Development of new concept for a Flipper machine

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MSc dissertation

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Abstract

This project was developed at Continental Mabor, at Lousado, together with *Direção de Engenharia 3*. The objective was to develop a new concept for a machine to perform one of the steps of the tyre construction, which is the step of wrapping the flipper around the bead.

This new machine is intended to replace the machine that currently performs this operation. The existing machine is very simple, little automated, with low productivity (only can produce 2500 units per day) and presents results with not sufficiently high quality. On this machine, the bead is initially placed on a set of rollers, the operator, pushing buttons, drives a small rotating drum that makes the bead spin and perform a full turn throw plates which promote the wrapping of the flipper around the bead. At the end, the operator, manually, performs the cutting of the strip. The final objective is to elaborate a tender specification to put forward to possible suppliers for this new concept machine. The new machine must cover all the weaknesses of the current machine and incorporate a front frame part of a building machine, the winding drum. This part already has the capability to perform the main task of wrapping the flipper around the beads. The control system must be developed in compliance with the electrical standard specification of Continental (MES Continental).

At the starting point of this project it was gathered as much information as possible to help the development, such as: range of dimensions of the material to be worked on the machine, quality requirements, productivity requirements and analysis of the mechanisms and processes already existent at the company were made as well. With all data gathered, the general scheme concept for the new machine was defined. Therefore, after the initial general considerations, the process, the structure and the components of the different modules integrating the machine were also defined. The machine will be made of an initial unwinder followed by a loop to avoid stretches on the material. After, there is a conveyor where the automatic cutting system will be installed. Then, the strips go to a feeding conveyor whose main function is to feed them to the winding drum where the wrapping main task occurs.

As the mechanical parts were defined, the specification of the control system was defined in compliance with MES Continental. Basic machine equipment, software for the programming and operative system were defined. A schematic with the structure for the communication between all the electrical components was developed.

At the end, it was understood that all the objectives were reached successfully. Additionally, it was envisaged that this new machine may bring a large improvement regarding the current situation mainly in terms of product quality and productivity (this new machine has the capability to produce 10 000 units per day). Regarding costs, as the new solution allows for a significantly increase in the tyres production capability and its production and installation will cost less than 100 000€, the investment is justified.

Resumo

Este trabalho foi desenvolvido na Continental Mabor, em Lousado, em conjunto com a Direção de Engenharia 3. O objetivo foi desenvolver um novo conceito de máquina para fazer uma das etapas da construção de um pneu, que é envolver o flipper no talão.

Pretende-se que esta máquina substitua uma já existente para a mesma aplicação, mas que é muito simples, pouco automatizada, com baixa produtividade (apenas consegue produzir 2500 unidades por dia) e com resultados de insuficiente qualidade. Nesta máquina o talão é inicialmente posicionado num conjunto de rolos, o operador pressiona botoneiras que acionam os rolos e fazem o talão rodar e passar por entre duas chapas que promovem o envolvimento do flipper no talão. No final o operador corta manualmente a tira de flipper. O objetivo final é elaborar um caderno de encargos para ser entregue a um potencial fornecedor para a sua construção. A nova máquina deve colmatar todas as debilidades da atual e incorporar ainda uma parte de uma máquina de construção, o tambor de enrolamento. Este dispõe de toda a capacidade para executar a tarefa principal de envolver o flipper nos talões. O sistema de controlo deve ser desenvolvido de acordo com a especificação elétrica da Continental (MES Continental).

Para realizar este projeto começou-se por reunir o máximo de informação possível como: gama de dimensões do material que se pretende trabalhar na máquina, requisitos de qualidade, requisitos de produtividade e até mesmo análise de mecanismos e processos já existentes na fábrica. Com todos os dados reunidos, um esquema de conceito geral da máquina foi definido. Assim, após as considerações gerais iniciais, foram definidos o processo, a estrutura e os principais componentes dos módulos que integram a máquina. Esta será composta por um desbobinador inicial seguindo-se um loop para evitar esticamentos indesejáveis. De seguida existe um *conveyor* onde está instalado o sistema de corte automático. As tiras passam depois para o conveyor de alimentação que tem como função entrega-las ao tambor de enrolamento para que possam ser envolvidas nos talões.

Definida a parte mecânica encetou-se a especificação do controlo de acordo com o MES Continental. Para tal foram escolhidos e definidos os componentes principais, o software de programação, a organização da HMI e o sistema operativo. Foi desenvolvido um esquema com a estrutura da comunicação entre os diversos componentes.

No final concluiu-se que os objetivos foram alcançados com sucesso. Para além disso considera-se que com esta nova máquina deve haver uma grande melhoria em relação à situação atual em termos de qualidade do produto e de produtividade (a nova máquina tem a capacidade de produzir cerca de 10 000 unidades por dia). Relativamente a custos, visto que esta nova solução permite um aumento considerável na produção diária de pneus da fábrica e que o custo da sua produção e instalação não deve ultrapassar os 100 000€, considera-se que o investimento é justificado.

Acknowledgments

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To Eng. Alberto Pereira, my supervisor at Continental Mabor, for the permanent monitoring of the project as well. Apart from the suggestions for the improvement of the project he helped me both in terms of technical knowledge, which went beyond the theme of the project and in terms of general knowledge of the business world and personal relationships.

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List of abbreviations

AC – Alternating current;

CMIP – Continental Mabor – Indústria de pneus;

DC – Direct current;

HMI – Human machine interface;

IPC – Industrial personal computer;

IT – Information technology;

MES – Manufacturing execution system;

OPC – Open Platform Communications;

PC – Personal computer;

PLC – Programmable logic controller;

PTFE – Polytetrafluoroethylene;

SUV – Sport utility vehicle;

UPS – Uninterruptable power supply;

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1. Introduction

1.1. Framework

Continental Mabor – Indústria de Pneus, SA is one of Continental AG Group's factories whose purpose is to produce tyres. Two of the integrant components of a tyre are the bead and the flipper. The bead is a square profile ring made of steel wires wrapped in rubber. This component is the one which fixes and adjusts the tyre to the rim, being its main function sealing and preventing the tyre from sliding over the rim during braking or acceleration of a vehicle. On high performance tyres the bead is wrapped inside a rubber strip, made of textile fabric lines, to improve its resistance. This strip is called the "Flipper".

Currently, the flipper is applied in one of two ways: either on a machine designed just for that single purpose or on a tyre building machine along with the other tyre components.

So, the process sequence (that includes the bead) to build a tyre that contains a flipper is:

1st option:

1- Bead construction on the bead building machine and application of wedge on APEX (bead-wedge applicator machine. Note: the wedge itself is called "APEX" as well);
2- Tyre construction on tyre building machine (KM short designation), being the flipper applied at this phase along with the other components.

2nd option:

1- Bead construction and application of wedge (Bead building machine and APEX machine);
2- Flipper application on bead (flipper application machine);
3- Tyre construction (KM);

The 1st option would be ideal. However, the application of the flipper step makes the cycle time of the construction of a tyre too long. Therefore, the 2nd option is preferred since it allows the optimization of the performance of the tyre building machines, increasing the number of produced tyres.

The machine that currently performs the flipper application according to the 2nd option is old, little automated, without sufficient quality control, of slow production and with insufficiently updated safety implemented.

Due to market demands and the continuous improvement strategy of the company and having in mind the reasons listed above it has been decided to develop a new machine to perform specifically the flipper application on a bead.

For faster development of this project it has been appointed that an existing front frame part of a KM machine should be used, as this new machine may have a structure and similar process to a KM machine.

1.2. The company

The Continental Group (Continental AG) was founded in 1871 in Hannover, Germany.

In the beginning, manufacturing included soft rubber products and solid tyres for carriages and bicycles (Mabor, 2018).

In 1898, Continental started the production of automobile pneumatic tyres. Initially, they were produced without any tread. This changed in 1904 when Continental became the first company worldwide to develop grooved tyres for automobiles (Mabor, 2018; Continental, 2018a).

Today, Continental is among the 5 largest automobile tyre suppliers worldwide and its activity goes far beyond the production of tyres. Currently, Continental is a supplier of “brake systems”, “systems and components for powertrains and chassis”, “instrumentation”, “infotainment solutions”, “vehicle electronics” and “tyres and technical elastomers” contributing in this way to enhance driving safety and global climate protection (Continental, 2018a).

The Group, according to data from the end of 2017, is present in 61 countries, 554 different locations and has more than 235 thousand employees.

Figure 1.1 – Key facts from 2017 (Continental, 2018b).

Continental Mabor – Indústria de Pneus, S.A. (CMIP) is one of the factories from Continental AG Group that produces tyres. It's placed at Lousado, Vila Nova de Famalicão - Portugal and has got about 2000 employees.

CMIP was born in 1989 when *Mabor – Manufatura Nacional de Borracha, S.A.*, the first factory to produce tyres in Portugal, was bought by Continental AG (Mabor, 2018).

The production of the company is, currently, very diversified both on tyre dimensions, types and brands. CMIP includes in its portfolio tyres for SUVs (Sport Utility Vehicles), high performance tyres, ContiSeal tyres and ContiSilent tyres. The daily production is over 60 000 tyres, the majority is being intended to export (Mabor, 2018).

This project was developed together with *Direção de Engenharia 3*. This department is responsible for a group of machines on the production preparation area which are: the bead building machines, APEX's machines and cutting and slitting machines. The main responsibilities of this department are:

- To elaborate and develop the procedures and plans for planned maintenance (predictive and preventive) and coordinate corrective maintenance in the area;
- To maximize the availability of machines for production;
- To support the implementation of corrective actions on equipment and installations, from the developed action plans;
- To support the training of the elements of Production on the operations of new equipment;
- To introduce improvements in equipment to optimize their capacity;
- To execute all projects of development and installation of new machines;
- To keep all facilities in the area in good condition;
- To ensure the availability of the necessary energy resources, optimizing their use. (Mabor, 2018).

1.3. Objectives

The objective of this project is to develop a new concept of machine for the flipper application that fulfils the requirements of the final product. To achieve that it is necessary to define the process, the structure and components of the different modules that integrates the machine, the electrical and the automation system.

It is important that the project considers the use of the front frame part of an existing KM machine as previously mentioned, for a speedier development.

It is required to develop improvement solutions regarding the current solution, mainly regarding the stretching of flipper strips and also including an automatic cutting. The electrical system must be developed in compliance with the MES Continental (Manufacturing Execution System).

At the end of this project it is intended to have a tender specification taking into account all the requirements to be put forward to possible suppliers.

1.4. Report structure

This report is divided in five chapters:

1. The first chapter is an introduction in which the purpose is to present a framework of the project, its main objectives and provide a short presentation of the company where the project was developed.
2. The second chapter presents a technical background for the project. A brief overview of a tyre production stages is presented and an introduction to machine design guidelines is also provided. A description of the machine that currently performs the flipper application is also given and the main points for improvement are presented as well.
3. On chapter three the basic requirements that the new machine must fulfil are described and the general pre-requirements for the development of the project are presented.
4. The fourth chapter is where the project development is presented. It starts with main constrains for the general configuration and the process. Then a description of each module, the main components and the electrical and automation system are defined.
5. Chapter five presents the main conclusions and attempts to provide suggestions for forthcoming works.

2. Technical background

2.1. The tyre

“*The tyre is a complex technical component of today’s motor cars and must perform a variety of functions. It must cushion, dampen, assure good directional stability, and provide long-term service. Most important of all, however, it must be capable of transmitting strong longitudinal and lateral forces (during braking, accelerating and cornering manoeuvres) in order to assure optimal and reliable roadholding quality. It must be able to do all of this even when the road provides little traction in wet or slippery conditions or when the road is covered with snow or ice.*” (Continental Reifen, 2013).

The tyre was invented by Dunlop in 1888, at first just for bicycles and later for automobiles. As mentioned before, *“In 1898 Continental started producing so called “pneumatics”, tyres capable of giving a more comfortable (cushioned) ride and enabling automobiles to travel at higher speeds.”* (Continental Reifen, 2013).

Over the years the tyre has evolved both in terms of materials and elements it is made of. In addition, there are European standards to be respected which influence the quantity of certain materials used. Figure 2.1 shows the standard percentage of each material used on a Continental tyre.

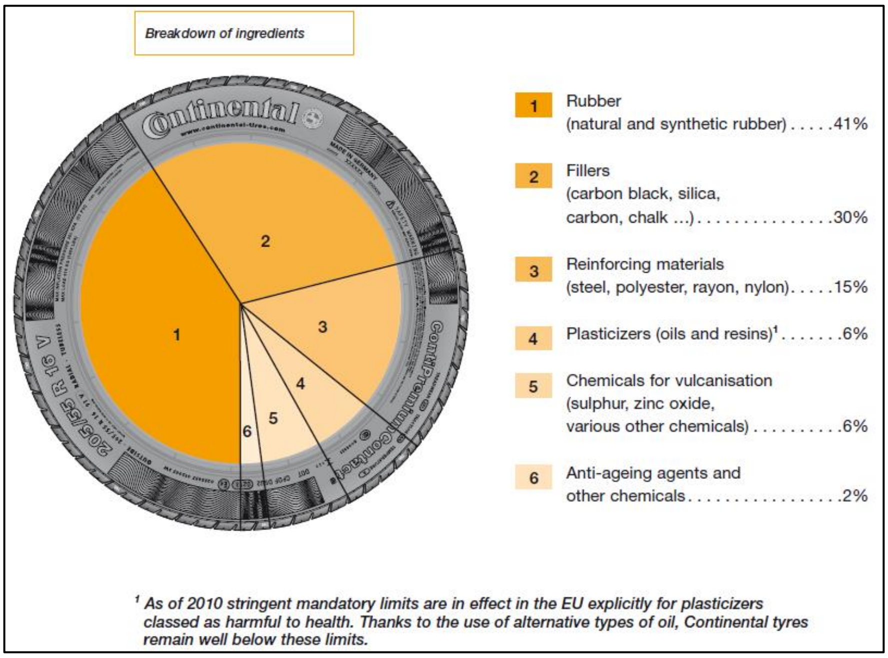


Figure 2.1 – Percental distribution of materials in a Continental tyre, example presented: 205/55 R 16 91 W ContiPremiumContact (Continental Reifen, 2013)

A modern tyre is made of several components, each with very specific functions so that together they can ensure the required adhesion, resistance and safety for driving. The tyre components and their functions are:

Tread – ensures high mileage, good road grip and water expulsion;
Jointless cap plies – enable high speeds;
Steel-cord belt plies – optimise directional stability and rolling resistance;
Textile cord ply – controls internal pressure and maintains the tyre's shape;
Inner liner – makes the tyre airtight;
Side wall – protects from external damage;
Flipper – promotes directional stability and precise steering response;
Bead apex – promotes directional stability, steering performance and comfort level;
Bead core – ensures firm seating on the rim;
(Continental Reifen, 2013)

The components most highlighted in this report are the "bead" and the "flipper". On Figure 2.2 it is possible to see the shape and the position of a bead and flipper on a tyre.

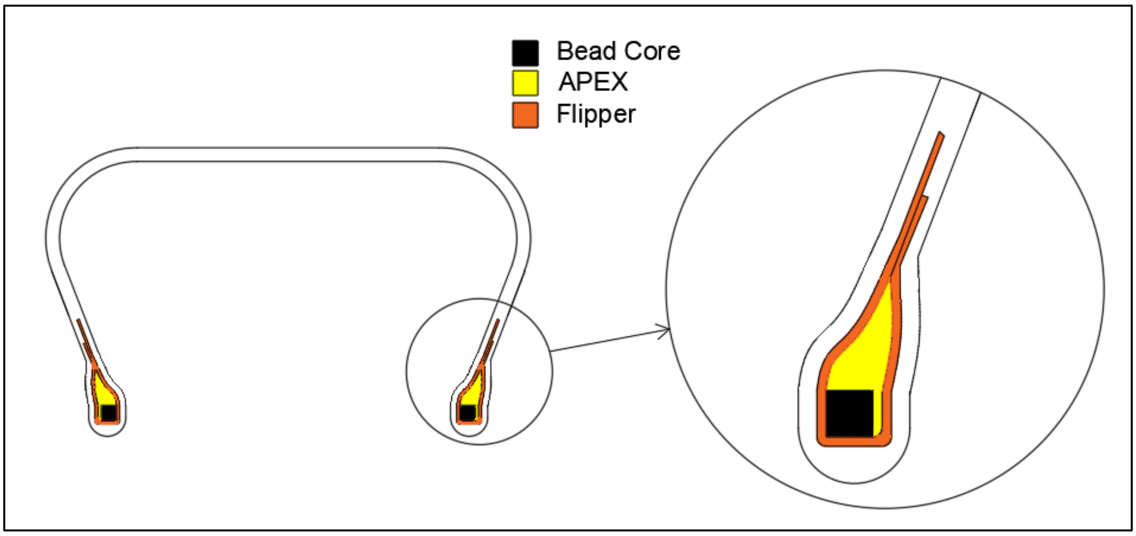


Figure 2.2 – Sectional drawing of a tyre; highlight to bead, apex and flipper.

2.2. Current flipper application machine

The machine that currently makes the flipper application around the bead is very simple but fully manual. This machine has two main modules. There is an unwinder and the module where the wrapping operation is performed.

At the beginning of the process the bead is positioned (Figure 2.3).

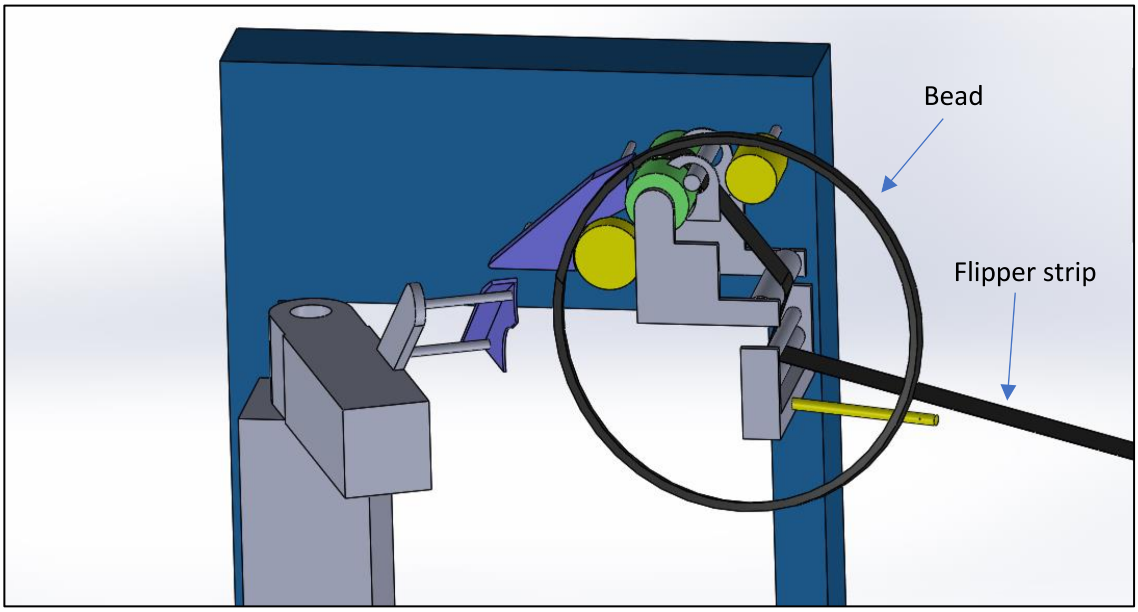


Figure 2.3 – Placing of bead in flipper machine.

Afterwards, two plates apply lateral pressure to perform the wrapping operation and ensure the bonding of the strip. These plates are represented with a purple colour on Figure 2.4.

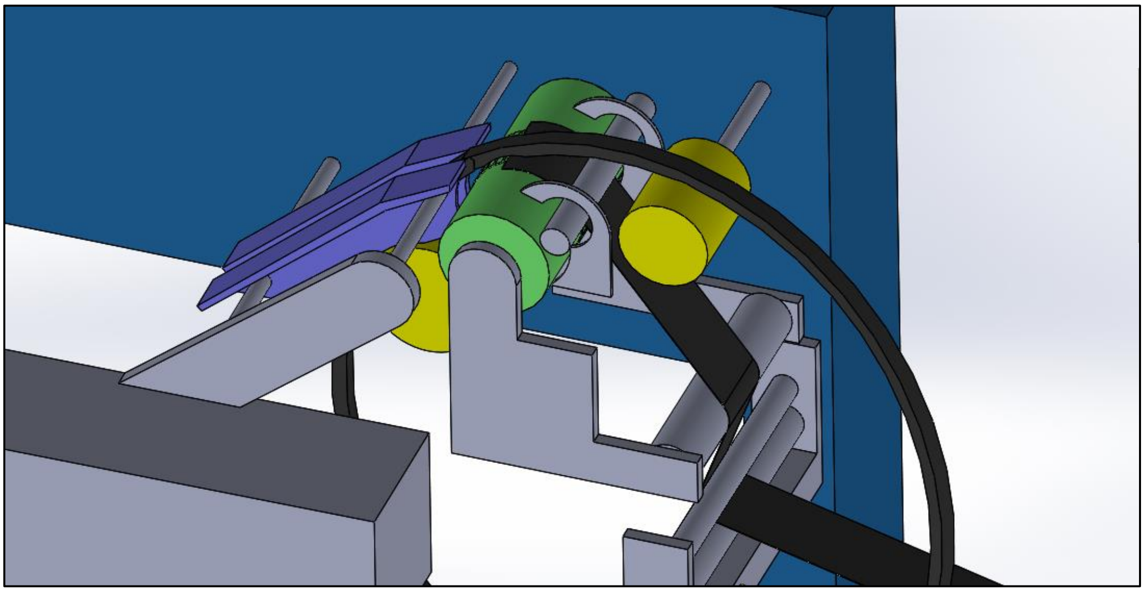


Figure 2.4 – Flipper machine ready to perform the wrapping operation.

A small rotating drum makes the bead spin and make a full turn. This drum is shown with a green colour on all figures presented on this chapter. The final cutting of the strip is performed manually by the operator.

On Figure 2.5 a sketch of this machine can be seen, including the unwinder.

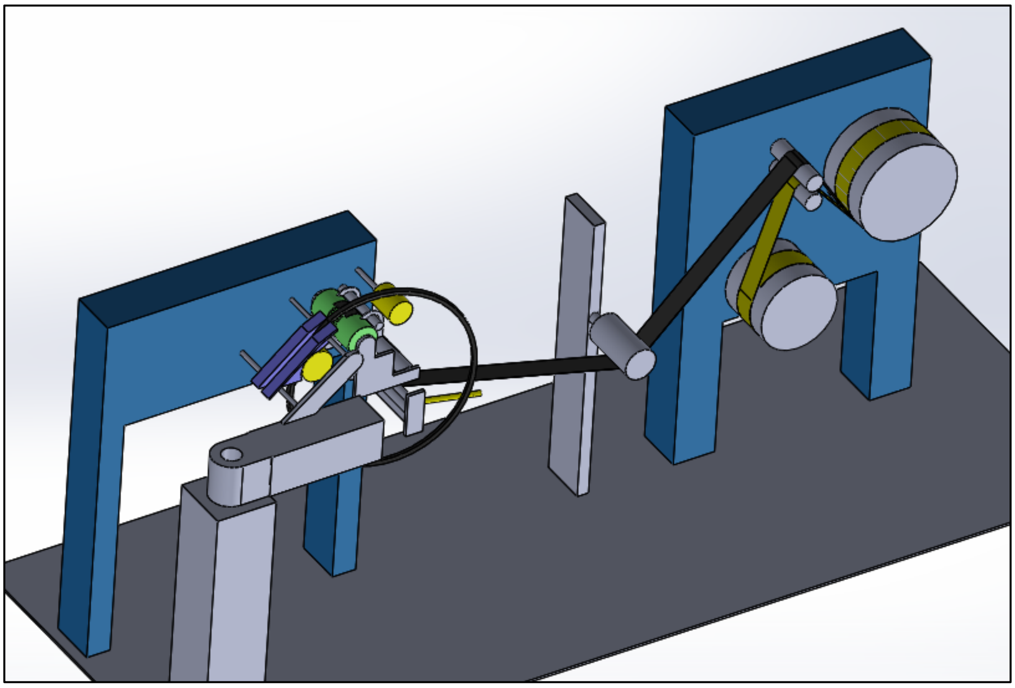


Figure 2.5 – Flipper machine simulation.

As this is a nearly manual process and having no control sensors, the quality of the final product is often affected. The stretching of the strip and the step values are parameters which are not duly controlled on this machine. These parameters must be supervised on the new machine. There are three kinds of steps: overlap, step of the splice and step of turning. They are going to be described further.

This current machine does not have a high productivity. The cycle time is around 30 seconds to obtain one bead with flipper. This cycle time does not allow a production of more than 2500 beads with flipper per day. The number of tyres with flipper required per day is around 2000. However, the flipper is applied directly on the KM machines, in most cases (approximately 1300). As demonstrated, this process does not bring further advantages regarding the productivity of the KM machines, however the quality of the final product is better this way.

Another important issue to be improved is the safety compliance. This machine has little safety incorporated, which means that the operator's physical integrity will not be fully regarded if something unexpected happen.

2.3. Machine design

Engineering design can be defined as: *"The process of applying various scientific techniques and principles with the intention of defining a sufficiently detailed device, method or system to enable its execution" (Norton, 2013).*
A machine can be defined in many ways: among them is "*a device which modifies force or movement*" (Norton, 2013). The mention of forces and motion is crucial since, by converting one form of energy into another, machines create movement and develop forces. The task of an engineer is to define and calculate those movements, forces and energy changes to determine dimensions, shapes and materials required for each piece that is part of a machine and so perform the desired function without failures. This is the essence of machine design (Norton, 2013).

However, until the machine is ready to perform its function the project goes through several phases. Several design methodologies were created to help organize the unstructured problem presented at the beginning of a project when the definition is vague and there are many possible solutions. One of them is presented by Norton (2013) and includes 10 steps:

1. Identification of the need;
2. Support research;
3. Definition of objectives;
4. Task specifications;
5. Synthesis;
6. Analysis;
7. Selection;
8. Detailed design;
9. Prototype and test;
10. Production;

The first step usually consists of an undefined and vague exposure of the problem, important to be exposed and identified. The development of further information is made with Support research (step 2), which is necessary to define and understand the problem completely. The Definition of objectives (step 3) can now be done in a most reasonable and realistic way than it was at step 1, with the contribution of different players. Step 4 asks for a creation of a detailed set of Task specifications which limit the problem and its reach. It is at the Synthesis (5) stage that several design alternatives are brought forward, usually without considering their value or quality. It can also be called the Design and Invention stage, in which the highest possible number of creative solutions are generated. On step 6, the possible solutions from the previous step are analysed and accepted, rejected or modified. The most promising solution is selected on step 7. When an acceptable project is selected, the Detailed Project (step 8) can be performed. Project analysis is then done using sketches, free-body diagrams, mathematical models, simulations, etc., and the project safety or failure is determined. It is made the decision to proceed with the project or iterate to find a better solution by returning to an earlier stage of the process if necessary. The actual construction of the project is done for the first time as a prototype on step 9 and finally in quantity on step 10 (Production) (Norton, 2013).

In the case of this particular project, the identification of the need (step 1) was made by Continental Mabor. The following steps up to the Selection (step 7), including, were made within the scope of this work, with the final objective of delivering a detailed tender specification to a supplier who will carry out the Detailed Design and Prototype steps. The final stage of production will again be in charge of Continental if the result is successful.

3. General prerequisites and basic requirements

The first step was to analyse the problem and to gather all specifications required for the final product and the machine. Then the concept, the process and the main modules of the machine were defined. From this point, now it was possible to identify the different parts of each module and specify them in more detail.

As already explained, it is intended to develop the project of a machine which can perform the wrapping operation of the flipper strip around the bead in an automatic way, better fulfilling, and with higher quality, the requirements and complying fully with safety rules. To achieve that it is assumed that a tyre building machine front frame is to be reused. This module is where the wrapping main task is going to happen and it is going to be called from now on as the “winding drum”. With this module it’s possible, at the end of each cycle, to obtain two beads wrapped inside the flipper strip. The module can be seen on Figure 3.1.

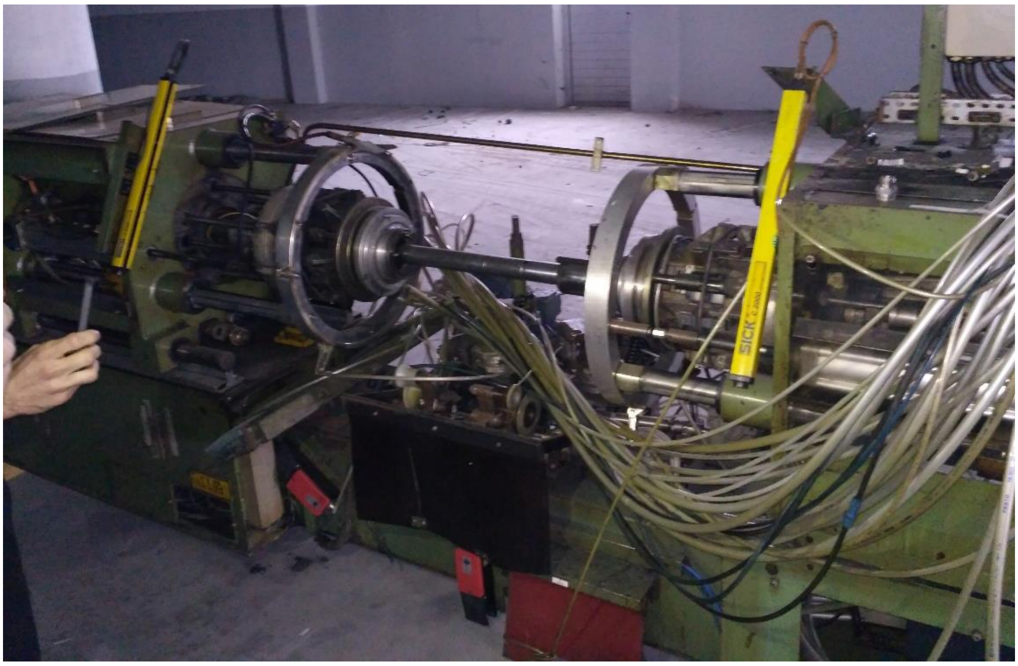


Figure 3.1 – Winding drum front frame available for the machine.

The required machine must be capable of performing reduced time cycles for a large range of rim diameters, which means it must have an adequate height adjustment so that the strips are always fed tangentially to the drum. The flipper strip itself may have different widths.

Regarding quality requirements, it is important to ensure that the strips are well guided so that there are no oscillations or deviations during the application and also to assure they will be centred on the correct position. It is essential that the strips are cut with a precise length in order not to end with too much or too little overlap at the end of the winding. The cutting must be made with the same angle as the slope of the fabric textile lines. These requirements are described in detail below.

Dimensions limits

The machine must be prepared to produce a wide range of dimensions concerning rim diameters, strips widths and even strips lengths. On table 3.1, it can be found the required values for production on this machine. However, it should also be prepared to produce size 24” rims, to preclude future situations.

Table 3.1 – Required values of rim diameters, strips widths and strips lengths to produce on the new machine.

Rim diameter [inches]	Strip width [mm]	Strip length [mm]
16	90	1317
17	90	1411
17	90	1417
18	90	1493
19	90	1573
20	90	1531
20	90	1570
20	75	1580
20	90	1654

Quality requirements

Concerning the quality of the final product, it is important that all movements from the feeder components are well synchronized in order to avoid undesired stretching on flipper strips. Regarding the step gaps (Figure 3.2) there are two kinds:

- Step of the splice, which should be, ideally, 0 mm having a margin of tolerance of ±3 mm;
- Step of turning, which should be, ideally, 12 mm having a margin of tolerance of ±5 mm;

There is also a standardized value for the overlap, which is, ideally, 8 mm with a margin of tolerance of ±5 mm;

These values are shown below on an illustrative figure for better understanding.

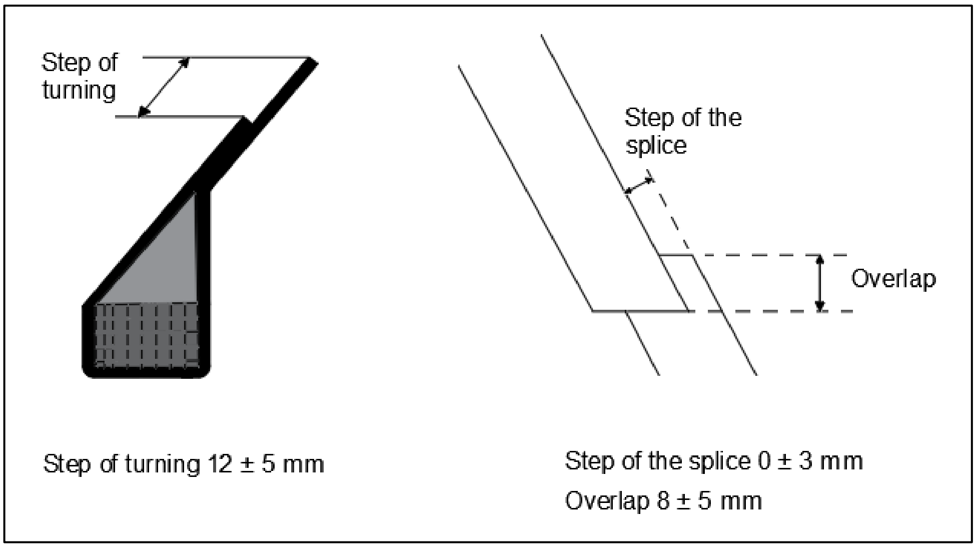


Figure 3.2 – Quality requirements.

Cycle time

Cycle time must be below 15 seconds.

Winding drum

The winding drum which is available for the development of the project (Figure 3.3) has already the capability to perform the main task of this machine. This task is described in detail on chapter 4.1.2.

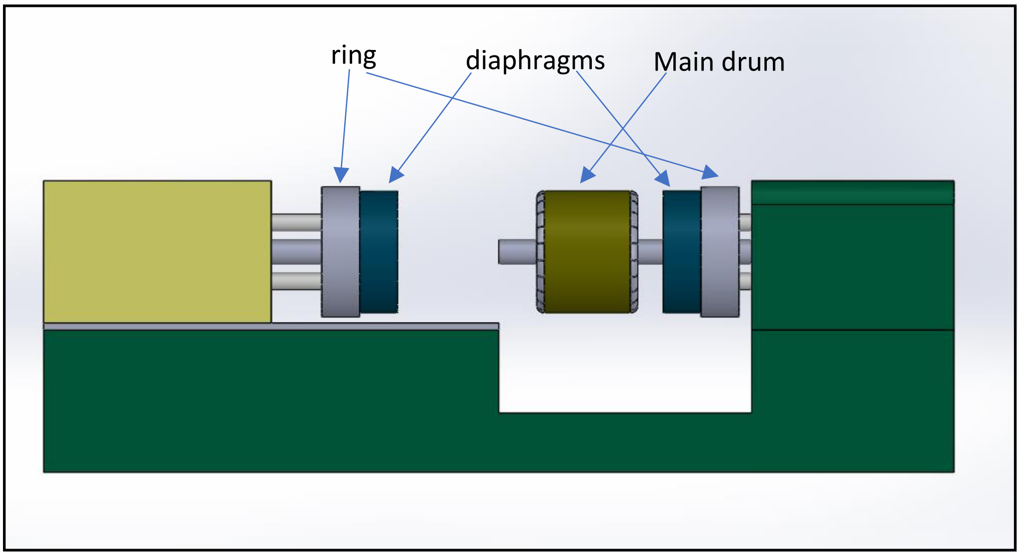


Figure 3.3 – Winding drum main components.

The movements/systems existing on the winding drum that allow the wrapping process are:

- Rotation of the drum and of the diaphragms driven by a servomotor capable to perform high rotation speeds considering the weights involved;
- Expansion of the drum by a wedge system pneumatically actuated;
- Expansion of the diaphragms;
- Axial movement of the rings to: lean the diaphragms against the drum; transport the beads; and push the expanded diaphragms against the expanded drum to finalize the wrapping process;
- Air blowing jet to transport one bead from one end of the winding drum, where the operator places the beads, to the other end of the winding drum. This transport is helped by the rotation of the drum.

Flipper strip

The drum has the capability to perform the wrapping operation with two strips at the same time, which means that each cycle can produce two beads with flipper. The flipper strips are brought to the machine winded up on reels to be unwinded at the beginning of the process of feeding.

As previously mentioned, the flipper is a strip made of rubber and textile fabric lines to improve its resistance. These lines are positioned with a standard slope of 30°. On figure 3.4 it can be seen the slope of these lines.

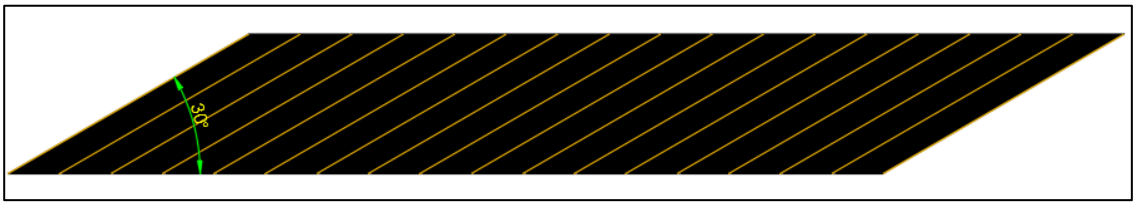


Figure 3.4 – Slope of the lines on the flipper strip.

4. Project development

4.1. Initial general definitions

4.1.1. General configuration

To ensure a cycle time of 15 seconds some measurements were performed to determine the time it takes for the process of wrapping the flipper strips around the beads. Since this process does not currently exist, the measurements were based on the KM process and, therefore, the values obtained are approximate. It was found that the wrapping process takes about 10 seconds, regardless of the size of the bead. This process includes all the steps after the feeding of the flipper strips and ends when the operator removes the final product from the winding drum. This process is shown in detail on chapter 4.1.2.

To obtain a general concept for the machine three main ideas were considered. The first one is the simpler solution. On this configuration, the machine is built of a “let off”, a loop, a feeding conveyor with the cutting system on the end of the conveyor and the winding drum (Figure 4.1). The conveyor transports the strips to feed the winding drum so it can perform the main task. Almost at the end of the main task, the cut must be performed and, afterwards, the main task continues.

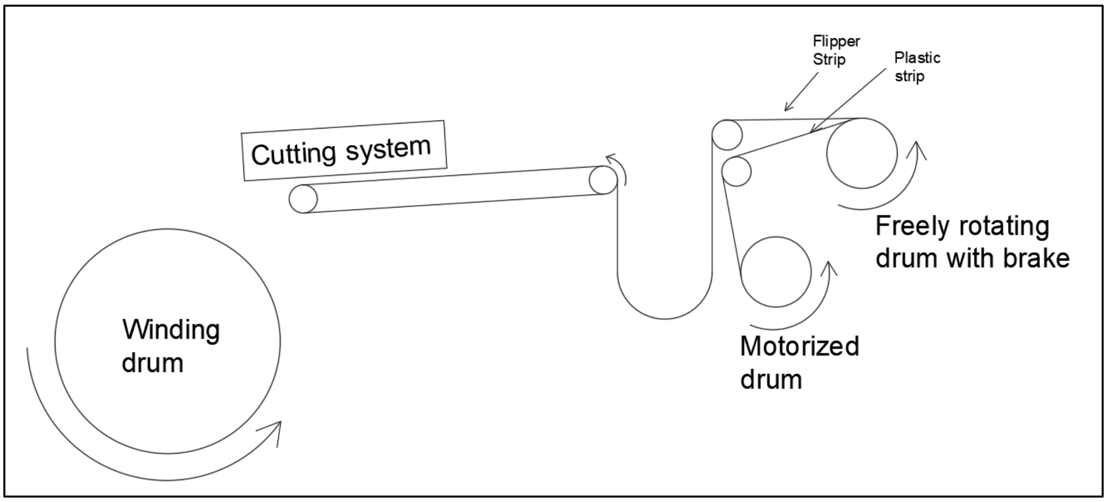


Figure 4.1 – First general concept for the machine.

However, this could bring some issues in terms of productivity. To ensure the cycle time the strips must be cut, and prepared, in advance. The maximum time this subprocess can take, considering the advanced preparation benefits, is the time of the wrapping process, which is 10 s. Later, on chapter 4.2.9., the operating times of different parts of the machine are presented, demonstrating how this cycle time can be fulfilled.

To reduce the cycle time, the second solution has two conveyors added to the feeding of the flipper strips to the winding drum. On this solution each strip has its own feeding conveyor (Figure 4.2).

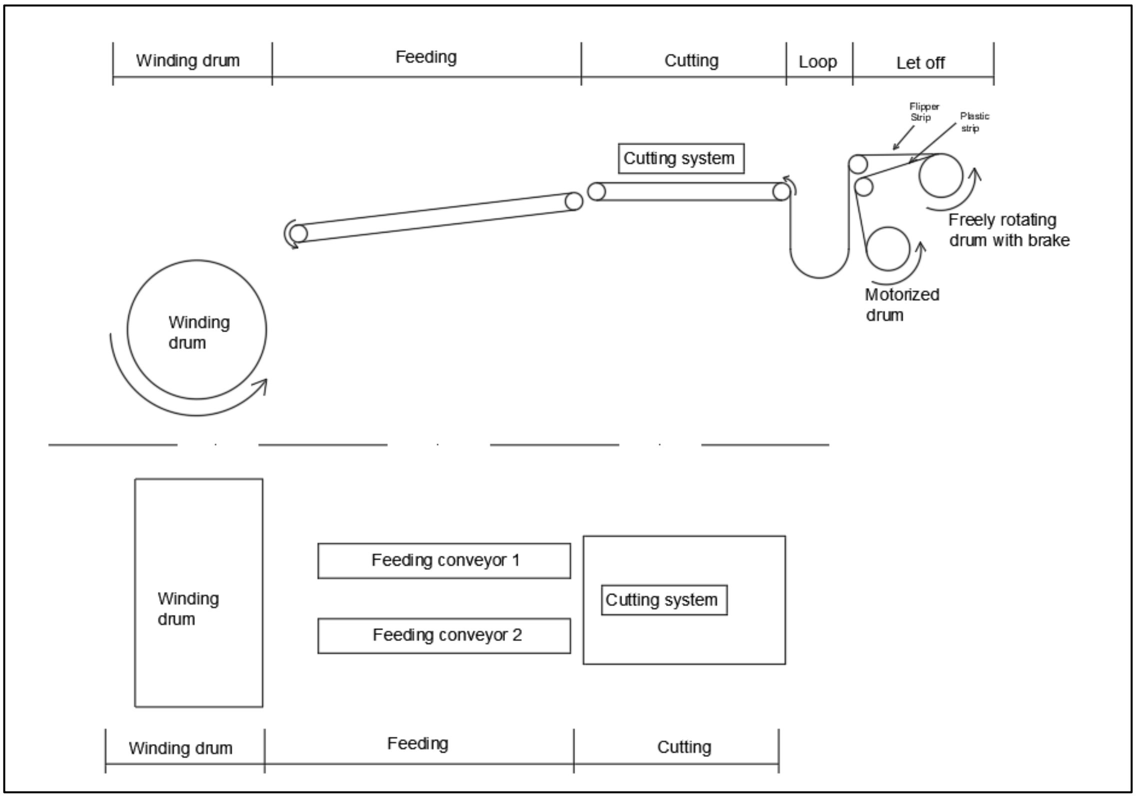


Figure 4.2 – Second general concept for the machine.

However, this solution requires more components, more motors, more sensors, etc. and in terms of process does not bring advantages if, instead of two feeding conveyor, only one feeding conveyor perform the feeding of the winding drum.

On full dialogue with staff members from *Direção de Engenharia 3* and from the production department, a concept for the machine, which was considered to better fulfil all requirements, was chosen. On Figure 4.3 it is shown the sketch that represents the general concept for the machine.

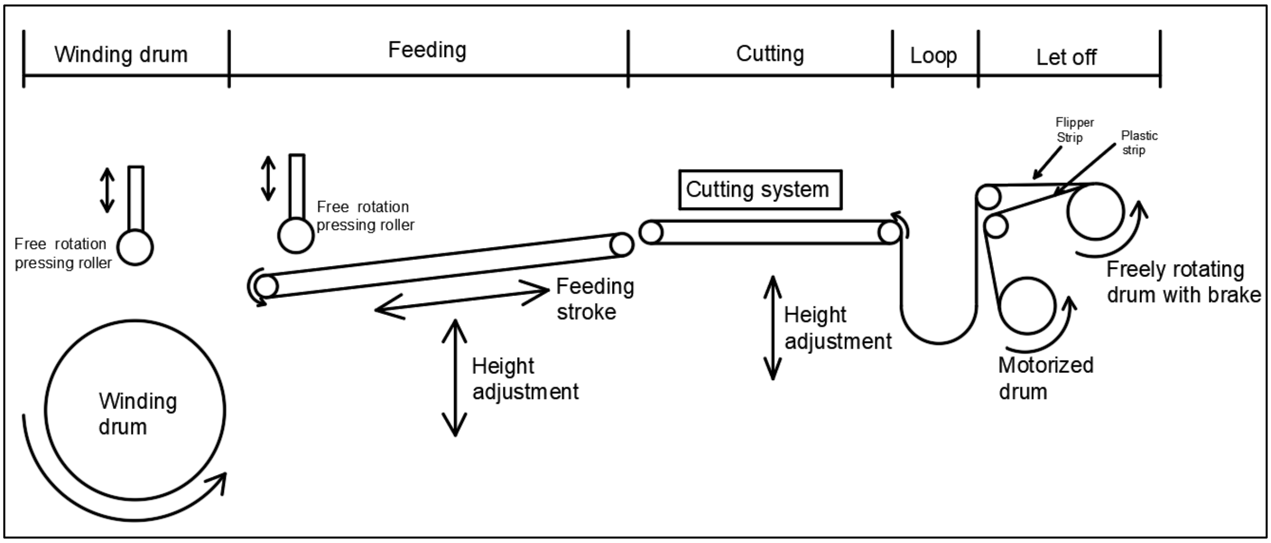


Figure 4.3 – Sketch of the general concept for the machine.

The material to be worked, the flipper, is winded on a reel. Due to the adhesive properties of the flipper, there is a plastic strip also wound to keep the layers with no contact.

In a general way, the general configuration and process of this new machine can be as follow:

- The reel is assembled on an unwinder, called "let off". This unit unwinds the flipper through the winding of the plastic strip which is wound on a small motorized winding drum.
- A free loop to ensure that the machine is continuously working and it avoids stretches on the material;
- A first conveyor where the cutting of the strips is performed automatically, with the adequate length;
- A second conveyor that houses the strips after cutting, ready to be fed to the winding drum; this second conveyor is built on a moveable basis with a linear movement in order to adjust to the winding drum during the feed stage; at the end of this conveyor there is a pressing roller to introduce some tension on the strips while they are being winded around the winding drum;
- A winding drum where the main task of wrapping of the strips around the beads is performed; On top of the winding drum there is a pressing roller to guarantee the adhesion between the strips and the drum;
- The machine will also have a height adjustment on the feeding so it can be adjustable for all rim sizes.

The main process and the preparation process will be described on chapter 4.1.2.

4.1.2. Process description

The process is divided into two subprocesses working in parallel and synchronized with each other:

- one is the strips preparation;
- the other one is the wrapping main task.

The winding drum module consists mainly of a drum which is built out of several segments, allowing the drum radial expansion, and by two diaphragms, located on each side of the drum. The diaphragms expand as the turning of the strips occur. The strips are applied at the point where the drum and the diaphragms get in touch.

Therefore, in a general way, the main operation has the following sequence:

- Placing the beads on the winding drum, manually by the operator at one end of the drum. Afterwards, one of the beads is transported to the other end by an air blowing jet which is helped by the rotation of the drum; after this step the remaining process occurs automatically until the end when the operator manually removes the wrapped beads;
- Feeding conveyor advancing and winding of the strips over the drum; at the end of the feeding stage the conveyor returns to its original retracted position. While this conveyor is feeding the winding drum, the drive of the cutting conveyor must be disabled.
- Positioning and fastening of beads; this process is performed automatically by rings that are already part of the winding drum;
- Drum expansion;
- Diaphragms expansion to wrap the flipper strips around the beads.

A diagram of the described sequence is presented below.

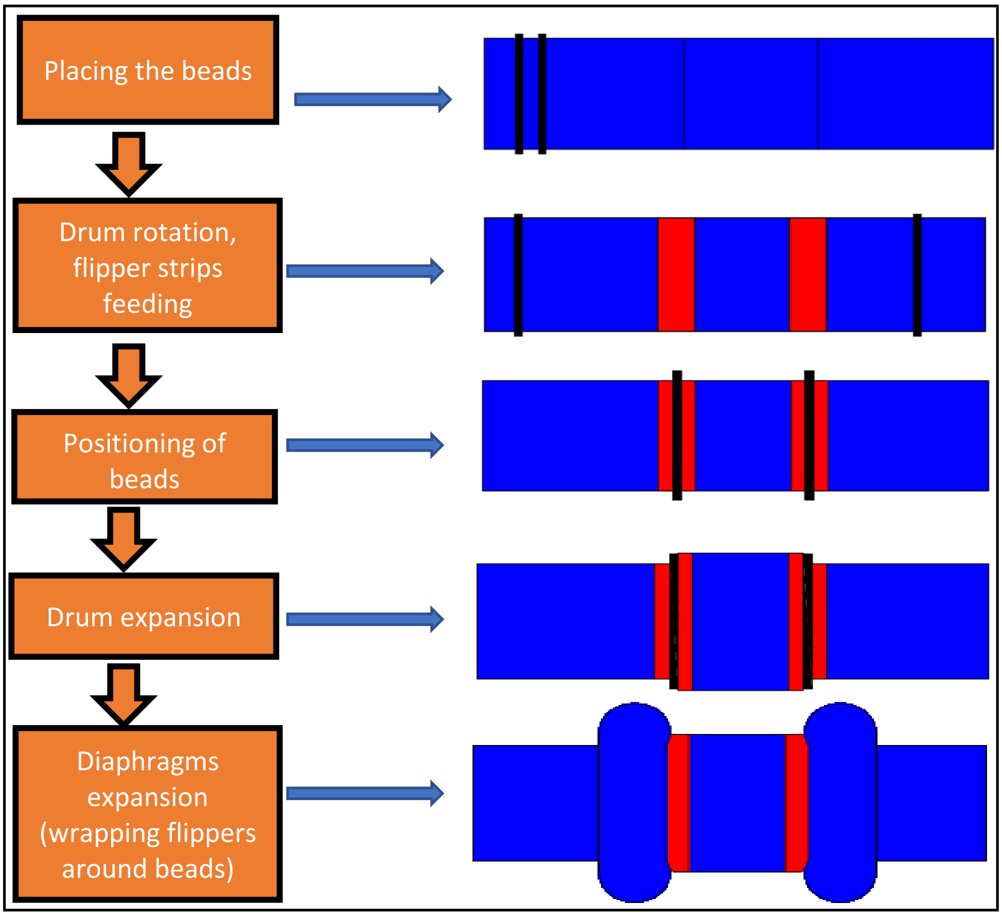


Figure 4.4 – Main task process: alternative 1.

Alternatively, the drum expansion can be performed before the positioning and the fastening of beads. This alternative has the advantage of being sure that the bead leans against the drum, however it is not safe to say that the strips will keep up the expanded drum profile correctly due to their small width. The choice of the best process requires experimental validation. This alternative process is described by the following sequential diagram:

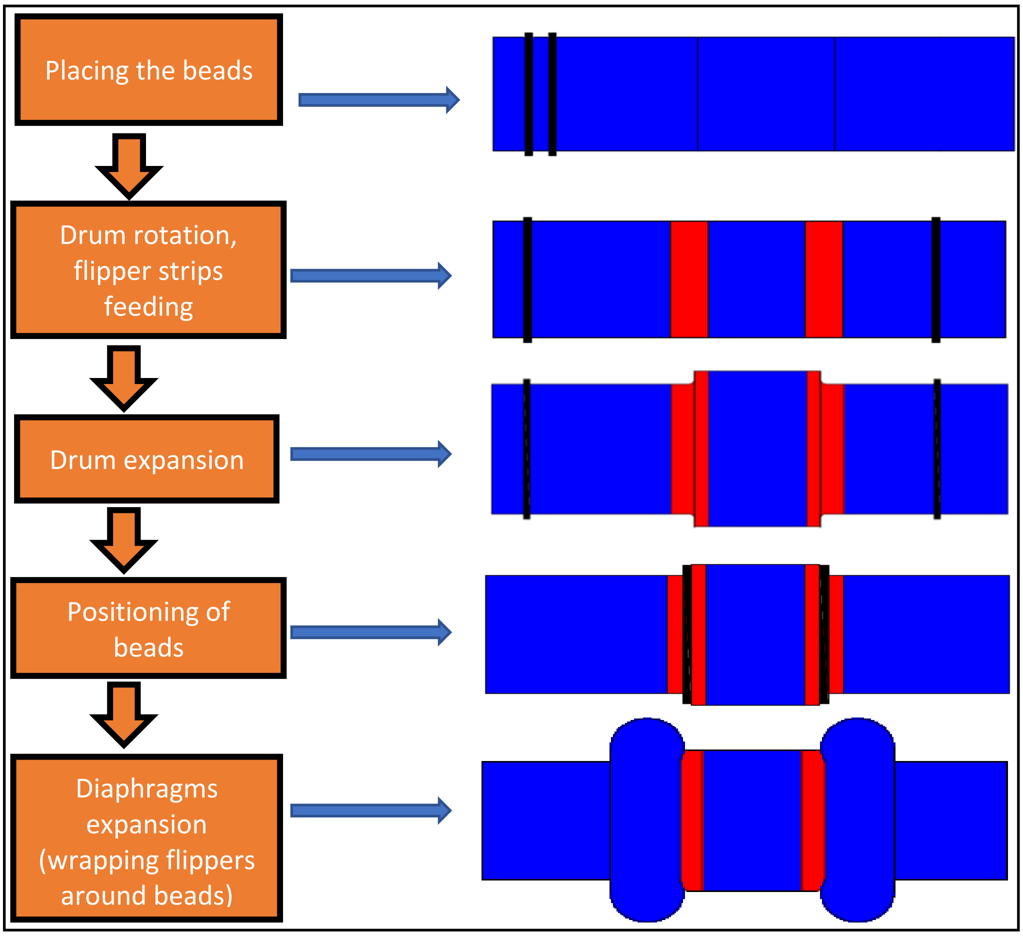


Figure 4.5 – Main task process: alternative 2.

The secondary operation which prepares the material to feed the winding drum to perform the main task has the following sequence:

- The two conveyors move the strips forward until they reach the length to cut;
- Cutting of the strips;
- Only the feeding conveyor moves the strips so that they are positioned and ready to be transferred to the winding drum. The drive of the cutting conveyor must be disabled on this stage, the same way as during the winding of the strips around the winding drum.

There is still the loop replacement operation when it reaches minimum values.

This entire process is, on chapter 4.5., described in detail using grafcet representation.

4.2. Modules description

In this subchapter the solutions found for the constitution and operation of each module of the machine are presented.

Each module is, first, described in detail and their mechanical components are specified to ensure the correct operation. Afterwards, the movements performed by the moving parts of the machine and the drive systems will be characterized with as much detail as possible through calculations, graphs or by using datasheets of the components responsible for the drives. After, the final configuration of the machine and the main safety devices are presented. The sensors that ensure the correct operation of the machine are then presented on chapter 4.4.

First a scheme is introduced that presents the different machine modules and the order in which they are organized.

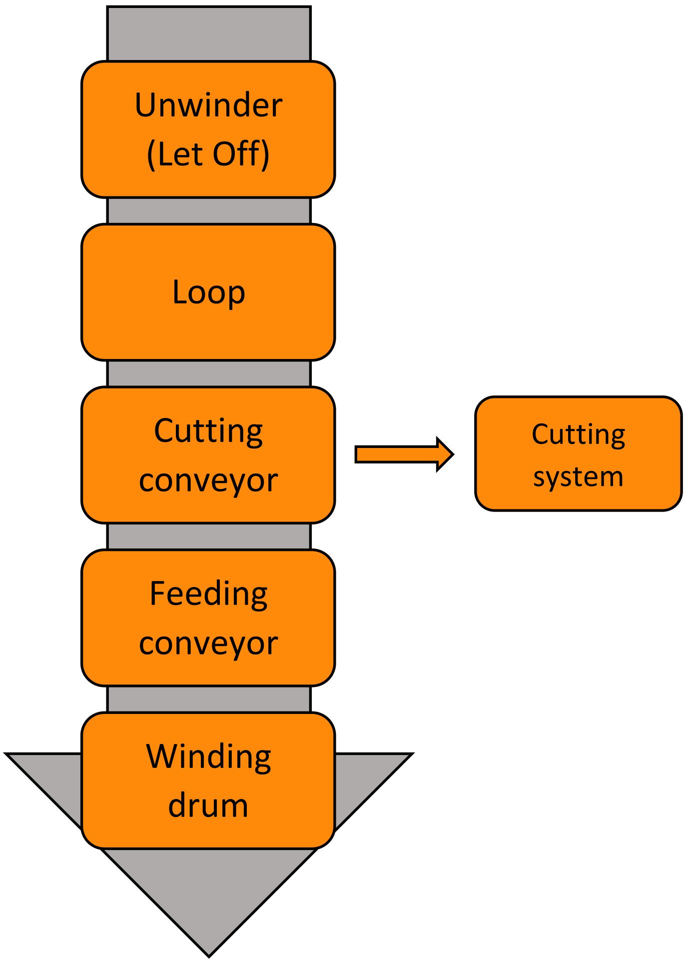


Figure 4.6 – Scheme of the organization for the machine.

4.2.1. "Let off"

This is the first station, where the flipper strip reels are unwinded and precedes the loop.

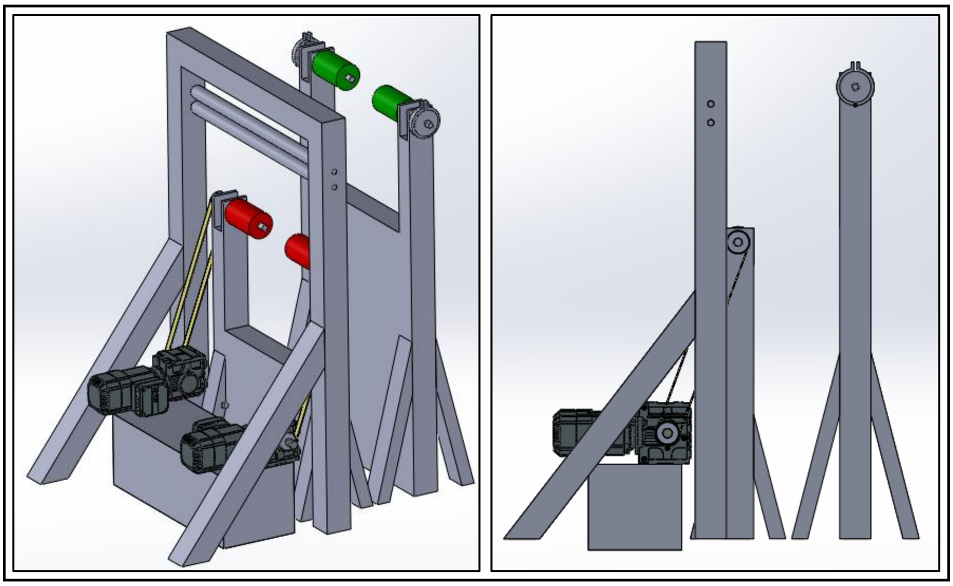


Figure 4.7 - Let off, isometric view (a); side view (b).

The reels to be unwinded are located over the green rolls shown on Figure 4.7, a). The plastic material that comes with the flipper strip is winded up around the red rolls, which are driven by an induction motor with constant rotational speed. Despite the diameter variation over time, the reels are going to be unwinded at a speed able to replace the loop for any diameter of the reel. To successfully detach the strips from the plastic material, there are two separator rollers located at 1400 mm of height and with a distance to the cutting conveyor of about 600mm. The flipper strip path is over both rollers, forming, then, the loop while the plastic material path is between the rollers.

The motor on Figure 4.7 transmits the movement to the red reel by 1:1 chain or belt. A SEW 4-pole gearmotor with a power output of 0,37 kW must be foreseen, with an output gear speed of about 42 rpm. This is the specification of the motor used on the equivalent system at KM machines. As this system is basically the same as the systems used on KM machines to perform the unwinding of the flipper strips, it was not necessary to calculate the power or the torque of the motor considering the reels weight, it was simply copied.

The system also has a brake that acts permanently on the shaft of the strip reel. The force of this brake is adjusted by a screw. The brake should impose a small force just to counteract the forces of inertia of the reel but it allows the drive of the motor. This way it is assured that the reel stops the rotation movement when the motor is deactivated. This component can be observed in better detail on Figure 4.8 by the yellow component.

The axial fastening of the reels is intended to be made with manually-placed clamps for a fast reel exchange.

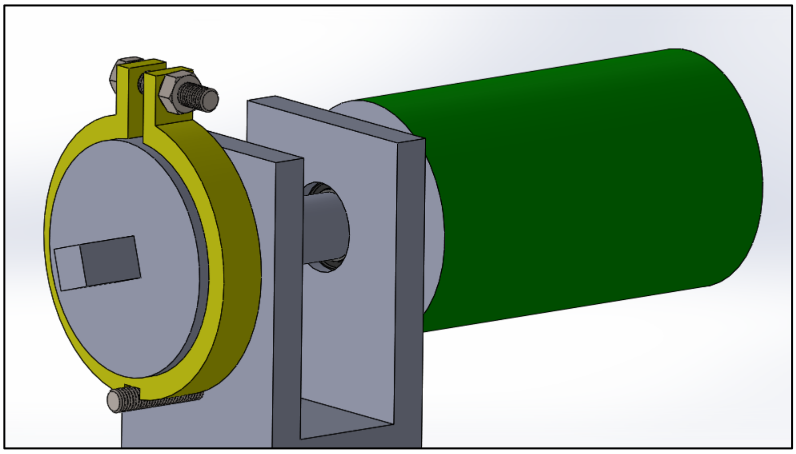


Figure 4.8 – Components of reel fixing.

4.2.2. Compensation loop

The loop exists to allow the process to run without undesirable stretching of the flipper. It must house a sufficient strip length in order to assure that the loop is never empty. As the machine must be prepared to work, in the future, with rim size 24”, the loop should have the capacity to house at least 2000 mm of strip, if at the end of the cycle it was simply replaced.

However, if the control is made by two photoelectric sensors, only 1500 mm are required. One of the sensors is positioned at a lower level, corresponding to 1500 mm of loop, and the other one at a higher level, corresponding to 1000 mm of loop. This reduction represents an advantage because a lower length of strip in the loop represents less forces applied on the material due to its own weight and so, less stretching. The control system is simple, every time the strip reaches the upper limit the motor starts. It stays “on” until the lower limit sensor is reached. With the motor working at 42 rpm it’s guaranteed that the loop is never lost.

The position of the sensors must be adjustable.

4.2.3. Cutting conveyor

The cutting conveyor is located after the loop and its purpose is to do the cutting of the strips to the correct length. It is composed of toothed rolls and belts and equal-sided angles 70x70x7 mm as structure.

The working diameter of this conveyor is 50 mm. In order to be able to incorporate the cutting system this conveyor needs having two separated belts, with 280 mm gap between them. The width of each belt is 140 mm and the working length of the conveyor is 1000 mm.

The conveyor has to be fixed to the support structure, both transversal and longitudinally. At the beginning of the conveyor there is a pressing roller to allow for a better adhesiveness between the strips and the conveyor belt, simply by the action of its weight. This system can be seen on Figure 4.9, represented with a green colour.

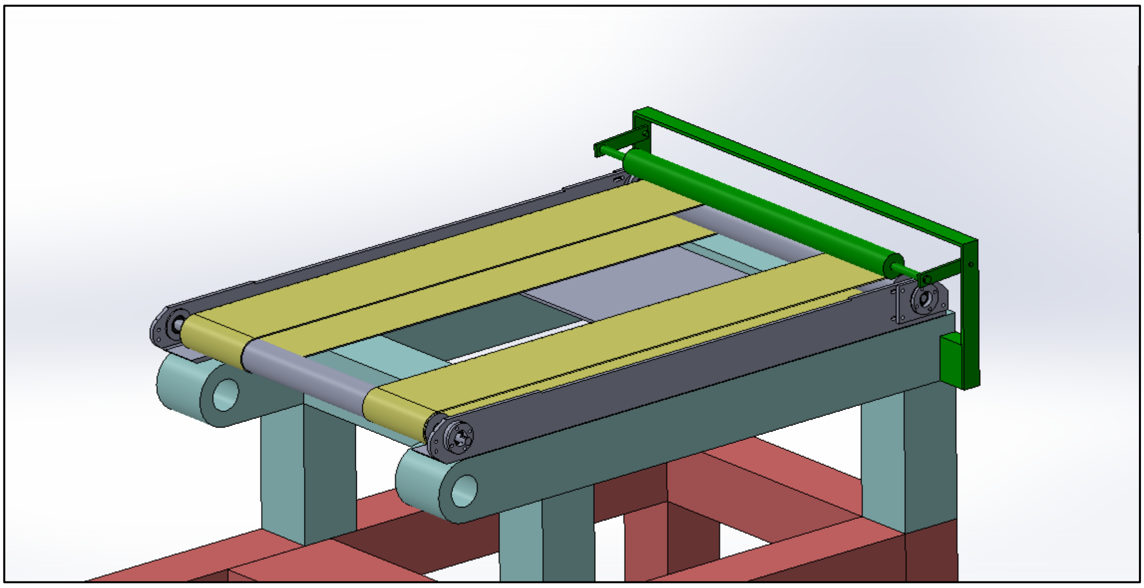


Figure 4.9 – Cutting conveyor.

The conveyor's belt also needs having a tensioning adjustment system.

4.2.4. Cutting system

The cutting of the material strips is accomplished by a rotating disk that rotates against a counter-blade by friction. To make sure the disk remains in touch with the counter-blade, it must be pressed by the action of a spring, as shown on Figure 4.10.

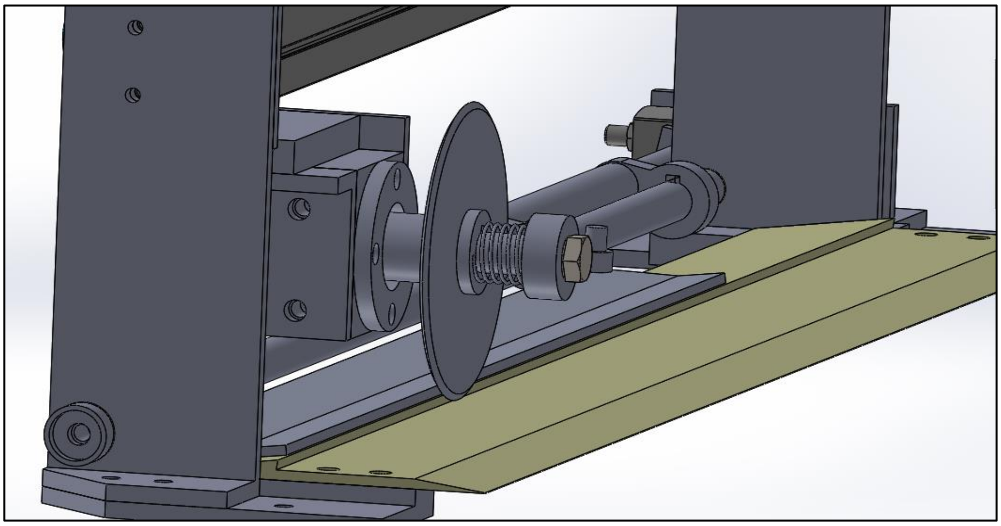


Figure 4.10 – Cutting blade and counter-blade.

This system is subjected to very small payloads and forces. Through a Festo software for dimensioning linear drives, inputting exaggerated payloads, speeds and strokes resulted that the linear drive EGC-50 could support this system and that the power and torque necessary to perform the drive are over 100 W and 0,4 Nm, respectively. The movement of the disk is then performed by an electromechanical drive from Festo whose reference is EGC-50-500-TB-KF-0H-GK, driven by a servomotor from Siemens whose reference is 1FK7022-5AK71-1DA0. The motor has a nominal torque of 0,6 Nm, a nominal power of 0,4 kW and a rated speed of 6000 rpm. On appendix A it may be consulted the datasheet of the linear drive and on appendix B the datasheet of the motor.

For the strip not to be dragged and stay in place during the cutting stage there is a pressing plate driven by a single-acting pneumatic cylinder, of pulling action, from Festo whose reference is AEN-20-10-A-P-A (as shown on Figure 4.11). The cylinder, when not actuated, lifts the pressing

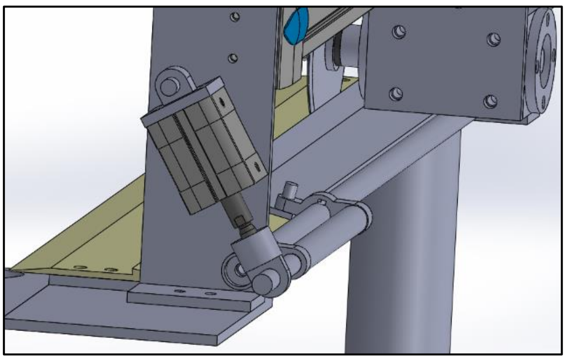


Figure 4.11 – Drive cylinder of fixing plate.

plate. When actuated fixes the strip against the counter-blade, being the force adjusted by the pressure inside the cylinder chamber. The pressure must be high enough so that the strip can't move during the cutting process, but not excessively high not to damage the mechanical components of this system. This way the limit switches are not needed to control this movement. To transmit the torque to the whole pressing plate there are two keyed joints in the shaft performing that function, one on each end of the plate.

The cut has to be, as it has been already mentioned, with a certain angle (Figure 4.12).

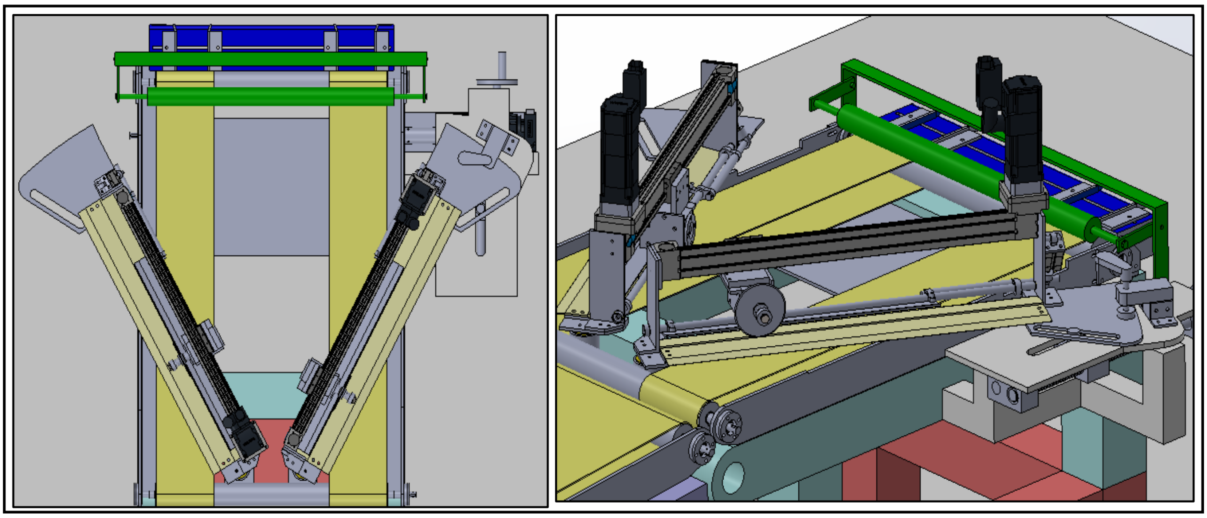


Figure 4.12 – Position of cutting system on the cutting conveyor.

This angle must be adjustable, although the standard angle is 30º.

The rotation centre of the system is placed at the support foot. It includes a self-lubricating bushing to smooth the movement and to minimize wear. At the other end of the system there is a plate where the fastening is made according to the desired angle. The different angles scale are marked on the plate. The cutting edge is aligned with the rotation centre of the system to make the angle reading and the adjustment easy.

The adjustment is performed by the machine operator using a hand crank which drives a screw/nut system (Figure 4.13).

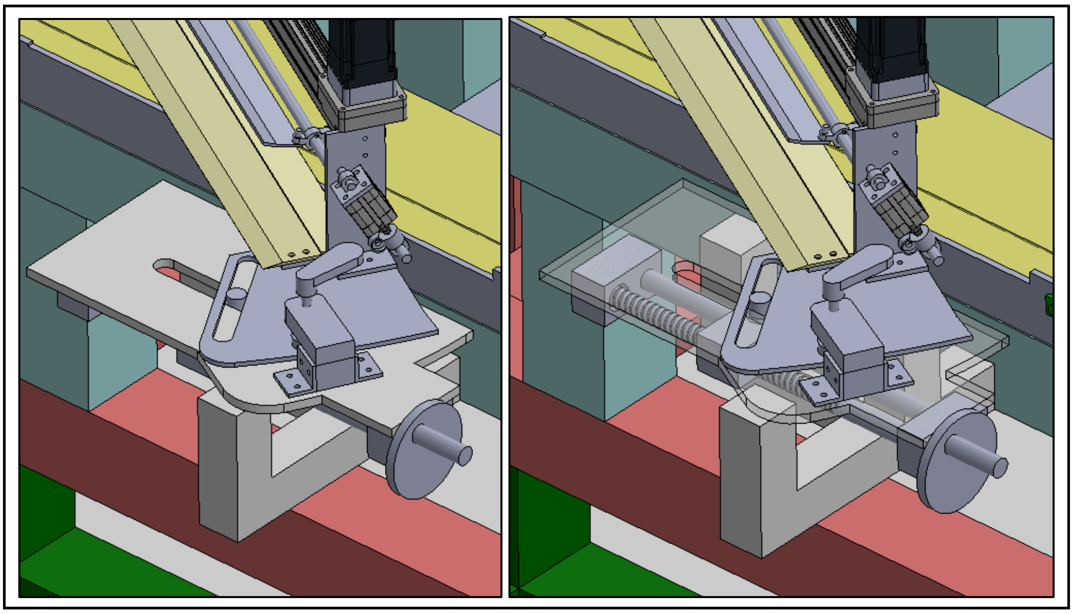


Figure 4.13 - Cutting angle adjustment system.

An existing pin on the nut block moves along a rip on the support plate of the system. The rip has a slope of 30º regarding the cutting edge. This slope allows to reduce the traveling path of the nut comparatively to a rip that is parallel to the cutting edge. The rip must be long enough to allow an angle range from 25º to 35º.

To prevent the rotation of the nut there is a circular profile guide as shown on Figures 4.14 and 4.15.

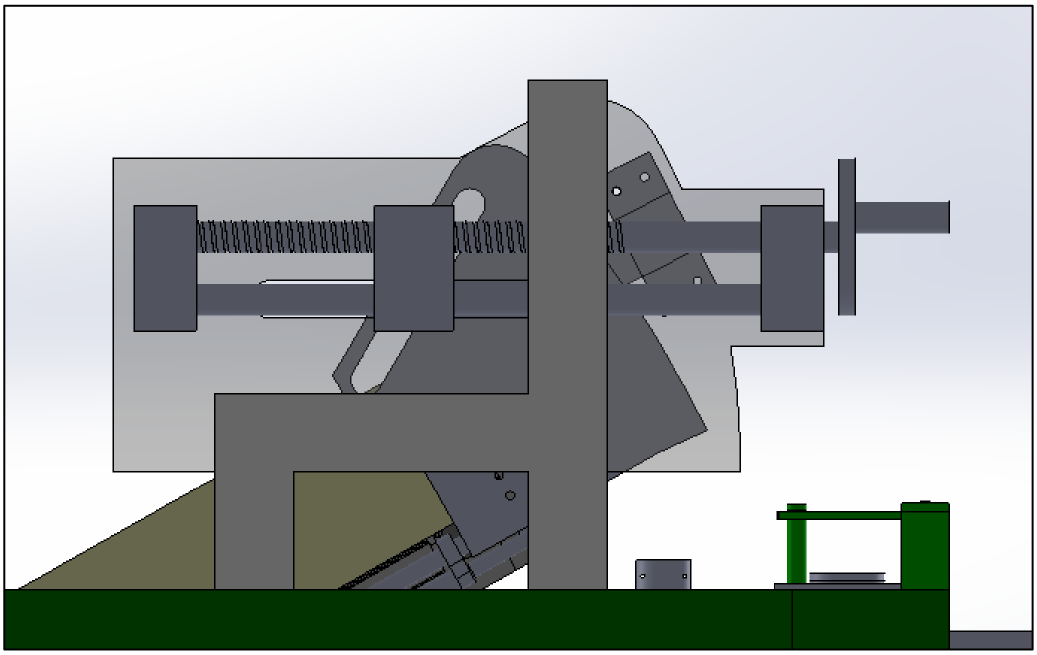


Figure 4.14 - Bottom view of angle adjustment system.

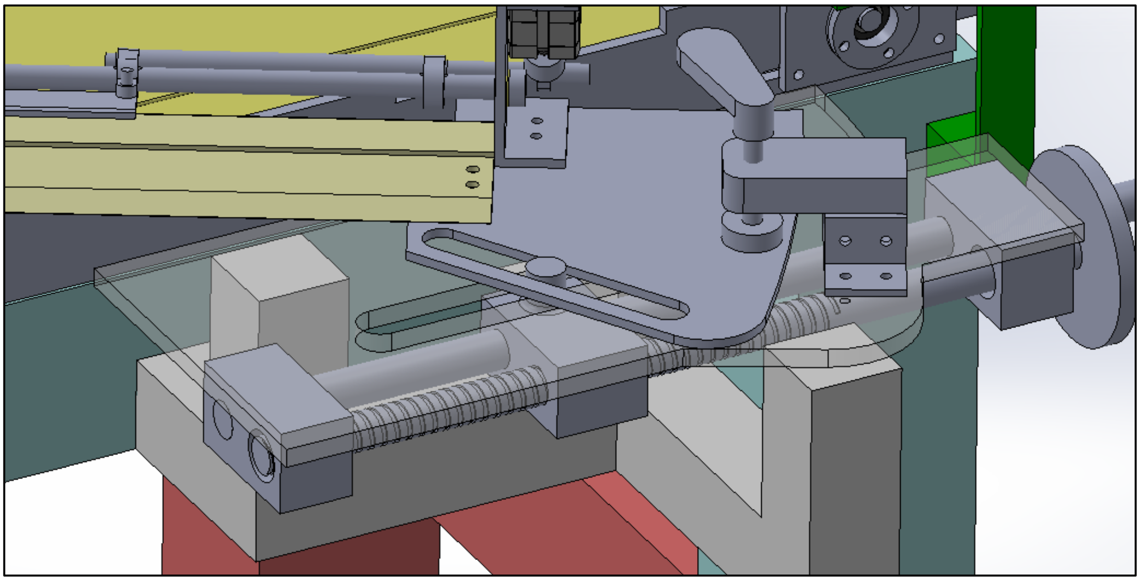


Figure 4.15 - Highlight for the circular section guide.

The angle adjustment system is fixed into the cutting conveyor's support. The structure of this system is made of square tubular profiles of dimensions 50x50x4mm as it can be seen on Figures 4.13 and 4.17.

The system is fixed by a screw clamp manually driven. This assembly is shown on Figure 4.16.

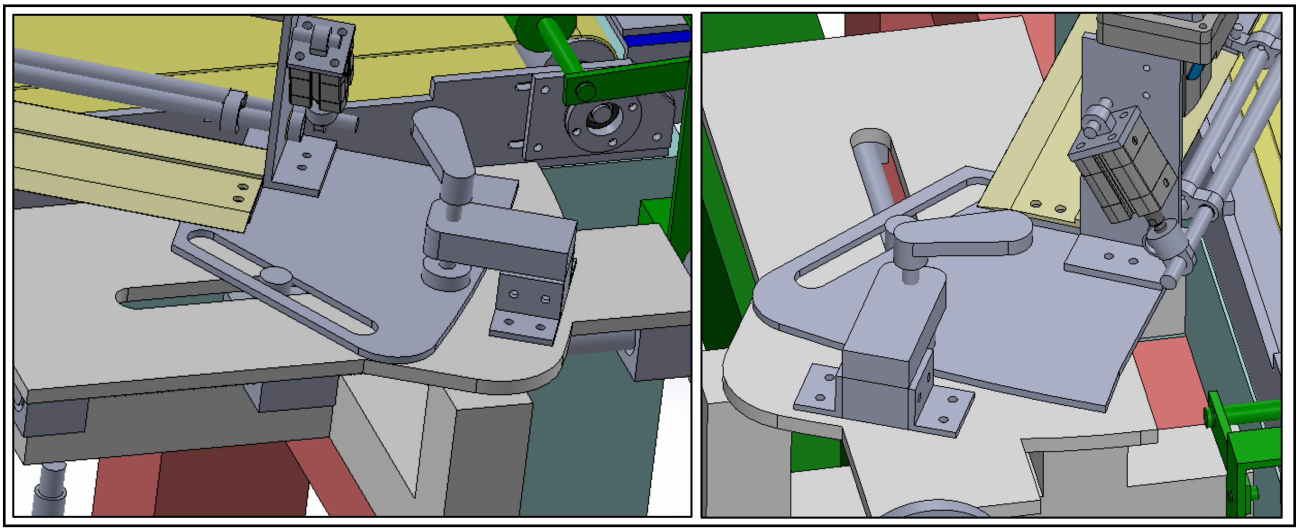


Figure 4.16 – Screw clamp to fix cutting system.

Figure 4.17 shows the complete cutting system.

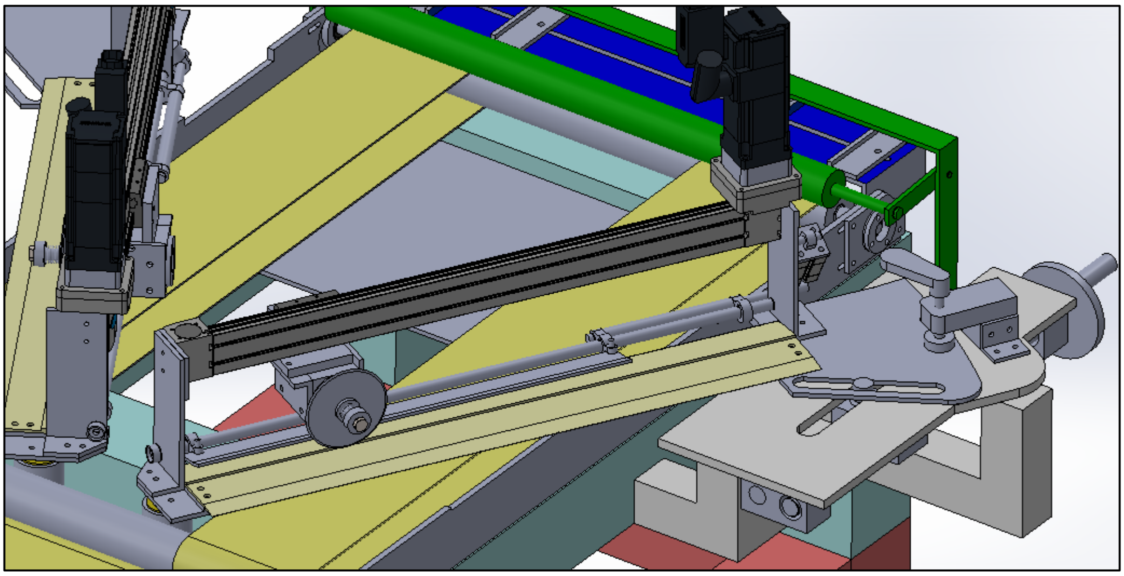


Figure 4.17 – Complete cutting system.

4.2.5. Feeding conveyor

This conveyor follows the cutting conveyor and it is responsible for the feeding of the flipper strips to the winding drum.

Like the cutting conveyor, it consists of toothed roll and belt and equal-sided angles 70x70x7mm as structure. The working diameter of this conveyor is also 50mm. In order to house a complete flipper strip, this conveyor needs a working length of 2000mm and 560mm of width, to match the cutting conveyor's total width.

This conveyor must be longitudinally free so it can move forward and backward in order to feed the strip to the winding drum. This movement is performed with the help of four-row linear ball guides. The selected guides are from Schaeffler whose reference is KUVE15-B. This movement is driven by a servomotor and two pulleys and belt. This drive system is shown in detail below on subchapter 4.2.9.

At the end there is a free rotation pressing roller that moves up and down driven by a single-acting pneumatic cylinder, of pushing action, from Festo whose reference is ESNU-12-30-P-A. This roller provides the necessary pressing over the strips when they are being winded around the winding drum. The cylinder is fixed by clevis joints at each end which allow it to articulate.

The conveyor can be observed on Figure 4.18.

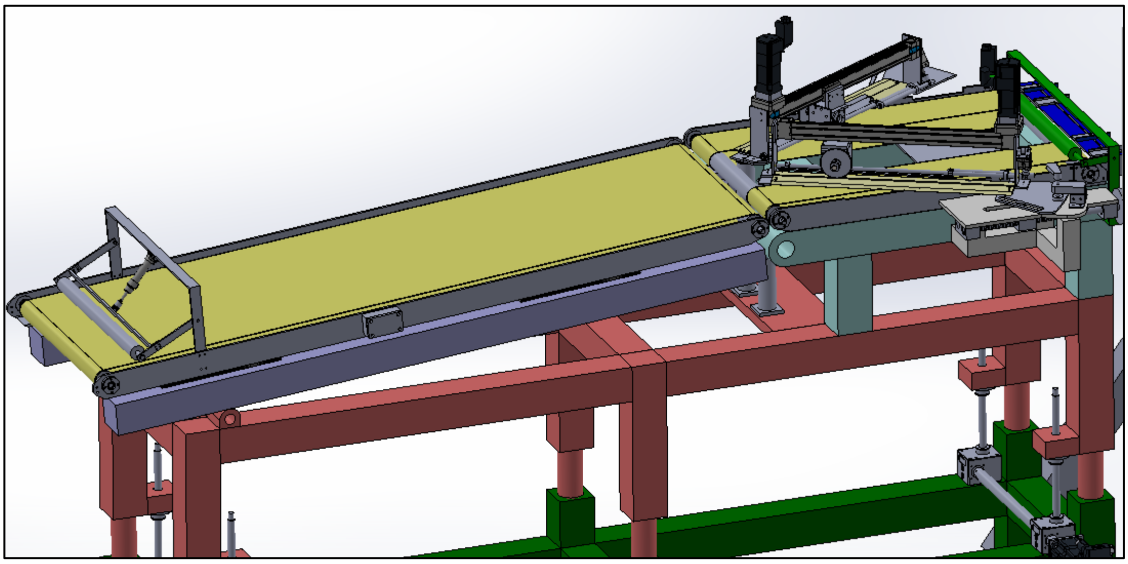


Figure 4.18 – Feeding conveyor.

This conveyor has a slope of 5° to facilitate the application of the strips on the winding drum, as shown on Figure 4.19.

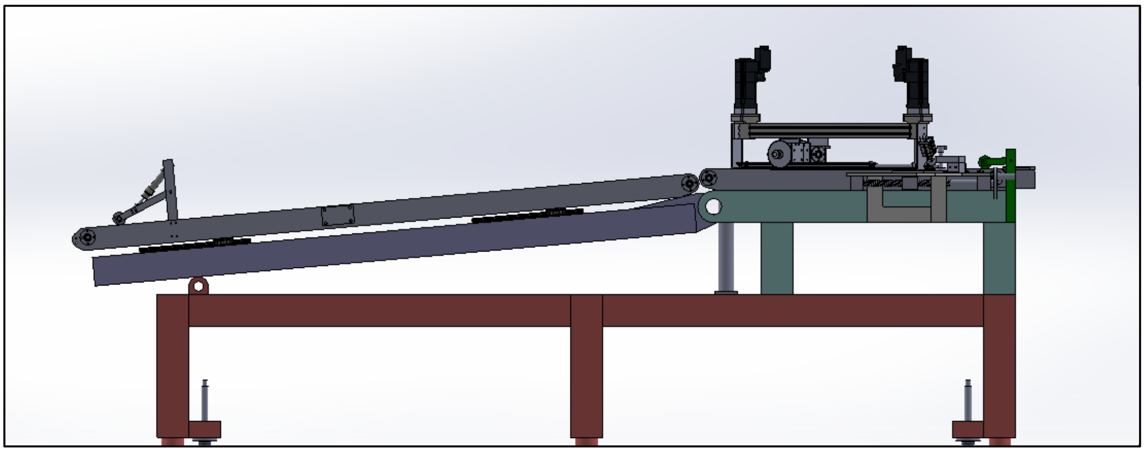


Figure 4.19 - Side view of conveyor and relative position on machine.

4.2.6. Guidance system

The lateral guiding of the strips is one of the most important elements of the machine because it assures the final quality of the product. Guidance is performed at two locations along the machine: at the beginning of the cutting conveyor and at the end of the feeding conveyor so that it guides the strips throughout the entire winding process (Figure 4.20).

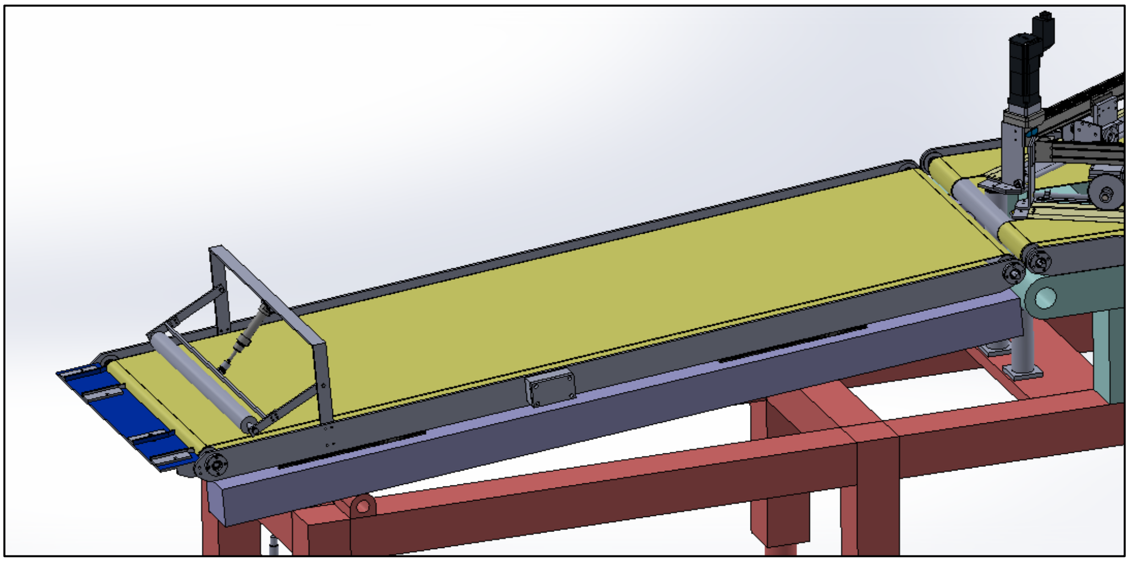


Figure 4.20 – Guidance system (in blue colour).

However, this is a simple mechanism, of manual adjustment, possibly through a hand crank or simply through a fastening screw. The centre position of the strips must also have an adjustment possibility. The standard gap between the centre of the strips is 380mm. The materials used on this system must be coated with PTFE (Polytetrafluoroethylene) to minimize friction between the guidance system and the flipper strips. A sketch of this system can be seen on Figure 4.21 for a better understanding.

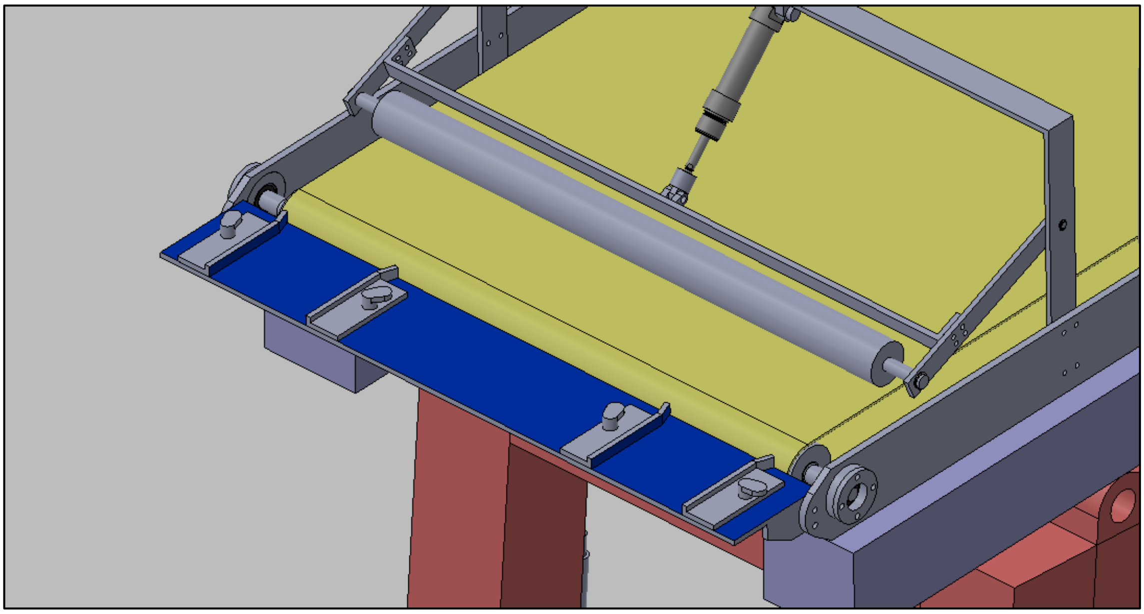


Figure 4.21 - Guidance system at the end of the delivery conveyor (in blue colour), version with fixing screws.

The guidance bar should be numbered with a metric scale, just like a ruler, so that there is a visual confirmation of the values that are being used. This is important for an easy alignment of the beginning and ending guides.

4.2.7. Winding drum

The winding drum is the module where the main task is performed and where the operator performs most of his work. As it was already mentioned, an existing machine part will be refurbished and used to build this module. On Figures 4.22 and 4.23 it's possible to have an idea of the general view of this component.

Figure 4.22 – Winding drum (1).

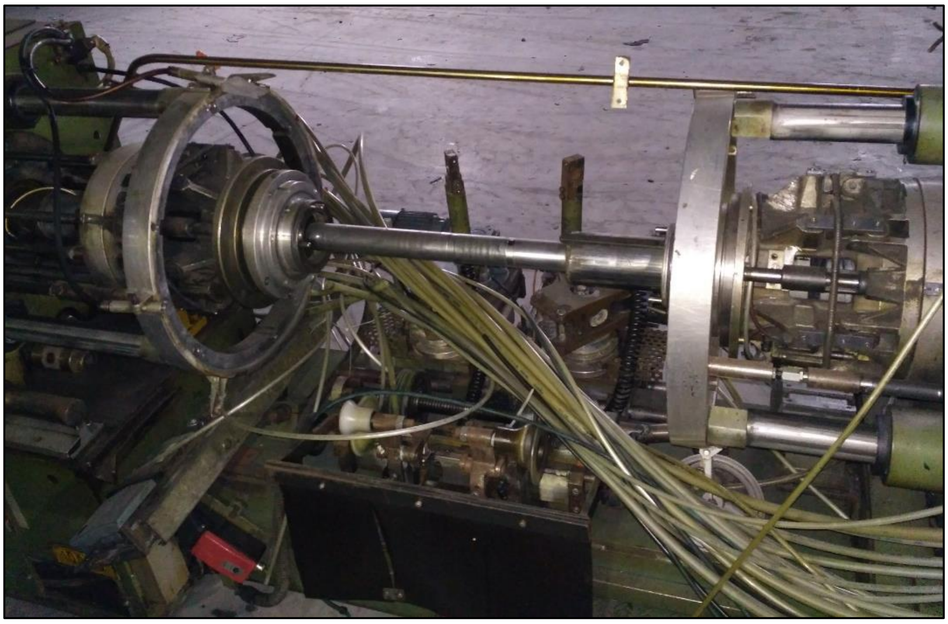


Figure 4.23 – Winding drum (2).

The tooling is mounted on this component. The tooling includes an expansible drum, at the middle, and also two diaphragms, one on each side of the drum, that will allow the wrapping of the strips around the beads when the diaphragms expand. On Figure 4.24 it may be seen a sketch of the drum with the tooling mounted. The central part in dark yellow presents the drum and the diaphragms are shown in blue. On the drum it is possible to see the segments that will allow its expansion.

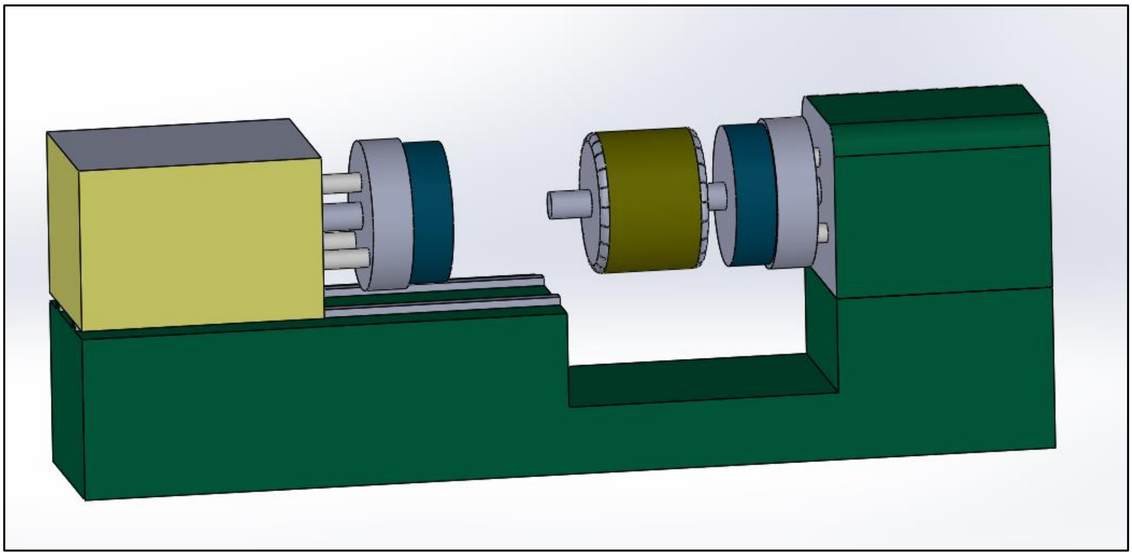


Figure 4.24 – Simulation of winding drum with tooling.

On this module, some modifications are necessary to be performed, mainly on the central drum, in order to achieve a final product according to the given specifications.

Two main challenges were identified. The first is the lack of friction between the strips and the drum. The second is the fact that, in case of reusing the existing segments in the drum, the material will present an inadequate curvature at the end of the wrapping process. This curvature doesn't allow to use the final product on the KM machines. On Figure 4.25 an example of how this curvature can be is shown for a better understanding.

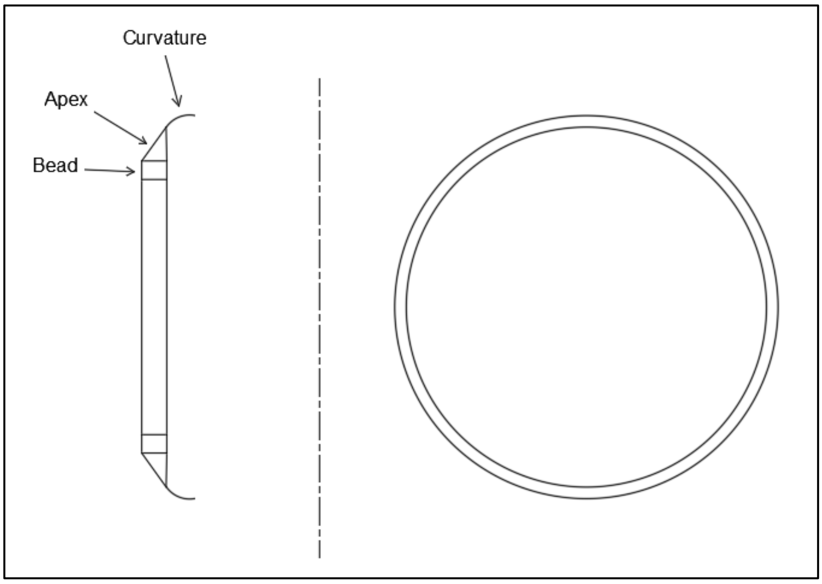


Figure 4.25 - Scheme of the curvature problem at the end of the process.

To solve these two challenges, the segments had to be redesigned.

Currently used segments are a single piece, however these new segments are made of several elements and moving parts.

On Figure 4.26 it may be seen the concept and design used for these new segments.

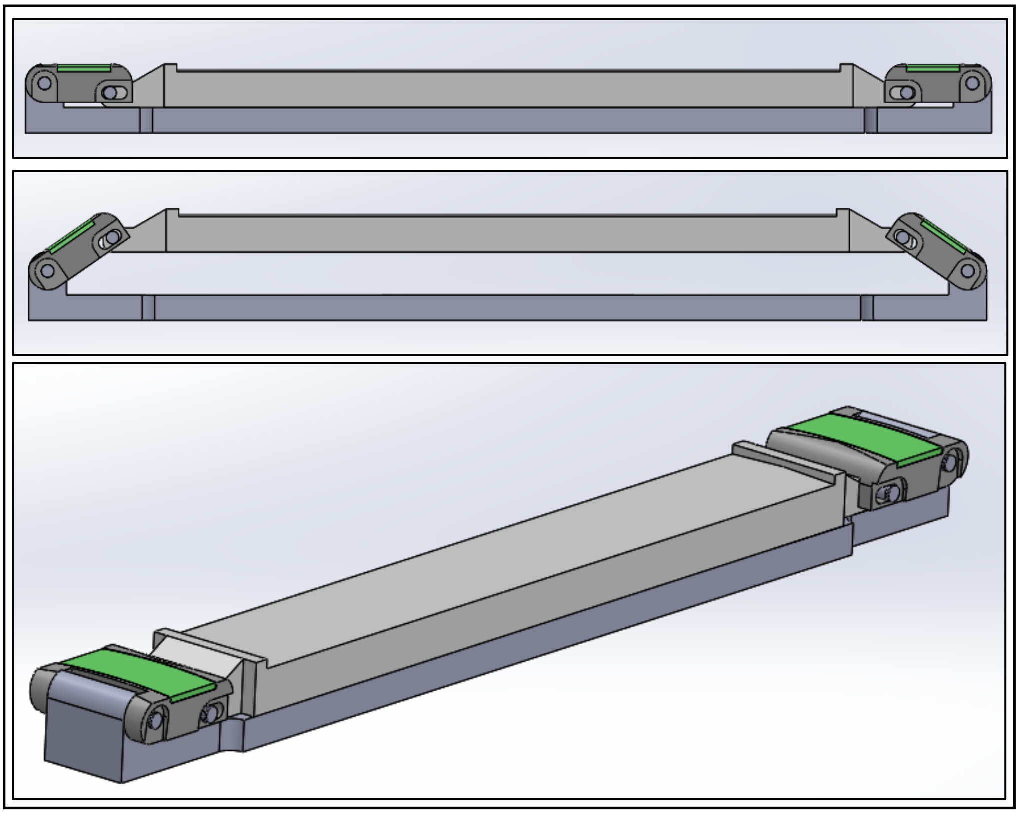


Figure 4.26 - Segment appearance with closed drum (a); segment appearance with expanded drum (b); overview of the new segment (c).

Considering Figure 4.26 analysis it's possible to see the initial state of the segment, (a), and, afterwards, how it looks with the expanded drum, (b). The drum expansion and the segment opening movements are performed by a wedge system. The wedge system is driven pneumatically. This opening of this segment is the proposed solution to prevent the curvature issue from happening. Regarding the friction issue, strips of adherent material were incorporated into the segment ends.

The segments return to the initial state when the pneumatic system is deactivated and the wedge system retracts due to a spring.

On Figure 4.27 it's possible to see a sketch of a non-expanded drum montage with the new segments.

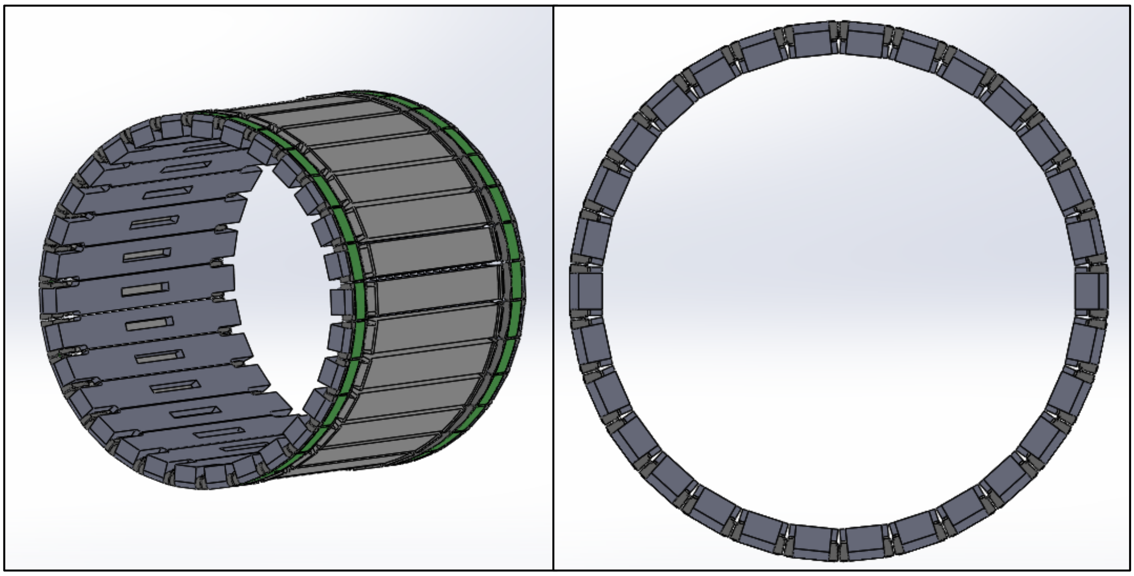


Figure 4.27 – Simulation of drum assembly with new segments.

On appendix C the construction drawings of each one of the pieces that constitute the set of segments are shown.

For an effective friction between the flipper strips and the drum it is also necessary a final pressing roller. This roll is placed above the drum and it consists of a free rotation pressing roller and two linear recirculating ball bearing guides. This module is driven by a double-acting pneumatic cylinder. On Figure 4.28 this module is shown.

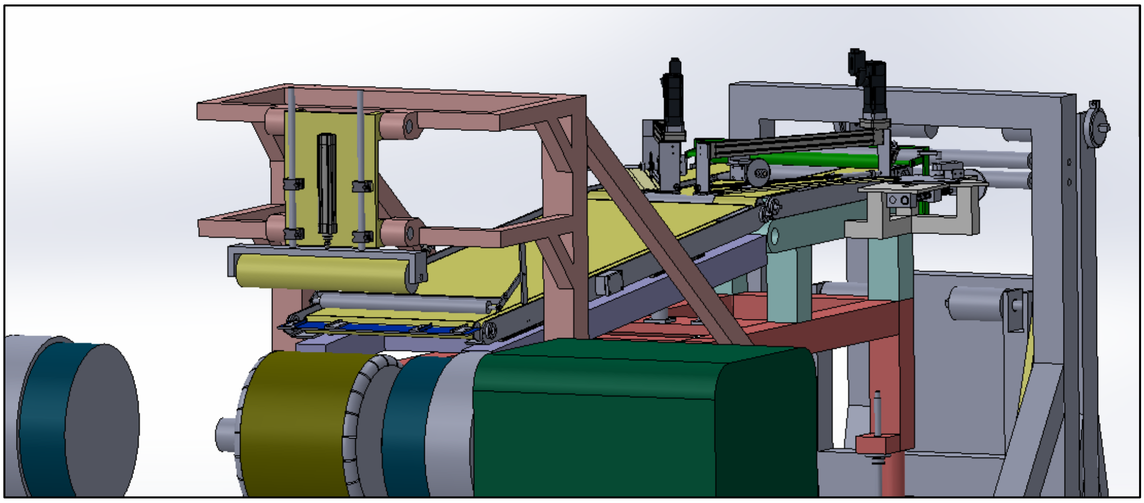


Figure 4.28 – Sketch of pressing roller.

This pressing module has a linear stroke of 200mm for all rim sizes because its structure is fixed to the conveyors structure and it is moved by the height adjustment which will be described later. This can be seen on Figure 4.29.

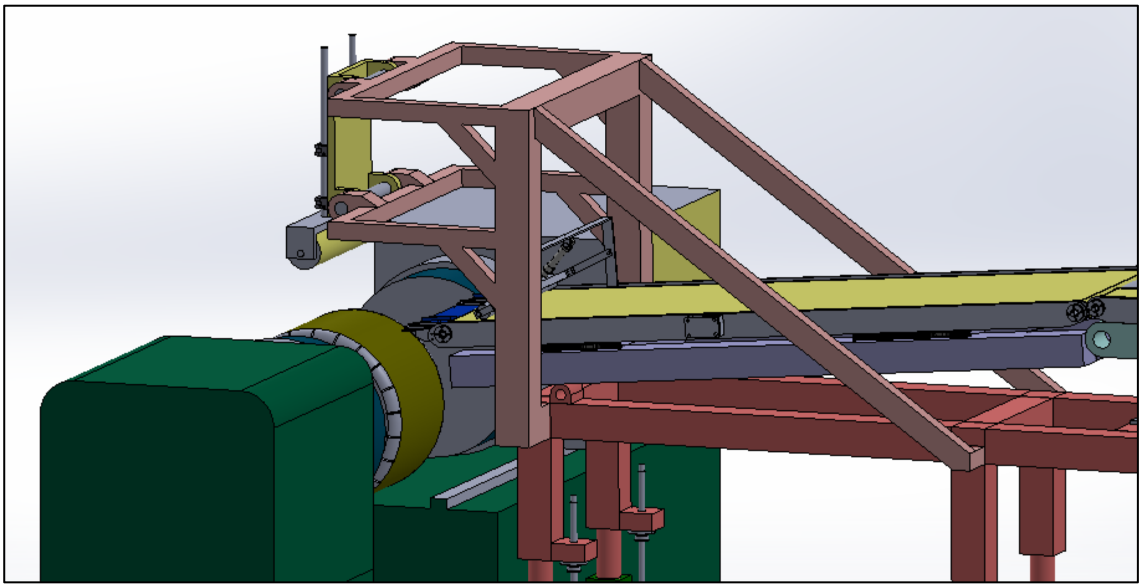


Figure 4.29 – Highlight for the support structure of the pressing roller system.

4.2.8. Transport of the strips

The transport of the strips is performed by a single servomotor. The transmission is made with pulleys and toothed belt. As the working diameter of the conveyors is the same, the drive pulleys of each conveyor must be equal as well, to ensure the synchronism. From the pulley on the servomotor shaft to the drive pulleys of the conveyors there is a 2:1 reduction. Besides this, the servomotor comes equipped with a 4:1 planetary gearbox. As the cutting conveyor is not meant to be always working, for a good machine performance, there is a toothed electromagnetic drive clutch. Example: during the winding application of the strips around the drum the cutting conveyor cannot move. This system can be seen on Figure 4.30 and its relative position on the machine on Figure 4.31.

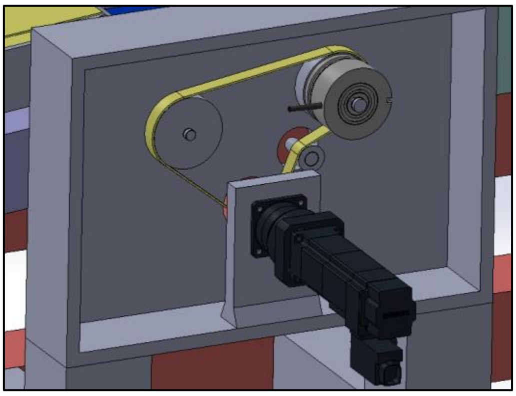


Figure 4.30 – Motion transmission system for advancing the strip.

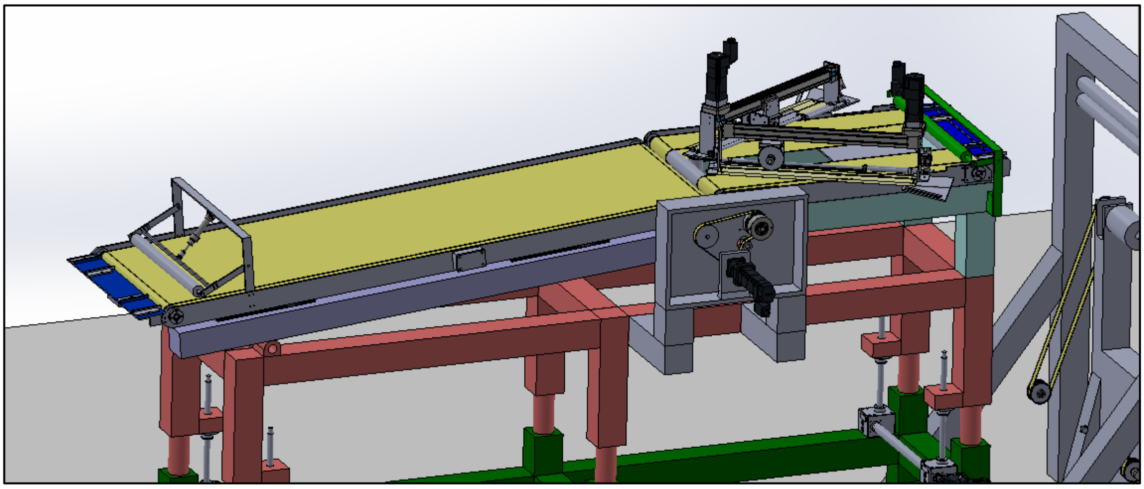


Figure 4.31 – Overview of the feed of the machine, highlight for the transmission system for advancing of the strip.

The transport of the strip to the cutting position must be made in less than 5 s. The most demanding requirement, mainly in terms of speed, is for the positioning of the longest strip with a value of 1654mm.

The positioning control is going to be done according to the function:

$$x = A\ sen^2\left(\frac{\Pi}{2} * \frac{t}{T}\right) \qquad (4.1)$$

- x = position over time t;
- A = distance to advance;
- T = Total time of the movement;

In this way it's possible to obtain a most precise positioning and also accelerations with smoother variations when compared to a profile with acceleration and deceleration ramps and a fairly constant velocity stage.

Figures 4.32 and 4.33 show the charts obtained from the position and the velocity profile, respectively, over the time of this movement.

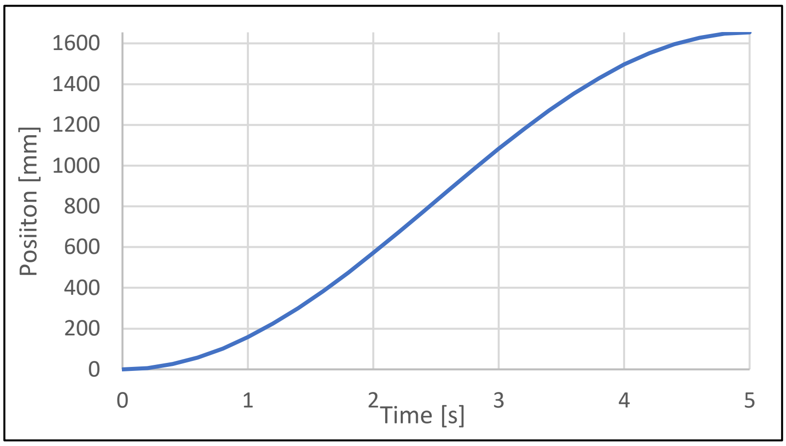


Figure 4.32 – Position over time, forward movement of the strip.

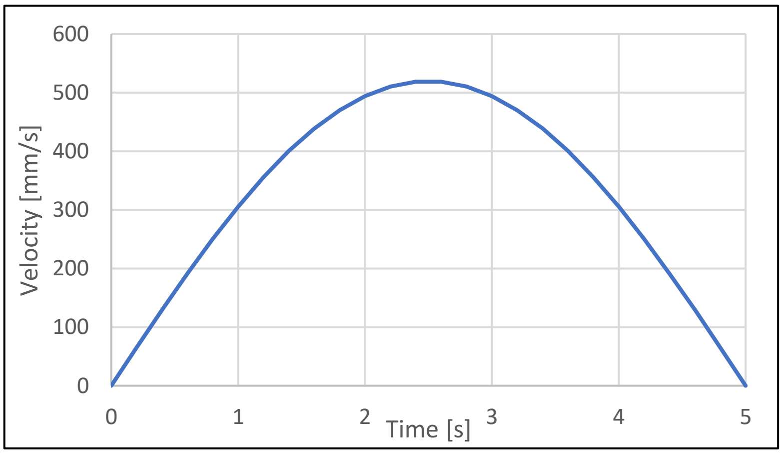


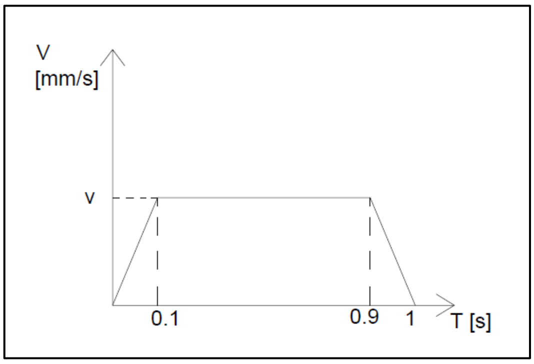
Figure 4.33 – Velocity over time, forward movement of the strip.

In the chart of Figure 4.33 it can be seen that the maximum velocity is about 520mm/s reached at 2,5 seconds.

Knowing that the radius of conveyor is 25mm and that there is an 8:1 reduction in the system, the maximum rotation speed of the servomotor is:

$$\frac{520}{25} * \frac{30}{\Pi} * 8 = 1589\, rpm \tag{4.2}$$

The winding of the strip around the drum must be done within 1 second, with an acceleration time of 0,1 seconds. In this case, as the strips are already cut with the required length, such precision of positioning is not necessary. It is only necessary to ensure a complete rotation of the drum. The velocity profile is represented below.



This way the maximum winding speed is:

$$\frac{v}{2} * \ 0{,}1 + v * 0{,}8 + \frac{v}{2} * 0{,}1 = 1654 <=> \ v = 1838\, mm/s \tag{4.3}$$

The rotation speed of the servomotor, taking into account that it should be about 1% lower than the drum velocity so that the strip can have some tension, is then:

$$\frac{1838}{25} * \frac{30}{\Pi} * 8 * 0{,}99 = 5560\, rpm \tag{4.4}$$

As the strip presents an irrelevant load over the servomotor, this was selected taking into account only the rotation speed.

The chosen servomotor is from Siemens, it has a nominal velocity of 6000 rpm, a static torque of 0,8 Nm and 400 W nominal power. It comes equipped with a 4:1 planetary gearbox as it was already mentioned. The reference of this component is 1FK7022-5AK71-1DG5-Z J02. On appendix B it may be consulted the datasheet of this motor.

4.2.9. Movement of the feeding conveyor

This movement is performed by a system with two pulleys and toothed belt. This system is driven by a servomotor. In order to allow this movement, the coupling of the conveyor's roller to the pulley responsible for the advancement of the strips is made by one universal telescopic joint. The linear path intended for this movement is 250mm, to be executed in 0,75 seconds. This movement also needs precise positioning and regarding accelerations it is more critical due to the load involved. So, for the control, it will be used the function 4.1.

For this movement A = 250 mm and T = 0,75s. On Figures 4.34, 4.35 and 4.36 it is possible to analyse the profiles of position, velocity and acceleration throughout the period of the movement.

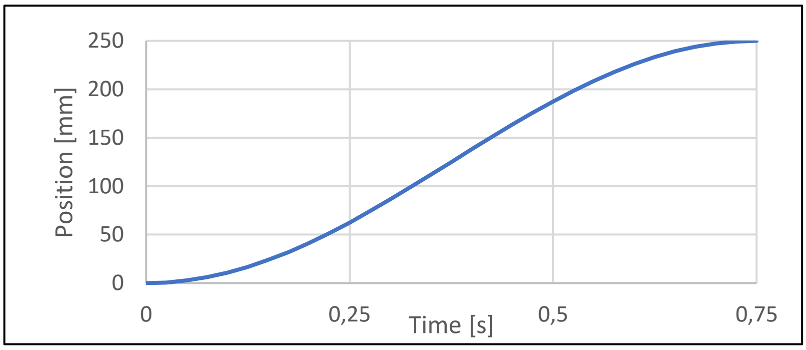


Figure 4.34 – Position over time, movement of conveyor advance.

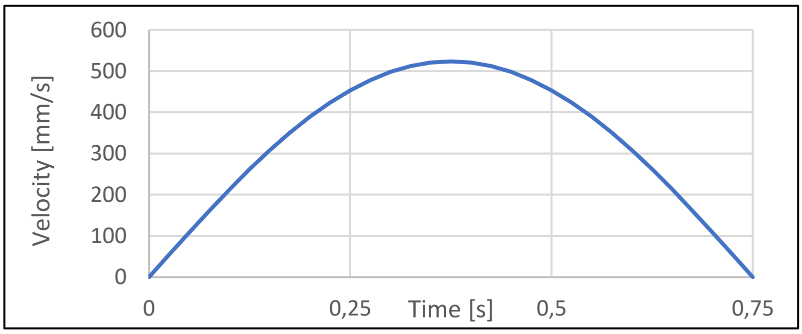


Figure 4.35 – Velocity over time, movement of conveyor advance.

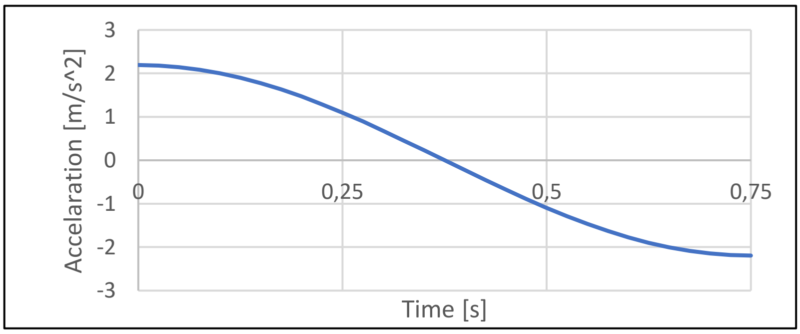


Figure 4.36 - Acceleration over time, movement of conveyor advance.

The sectioned pulleys are "timing belt" type, with T10 profile. More specifically, the pulleys 40 T10 / 12-2, which have 12 teeth and a primitive diameter of 38,20 mm, were selected. This configuration results from a calculation on a software developed by Optibelt. The results can be consulted on appendix D.

The maximum velocity reached by the conveyor is, from the chart of Figure 4.35, 524 mm/s reached at 0,375 seconds.

So, the maximum rotation speed reached by the servomotor, knowing it is going to have a planetary gearbox with a 10:1 reduction, is:

$$\frac{524}{38{,}20/2} * \frac{30}{\Pi} * 10 = 2620\ rpm \tag{4.5}$$

On the other hand, assuming that the conveyor mass is about 60 Kg and taking into account the 5º slope, the maximum force required is:

Maximum acceleration: 2,19 m/s^2, by analysis of the function referring to the chart of Figure 4.36;

Maximum force: $F = 60 * 2{,}19 + 60 * 9{,}81 * sin(5^{\circ}) = 182{,}7\ N$ (4.6)

And the maximum torque applied to the servomotor is: $T = F * \frac{r}{i} + m * g * 4\ \mu * \frac{r}{i}$

- r = pulley radius;
- i = reduction;
- g = acceleration of gravity;
- µ = coefficient of friction of the linear guide;

$$T = 182{,}7 * \frac{0{,}0382}{2 * 10} + 60 * 9{,}81 * 4 * 0{,}002 * \frac{0{,}0382}{2 * 10} = 0{,}358\ Nm \tag{4.7}$$

The calculated power is: $P = 182{,}7 * 0{,}524 = 96\ W$ (low);

The chosen servomotor is from Siemens, it has a nominal velocity of 6000 rpm, a static torque of 0,8 Nm and 400 W nominal power. It also comes equipped with a 10:1 planetary gearbox as it was already mentioned. It's important that it comes equipped with a brake due to the slope of the conveyor. The reference of this component is

1FK7022-5AK71-1DH5-Z-J09. On appendix B it may be consulted the datasheet of this motor.

The system and its relative location on the feeding conveyor can be seen on Figures 4.37 and 4.38.

The system should also have a belt tensioning adjustment.

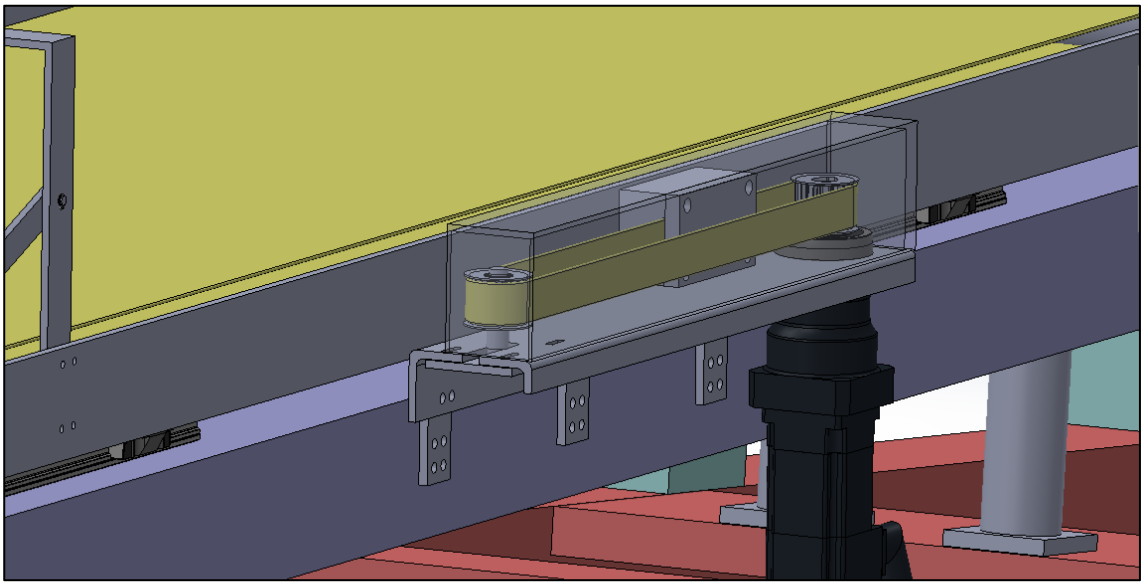


Figure 4.37 - Conveyor advancing system.

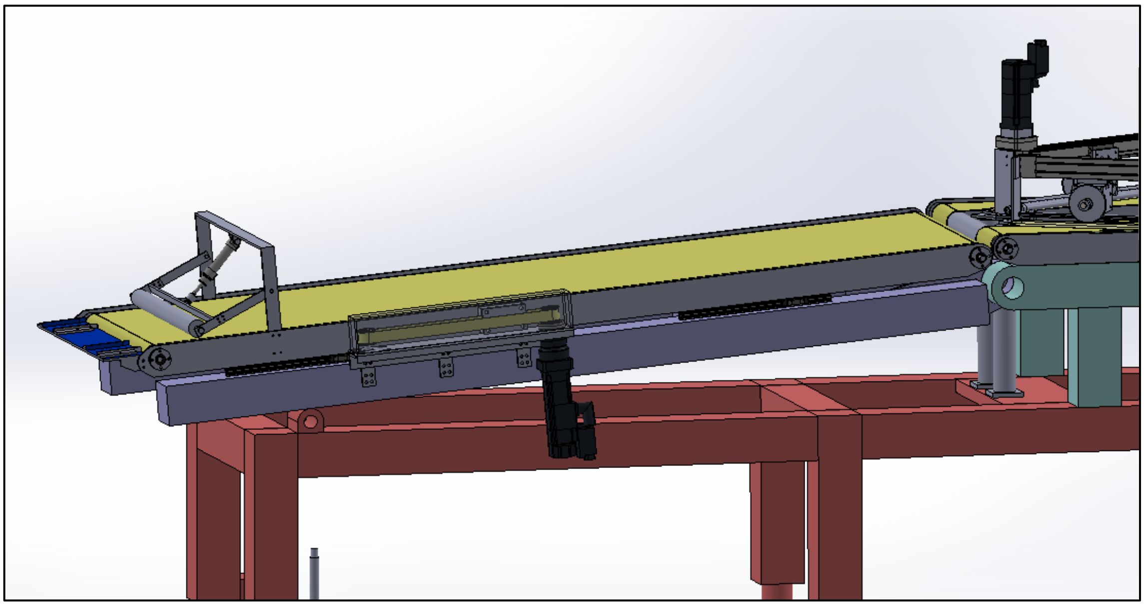


Figure 4.38 – Conveyor advancing system relative position on feeding conveyor.

Total cycle time for preparation task

Considering the cycle times presented on the last chapters it results that the total cycle time of the preparation task is:

- Retract of feeding conveyor……………………………… 0,75 s;
- Transport of the strips to the cutting position………… 5 s;
- Cutting……………………………………………………………2 s;
- Positioning of the strips……………………………………….1 s;
- Advancement of feeding conveyor……………………… 0,75 s;

Total = 9,5 s.

This way, the maximum cycle time of 10 seconds for the preparation defined on chapter 4.1.1. is ensured.

As at the end of each cycle results two final products, with three shifts of seven hours each it is possible to obtain 10 080 beads with flipper per day. A raise of 7500 (300%) units regarding the current solution, considering a total cycle time of 15 s on this new machine.

$$2 * \frac{21\text{h} * 3600\text{ s}}{15\text{ s}} = 10\ 080\text{ units} \tag{4.8}$$

The time required for the application of the flipper on the KM machine is over 10 s each cycle. Currently, over 1300 flipper applications per day are performed on KM machines. It is possible then to free the machines 3,6 h per day to produce more tyres.

$$1300 * \frac{10\text{ s}}{3600} = 3{,}6\text{ h} \tag{4.9}$$

This value may represent a raise on production of over 180 units per day. In one year the obtained value is:

$$180 * 30 * 12 \ \cong 65\ 000\text{ tyres} \tag{4.10}$$

From some budgets acquired from suppliers, the construction and installation of the machine will be less than 100 000€. Therefore, the investment is plainly justified.

4.2.10. Height adjustment

The height adjustment of the machine is important due to the range of rim sizes that are intended to be produced. The adjustment is made using four points with cubic screw jack assemblies from Kelston with a 16:1 worm reduction. The possible linear path is 300mm, the screw pitch is 0,5 mm/rev and each assembly can hold up to 10kN. The reference of this component is C037-R-050-0300S-N. Two servomotors drive the system. Each servomotor drives two screw jack assemblies which are connected by a shaft. Each one of these systems is placed at each end of the structure, for better weight distribution.

A sketch of this system can be seen on Figure 4.39. The part of the structure which moves along with the nut is shown in red, and the fixed part that supports the screw can be seen as green.

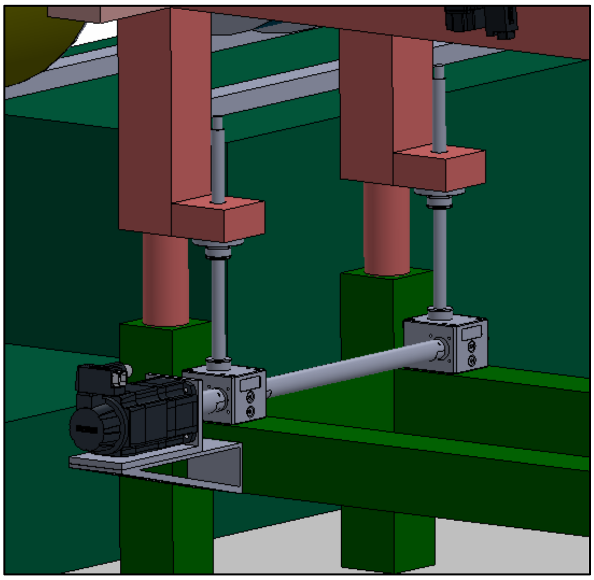


Figure 4.39 – Height adjustment system (1).

The structure and the components which have to be lifted have an estimated mass of 750 kg, and, therefore, an approximate weight force of 7500 N. It is intended that the 300mm of path is executed with a velocity of 15 mm/s, due to the 1800 rpm limit input speed on the screw.

Considering that the weight is evenly distributed, although it is not accurate, each system will support 3750 N. It turns out that each motor needs 3750 * 0,015 = 56 W of average power.

Considering the datasheet of this product (appendix E), the input torque to lift a 10kN load with a single screw is 2,78 Nm.

Based on these obtained and calculated data, a SIEMENS servomotor with static torque of 3 Nm, a nominal speed of 6000 rpm and 1 kW nominal Power was chosen. The motor also comes equipped with a brake to ensure that the load doesn't move the drive when it is not running. The reference of this motor is 1FK7042-2AK71-1DB0. On appendix B it may be consulted the datasheet of this motor.

On Figure 4.40 it may be seen a sketch of these two systems on the machine.

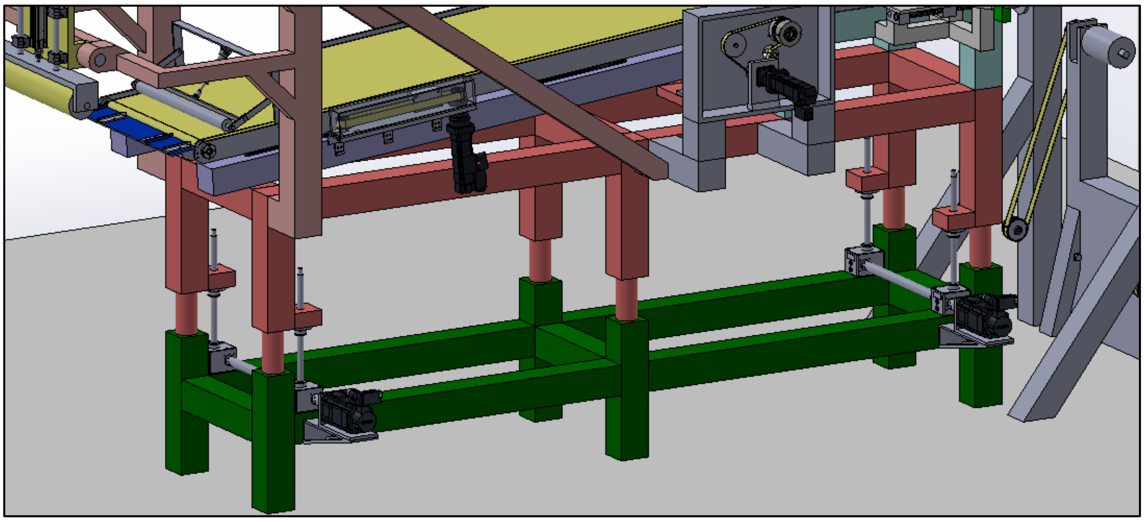


Figure 4.40 – Height adjustment system (2).

The guiding of the structure is made by the 6 legs of the structure, of rectified and lubricated cylindrical form (Figure 4.41).

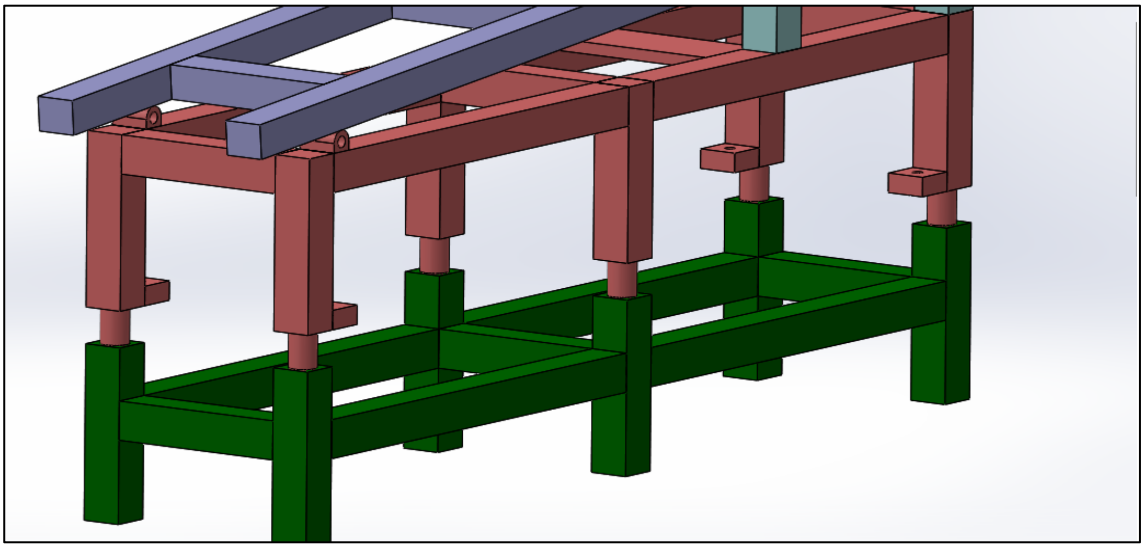


Figure 4.41 – Height adjustment guidance system.

4.2.11. Structure

The structure of the machine is made of square tubular profiles of dimensions 100x100x10mm, the main structure is represented on Figure 4.42.

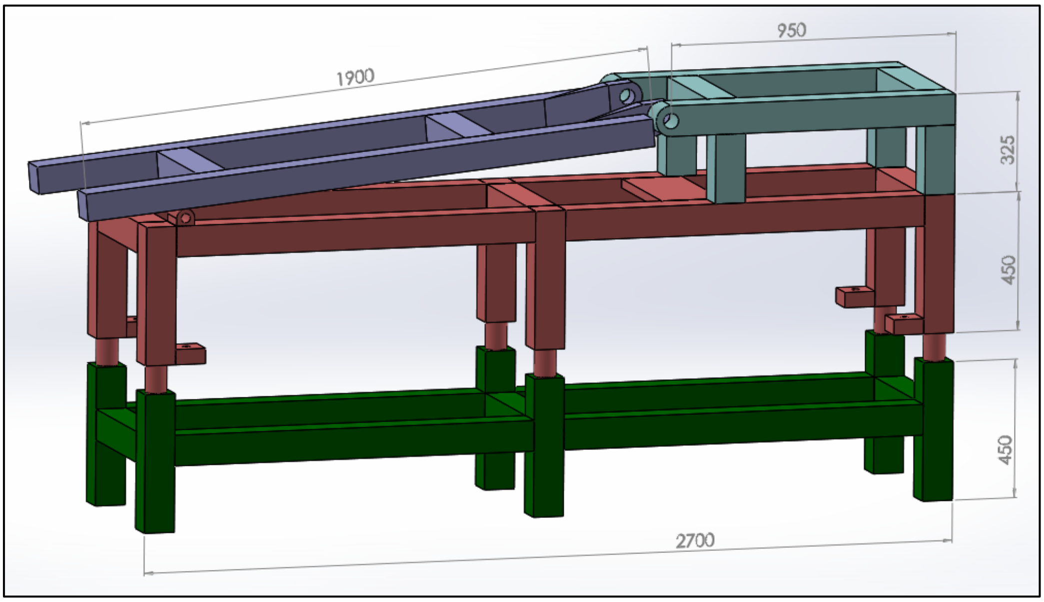


Figure 4.42 – Machine main structure.

The length and the width of the structures seen in green and red are 2700mm and 650 mm, respectively. The height of the green structure is 450mm and the height of the red structure is also 450mm.

The length of the shown structure in grey is 1900mm and the length of the blue one is 950mm (from the end to the centre of the hole). The width of both is 650mm as well. The height of the blue structure is 325mm.

The shown structure in grey has to be lowered regarding the shown structure in blue so that the feeding conveyor is also lowered relatively to the cutting conveyor for a better transition of the strips (Figure 4.43).

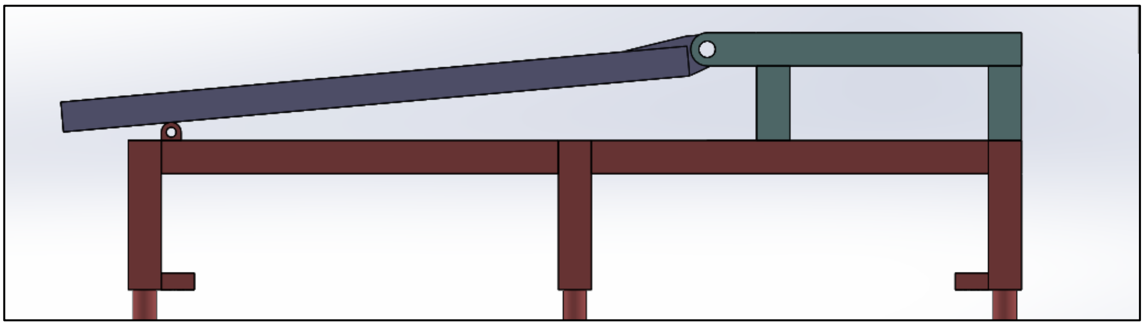


Figure 4.43 – Detail of lowering of the structure.

4.2.12. Final configuration

On Figure 4.44 the final complete configuration of this new machine is shown.

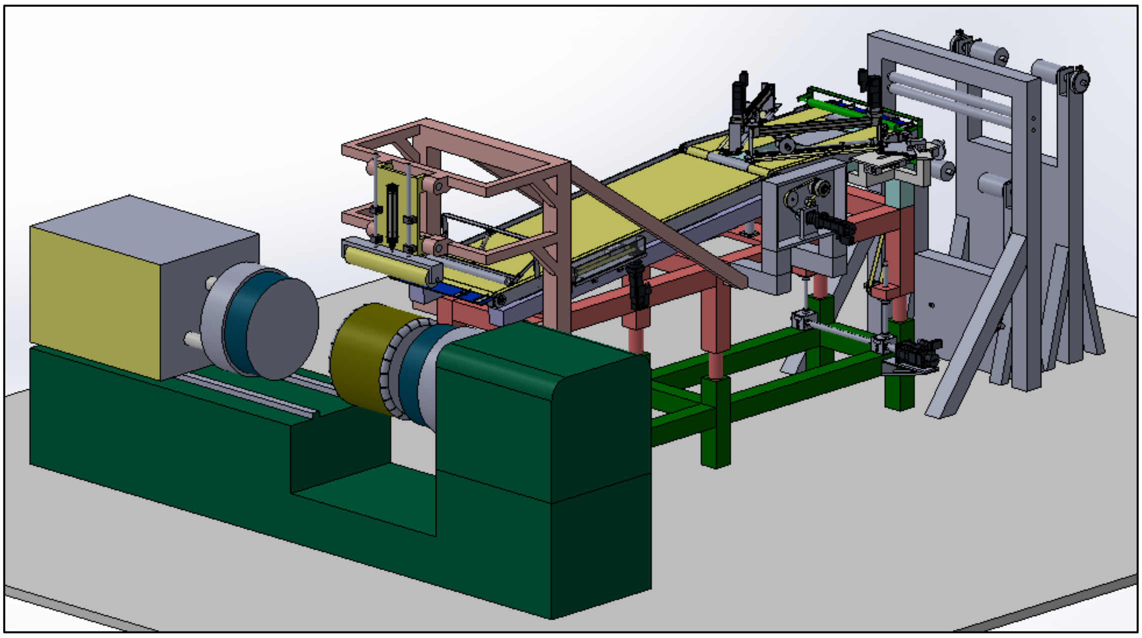


Figure 4.44 – Sketch of machine final configuration.

4.2.13. Safety

As this machine has several moving parts as: pressing rollers, winding drums, conveyors, etc. and two cutting systems, it is necessary to have some safety devices to reduce or eliminate risks for the operator, or for any other intervener.

It was chosen to isolate the machine completely. This way nobody has access to the machine while it is running on automatic mode. On Figure 4.45 it is shown how the machine is protected. There are safety grids on the sides of the machine with two safety doors represented in red to facilitate operations of maintenance. On the back there is an opening to facilitate the reels changing protected by safety beams, represented in blue.

On the winding drum there are safety beams as well to protect the operator when this component is operating on automatic mode. All automatic modes must stop when any safety device is triggered.

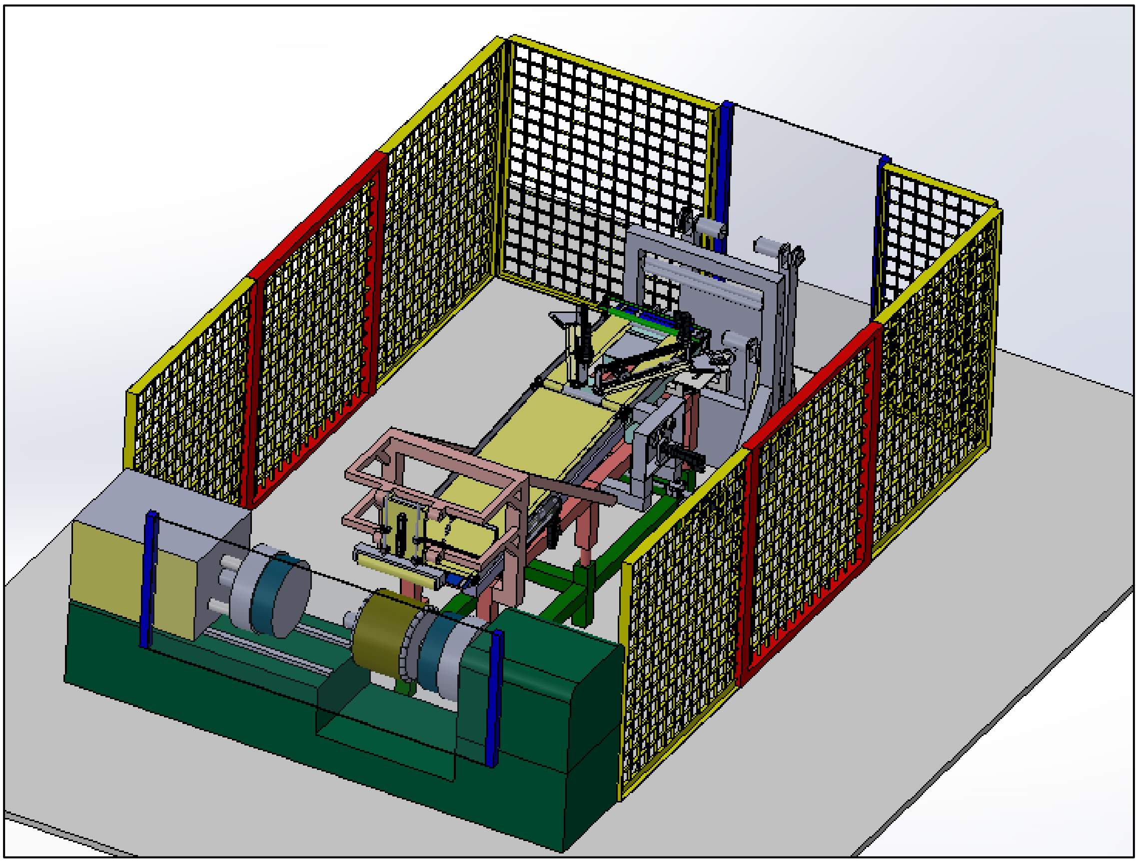


Figure 4.45 – Safety devices implemented on the machine.

4.3. Summary of parameters

Table 4.1 – Summary of parameters (1).

Module	Parameter	Requirements
Let off	Motor rotation speed	Constant speed of 42 rpm
	Motor Power	0,37 kW
Cutting conveyor	Working length	1000 mm
	Width of each belt	140 mm
	Gap between belts	280 mm
Cutting system	Linear velocity	180 mm/s
	Standard cut angle	30°
Feeding conveyor	Working length	2000 mm
	Width	560 mm
	Slope	5°
Transport of the strips	Maximum rotation speed	1589/5560 rpm
	Servomotor	1FK7022-5AK71-1DG5-Z J02
Movement of the feeding conveyor	Maximum rotation speed	2620 rpm
	Period	0,75 seconds
	Servomotor	1FK7022-5AK71-1DH5-Z J09
Height adjustment	Cubic Screw Jack	C037-R-050-0300S-N
	Path	300 mm
	Linear velocity	15 mm/s
	Servomotor	1FK7042-2AK71-1DB0

Table 4.2 – Summary of parameters (2)

	Parameter	Requirements
Quality	Step of the amendment	0 ± 3 mm
	Step of turning	12 ± 5 mm
	Overlap	8 ± 5 mm
Range	Width of the strip	75 - 90 mm
	Rim	16” – 20”
	Length of the strip	1317 – 1654 mm
Productivity	Cycle time	<15 seconds

4.4. Sensors

For a correct operation of the machine, in order to ensure the process and its quality, it will be necessary to consider several sensors. This chapter will describe the selected sensor types, their locations on the machine and their functions will be described.

"Let off" and "loop"

On this module it is necessary to consider six photoelectric sensors:

- 2 sensors will be used to detect a break of the material or the end of a reel, triggering, whenever any of these cases happen, a warning to the operator is sent and he will proceed as necessary;
- 4 sensors will be used for the loop control of each strip because each loop has its own control and drive. Two sensors define the lower limits, turning off the motor every time this limit is reached. The other two define the upper limit of each loop, starting the motor every time this limit is reached, as well.

Cutting system

On each cutting system, two digital inductive proximity sensors and two mechanical limiting switches were considered:

- One of the inductive sensors will be used to indicate that the cylinder, and consequently the pressing plate, is already on working position and the strips are prevented from moving, so that the cutting can be performed.
- The other inductive sensor will be used at one end of the blade linear path to work as the encoder calibrator of the servomotor.
- The mechanical sensors will be placed near the ends of the blade path to disable the motor movement if it reaches, for some exceptional reason, these critical points.

Feeding conveyor

On this component of the machine, two digital capacitive proximity sensors and one digital inductive proximity sensor will be used.

The capacitive sensors are going to be responsible for the strips positioning at the end of cutting. These will be placed on the final guiding so that when the strips reach this spot the conveyor stops the transport of the strips. The strips are now waiting until they can be wounded around the drum. On the other hand, these sensors will also have the purpose of confirming that the strips have in fact been successfully fed to the winding drum. This confirmation is given as soon as the sensors fail to detect the strips.

The purpose of the inductive sensor is to mark the recoil position of the conveyor and to input a null value on the motor encoder responsible for this movement. This way, errors of the movement by accumulation are avoided. This sensor also works as an encoder calibrator if necessary.

Height adjustment

This system will work with a digital inductive proximity sensor and two mechanical sensors.

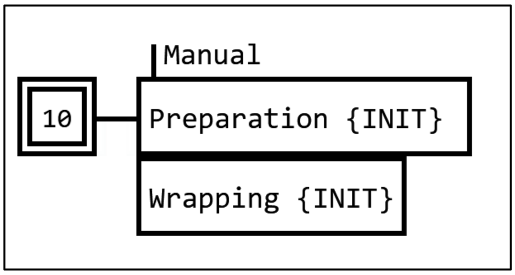
The inductive sensor works as an encoder calibrator of the servomotors which are responsible for this movement. The mechanical sensors will work as safety limit switches in case something unexpected happens.

Servomotors

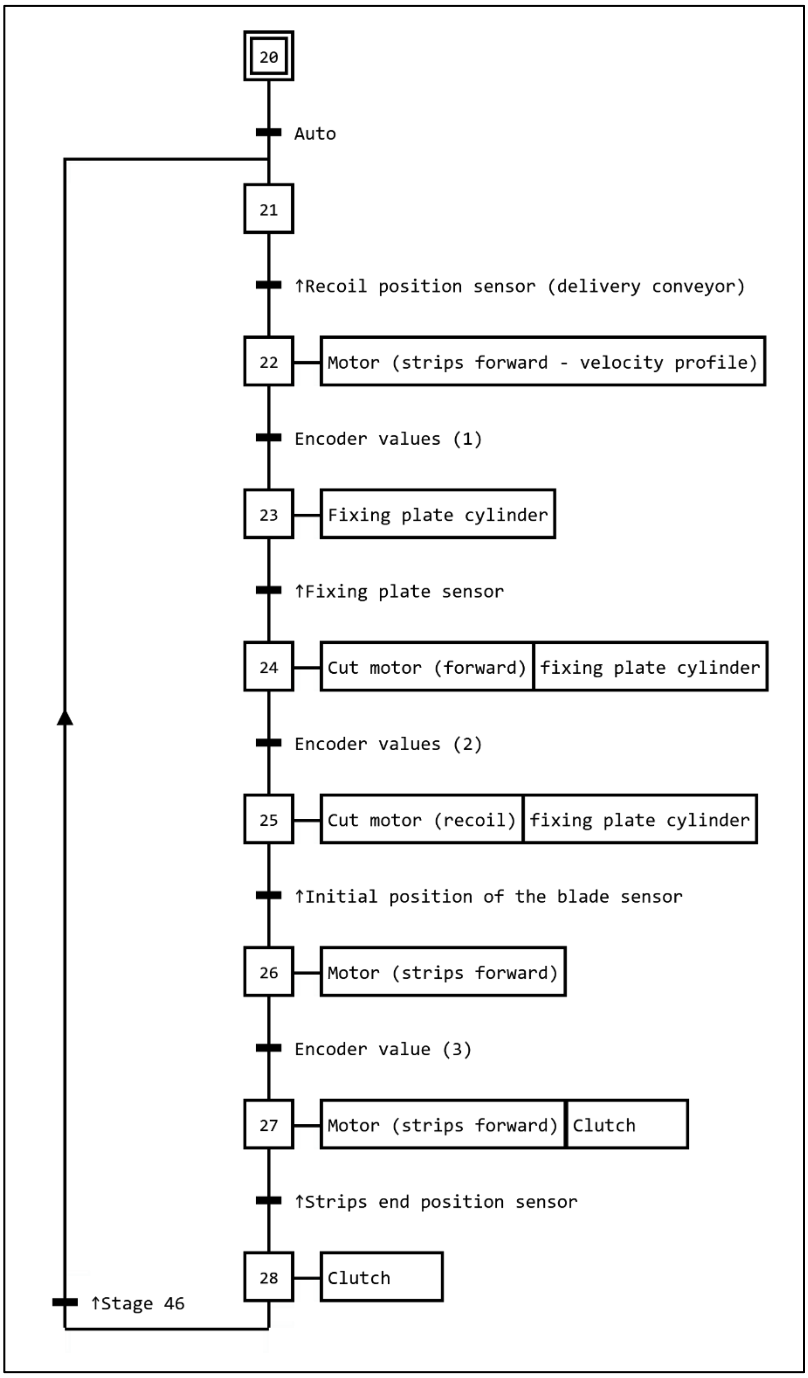
All servomotors are equipped with incremental encoders with driveCLiQ interface from Siemens.

4.5. Grafcet's

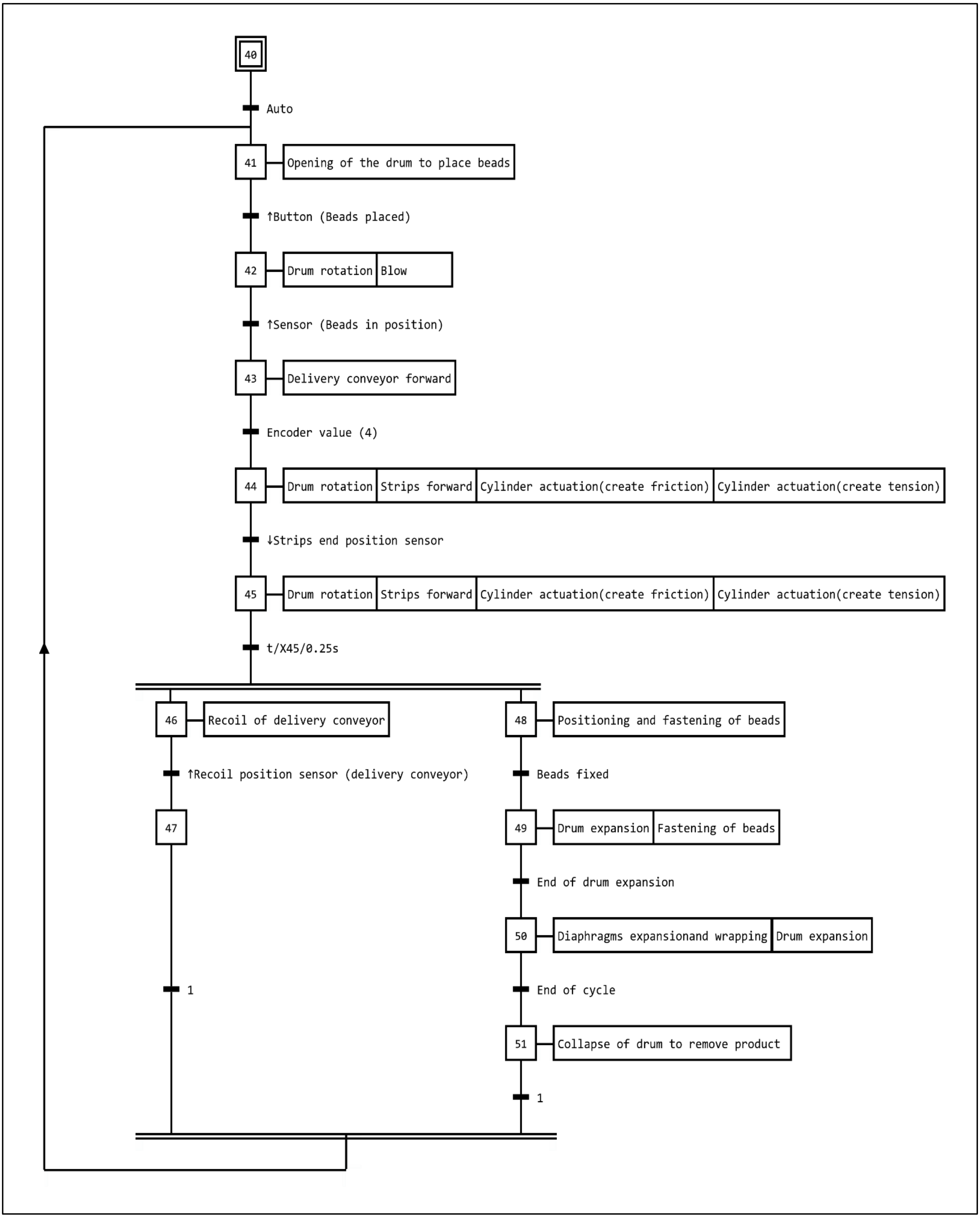
Initializer (man/auto):



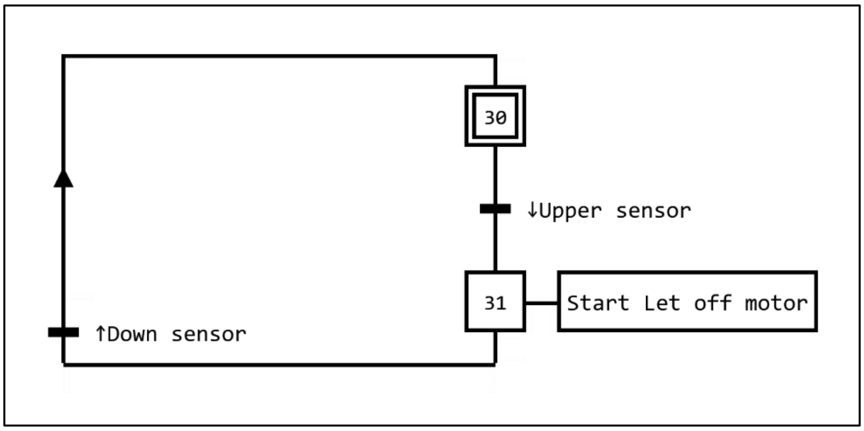
Preparation:



Wrapping:


40
Auto
41
Opening of the drum to place beads
↑Button (Beads placed)
42
Drum rotation
Blow
↑Sensor (Beads in position)
43
Delivery conveyor forward
Encoder value (4)
44
Drum rotation
Strips forward
Cylinder actuation(create friction)
Cylinder actuation(create tension)
↓Strips end position sensor
45
Drum rotation
Strips forward
Cylinder actuation(create friction)
Cylinder actuation(create tension)
t/X45/0.25s
46
Recoil of delivery conveyor
↑Recoil position sensor (delivery conveyor)
47
1
48
Positioning and fastening of beads
Beads fixed
49
Drum expansion
Fastening of beads
End of drum expansion
50
Diaphragms expansionand wrapping
Drum expansion
End of cycle
51
Collapse of drum to remove product
1

Loop:



4.6. Electrical and Automation Specification

The electrical and automation specification must be defined in compliance with the MES Continental. Hence, several components and characteristics that ensure the correct drive of the mechanical parts, the communication among the several components, the interaction with operators and their safety are already predefined by that document and they cannot change.

On this chapter there are presented some definitions for basic components, software, and a communication interface schematic which are the features that were thought and chosen on the framework of this report. The complete document is presented on appendix F.

4.6.1. Basic requirements

The electrical control system consists of:

- IPC – Central machine control system;
- Uninterruptable Power Supply (UPS), with automatic shutdown concept for IPC's;
- Field Bus technology – distributed I/O's;
- High speed fieldbus communication – EtherCAT as general bus system and Profinet IRT for the drive systems;
- WinCC flexible application preferred for HMI system;
- Ergonomic main Panel, with the possibility of height adjustment;
- Open interface based on standard Ethernet connection – OPC capability;
- Interface to central IT systems for production planning, order handling, etc;
- Energy efficient design and energy monitoring capability;
- Label printer.

4.6.2. Hardware

<u>Basic requirements</u>

- Industrial PC for machine control, process visualization and machine operation, including control of all safety functions;
- Distributed fieldbus system technology has to be used to a maximum within reason to connect peripheral devices to the PLC system:
    - I/O's (sensors/actuators);
    - Electrical drives (servo);
    - Etc.

- Automation System to be built modular in order to minimize cable lengths and optimize installation works.
- Drive system with digital technology have to be applied for variable speed control;
- Servomotors and feedback cables have to be connected directly to the drive system.

Hardware architecture

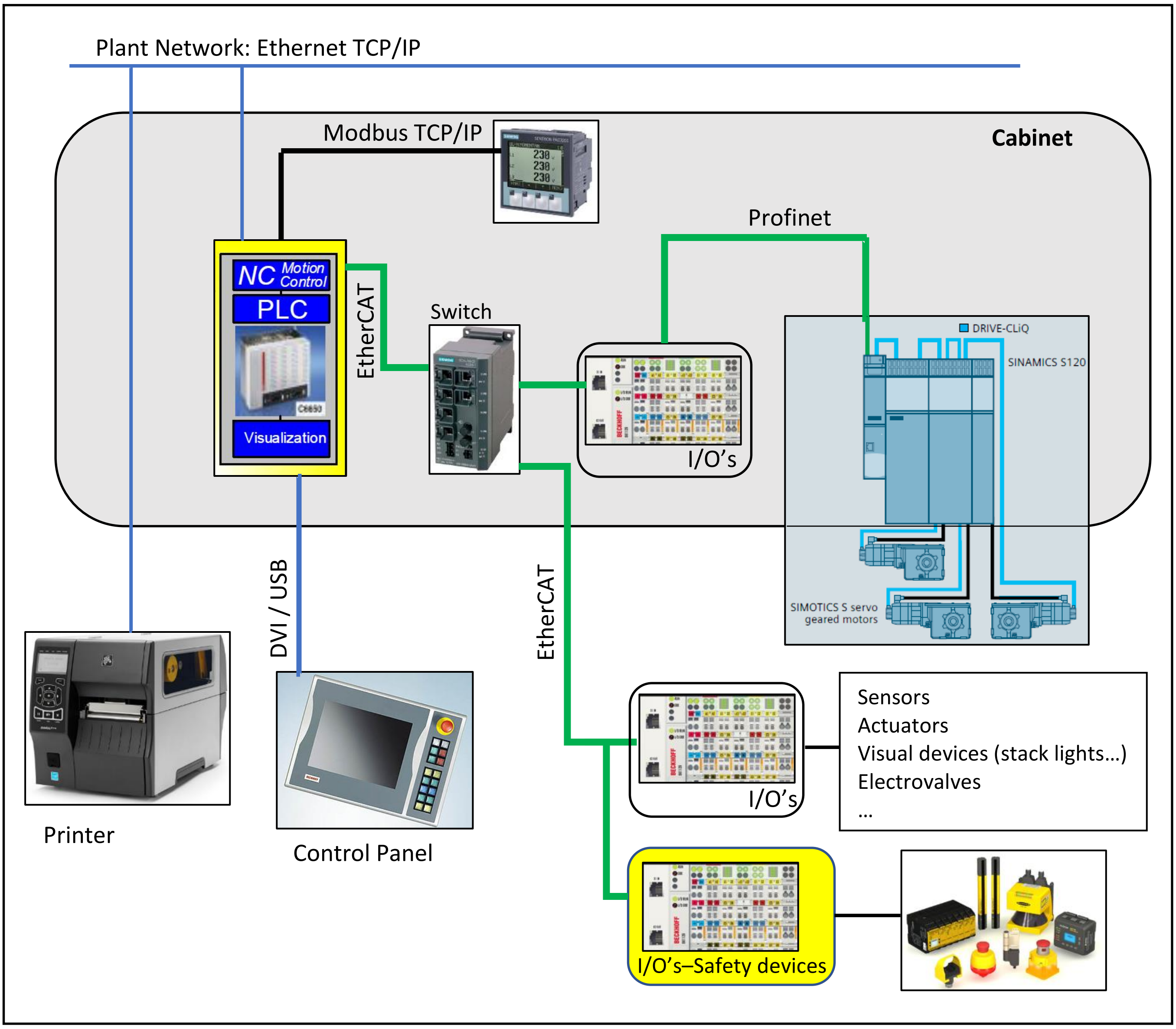


Figure 4.46 – Scheme of architecture hardware.

Safety devices

To reduce or eliminate risks for the operator, or for any other intervener, it's necessary to install safety devices on the machine.

The machine is made of several moving components whose automatic mode must be interrupted if physic boundaries, which could compromise the safety of the operators, are crossed.

The machine must be surrounded by safety devices, whose purpose is to deactivate immediately the automatic mode and keep it deactivated until all the required safety preconditions are met.

The machine must also be equipped with several emergency stop devices by means of which imminent or existing danger situations may be avoided.

The machine must comply with current safety standards.

Basic machine equipment

Table 4.3 – Basic machine equipment (1).

Item	Manufacturer	Type	Remarks
IPC System / Bus components			
IPC	Beckhoff	C6650-0040	PC-based PLC system, Intel Core i7, 2.3 GHz, 4 cores, 8GB RAM, 120GB SSD + 1TB HDD Microsoft Windows 7 Ultimate, 64 bit, English
Control Panel	Beckhoff	CP2919	
K-bus terminals E-bus terminals	Beckhoff		
Flexible Safety Controller	Beckhoff	TwinSafe EL6900	EtherCAT Safety Controller
I/O's Flexible Safety Device	Beckhoff	TwinSafe EL x90x	I/O's
Fieldbus communication	Beckhoff	EtherCAT	I/O's
		Profinet IRT	Drive system

Table 4.4 – Basic machine equipment (2).

Item	Manufacturer	Type	Remarks
Machine - Equipment			
AC – Gearing Motor	SEW	DRS for P<0.75 kW	▪ Efficiency class: IE1 ▪ IS connector ▪ Isolation class F ▪ Thermistor motor protection TF ▪ Supply voltage: 400V AC 50 Hz ▪ Brake voltage: 230V AC (option)
Servomotor	Siemens	1FK7	Brake: 24 V DC DRIVE-CLiQ

Table 4.5 – Basic machine equipment (3).

Item	Manufacturer	Type	Remarks
IT/Network			
Switch	Siemens	Scalance X206-1	Managed type
Cabinet			
Servo Drive System	Siemens	Sinamics S120	▪ With active line module ▪ With Profinet/Profisafe interface CU320-2 PN Type 6SL3040-1MA01-0AA0 Profinet; ▪ Compact flash card with firmware performance expansion 6SL3054-0EJ01-1BA0; ▪ BOP Operator Panel 6SL3055-0AA00-4BA0;
UPS	Beckhoff	C9900	
DC Power supply	Siemens	SITOP	
Power Monitoring	Siemens	SENTRON PAC3200	▪ 7KM2111-1BA00-3AA0 ▪ ModBus TCP connection ▪ With MBS current transform

4.6.3. Software

Basic requirements

All IT systems related PLC variables must be published as global variables in order to be readily accessible via OPC. Even if the hardware equipment is not required the PLC must be prepared.

Control software

Process control and quality monitoring requirements have to be fulfilled. For all process and quality relevant parameters a visualization shall display actual values, tolerances and action limits.

Basic machine software

Table 4.6 – Basic machine software.

Item	Manufacturer	Type	Remarks
Operating System	Microsoft OEM License	Windows 7 Ultimate SPS1	English Desktop active
Database	Microsoft	MS SQL 2012 Express	
PLC – Software	Beckhoff	TwinCat 2	V2.11
Communication / OPC server	Beckhoff	TwinCat OPC-Server (DA)	
HMI	Siemens	WinCC Flexible 2008 + SP3	

5. Conclusions and forthcoming works

5.1. Conclusions

The main objective was to develop a new concept of a flipper machine and to elaborate a set of specifications so it can be put forward to possible suppliers.

To achieve that, several phases were completed as: to understand the problem, research, discuss and present solutions. It was an enriching experience to go through all these steps and difficulties in the business world when such project is developed.

Comparing with the current flipper machine, the improvements this new machine can bring are undeniable both in terms of process, safety and also in terms of quality of the final product.

The presented solution, which incorporates the KM front frame part and the automatic cutting, is possible to improve the productivity on a large scale. The requirement of 15 seconds of cycle time was ensured and, as demonstrated on chapter 4.2.9., the investment is plainly justified.

As demonstrated throughout the report, with this new solution it is possible to control the quality parameters, which is a great advantage regarding the current solution.

The fact that the process and the constituent modules of the machine are inspired by systems already existent on the company it's also an advantage, mainly in terms of maintenance, since they are not totally new.

At the end, a detailed tender specification was developed with success to be put forward to possible suppliers. On the specification, the electrical and control system were developed in compliance with the MES Continental, as required.

It is considered that the project was completed successfully since the objectives proposed at the beginning were achieved.

5.2. Forthcoming works

In order to continue with this project, the next step would be to present the tender specification for contest so that the suppliers can present a budget. Afterwards a discussion with the supplier should take place about the technology and performance of the presented solution to ensure that the content is shared and understood by everyone. Eventually it's possible to accept improving solutions to the design. Finally, the installation of the machine must be monitored, its tuning must be done and its operation must be tested. At this phase the best process for the wrapping task must be chosen, as it was previously mentioned on the report, through experimental validation.

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Appendix A:

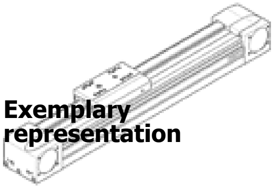
Datasheet of electromechanical drive from Festo

toothed belt axis
EGC-50-   -TB-KF

Part number: 556812

☆ Core product range

With recirculating ball bearing guide



Data sheet

Overall data sheet – Individual values depend upon your configuration.

Feature	Value
Effective diameter of drive pinion	18.46 mm
Working stroke	50 ... 1,900 mm
Size	50
Toothed-belt stretch	0.094 %
Toothed-belt pitch	2 mm
Assembly position	Any
Guide	Recirculating ball bearing guide
Design structure	Electromechanical linear axis With toothed belt
Motor type	Stepper motor Servomotor
Max. acceleration	50 m/s2
Max. speed	3 m/s
Repetition accuracy	±0,08 mm
Duty cycle	100%
Protection class	IP40
Ambient temperature	-10 ... 60 °C
Area moment of inertia 2nd degree Ix	84E+03 mm4
Area moment of inertia 2nd degree Iy	114E+03 mm4
Max. force Fy	650 N
Max. force Fz	650 N
Max. idling displacement resistance	8 N
Max. torque Mx	3.5 Nm
Max. feed force Fx	50 N
Torsional mass moment of inertia It	42.5E+03 mm4
Mass moment of inertia JH per metre of stroke	0.026 kgcm2
Mass moment of inertia JL per kg of working load	0.85 kgcm2
Feed constant	58 mm/U
Material of end caps	Wrought Aluminium alloy Anodised
Material of profile	Wrought Aluminium alloy Anodised
Materials note	Contains PWIS substances Conforms to RoHS
Material drive cover	Wrought Aluminium alloy Anodised
Material guide slide	Steel
Material guide rail	Steel
Material pulleys	High alloy steel, non-corrosive
Material slide	Wrought Aluminium alloy Anodised
Material toothed belt clamping piece	Nickel plated
Material toothed belt	polychloroprene with glass cord and nylon coating

Appendix B:

Datasheets of servomotors

SIEMENS

Data sheet for SIMOTICS S-1FK7

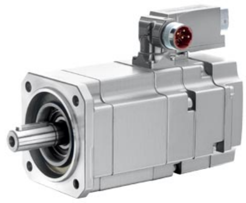


Figure similar

MLFB-Ordering data 1FK7022-5AK71-1DA0

Client order no. :
Order no. :
Offer no. :
Remarks :

Item no. :
Consignment no. :
Project :

Engineering data

Rated speed	6000 rpm
Number of poles	6
Rated torque (100 K)	0.6 Nm
Rated current	1.4 A
Static torque (60 K)	0.70 Nm
Static torque (100 K)	0.8 Nm
Stall current (60 K)	1.5 A
Stall current (100 K)	1.8 A
Moment of inertia	0.280 kgcm²
Efficiency	86.0 %

Physical constants

Torque constant	0.46 Nm/A
Voltage constant at 20° C	29.0 V/1000*min^{-1}
Winding resistance at 20° C	4.20 Ω
Rotating field inductance	9.1 mH
Electrical time constant	2.20 ms
Mechanical time constant	1.70 ms
Thermal time constant	18 min
Shaft torsional stiffness	3000 Nm/rad
Net weight of the motor	1.8 kg

Mechanical data

Motor type	Permanent-magnet synchronous motor
Motor type	Compact
Shaft height	28
Cooling	Natural cooling
Radial runout tolerance	0.035 mm
Concentricity tolerance	0.08 mm
Axial runout tolerance	0.08 mm
Vibration severity grade	Grade A
Connector size	1
Degree of protection	IP64
Design acc. to Code I	IM B5 (IM V1, IM V3)
Temperature monitoring	Pt1000 temperature sensor
Electrical connectors	Connectors for signals and power rotatable
Color of the housing	without
Holding brake	without holding brake
Shaft extension	Feather key
Encoder system	Encoder IC22DQ: incremental encoder 22 bits (resolution 4194304, encoder-internal 2048 S/R) + commutation position 11 bits

SIEMENS

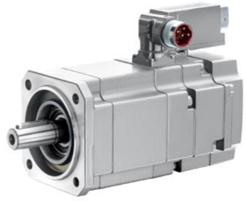


Figure similar

MLFB-Ordering data **1FK7022-5AK71-1DA0**

Optimum operating point

Optimum speed	6000 rpm
Optimum power	0.4 kW

Limiting data

Max. permissible speed (mech.)	10000 rpm

Recommended Motor Module

Rated inverter current	3 A
Maximum inverter current	6 A
Maximum torque	2.65 Nm

SIEMENS

Data sheet for SIMOTICS S-1FK7 servo geared motor

Figure similar

MLFB-Ordering data **1FK7022-5AK71-1DG5-Z**
J02

Client order no. :
Order no. :
Offer no. :
Remarks :

Item no. :
Consignment no. :
Project :

Engineering data

Rated speed	6000 rpm
Number of poles	6
Rated torque (100 K)	0.6 Nm
Rated current	1.4 A
Static torque (60 K)	0.70 Nm
Static torque (100 K)	0.8 Nm
Stall current (60 K)	1.5 A
Stall current (100 K)	1.8 A
Moment of inertia	0.430 $kgcm^2$

Physical constants

Torque constant	0.46 Nm/A
Voltage constant at 20° C	29.0 V/1000*min^{-1}
Winding resistance at 20° C	4.20 Ω
Rotating field inductance	9.1 mH
Electrical time constant	2.20 ms
Mechanical time constant	1.70 ms
Thermal time constant	18 min
Shaft torsional stiffness	3000 Nm/rad
Net weight of the motor	3.7 kg

Recommended Motor Module

Rated inverter current	3 A
Maximum inverter current	6 A
Maximum torque	2.65 Nm

Mechanical data

Motor type	Permanent-magnet synchronous motor
Motor type	Compact
Shaft height	28
Cooling	Natural cooling
Radial runout tolerance	0.035 mm
Concentricity tolerance	0.08 mm
Axial runout tolerance	0.08 mm
Vibration severity grade	Grade A
Connector size	1
Degree of protection	IP65 and DE flange IP67
Design acc. to Code I	IM B5 (IM V1, IM V3)
Temperature monitoring	Pt1000 temperature sensor
Electrical connectors	Connectors for signals and power rotatable
Color of the housing	Standard (Anthracite RAL 7016)
Holding brake	without holding brake
Shaft extension	Plain shaft
Encoder system	Encoder IC22DQ: incremental encoder 22 bits (resolution 4194304, encoder-internal 2048 S/R) + commutation position 11 bits

SIEMENS

Figure similar

MLFB-Ordering data **1FK7022-5AK71-1DG5-Z**
J02

Gearbox data

Gearbox type	Planetary gearbox SP+
Designation	SP 060S-MF1
Gearbox shaft end	With feather key
Gear ratio + steps	4 (1-step)
Motor speed S3-60 %	6000 rpm
Motor speed S1	3300 rpm
Output torque S1	26 Nm
Rated output torque at duty type S3-60 %	40 Nm

Moment of inertia of gearbox	0.150 kgcm²
Radial output shaft loading, max.	2700 N
Axial output shaft load, max.	2400 N
Efficiency of gearbox	0.97
Torsional backlash	4
Gearbox weight	1.90 kg

Limiting data

Max. permissible speed (mech.)	10000 rpm

Special design

J02	Mounting of SP+ planetary gearbox

SIEMENS

Figure similar

Data sheet for SIMOTICS S-1FK7 servo geared motor

MLFB-Ordering data 1FK7022-5AK71-1DH5-Z
J09

Client order no. :
Order no. :
Offer no. :
Remarks :

Item no. :
Consignment no. :
Project :

Engineering data

Rated speed	6000 rpm
Number of poles	6
Rated torque (100 K)	0.6 Nm
Rated current	1.4 A
Static torque (60 K)	0.70 Nm
Static torque (100 K)	0.8 Nm
Stall current (60 K)	1.5 A
Stall current (100 K)	1.8 A
Moment of inertia	0.440 kgcm²

Physical constants

Torque constant	0.46 Nm/A
Voltage constant at 20° C	29.0 V/1000*min^{-1}
Winding resistance at 20° C	4.20 Ω
Rotating field inductance	9.1 mH
Electrical time constant	2.20 ms
Mechanical time constant	1.70 ms
Thermal time constant	18 min
Shaft torsional stiffness	3000 Nm/rad
Net weight of the motor	3.9 kg

Recommended Motor Module

Rated inverter current	3 A
Maximum inverter current	6 A
Maximum torque	2.65 Nm

Mechanical data

Motor type	Permanent-magnet synchronous motor
Motor type	Compact
Shaft height	28
Cooling	Natural cooling
Radial runout tolerance	0.035 mm
Concentricity tolerance	0.08 mm
Axial runout tolerance	0.08 mm
Vibration severity grade	Grade A
Connector size	1
Degree of protection	IP65 and DE flange IP67
Design acc. to Code I	IM B5 (IM V1, IM V3)
Temperature monitoring	Pt1000 temperature sensor
Electrical connectors	Connectors for signals and power rotatable
Color of the housing	Standard (Anthracite RAL 7016)
Holding brake	with holding brake
Shaft extension	Plain shaft
Encoder system	Encoder IC22DQ: incremental encoder 22 bits (resolution 4194304, encoder-internal 2048 S/R) + commutation position 11 bits

SIEMENS

Figure similar

MLFB-Ordering data **1FK7022-5AK71-1DH5-Z**
J09

Gearbox data

Gearbox type	Planetary gearbox SP+
Designation	SP 060S-MF1
Gearbox shaft end	With feather key
Gear ratio + steps	10 (1-step)
Motor speed S3-60 %	6000 rpm
Motor speed S1	4000 rpm
Output torque S1	17 Nm
Rated output torque at duty type S3-60 %	32 Nm

Moment of inertia of gearbox	0.090 kgcm²
Radial output shaft loading, max.	2700 N
Axial output shaft load, max.	2400 N
Efficiency of gearbox	0.97
Torsional backlash	4
Gearbox weight	1.90 kg

Limiting data

Max. permissible speed (mech.)	10000 rpm

Holding brake

Holding brake version	Permanent-magnet brake
Holding torque	1.0 Nm
Power supply voltage	DC 24 V ± 10 %
Coil current	0.3 A
Opening time	30 ms
Closing time	20 ms
Highest braking work	8 J

Special design

J09	Mounting of SP+ planetary gearbox

SIEMENS

Data sheet for SIMOTICS S-1FK7

MLFB-Ordering data **1FK7042-2AK71-1DB0**

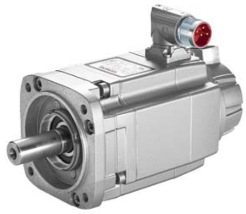


Figure similar

Client order no. :
Order no. :
Offer no. :
Remarks :

Item no. :
Consignment no. :
Project :

Engineering data

Rated speed	6000 rpm
Number of poles	8
Rated torque (100 K)	1.5 Nm
Rated current	2.5 A
Static torque (60 K)	2.50 Nm
Static torque (100 K)	3.0 Nm
Stall current (60 K)	3.5 A
Stall current (100 K)	4.4 A
Moment of inertia	3.200 kgcm²
Efficiency	89.0 %

Physical constants

Torque constant	0.68 Nm/A
Voltage constant at 20° C	44.5 V/1000*min^{-1}
Winding resistance at 20° C	1.15 Ω
Rotating field inductance	8.6 mH
Electrical time constant	7.50 ms
Mechanical time constant	2.15 ms
Thermal time constant	30 min
Shaft torsional stiffness	15500 Nm/rad
Net weight of the motor	5.3 kg

Mechanical data

Motor type	Permanent-magnet synchronous motor
Motor type	Compact
Shaft height	48
Cooling	Natural cooling
Radial runout tolerance	0.040 mm
Concentricity tolerance	0.08 mm
Axial runout tolerance	0.08 mm
Vibration severity grade	Grade A
Connector size	1
Degree of protection	IP64
Design acc. to Code I	IM B5 (IM V1, IM V3)
Temperature monitoring	Pt1000 temperature sensor
Electrical connectors	Connectors for signals and power rotatable
Color of the housing	Standard (Anthracite RAL 7016)
Holding brake	with holding brake
Shaft extension	Feather key
Encoder system	Encoder IC22DQ: incremental encoder 22 bits (resolution 4194304, encoder-internal 2048 S/R) + commutation position 11 bits

SIEMENS

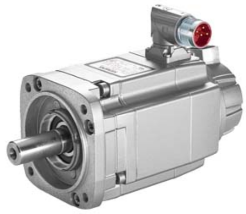


Figure similar

MLFB-Ordering data **1FK7042-2AK71-1DB0**

Optimum operating point

Optimum speed	5000 rpm
Optimum power	1.0 kW

Limiting data

Max. permissible speed (mech.)	9000 rpm

Holding brake

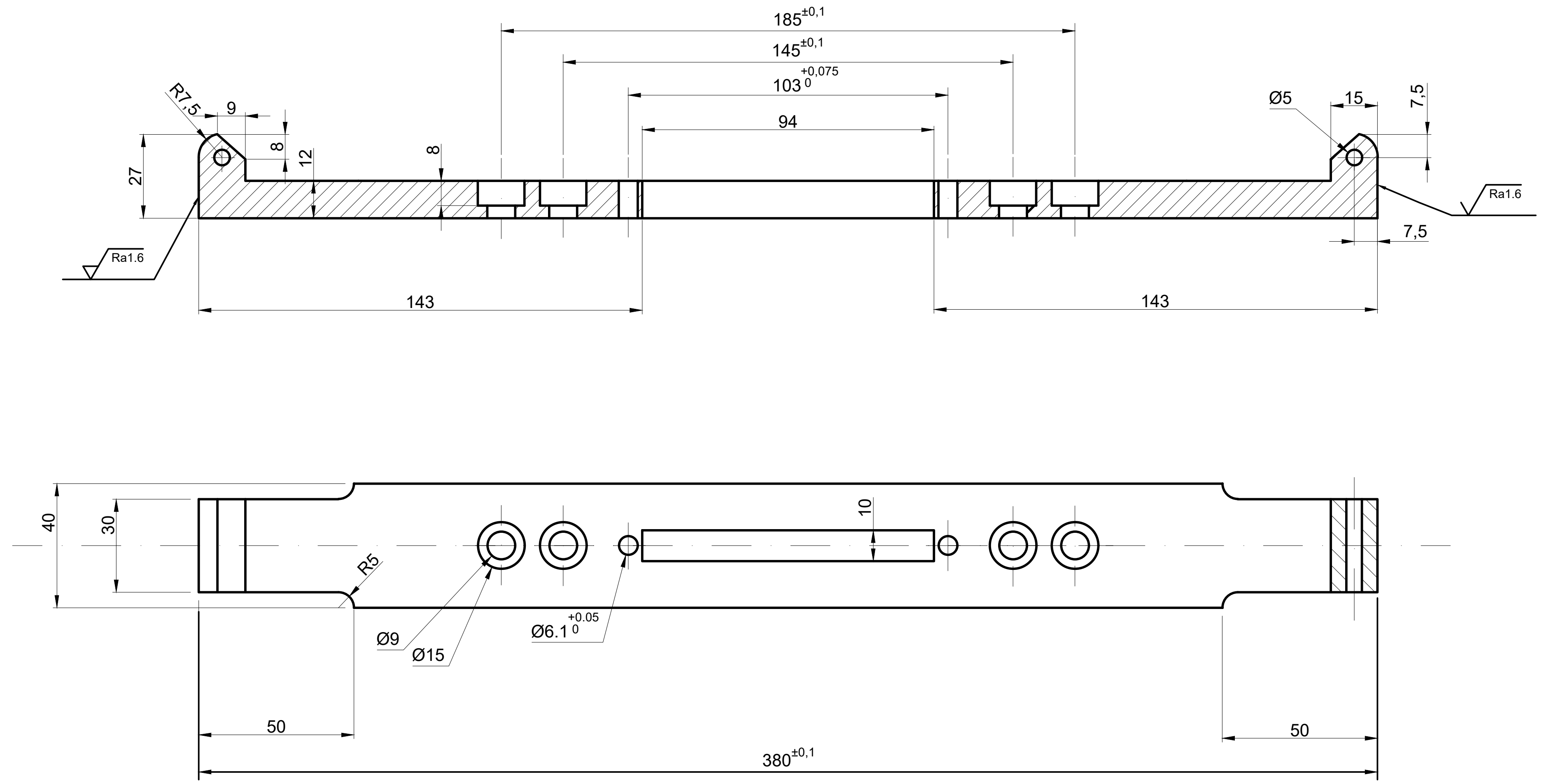
Holding brake version	Permanent-magnet brake
Holding torque	4.0 Nm
Power supply voltage	DC 24 V ± 10 %
Coil current	0.5 A
Opening time	70 ms
Closing time	30 ms
Highest braking work	150 J

Recommended Motor Module

Rated inverter current	5 A
Maximum inverter current	15 A
Maximum torque	10.30 Nm

Appendix C:

CAD 2D: segment parts

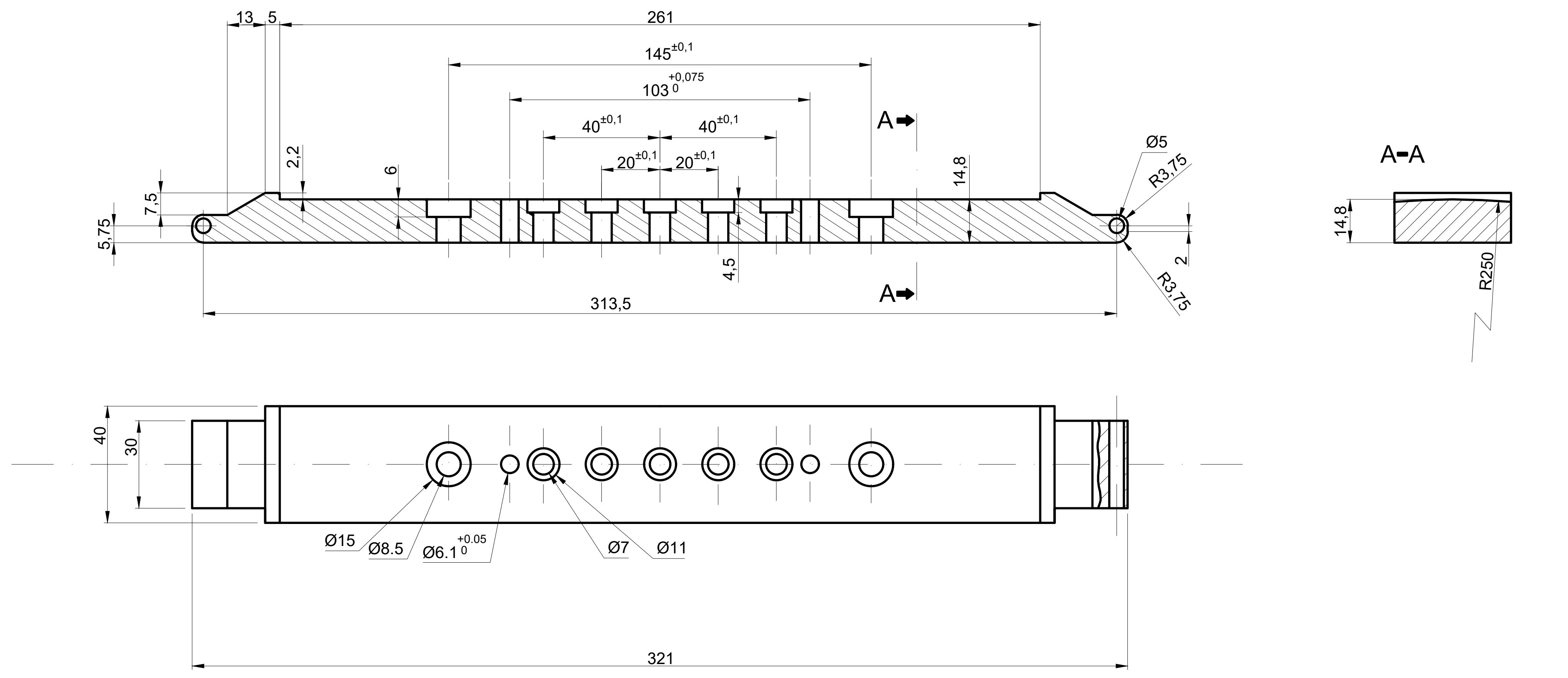


ISO 8015
ISO 2768 - mK

Ra6.3 (Ra1.6)

		Nº of drawing	
		CAD file name	
	Date	Name	Material: AlZn5Mg3Cu
Designer		Luís Peixoto	
Reviewer			Designation: Part 1 - Drum segment
Approved by			Scale: 1:2

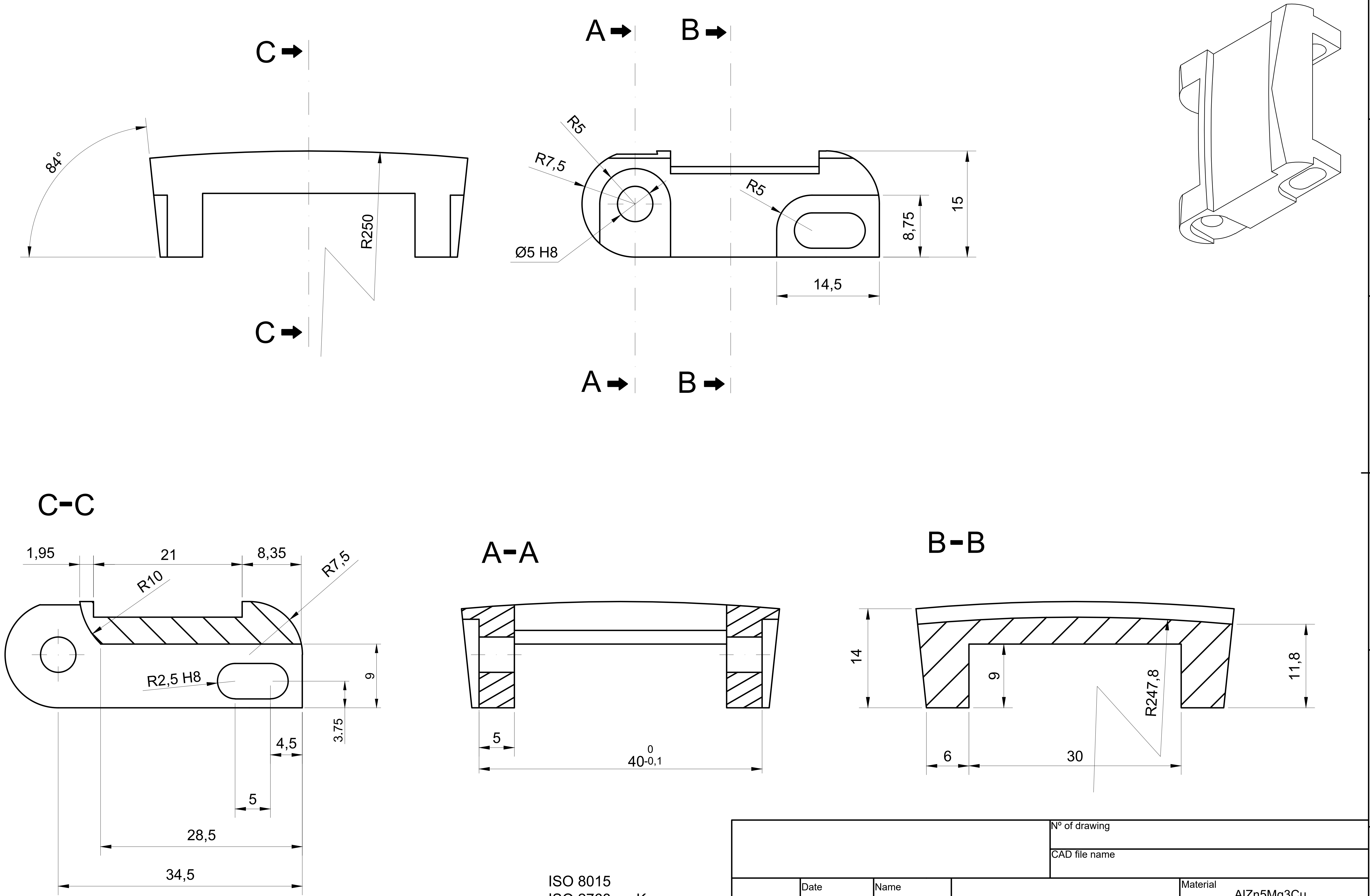
A3



ISO 8015
ISO 2768 - mK

Ra6.3

				Nº of drawing	
				CAD file name	
	Date	Name		Material	AlZn5Mg3Cu
Designer		Luís Peixoto	Designation		Scale
Reviewer			Part 2 - Drum segment		1:2
Approved by					A3

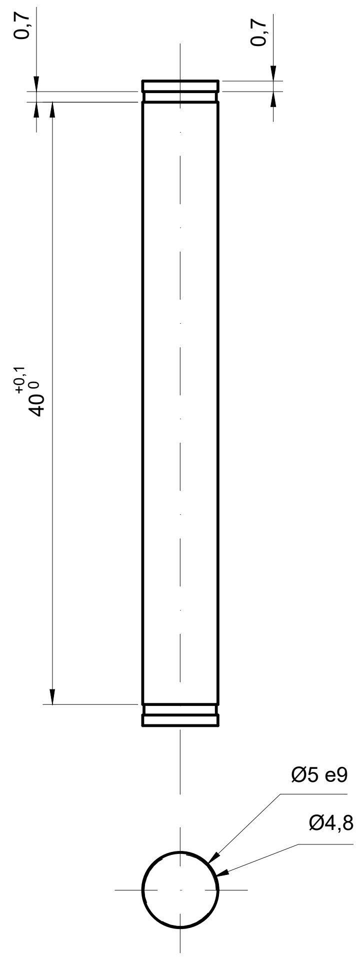


ISO 8015
ISO 2768 - mK

Ra6.3

			Nº of drawing	
			CAD file name	
	Date	Name		Material AlZn5Mg3Cu
Designer		Luís Peixoto	Designation	
Reviewer			Part 3 - Drum segment	Scale 2:1
Approved by				A3

1	2	3	4



ISO 8015
ISO 2768 - mK

Ra6.3

	Nº of drawing
	CAD file name

	Date	Name		Material: AlZn5Mg3Cu	
Designer		Luís Peixoto	Designation		Scale
Reviewer			Part 4 - Drum segment		2:1
Approved by					

A4

Appendix D:

Pulley-Belt Calculation – Optibelt

Optibelt-CAP Drive Calculation

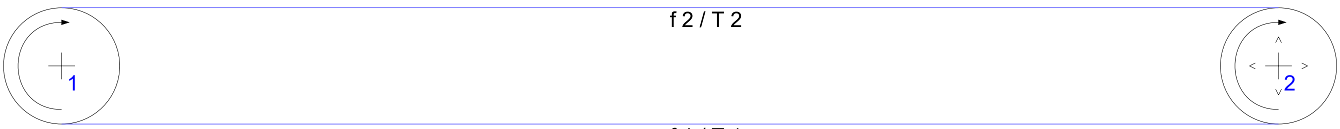
Sender

Tel. No. :
Fax No. :
E-Mail :
Internet :

Tel. No. :
Fax No. :
E-Mail :
Internet :

Length-Calculation

Calc.-No.	: C000000021	Date	: 14.06.2018	SN	: 88145161
Project	: 0001	Drawing No.	: 0001	Drive	: 0001



timing belt profile Optibelt ALPHA Timing Belts 25 T 10/ 920

Standard pitch length	Lw :	920	mm
Number of teeth	zr :	92	
Pitch	t :	10	mm
Width	b :	25	mm
Belt speed	v :	0.52	m/s
Actual service factor	c2 :	2.89	
Transmitted power	PÜ :	0.28	kW

Our 'General Conditions of Sale' are applicable.

Release 6.513 24.07.2017 Pricelist 06/2012

Length-Calculation

Calc.-No.	: C000000021	Date	:	14.06.2018	SN	:	88145161
Project	: 0001	Drawing No.	:	0001	Drive	:	0001

pulley 1 40 T10/12-2 through bored (Bore-diameter 16 mm)

Diameter	dw_1 :	38.20	mm
Number of teeth	z :	12	
Teeth in mesh	ze :	6	
Speed	n_1 :	262	1/min
Actual drive ratio	i :	---	
power	P_{an} :	0.10	kW
Torque	Nm :	3.6	Nm
Static belt tension	T_1 :	103	N
Shaft load	Sa :	206	N
Span length	L :	400.00	mm
frequence	f_1 :	38.27	Hz
x-coordinate	x :	0.00	mm
y-coordinate	y :	0.00	mm

pulley 2 40 T10/12-2 through bored (Bore-diameter 16 mm)

Diameter	dw_2 :	38.20	mm
Number of teeth	z :	12	
Teeth in mesh	ze :	6	
Speed	n_2 :	262	1/min
Actual drive ratio	i :	1.00	
power	P_{ab} :	0.10	kW
Torque	Nm :	3.6	Nm
Static belt tension	T_2 :	103	N
Shaft load	Sa :	206	N
Span length	L :	400.00	mm
frequence	f_2 :	38.27	Hz
x-coordinate	x :	400.00	mm
y-coordinate	y :	0.00	mm
X-input coordinate	xs :	400.00	mm
Y-input coordinate	ys :	0.00	mm
X-deviation from theoretical	Dxs :	0.00	mm
Y-deviation from theoretical	Dys :	0.00	mm

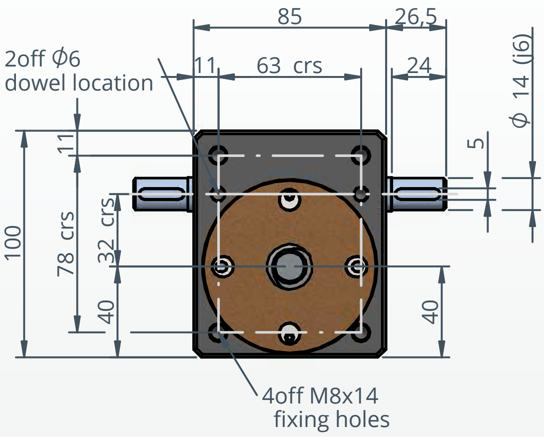
Appendix E:

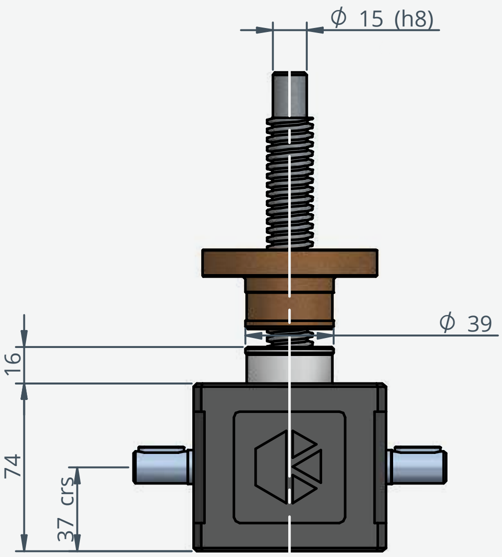
Datasheet of Kelston cubic screw jack

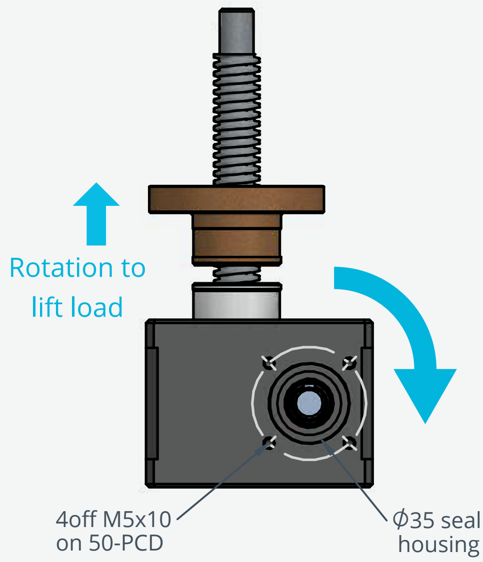
Cubic Screw Jack

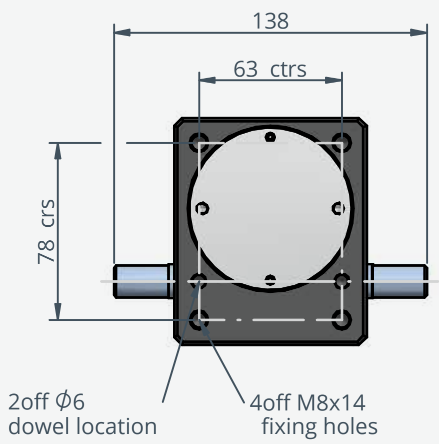
C037 Rotating screw

10kN
nominal capacity







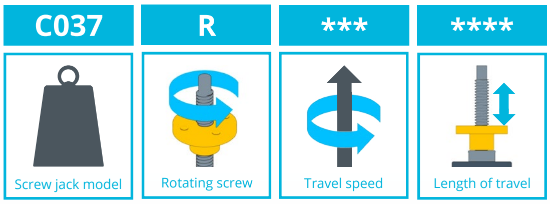


C037 Technical data

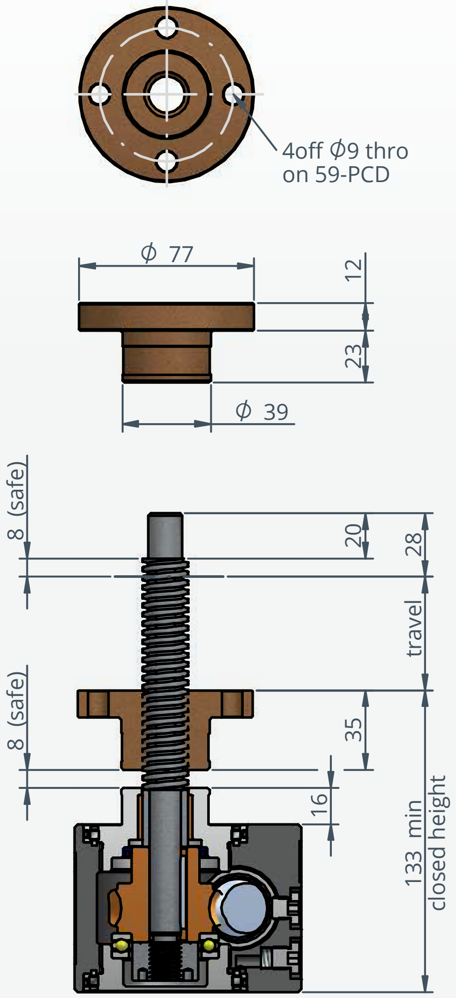
	High ratio / single start trapazoidal	High ratio / double start trapazoidal	Low ratio / single start trapazoidal	Low ratio / double start trapazoidal
Travel rate of wormshaft (mm/rev)	0.25	0.5	1.0	2.0
Worm gear ratio	16:1	16:1	4:1	4:1
Lifting screw diameter (mm)	Tr 20x4	Tr 20x8	Tr 20x4	Tr 20x8
Pitch (mm)	4.0	4.0	4.0	4.0
Lead (mm)	4.0	8.0	4.0	8.0
Root diameter (mm)	15.5	15.5	15.5	15.5
Input torque required to lift 10kN	1.95Nm	2.78Nm	5.4Nm	7.75Nm

Cubic Screw Jack

C037 Rotating screw



Precision machined 6082T6 aluminium body, manufactured from a solid billet.
Nickel plated, steel end caps and screw covers with stainless steel keys and fasteners further enhance corrosion resistance.



Mounting

The screw jack body features threaded fixing holes and dowel location hole on both mounting faces, allowing the screw jack to operate in an upright or inverted position.

Gearset

Case hardened and precision ground wormshaft, paired with a CA104 aluminium bronze wormwheel for added durability, supported by quality bearings and seals.

Standard large diameter CA104 aluminium bronze lifting nut allowing M8 mounting fasteners.

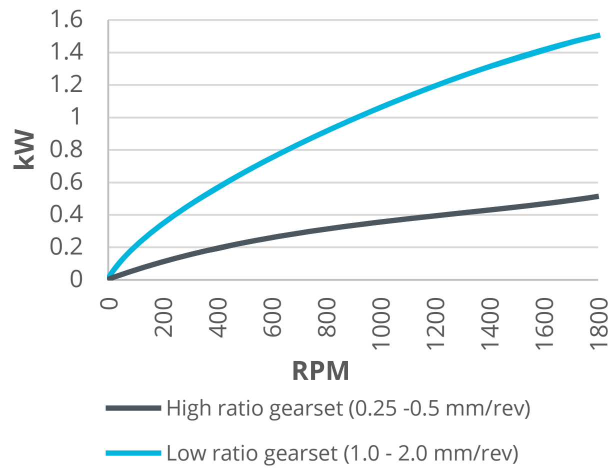
Lubrication

A sealed gearset chamber allows the use of a semifluid lubricant for running speed up to 1800rpm.

C037 Linear Travel Speed mm/min

Rotation speed of wormshaft rpm	Travel rate mm/rev			
	0.25	**0.5**	**1.0**	**2.0**
100	25	50	100	200
200	50	100	200	400
400	100	200	400	800
600	150	300	600	1200
800	200	400	800	1600
1000	250	500	1000	2000
1200	300	600	1200	2400
1400	350	700	1400	2800
1600	400	800	1600	3200
1800	450	900	1800	3600

C037 Power limit (kW) for 400 hours operation



SHEET 2 OF 2

Appendix F:

MES Continental – Electrical Specification

1. Electrical and Automation Specification

1.1. Basic requirements

The electrical control system consists of:

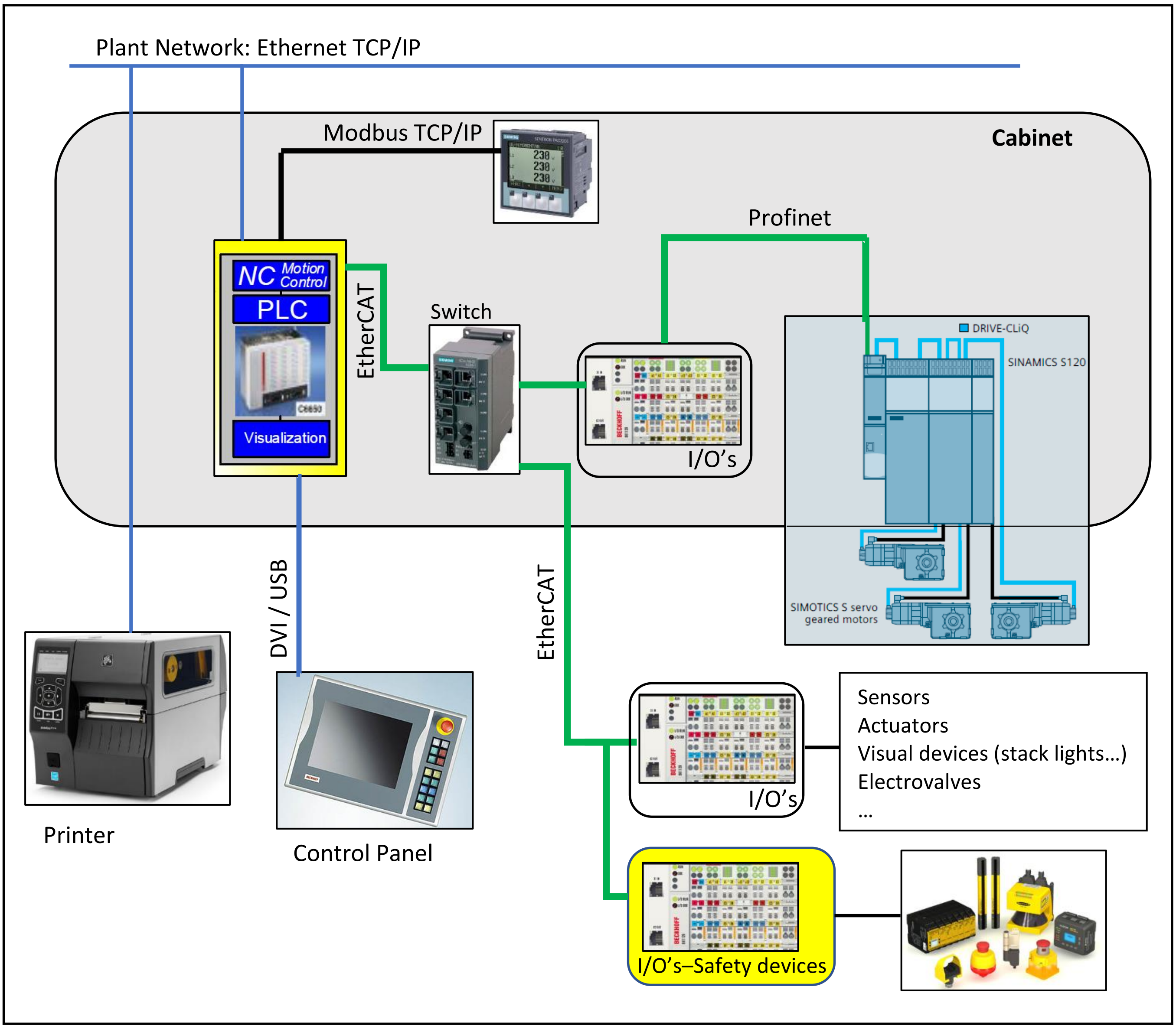
- IPC – Central machine control system;
- Uninterruptable Power Supply (UPS), with automatic shutdown concept for IPC's;
- Field Bus technology – distributed I/O's;
- High speed fieldbus communication – EtherCAT as general bus system and Profinet IRT for the drive systems;
- WinCC flexible application preferred for HMI system;
- Different software menus for machine operation;
- Ergonomic main Panel, with the possibility of height adjustment;
- Open interface based on standard Ethernet connection – OPC capability;
- Interface to central IT systems for production planning, order handling, etc;
- Energy efficient design and energy monitoring capability;
- Label printer.

1.2. Hardware

1.2.1. <u>Basic requirements</u>

- Industrial PC for machine control, process visualization and machine operation, including control of all safety functions;
- Distributed fieldbus system technology has to be used to a maximum within reason to connect peripheral devices to the PLC system:
    - I/O's (sensors/actuators);
    - Electrical drives (servo);
    - Etc.
- Automation System to be built modular in order to minimize cable lengths and optimize installation works.
- Drive system with digital technology have to be applied for variable speed control;
- Servomotors and feedback cables have to be connected directly to the drive system.

1.2.2. Hardware architecture



1.2.3. Wiring

Single wire marking:

- Electrical cabinet has to be equipped with single wire marking.
- Machine – field installations with single core identification.

1.2.4. Label Printer

Machine to be prepared for integration of label printer. Mandatory preparation includes:

- Power supply connection for a printer (power outlet in the machine);
- Connection to Plant Network (Ethernet) directly;

1.2.5. Safety devices

To reduce or eliminate risks for the operator, or for any other intervener, it's necessary to install safety devices on the machine.

The machine is made of several moving components whose automatic mode must be interrupted if physic boundaries, which could compromise the safety of the operators, are crossed.

The machine must be surrounded by safety devices, whose purpose is to deactivate immediately the automatic mode and keep it deactivated until all the required safety preconditions are met.

The machine must also be equipped with several emergency stop devices by means of which imminent or existing danger situations may be avoided.

The machine must comply with current safety standards.

1.2.6. Basic machine equipment

Item	Manufacturer	Type	Remarks
IPC System / Bus components			
IPC	Beckhoff	C6650-0040	PC-based PLC system, Intel Core i7, 2.3 GHz, 4 cores, 8GB RAM, 120GB SSD + 1TB HDD Microsoft Windows 7 Ultimate, 64 bit, English
Control Panel	Beckhoff	CP2919	
K-bus terminals E-bus terminals	Beckhoff		
Flexible Safety Controller	Beckhoff	TwinSafe EL6900	EtherCAT Safety Controller
I/O's Flexible Safety Device	Beckhoff	TwinSafe EL x90x	I/O's
Fieldbus communication	Beckhoff	EtherCAT	I/O's
		Profinet IRT	Drive system

Item	Manufacturer	Type	Remarks
Machine - Equipment			
AC – Gearing Motor	SEW	DRS for P<0.75 kW DRN for P>=0.75 kW	▪ Efficiency class: IE1 for DRS and IE3 for DRN ▪ IS connector (for motor up to 4 kW) ▪ Isolation class F ▪ Thermistor motor protection TF ▪ Supply voltage: 400V AC 50 Hz ▪ Brake voltage: 230V AC (option)
Servomotor	Siemens	1FK7	Brake: 24 V DC DRIVE-CLiQ
Command Devices	Siemens	3SU1	▪ Metal version ▪ Installed in metallic housing

Item	Manufacturer	Type	Remarks
IT/Network			
Switch	Siemens	Scalance X206-1	Managed type
Ethernet Replicator * To be used only if required for internal network for Beckhoff platform	Beckhoff	ES2008 /2016	8x or 16x RJ45 port
Label Printer	Zebra	ZT410	▪ Network printer; ▪ Include option cuter;
Plant Network / IPC		Ethernet TCP/IP	
Cabinet			
Servo Drive System	Siemens	Sinamics S120	▪ With active line module ▪ With Profinet/Profisafe interface CU320-2 PN Type 6SL3040-1MA01-0AA0 Profinet; ▪ Compact flash card with firmware performance expansion 6SL3054-0EJ01-1BA0; ▪ BOP Operator Panel 6SL3055-0AA00-4BA0;
Cabinet	Rittal	TS8	
Busbar System	Rittal/Siemens	SV / 8SU/3RV29	
Cabinet cooling * Cooling type depending on receiving plant	Pfannemberg	Ecool DTI type	Door mounted
UPS	Beckhoff	C9900	
DC Power supply	Siemens	SITOP	
DC Power Distribution	Murr	Mico Power Control	
Power Monitoring	Siemens	SENTRON PAC3200	▪ 7KM2111-1BA00-3AA0 ▪ ModBus TCP connection ▪ With MBS current transform
DC Buffer Module	Murr	MB CAP	
Front Panel Interface	Murr	MSDD	With RJ45 and Socket plug insert.

1.3. Software

1.3.1. Basic requirements

All IT systems related PLC variables must be published as global variables in order to be readily accessible via OPC. Even if the hardware equipment is not required the PLC must be prepared.

1.3.2. IPC management

All IPC have to be prepared with a Conti basic image according to hardware and software requirements.

For the machine operation it is required to:

- Integrate the IPC into Tiremes – domain;
- Run all applications with Windows "Power Users" rights;
- Set a domain service account as Windows auto – login user;
- Configure auto-start-up of all HMI applications;

A standard machine operation with administrative rights is not permitted.

1.3.3. Control software

Process control and quality monitoring requirements have to be fulfilled. For all process and quality relevant parameters a visualization shall display actual values, tolerances and action limits.

1.3.4. Process visualization system

Basic requirements

- The system shall provide visualization screens for diagnostic, recipe management, machine settings, current values, trending, etc. More detailed information can be found below on visualization screens table.
- Operation of the machine in manual and automatic mode:
    - Automatic operation from HMI;
    - Manual operation with separate Pushbutton panels;
    - Frequently used machine functions (e.g. operation selection, fault reset, etc.) to be activated by panel mounted push buttons;
- The basic screen layout shall display schematic line status, providing the user with an overview of the process sequences and important actual values;
- Process parameters (e.g. set point) can be modified by direct entry of figures or by adjustment with keys;
- Full diagnostic for safety devices to be provided (application and system diagnostics). Graphical overview from the machine to be provided with safety devices status, including sensors involved in the safety logic (e.g. pressure switch). For TwinSAFE Continental standard library to be used.
- Input values are always subjected to a plausibility check and are only transferred to the machine when they are within a certain permissible range;
- Communication between visualization systems and PLC to be monitored. Lack of communication or slow communication shall generate error messages and do not lead the machine to unknown/uncertain state.
- Label printing software functionality per default is done via interface to the manufacturing systems. Data is exchanged through OPC interface;
- Machine software has to be prepared to print-out production labels for carriers. The required label information (bar code / prod. code, prod. date, prod. parameter, operator, shift, usage time, etc.) and format has to be adapted to the plant specific requirements. (optional)

Visualization screens

Group	Screen	Remarks
Basic Depending on selected machine operation mode. Provision of all user relevant information and functions	- Manual mode (display of actual value of selected machine station) - Automatic mode (display of current step process, phase flow, error and operating message/actual values, etc.) - Automatic stop mode (Manual modification of machine sequence and material length, display of current process step, phase flow, error and operating message)	- Modification possibility for operator to optimize process parameter; - Status line on all screens (date, time, recipe code, user, counter); - Display of error messages with highest priority on all screens; - GUI link for manufacturing systems for all modes;
Recipe management Storage and handling of process, product and machine parameters.	- Standard recipe screen buttons to be provided (Activate, Reset, Force Activation, Recipe Values, Recipe Client Link); - Next recipe header data; - Active recipe header data; - Enable recipe activation status; - Recipe to activate status; - Transfer diagnostics errors; - Recipe values.	- Recipe values to only be displayed without any editing functions;
Machine setting management Storage and handling of basic machine settings for the different machine components. The values are not part of a production recipe.	- Working data (e.g. tolerances, placements)	- Indication of exceeded tolerances; - Status line on all screens (date, time, recipe codes, user, counter);
Reports	Production report (shift / total production)	Print-out
Fault management Display, storage and handling of alarms	- Alarm screen; - Event logger; - I/O status – PLC variable; - Status; - Alarm help; - Machine graphical representation with safety devices status representation;	- Fault history date time and failure; - Different alarm levels for process problems, machine alarms; - Depending on alarm level manual or automatic fault acknowledge; - Detailed alarm description, direct link to affected device with reference to the circuit diagram and location;

Actual values Display of current machine settings	- Actual values; - I/O – PLC status; - Machine times; - Service for external devices;	- Display of the most important interface data values / signals; - Display of material IDs and status, order, carriers;
User management	- Login mask - Editor (Add / delete user User classification) - User rights;	User level - Administrator; - Operator; - Supervisor - Maintenance;
Archive Documentation of external intervention in the machine controls	- Fault history; - History of recipe and machine parameter changes;	- Print-out; - Storage on local system;
Maintenance	- Setpoints; - Calibration; - Motors; - Maintenance systems data block overview; - PLC safety compilation number; - Troubleshoot help;	A troubleshooting manual shall be provided to explain Alarm messages in details and guide maintenance people to identify a root cause of an alarm.

1.3.5. Basic machine software

Item	Manufacturer	Type	Remarks
Operating System	Microsoft OEM License	Windows 7 Ultimate SPS1	English Desktop active
Database	Microsoft	MS SQL 2012 Express	
PLC – Software	Beckhoff	TwinCat 2	V2.11
Communication / OPC server	Beckhoff	TwinCat OPC-Server (DA)	
HMI	Siemens	WinCC Flexible 2008 + SP3	