	Description
	50040097	KD 01-5-BA	Connector	Connection: Connector, M12, Axial, Female, A-coded, 5 -pin

Mounting technology - Rod mounts

	Part no.	Designation	Article	Description
	50127177	BTU 008M-D10	Mounting system	Design of mounting device: Mounting system Fastening, at system: Sheet-metal mounting, For 10 mm rod Mounting bracket, at device: Screw type Type of mounting device: Turning, 360°, Adjustable, Clampable Material: Metal

Mounting technology - Other

	Part no.	Designation	Article	Description
	50104791	BT 8-01	Mounting device	Fastening, at system: Through-hole mounting Mounting bracket, at device: Screw type Material: Metal

Part no.: 50104783 – BPS 8 SM 102-01 – Bar code positioning system

Bar code tape

	Part no.	Designation	Article	Description
	50106467	BCB 8 005	Bar code tape	Dimensions: 47 mm x 5,000 mm Grid dimension: 30 mm
	50104792	BCB 8 010	Bar code tape	Dimensions: 47 mm x 10,000 mm Grid dimension: 30 mm
	50104793	BCB 8 020	Bar code tape	Dimensions: 47 mm x 20,000 mm Grid dimension: 30 mm
	50104794	BCB 8 030	Bar code tape	Dimensions: 47 mm x 30,000 mm Grid dimension: 30 mm
	50104795	BCB 8 040	Bar code tape	Dimensions: 47 mm x 40,000 mm Grid dimension: 30 mm
	50104796	BCB 8 050	Bar code tape	Dimensions: 47 mm x 50,000 mm Grid dimension: 30 mm
	50104797	BCB 8 060	Bar code tape	Dimensions: 47 mm x 60,000 mm Grid dimension: 30 mm
	50104798	BCB 8 070	Bar code tape	Dimensions: 47 mm x 70,000 mm Grid dimension: 30 mm
	50104799	BCB 8 080	Bar code tape	Dimensions: 47 mm x 80,000 mm Grid dimension: 30 mm

Part no.: 50104783 – BPS 8 SM 102-01 – Bar code positioning system

	Part no.	Designation	Article	Description
	50104800	BCB 8 090	Bar code tape	Dimensions: 47 mm x 90,000 mm Grid dimension: 30 mm
	50104801	BCB 8 100	Bar code tape	Dimensions: 47 mm x 100,000 mm Grid dimension: 30 mm
	50104802	BCB 8 110	Bar code tape	Dimensions: 47 mm x 110,000 mm Grid dimension: 30 mm
	50104803	BCB 8 120	Bar code tape	Dimensions: 47 mm x 120,000 mm Grid dimension: 30 mm
	50104804	BCB 8 130	Bar code tape	Dimensions: 47 mm x 130,000 mm Grid dimension: 30 mm
	50104805	BCB 8 140	Bar code tape	Dimensions: 47 mm x 140,000 mm Grid dimension: 30 mm
	50104806	BCB 8 150	Bar code tape	Dimensions: 47 mm x 150,000 mm Grid dimension: 30 mm
	50106468	BCB 8 200	Bar code tape	Dimensions: 47 mm x 200,000 mm Grid dimension: 30 mm
	50104809	BCB 8 special length 25mm high	Bar code tape	Dimensions: 25 mm Grid dimension: 30 mm
	50104808	BCB 8 special length 30mm high	Bar code tape	Dimensions: 30 mm Grid dimension: 30 mm

Part no.: 50104783 – BPS 8 SM 102-01 – Bar code positioning system

	Part no.	Designation	Article	Description
	50104807	BCB 8 special length 47mm high	Bar code tape	Dimensions: 47 mm Grid dimension: 30 mm

SIEMENS

Data sheet 3SE5112-0CH01

SIRIUS POSITION SWITCH METAL HOUSING 40MM TO EN50041 DEVICE CONNECTION 1X (M20X1,5) 1NO/ 1NC SNAP-ACTION CONTACTS ROTARY ACTUATOR RIGHT/LEFT ADJUSTABLE, METAL LEVER 27MM LONG AND PLASTIC ROLLER 19MM

Figure similar

Product designation	standard position switch
Manufacturer's article number	
• of the supplied basic switch	3SE5112-0CA00
• of the supplied actuator head for position switches	3SE5000-0AH00
• of the supplied operating lever	3SE5000-0AA01
• of the supplied switching contacts	3SE5000-0CA00
• of the supplied empty enclosure with cover	3SE5112-0AA00

General technical data:	
Product function	
• positive opening	Yes
Insulation voltage	
• rated value	400 V
Surge voltage resistance rated value	6 kV
Protection class IP	IP66/IP67
Degree of pollution	class 3
Shock resistance	
• acc. to IEC 60068-2-27	30 g / 11 ms
Vibration resistance	

• acc. to IEC 60068-2-6	0.35 mm/5g
Mechanical service life (switching cycles)	
• typical	15 000 000
Electrical endurance (switching cycles)	
• at AC-15 at 230 V typical	100 000
Electrical endurance (switching cycles) with contactor 3RH11, 3RT1016, 3RT1017, 3RT1024, 3RT1025, 3RT1026 typical	10 000 000
Electrical operating cycles in one hour with contactor 3RH11, 3RT1016, 3RT1017, 3RT1024, 3RT1025, 3RT1026	6 000
Thermal current	6 A
Equipment marking	
• acc. to DIN EN 61346-2	B
• acc. to DIN EN 81346-2	B
Continuous current of the C characteristic MCB	1 A; for a short-circuit current smaller than 400 A
Continuous current of the quick DIAZED fuse link	10 A; for a short-circuit current smaller than 400 A
Continuous current of the DIAZED fuse link gG	6 A
Active principle	mechanical
Repeat accuracy	0.05 mm
Minimum actuating torque in activation direction	0.25 N·m
Operating current at AC-15	
• at 24 V rated value	6 A
• at 125 V rated value	6 A
• at 230 V rated value	6 A
• at 400 V rated value	4 A
Operating current at DC-13	
• at 24 V rated value	3 A
• at 125 V rated value	0.55 A
• at 230 V rated value	0.27 A
• at 400 V rated value	0.1 A

Enclosure:

Design of the housing	block, narrow
Material of the enclosure	metal
Coating of the enclosure	cathodic immersion coating
Design of the housing acc. to standard	Yes

Drive Head:

Standard-compliant actuator head	EN 50041, design A
Shape of the switch head	roller
Design of the switching function	positive opening

Connections/ Terminals:

Type of electrical connection	screw-type terminals

Mechanical data:

Cable entry type	1x (M20 x 1.5)

Communication/ Protocol:

Design of the interface	without

Ambient conditions:

Ambient temperature	
• during operation	-25 ... +85 °C
• during storage	-40 ... +90 °C

Installation/ mounting/ dimensions:

Mounting position	any
Mounting type	screw fixing

Certificates/approvals

General Product Approval				Functional Safety/Safety of Machinery	Declaration of Conformity
CCC	CSA	UL		Baumusterprüfbescheinigung	EG-Konf.

Test Certificates	other
spezielle Prüfbescheinigungen	Bestätigungen

Further information

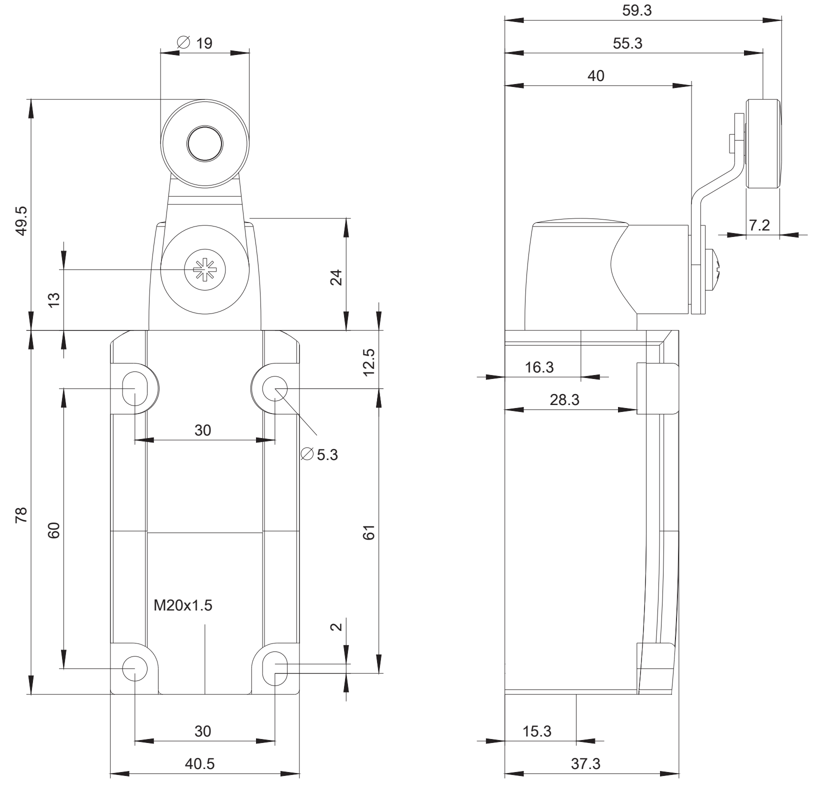
Information- and Downloadcenter (Catalogs, Brochures,…)
http://www.siemens.com/industrial-controls/catalogs

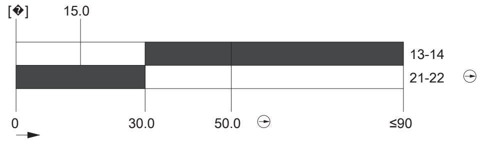
Industry Mall (Online ordering system)
https://mall.industry.siemens.com/mall/en/en/Catalog/product?mlfb=3SE51120CH01

Cax online generator
http://support.automation.siemens.com/WW/CAXorder/default.aspx?lang=en&mlfb=3SE51120CH01

Service&Support (Manuals, Certificates, Characteristics, FAQs,...)
https://support.industry.siemens.com/cs/ww/en/ps/3SE51120CH01

Image database (product images, 2D dimension drawings, 3D models, device circuit diagrams, EPLAN macros, ...)
http://www.automation.siemens.com/bilddb/cax_de.aspx?mlfb=3SE51120CH01&lang=en





last modified: 11.03.2016

Online data sheet

IME18-05BPSZC0S

IME

INDUCTIVE PROXIMITY SENSORS

Sensor Intelligence.

IME18-05BPSZC0S | IME
INDUCTIVE PROXIMITY SENSORS

Ordering information

Type	Part no.
IME18-05BPSZC0S	1040934

Other models and accessories → www.sick.com/IME

Detailed technical data

Features

Housing	Cylindrical thread design
Housing	Standard
Thread size	M18 1
Diameter	Ø 18 mm
Sensing range S_n	5 mm
Safe sensing range S_a	4.05 mm
Installation type	Flush
Switching frequency	1,000 Hz
Connection type	Male connector M12, 4-pin
Switching output	PNP
Output function	NO
Electrical wiring	DC 3-wire
Enclosure rating	IP67 [1]

[1] According to EN 60529.

Mechanics/electronics

Supply voltage	10 V DC ... 30 V DC
Ripple	≤ 10 %
Voltage drop	≤ 2 V [1]
Current consumption	10 mA [2]
Time delay before availability	≤ 100 ms
Hysteresis	5 % ... 15 %

[1] At I_a max.
[2] Without load.
[3] Ub and Ta constant.
[4] Of Sr.

Reproducibility	≤ 2 % [3) 4)]
Temperature drift (of S_r)	± 10 %
EMC	According to EN 60947-5-2
Continuous current I_a	≤ 200 mA
Short-circuit protection	✓
Reverse polarity protection	✓
Power-up pulse protection	✓
Shock and vibration resistance	30 g, 11 ms/10 Hz ... 55 Hz, 1 mm
Ambient operating temperature	–25 °C ... +75 °C
Housing material	Metal, Nickel-plated brass
Sensing face material	Plastic, Plastic
Housing length	69 mm
Thread length	52 mm
Tightening torque, max.	≤ 40 Nm
UL File No.	NRKH.E181493

1) At I_a max.
2) Without load.
3) Ub and Ta constant.
4) Of Sr.

Reduction factors

Note	The values are reference values which may vary
St37 steel (Fe)	1
Stainless steel (V2A, 304)	Approx. 0.8
Aluminum (Al)	Approx. 0.45
Copper (Cu)	Approx. 0.4
Brass (Br)	Approx. 0.4

Installation note

Remark	Associated graphic see "Installation"
B	18 mm
C	18 mm
D	15 mm
F	40 mm

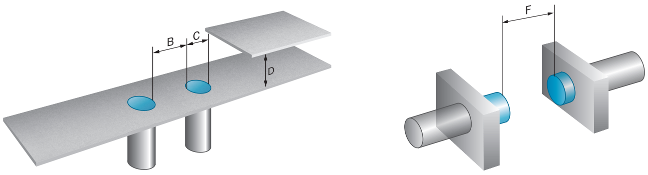
Classifications

ECl@ss 5.0	27270101
ECl@ss 5.1.4	27270101
ECl@ss 6.0	27270101
ECl@ss 6.2	27270101
ECl@ss 7.0	27270101
ECl@ss 8.0	27270101
ECl@ss 8.1	27270101
ECl@ss 9.0	27270101

ETIM 5.0	EC002714
ETIM 6.0	EC002714
UNSPSC 16.0901	39122230

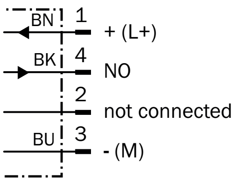
Installation note

Flush installation



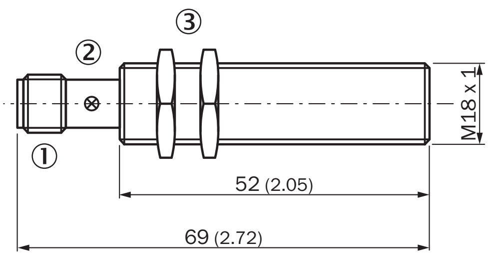
Connection diagram

Cd-007



Dimensional drawing (Dimensions in mm (inch))

IME18 Standard, connector, flush



① Connection
② Indication LED
③ Fastening nuts (2x); width across 24, metal

Recommended accessories

Other models and accessories ➜ www.sick.com/IME

	Brief description	Type	Part no.
Universal bar clamp systems			
	Universal bar clamp for mounting bars with 12 mm diameter, Zinc diecast, without mounting plate and screws	BEF-KHS-KH3	5322626
Mounting brackets and plates			
	Mounting plate for M18 sensors, steel, zinc coated, without mounting hardware	BEF-WG-M18	5321870
	Mounting bracket for M18 sensors, steel, zinc coated, without mounting hardware	BEF-WN-M18	5308446
Terminal and alignment brackets			
	Clamping block for round sensors M18, without fixed stop, plastic (PA12), glass-fiber reinforced, mounting hardware included	BEF-KH-M18	2051481
	Clamping block for round sensors M18, with fixed stop, plastic (PA12), glass-fiber reinforced, mounting hardware included	BEF-KHF-M18	2051482
Plug connectors and cables			
	Head A: female connector, M12, 4-pin, straight, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 2 m	YF2A14-020VB3XLEAX	2096234
	Head A: female connector, M12, 4-pin, straight, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 5 m	YF2A14-050VB3XLEAX	2096235
	Head A: female connector, M12, 4-pin, straight, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 10 m	YF2A14-100VB3XLEAX	2096236
	Head A: female connector, M12, 4-pin, angled, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 2 m	YG2A14-020VB3XLEAX	2095895
	Head A: female connector, M12, 4-pin, angled, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 5 m	YG2A14-050VB3XLEAX	2095897
	Head A: female connector, M12, 4-pin, angled, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 10 m	YG2A14-100VB3XLEAX	2095898
	Head A: female connector, M12, 4-pin, straight Head B: - Cable: unshielded	DOS-1204-G	6007302
	Head A: female connector, M12, 4-pin, angled Head B: - Cable: unshielded	DOS-1204-W	6007303

SICK AT A GLANCE

SICK is one of the leading manufacturers of intelligent sensors and sensor solutions for industrial applications. A unique range of products and services creates the perfect basis for controlling processes securely and efficiently, protecting individuals from accidents and preventing damage to the environment.

We have extensive experience in a wide range of industries and understand their processes and requirements. With intelligent sensors, we can deliver exactly what our customers need. In application centers in Europe, Asia and North America, system solutions are tested and optimized in accordance with customer specifications. All this makes us a reliable supplier and development partner.

Comprehensive services complete our offering: SICK LifeTime Services provide support throughout the machine life cycle and ensure safety and productivity.

For us, that is "Sensor Intelligence."

WORLDWIDE PRESENCE:

Contacts and other locations **www.sick.com**

SIEMENS

Data sheet 3SU1001-1HB20-0AA0

EMERGENCY STOP MUSHR. PUSHB., CAN BE ILLUMINATED, 22MM, ROUND, PLASTIC, RED, 40MM, POSITIVE LATCHING, ROTATE TO UNLATCH

Figure similar

product brand name	SIRIUS ACT
Product designation	Commanding and signaling devices
Design of the product	EMERGENCY STOP mushroom pushbutton
Enclosure:	
Number of command points	1
Actuator:	
Design of the operating mechanism	EMERGENCY STOP mushroom pushbutton; tamper-proof
Manner of function of the actuating element	Latching
Product expansion optional Light source	Yes
Color	
• of the actuating element	Red
Material of the actuating element	plastic
Shape of the actuating element	round
Outer diameter of the actuating element	40 mm
Type of unlocking device	rotate-to-unlatch mechanism
Number of switching positions	2
Front ring:	
Product component front ring	No

General technical data:

Product function	
• positive opening	Yes
• EMERGENCY OFF function	Yes
• EMERGENCY STOP function	Yes
Protection class IP	IP66, IP67, IP69(IP69K)
Degree of protection NEMA rating	NEMA 1, 2, 3, 3R, 4, 4X, 12
Shock resistance	
• acc. to IEC 60068-2-27	Sinusoidal half-wave 50 g / 11 ms
• for railway applications acc. to DIN EN 61373	Category 1, Class B
Vibration resistance	
• acc. to IEC 60068-2-6	10 ... 500 Hz: 5g
• for railway applications acc. to DIN EN 61373	Category 1, Class B
Operating frequency maximum	600 1/h
Mechanical service life (switching cycles)	
• typical	300 000
Equipment marking	
• acc. to DIN EN 61346-2	S
• acc. to DIN EN 81346-2	S

Safety related data:

B10 value	
• with high demand rate acc. to SN 31920	100 000

Ambient conditions:

Ambient temperature	
• during operation	-25 ... +70 °C
• during storage	-40 ... +80 °C

Installation/ mounting/ dimensions:

Shape of the installation opening	round
Mounting diameter	22.3 mm
Mounting height	45.3 mm
Installation width	40 mm
Installation depth	26.3 mm

Certificates/approvals

General Product Approval				Declaration of Conformity	other
CSA	UL	VDE	EAC	EG-Konf.	Bestätigungen

Further information

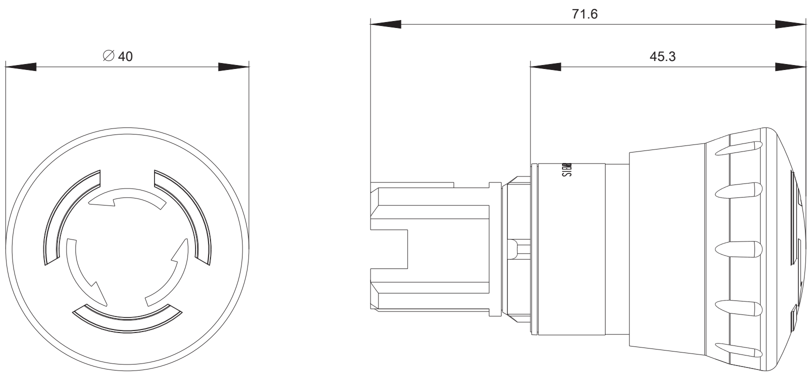
Information- and Downloadcenter (Catalogs, Brochures,…)
http://www.siemens.com/industrial-controls/catalogs

Industry Mall (Online ordering system)
https://mall.industry.siemens.com/mall/en/en/Catalog/product?mlfb=3SU10011HB200AA0

Cax online generator
http://support.automation.siemens.com/WW/CAXorder/default.aspx?lang=en&mlfb=3SU10011HB200AA0

Service&Support (Manuals, Certificates, Characteristics, FAQs,...)
https://support.industry.siemens.com/cs/ww/en/ps/3SU10011HB200AA0

Image database (product images, 2D dimension drawings, 3D models, device circuit diagrams, EPLAN macros, ...)
http://www.automation.siemens.com/bilddb/cax_de.aspx?mlfb=3SU10011HB200AA0&lang=en



last modified: 24.02.2016

SIEMENS

Data sheet 3SU1001-6AA40-0AA0

INDICATOR LIGHT, 22MM, ROUND, PLASTIC, GREEN, SMOOTH LENS

Figure similar

product brand name		SIRIUS ACT
Product designation		Commanding and signaling devices
Design of the product		Pilot Light
Actuator:		
Color		
• of the actuating element		Green
Material of the actuating element		plastic
Shape of the actuating element		round
Outer diameter of the actuating element	mm	29.45
Front ring:		
Product component front ring		No
General technical data:		
Vibration resistance		
• acc. to IEC 60068-2-6		10 ... 500 Hz: 5g
Equipment marking		
• acc. to DIN EN 61346-2		P
• acc. to DIN EN 81346-2		P
Ambient conditions:		
Ambient temperature		
• during operation	°C	-25 ... +70
• during storage	°C	-40 ... +80
Installation/ mounting/ dimensions:		
Height	mm	29.45

Width	mm	29.45
Shape of the installation opening		round
Mounting diameter	mm	22

Certificates/ approvals:

Further information

Information- and Downloadcenter (Catalogs, Brochures,…)
http://www.siemens.com/industrial-controls/catalogs

Industry Mall (Online ordering system)
http://www.siemens.com/industrymall

Cax online generator
http://support.automation.siemens.com/WW/CAXorder/default.aspx?lang=en&mlfb=3SU10016AA400AA0

Service&Support (Manuals, Certificates, Characteristics, FAQs,...)
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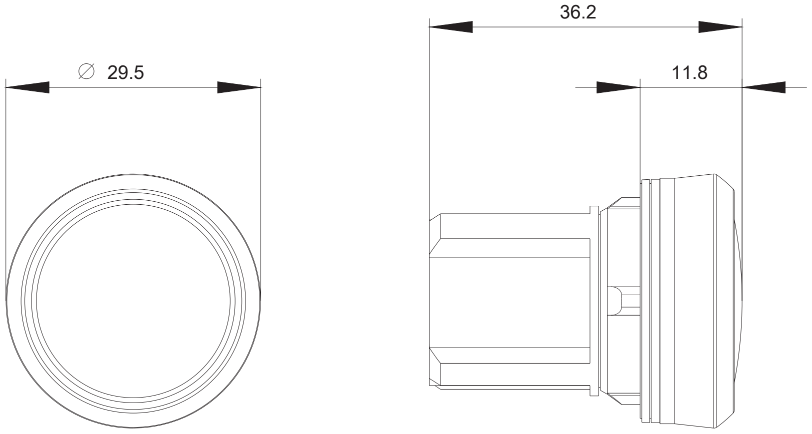
Image database (product images, 2D dimension drawings, 3D models, device circuit diagrams, EPLAN macros, ...)
http://www.automation.siemens.com/bilddb/cax_de.aspx?mlfb=3SU10016AA400AA0&lang=en



last modified: 09.03.2015

SIEMENS

Data sheet 3SU1001-6AA30-0AA0


Figure similar

INDICATOR LIGHT, 22MM, ROUND, PLASTIC, YELLOW, SMOOTH LENS

product brand name		SIRIUS ACT
Product designation		Commanding and signaling devices
Design of the product		Pilot Light
Actuator:		
Color		
• of the actuating element		Yellow
Material of the actuating element		plastic
Shape of the actuating element		round
Outer diameter of the actuating element	mm	29.45
Front ring:		
Product component front ring		No
General technical data:		
Vibration resistance		
• acc. to IEC 60068-2-6		10 ... 500 Hz: 5g
Equipment marking		
• acc. to DIN EN 61346-2		P
• acc. to DIN EN 81346-2		P
Ambient conditions:		
Ambient temperature		
• during operation	°C	-25 ... +70
• during storage	°C	-40 ... +80
Installation/ mounting/ dimensions:		
Height	mm	29.45

Width	mm	29.45
Shape of the installation opening		round
Mounting diameter	mm	22

Certificates/ approvals:

Further information

Information- and Downloadcenter (Catalogs, Brochures,…)
http://www.siemens.com/industrial-controls/catalogs

Industry Mall (Online ordering system)
http://www.siemens.com/industrymall

Cax online generator
http://support.automation.siemens.com/WW/CAXorder/default.aspx?lang=en&mlfb=3SU10016AA300AA0

Service&Support (Manuals, Certificates, Characteristics, FAQs,...)
http://support.automation.siemens.com/WW/view/en/3SU10016AA300AA0/all

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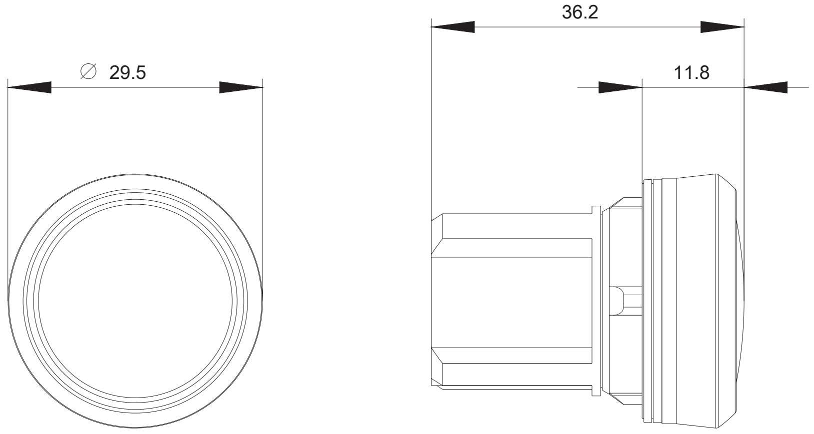
http://www.automation.siemens.com/bilddb/cax_de.aspx?mlfb=3SU10016AA300AA0&lang=en



last modified: 09.03.2015

Online data sheet

GL6-P3211

G6

MINIATURE PHOTOELECTRIC SENSORS

SICK
Sensor Intelligence.

Illustration may differ

Ordering information

Type	Part no.
GL6-P3211	1068921

Other models and accessories → www.sick.com/G6

Detailed technical data

Features

Sensor/ detection principle	Photoelectric retro-reflective sensor, Dual lens
Dimensions (W x H x D)	12 mm x 31.5 mm x 21 mm
Housing design (light emission)	Rectangular
Sensing range max.	≤ 6 m [1]
Sensing range	≤ 5 m [1]
Type of light	Visible red light
Light source	PinPoint LED [2]
Light spot size (distance)	Ø 8 mm (350 mm)
Wave length	650 nm
Adjustment	Potentiometer, 270°

[1] Reflector PL80A.
[2] Average service life: 100,000 h at T_U = +25 °C.

Mechanics/electronics

Supply voltage	10 V DC ... 30 V DC [1]
Ripple	± 10 % [2]

[1] Limit values when operated in short-circuit protected network: max. 8 A.
[2] May not exceed or fall below U_v tolerances.
[3] Without load.
[4] At Uv > 24 V, IA max. = 50 mA.
[5] Signal transit time with resistive load.
[6] With light/dark ratio 1:1.
[7] A = V_S connections reverse-polarity protected.
[8] B = inputs and output reverse-polarity protected.
[9] D = outputs overcurrent and short-circuit protected.
[10] Temperature stability following adjustment +/-10 °C.

Power consumption	30 mA [3]
Switching output	PNP
Switching mode	Light/dark switching
Switching mode selector	Selectable via light/dark selector
Signal voltage PNP HIGH/LOW	V_S - (≤ 3 V) / approx. 0 V
Output current $I_{max.}$	≤ 100 mA [4]
Response time	< 625 μs [5]
Switching frequency	1,000 Hz [6]
Connection type	Connector M8, 3-pin
Circuit protection	A [7] B [8] D [9]
Protection class	III
Weight	20 g
Polarisation filter	✓
Housing material	Plastic, ABS/PC
Optics material	Plastic, PMMA
Enclosure rating	IP67
Ambient operating temperature	–25 °C ... +55 °C [10]
Ambient storage temperature	–40 °C ... +70 °C
UL File No.	NRKH.E348498 & NRKH7.E348498

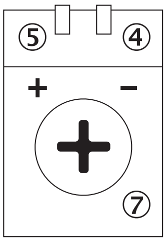
[1] Limit values when operated in short-circuit protected network: max. 8 A.
[2] May not exceed or fall below U_V tolerances.
[3] Without load.
[4] At Uv > 24 V, IA max. = 50 mA.
[5] Signal transit time with resistive load.
[6] With light/dark ratio 1:1.
[7] A = V_S connections reverse-polarity protected.
[8] B = inputs and output reverse-polarity protected.
[9] D = outputs overcurrent and short-circuit protected.
[10] Temperature stability following adjustment +/-10 °C.

Classifications

ECl@ss 5.0	27270902
ECl@ss 5.1.4	27270902
ECl@ss 6.0	27270902
ECl@ss 6.2	27270902
ECl@ss 7.0	27270902
ECl@ss 8.0	27270902
ECl@ss 8.1	27270902
ECl@ss 9.0	27270902
ETIM 5.0	EC002717
ETIM 6.0	EC002717
UNSPSC 16.0901	39121528

Adjustments possible

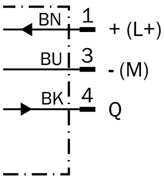
Adjustment possibility



④ LED indicator green: Supply voltage active
⑤ LED indicator yellow: Status of received light beam
⑦ Sensitivity control: potentiometer

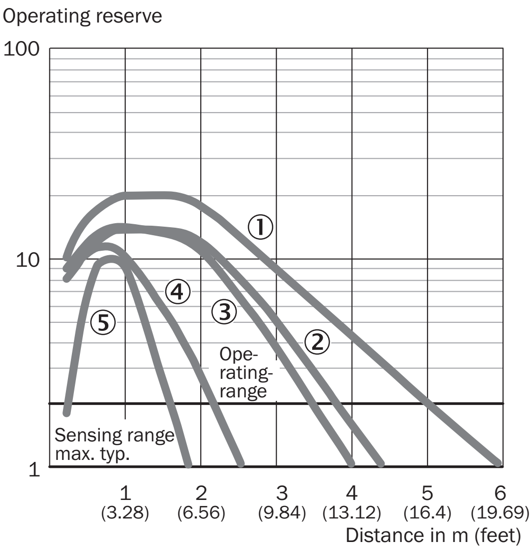
Connection diagram

Cd-045



Characteristic curve

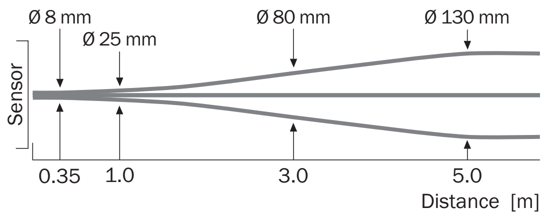
GL6



① Reflector PL80A
② Reflector PL40A
③ Reflector P250
④ Reflector PL20A
⑤ Reflective tape REF-IRF-56

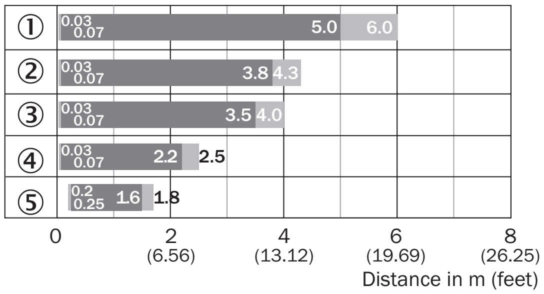
Light spot size

GL6, GL6G



Sensing range diagram

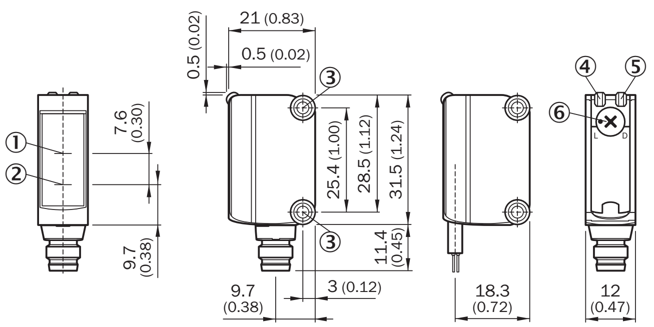
GL6, GL6G



Sensing range
Sensing range max.

① Reflector PL80A
② Reflector PL40A
③ Reflector P250
④ Reflector PL20A
⑤ Reflective tape REF-IRF-56

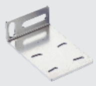
Dimensional drawing (Dimensions in mm (inch))



① Optical axis, receiver
② Optical axis, sender
③ Mounting holes M3
④ LED indicator green: Supply voltage active
⑤ LED indicator yellow: Status of received light beam
⑥ Light/ dark rotary switch: L = light switching, D = dark switching

Recommended accessories

Other models and accessories ➜ www.sick.com/G6

	Brief description	Type	Part no.
Universal bar clamp systems			
	Clamp bar to fix G6 and W16 sensors on rods of 10 mm, clamp-on design up to 4 mm wall thickness, aluminum (clamp bar), stainless steel (bracket), clamp bar mounting and clamp function, mounting bracket, mounting hardware	BEF-KHS-ISG6	2075080
Device protection (mechanical)			
	Stainless steel 1.4301 (SVS 304), 3 mm thick protective sleeve for G6, stainless steel 1.4301, mounting hardware included	BEF-SG-G6-01	2069044
Mounting brackets and plates			
	Stainless steel (1.4301)	BEF-WN-G6	2062909
Plug connectors and cables			
	Head A: female connector, M8, 3-pin, straight, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 2 m	YF8U13-020VA1XLEAX	2095860
	Head A: female connector, M8, 3-pin, straight, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 5 m	YF8U13-050VA1XLEAX	2095884
	Head A: female connector, M8, 3-pin, angled, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 2 m	YG8U13-020VA1XLEAX	2096165
	Head A: female connector, M8, 3-pin, angled, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 5 m	YG8U13-050VA1XLEAX	2096166
Masks			
	Slit mask, vertical slots, slot width: 1.0 mm, 2 pieces, black, Aluminum, Slit mask (2 pieces)	BEF-SLIT MASK-G6	2075254
Reflectors			
	Rectangular, screw connection, 47 mm x 47 mm, PMMA/ABS, Screw-on, 2 hole mounting	P250	5304812
	Rectangular, screw connection, 56 mm x 28 mm, PMMA/ABS, Screw-on, 2 hole mounting	PL30A	1002314
	Rectangular, screw connection, 80 mm x 80 mm, PMMA/ABS, Screw-on, 2 hole mounting	PL80A	1003865
	Self-adhesive	REF-IRF-56	5314244
	Round, plugable for metal plates, PMMA/ABS, Plug-in for sheets	PL22-3	1004488

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WORLDWIDE PRESENCE:

Contacts and other locations www.sick.com

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Online data sheet

P250

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P250

Ordering information

Type	Part no.
P250	5304812

Other models and accessories ➜ www.sick.com/

Detailed technical data

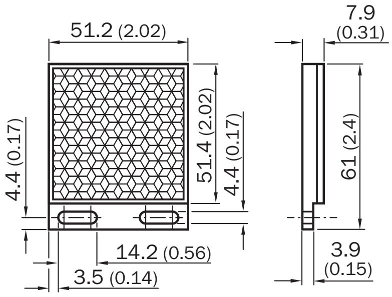
Technical specifications

Accessory group	Reflectors
Accessory family	Angular
Description	Rectangular, screw connection
Mounting system type	Screw-on, 2 hole mounting
Ambient operating temperature	–20 °C ... +65 °C
Reflective area	47 mm x 47 mm
Material	PMMA/ABS

Classifications

ECl@ss 5.0	27279203
ECl@ss 5.1.4	27279203
ECl@ss 6.0	27279203
ECl@ss 6.2	27279203
ECl@ss 7.0	27279203
ECl@ss 8.0	27279203
ECl@ss 8.1	27279203
ECl@ss 9.0	27273601
ETIM 5.0	EC002467
ETIM 6.0	EC002467
UNSPSC 16.0901	39111827

Dimensional drawing (Dimensions in mm (inch))



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Online data sheet

WL2SG-2F3235

W2SG-2

MINIATURE PHOTOELECTRIC SENSORS

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Illustration may differ

Ordering information

Type	Part no.
WL2SG-2F3235	1063647

Other models and accessories → www.sick.com/W2SG-2

Detailed technical data

Features

Sensor/ detection principle	Photoelectric retro-reflective sensor, autocollimation
Dimensions (W x H x D)	7.7 mm x 21.8 mm x 13.5 mm
Housing design (light emission)	Rectangular
Sensing range max.	0 m ... 1.2 m [1)]
Sensing range	0 m ... 0.55 m [1)]
Type of light	Visible red light
Light source	PinPoint LED [2)]
Light spot size (distance)	Ø 12 mm (250 mm)
Wave length	640 nm
Adjustment	Cable
AutoAdapt	✓
Special applications	Detecting transparent objects
Special features	Detecting transparent objects

1) Reflector P250F.

2) Average service life: 100,000 h at T_U = +25 °C.

Mechanics/electronics

Supply voltage	10 V DC ... 30 V DC [1]
Ripple	≤ 5 V_{pp} [2]
Power consumption	20 mA [3]
Switching output	PNP
Switching mode	Dark switching
Output current $I_{max.}$	< 50 mA
Response time	< 0.5 ms [4]
Switching frequency	1,000 Hz [5]
Connection type	Cable with M8 male connector, 4-pin, 200 mm [6]
Cable material	PVC
Cable diameter	Ø 3 mm
Circuit protection	A [7] B [8] D [9]
Polarisation filter	✓
Housing material	Plastic, ABS/PC
Optics material	Plastic, PMMA
Enclosure rating	IP67
Special feature	Detecting transparent objects
Ambient operating temperature	–20 °C ... +50 °C
Ambient storage temperature	–40 °C ... +75 °C
UL File No.	NRKH.E181493

[1] Limit values.
[2] May not exceed or fall below U_V tolerances.
[3] Without load.
[4] Signal transit time with resistive load.
[5] With light/dark ratio 1:1.
[6] Do not bend below 0 °C.
[7] A = V_S connections reverse-polarity protected.
[8] B = output reverse-polarity protected.
[9] D = outputs overcurrent and short-circuit protected.

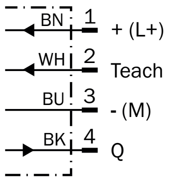
Classifications

ECl@ss 5.0	27270902
ECl@ss 5.1.4	27270902
ECl@ss 6.0	27270902
ECl@ss 6.2	27270902
ECl@ss 7.0	27270902
ECl@ss 8.0	27270902
ECl@ss 8.1	27270902
ECl@ss 9.0	27270902
ETIM 5.0	EC002717
ETIM 6.0	EC002717

UNSPSC 16.0901	39121528

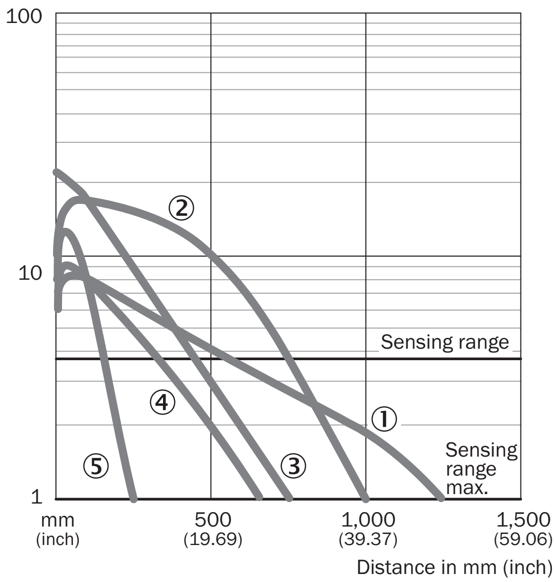
Connection diagram

Cd-092



Characteristic curve

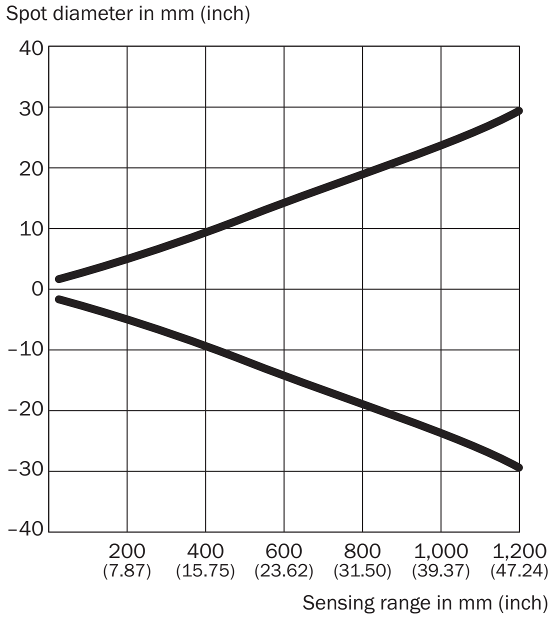
WL2S-2



① Reflector P250F
② Reflector PL20F
③ Reflective tape REF-AC1000
④ PL10F reflector
⑤ Reflector PL8FH

Light spot size

WL2S-2

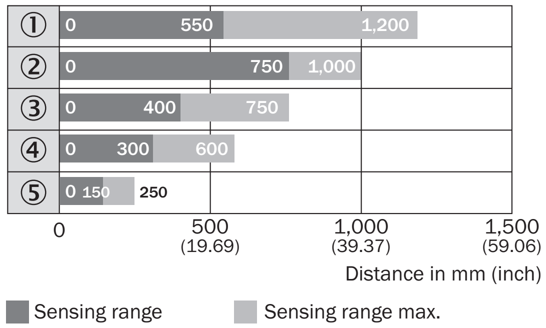


Dimensions in mm (inch)

Sensing range	Spot diameter
20 (0.79)	3.4 (0.13)
100 (3.94)	6.5 (0.26)
250 (9.84)	12.0 (0.47)
500 (19.69)	34.0 (1.34)
1,000 (39.37)	48.0 (1.89)
1,200 (47.24)	60.0 (2.36)

Sensing range diagram

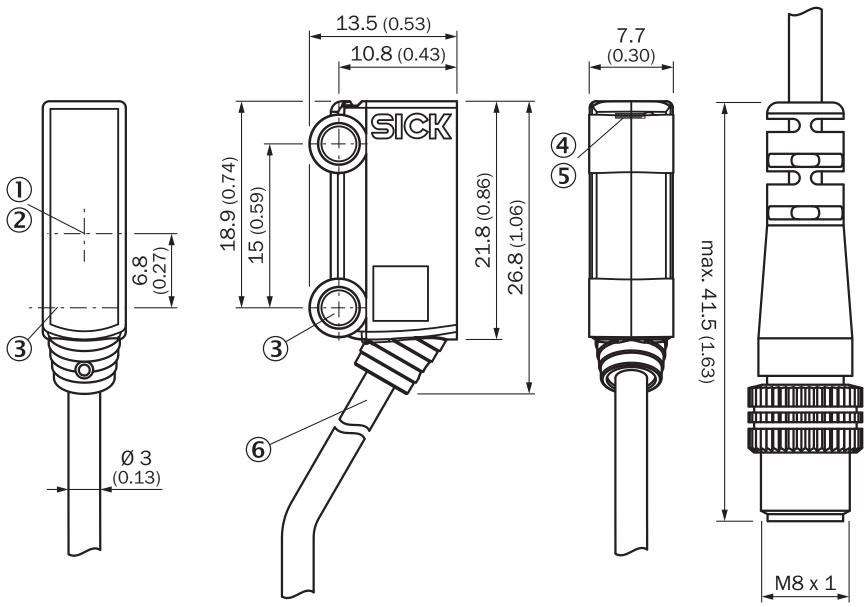
WL2S-2



① Reflector P250F
② Reflector PL20F
③ Reflective tape REF-AC1000
④ PL10F reflector
⑤ Reflector PL8FH

Dimensional drawing (Dimensions in mm (inch))

WL2S-2

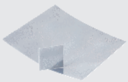


① Optical axis, receiver
② Optical axis, sender
③ Middle axis fixing hole Ø 3.2 mm
④ LED indicator green: Supply voltage active
⑤ LED indicator yellow: Status of received light beam
⑥ Connection

Recommended accessories

Other models and accessories ➜ www.sick.com/W2SG-2

	Brief description	Type	Part no.
Mounting brackets and plates			
	Mounting bracket for floor mounting, steel, zinc coated, without mounting hardware	BEF-W2S-A	4034748
	Mounting bracket for wall mounting, steel, zinc coated, without mounting hardware	BEF-W2S-B	4034749
Terminal and alignment brackets			
	Ball clamp bracket, Plastic, mounting hardware included	BEF-GH-MINI01	2023160
Plug connectors and cables			
	Head A: female connector, M8, 4-pin, straight, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 2 m	YF8U14-020VA3XLEAX	2095888
	Head A: female connector, M8, 4-pin, straight, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 5 m	YF8U14-050VA3XLEAX	2095889

	Brief description	Type	Part no.
	Head A: female connector, M8, 4-pin, angled, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 2 m	YG8U14-020VA3XLEAX	2095962
	Head A: female connector, M8, 4-pin, angled, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 5 m	YG8U14-050VA3XLEAX	2095963
Reflectors			
	Rectangular, screw connection, 80 mm x 80 mm, PMMA/ABS, Screw-on, 2 hole mounting	PL80A	1003865
	Fine triple reflector, screw connection, suitable for laser sensors, 47 mm x 47 mm, PMMA/ABS, Screw-on, 2 hole mounting	P250F	5308843
	Fine triple reflector, screw connection, suitable for laser sensors, 18 mm x 18 mm, PMMA/ABS, Screw-on, 2 hole mounting	PL10F	5311210
	Fine triple reflector, screw connection, suitable for laser sensors, 38 mm x 16 mm, PMMA/ABS, Screw-on, 2 hole mounting	PL20F	5308844
	Fine triple reflector, screw connection, suitable for laser sensors, 56 mm x 28 mm, PMMA/ABS, Screw-on, 2 hole mounting	PL30F	5326523
	Fine triple reflector, screw connection, suitable for laser sensors, 76 mm x 45 mm, PMMA/ABS, Screw-on, 2 hole mounting	PL81-1F	5325060
	Fine triple, not self-adhesive, high temperature up to 99 °C, ø 10 mm, ø Reflexionsfläche 8 mm, PMMA/ABS	PL8FH	5328583
	Suitable for laser sensors, self-adhesive, cut, see alignment note, 56.3 mm x 56.3 mm, self-adhesive	REF-AC1000-56	4063030
	Fine triple reflector, chemically resistant, screw connection, 18 mm x 18 mm, Plastic, Screw-on, 2 hole mounting	PL10F CHEM	5321636
	Chemically resistant, screw connection, suitable for laser sensors, 16 mm x 38 mm, Plastic, Screw-on, 2 hole mounting	PL20F-CHEM	5326089
	Stainless steel reflector, hygienic design, chemically resistant, enclosure rating IP69K, D12 adapter shaft, PMMA front screens, 25 mm x 25 mm, Stainless steel V4A (1.4404, 316L), D12-adapter shaft	PLH25-D12	2063404
	Stainless steel reflector, hygienic design, chemically resistant, Enclosure rating IP 69K, M12-adapter thread, PMMA front screens, 25 mm x 25 mm, Stainless steel V4A (1.4404, 316L), M12-adapter thread	PLH25-M12	2063403
	Stainless steel reflector, washdown design, chemically resistant, IP 69K enclosure rating, screw connection, PMMA front screens, 14 mm x 14 mm, Stainless steel V4A (1.4404, 316L), Screw-on, 2 hole mounting	PLV14-A	2063405

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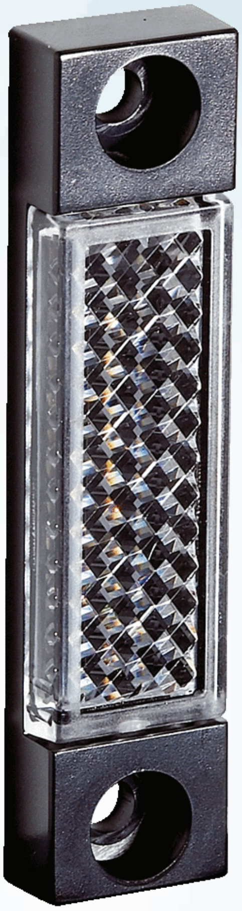

P45A

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Ordering information

Type	Part no.
P45A	5320027

Other models and accessories ➜ www.sick.com/

Detailed technical data

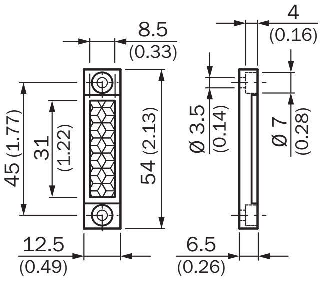
Technical specifications

Accessory group	Reflectors
Accessory family	Angular
Description	Rectangular, screw connection
Mounting system type	Screw-on, 2 hole mounting
Ambient operating temperature	–20 °C ... +65 °C
Reflective area	31 mm x 8.5 mm
Material	PMMA/ABS

Classifications

ECl@ss 5.0	27279203
ECl@ss 5.1.4	27279203
ECl@ss 6.0	27279203
ECl@ss 6.2	27279203
ECl@ss 7.0	27279203
ECl@ss 8.0	27279203
ECl@ss 8.1	27279203
ECl@ss 9.0	27273601
ETIM 5.0	EC002467
ETIM 6.0	EC002467
UNSPSC 16.0901	39111827

Dimensional drawing (Dimensions in mm (inch))



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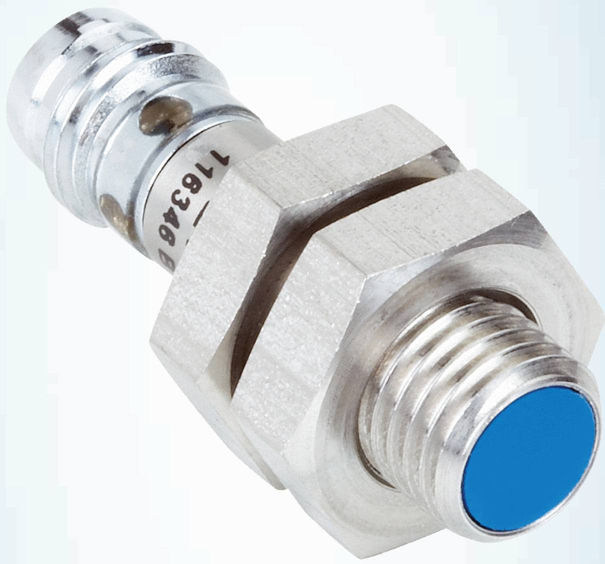
Online data sheet



IM08-1B5PS-ZTK

IM Standard

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INDUCTIVE PROXIMITY SENSORS

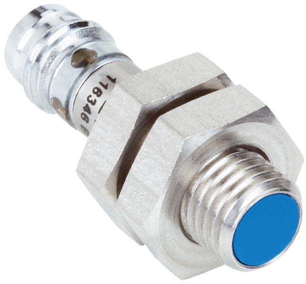


Illustration may differ

Ordering information

Type	Part no.
IM08-1B5PS-ZTK	6020112

Other models and accessories ➜ www.sick.com/IM_Standard

Detailed technical data

Features

Housing	Cylindrical thread design
Housing	Short-body
Thread size	M8 x 1
Diameter	Ø 8 mm
Sensing range S_n	1.5 mm
Safe sensing range S_a	1.22 mm
Installation type	Flush
Switching frequency	5,000 Hz
Connection type	Connector M8, 3-pin
Switching output	PNP
Output function	NO
Electrical wiring	DC 3-wire
Enclosure rating	IP67 [1)]

1) According to EN 60529.

Mechanics/electronics

Supply voltage	10 V DC ... 30 V DC
Ripple	≤ 20 % [1)]
Voltage drop	≤ 2 V [2)]
Current consumption	10 mA [3)]
Time delay before availability	≤ 10 ms
Hysteresis	≤ 10 %
Reproducibility	≤ 5 % [4)] [5)]

1) Of V_S.

2) At I_a max.

3) Without load.

4) Ub and Ta constant.

5) Of Sr.

Temperature drift (of S_r)	± 10 %
EMC	According to EN 60947-5-2
Continuous current I_a	≤ 200 mA
Short-circuit protection	✓
Reverse polarity protection	✓
Power-up pulse protection	✓
Shock and vibration resistance	30 g, 11 ms / 10 ... 55 Hz, 1 mm
Ambient operating temperature	–25 °C ... +70 °C
Housing material	Metal, Nickel-plated brass
Sensing face material	Plastic, Plastic
Housing length	29 mm
Thread length	12 mm
Tightening torque, max.	4 Nm

1) Of V_S.
2) At I_a max.
3) Without load.
4) Ub and Ta constant.
5) Of Sr.

Reduction factors

Note	The values are reference values which may vary
Stainless steel (V2A, 304)	Approx. 0.8
Aluminum (Al)	Approx. 0.45
Copper (Cu)	Approx. 0.4
Brass (Br)	Approx. 0.5

Installation note

Remark	Associated graphic see "Installation"
A	1.5 mm
B	2 mm
C	8 mm
D	4.5 mm
E	0 mm
F	12 mm

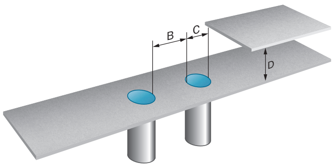
Classifications

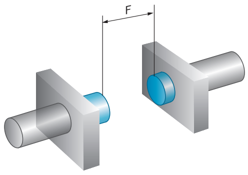
ECl@ss 5.0	27270101
ECl@ss 5.1.4	27270101
ECl@ss 6.0	27270101
ECl@ss 6.2	27270101
ECl@ss 7.0	27270101
ECl@ss 8.0	27270101
ECl@ss 8.1	27270101
ECl@ss 9.0	27270101

ETIM 5.0	EC002714
ETIM 6.0	EC002714
UNSPSC 16.0901	39122230

Installation note

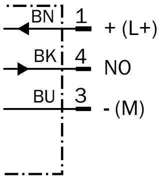
Flush installation





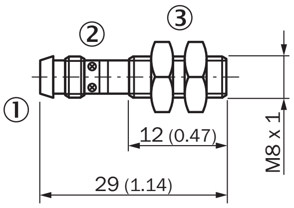
Connection diagram

Cd-002



Dimensional drawing (Dimensions in mm (inch))

IM08, male connector, flush



① Connection
② Indication LED
③ Fastening nuts (2x); width across 13, metal

Recommended accessories

Other models and accessories ➜ www.sick.com/IM_Standard

	Brief description	Type	Part no.
Mounting brackets and plates			
	Mounting plate for M8 sensors, steel, zinc coated, without mounting hardware	BEF-WG-M08	5321722
	Mounting bracket for M8 sensors, steel, zinc coated, without mounting hardware	BEF-WN-M08	5321721
Terminal and alignment brackets			
	Clamping block for round sensors M8, without fixed stop, plastic (PA12), glass-fiber reinforced, mounting hardware included	BEF-KH-M08	2051477
Plug connectors and cables			
	Head A: female connector, M8, 3-pin, straight, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 2 m	YF8U13-020VA1XLEAX	2095860
	Head A: female connector, M8, 3-pin, straight, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 5 m	YF8U13-050VA1XLEAX	2095884
	Head A: female connector, M8, 3-pin, angled, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 2 m	YG8U13-020VA1XLEAX	2096165
	Head A: female connector, M8, 3-pin, angled, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 5 m	YG8U13-050VA1XLEAX	2096166
	Head A: female connector, M8, 3-pin, straight Head B: - Cable: unshielded	DOS-0803-G	7902077
	Head A: female connector, M8, 3-pin, angled Head B: - Cable: unshielded	DOS-0803-W	7902078
	Head A: male connector, M8, 3-pin, straight Head B: - Cable: unshielded	STE-0803-G	6037322

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WTB8L-P2231

W8 Laser

MINIATURE PHOTOELECTRIC SENSORS

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Illustration may differ

Ordering information

Type	Part no.
WTB8L-P2231	6033221

Included in delivery: BEF-W100-A (1)

Other models and accessories ➜ www.sick.com/W8_Laser

Detailed technical data

Features

Sensor/ detection principle	Photoelectric proximity sensor, Background suppression
Dimensions (W x H x D)	11 mm x 31 mm x 20 mm
Housing design (light emission)	Rectangular
Sensing range max.	30 mm ... 300 mm [1)]
Sensing range	40 mm ... 300 mm [1)]
Type of light	Visible red light
Light source	Laser [2)]
Light spot size (distance)	Ø 1.5 mm (300 mm)
Wave length	650 nm
Laser class	1
Adjustment	Potentiometer, 4 turns
Special applications	Detecting small objects, Detection of objects moving at high speeds
Test input sender off	TE to +Vs

1) Object with 90 % reflectance (referred to standard white, DIN 5033).

2) Average service life: 100,000 h at T_U = +25 °C.

Mechanics/electronics

Supply voltage	10 V DC ... 30 V DC [1)]

1) Limit values when operated in short-circuit protected network: max. 8 A.

2) May not exceed or fall below U_V tolerances.

3) Without load.

4) Signal transit time with resistive load.

5) With light/dark ratio 1:1.

6) A = V_S connections reverse-polarity protected.

7) B = inputs and output reverse-polarity protected.

8) D = outputs overcurrent and short-circuit protected.

Ripple	± 10 % [2]
Power consumption	30 mA [3]
Switching output	PNP
Switching mode	Light/dark switching
Switching mode selector	Selectable via light/dark rotary switch
Signal voltage PNP HIGH/LOW	Approx. V_S – 1.8 V / 0 V
Output current $I_{max.}$	≤ 100 mA
Response time	≤ 0.25 ms [4]
Switching frequency	2,000 Hz [5]
Connection type	Male connector M8, 4-pin
Circuit protection	A [6] B [7] D [8]
Weight	10 g
Housing material	Plastic, ABS
Optics material	Plastic, PMMA
Enclosure rating	IP67
Items supplied	Stainless steel mounting bracket (1.4301/304) BEF-W100-A
Ambient operating temperature	–10 °C ... +50 °C
Ambient storage temperature	–40 °C ... +70 °C

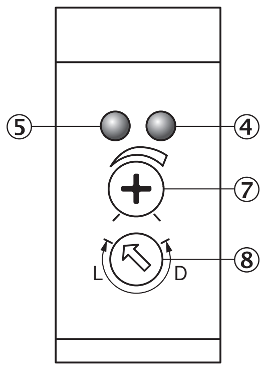
[1] Limit values when operated in short-circuit protected network: max. 8 A.
[2] May not exceed or fall below U_V tolerances.
[3] Without load.
[4] Signal transit time with resistive load.
[5] With light/dark ratio 1:1.
[6] A = V_S connections reverse-polarity protected.
[7] B = inputs and output reverse-polarity protected.
[8] D = outputs overcurrent and short-circuit protected.

Classifications

ECl@ss 5.0	27270904
ECl@ss 5.1.4	27270904
ECl@ss 6.0	27270904
ECl@ss 6.2	27270904
ECl@ss 7.0	27270904
ECl@ss 8.0	27270904
ECl@ss 8.1	27270904
ECl@ss 9.0	27270904
ETIM 5.0	EC002719
ETIM 6.0	EC002719
UNSPSC 16.0901	39121528

Adjustments possible

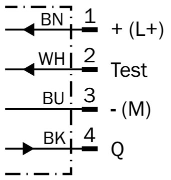
WTB8



④ Orange LED indicator : switching output active
⑤ LED indicator green: stability indicator
⑦ Adjustment of sensing range
⑧ Light/ dark rotary switch: L = light switching, D = dark switching

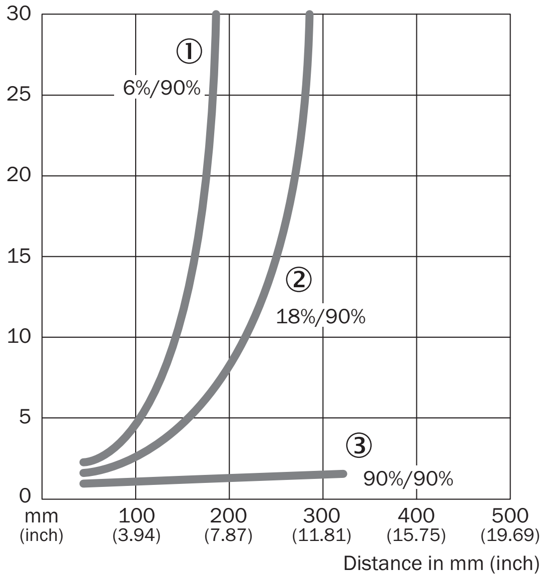
Connection diagram

Cd-078



Characteristic curve

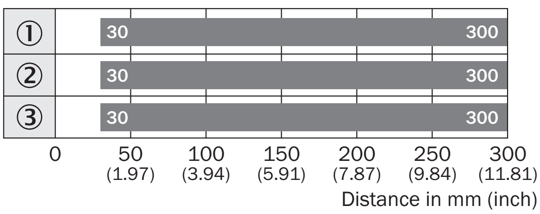
WTB8L, 300 mm



① Sensing range on black, 6% remission
② Sensing range on gray, 18 % remission
③ Sensing range on white, 90% remission

Sensing range diagram

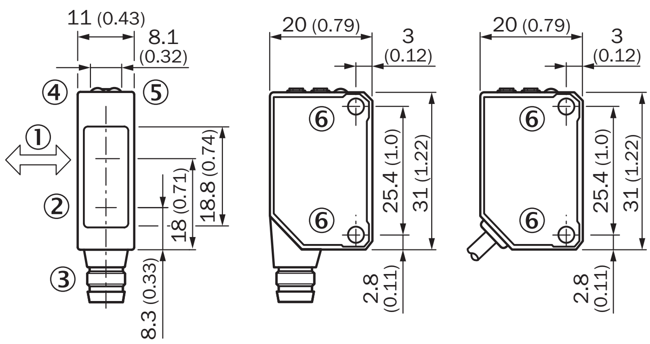
WTB8, 300 mm



Sensing range

① Sensing range on black, 6% remission
② Sensing range on gray, 18 % remission
③ Sensing range on white, 90% remission

Dimensional drawing (Dimensions in mm (inch))



① Standard direction
② Center of optical axis, sender
③ Connection
④ Orange LED indicator : switching output active
⑤ LED indicator green: stability indicator
⑥ Threaded mounting hole M3

Recommended accessories

Other models and accessories ➔ www.sick.com/W8_Laser

	Brief description	Type	Part no.
Universal bar clamp systems			
	Plate N08 for universal clamp bracket, Zinc plated steel (sheet), Zinc die cast (clamping bracket), Universal clamp (5322626), mounting hardware	BEF-KHS-N08	2051607
Device protection (mechanical)			
	Safety bracket for floor mounting, Stainless steel 1.4571, mounting hardware included	BEF-SW-W4S	2051497
Mounting brackets and plates			
	Mounting bracket for wall mounting, stainless steel, mounting hardware included	BEF-W100-A	5311520
	Mounting bracket for floor mounting, steel, zinc coated, mounting hardware included	BEF-W100-B	5311521
Plug connectors and cables			
	Head A: female connector, M8, 4-pin, straight, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 2 m	YF8U14-020VA3XLEAX	2095888
	Head A: female connector, M8, 4-pin, straight, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 5 m	YF8U14-050VA3XLEAX	2095889

	Brief description	Type	Part no.
	Head A: female connector, M8, 4-pin, angled, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 2 m	YG8U14-020VA3XLEAX	2095962
	Head A: female connector, M8, 4-pin, angled, A-coded Head B: Flying leads Cable: Sensor/actuator cable, PVC, unshielded, 5 m	YG8U14-050VA3XLEAX	2095963
	Head A: female connector, M8, 4-pin, straight Head B: - Cable: unshielded	DOS-0804-G	6009974
	Head A: female connector, M8, 4-pin, angled Head B: - Cable: unshielded	DOS-0804-W	6009975

SICK AT A GLANCE

SICK is one of the leading manufacturers of intelligent sensors and sensor solutions for industrial applications. A unique range of products and services creates the perfect basis for controlling processes securely and efficiently, protecting individuals from accidents and preventing damage to the environment.

We have extensive experience in a wide range of industries and understand their processes and requirements. With intelligent sensors, we can deliver exactly what our customers need. In application centers in Europe, Asia and North America, system solutions are tested and optimized in accordance with customer specifications. All this makes us a reliable supplier and development partner.

Comprehensive services complete our offering: SICK LifeTime Services provide support throughout the machine life cycle and ensure safety and productivity.

For us, that is "Sensor Intelligence."

WORLDWIDE PRESENCE:

Contacts and other locations www.sick.com

Online data sheet

CLV621-1120

CLV62x

BAR CODE SCANNERS

Sensor Intelligence.

Ordering information

Type	Part no.
CLV621-1120	1041787

Other models and accessories → www.sick.com/CLV62x

Detailed technical data

Features

Version	Long Range
Connection type	Ethernet
Reading field	Front
Scanner design	Raster scanner
Focus	Fixed focus
Light source	Visible red light (655 nm)
MTBF	40,000 h
Laser class	2 (IEC 60825-1:2014, EN 60825-1:2014)
Aperture angle	≤ 50°
Scanning frequency	400 Hz ... 1,200 Hz
Code resolution	0.35 mm ... 1 mm
Reading distance	60 mm ... 730 mm [1)]
Raster height, number of lines, at distance	15 mm, 8, 200 mm

[1)] For details see reading field diagram.

Performance

Bar code types	All current code types, Code 39, Code 128, Code 93, Codabar, GS1-128 / EAN 128, UPC / GTIN / EAN, Interleaved 2 of 5, Pharmacode, GS1 DataBar, Telepen, MSI/Plessey
Print ratio	2:1 ... 3:1
No. of codes per scan	1 ... 20 (Standard decoder) 1 ... 6 (SMART620)
No. of codes per reading interval	1 ... 50 (auto-discriminating)
No. of characters per reading interval	1,500 500 (for multiplexer function in CAN operation)
No. of multiple readings	1 ... 99

Interfaces

Ethernet	✔, TCP/IP

Online data sheet | 2018-08-13 20:43:29
Subject to change without notice

Function	Host, AUX
Data transmission rate	10/100 MBit/s
PROFINET	✓
Function	PROFINET Single Port, PROFINET Dual Port (optional via external connection module CDF600-2)
Data transmission rate	10/100 MBit/s
EtherNet/IP™	✓
Data transmission rate	10/100 MBit/s
EtherCAT®	✓
Type of fieldbus integration	Optional over external fieldbus module CDF600
Serial	✓, RS-232, RS-422, RS-485
Function	Host, AUX
Data transmission rate	2,400 Baud ... 115.2 kBaud, AUX: 57.6 kBaud (RS-232)
CAN	✓
Function	SICK CAN sensor network CSN (master/slave, multiplexer/server)
Data transmission rate	20 kbit/s ... 1 Mbit/s
CANopen	✓
Data transmission rate	20 kbit/s ... 1 Mbit/s
PROFIBUS DP	✓
Type of fieldbus integration	Optional over external fieldbus module CDF600-2
DeviceNet™	✓
Type of fieldbus integration	Optional, over external connection module CDM + CMF
Switching inputs	3 ("Sensor 1", 2 inputs via optional parameter storage CMC600 in CDB620/CDM420)
Switching outputs	2 (Via optional CMC600 parameter memory in CDB620/CDM420)
Reading pulse	Switching inputs, non-powered, serial interface, auto pulse, CAN
Optical indicators	6 LEDs (Ready, Result, laser, Data, CAN, LNK TX)
Acoustic indicators	Beeper/buzzer (can be switched off, can be allocated as a result indication function)
Configuration software	SOPAS ET

Mechanics/electronics

Electrical connection	2 x M12 cylindrical connectors (12-pin male connector, 4-pin female connector) on swivel connector
Operating voltage	10 V DC ... 30 V DC
Power consumption	4.5 W
Housing	Aluminum die cast
Housing color	Light blue (RAL 5012)
Front screen	Glass
Enclosure rating	IP65 (DIN 40 050)
Protection class	III (VDE 0106/IEC 1010-1)
Weight	205 g, without connecting cable
Dimensions (L x W x H)	61 mm x 66 mm x 38 mm [1)]

[1)] Swivel connector is 15 mm longer.

Ambient data

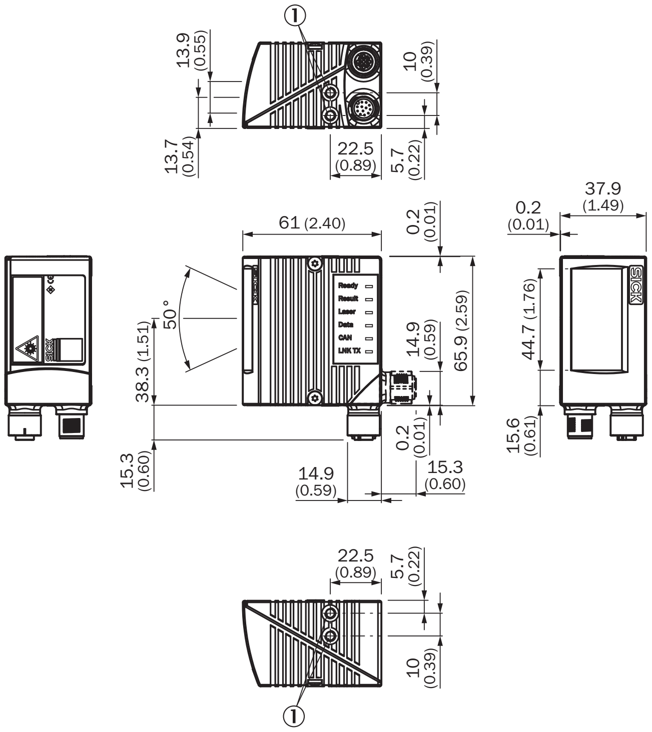
Electromagnetic compatibility (EMC)	EN 61000-6-3 (2001-10) / EN 61000-6-2:2005
Vibration resistance	EN 60068-2-6 (1995)
Shock resistance	EN 60068-2-27 (1993)
Ambient operating temperature	0 °C ... +40 °C
Storage temperature	–20 °C ... +70 °C
Permissible relative humidity	90 %, Non-condensing
Ambient light immunity	2,000 lx, on bar code
Bar code print contrast (PCS)	≥ 60 %

Classifications

ECl@ss 5.0	27280102
ECl@ss 5.1.4	27280102
ECl@ss 6.0	27280102
ECl@ss 6.2	27280102
ECl@ss 7.0	27280102
ECl@ss 8.0	27280102
ECl@ss 8.1	27280102
ECl@ss 9.0	27280102
ETIM 5.0	EC002550
ETIM 6.0	EC002550
UNSPSC 16.0901	43211701

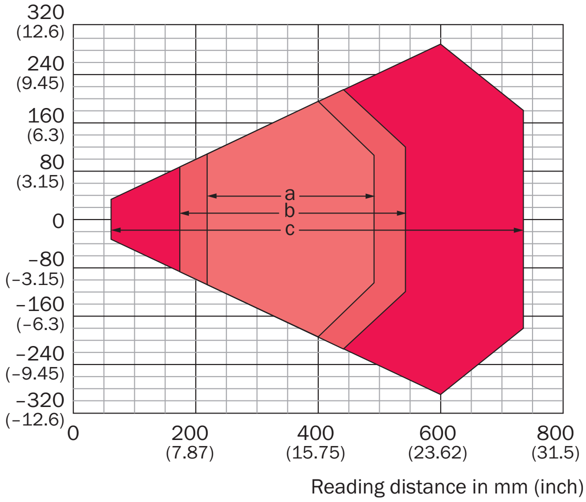
Dimensional drawing (Dimensions in mm (inch))

CLV62x Ethernet, front



① M5

Reading field diagram



Resolution

- a: 0.35 mm (13.8 mil)
- b: 0.50 mm (19.7 mil)
- c: 1.00 mm (39.4 mil)

Recommended accessories

Other models and accessories ➜ www.sick.com/CLV62x

	Brief description	Type	Part no.
Mounting brackets and plates			
	Bracket with adapter board	Mounting bracket	2042902
Plug connectors and cables			
	Head A: male connector, M12, 4-pin, straight, D-coded Head B: male connector, RJ45, 8-pin, straight Cable: Ethernet, twisted pair, PUR, halogen-free, shielded, 2 m	SSL-2J04-G02ME	6034414
Modules			
	Small connection module for one sensor, 4 cable glands, base for CMC600	CDB620-001	1042256
	Modular connection module for one sensor	CDM420-0001	1025362

SICK AT A GLANCE

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Comprehensive services complete our offering: SICK LifeTime Services provide support throughout the machine life cycle and ensure safety and productivity.

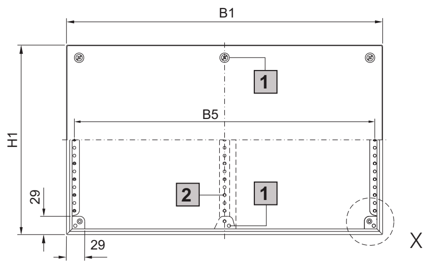
For us, that is “Sensor Intelligence.”

WORLDWIDE PRESENCE:

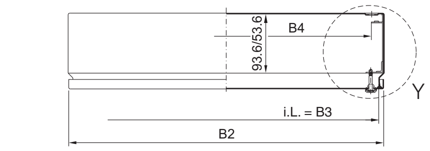
Contacts and other locations www.sick.com

Small enclosures

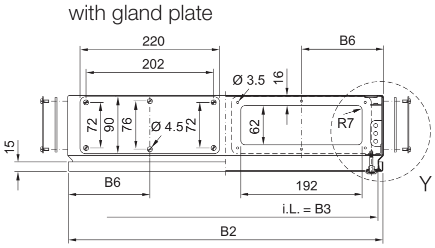
Terminal boxes KL



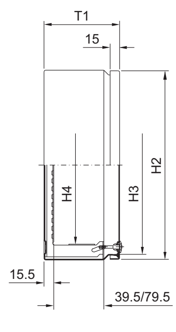
without gland plate



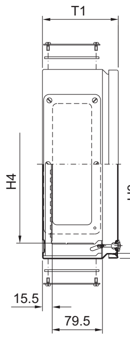
with gland plate



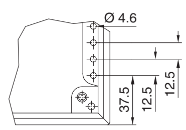
without gland plate



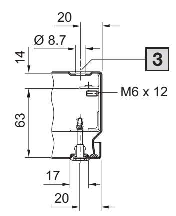
with gland plate



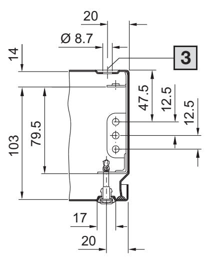
Detail X



Detail Y
T1 = 80



Detail Y
T1 = 120



B1 = Overall width
B2 = Cover width
B3 = Clearance width of enclosure
B4 = Clearance/width between profile strips
B5 = Distance between axes of the mounting holes in the profile strips
B6 = Distance from outer edge of enclosure – centre of gland plate

H1 = Overall height
H2 = Cover height
H3 = Clearance height of enclosure
H4 = Clearance frame/height between profile strips

T1 = Overall depth

1 Only with W ≥ 600 mm
2 Only with W = 800 mm
3 Drilled hole does not apply to stainless steel version

i.L. = Clearance width

Model No. KL			Width dimensions mm						Height dimensions mm				Depth dimensions mm
without gland plate	with gland plate	Stainless steel without gland plate	B1	B2	B3	B4	B5	B6	H1	H2	H3	H4	T1
1514.510	**–**	**1521.010**	150	148	132	109	125	–	150	148	132	–	80
1528.510	**–**	**–**	200	198	182	159	175	–	150	148	132	–	80
1516.510	**–**	**1523.010**	200	198	182	159	175	–	200	198	182	–	80
1515.510	**–**	**1522.010**	300	298	282	259	275	–	150	148	132	–	80
1517.510	**–**	**1524.010**	300	298	282	259	275	–	200	198	182	–	80
1518.510	**–**	**–**	400	398	382	359	375	–	200	198	182	–	80
1519.510	**–**	**–**	600	598	582	559	575	–	200	198	182	–	80
1500.510	**–**	**1527.010**	150	148	132	109	125	–	150	148	132	100	120
1529.510	**–**	**–**	200	198	182	159	175	–	150	148	132	100	120
1502.510	**–**	**1528.010**	200	198	182	159	175	–	200	198	182	150	120
1501.510	**1530.510**	**–**	300	298	282	259	275	150	150	148	132	100	120
1503.510	**1531.510**	**1529.010**	300	298	282	259	275	150	200	198	182	150	120
1507.510	**1535.510**	**1526.010**	300	298	282	259	275	150	300	298	282	250	120
1589.510	**–**	**–**	400	398	382	359	375	–	150	148	132	100	120
1504.510	**1532.510**	**1525.010**	400	398	382	359	375	200	200	198	182	150	120
1508.510	**1536.510**	**1530.010**	400	398	382	359	375	200	300	298	282	250	120
1511.510	**1539.510**	**–**	400	398	382	359	375	200	400	398	382	350	120
1505.510	**1533.510**	**–**	500	498	482	459	475	130	200	198	182	150	120
1509.510	**1537.510**	**–**	500	498	482	459	475	130	300	298	282	250	120
1506.510	**1534.510**	**–**	600	598	582	559	575	150	200	198	182	150	120
1510.510	**1538.510**	**–**	600	598	582	559	575	150	300	298	282	250	120
1512.510	**1540.510**	**–**	600	598	582	559	575	150	400	398	382	350	120
1527.510	**1542.510**	**–**	800	798	782	759	775	150	200	198	182	150	120
1513.510	**1541.510**	**–**	800	798	782	759	775	150	400	398	382	350	120

SIEMENS

Data sheet 6GK5795-6MN10-0AA6

Product type designation	**Antenna ANT795-6MN** IWLAN ANTENNA ANT 795-6MN WITH OMNIDIRECTIONAL CHARACTERISTIC INCL. N-FEMALE CONNECTOR: 6/8 DBI; IP65 (-40-+70 DGR C), 2.4/5GHZ; WI-FI COMPLIANCE AND NATIONAL APPROVALS; MOUNTING ON ROOF AND VEHICLES; COMPACT MANUAL ON PAPER GERMAN / ENGLISH; SCOPE OF SUPPLY: 1X ANT795-6MN, 1X TERMINATING RESISTANCE TI795-1R FOR MOUNTING USE MOUNTING SUPPORT 6GK5795-6MN01-0AA6

Wireless frequencies	
Type of mobile network / is supported	WLAN
Operating frequency	
• for WLAN in 2.4 GHz frequency band	2.4 ... 2.7 GHz
• for WLAN in 5 GHz frequency band 1	3.4 ... 3.7 GHz
• for WLAN in 5 GHz frequency band 2	4.9 ... 5.935 GHz

Electrical data	
Impedance	50 Ω
Polarization	linear vertical
Radiation characteristic	omnidirectional
Antenna gain compared to spherical radiator	
• of the WLAN antenna / in the 2.4 GHz frequency band	6 dB
• of the WLAN antenna / in the 5 GHz frequency band	8 dB
Standing wave ratio (VSWR) / maximum	1.8
Radiating angle of the antenna	
• in the 2.4 GHz frequency band / horizontal	360°

• in the 5 GHz frequency band / horizontal	150°
Opening angle / Note	Note the antenna diagram regarding horizontal beam angle
Type of electrical connection / of the antenna	N-Connector
Design of plug-in connection	female
Angle of inclination / downward / maximum	0°
Transmit power / maximum	75 W; at 25° ambient temperature
Range / with clear line of sight / without disturbance	200 m; Remark: the distance can be much less and is depending on the space around, on the wireless standard in use, on the data rate and on the antenna installed on the partner station

Mechanical data

Material	
• of outer shell	Polycarbonate

Permitted ambient conditions

Ambient temperature	
• during operation	-40 ... +80 °C
• during storage	-40 ... +80 °C
• during transport	-40 ... +80 °C
Protection class IP	IP65
Wind load / maximum	10 N; at 160 km/h

Design, dimensions and weight

Width	86 mm
Height	43 mm
Depth	86 mm
Net weight	300 g
Mounting type	
• mast mounting	No
• wall mounting	Yes
• roof mounting	Yes
• directly on the device	No

Product properties, functions, components / general

Product feature / silicon-free	Yes

Standards, specifications, approvals

Certificate of suitability	Railway application in accordance with NF-F-16-101, NF-F-16-102
Certificate of suitability	
• RoHS conformity	Yes
• Railway application in accordance with EN 50124-1	Yes
• Railway application in accordance with EN 50155	Yes

Wireless approval	Current national approvals can be found on the Internet under www.siemens.com/funkzulassungen
Further Information / Internet Links	
Internet-Link	
• to website: Selector SIMATIC NET SELECTION TOOL	http://www.siemens.com/snst
• to website: Industrial communication	http://www.siemens.com/simatic-net
• to website: Industry Mall	https://mall.industry.siemens.com
• to website: Information and Download Center	http://www.siemens.com/industry/infocenter
• to website: Image database	http://automation.siemens.com/bilddb
• to website: CAx Download Manager	http://www.siemens.com/cax
• to website: Industry Online Support	https://support.industry.siemens.com

last modified: 10.02.2016

ANNEX 7

Final Calculations

CONSOVEYO KÖRBER SOLUTIONS

Assunto / Subject: Master's Thesis - Final Calculation of Reactions in the Vehicle Supports and Stability Check

Design calculations

Referência / Reference	Autor / Author	Aprovado por / Approved by	Folha / Sheet
	João Fernandes		1
	Data / Date	**Data / Date**	**Folhas / Sheets**
	15/06/2018		2

Data:

$m_{vehicle\ (no\ robot)} = 278\ kg$

$m_{robot} = 22\ kg$

$m_{load} = 100\ kg$ (50 kg / box)

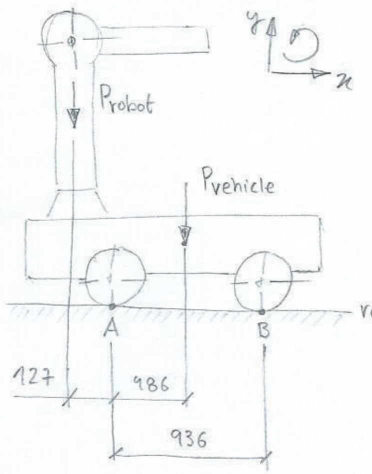
$a_{travelling} = 1,25\ m/s^2$

$g = 9,81\ m/s^2$

Assumptions:

i) Consider the same assumptions and equations considered in the document "Preliminary Calculation of Reactions in the Vehicle Supports and Stability Check", adjusting the dimensions according to the shuttle vehicle diagrams.

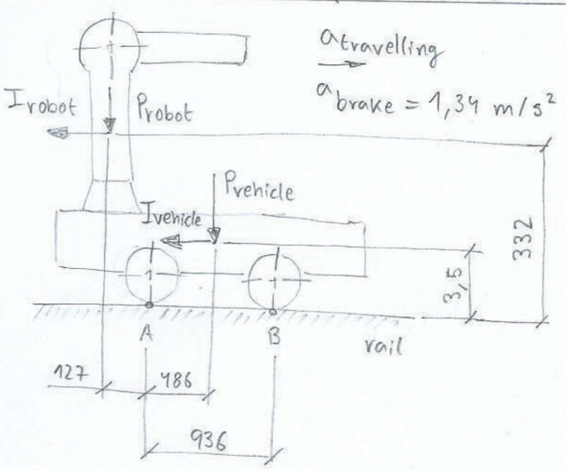
Calculation of the Static Reactions (Vehicle Unloaded):



$$\begin{cases} \Sigma F_y = 0 \\ \Sigma M_A = 0 \end{cases} \Rightarrow \begin{cases} R_{A,stat} = 1556\ N > 0 \quad ok! \\ R_{B,stat} = 1387\ N > 0 \quad ok! \end{cases}$$

$\Sigma M_{stabilising} = 1\ 298\ 232\ N \cdot mm$

Calculation of the Dynamic Reactions (Vehicle Unloaded):



→ Travelling Acceleration:

$$\begin{cases} \Sigma F_y = 0 \\ \Sigma M_A = 0 \end{cases} \Rightarrow \begin{cases} R_{A,dyn} = 1567\ N > 0 \quad ok! \\ R_{B,dyn} = 1376\ N > 0 \quad ok! \end{cases}$$

$\Sigma M_{overturning} = 10\ 346\ N \cdot mm$

→ Brake Acceleration:

$$\begin{cases} \Sigma F_y = 0 \\ \Sigma M_A = 0 \end{cases} \Rightarrow \begin{cases} R_{A,dyn} = 1568\ N > 0 \quad ok! \\ R_{B,dyn} = 1375\ N > 0 \quad ok! \end{cases}$$

$\Sigma M_{overturning} = 11\ 091\ N \cdot mm$

CONSOVEYO KÖRBER SOLUTIONS	Assunto / Subject: Master's Thesis - Final Calculation of Reactions in the Vehicle Supports and Stability Check				
Design calculations					
Referência / Reference	Autor / Author: João Fernandes	Aprovado por / Approved by	Folha / Sheet: 2		
	Data / Date: 15/06/2018	Data / Date	Folhas / Sheets: 2		

Calculation of the Static Reactions (Vehicle Loaded):

$$\begin{cases} \sum F_y = 0 \\ \sum M_A = 0 \end{cases} \Rightarrow \begin{cases} R_{A,stat} = 2028 \text{ N} > 0 \quad \text{ok!} \\ R_{B,stat} = 1896 \text{ N} > 0 \quad \text{ok!} \end{cases}$$

$\sum M_{stabilising} = 1\,779\,656 \text{ N·mm}$

Calculation of the Dynamic Reactions (Vehicle Loaded):

→ Travelling Acceleration:

$$\begin{cases} \sum F_y = 0 \\ \sum M_A = 0 \end{cases} \Rightarrow \begin{cases} R_{A,dyn} = 2039 \text{ N} > 0 \quad \text{ok!} \\ R_{B,dyn} = 1885 \text{ N} > 0 \quad \text{ok!} \end{cases}$$

$\sum M_{overturning} = 10\,784 \text{ N·mm}$

Stability Check:

→ Vehicle Unloaded (travelling acceleration):

$\nu = 125,5 > 1,5$ ok!

→ Vehicle Unloaded (brake acceleration):

$\nu = 117 > 1,5$ ok!

→ Vehicle Loaded (travelling acceleration):

$\nu = 164,6 > 1,5$ ok!

Customer	
Project	**Travelling System** **Final Calculation of the Travelling Gearmotor**
Person in charge	
File	*SEW WORKBENCH-CÁLCULO MOTOREDUTOR DE TRANSLAÇÃO-0000.SEWPRO*
Date	*2018-11-06*

Important: The data you have provided us with serves as a basis for our evaluation or selection. The correctness and completeness of this data is assumed for the intended use of the drive. Please confirm that the data is correct, including the assumptions we have made. In particular, contact SEW if there are deviating ambient conditions.

The choosen drive unit contain descriptions and standard properties and standard options, which can be changed later.

Standard catalog data

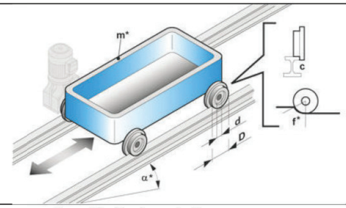
*) = Values will be defined later.

Catalog designation		**R27DRN90S4BE2/TF**			
Rated motor speed	[1/min]	1455	Output speed	[1/min]	291
Gear ratio		5	Service factor fb		2,6
Output torque	[Nm]	36			
Mounting position		M1	Terminal box position	[°]	*
Output shaft	[mm]	25x50	Permitted output overhung load (ne=1500 1/rpm and rated gear torque)	[N]	1770
Flange	[mm]	-			
Rated motor power	[kW]	1,1	Cyclic duration factor		S1-100%
Motor frequency	[Hz]	50	Design specification		IEC/EUROPA
Motor voltage (Connect motor in delta)	[V]	230/400	Wiring diagram		R13
Rated motor current	[A]	2.55	cos phi		0,73
Thermal class		*	Enclosure		*
Brake voltage	[V]	*	choosen Braking torque (reduced)	[Nm]	5
Brake control		*			
Weight (gear unit without oil)	[kg]	26,6			

Input data

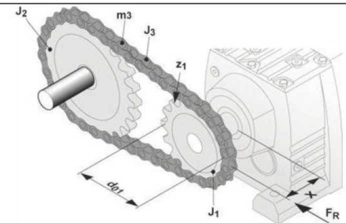
Movement - Transmission : Horizontal/inclined - carrying wheel

Constant data		
Values for rolling friction		
- Carrying wheel diameter (D)	[mm]	125
- Bearing diam. (ca. 1/5 carrying wheel diam.) (d)	[mm]	25
- Wheel flange coefficient (c)		0,002
- Bearing coefficient		0,005
Number of drives and ambient conditions		
- Number of drives		1
- Ambient conditions: 0-40°C, <1000m above sea level		
Determine static power by		
- Rolling friction		



The values marked with * are entered in the travel diagram.

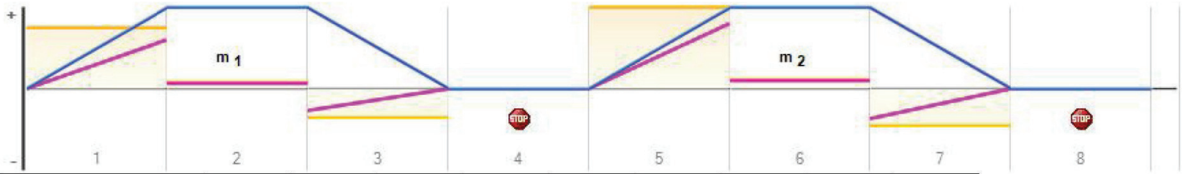
Additional gear		
Gear ratio and efficiency		
- Additional gear ratio		1
- Load efficiency	[%]	90
Mass moments of inertia		
- Mass mom. of inertia of wheel/disc 1 (J1)	[kgm²]	0,000223207
- Mass mom. of inertia of wheel/disc 2 (J2)	[kgm²]	0,000223207
- Weight of chain/belt (m3)	[kg]	0,72
- Pitch diameter on the drive end (d01)	[mm]	69,11
Forces		
- Pitch diameter (determine overhung load) (d01)	[mm]	69,11
- Additional radial force (FR) pro Antrieb	[N]	0
- Transm. elem. factor for overh.load		1,25
- Number of teeth on drive end (z1)		14-19



- dimension x of the radial force (x)	[mm]	25,5
- Radial force acting on center of shaft end		

Drive data		
Motor data		
- DR.. - Asynchronous AC motor		
- DR../FG - Integral motor (or as stand-alone motor)		
- System voltage	[V]	400
- Min./Max. moment of inertia fac.		1 / 50
- With forced cooling fan		No
- Number of poles		4
- Base frequency / max. frequ.	[Hz]	87 / 87
- Efficiency class: IE3 = Premium efficiency		
- With encoder		No
Gear unit data		
- R - Helical gear unit		
- R, RX - Foot-mounted		
- Mounting position		M1
- Adapter		No

- Frequency and design specification :Europe / other countries (IEC 50Hz)		
- Max. start-up torque	[%]	150
- Mechanical brake: Standard brake		
- Manual motor selection		No
- Connection type: Delta connection (230/400V)		
- Power utilization : Power times the square root of 3		
- With Z fan		No
- With high-speed excitation, ts = 0, Cut-off in the AC and DC circuits		
- Safety factor torque		1
- Selected max. speed	[1/min]	3000
- Manual gear unit selection		No



travel section		1	2	3	4	5	6	7	8
Travel data									
- Mass	[kg]	300	300	300	300	400	400	400	400
- Direction of Inclination		↔	↔	↔	•	↔	↔	↔	•
- Type of acceleration		L	-	L	-	L	-	L	-
- Start velocity	[m/s]	0	3	3	0	0	3	3	0
- End velocity	[m/s]	3	3	0	0	3	3	0	0
- Acceleration	[m/s²]	1.25	0	-1.25	0	1.25	0	-1.25	0
- Distance	[mm]	3600	7200	3600	0	3600	7200	3600	0
- Position	[mm]	3600	10800	14400	14400	18000	25200	28800	28800
- Accumulated time	[s]	2.4	4.8	7.2	9.6	12	14.4	16.8	19.2
Application load									
- Stat. torque (SEW output shaft)	[Nm]	3.951	3.951	3.951	0	5.268	5.268	5.268	0
- Stat. + dyn. torque (SEW output shaft)	[Nm]	32.91	3.951	-15.06	0	43.88	5.268	-20.07	0
- Stat. overhung load + fz (SEW output shaft)	[N]	142.9	142.9	142.9	0	190.6	190.6	190.6	0
- Stat. + dyn. overhung load + fz (SEW output	[N]	1191	142.9	544.7	0	1587	190.6	726	0
Motor load + motor speeds									
- Stat. torque on SEW motor (thermal)	[Nm]	0.8147	0.8147	0.8147	0	1.086	1.086	1.086	0
- Stat. + dyn. torque on SEW motor (thermal)	[Nm]	7.366	0.8147	-3.501	0	9.626	1.086	-4.473	0
- Stat. torque on SEW motor (mechanical)	[Nm]	0.8147	0.8147	0.8147	0	1.086	1.086	1.086	0
- Stat. + dyn. torque on SEW motor (mechanical)	[Nm]	6.792	0.8147	-2.927	0	9.052	1.086	-3.899	0
- Inertia ratio ext./int.		8.189	8.189	8.189	8.189	10.91	10.91	10.91	10.91
- Max.motor speed	[1/min]	2292	2292	2292	0	2292	2292	2292	0
- Braking work	[J]	-	-	-	0	-	-	-	0
- Brake load	[%]	-	-	-	0	-	-	-	0
- Stopping accuracy	[mm]	-	-	-	0	-	-	-	0

Konstantdaten Fahrdiagramm

- Direction		+
- Time	[s]	2.4
- Lever arm of rolling friction	[mm]	0.9
- Inclination	[°]	0
- Load efficiency	[%]	90

- Additional torque	[Nm]	0
- Addition friction force	[N]	0
- Additional force	[N]	0
- Additional moment of inertia	[kgm²]	0

Emergency stop results for max. emergency stop braking torque in travel section:6

Braking distance	[mm]	3420
Braking time	[s]	2,272
Braking work	[J]	1355
Brake load	[%]	13,93
Stopping accuracy	[mm]	410,4
motor speed during brake application	[1/min]	2290
Number of braking operations until readjustment		132808

Acceleration	[m/s²]	-1,326
Max. torque from braking (SEW output shaft)	[Nm]	-22,61
Max. overhung load (SEW output shaft)	[N]	817,7
Max. axial force (SEW output shaft)	[N]	0

The brake application time t2l for cut-off in the AC circuit as specified in the brake’s technical data only applies for a separate power supply.

Result data / 1 x R27DRN90S4BE2/TF, i=5

Customer machine / gear unit

Result data with reference to gear unit output (only customer end without dynamic portion of the motor Jmot + Jgear)		
Max. acceleration	[m/s²]	1,25
Max. decelaration	[m/s²]	-1,25
Mean velocity	[m/s]	1,5
Max velocity	[m/s]	3
Max. torque during motor operation	[Nm]	43,88
Max. regenerative torque	[Nm]	-20,07
cubic torque	[Nm]	25,46
Max. static application torque	[Nm]	5,268
Max. overhung load (+ fz)	[N]	1587
cubic overhung load (+ fz)	[N]	921
Max. axial load (+ fz)	[N]	0
Gear unit load at max. application torque (in relation to the max. permitted output torque))	**[%]**	**46,2**
Gear unit load at max. application overhung load (based on max. permitted output overhung load = 1712,0 N; x = 25,5mm)	**[%]**	**92,7**

Motor

Result data with reference to motor shaft (with dynamic portion of the motor Jmot + Jgear)		
Max. acceleration	[°/s²]	10364
Max. decelaration	[°/s²]	-10364
Mean motor speed	[1/min]	1146
Max. motor speed	[1/min]	2292
transition speed	[1/min]	2532
Max. mechanical braking time	[s]	0
Max. torque during motor operation	[Nm]	9,626
Max. regenerative torque	[Nm]	-4,4
R.m.s. square torque (mechanical)	[Nm]	4,372
R.m.s. square torque (thermal)	[Nm]	4,745
Max. static motor torque (mechanical)	[Nm]	1,086
Max. static motor torque (thermal)	[Nm]	1,086
Travel sections with max. load		5
Motor utilization at S1 and mean speed	**[%]**	**66,03**
Max. torque based on rated motor torque	**[%]**	**134**
Max. motor current	**[A]**	**5,473**
Max. inertia ratio Jext/mot		**10,91**
Max. load inertia (without efficiency)	**[kgm²]**	**0,06262**
Max. regenerative power	**[kW]**	**-1,058**
Mean braking power (only regenerative travel sections)	**[kW]**	**-0,4717**
Regenerative cyclic duration factor	**[%]**	**25**
Regenerative energy	**[J]**	**-2264**
Torque setting range		**0**

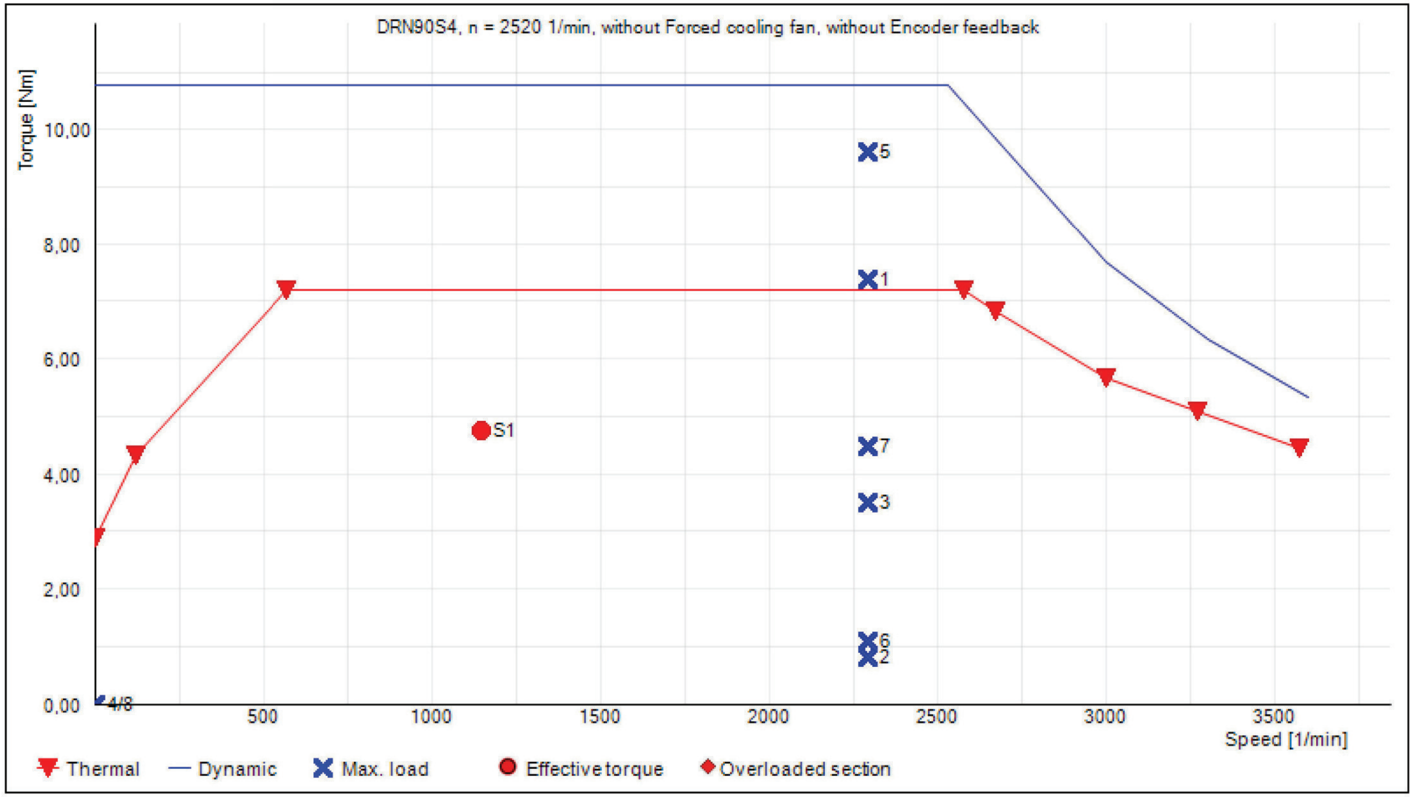
Project comments

Drive data

Gear unit		
Catalog designation	R27	
Gear ratio		5
Number of stages		2
Smallest possible pinion shaft end	[mm]	10
Largest possible pinion shaft end	[mm]	18
Mass moment of inertia (gear unit)	[kgm²]	0,000058
Permitted output overhung load	[N]	860
Torque Efficiency (ne=1400 rpm)	[Nm] / [%]	95 / 97

Motor (Delta connection, 87Hz Base frequency, Power times the square root of 3)		
Catalog designation	DRN90S4	
Motor power (Power times the square root of 3)	[kW]	1,1 (1,9)
Motor speed (87Hz Base frequency)	[1/min]	1455 (2530)
Cyclic duration factor		S1-100%
Rated torque	[Nm]	7,2
Rated voltage	[V]	230/400
Rated current (Power times the square root of 3)	[A]	2,55 (4,4)
Starting torque	[%]	270
mean start-up torque	[%]	210
Mass moment of inertia of the motor	[kgm²]	0,005268
Pinion shaft end/shaft end	[mm]	12
Brake type:		BE2B
Maximum braking torque	[Nm]	20
choosen Braking torque	[Nm]	5
Brake reaction time	[s]	0,017
Mass moment of inertia of the brake	[kgm²]	0,00047
Braking work until inspection/maintenance	[J]	180000000

Diagrams



DRN90S4, n = 2520 1/min, without Forced cooling fan, without Encoder feedback
Torque [Nm]
10,00
8,00
6,00
4,00
2,00
0,00
500
1000
1500
2000
2500
3000
3500
Speed [1/min]
5
1
7
3
6
2
4/8
S1
Thermal
Dynamic
Max. load
Effective torque
Overloaded section

CONSOVEYO KÖRBER SOLUTIONS	Assunto *Subject*	Master's Thesis - Final Calculation of the Guiding Wheels and the Travelling Wheels			
Design calculations					
Referência *Reference*	Autor *Author*	João Fernandes	Aprovado por *Approved by*	Folha *Sheet*	1
	Data *Date*	16/06/2018	Data *Date*	Folhas *Sheets*	2

Data:

$m_{vehicle} = 300$ kg

$m_{load} = 100$ kg (50 kg/box)

$v_{travelling} = 3{,}0$ m/s $= 10{,}8$ km/h

μ_{stat} (PU/steel) $= 0{,}55$

$g = 9{,}81$ m/s^2

→ Catálogo Brauer:

C_1 (continuous running) $= 0{,}75$

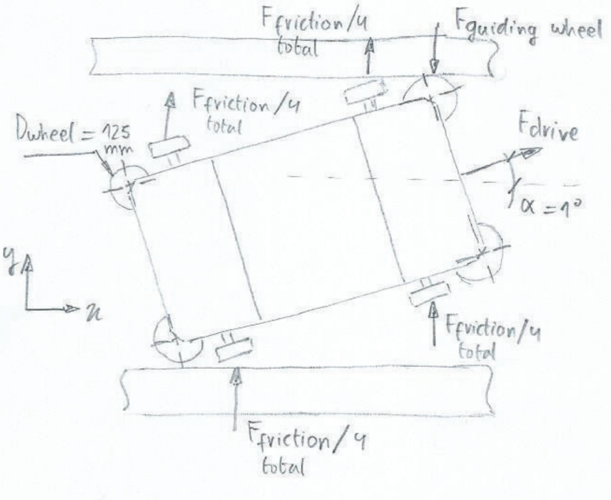
C_2 (surface speed 10-16 km/h) $= 0{,}7$

C_3 (driving wheels) $= 0{,}7$

→ Document "Final Calculation of the Travelling Gearmotor" → $M^{máx}_{stat+dyn} = 44{,}2$ N.m

Calculation of the Guiding Wheels (Vehicle Loaded):

i) Consider the same assumptions and equations considered in the document "Preliminary Calculation of the Guiding Wheels and the Travelling Wheels".



$F_{drive} = M^{max}_{stat+dyn} / \left(\frac{D_{wheel}}{2}\right) \Leftrightarrow$

$\Leftrightarrow F_{drive} = 43{,}9 / \frac{0{,}125}{2} \Leftrightarrow F_{drive} = 707$ N

$\Sigma F_y = 0 \Rightarrow F_{guiding\ wheel} = 1091$ N

→ Guiding Wheel Selection:

Brauer → Polyurethane H75/35 → $P_{max} = 300$ kgf $= 2943$ N

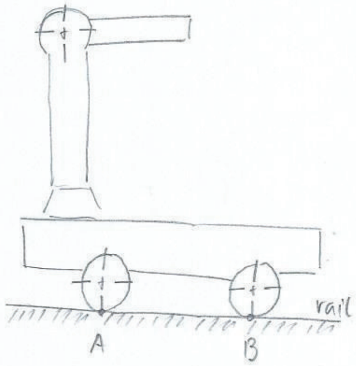
$P_{max\ corr} = 1545$ N

$CS = 1{,}4 > 1$ OK!

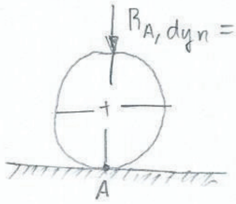
CONSOVEYO KÖRBER SOLUTIONS	Assunto / *Subject*: Master's Thesis – Final Calculation of the Guiding Wheels and the Travelling Wheels		
Design calculations			
Referência / *Reference*	Autor / *Author*: João Fernandes	Aprovado por / *Approved by*	Folha / *Sheet*: 2
	Data / *Date*: 16/06/2018	Data / *Date*	Folhas / *Sheets*: 2

Calculation of the Travelling Wheels (Vehicle Loaded):

i) Consider the same assumptions and equations considered in the document "Preliminary Calculation of the Guiding Wheels and the Travelling Wheels".



Maximum Dynamic Reactions ⇒ Wheels A



(2x wheels) ⇒ $F_{trav.\ wheels} = \frac{R_{A,dyn}}{2} = \frac{2039}{2} = 1019{,}5N$

→ Travelling Wheel Selection:

Brauer → Polyurethane H125/40 → $P_{max} = 530$ kgf $= 5199$ N

$P_{max} = 1911$ N

$CS = 1{,}87 > 1$ ok!

Shaft design and calculation | Shaft calculation | Clear table of results

i Check lines:7.4;

ii **Project information**

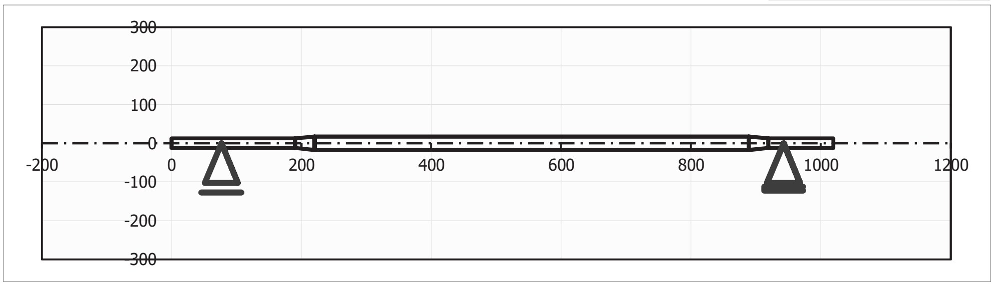
Author ☐	**Date** ☐	**Project No.** ☑
João Fernandes	2018-06-08	111-111
File name		
MITCalc-Cálculo Veio Motriz-0001.xlsb		
Project Name ☐		
Travelling System - Calculation of the Driving Shaft		
Basic Info ☐		
Project Notes ☑		
Comments		

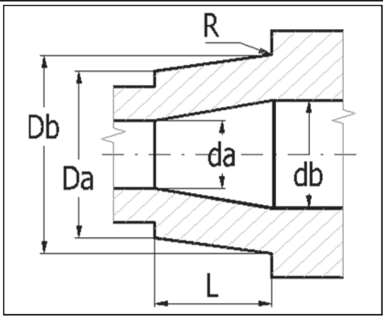
? **Input sectinon**

1.0 Preliminary shaft diameter design

2.0 Shaft shape and dimensions

2.1 The scale of the displayed shaft diameter. ☑ Calculation units: SI Units (N, mm, kW...)





2.2

Table	1	2	3	4	5	6	7	8	9	10
Origin	0,00	190,00	220,00	889,00	919,00	1019,00	1019,00	1019,00	1019,00	1019,00
L	190,000	30,000	669,000	30,000	100,000					
ø Da	25,000	25,000	35,000	35,000	25,000					
ø Db	25,000	35,000	35,000	25,000	25,000					
ø da										
ø db										
R										

2.3 Total length of the shaft: 1019,00 [mm]

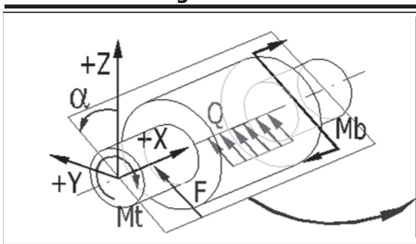
2.4 X-coordinate of the left support (bearing): Free 76,50 ○ [mm]

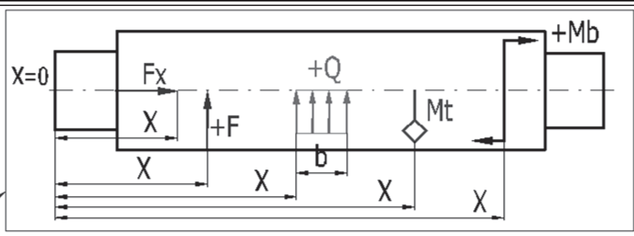
2.5 X-coordinate of the right support (bearing): Fixed 942,50 ◉ [mm]

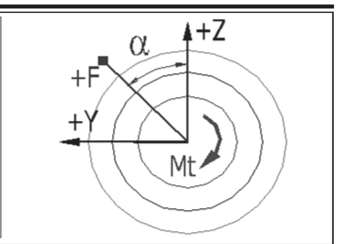
2.6 The shaft surface (Roughness Ra): E...Rough machined (3,2)

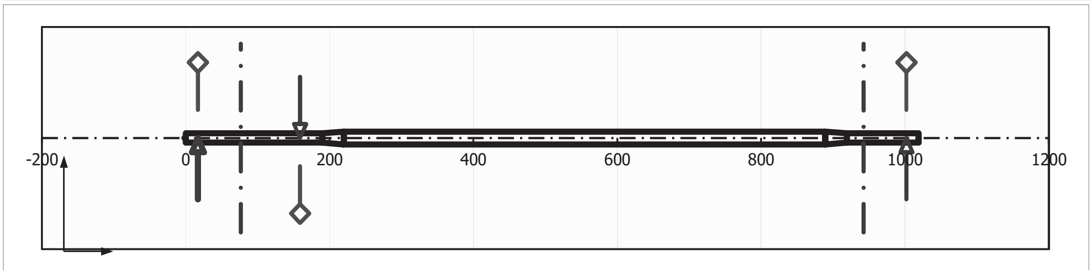
3.0 Notches and necking-down on the shaft

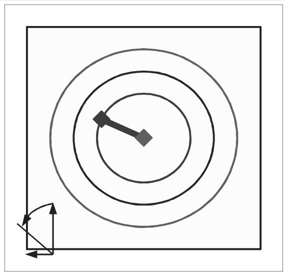
4.0 Loading of the shaft











4.1 Loading

	X	Fx	F	alfa	Mt	Mb	alfa	Q	b	alfa
	[mm]	[N]		[°]	[Nm]		[°]	[N/mm]	[mm]	[°]
1	17,00		1019,5		-21,94					
2	159,00		-1270,0	65	43,88					
3	1002,00		1019,5		-21,94					

4										
5										
6										
7										
8										
9										
10										

5.0 Rotating masses

6.0 Material and the type of loading

6.1	Shaft material (Ultimate tensile strength min-max)			
	A...Structural steel (350 - 700)		595	[MPa]
6.2	Ultimate tensile strength	Su/Rm	590	[MPa] ☐
6.3	Yield strength in tension	S_Y/Re	310	[MPa]
6.4	Yield strength in bending	S_{Yb}/Re_b	449	[MPa]
6.5	Yield strength in shear	S_{Ys}/Re_s	242	[MPa]
6.6	**For reversed loading**			
6.7	Fatigue limit - tension-press	σ_C	226	[MPa]
6.8	Fatigue limit - bending	σ_{eC}	292	[MPa]
6.9	Fatigue limit - torsion	τ_C	208	[MPa]
6.10	**For cyclic loading**			
6.11	Fatigue limit - tension-press	σ_{hC}	339	[MPa]
6.12	Fatigue limit - bending	σ_{ehC}	437	[MPa]
6.13	Fatigue limit - torsion	τ_{hC}	239	[MPa]
6.14	Specific mass	Ro	7850,0	[kg/m^3]
6.15	Modulus of elasticity in tensi	E	210000	[MPa]
6.16	Modulus of elasticity in shea	G	80000	[MPa]

6.17	Dead load		Yes
6.18	Max. displayed coefficient of safety		20
6.19	Stress ratio factor	α_0	1,15 ☑
6.20	**Coefficient of maximum loading**		
6.21	Bending		1,00
6.22	Radial load		1,00
6.23	Torsion		1,00
6.24	Tension/Compression		1,00
6.25	**Loading conditions**		
6.26	Loading from bending moment		B...Repeated
6.27	Loading from radial force		B...Repeated
6.28	Load from torsional moment		C...Reversed
6.29	Loading from tension/pressure force		A...Static
6.30	**Dynamic strength check**		
6.31	Impact from shaft surface		Yes
6.32	Impact from shaft size		Yes
6.33	Impact from stress concentration (notc		Yes

? **Results section**

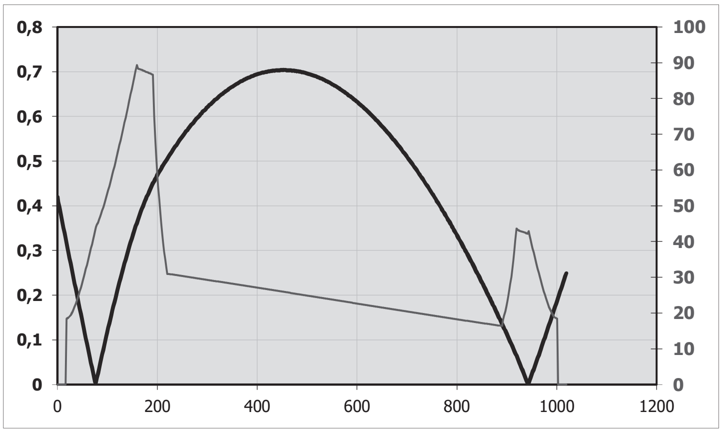
7.0 Results - summary

			x	y	z	Σ y+z	
7.1	Reaction in the support R1		0	1041,35916	-503,27196	1156,59481	[N]
7.2	Reaction in the support R2		0	109,65173	-935,09882	941,505876	[N]
7.3	Total shaft weight	m		6,51	[kg]		
7.4	Maximum deflection	y		**0,7037**	[mm]		
7.5	Maximum torsional deflectio	φ		0,0722	[°]		
7.6	Angular deflection in R1	ϑ		0,2974	[°]		
7.7	Angular deflection in R2	ϑ		0,1690	[°]		
7.8	Max. bending stress	σ_e		87,3	[MPa]		
7.9	Max. stress in shear	τ_s		2,4	[MPa]		
7.10	Max. stress in torsion	τ_t		7,2	[MPa]		
7.11	Max. stress in tension/press	σ_g		0,0	[MPa]		
7.12	Max. equivalent stress	σ_r		89,3	[MPa]		
7.13	Min. static safety	SF_{St}		5,04			
7.14	Min. dynamic safety	SF_D		7,22			
7.15	Critical speed (A)	n_c		0,0	[/min]		
	Critical speed (B)	n_c		5114,5	[/min]		
	Critical speed (C)	n_c		4555,7	[/min]		

7.17 Graph

16...Deflection - Sum [mm]

30...Equivalent stress [MPa]



Shaft freely rotating in bearings, overhung rotating disc (K=0,9)

7.16 **Results for X co-ordinate**	0,00	17,00	76,50	159,00	509,00	942,50	1002,00	1019,00
16...Deflection - Sum [mm]	0,41945009	0,32833079	0,005679	0,36102441	0,69354225	0,00278473	0,18729326	0,24888871
27...Torsion angle [°]	0	0	-0,0242165	-0,0584536	-0,0088106	0,04794235	0,07215886	0,07215886
30...Equivalent stress [MPa]	0	0,004636	42,8793094	89,3275664	24,7150984	42,2003817	18,3999338	0
41...Safety coefficient (static)	20	20	10,5904	5,03713666	18,2098301	10,7174199	20	20
42...Safety coefficient (dynamic)	20	20	13,0980941	7,22091285	20	13,4596082	19,7058258	20

medias

Bearing analysis

Calculation / Installation proposal

Date: 2018-11-08 13:27:14

Attention

Please see list of warnings at the end of print out.

Table of contents

1 Input

Bearing:

Designation	RAY25-XL	
Inside diameter	d	25.000 mm
Outside diameter	D	52.000 mm
Width	B	15.000 mm
Basic dynamic load rating	C	14900 N
Basic static load rating	C0	7800 N
Fatigue limit load	Cu	395 N
Load carrying capacity of housing, radial	C_0r_G	3650.00 N
Limiting speed	n_lim	8000.0 1/min
Limiting speed, grease	n_lim_g	16700.0 1/min

Basic frequency factors related to 60/min:

Overrolling frequency factor on outer ring	BPFFO	3.5746
Overrolling frequency factor on inner ring	BPFFI	5.4254
Overrolling frequency factor on rolling element	BSFF	2.3285

Ring pass frequency factor on rolling element	RPFFB	4.6570
Speed factor of rolling element set for rotating inner ring	FTFF_i	0.3972
Speed factor of rolling element set for rotating outer ring	FTFF_o	0.6028

Lubrication data:

Permitted lubricants	Only grease	
Type of lubrication	grease	
Type of grease	user defined	
ISO VG class	ISO VG 220	
Contamination	normal cleanliness	
External heat flow	dQ/dt	0.0 kW

Other conditions:

Ambient temperature	t	20 °C
Requisite reliability	90 %	
Condition of rotation	rotating inner ring	
Clearance group	CN	

Load Loadcase 1:

Time portion	q	100.000 %
Speed	n_i	458.40 1/min
Type of movement	rotating	
Radial load	Fr	1157.0 N
Axial load	Fa	0.0 N
Mean operating temperature	T	70 °C

2 Results

Overrolling frequencies Loadcase 1:

Overrolling frequency on outer ring	BPFO	27.3098 1/s
Overrolling frequency on inner ring	BPFI	41.4502 1/s
Overrolling frequency on rolling element	BSF	17.7899 1/s
Ring pass frequency on rolling element	RPFB	35.5798 1/s
Speed of rolling element set	FTF	3.0344 1/s

Load factors and equivalent loads Loadcase 1:

Equivalent static load	P0	1157.00 N
Equivalent dynamic load	P_i	1157.00 N

Lubrication Loadcase 1:

Operating viscosity	ny	51.6 mm²/s
Reference viscosity	ny1	44.8 mm²/s
Viscosity ratio	kappa	1.15
Life adjustment factor	a_ISO	7.21

Bearing behavior RAY25-XL:

Static load safety factor	S0_min	6.742
Minimum load safety factor of housing, radial	Sg_r_min	3.2
Minimum load safety factor of housing, axial	Sg_a_min	> 100.0

Total rating life in hours (nominal)	Lh10	77651 h
Modified rating life in hours	Lh_nm	559631 h
Maximum equivalent static load	P0_max	1157.00 N
Equivalent speed	n	458.4 1/min
Equivalent dynamic load	P	1157.00 N

3 Warnings

Do not overspecify the bearing - A rating life (to ISO 281) greater than 60000 hours usually leads to overspecified bearing arrangements.

The relubrication interval cannot be calculated for the grease used.

---

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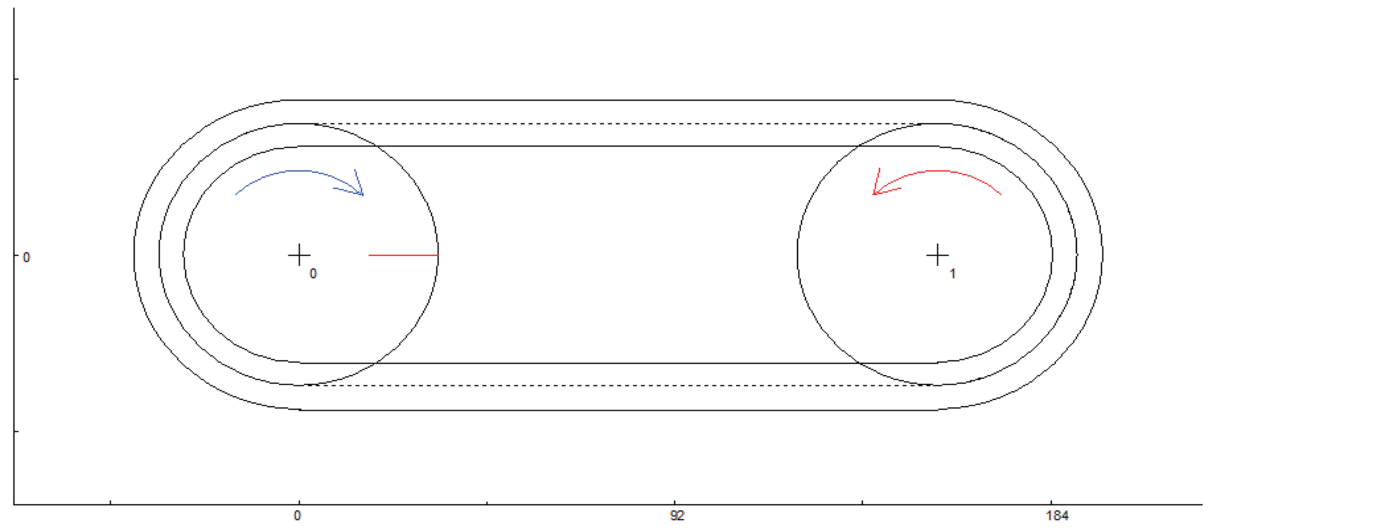
2018-11-08 13:27:14 (11.0)

iwis Chain Engineering
08.11.2018

Company:	ISEP	Phone:	228340500
Name:	Fernandes	eMail:	
Adress:	Rua Dr. A. Bernardino de Almeida, 431	Project:	Iwis-Cálculo Corrente 08B-2-0001.iw
City:	4200-072 Porto	Editor:	João Fernandes

Chain Drive Figure:



Chain Drive Data:

No.	Teeth	X [mm]	Y [mm]	RwC [mm]	Pos.	Torque [Nm]	Force [N]	In-, Outgoing Angle [°]	
0	17	0.00	0.00	40.7	i	0.0	0.0	270.0	90.0
1	17	157.00	0.00	40.7	i	43.9	0.0	90.0	270.0

Chain		D 85 ML
Standard		8187
Pitch	[mm]	12.700
Height of Plate	[mm]	12.2

Total Length	[mm]	529.9
Number of Links		41.7
Even Number of Links		42

Load Assumption:

Pulling Force	[N]	1269.8
Force from Tensioner	[N]	0.0
Centrifugal Force	[N]	3.7
Total Chain Force under Load	[N]	1273.4

Revolutions of Driving Sprocket	[rpm]	458.4
Chain Velocity	[m/s]	1.65
Total Elastic Strain of Chain	[mm]	0.19

External Factors:

Shock Faktor	2.00	Lubrication Factor	1.00

iwis Chain Engineering
08.11.2018

Results:

Pressure on Bearing Area		
calculated	[N/cm²]	1273.43
allowed	[N/cm²]	1720.23

Drive Capacity		
calculated	[W]	2100.5
corrected	[W]	5167.6

Static Fracture Surety
S stat (> 7)
31.4

Dynamic Fracture Surety
S dyn (> 5)
15.7

Expected Durability*
Working Hours
> 20 000

* refer to 3.0% relative Chain Elongation

The selected chain satisfies the requirements of expected durability of 15000 h

Questions:

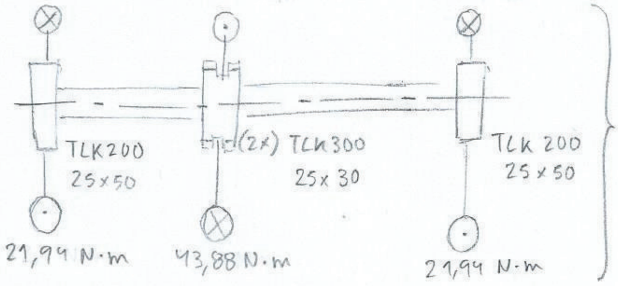
iwis-Responsible:	
Phone:	
eMail:	

CONSOVEYO KÖRBER SOLUTIONS	Assunto / Subject: Master's Thesis – Travelling System – Calculation of the Locking Assemblies Tollok		
Design calculations			
Referência / Reference	Autor / Author: João Fernandes	Aprovado por / Approved by	Folha / Sheet: 1
	Data / Date: 21/01/2018	Data / Date	Folhas / Sheets: 2

Data:

Document "Final Calculation of the Travelling Gearmotor" $\Rightarrow M^{máx}_{stat+dyn} = 44,2$ N.m

(2x) Driving Wheels $\Rightarrow M_{t/wheel} = \frac{M^{máx}_{stat+dyn}}{2} = \frac{43,88}{2} = 21,94$ N.m

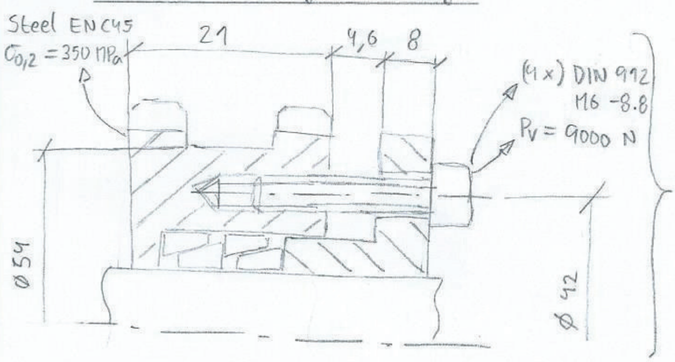


Driving Wheels Assembly

Calculation of the Locking Assembly for the Driving Sprocket:

$\Rightarrow$ Selected Locking Assembly: (2x) TLK 300 $\underbrace{25 \times 30}_{d \times D}$ $\Rightarrow P_t = 10000$ N; $L_1 = 10,6$ mm (5,3 mm/locking assembly)

$P_a \leq 36000$ N; $p_n = 95$ MPa



Assembly Type II; C = 0,8

(Tollok Catalog – Page 38)

$P_a = N^o \text{ of bolts} \cdot P_v \Leftrightarrow P_a = 4 \cdot 9000 \Leftrightarrow P_a = 36000 \text{ N} \leq 36000 \text{ N}$ ok!

$M_t \text{ transmissible} = \frac{P_a - P_t}{0,54} \cdot 0,12 \cdot \frac{d}{2000} \Leftrightarrow M_t \text{ transmissible} = \frac{36000 - 10000}{0,54} \cdot 0,12 \cdot \frac{25}{2000} \Leftrightarrow$

$\Leftrightarrow M_t \text{ transmissible} = 72 \text{ N.m} \Rightarrow (2x) \text{ TLK 300} \Rightarrow M_t = M_t \text{ transmissible} \cdot 1,55 \Leftrightarrow$

$\Leftrightarrow M_t = 72 \cdot 1,55 \Leftrightarrow M_t = 112 \text{ N.m} > 43,88 \text{ N.m}$ ok!

$S_f \geq d_g \cdot 1,3 \Leftrightarrow S_f \geq 6 \cdot 1,3 \Leftrightarrow S_f \geq 7,8 \text{ mm} < 8 \text{ mm}$ ok!

$l \geq D + 12 + d_g \Leftrightarrow l \geq 30 + 12 + 6 \Leftrightarrow l \geq 48 \text{ mm} = \varnothing 42 \text{ mm}$ nok!

(2x) TLK 300 $\Rightarrow w \geq 3,5$ mm $< 4,6$ mm ok

$C = 0,8$; $\sigma_{0,2} = 350$ MPa; $p_n = 95$ MPa $\Rightarrow K = 1,25$ (Tollok Catalog – Page 39)

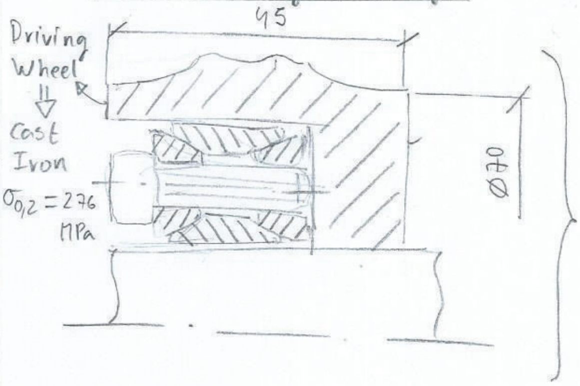
$D_M \geq D \cdot K \Leftrightarrow D_M \geq 30 \cdot 1,25 \Leftrightarrow D_M \geq 37,5 \text{ mm} < \varnothing 54 \text{ mm}$ ok!

CONSOVEYO KÖRBER SOLUTIONS	Assunto / Subject: Master's Thesis – Travelling System – Calculation of the Locking Assemblies Tollok		
Design calculations			
Referência / Reference	Autor / Author: João Fernandes	Aprovado por / Approved by	Folha / Sheet: 2
	Data / Date: 21/01/2018	Data / Date	Folhas / Sheets: 2

$B \geqslant 2 \cdot L_1 \Leftrightarrow B \geqslant 2 \cdot 10{,}6 \Leftrightarrow B \geqslant 21{,}2 \text{ mm} \simeq 21 \text{ mm}$ ok!

Calculation of the Locking Assembly for the Driving Wheels:

→ Selected Locking Assembly: TLK 200 $\underbrace{25 \times 50}_{d \times D}$ → $M_t = 400$ N·m ; $L_1 = 17$ mm ; $p_n = 100$ MPa



Assembly Type II ; $C = 0{,}8$

(Tollok Catalog – Page 38)

$M_t = 400 \text{ N·m} > 21{,}94 \text{ N·m}$ ok!

$C = 0{,}8$; $\sigma_{0,2} \simeq 270$ MPa ; $p_n = 100 \Rightarrow K = 1{,}36$ (Tollok Catalog – Page 39)

$D_M \geqslant D \cdot K \Leftrightarrow D_M \geqslant 50 \cdot 1{,}36 \Leftrightarrow D_M \geqslant 68 \text{ mm} < 70 \text{ mm}$ ok!

$B \geqslant 2 \cdot L_1 \Leftrightarrow B \geqslant 2 \cdot 17 \Leftrightarrow B \geqslant 34 \text{ mm} < 45 \text{ mm}$ ok!

Calculation of pinned couplings

i **Calculation without errors.**

ii ☑ **Project information**

Author	Date	Project No.
João Fernandes	2018-06-09	111-111

File name
MITCalc-Cálculo Pino Roda de Guiagem-0000.xlsb

Project Name
Travelling System - Calculation of the Guiding Wheel Axle

Basic Info

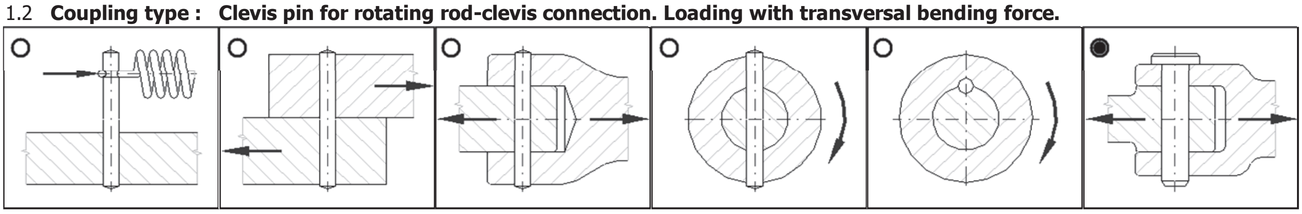
Project Notes
Comments

Input section

1.0 ☑ Loading and basic parameters of the coupling

1.1 Calculation units: SI Units (N, mm, kW...)

1.2 **Coupling type : Clevis pin for rotating rod-clevis connection. Loading with transversal bending force.**

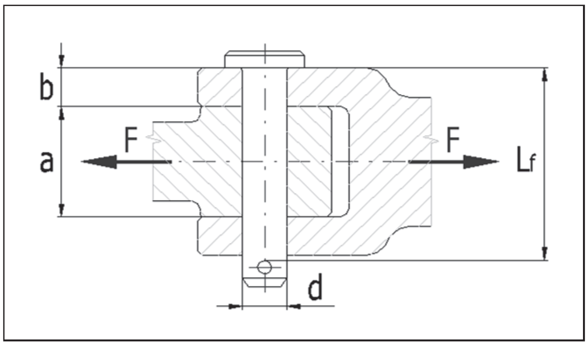


1.3	**Connection loading**				1.13	**Clevis materiál (min. tensile strength)**				
1.4	Transferred power	P	7,46	[kW]	1.14	B...Structural steel (500)				
1.5	Shaft speed	n	1500,0	[/min]	1.15	Ultimate tensile strength	S_{Umin}	435,0	[MPa]	
1.6	Torque	T	47,49	[Nm]	1.16	Permissible pressure (fixed fit)	p_A	125,0	[MPa]	
1.7	Acting force	F	1091,0	[N]	1.17	Permiss. pressure (running fit)	p_A	30,0	[MPa]	
1.8	**Operational and mounting parameters of the coupling**				1.18	**Rod material (min. tensile strength)**				
1.9	Type of loading		Repeated Load		1.19	F...High-grade and alloy steel (700)				
1.10	Type of pin		Full pin		1.20	Ultimate tensile strength	S_{Umin}	700,0	[MPa]	
1.11	Type of fit		Running fit		1.21	Permissible pressure (fixed fit)	p_A	200,0	[MPa]	
1.12	Desired safety	s_f	2,50		1.22	Permiss. pressure (running fit)	p_A	35,0	[MPa]	

2.0 ☑ Design of coupling dimensions

2.1	**Pin selection, coupling parameters**				2.9	**Pin material (min. tensile strength)**			
2.2	ISO 2341 A - Clevis pins with head				2.10	D...Structural steel (700)			
2.3	Allowable range of pin diameters		3 ~ 100		2.11	Ultimate tensile strength	S_{Umin}	1220,0	[MPa]
2.4	Number of pins in connection		1		2.12	Permissible pressure (fixed fit)	p_A	1080,0	[MPa]
2.5	**Reduction factors**		☑		2.13	Permiss. pressure (running fit)	p_A	360,0	[MPa]
2.6	Load distribution factor	K_L	1,00		2.14	Permissible shear stress	τ_A	610,0	[MPa]
2.7	Service factor (pressure)	K_{Sp}	1,25		2.15	Permissible bending stress	σ_A	594,0	[MPa]
2.8	Service factor (bending, shearing)	K_{Sb}	1,43						

2.16	**Coupling dimensions**			
2.17	Rod width	a	35,0000	[mm]
2.18	Clevis width	b	5,0000	[mm]
2.19	Recommended pin diameter		20,6 ~ 23,3	[mm]
2.20	Searching for a suitable pin		< Search >	
2.21	Pin diameter	d	12,0000 (12)	[mm]
2.22	Allowable range of pin lengths		24 ~ 120	[mm]
2.23	Pin length	L	50,0000 (50)	[mm]
2.24	Min. functional length of pin	L_{fmin}	45	[mm]
2.25	Functional length of pin	L_f	47,0000	[mm]

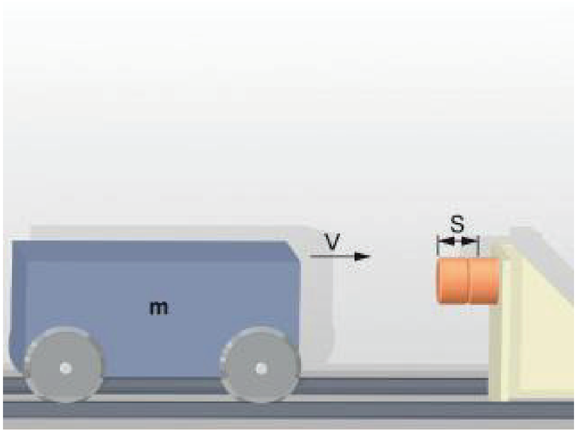


3.0 ☑ Strength checks of the coupling

3.1	**Pin check for shearing**				3.9	**Check of contact pressure : Pin - Clevis**			
3.2	Permissible shear stress	τ_A	610,0	[MPa]	3.10	Permissible pressure	p_A	30,0	[MPa]
3.3	Comparative stress	τ	6,9	[MPa]	3.11	Comparative pressure	p	11,4	[MPa]
3.4	Safety		88,44		3.12	Safety		2,64	
3.5	**Pin check for bending**				3.13	**Check of contact pressure : Pin - Rod**			
3.6	Permissible bending stress	σ_A	594,0	[MPa]	3.14	Permissible pressure	p_A	35,0	[MPa]
3.7	Comparative stress	σ	51,7	[MPa]	3.15	Comparative pressure	p	3,2	[MPa]
3.8	Safety		11,48		3.16	Safety		10,78	

B. Mass without force, horizontal

Weforma



Customer data

Mass	m:	400	kg
Impact speed	v:	3	m/s
Strokes per hour	X:	1	1/h
Number of parallel buffers	n:	2	
Stroke	S:	Auto	mm

Selection

Model	WCB-080-120-6-B	
Article number	CB080120-6B	
Rate of utilization/stroke	45.9	%
Stroke	96.0	mm
Kinetic energy per stroke	900.00	Nm
Propelling energy p. stroke:	0.00	Nm
Total energy per stroke	900.00	Nm
Total energy per hour	900.00	Nm
Effective mass	200.00	kg
Counterforce	Click	N
Impact speed	3.00	m/s

Technical data per buffer at + 20° C

Warranty claims for calculated and selected products are only accepted after written confirmation of the selection.

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Customer	
Project	**Extraction System** **Calculation of the Servo Gearmotor**
Person in charge	
File	*SEW - CÁLCULO MOTOREDUTOR DE TRANSLAÇÃO.SEWPRO*
Date	*2018-05-16*

SEW Workbench

v2.22.550.1

Applikationsreport

Project planning - controlled drives

Important: The data you have provided us with serves as a basis for our evaluation or selection. The correctness and completeness of this data is assumed for the intended use of the drive. Please confirm that the data is correct, including the assumptions we have made. In particular, contact SEW if there are deviating ambient conditions.

The choosen drive unit contain descriptions and standard properties and standard options, which can be changed later.

Standard catalog data

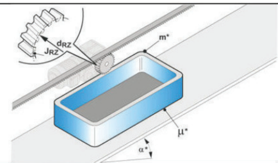
*) = Values will be defined later.

Catalog designation		**RF07CMP40M/BK/KY/(Encoder)/(Connector)**			
Rated motor speed	[1/min]	3000	Output speed	[1/min]	129
Gear ratio		23,32			
Output torque	[Nm]	18			
Service factor fb		2,7			
Mounting position		M1	Terminal box position	[°]	*
Output shaft	[mm]	20x40	Permitted output overhung load	[N]	900
Flange	[mm]	*			
Continuous static torque	[Nm]	0,8	Cyclic duration factor		S1-100%
System voltage	[V]	400	Wiring diagram		DT11
Continuous static current	[A]	0,95	Max. permitted current	[A]	6
Thermal class		F	Enclosure		IP65
Brake voltage	[V]	*	choosen Braking torque	[Nm]	1.9
Brake control		*			
Weight (gear unit without oil)	[kg]	4,63			

Input data

Movement - Transmission : Horizontal/inclined - gear wheel, gear rack

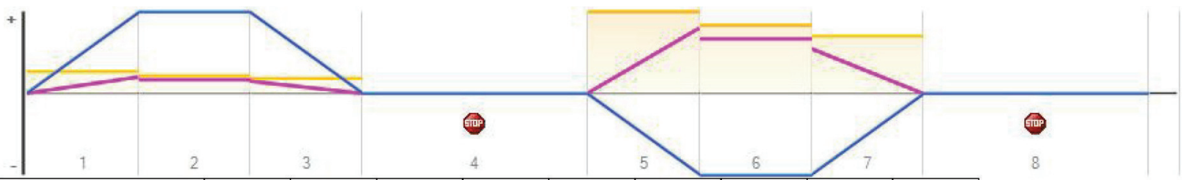
Constant data		
Transmission values for gear drives		
- Pitch diameter driving wheel (dRZ)	[mm]	76
- Mass mom. of inertia of the driv. wheel (JZK1)	[kgm²]	0,000144369
Number of drives and ambient conditions		
- Number of drives		1
- Ambient conditions: 0-40°C, <1000m above sea level		
Determine static power by		
- Sliding friction (values are entered in the 'travel diagram' window)		



The values marked with * are entered in the travel diagram.

Drive data		
Motor data		
- CMP - Synchronous servomotor		
- CMP - Flange-mounted		
- Max. start-up torque	[%]	300
- Rated speed	[1/min]	3000
- With forced cooling fan		No
- With encoder		Yes
Gear unit data		
- R - Helical gear unit		
- RF, RXF - Flange-mounted		
- Mounting position		M1
- Adapter		No

- System voltage	[V]	400
- Min./Max. moment of inertia fac.		5 / 15
- Mechanical brake: Standard brake		
- Manual motor selection		No
- With high-speed excitation, ts = 0, Cut-off in the AC and DC circuits		
- Safety factor torque		1
- Selected max. speed	[1/min]	-
- Manual gear unit selection		No



travel section		1	2	3	4	5	6	7	8
Travel data									
- Mass	[kg]	17.5	17.5	17.5	17.5	67.5	67.5	67.5	67.5
- Direction		+	+	+	+	-	-	-	-
- Direction of Inclination		↔	↔	↔	•	↔	↔	↔	•
- Type of acceleration		L	-	L	-	L	-	L	-
- Start velocity	[m/s]	0	0.45	0.45	0	0	-0.45	-0.45	0
- End velocity	[m/s]	0.45	0.45	0	0	-0.45	-0.45	0	0
- Acceleration	[m/s²]	0.9	0	-0.9	0	0.9	0	-0.9	0
- Time	[s]	0.5	0.5	0.5	1	0.5	0.5	0.5	1
- Distance	[mm]	112.5	225	112.5	0	-112.5	-225	-112.5	0
- Position	[mm]	112.5	337.5	450	450	337.5	112.5	0	0
- Accumulated time	[s]	0.5	1	1.5	2.5	3	3.5	4	5
Application load									
- Stat. torque (SEW output shaft)	[Nm]	3.262	3.262	3.262	0	12.58	12.58	12.58	0
- Stat. + dyn. torque (SEW output shaft)	[Nm]	3.93	3.262	2.72	0	15.15	12.58	10.5	0
Motor load + motor speeds									
- Stat. torque on SEW motor (thermal)		0.1504	0.1504	0.1504	0	0.5801	0.5801	0.5801	0
- Stat. + dyn. torque on SEW motor (thermal)		0.2022	0.1504	0.1044	0	0.7195	0.5801	0.4632	0
- Stat. torque on SEW motor (mechanical)		0.1504	0.1504	0.1504	0	0.5801	0.5801	0.5801	0
- Stat. + dyn. torque on SEW motor (mechanical)		0.189	0.1504	0.1177	0	0.7063	0.5801	0.4764	0
- Inertia ratio ext./int.		2.531	2.531	2.531	2.531	8.063	8.063	8.063	8.063
- Max.motor speed	[1/min]	2637	2637	2637	0	2637	2637	2637	0
- Braking work	[J]	-	-	-	0	-	-	-	0
- Brake load	[%]	-	-	-	0	-	-	-	0
- Stopping accuracy	[mm]	-	-	-	0	-	-	-	0

Konstantdaten Fahrdiagramm

- Friction factor		0.45
- Inclination	[°]	0
- Load efficiency	[%]	90
- Additional torque	[Nm]	0
- Addition friction force	[N]	0

- Stat. overhung load + fz (SEW output shaft)	[N]	0
- Stat. + dyn. overhung load + fz (SEW output shaft)	[N]	0
- Additional force	[N]	0
- Additional moment of inertia	[kgm²]	0

Emergency stop results for max. emergency stop braking torque in travel section:6

Braking distance	[mm]	12,14
Braking time	[s]	0,04206
Braking work	[J]	3,44
Brake load	[%]	6,142
Stopping accuracy	[mm]	1,456
motor speed during brake application	[1/min]	2128
Number of permitted emergency stops per hour		326
Number of total permitted emergency stops		32561

Acceleration	[m/s²]	-33,77
Max. torque from braking (SEW output shaft)	[Nm]	-65,51
Max. overhung load (SEW output shaft)	[N]	0
Max. axial force (SEW output shaft)	[N]	0

The brake application time t2l for cut-off in the AC circuit as specified in the brake's technical data only applies for a separate power supply.

Emergency stop results for selected travel section:6

Braking distance	[mm]	12,14
Braking time	[s]	0,04206
Braking work	[J]	3,44
Brake load	[%]	6,142
Stopping accuracy	[mm]	1,456
motor speed during brake application	[1/min]	2128
Number of permitted emergency stops per hour		326
Number of total permitted emergency stops		32561

Acceleration	[m/s²]	-33,77
Max. torque from braking (SEW output shaft)	[Nm]	-65,51
Max. overhung load (SEW output shaft)	[N]	0
Max. axial force (SEW output shaft)	[N]	0

The brake application time t2l for cut-off in the AC circuit as specified in the brake's technical data only applies for a separate power supply.

Result data / 1 x RF07CMP40M/BK/KY/../.., i=23,32

Customer machine / gear unit

Result data with reference to gear unit output (only customer end without dynamic portion of the motor Jmot + Jgear)			
Max. acceleration	a	[m/s²]	0,9
Max. decelaration	-a	[m/s²]	-0,9
Mean velocity	vmittel	[m/s]	0,18
Max velocity	vmax	[m/s]	0,45
Max. torque during motor operation	Mmax	[Nm]	15,15
Max. regenerative torque	-Mmax	[Nm]	0
Max. static application torque	Mstat_max	[Nm]	12,58
Medium output speed	nam	[1/min]	45,23
Effective torque	Maeff	[Nm]	12,3
cubic torque	Makub	[Nm]	10,31
Speed ratio	fk		0,6808
Thermic torque	Math	[Nm]	8,301
Max. overhung load (+ fz)	FRmax	[N]	0
cubic overhung load (+ fz)	FRkub	[N]	0
Max. axial load (+ fz)	FAmax	[N]	0
Gear unit load at max. application torque (Mmax to Mapk)		**[%]**	**29,7**
Gear unit load at effective application torque (Maeff to Mamax)		**[%]**	**24,59**
Gear unit load at cubic application torque (Macubic to Mamax/fK)		**[%]**	**14,04**
Gear unit load at max. application overhung load (based on max. permitted output overhung load = 0,0 N; x = L/2)		**[%]**	**0**
Gear unit load at cubic application overhung load (FRcubic to FRamax)		**[%]**	**0**

For preloaded drives (toothed belts, flat belts, narrow belts, and pinion / gear rack), the cubic overhung load (FRcub) equals the maximum overhung load (FRmax).

Motor

Result data with reference to motor shaft (with dynamic portion of the motor Jmot + Jgear)		
Max. acceleration	[°/s²]	31644
Max. decelaration	[°/s²]	-31644
Mean motor speed	[1/min]	1055
Mean thermic motor speed	[1/min]	1288
Max. motor speed	[1/min]	2637
Max. mechanical braking time	[s]	0
Max. torque during motor operation	[Nm]	0,7195
Max. regenerative torque	[Nm]	0
R.m.s. square torque (mechanical)	[Nm]	0,3388
R.m.s. square torque (thermal)	[Nm]	0,34
Max. static motor torque (mechanical)	[Nm]	0,5801
Max. static motor torque (thermal)	[Nm]	0,5801
Travel sections with max. load		5
Motor utilization at S1 and mean speed	**[%]**	**42,5**
Max. torque based on rated motor torque	**[%]**	**89,9**
Max. motor current	**[A]**	**0,8378**
Max. inertia ratio Jext/mot		**8,063**
Max. load inertia (without efficiency)	**[kgm²]**	**0,0001935**
Max. regenerative power	**[kW]**	**0**
Mean braking power (only regenerative travel sections)	**[kW]**	**0**
Regenerative cyclic duration factor	**[%]**	**0**
Regenerative energy	**[J]**	**0**

Project comments

Drive data

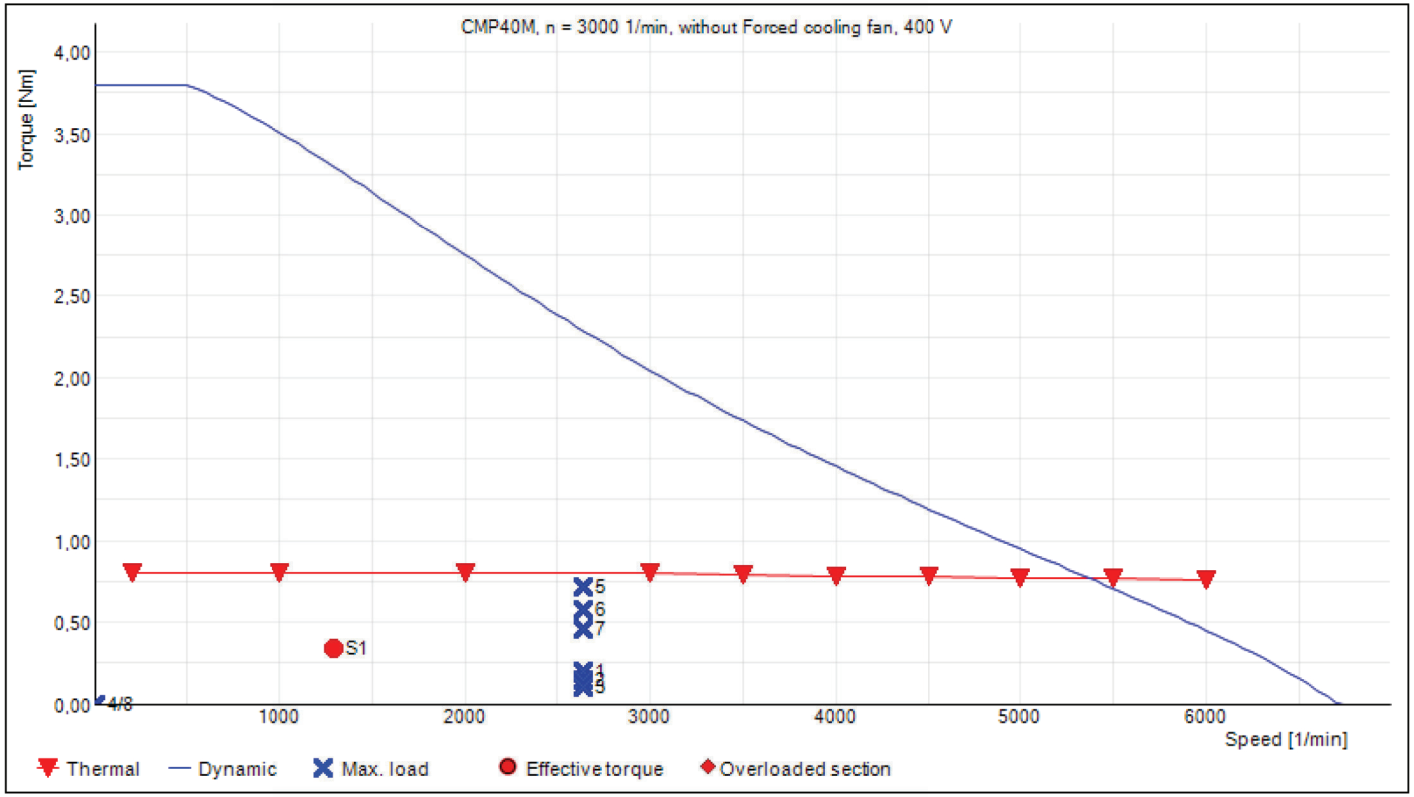
Gear unit

Catalog designation	RF07	
Gear ratio		23,32
Number of stages		3
Smallest possible pinion shaft end	[mm]	10
Largest possible pinion shaft end	[mm]	12
Mass moment of inertia (gear unit)	[kgm²]	0,000014
Permitted output overhung load	[N]	980
Peak torque (ne=1400 1/rpm)	[Nm]	51
emergency stop torque (ne=1400 1/rpm)	[Nm]	85
Permitted overh. load at peak torque	[Nm]	1223
Perm. overh. load at emergency stop torque	[N]	1669,4
Torque Efficiency (ne=1400 rpm)	[Nm] / [%]	50 / 93

Motor

Catalog designation	CMP40M	
Speed	[1/min]	3000
Rated torque	[Nm]	0,8
Cyclic duration factor		S1-100%
System voltage	[V]	400
Rated current	[A]	0,95
Max. current	[A]	6
Mass moment of inertia of the motor	[kgm²]	0,000015
Pinion shaft end/shaft end	[mm]	10
Permitted maximum speed	[1/min]	3000
Brake type:		BK01
M4 120°	[Nm]	1,9
M1m	[Nm]	1,4
M1max	[Nm]	3,4
Brake application time	[s]	0,02
Brake reaction time	[s]	0,035
Mass moment of inertia of the brake	[kgm²]	0,000009
Ciclos de conmutación del freno admisibles		>10000000
Permitted braking work per brake application	[J]	56
Braking work until inspection/maintenance	[J]	112000

Diagrams


CMP40M, n = 3000 1/min, without Forced cooling fan, 400 V
Torque [Nm]
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
1000
2000
3000
4000
5000
6000
Speed [1/min]
S1
5
6
7
4/8
Thermal
Dynamic
Max. load
Effective torque
Overloaded section

Shaft design and calculation | **Shaft calculation** | **Clear table of results**

i Check lines:7.5;

ii Project information

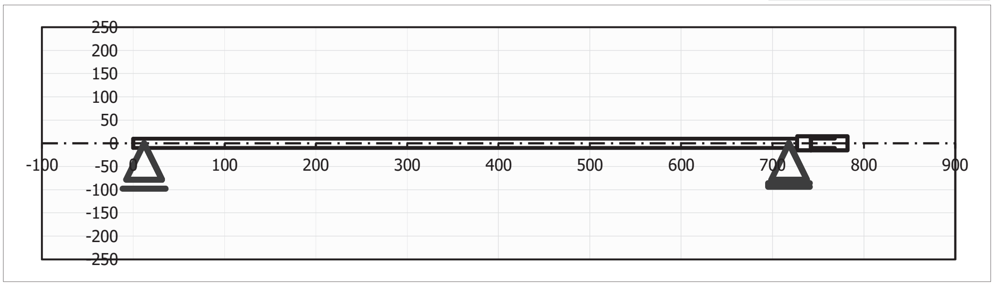
Author ☐	**Date** ☐	**Project No.** ☑
João Fernandes	2018-06-09	111-111
File name		
MITCalc-Cálculo Veio Motriz-0001.xlsb		
Project Name ☐		
Extraction System - Calculation of the Driving Shaft		
Basic Info ☐		
Project Notes ☑		
Comments		

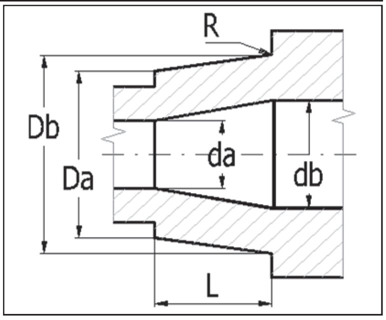
? **Input sectinon**

1.0 Preliminary shaft diameter design

2.0 Shaft shape and dimensions

2.1 The scale of the displayed shaft diameter. ☑ Calculation units: SI Units (N, mm, kW...)





2.2 Table

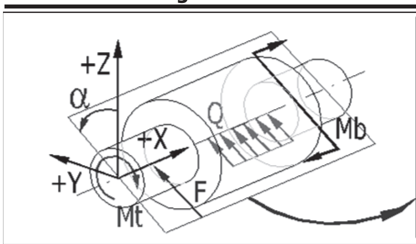
	1	2	3	4	5	6	7	8	9	10
Origin	0,00	727,00	742,00	782,00	782,00	782,00	782,00	782,00	782,00	782,00
L	727,000	15,000	40,000							
ø Da	20,000	30,000	30,000							
ø Db	20,000	30,000	30,000							
ø da			20,000							
ø db			20,000							
R										

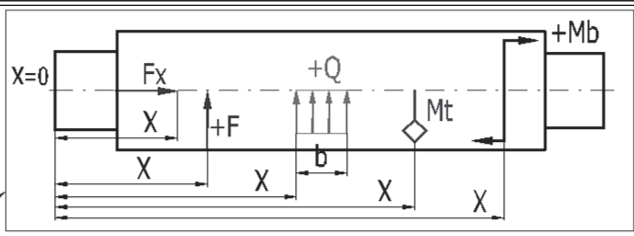
2.3	Total length of the shaft		782,00	[mm]
2.4	X-coordinate of the left support (bearing)	Free	12,00 ○	[mm]
2.5	X-coordinate of the right support (bearing)	Fixed	718,00 ◉	[mm]

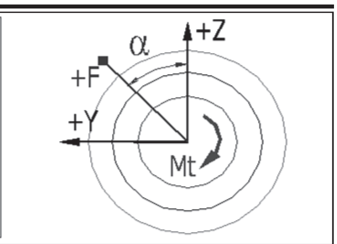
2.6 The shaft surface (Roughness Ra): E...Rough machined (3,2)

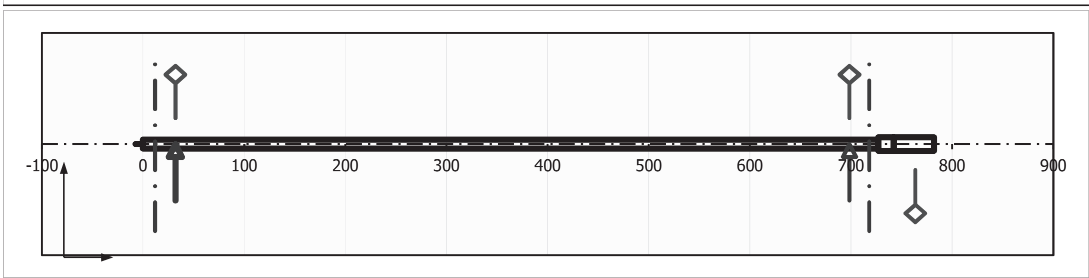
3.0 Notches and necking-down on the shaft

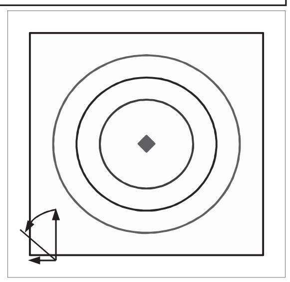
4.0 Loading of the shaft











4.1 Loading

	X	Fx	F	alfa	Mt	Mb	alfa	Q	b	alfa
	[mm]	[N]		[°]	[Nm]		[°]	[N/mm]	[mm]	[°]
1	32,00		200,0		-7,60					
2	698,50		200,0		-7,60					
3	763,50				15,20					

4										
5										
6										
7										
8										
9										
10										

5.0 Rotating masses

6.0 Material and the type of loading

6.1	Shaft material (Ultimate tensile strength min-max)				6.17	Dead load	Yes
	A...Structural steel (350 - 700)		595	[MPa]	6.18	Max. displayed coefficient of safety	50
6.2	Ultimate tensile strength	Su/Rm	590	[MPa] ☐	6.19	Stress ratio factor α_0	1,15 ☑
6.3	Yield strength in tension	S_Y/Re	307	[MPa]	6.20	**Coefficient of maximum loading**	
6.4	Yield strength in bending	S_{Yb}/Re_b	400	[MPa]	6.21	Bending	1,00
6.5	Yield strength in shear	S_{Ys}/Re_s	215	[MPa]	6.22	Radial load	1,00
6.6	**For reversed loading**				6.23	Torsion	1,00
6.7	Fatigue limit - tension-press	σ_C	201	[MPa]	6.24	Tension/Compression	1,00
6.8	Fatigue limit - bending	σ_{eC}	260	[MPa]	6.25	**Loading conditions**	
6.9	Fatigue limit - torsion	τ_C	186	[MPa]	6.26	Loading from bending moment	B...Repeated
6.10	**For cyclic loading**				6.27	Loading from radial force	B...Repeated
6.11	Fatigue limit - tension-press	σ_{hC}	302	[MPa]	6.28	Load from torsional moment	C...Reversed
6.12	Fatigue limit - bending	σ_{ehC}	390	[MPa]	6.29	Loading from tension/pressure force	A...Static
6.13	Fatigue limit - torsion	τ_{hC}	213	[MPa]	6.30	**Dynamic strength check**	
6.14	Specific mass	Ro	7850,0	[kg/m^3]	6.31	Impact from shaft surface	Yes
6.15	Modulus of elasticity in tensi	E	210000	[MPa]	6.32	Impact from shaft size	Yes
6.16	Modulus of elasticity in shea	G	80000	[MPa]	6.33	Impact from stress concentration (notc	Yes

? **Results section**

7.0 Results - summary

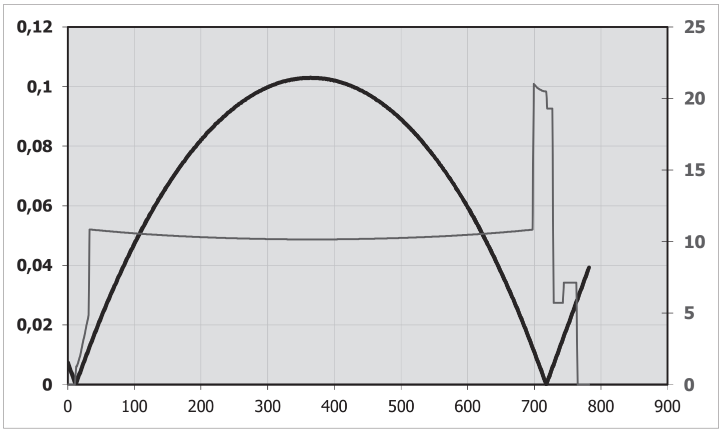
		x	y	z	Σ y+z	
7.1	Reaction in the support R1	0	0	-191,10524	191,105241	[N]
7.2	Reaction in the support R2	0	0	-189,22859	189,228589	[N]

7.17 Graph

16...Deflection - Sum [mm]

30...Equivalent stress [MPa]

7.3	Total shaft weight	m	2,00	[kg]
7.4	Maximum deflection	y	0,1030	[mm]
7.5	Maximum torsional deflectio	φ	**0,2571**	[°]
7.6	Angular deflection in R1	ϑ	0,0353	[°]
7.7	Angular deflection in R2	ϑ	0,0351	[°]
7.8	Max. bending stress	σ_e	4,9	[MPa]
7.9	Max. stress in shear	τ_s	0,6	[MPa]
7.10	Max. stress in torsion	τ_t	-9,7	[MPa]
7.11	Max. stress in tension/press	σ_g	0,0	[MPa]
7.12	Max. equivalent stress	σ_r	21,0	[MPa]
7.13	Min. static safety	SF_{St}	20,31	
7.14	Min. dynamic safety	SF_D	7,07	
7.15	Critical speed (A)	n_c	0,0	[/min]
	Critical speed (B)	n_c	5022,2	[/min]
	Critical speed (C)	n_c	4406,4	[/min]



Shaft freely rotating in bearings, rotating disc between the bearings (K=1)

7.16 **Results for X co-ordinate**	12,00	32,00	698,50	718,00	763,50			
16...Deflection - Sum [mm]	0,00064837	0,01172665	0,01237324	7,5939E-05	0,02771563	0,00739587	0,00739587	0,00739587
27...Torsion angle [°]	0	0	-0,2308728	-0,2449636	-0,2570766	0	0	0
30...Equivalent stress [MPa]	0,00285209	4,8617911	10,8297138	20,488902	7,11960236	0	0	0
41...Safety coefficient (static)	50	50	38,995925	20,9189837	50	50	50	50
42...Safety coefficient (dynamic)	50	50	30,8609735	15,4834007	43,0847318	50	50	50

medias

Bearing analysis

Calculation / Installation proposal

Date: 2018-11-09 22:22:16

Attention

Please see list of warnings at the end of print out.

Table of contents

1 Input

Bearing:

Designation	2204-2RS-TVH	
Inside diameter	d	20.000 mm
Outside diameter	D	47.000 mm
Width	B	18.000 mm
Basic dynamic load rating	C	10100 N
Basic static load rating	C0	2600 N
Fatigue limit load	Cu	161 N
Limiting speed	n_lim	9400.0 1/min
Limiting speed, grease	n_lim_g	15400.0 1/min

Basic frequency factors related to 60/min:

Overrolling frequency factor on outer ring	BPFFO	4.8666
Overrolling frequency factor on inner ring	BPFFI	7.1334
Overrolling frequency factor on rolling element	BSFF	2.5090
Ring pass frequency factor on rolling element	RPFFB	5.0180

Speed factor of rolling element set for rotating inner ring	FTFF_i	0.4056
Speed factor of rolling element set for rotating outer ring	FTFF_o	0.5944

Lubrication data:

Permitted lubricants	Only grease	
Type of lubrication	grease	
Type of grease	user defined	
ISO VG class	ISO VG 460	
Contamination	normal cleanliness	
External heat flow	dQ/dt	0.0 kW

Other conditions:

Ambient temperature	t	20 °C
Requisite reliability	90 %	
Condition of rotation	rotating inner ring	

Load Loadcase 1:

Time portion	q	100.000 %
Speed	n_i	500.00 1/min
Type of movement	rotating	
Radial load	Fr	191.0 N
Axial load	Fa	0.0 N
Mean operating temperature	T	70 °C

2 Results

Overrolling frequencies Loadcase 1:

Overrolling frequency on outer ring	BPFO	40.5553 1/s
Overrolling frequency on inner ring	BPFI	59.4447 1/s
Overrolling frequency on rolling element	BSF	20.9081 1/s
Ring pass frequency on rolling element	RPFB	41.8163 1/s
Speed of rolling element set	FTF	3.3796 1/s

Load factors and equivalent loads Loadcase 1:

Equivalent static load	P0	191.00 N
Equivalent dynamic load	P_i	191.00 N

Lubrication Loadcase 1:

Operating viscosity	ny	92.5 mm²/s
Reference viscosity	ny1	44.7 mm²/s
Viscosity ratio	kappa	2.07
Life adjustment factor	a_ISO	50.00

Bearing behavior 2204-2RS-TVH:

Static load safety factor	S0_min	13.613
Total rating life in hours (nominal)	Lh10	> 1000000 h
Modified rating life in hours	Lh_nm	> 1000000 h
Maximum equivalent static load	P0_max	191.00 N
Equivalent speed	n	500.0 1/min

Equivalent dynamic load	P	191.00 N

3 Warnings

Do not overspecify the bearing - A rating life (to ISO 281) greater than 60000 hours usually leads to overspecified bearing arrangements.

The relubrication interval cannot be calculated for the grease used.

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2018-11-09 22:22:16 (11.0)

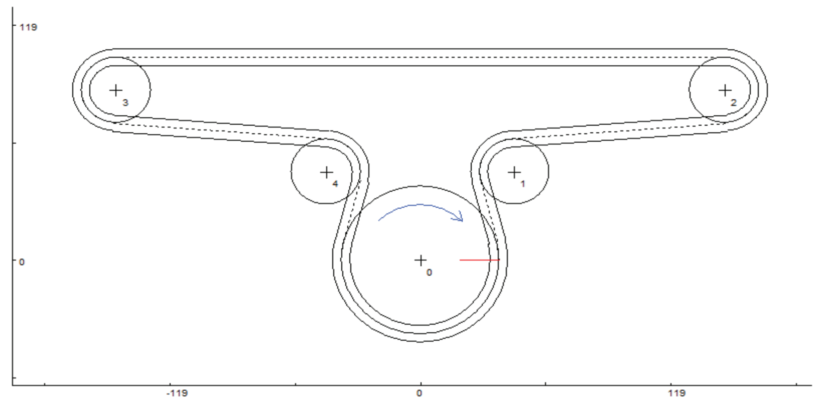
iwis Chain Engineering

10.11.2018

Company:	
Name:	
Adress:	
City:	

Phone:	
eMail:	
Project:	Extraction System-Calculation of the Driving Chain
Editor:	João Fernandes

Chain Drive Figure:



Chain Drive Data:

No.	Teeth	X [mm]	Y [mm]	RwC [mm]	Pos.	Torque [Nm]	Force [N]	In-, Outgoing Angle [°]	
0	25	0.00	0.00	42.1	i	0.0	200.0	165.4	14.6
1	11	45.00	45.00	21.0	o	0.0	0.0	194.6	94.3
2	11	145.00	86.50	21.0	i	0.0	0.0	274.3	90.0
3	11	-145.00	86.50	21.0	i	0.0	0.0	90.0	265.7
4	11	-45.00	45.00	21.0	o	0.0	0.0	85.7	345.4

Chain		G 67 ML
Standard		8187
Pitch	[mm]	9.525
Height of Plate	[mm]	8.2

Total Length	[mm]	859.1
Number of Links		90.2
Even Number of Links		92

Load Assumption:

Pulling Force	[N]	200.0
Force from Tensioner	[N]	0.0
Centrifugal Force	[N]	0.1
Total Chain Force under Load	[N]	200.1

Revolutions of Driving Sprocket	[rpm]	113.1
Chain Velocity	[m/s]	0.45
Total Elastic Strain of Chain	[mm]	0.01

External Factors:

Shock Faktor	1.50

Lubrication Factor	1.00

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10.11.2018

iwis antriebssysteme
wir bewegen die welt

Results:

Pressure on Bearing Area		
calculated	[N/cm²]	714.58
allowed	[N/cm²]	1151.49

Drive Capacity		
calculated	[W]	89.8
corrected	[W]	570.1

Static Fracture Surety	Dynamic Fracture Surety	Expected Durability*
S stat (> 7)	S dyn (> 5)	Working Hours
55.0	**36.7**	**> 20 000**

* refer to 3.0% relative Chain Elongation

The expected durability refer to 3% relative chain elongation amounts to 62764 working hours.

Questions:

iwis-Responsible:	
Phone:	
eMail:	

CAUTION, IMPORTANT NOTICE!

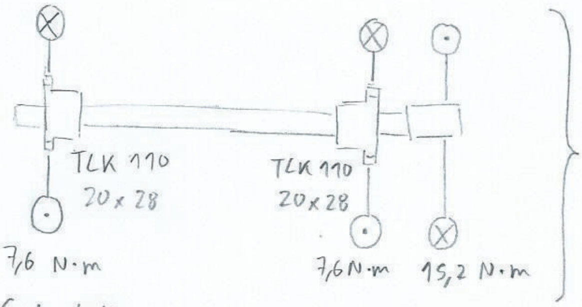
Our calculation program is only designed to give you an initial overview of our assortment. You should never use the result listed there as the basis for an order. For this, please contact our competent employees, who would be glad to make you an individual offer. We therefore assume no responsibility and make no guarantee for the correctness of the information delivered and for the orders, which are placed on the basis of the calculation program. The listed calculation result also does not represent an offer of iwis antriebssysteme GmbH & Co. KG (iwis ketten)

CONSOVEYO KÖRBER SOLUTIONS	Assunto / Subject: Master's Thesis - Extraction System - Calculation of the Locking Assembly Tollok		
Design calculations			
Referência / Reference	Autor / Author: João Fernandes	Aprovado por / Approved by	Folha / Sheet: 1
	Data / Date: 20/05/2018	Data / Date	Folhas / Sheets: 1

Data:

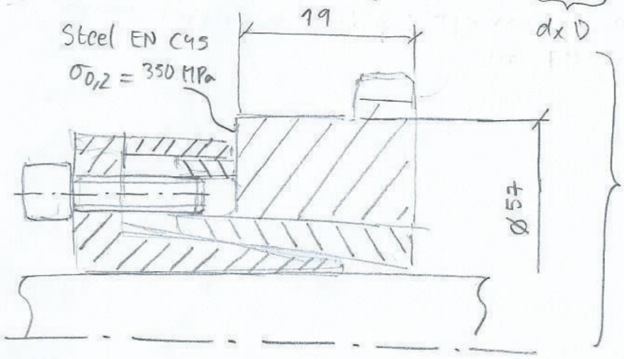
Document "Calculation of the Extraction Servo Gearmotor" $\Rightarrow M^{máx}_{stat+dyn} = 15,15 \text{ N·m}$

(2x) Driving Sprockets $\Rightarrow M_{t/sprocket} = \frac{M^{máx}_{stat+dyn}}{2} = \frac{15,15}{2} = 7,6 \text{ N·m}$



Calculation of the Locking Assembly for the Driving sprockets:

$\Rightarrow$ Selected Locking Assembly: TLK 110 20x28 ($d \times D$) $\Rightarrow M_t = 220$ N·m; $L_1 = 18$ mm; $p_n = 115$ MPa



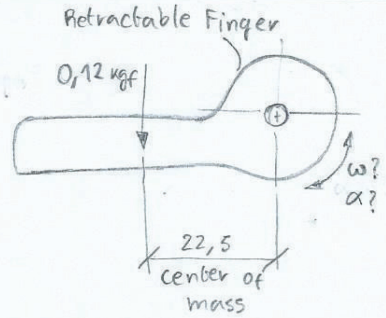
$M_t = 220 \text{ N·m} > 7,6 \text{ N·m}$ ok!

$C = 1$; $\sigma_{0,2} = 350$ MPa ; $p_n = 115$ MPa $\Rightarrow K = 1,41$ (Tollok Catalog - Page 39)

$D_n \geq D \cdot K \Leftrightarrow D_n \geq 28 \cdot 1,41 \Leftrightarrow D_n \geq 39,48 \text{ mm} < 57 \text{ mm}$ ok!

$B \geq L_1 \Leftrightarrow B \geq 18 \text{ mm} < 19 \text{ mm}$ ok!

CONSOVEYO KÖRBER SOLUTIONS	Assunto / Subject: Master's Thesis – Extraction System – Calculation of the DC Drive for the Retractable Fingers		
Design calculations			
Referência / Reference	Autor / Author: João Fernandes	Aprovado por / Approved by	Folha / Sheet: 1
	Data / Date: 21/05/2018	Data / Date	Folhas / Sheets: 2



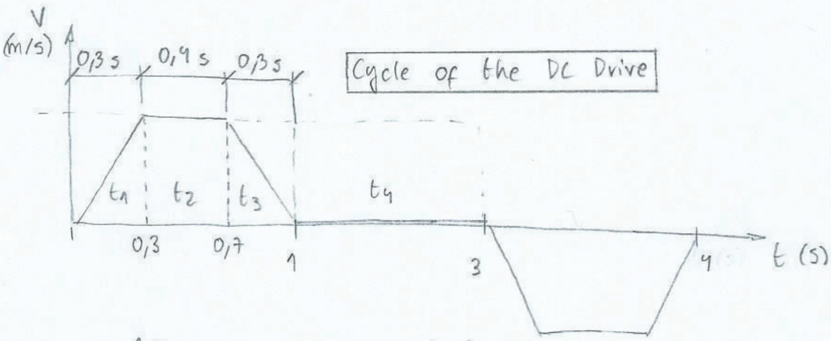
Data:

$\Delta\varphi_{total} = \frac{\pi}{2}$ rad ; $e = 22,5$ mm

$t_{\varphi_{total}} = 1$ s $(t_{accel} = t_{desac} = 0,3$ s$)$; $t_{stopped} = 2$ s

$m_{finger} = 0,12$ kg ; $\eta_L = 0,9$; $g = 9,81$ m/s^2

Kinematics and Loads on the DC Drive:



$$\omega_{max} = \frac{\Delta\varphi_2}{\Delta t_2} \Leftrightarrow \omega_{máx} = \frac{0,4 \cdot (\pi/2)}{0,4} \Leftrightarrow \omega_{máx} = 1,57 \text{ rad/s} \Rightarrow n_{máx} = \frac{30}{\pi} \cdot \omega_{máx} \Leftrightarrow$$

$$\Leftrightarrow n_{máx} = \frac{30}{\pi} \cdot 1,57 \Leftrightarrow$$

$$\Leftrightarrow n_{máx} = 15 \text{ rpm}$$

$$\alpha = \frac{\omega_{max}}{\Delta t_1} \Leftrightarrow \alpha = \frac{1,57}{0,3} \Leftrightarrow \alpha = 5,23 \text{ rad/s}^2$$

Section 1

$$a_{t_1} = \alpha \cdot e \Leftrightarrow a_{t_1} = 5,23 \cdot 22,5E-3 \Leftrightarrow a_{t_1} = 0,12 \text{ m/s}^2$$

$$M_{t_1} = M_{stat.} + M_{dyn} \Leftrightarrow M_{t_1} = m_{finger} \cdot g \cdot \frac{1}{\eta_L} \cdot e + m_{finger} \cdot a_{t_1} \cdot \frac{1}{\eta_L} \cdot e \Leftrightarrow$$

$$\Leftrightarrow M_{t_1} = 0,12 \cdot 9,81 \cdot \frac{1}{0,9} \cdot 22,5E-3 + 0,12 \cdot 0,12 \cdot \frac{1}{0,9} \cdot 22,5E-3 \Leftrightarrow M_{t_1} = 0,0299 \text{ N} \cdot \text{m}$$

Section 2

$$a_{t_2} = 0 \Rightarrow V = const$$

$$M_{t_2} = M_{stat.} \Leftrightarrow M_{t_2} = m_{finger} \cdot g \cdot \frac{1}{\eta_L} \cdot e \Leftrightarrow M_{t_2} = 0,12 \cdot 9,81 \cdot \frac{1}{0,9} \cdot 22,5E-3 \Leftrightarrow$$

$$\Leftrightarrow M_{t_2} = 0,0294 \text{ N} \cdot \text{m}$$

CONSOVEYO KÖRBER SOLUTIONS	Assunto *Subject* Master's Thesis - Extraction System - Calculation of the DC Drive for the Retractable Fingers		
Design calculations			
Referência *Reference*	Autor *Author* João Fernandes / Data *Date* 21/05/2018	Aprovado por *Approved by* / Data *Date*	Folha *Sheet* 2 / Folhas *Sheets* 2

Section 3

$a_{t_3} = a_{t_1} = 0{,}12 \ m/s^2$

$M_{t_3} = M_{stat} - M_{dyn} \Leftrightarrow M_{t_3} = 0{,}0294 - m_{finger} \cdot a_{t_3} \cdot \eta_L \cdot e \Leftrightarrow$

$\Leftrightarrow M_{t_3} = 0{,}0294 - 0{,}12 \cdot 0{,}12 \cdot 0{,}9 \cdot 22{,}5E-3 \Leftrightarrow M_{t_3} = 0{,}0291 \ N \cdot m$

i) It was considered that the portions of the static and dynamic torques are equal in the three sections - acceleration, constant speed, deceleration - for the sake of safety in the calculations. In real situation, the torque decreases along the stroke of the finger because the center of mass is approaching the axis of rotation.

$$M_{RMS} = \sqrt{\frac{M_{t_1}^2 \cdot t_1 + M_{t_2}^2 \cdot t_2 + M_{t_3}^2 \cdot t_3}{t_{ciclo}}} \Leftrightarrow M_{RMS} = \sqrt{\frac{0{,}0299^2 \cdot 0{,}3 + 0{,}0294^2 \cdot 0{,}4 + 0{,}0291^2 \cdot 0{,}3}{3}} \Leftrightarrow$$

$\Leftrightarrow M_{RMS} = 0{,}017 \ N \cdot m$

$\varnothing_{máx\ motor} = 24 \ mm$

→ Selected DC Drive : Maxon GP 22 B + A-max 22 GB