TAMPERE UNIVERSITY OF TECHNOLOGY

ÁLVARO RESÚA REY

DESINGN OF A SMART CARRIER FOR ASSET-AWARENESS PRODUCTION

Master of Science Thesis

Examiner: Professor José L. Martínez Lastra
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ABSTRACT

TAMPERE UNIVERSITY OF TECHNOLOGY

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The adaptation of new technology to production system is an open challenge. The most advanced devices allow producing faster, cheaper and better, helping to fulfil the market needs. The companies are under pressure to satisfy the changing requirements from customers.

Production lines have limited resources, making a perfect use of them is nowadays mandatory, due to the fact that the lifecycle of the products are shorter and in consequence the manufacturing lines lifecycle is being reduced. To increase the profitably, the bottlenecks and no operational time of the robots have to be avoided, or minimize them in order to arrive to a balanced line where the idle time of each robot is reduced to the minimum. To achieve this scenario, during last years, many fields such as monitoring, automatic quality control, asset-aware and self-recovery have got momentum.

The purpose of this Master Thesis is the design, production, and integration of a transport system with asset-aware capabilities for an existing manufacturing line.

The different devices to allow gathering the necessary data must be found, analysed, tested and incorporated to the transport element. The design of the new system counts for many aspects apart from the traditional functional design, such as imperceptible as wireless communication or ease robots reprograming.

At the same time all this work has been done looking forward to design a transport system that could be easily implemented in the line, making the changes as fast as possible.

PREFACE

This Master Thesis has been carried out in the Department of Production Engineering in the FAST laboratory during my Erasmus exchange program in the course 2011-2012.

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Special thanks go to Pmar. With him I spent a different Christmas in Berlin, the first time far from our families. His visit to Tampere and his help were absolutely necessary.

This thesis is dedicated to Susana del Rocío for everything we have shared together in cool and dark Finnish Winter.

Tampere, 20th of May 2012

ÁLVARO RESÚA REY

"I haven't failed 999 times, I've found 999 ways not to make the electric light bulb."

Thomas Alva Edison.

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LIST OF SYMBOLS AND ABBREVIATIONS

APIS	Advanced Pallet Information System
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CAQ	Computer-Aided Quality
CATIA	Computer Aided Three Dimensional Interactive Application
CCID	Chip Card Interface Device
CIM	Computer-Integrated Manufacturing
DC	Direct Current
ECMA	European Computer Manufacturers Association
ERP	Enterprise Resource planning
ETSI	European Telecommunications Standards Institute
FAST	Factory Automation Systems Technologies
FMEA	Failure Mode and Effects Analysis
FMS	Flexible Manufacturing Systems
GPS	Global Positioning System
HMI	Human Machine Interface
I/O	Input/Output
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
INS	Inertial Navigation System
IPv6	Internet Protocol version 6
IrDA	Infrared Data Association
ISO	International Organization for Standardization
JIT	Just In Time
MMSI	Maritime Mobile Service Identity
NASA	National Aeronautics and space Administration
NFC	Near Field Communication
OCR	Optical Character Recognition
PCBA	Printed Circuit Board Assembly
PDA	Personal Digital Assistant
PLC	Programmable Logic Controller
PPC	Production Planning and control
RFID	Radio Frequency Identification
RPN	Risk Priority Number
RS	Record Separator
RTU	Remote Terminal Unit
SMS	Short Message Service

SOAP	Simple Object Access Control
URI	Uniform Resource Identify
URL	Uniform Resource Locator
USB	Universal Serial Bus
XML	Extensible Markup Language
6LoWPAN	IPv6 over Lower power Wireless Personal Area Networks
2D	Two-Dimensional
3D	Three-Dimensional
μ	Friction coefficient
μ_k	Coefficient of kinematic friction
μ_s	Coefficient of static friction
D	Detection rating
F_f	Friction Force
F_n	Normal Force
M_r	Total Messages
M_t	Received Messages
O	Occurrence rating
R	Result
S	Severity rating

1. INTRODUCTION

The global situation is changing, it is not enough to know the present likes of the society, so the manufacturing industry has to anticipate the population needs. The companies have to design and manufacture the products before the competition does and before the people asking for them, otherwise it would be too late. Every business faces the continuing challenge of maintaining a flow of successful new product/service introductions into the marketplace. As life cycles become even shorter and demand more volatile, begin able to respond to changes in customer requirements and to exploit new technology-based opportunities has become a key competitive capability [Christopher 2002].

The firms know that analysis and study of the market is essential, the success in some cases can be attributed to how companies understand the customers. Henry Ford, with the Ford T case, was an example of how the market does not adapt itself to the production, the production must adapt to the market even if you make it cheaper, better, with high quality and so on, business has to be renewed all the time. In fact there is a typology of Design typology which is responsibility of this task, Research on Customer Needs: researches customer and market needs and creates appropriate methods and tools for getting improved access and better understanding of requirements [Birkhofer 2011].

The customer ultimately decides whether your company will be successful [Merrill 2009]. In the present marketing the product differentiation is a strong factor to achieve a desired product, thus attaining a successful company. Making a good product is not enough to sell it, it is important to achieve another target, differentiation. To get it in some cases it is necessary the individualization of the product. It means each person wants the same functional product but with different appearance. It is known in the automotive sector, where the customization is a main feature. It can be chosen the colour, upholstery, type of lights, navigation system, tires, seats, and so on.

Many companies face fierce competition in increasingly global industries. In their search for synergy and learning potential across international activities, they find their individual and industrial customers having increasingly differentiated aspirations, which result in country market segments becoming smaller and smaller [Mühlbacher 2006]. Adapting to these conditions entail studying the likes in small groups, so the customization of the products in mass production is a new requirement when the manufacturing line is being designed. Nowadays the majority of the manufacturing industries do not do the exactly same product in their lines, it means that each product passes through different cells, or different operations depending on the required output custom. It provides a strategic advantage and extra economic value to the product. The industry needs systems which are able to combine low unit cost with the flexibility of personalised products. Those systems are called FMS (Flexible Manufacturing Systems). The FMS give the factories a better response in time, lower unit cost and quality under an improved level of management and capital control. The flexibility of a competitor's production system determines the speed with which it can make changes in the physical characteristics of a product or its package [Mühlbacher 2006].

It is known that the market is each day much more demanding in all aspects. For several years ago one big change is occurring, especially in the production. Nowadays the big companies are working with a system called Just In Time, (JIT). Just a few years ago the companies studied how is the best way to achieve low costs in this area, getting discounts, buying lots of products and so on. This kinds of stock management involved spending of one's own resources. The enterprise has to have space to storage and to have an important control over the stock in the warehouse, that meant that factories couldn't use all the space in theirs buildings, they need to have employees checking the stocks and so on. On the other hand, not using the JIT implies that they need large amounts of flow-cash to pay the suppliers so they must pay high interest rates to the banks to get cash. The production strategy, JIT has a lot of advantages:

- Minimizing needed storage space.
- Reduces the setup time.
- Production scheduling and work hour consistency synchronized with demand.
- Increased emphasis on supplier relationships.

These benefits allow the factories to be more productive and they can adapt themselves quickly to the markets demand. The JIT is channelled to save money in several ways; therefore the companies are using this production strategy.

The Cost of quality is used to know where it has to modify the productive process within the global point of view. This makes it possible to focus efforts on correct points and prioritize the projects with the best criteria.

In the manufacturing companies the cost of quality can be around 20% of the total turnover. [Booker 2001]. With this data it is not strange that the firms are interested in having a better control in their products. The ideal is to have a quality control which is able to check one hundred per cent of pieces, this is called: Total quality control. attaining these kinds of control sometimes is not easy, new workcells, instrumentation, work tables and so on are required, despite this, many enterprises, with more or less success, are working in this field to decrease the cost of quality.

Recently, one decision of telecommunications specialist Mitel used cost of quality to drive its corrective action system and understood how cost of quality is really a medium for translating your wealth of measurement data into the dollar language of business [Merrill 2009]. This example gives us an idea how the manufacturing market must be focused; to translate the quality into dollar.

Traceability can be defined as association of all components, machines, workers, suppliers, transport systems, dates and so on which were used in the manufacturing process for each individual product. Each product is “unique” thereby we can get completeness of the information about every step in a process chain.

The traceability can be applied in all inputs or in a part of them. Whether the traceability is complete the product tracking is possible, so that if we detect some defect in a product or a collection of product it is easy to find the element or elements which did fail. For enterprises, internally, is a big help, because they can know where the mistake is and correct it. However the main advantage for customers is that if an important fail is detected and the element which caused the fail is found all products affected can be retired quickly.

In recent years, the asset-awareness and self-recovery techniques have gain importance. The research topics focus on embedded asset-awareness using semantics, 3D visualization, and monitoring [Vidales 2011]. Asset-aware inform when recourses are not available, it means that if one or more components of the productive system are not operative the factory can recognize them. Thereby the system is “aware” of which are the available “assets”.

The most cases the “no availability” in devices, robots, transport systems, space and so on, is just temporally. So that in a few minutes or seconds said components are ready again. Self-recovery gives to the system the capability for to use newly the components when they are operative conditions.

Assembly lines with returnable pallets are common in many manufacturing companies. One of their advantages is to better control the flow of products and its position to perform transportation or work, since they have, in majority of cases, independent movement in each station.

Using pallets within manufacturing lines contributes to achieve standardization. The line (handling equipment) is designed to move pallets, therefore their design does not depend on which product is manufactured. Moreover, it is easier to carry out activities related to the quality control, traceability, localization and so on.

2. PROBLEM DESCRIPTION

The aim of this chapter is to represent the situation before the actions, and to give an outline about the entire system. It is necessary know how is the manufacturing line to understand some constrains. Thanks to this chapter it will be easy to comprehend how the system works without new devices.

2.1 Production system

The manufacturing line in which the improvements have been done is a production system consisting of eleven workcells (one more will be attached in the near future); all of them are interconnected via conveyor belt. Except the buffer (cell 7), each cell has the same robot, SONY SRX-611, they are connected through DeviceNet nodes to an OMRAM PLC. Ten of the eleven workstations are able to perform the same functions, drawing different components of mobile phones. One of them is designed to supply the system with new paper for drawing and it removes the final pictures too.

Each workstation contains acrylic doors to avoid operators being in contact with equipment in movement. Safety components such as interlock door switches and emergency buttons are connected to safety relays. Figure 1 illustrates the architecture of the original system for one workstation, the automation components and the used communication protocols.

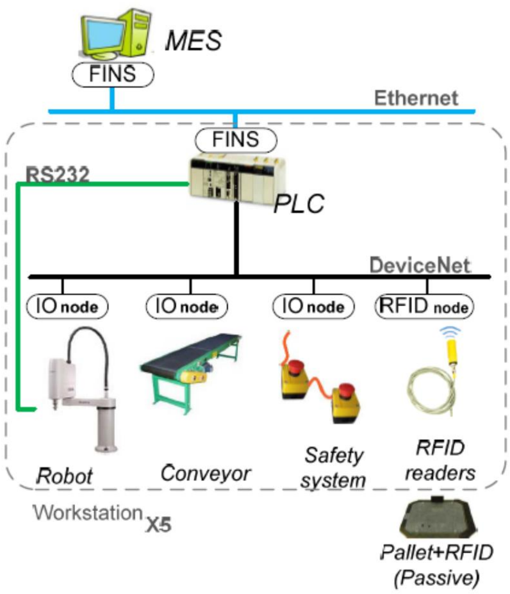


Figure 1. *Original system architecture [Gonzalez 2012]*

The goal of the Fastory line is to simulate the assembly of mobile phones without using real components. For this purpose it was decided to draw the mobile phone components (frame, keyboard and screen). Each drawing simulates an assembly operation. In order to add complexity to the system, each component can be drawn in three different colours. In figure 2 are shown all the workcells of the Fastory line.

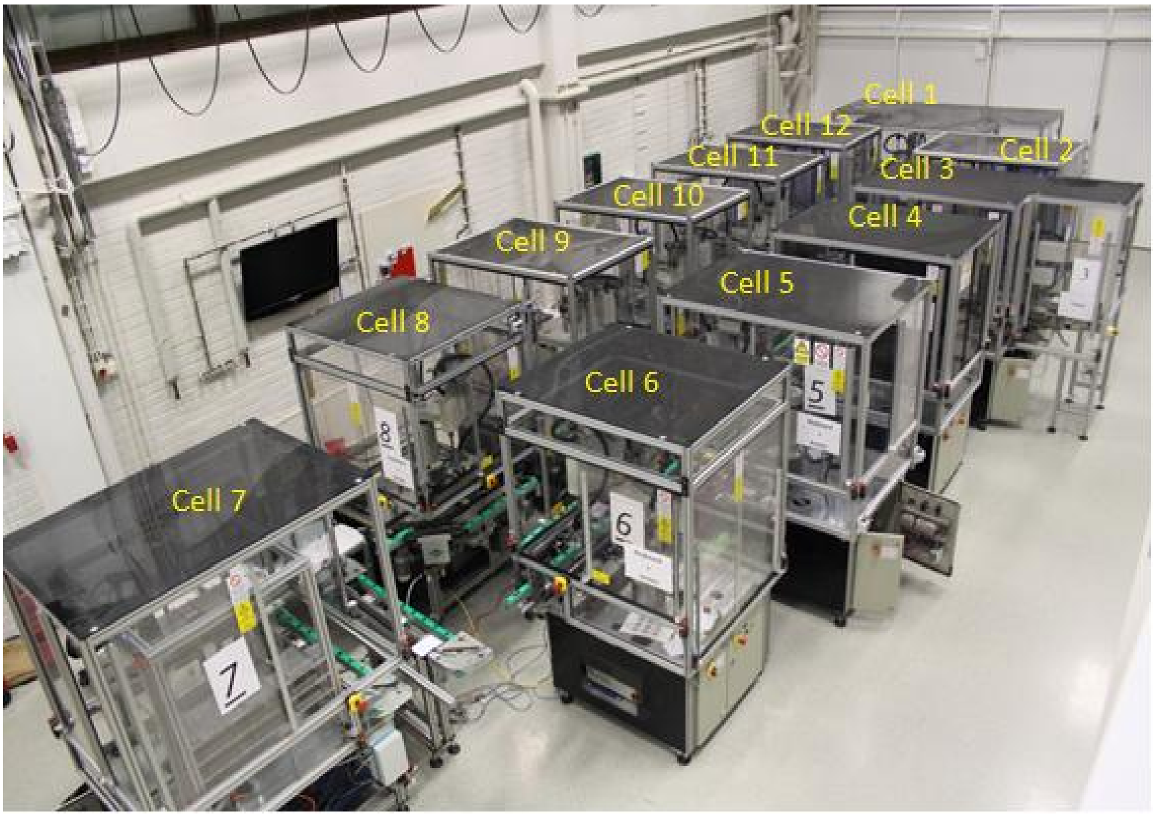


***Figure 2**. Fastory line*

Over the main conveyor which interconnects the cells there are several pallets. The pallets are used as a support for the paper, it permits the robots to draw. To stop the pallet in a specific point a pneumatic device is used, it maintains the pallet stopped in the same position.

The normal function of the manufacturing system will be explained in the next paragraphs, it is only a general overview to understand the main functions, but the real line is much more complicated, particularly the communication system.

On the loading station (cell 1) the robot picks up the completed picture, and puts it in a specific pallet for final products. With the suction cups the robot can put a new paper for drawing. When the pallet has the sheet of paper and the frame holding, it continues to the next cell.

The pallet continues through the main conveyor belt reaching the entrance of cell number two. At this point the system must decide between two options, if the pallet will be *processed* or *bypassed*. Generally, if the cell is ready to draw the pallet, then it will be processed, in case the robot is busy the pallet will be bypassed. The cell gets information about which is/are the requested operation/operations, if the robot can perform this operation the pallet goes in, else the pallet will go through to the next cell bypassed. In figure 3 it is explained how the pallets flow in both cases.

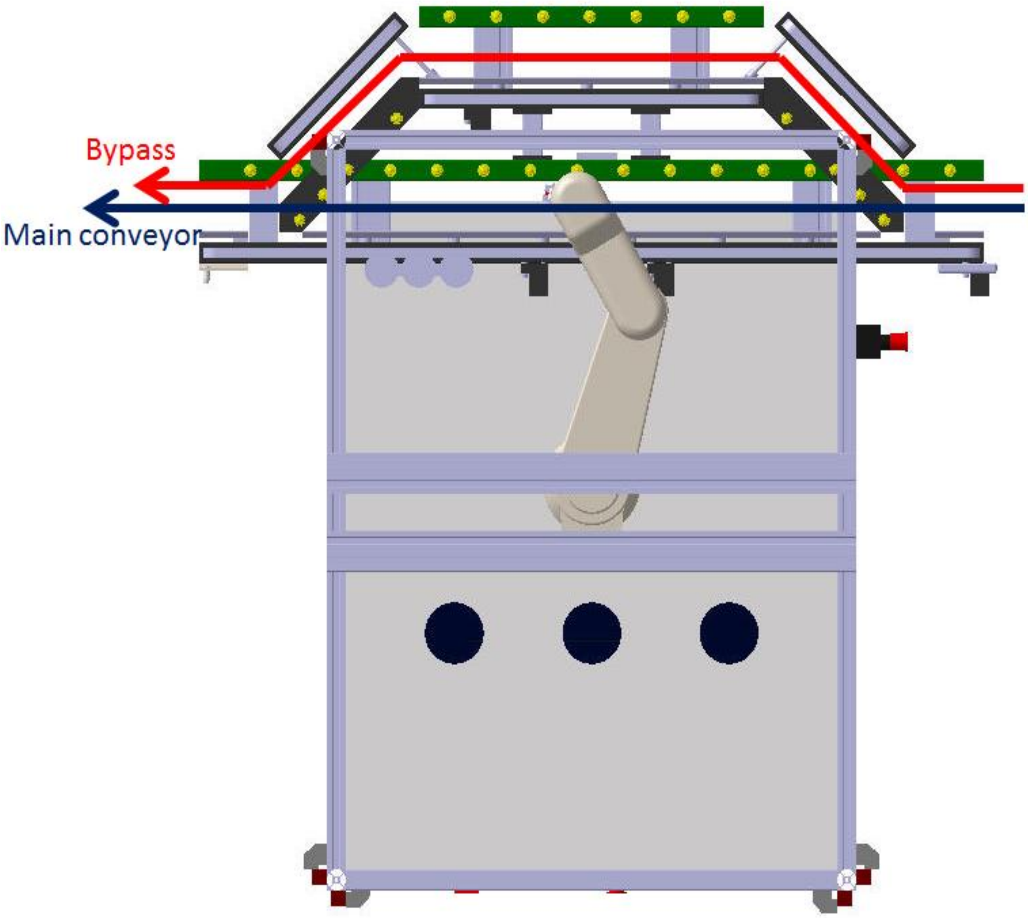


Figure 3. *Main conveyor and bypass conveyor*

Except the buffer which is not working within the line, the remaining cells work the same way as cell number two. They must choose between processing or bypassing each pallet, it depends on if the cell is starving at the moment or not.

The final product is a combination of several components; there are three elements (frame, keypad and screen) with three different colours and three shapes each component. We have nine types of each element, so if we combine all options we can get **seven hundred and twenty nine** different final products.

The line is configurable for unlike scenarios, depending on the required needs, so the robots do not work always with the same algorithm. In table 1 there are several examples about typical scenarios.

Table 1. *Example of scenarios for the manufacturing line*

Scenario	Description
All drawing cells can make any process	The cell checks the pallet, whether the pallet does not have the drawing done, and the robot is not busy, the cell will process all parts (keypad, screen and frame), if the pallet already is drawing the cell will be bypassed.
The cell can make only one part of all them	Some cells will draw the keypad, others the screen and another will make the frame of the mobile phone.
The cell can draw any component but with only one colour	The cell can make the keypad, screen or the frame, but only in one colour. For instance the cell draws all frames, screens and keypads but only in one colour.
The cell can draw all shapes in all colours but not all components	Each cell can make different shapes in all colours, but the robot can draw only one component. For example the cell can make the nine kinds of screen, but it cannot make keypads or frames

2.2 Problem Statement

The present manufacturing line is being modified to add some improvements. Horizontal and vertical integration of the devices are pursued. The control architecture is centralized thanks to the I/O nodes which connect the devices with the PLC, but distributed control architecture is wished. For achieving this kind of architecture smart remote terminal units (RTU) are being installed.

In addition the Fastory line will be provided with a new Advanced Pallet Information System (APIS). It is strongly related with asset-aware capabilities.

The objective of this thesis is giving the physical solutions for the new control architecture and allowing the implementation of electronic devices with asset-aware capabilities.

This thesis focuses on the mechanical design of the pallet and griper for cell 1. Manufacturing and implementation are also goals to achieve. The features of electronic devices and their dimensions will be considered, however communication between electronic devices and RTUs is beyond this work.

3. LITERATURE AND INDUSTRIAL PRACTICE REVIEW

The main goal of this chapter is to explain how the manufacturing systems and their current importance in the development of the countries' economies. Moreover, we will briefly explain RFID systems, focusing in the different existent types. It also will be explained, briefly, the identification systems and differences depending on their kind. Lastly, in order to show how manufacturing lines obtain some data we will mention devices with wireless technology.

3.1 Manufacturing

Manufacturing processes touch our lives every day [Niebel 1989]. Nowadays, we can find manufacturing processes within the creation process of any product of our daily routine. Manufacturing processes came from an assembly of several raw materials into the final shape we can finally observe. Figure 9 shows the life cycle of a manufactured product. Despite of the fact that manufacturing is a well-known process, some tasks involved in it as reuse and recycling must be improved.

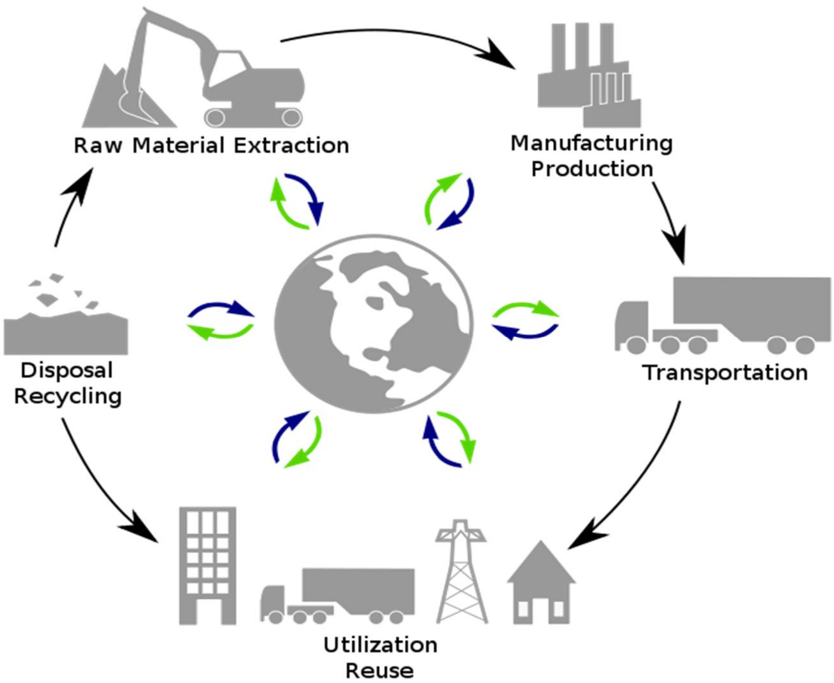


Figure 4. *Product's lifecycle*

In order to get a final product, manufacturing involves many elements as machines, tools, capitals, labor and so on. Relationships amongst many manufacturing activities are represented in figure 10.

The purpose of manufacturing is to cover the needs of the society through economic transition, thereby population can have the goods and the companies can receive compensation of their investments.

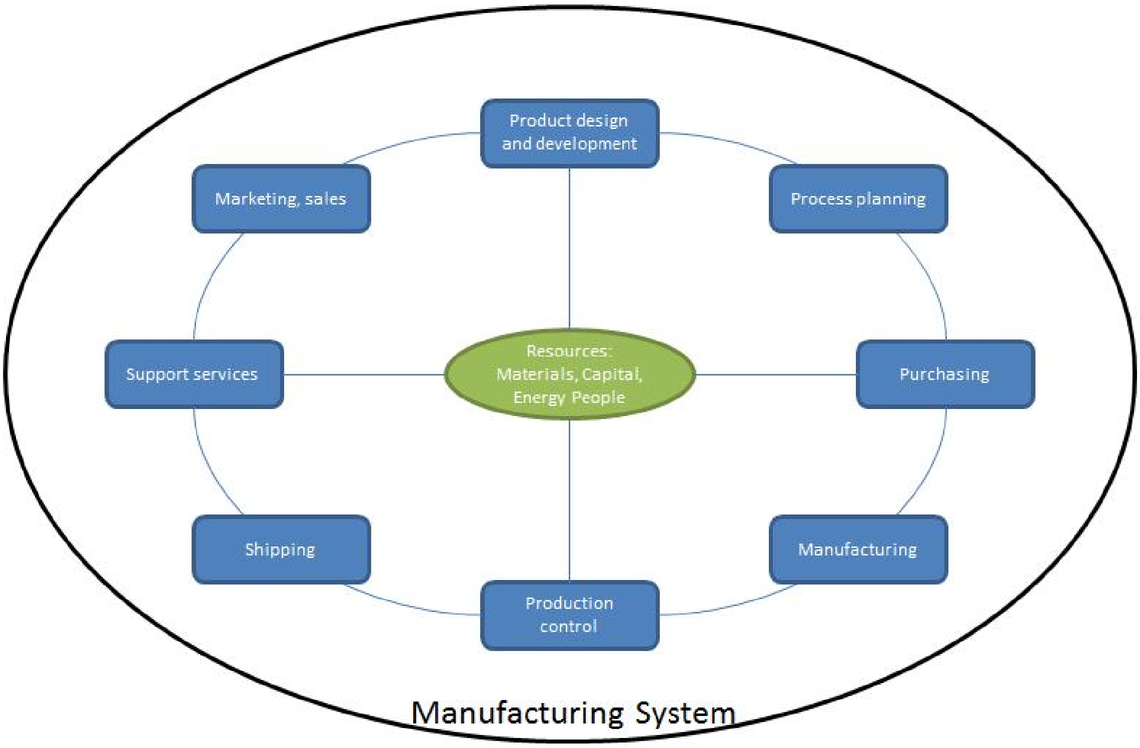


Figure 5*. Activities in manufacturing*

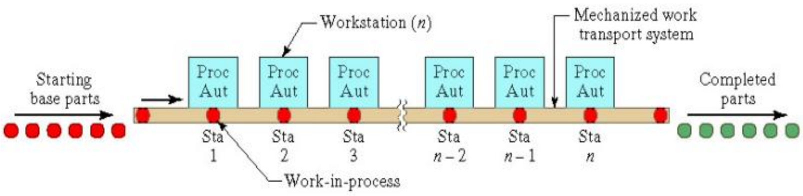
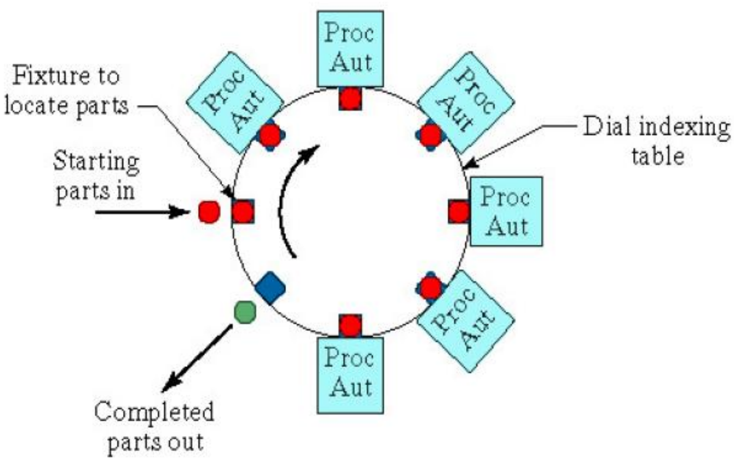
In the last years, manufacturing process won as much importance as to become and indicator of standard life of a country. The level of manufacturing activity is directly related to the economic health of a country [Niebel 1989]. Given the last analysed data, there is nothing to be surprised. European manufacturing value added in 2007 was €1750 billon [European 2009]. Furthermore the 25.4% of European working population is employed in the manufacturing sector [Eurostat], while it has expectations of increasing in the following years. Importance of manufacturing is proved, therefore sentences as manufacturing is the backbone of any industrialized nation [Kalpakjian 2008], are justified.

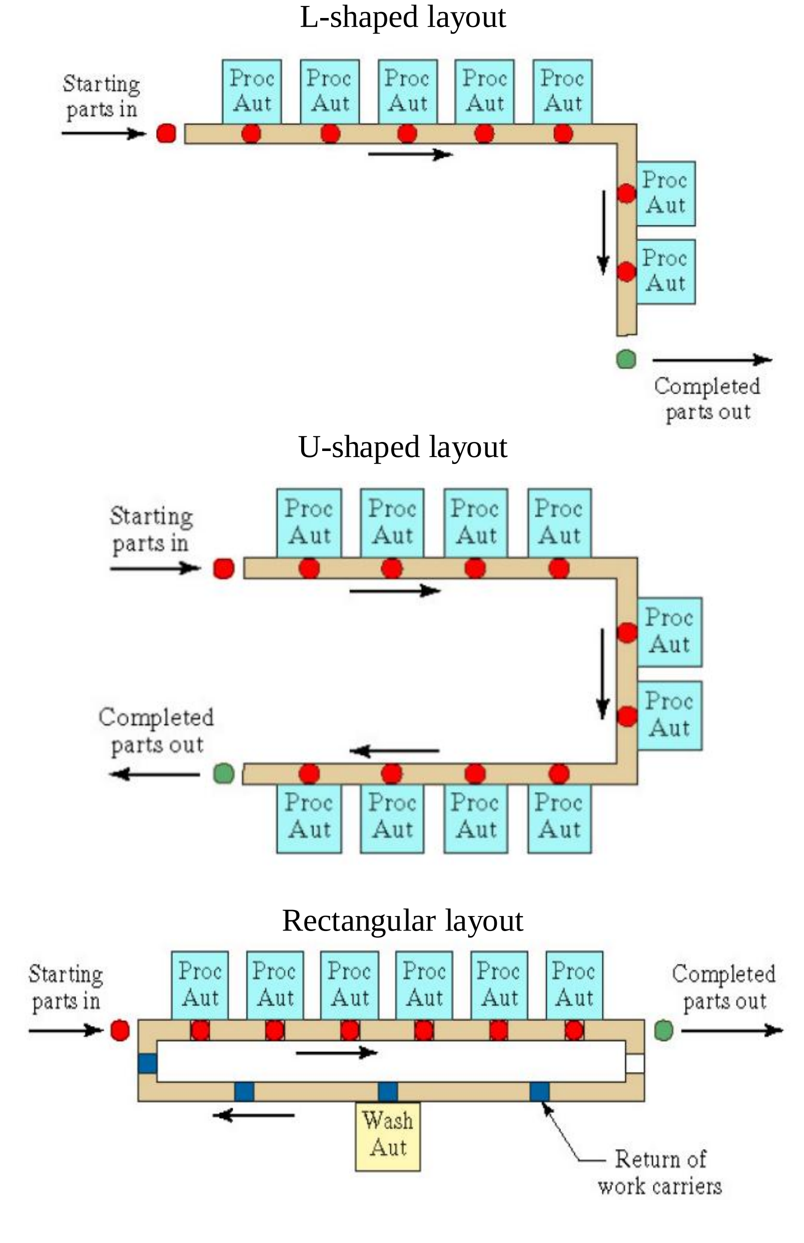
3.1.1 Production Lines

The manufacturing line object of this thesis, Fastory line, can be categorized within automated production lines. They are used for high production/assembly of parts and they have multiple workstations that are automated and linked together by a work handling system that transfers from one station to the next. The un-processed parts enter the automated production line and undergo a system of automated processing at various workstations along the fixed production line; the parts are passed from workstation to workstation by means of a mechanized work transport system, until the completely processed parts pass out of the automated production line after the last process occurs to the part at the final workstation in the system, in general each process is performed in an cell. In addiction the lines can have some extra cell to do quality control, buffer and so on. In the Fastory line there is a random access buffer and one place where the visual inspection with a smart camera is done.

A number of system configurations for the automated production line exist; these include: in-line configurations; segmented in-line configurations (for example, L-shaped layouts, U-shaped layouts, and Rectangular layouts); and rotary configurations. We have some examples in the table 2.

Table 2. *Systems configurations for automated production line [O'Sullivan]*

Configuration	Description
In Line 	Consists of a sequence of workstations in a straight-line arrangement. Common for machining big work pieces, such as automotive engine blocks, engine heads, and transmission cases. Can accommodate a large number of workstations, and buffer storage can also be planned for the configuration.
Rotary 	Consists of a circular worktable around which workparts are fixed to workholders. The worktable rotates to move each workpart, in turn, into each automated workstation which is located around the circumference of the worktable. The worktable is often called a dial, and the equipment is referred to as a dial indexing machine, or simply, indexing machine. Commonly limited to smaller workparts and relatively few workstations, and they cannot readily accommodate buffer storage capacity. However they require less floor space, and are generally less expensive than other configurations.



Segmented in-line: Consists of two or more straight-line transfer sections, where the segments are usually perpendicular to each other. Layout designs include the L-shaped layout, the U-shaped layout, and the Rectangular layout. Reasons for favouring segmented in-line over in-line configurations include: floor space considerations; reorientation of workparts to present different surfaces for machining in different line segments; the swift return of workholding fixtures (in the rectangular arrangement).

The automation can be described as it is the use of control systems and information technologies to reduce the human work in the production of goods. Usually the automation is the second step in a factory; the first one was the mechanization. The mechanization report advantages, in the next list there are some ones:

- Replacing human operators in tasks that involve hard physical or monotonous work.
- Replacing humans in tasks done in dangerous environments (i.e. fire, space, volcanoes, nuclear facilities, underwater, etc.)
- Performing tasks that are beyond human capabilities of size, weight, speed, endurance, etc.
- Economy improvement: Automation may improve in economy of enterprises, society or most of humanity. For example, when an enterprise invests in automation, technology recovers its investment; or when a state or country

increases its income due to automation like Germany or Japan in the 20th Century.

- Reduces operation time and work handling time significantly.
- Frees up workers to take on other roles.
- Provides higher level jobs in the development, deployment, maintenance and running of the automated processes.

Unfortunately the automation is not easy to implement, it is due to that the automation brings itself some disadvantages, the mains ones are in the next list:

- Security Threats/Vulnerability: An automated system may have a limited level of intelligence, and is therefore more susceptible to committing an error.
- Unpredictable development costs: The research and development cost of automating a process may exceed the cost saved by the automation itself.
- High initial cost: The automation of a new product or plant requires a huge initial investment in comparison with the unit cost of the product, although the cost of automation is spread among many products.

3.1.2 Conveyor System

Nowadays, due to the numerous benefits that conveyor systems provide, they are used across a wide range of industries. Conveyor systems allow quick and efficient transportation of an extended variety of materials, which make them very popular in the material handling and packaging industries. Many kinds of conveyors systems are currently available; thereby they had been developed according to the needs of different industries. For instance, in the automotive sector, they use power and free, one of the most famous ones. Figure 11 shows a power and free system is a car´s factory.

Figure 6. *Conveyor system in a car's factory*

Success of the conveyor system is based on its adaption to transportation needs of almost any industry. In spite of there are many conveyor systems, all of them have the next points in common:

- Conveyors are able to safely transport materials from one level to another, which when done by human labor would be strenuous and expensive.
- They can be installed almost anywhere, and are much safer than using a forklift or other machine to move materials.
- They can move loads of all shapes, sizes and weights. Also, many have advanced safety features that help prevent accidents.
- There are a variety of options available for running conveying systems, including the hydraulic, mechanical and fully automated systems, which are equipped to fit individual needs.

Unquestionably, there are many classifications for the conveyor systems, depending on which is the most important parameter. Table 3 can be a good example of an accurate list.

Table 3. *Conveyor systems*

Gravity roller conveyor	Gravity skatewheel conveyor
Automotive conveyors	Chain conveyor
Pharmaceutical conveyors	Lineshaft roller conveyor
Dust proof conveyors	Belt driven live roller conveyors
Overhead conveyors	Pneumatic conveyors
Chain driven live roller conveyor	Vibrating conveyors
Screw conveyor	Spiral conveyors
Vertical conveyors	Plastic belt conveyors
Flexible conveyors	Wire mesh conveyors
Bucket conveyors	Belt conveyor

The first conveyor belt was used in the 19^{th} century. In 1982 Thomas Robins made a conveyor belt used for carrying coal, ores and other products. Later Richard Sutcliffe invented the first conveyor belt to be use in coal mines, which meant a revolution in mining industry. The introduction of the conveyor belt system in the assembly line was in 1913, the responsible was Henry Ford.

Since then, conveyor belts have been gaining importance in automated distribution and warehousing, because of their reliability and endurance. They allow, in contribution with computer controlled pallet handling equipment more efficient retail, wholesale, and manufacturing distribution. Conveyor belts are considered a labor saving system that allow large volumes to move efficiently through a process, allowing companies to ship or receive higher volumes with smaller storage space and less labor expenses.

There are three different types of conveyor belts: **the basic belt**, **snake sandwich belt** and **long belt**. A basic belt conveyor consists of two or more pulleys that hold one continuous length of material. These types of belts can be motorized or require manual effort. As the belt moves forward, all the items on the belt are carried forward.

The belt is typically a smooth, rubberized material that covers the rollers. As the belt moves over the rollers, the items placed on the belt are transferred with a reduced amount of friction, due to the use of multiple rollers. Basic belt conveyors also have curved sections to allow the belt to move product around corners.

The snake sandwich conveyor consists of two separate conveyor belts that are set up parallel to each other and hold the product in place while moving along the belt. This type of belt is used to move items up steep inclines, up to 90 degrees. Created in 1979, the snake sandwich conveyor was designed as a simple, efficient method of moving rocks and other material out of a mine.

The long belt conveyor is a system of three drive units used to move materials over a long distance. The most important feature of this system is the ability of the rollers to handle both horizontal and vertical curves.

The basic belt has lot of evolutions, they are used to put the products directly over them or using some kind of structure. In general for assembly it is necessary some type of structure, in the Fastory line they are used pallets. The pallets thanks to the stoppers turn the basic conveyor belt in a Power&Free belt. It is really interesting, because the pallets can be stopped in the place where they are required. The line can stop some pallets and move the other ones, depending on the needs of the robots. The conveyors are running all the time, and the pallets are under control thanks to the stoppers, getting the control architecture easier, it is enough have the stoppers under control, independently of the conveyors. In the Figure 12 can be seen two examples of commercial stoppers.

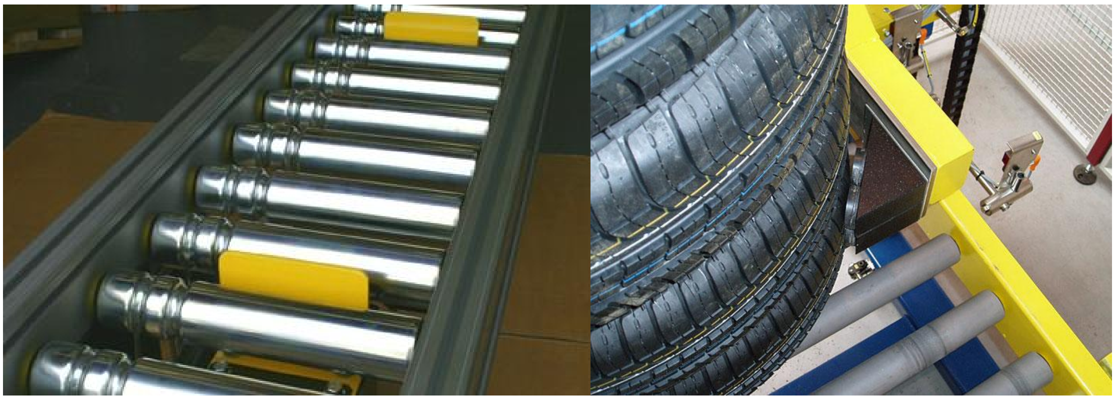


Figure 7. *Examples of stoppers in the conveyor lines*

3.2 Identification System

In the automated lines some sensors are required to detect the position of the components. There is a big variety of commercial sensors. Table 4 shows main commercial proximity sensors, and some features about them. Lines use to have proximity sensors, but this fact depends on specific requirements of each line, such as environmental.

Table 4. *Position sensors*

Type	Use
Inductive	Detection of metallic objects
Capacitive	Detection of metallic and no-metallic objects
Photoelectric	Use light sensitive elements to detect objects
Magnetic	Detects the presence of permanent magnets

In industrial environment the inductive sensors are preferred, skill as their resistance to shocks and dust, their cost, easiness to be installed and so on makes them the best choice. However there is one big disadvantage that prevents them from being the best option for any fields, this is that they do not recognize not metallic objects Factory line has seven inductive sensors installed in every drawing cell, and four more in other points of the line, obtaining a total of seventy four.

Inductive sensor is used to detect the pallet but we also need to know all the information about this pallet. Above are listed the main identification systems available in the market.

- Barcode (one or two dimensions)
- Infrared data association (IrDA)
- Magnetic Stripe
- Optical character recognition (ORC)
- Vision systems
- Radio frequency identification (RFID)
- Ultrasound identification
- Bluetooth

Products destined to commercial center use barcodes, currently 2D ones are gaining importance. Changing this system is really complicated because most of stores and customers have already interiorized this process.

However in manufacturing lines barcodes are avoided because they are very sensible to damages, similar problem that magnetic stripe. Perhaps, the most used system is RFID.

RFID provides a time/location reference for an object, but does not indicate that the object remains at that location, which is sufficient for applications that limit access, such as tracking objects entering and leaving a warehouse, or for objects moving on a fixed route, such as charging tolls for crossing a bridge. The industrial manufacturing lines can give more data. It can be studied and analysed getting some important information really useful to improve them.

3.3 Real-Time Locating System

Nowadays real time location awareness is being researched. This refers to devices that can passively or actively determine their location. Several years ago real time location systems were implanted in some sectors. For instance in maritime traffic using maritime mobile service identity (MMSI) or some logistic enterprises to control their vehicles on route, thanks to GPS systems.

The real time positioning systems are the next step to the identification point to point, these are installed in the majority parts of the system in the present manufacturing lines.

The accelerometers are sensors that measure proper acceleration. However, the proper acceleration measured by an accelerometer is not necessarily the coordinate acceleration (rate of change of velocity).

In the automotive industry the accelerometer is used to aid numerous systems in the cars. The device measures the vehicles acceleration, thus allowing the comparison between true acceleration and theoretical one, this last one obtained through other sensors. If the electronic system of the car detects variations between two accelerations consequently acts over the engine, brakes, clutch or any other part depending on the lecture, making the driving easier and more enjoyable.

The accelerometer can be also used in positioning systems. A good example of it is the Inertial Navigation System (INS). It is a navigation aid that uses a computer and accelerometers to continuously calculate via dead reckoning the position, orientation, and velocity (direction and speed of movement) of a moving object without the need for external references [WIKIPEDIA 2012.1].

A gyroscope is a device for measuring or maintaining orientation, based on the principles of angular momentum. Nowadays there are digital gyroscopes which are really small. they allow this way their installation in small products. Digital gyroscopes can contribute manufacturing localization systems, in the same way as accelerometers. In fact, the integration of the gyroscope has allowed for more accurate recognition of movement within a 3D space [WIKIPEDIA 2012.2]. Figure 13 shows a digital gyroscope, its dimensions are 4x4x1 mm.

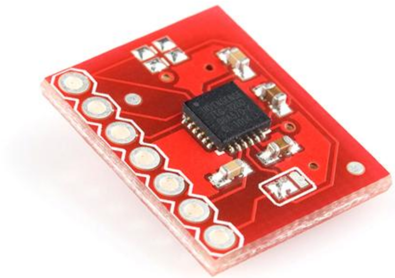


Figure 8. *Digital gyroscope*

3.4 Wireless Communication

At the present time, wireless technology is gaining importance. Some products that used to have physical connexions, such as keyboards for computers, mouse, headphones and so on, but manufacturers are changing their physical links for wireless technologies, reaching to a point in which, for example, the wireless mouse market is bigger than the traditional one.

Wireless communication has a wide range of use. Distances can be short, such as a few metres for television remote control, or as far as thousands or even millions of kilometres for deep-space radio communications. If we focus in short distances with internet protocol for small devices, there is special wireless model, it is **6LoWPAN.** Its name is an acronym of IPv6 over Low power Wireless Personal Area Networks. The standard used in 6LoWPAN is IEEE 802.15.4. It allows the communication with small devices which have this same wireless domain.

3.5 Computer-Aided Manufacturing

The idea of “digital manufacturing” was prominent the 1980s, when computer-integrated manufacturing was developed and promoted by machine tool manufacturers and the Computer and Automated Systems Association and Society of Manufacturing Engineers.

Years later the manufacturing which approaches of using computer to control the process, was named Computer-Integrated Manufacturing (CIM). CIM is a bunch of techniques such as:

- CAD (Computer-Aided Design)
- CAM (Computer-Aided Manufacturing)
- CAE (Computer-Aided Engineering)
- ERP (Enterprise Resource Planning)
- PPC (Production Planning and Control)
- CAQ (Computer-Aided Quality)

The techniques most used are the first three. In this thesis we use the first two of them, CAD and CAM. The use of both techniques allows that the pieces were manufactured without to print none blueprints The Computer Numerical Control machines are able to manufacture directly with the design files.

The software used to develop the designs and manufacturing is the Computer Aided Three-dimensional Interactive Application (CATIA). Specifically it is version 5 release 20, developed by Dassault Systems.

This software can be described as open, scalable, and easy to deploy, CATIA addresses the complete product development process from product concept specification through product-in-service and facilitates true collaborative engineering across disciplines, including style and shape design, mechanical design, equipment and systems engineering, digital mock-ups, machining, analysis, and simulation [Dassault 2012].

By using CATIA we save a lot of time, because the design a new component within existing set requires check, and sometimes, thousands of measures. If the set is not modelled in CATIA we need to take the measures manually to achieve the geometrical constraints. However whether the components are modelled we can still use CATIA, the checking is faster, safer, and easier.

Figure 9 shows how CATIA works to achieve a final product. First step is to draw a sketch and do one operation using it as a base. With those two actions we get a feature, then we can use as many features as we need them to achieve our final part. Using the appropriate combination of parts the final product is assembled.

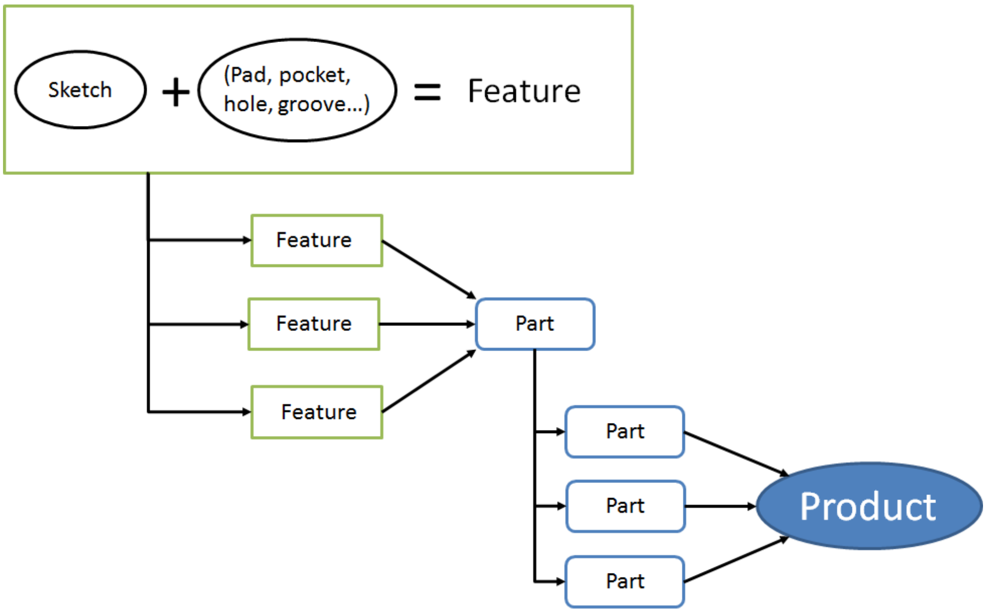


***Figure 9**. Example of a CATIAs tree*

In CATIA the reference system used is a Cartesian coordinates in three dimensions, it is formed of three axes, (X,Y,Z). In this Master Thesis the Z axis, is the vertical axis, so the plane formed for the axes (X,Y), is the floor plane.

3.6 Failure Mode Effects and Analyses (FMEA)

There is no doubt that mechanical design is a critical function in a production system. The quality of the product design is the most important factor in determining a commercial success and the value of the engineering work. In addition to visual and functional features, a proper design must be in a hand to hand with the manufacturing aspects because they are bounded together functionally, technologically, and economically [Groover 2008].

The industry has learned that design failures are always linked with the product, and they are really expensive for the manufacturers. In fact, they have invented several techniques to detect the risk failures in the products. Probably the most famous technique is the FMEA. It has been developed for the United States military and later for the National Aeronautics and Space Administration (NASA). However the introduction in the automotive sector (and its expansion) was too late. This happened after the big design failures in Ford, their model Pinto meant the inflexion point due its fails.

FMEA is a tool to systematize the product design, specifically the evaluation of the risk in the design. It is focused on preventing problems, enhancing safety, and increasing customer satisfaction.

There are several types of FMEA, for process, design, concept, equipment, service and so on. Each type is adapted to each user to get the best results in the way they are interested in. In Table 5 the model adapted for this work is shown.

Table 5*. Example of FMEA*

Item/ function	Potential Failure mode	Potential Failure effect	S	Potential Cause(s)	O	D	RPN
Wireless Signal	The accelerometer cannot send the signal properly	There is no information about acceleration and turning of the pallet	3	It is produced by the Faraday Cage	9	8	160

Item/ function	Recommended actions	New S	New O	New D	New RPN
Wireless Signal	Use plastic material to avoid the Faraday Cage	3	1	8	24

The columns 2, 3 and 5 in the first row, each one returns one question about failure, they are in the next list:

- Potential failure mode*: In what ways can the product fail?*
- Potential failure effect: *What is the impact on the key output variables once it fails?*
- Potential cause (s): *What causes the key input to go wrong?*

The columns 4, 6, and 7 are evaluation parameters, their range is 1-10; the last one is the design quality quantification.

Severity (S): Determine all failure modes based on the functional requirements and their effects. Number 1 means “no effect” while number 10 represents “hazardous”,

Occurrence (O): It values the number of the times it occurs. Number 1 representing “No known occurrence” and the number 10 means “failure is almost inevitable”.

Detection (D): It determinates how well we can detect a failed product or process. Number 1 is certain detection and Number 10 means undetected fail.

Risk Priority Number (RPN): It is the result of multiply the three previous numbers. (Severity x Occurrence x Detection). It is a parameter that gives us information about which are the first steps to improve the product. The new numbers (New O, New D, New D, and New RPN) are obtained after doing some recommended actions.

4. PROPOSED SOLUCTION

This chapter can be considered the most important of this thesis. The purpose in this point is to explain the proposed solution for each problem, sometimes it will be necessary to explain in great detail some constraints which are not easily detected without having a good knowledge about the Fastory line.

4.1 Current Line

In the loading station there are two external conveyors, independent from the main conveyor to move the pallets. These conveyors are used to feed the line with new paper and to remove the final products. If the cell is seen from the front part, the conveyor of the left side is the one for the input trays and the right side is the one for the output trays. There are two pneumatic cylinders working as elevators, they do the path between the I/O conveyors and the place which the robot uses like warehouse.

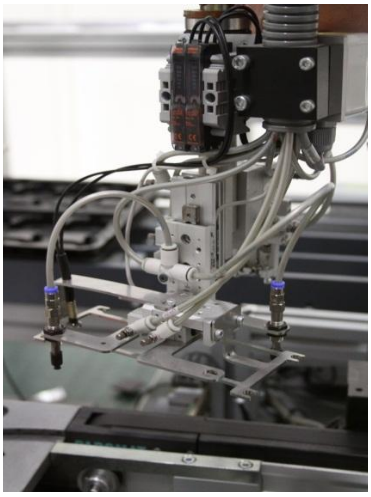


Figure 10. *Loading station, gripper detail*

The robot has a special gripper, it can be seen in figure 4, it was designed to change and fix the paper on the pallet. It has two suction cups, they are responsible of holding the paper while the changing operation is being done. The gripper also has a sensor to detect the paper holder, all the devices are placed in the same metallic structure. Another assembled element on the gripper is a structure to manipulate the paper holder, it is activated thanks to a pneumatic cylinder. The gripper is doubled, it means that the gripper can have two papers and two paper holders at the same time, the explanation can be depicted through figure 5, in which has a comparison between using a simple or a doubled gripper.

Figure 11. *On the left side, operations flow using double gripper. On the right side, operations flow using simple gripper*

The double gripper is justified thanks to the time saved in the operation, this way the paper changings operation time is reduced in a sixty per cent, when the traffic conditions are the ideals, this means that no pallets are waiting at the entrance of the loading station. In Figure 6 it can be seen how the double gripper is.

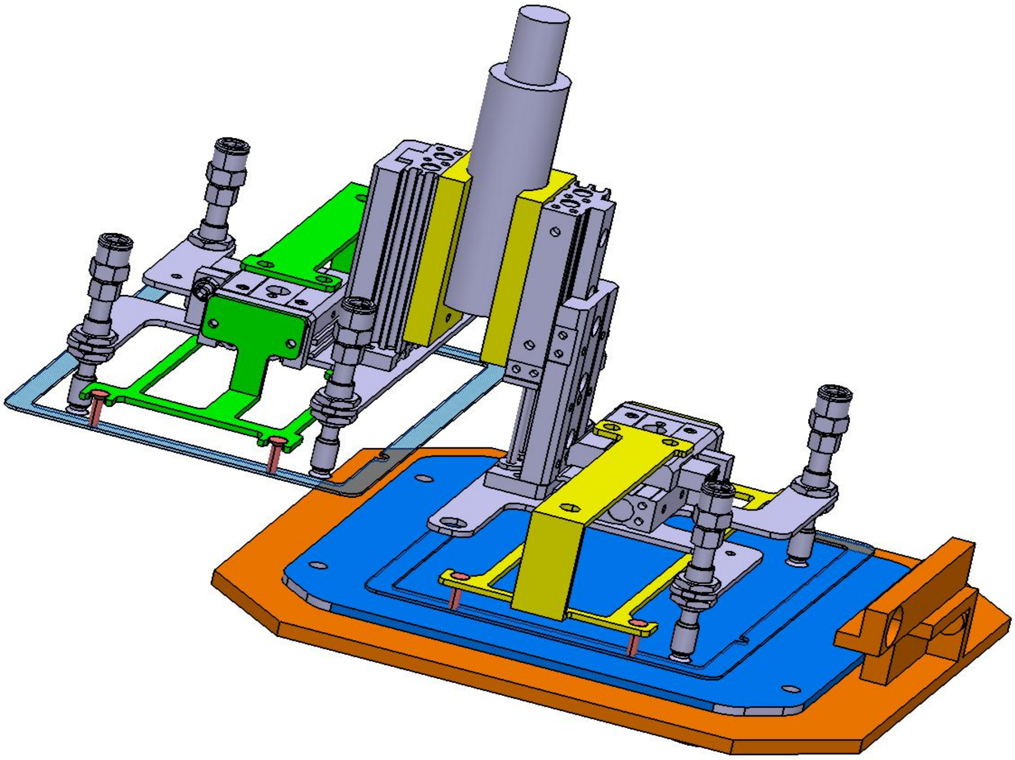


Figure 12. *Double gripper in detail*

The localization of the buffer in the line is in the middle of it. There are four workcells before and four workcells after the buffer. In this way the line gains flexibility, because the buffer can put new pallets in the main conveyor if it is necessary. The buffer has some extra pallets stored to solve this situation, but the buffer also can replace or store the pallets which are running through the line. Table 6 contains some functions of the buffer, the main ones. The buffer can solve other situations which are not considered in this table.

Table 6. *Examples of some operation modes of the buffer*

Action	Cases of use
Storing pallets	The pallet is assigned to a workcell and it does not work properly.
Putting pallets in the line	The line needs to make more different final models.
Replacing pallets	The system detects that there is a pallet with a fail (problem in the bearings, frame, magnets…).

The buffer has several main elements, transelevator and shelves. They can be recognized easily in figure 7. The physic operation of the buffer can be explained in a few steps. It can do two operations, placing the pallet over the shelf or placing it on the main conveyor.

Steps to store the pallet and to place it on the line:

1. Identify and stop the pallet over the lift.
2. Go up the pallet in the lift to the correct position for the transelevator.
3. The transelevator takes the pallet.
4. The transelevetor places the pallet in a shelf.

1. Identify the position of the pallet that is required.
2. The transelevator takes the pallet and places it over the lift.
3. The lift puts the pallet over the main conveyor.
4. The stopper is removed so the pallet can run through the line.

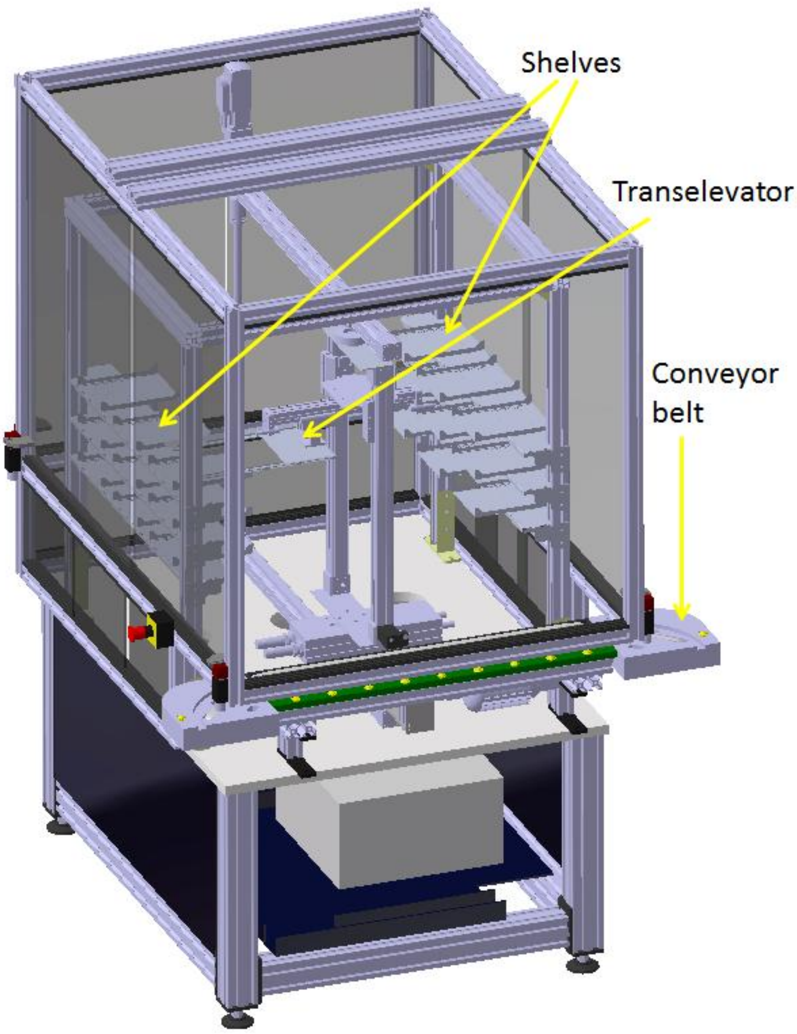


Figure 13. *Buffer and its main elements*

There are eight cells which can draw, all of them are similar. They have a robot with a special gripper adapted to take and use a pen. In the cell there are a pen station and a pen feeder. The pen station is a place where the robot puts the three pens, one of each colour, which are using for the drawings. The feeder pen has three structures, one for each colour, where there are eight pens, so there are twenty four in total stored. The feeder pen and its shape can be seen in figure 8.

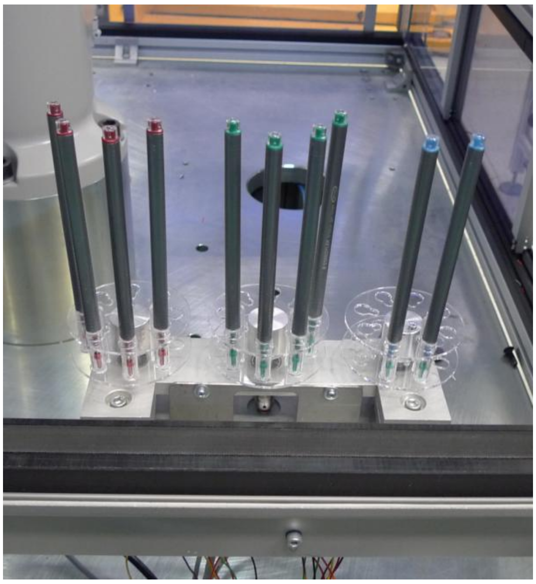


Figure 14. *Detail of the pen feeder*

The running of the workstation can be described as follows, when the pallet goes into the cell, through the main conveyor and not through the bypass, the robot will draw on the paper sheet. Depending on the required colour the robot will use the pen it has in its gripper or it will pick up another pen from the pen station. When the pens ink finishes the robot will automatically change the pen, for this the robot will leave the pen without ink and it will pick up a new pen from the feeder pen. Once the drawing is done the pallet will continue through the conveyor belt up to the next cell.

4.2 Identification system

The Fastory line already had an identification system. Its devices and its functionality can be summarized as follows: Each pallet of the line contains an RFID tag. RFID readers are placed in the conveyor stoppers to give the workstation controller information on which pallet is at each stopper. RFID readers are connected via DeviceNet interface that can process the RFID signal to a DeviceNet slave connected to the central PLC [Gonzalez 2012].

The question could be *why do we need a new identification system?* To answer this question it is necessary to understand some modifications which were made for other researchers.

RFID readers and PLC were OMROM and their communication was good, but they were part of a central architecture, and for some new research lines this distribute control architecture is required. PLCs were replaced for smart remote terminal units (RTU), specifically the chosen model is Inico S1000. The commercial product S1000 exhibits these following characteristics [Inico 2011]:

- Real-time control
- Digital and analog I/O
- Expansion I/O modules
- Embedded Web-based HMI
- Events and alarms reporting
- Web-based configuration
- Wireless support
- Enterprise integration using XML/SOAP

When the PLCs were removed the RFID system was cancelled, because the communication between old RFID readers and new RTUs is impossible, so the solution was to look for a new identification system.

Several kinds of identification system were previously mentioned in chapter 2, now an advantage/disadvantage comparison will be done. It can be seen in table 7, some characteristics are evaluated.

Table 7. *Identification systems and their features*

Technique	Durability	Cost	Read-write capability	Data density	Time to enter	Error data
RFID	High	Medium	Yes	High	Fast	Low
Car codes (1D)	Low	Low	Read	Low	Fast	Low
Bar codes (2D)	Medium	Medium	Read	Medium	Fast	Low
Magnetic Stripe	Medium	High	Yes	Very high	Medium	Low
Bluetooth	High	High	Yes	High	Very slow	Medium
IrDA	High	High	Yes	High	Slow	Medium
ORC	Medium	Medium	Read	Low	Medium	Medium
Vision systems	High	Very High			Depends on type	Depends on type

Our system requires that the tag has to be close to the reader, the code has to be read from a close distance, if not, the distance will add difficulties to the identification of the pallet, thus making possible a wrong identification, the reader could identify the pallet before or the one after the one indicated. Once the requirement is known, the decision is made, passive RFID tags are used. The passive ones do not have battery, so they can be read only at very short distances. The model of RFID tag will be explained in great detail afterwards, in point 4.3.

Chosen RFID readers are ones which have Near Field Communication (NFC). This is a technology that is gaining importance in the commercial market these last years. NFC provides a range of benefits to consumers and businesses, such as [NFCforum2012]:

- **Intuitive**: NFC interactions require no more than a simple touch.
- **Versatile**: NFC is ideally suited to the broadest range of industries, environments, and uses.
- **Open and standards-based**: The underlying layers of NFC technology follow universally implemented ISO, ECMA, and ETSI standards.
- **Technology-enabling**: NFC facilitates fast and simple setup of wireless technologies, such as Bluetooth, Wi-Fi, etc.).
- **Inherently secure**: NFC transmissions are short range (from a touch to a few centimetres).
- **Interoperable**: NFC works with existing contactless card technologies.
- **Security-ready**: NFC has built-in capabilities to support secure applications.

An advantage using NFC is that it is be possible to check the tags manually, therefore the objects associated to them, the pallets in Fastory line. This checking can be made through personal devices such as mobile phones, PDAs, tablets and so on.

The Main feature for choosing the reader was the communication protocol between the host and the contactless interface. Reader has a communication protocol very similar to the CCID protocol. This makes the communication with the S1000 possible.

Furthermore other features were analysed to decide the model of the reader. Reading distance, speed, cards supported and so on. The selected model is ACR 120 S-B1 from ACS Ltd. In the figure 14 is the model used in Fastory line.

Figure 15. *NFC reader. Model ACR 120 S-B [Smartcard 2012]*

NFC reader ACR 120 has another big advantage, it is a commercial reader, so its price is reasonable. In addition, its size is moderate, so it can be put in no bigger spaces. Other functionality features are in the next list [ACS 2011].

- Serial interface. Baud Rate =9600 bps (default) or 115200 bps, 8-N-1. Initial Baud Rate is determined by the existence of R12. A command is also provided for changing the baud rate while the reader is running.
- USB interface for power supply.
- CCID-like frame format (Binary format).
- Read/write speed up to 424 kbps.
- Built-in antenna for contactless tag access, with card reading distance of up to 50 mm (depending on tag type).
- NFC (ISO/IEC18092) tags.
- Supports new Mifare Cards Supports ISO 14443 Part 4 Type A and B, Mifare, FeliCa and all four types of tags, including Mifare Ultralight C, Mifare Plus and DESFire EV1.
- Supports all 3 modes of NFC: reader, card emulation and peer-to-peer modes.
- Built-in anti-collision feature (only one tag is accessed at any time).
- Selective card polling capability (especially useful when multiple cards are presented).
- User-controllable buzzer.
- OEM PCBA module version.
- RS485 interface for data transmission.
- PS/2 or DC power adaptor for power supply.
- Relay.

4.3 Real-time localization. Advanced pallet information system (APIS)

The technical solution for the localization is using gyroscopes and accelerometers. They will be installed in the pallet. It uses necessary a wireless communication. This Wireless communication is 6LoWPAN. It is an open standard which works well with individual sensor nodes.

There are not many devices with integrated accelerometer and gyroscope. If another requirement is wireless communication ability then the list is even shorter. We make a comparison between two devices; one is a prototype from Inico, and the other one is a commercial device from Sparkfun electronics.

***Table 8**. Comparison between wireless devices*

	Inico (Prototype)	Sparkfun (WiTilt v3.0)
Dimensions (mm)	105.5 x 61.0 x 21.6	72.4 x 55.9 x 18.5
Wireless communication	6LoWPAN	Bluetooth
Accelerometer	Triple axis (ST LIS3DH)	Triple axis (MMA7361)
Gyroscope	Triple axis (ST L3G4200D)	Single axis (MLX90609-150)

Table 8 shows the main features for both devices. The accelerometer is similar in both cases. The WiTilt v3.0 is more compact than Inico prototypes, it is its big advantage. Wireless capability in Sparkfun device is through Bluetooth, but the line needs 6LoWPAN, so Inico device is the most suitable. In addition, the WiTilt gyroscope is a single axis, so it limits its applications.

Figure 15 is a schema of the components and how they operate. The accelerometer and the gyroscope are inside Inico device, it communicates with Inico Wireless router, specifically, the model is 1-Z router. Wireless communication is via 6LoWPAN.

***Figure 16.** Wireless communication*

Further information about how the wireless signals are leaked and analysed to get the real time localization is beyond the scope of this thesis, in fact, it is being investigated by other researchers.

4.4 Tests to devices

Usually the commercial and industrial products have a list of characteristics; these are handed to the manufacturers. Normally they make tests under specific conditions, thus obtaining desired characteristics that are not the same in the real life conditions. Then it is not strange that the characteristics given of the product, such as speed, distances and detection, may not be the same once the product is used in a real situation, because of that these products have to be tested to know the real specifications they have..

The industrial characteristics in the bought products were tested in the most adverse conditions they could endure, this way the functional limits (real characteristics) were obtained.

4.4.1 NFC system

When the communication between the NFC reader and the S1000 was ready some tests were made over the Fastory line. Data which are necessary to determinate empirically are the written below:

1. Reading distance. (Real distance within Fastory line environment).
2. Reading speed and communication speed.
3. Reader stability and communication stability.
4. Detect other influential parameters.

NFC system was tested first with a normal stick tag. This kind of tags cannot be read over metallic components. In the first test the tag was placed over the metallic component, and the NFC reader could not detect it. The next was placed over the plastic part. In that localization the NFC reader could identify it so the next step was checking the maximum distance in that position. Distance will never be more than 25 mm to guarantee the reading. Probably the difference between theoretical data, about 50 mm and real data, no more than 25 is due to the presence of a lot of metallic components in the line.

Moreover it was observed that the stick tag has a very bad behaviour when it is near metallic components. This will prompt that the stick tag is not suitable for the Fastory line, because of the presence of metallic parts in all the line and the pallet in the future can contain more metallic devices, so in case the stick tag is placed it can create some conflicts with the future devices.

Table 9. *FMEA for RFID tags*

Item/function	Potential Failure mode	Potential Failure effect	S	Potential Cause(s)	O	D	RPN
RFID tags	The RFID reader cannot read the RFID tag	It is not possible to identify the pallet	4	There are interferences caused by metallic materials	8	5	160

Item/function	Recommended actions	New S	New O	New D	New RPN
RFID tags	Use RFID tags which can work within metallic materials	4	1	5	20

In the appendix, it can be consulted the complete (FMEA) made for the design of the pallet, but the part referring to the NFC tag can be seen in the table 9.

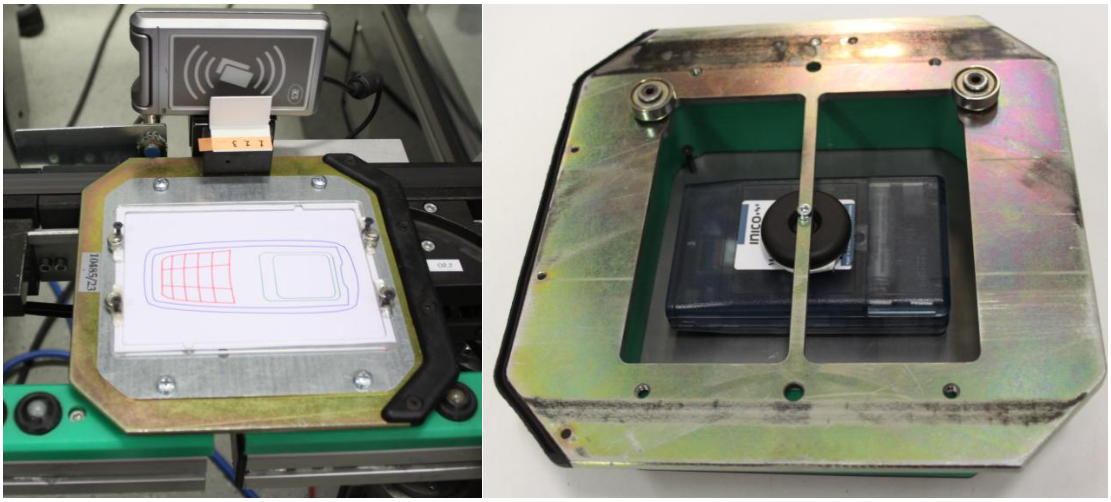


Figure 17. *In the left side can be seen the test prototype with a normal stick. In the right side the other model of RFID tag is depicted*

In Figure 16 there are two kinds of RFID tags represented. In the left case there is a stick which was placed over the “L” plastic piece. In the right picture a black RFID tag is assembled in the bottom part of the pallet. The black tag was also checked in the line, its results were higher than the first tag, especially because the second tag type is designed to be used over metallic components. Some tests were repeated placing the RFID tag in different points of the pallet.

NFC tags chosen are “all surface”, in other words, they can be used over metal seamlessly. Its size is diameter is 35 mm diameter x 5 mm thick. This NFC tag is a self-adhesive Polyamide tag that operates at 13.56 MHz wireless frequency and contains 64 bytes, 48 of them of usable read/write memory. Based on the Mifare Ultralight chip from NXP, this tag offers a permanent lock feature, therefore user data can be permanently configured read-only memory.

When attached to a metal surface this tag employs specially designed shielding to allow continued contactless use without interference. This durable and waterproof tag can be attached to surfaces by a screw through the central hole or by the adhesive back. In this case it is attached by a screw, it is specifically model M3x5.

Subject to memory size, this tag is suitable for storing

- Any type of URI including URLs, telephone numbers, SMS, e-mail and geo-locations.
- Plain text or a combination of plain text and a URI.

- vCards and signatures.

Typical application areas include:

- Smart posters, advertising displays, kiosks and bus stop advertisements.
- Handouts, brochures, leaflets, flyers and magazines.
- Contactless ID/ticketing.
- Embedding in devices.
- Public Transportation.
- Loyalty and payment.

This tag is NFC forum type 2 compliant and typically operates at a distance of up to 5cm depending on the power provided by the NFC enabled device. Figure 17 shows the two types of RFID tags and their shape.

Figure 18. *The tag on the left is the NFC stick used in the first tests. On the right is the final RFID tag*

4.4.2 Accelerometer

Once the device is ready to implementation, some important tests must be done. The main questions to be empirically solved are:

1. How does metal affect wireless connection?
2. Which is the maximum distance the device supports?

The first step is to have only one standard of comparison. The choice standard is to use the device in isolation conditions. In other words, the component does not have physic barrier, such as, walls or objects between the receiver router and accelerometer, so that the obtained results covering the device with metal and plastic are compared to the standard.

To detect how material affects the wireless signal the prototypes depicted in Figure 18, and someone more, were tested in the laboratory.

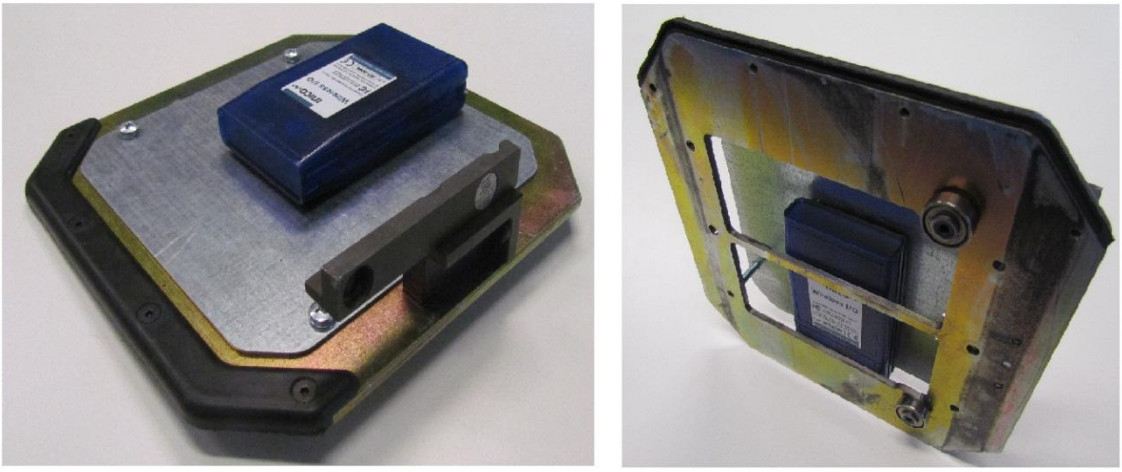


Figure 19. *On the left is the prototype 1. On the right is the prototype 2*

1. Standard. (There is no metal near the accelerometer. Distance to metal > 500 mm).
2. The device is above the metal piece. (Prototype 1).
3. The device is under the metal piece. (Prototype 2).
4. The device has metal over it. There is a plastic piece surrounding the device. (Prototype 3).
5. The device has metal over and under it. (Prototype 4).

When the prototypes are defined we define three distances to check the signal. They are presented in figure 19. The first area covers the maximum distance between wireless device and its receiving antenna if the pallet is moving through the line. The third distance is the furthest point inside the FAST-laboratory. The second distance is the intermediate point between the two previous limits.

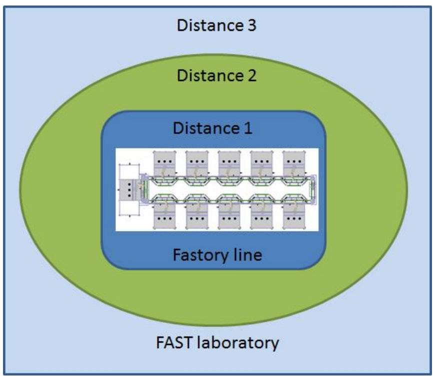


Figure 20. *Distances used for the accelerometer tests*

To facilitate the results of both questions we can see table 10. In rows are represented the prototypes and in the columns the areas appear. The base number for the percentages was ten, which means the accelerometer has sent ten messages for each distance and each prototype. The results were calculated as follows:

$$R = \frac{M_r}{M_t}$$

Where R is the result, M_r is the number of received messages and M_t is the total number of messages sent.

Table 10. *Percentage of signals received*

	Distance 1 (Line)	Distance 2	Distance 3 (Laboratory)
Prototype 1	100%	90%	50%
Prototype 2	100%	80%	50%
Prototype 3	100%	80%	30%
Prototype 4	80%	50%	10%

The manufacturing line is inside the first area, which is delimited for distance 1. The prototype 4 is not valid for the line. Probably with two metal parts, above and under the device, the signal is affected for them. The metal affects to the device, so we try to design plastic pieces, avoiding metal components. However the signal is strength enough, allowing a pallet with some metallic components. In figure 20 are depicted how the signal works in each area depending on the pallet.

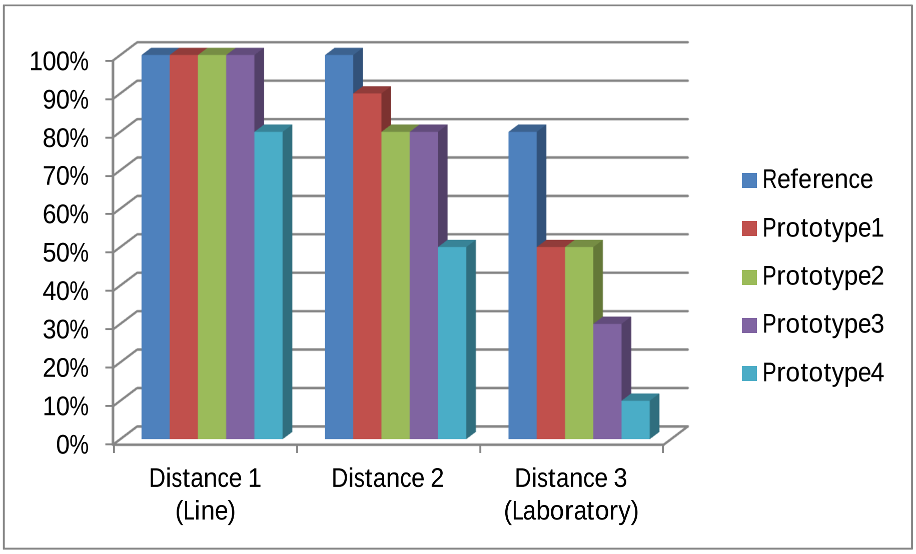


Figure 21. *Wireless signal for diferents distances dependig on the prototype*

4.5 Components of the previous pallet

The pallet which was used in the Fastory line is represented in the figure 21. It has several components, all of them will be commented and its functionality will be explained.

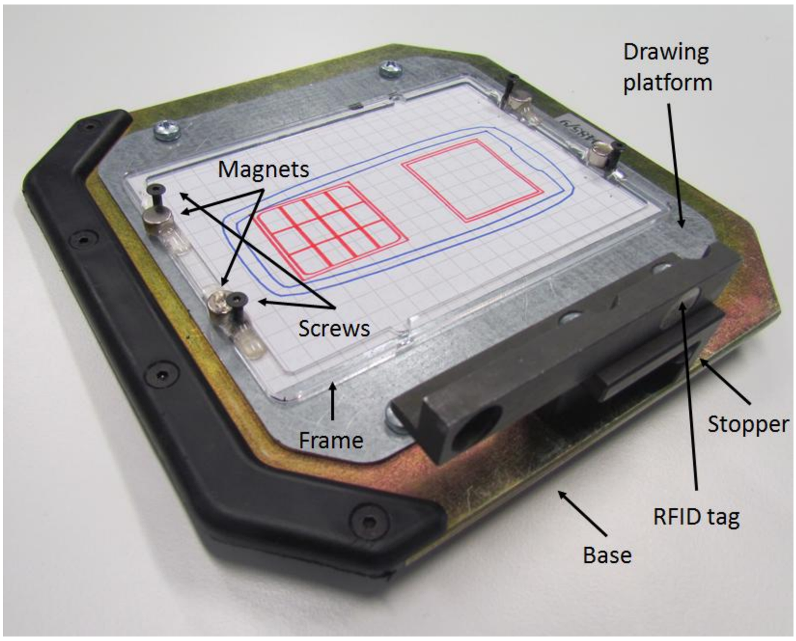


Figure 22. *Components of previous pallet*

The bearings are used to guide the pallet across the whole line. There are two in the bottom part of the pallet going inside the groove in the line. Their size is 6x19 mm. The groove has 20 mm, so there is a clearance of 1 mm. In figure 22 we can see how the groove is.

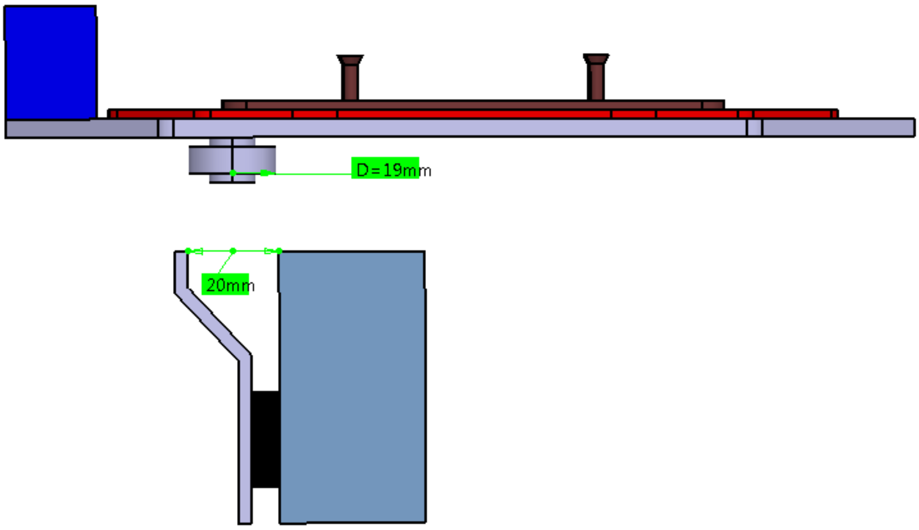


Figure 23. *Loading station, gripper detail*

The main component of the pallet is the base. Each component of the pallet is fixed to it with screws. It is square shaped, its size is 200x200x4 mm, and it has four chamfers, one in each corner. The base is designed to be able to be removed from the conveyor belt, the weight and shape were designed to avoid traction problems over the conveyor belt, because it is a common problem in this kind of belts.

On the front part the base has a plastic bumper. It is to decrease the violence of the impact with other pallets which are stopped in in a point due to a breakdown, bottleneck, tests and maintenance of the line and so on. The bumper prevents crashings between two metal parts, furthermore the plastic bumper has a special design allowing the absorption part of the impacts energy.

The stopper is a metallic element which is used to keep the pallet static in a certain place where is required. The stopper is fixed to the base with two screws, it has a plastic cushioning reducing the impact when the stopper, in the cell, crash with the stopper, in the pallet.

The paper used to draw the mobile phone is a normal sheet, its size is standard, ISO 216 A6 (148x105 mm). Before installing the quality inspection in the loading station of the Fastory line a grid sheet was used, but to improve the results of the smart camera the grid sheets were replaced for blank sheets, keeping the size A6.

Over the base there is a metallic flat piece. Its aim is to support the paper sheet in order that the robot can draws on the sheet seamlessly. Its thickness is 2 mm, it is enough to support the pressure forces (without bending) which the robot makes over the paper when it is draws. The paper's support is fixed to the base through four screws. This piece is magnetic, because magnets are used to fix the frame to it.

There is an element which avoids the movement of the paper. This piece is made of plastic material and its internal measures are (140x96 mm). Its thickness is 2 mm and its wide is 7 mm. It has four magnets fixed by glue, their function is keeping the paper fixed over the paper's support whereas the pallet is running in the manufacturing line. Also there are four small screws, their size is M3x8, they are necessary in the loading/unloading operation, because the gripper of the robot uses these four screws to pick up the frame.

4.6 Pallet design

When the new devices are chosen we need to adapt some components of the line in order so the new devices can work seamlessly. It is important having in mind the main aim, but the constraints which the line gives us cannot be forgotten.

Probably the component of the line which will need more modifications is going to be the pallet, but it entails that other components must be adapted to the new pallet. Basically the transformations will be realized in the loading station (Cell 1), but in the drawing cells, reprograming the robots and moving some physical components will be necessary. Every modification will be explained in throughout this chapter.

In order to facilitate the reader's compression, figure 23 can be observed. The mains pieces of the pallet and the gripper are mentioned, all of them are detailed in the next paragraphs.

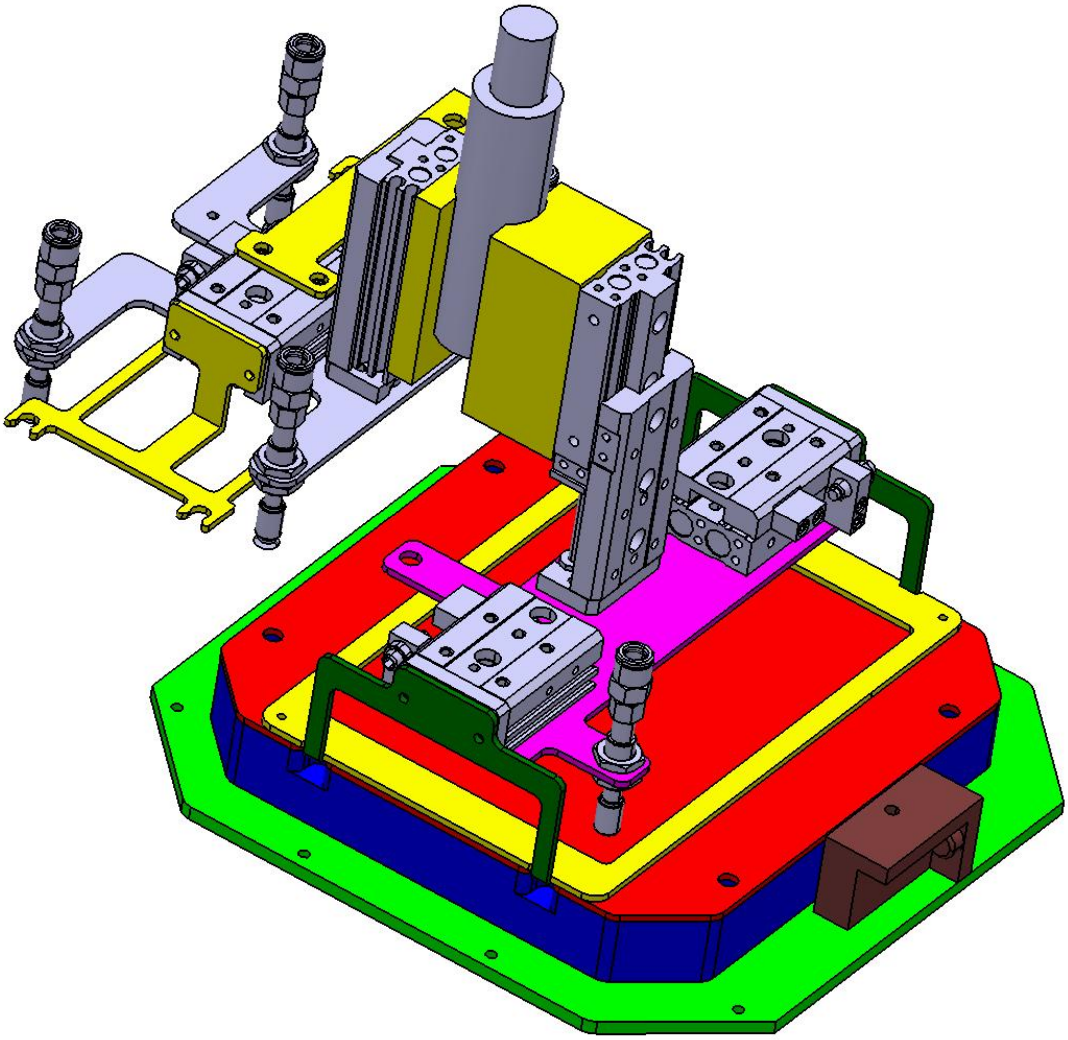


Figure 24. *Gripper and pallet as a whole*

4.6.1 Base

Previously it was commented that this piece was the most important, in fact, the rest of the components are fixed to it, so this element will condition the design of all the other components included in the pallet. When pieces make a product ones depend on others, but always there is one that is the "key piece". It means that it is not easy to modify it due to the consequences that it might have on the other components. In this case the base is our "key piece". Figure 24 depicts the main measures and the shape of the original base with the holes which are used to fix the other components.

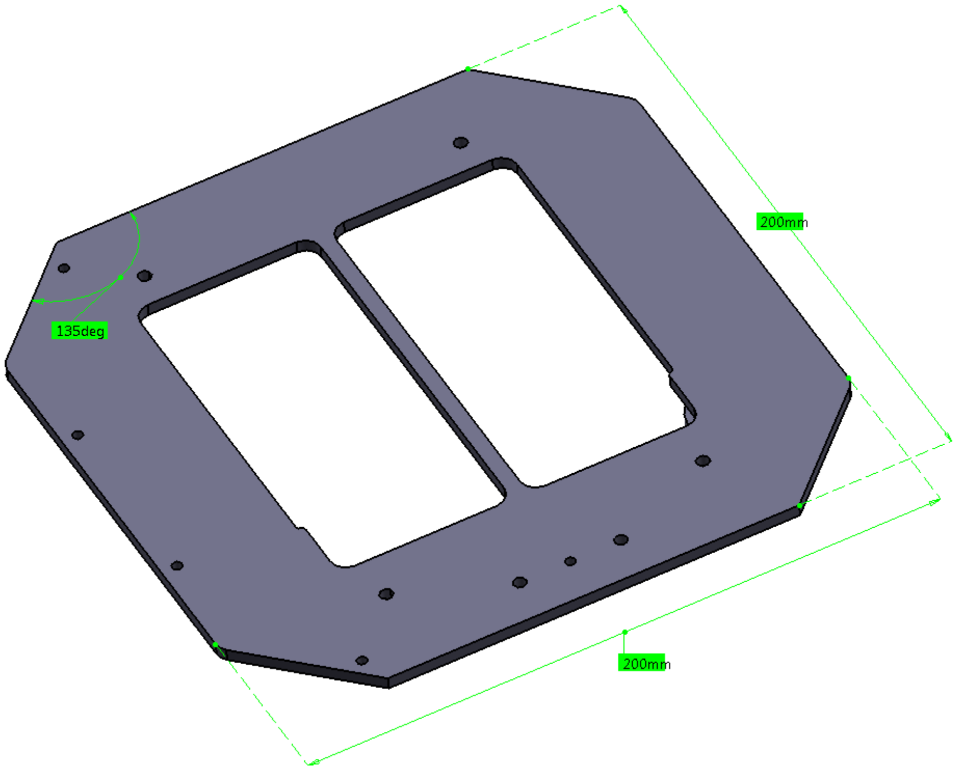


Figure 25. *Base of the pallet*

The main aim is incorporate the new devices, so the solution will be finding space to attach them. The problem can be defined as follows: *How can the required space be created in the pallet?* To solve this problem a brief Brainstorming was done, its results can be summarized in the next points:

- The pallet can be increased in the wide direction.
- The pallet can be increased in the length direction.
- The pallet can be increased in the high direction.
- Mix some or all of the previous solutions.

After the brainstorming and using its ideas several models were drawn in CATIA, the purpose is to find the best solution, thanks to the models in 3D it is easier to make this analysis. In figure 25 there are represented some ideas, increasing the length and the high. Increase the wide of the pallet was rejected from the beginning, because whether the pallet is wider a lot of the components must be modified in the line.

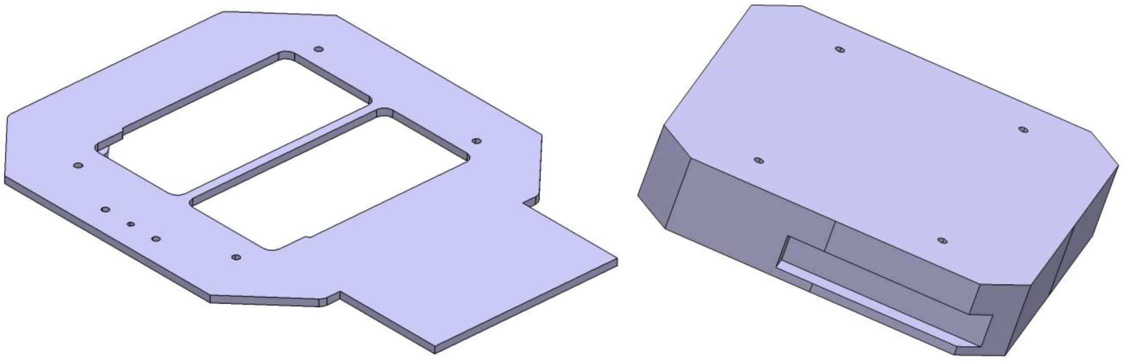


Figure 26. *Some ideas proposed to integrate the accelerometer*

Once that the prototypes were done in CATIA it was easy to make a brief comparison and to detect how could affect to the system whether we change the dimensions.

Table 11. *Comparison between three options to increase the volume*

	Make the pallet higher	**Make the pallet wider**	**Make the pallet lengthier**
Buffer reprograming	It is not necessary	Necessary, some parts of the buffer need to be changed	Necessary, some parts of the buffer need to be changed
Drawing cells reprograming	Only in Z axis	It is not necessary	It is not necessary
Load station reprograming	Necessary	It is not necessary	It is not necessary
Possibility to add other devices in a future	High	Low	Medium
Ease of implementation	Easy	Difficult	Medium
Performance over the belt	Good	Very bad	Bad

Analysing the options there is one that looks better than the others, especially whether ease of implementation is considered. Table 11 has some important points which were valorised in the first steps of the design. The final decision was **making the pallet higher**.

Once the decision is known, the next question is *which element will be modified to make the pallet higher?* It was evaluated if increasing the height of the base was a good solution. But there is a list of disadvantages if it is done such:

- It is difficult to manufacture.
- It is too heavy (The conveyor belt could have some problems).
- It creates interference with some devices (there will be more metallic material).
- It is expensive.

To ensure the functionality of the pallet and to avoid problems with the electronic devices the original base will be respect, so the modifications will be made make in other components of the pallet. The base will only have a small modification which will be explained later.

4.6.2 Drawing platform

The drawing platform was used until now fulfils three requirements:

- It is flat.
- It is tough. (It does not bend when the robot draws).
- It is magnetic.

Two of them are required in the new model, it must be flat and tough. The third point it is not required, because the system to put/remove the frame will be changed -it will be explained in the point 4.6 of this chapter-, so the platform can be made from no magnetic material.

The shape of this element is a plate of metallic material, and it is manufactured by laser cutting. The contour of this piece will be defined for the component which is localized under it. Getting a continuous form in the whole pallet, this gives the pallet harmonic design lines. Figure 26 shows how the pallet shape is.

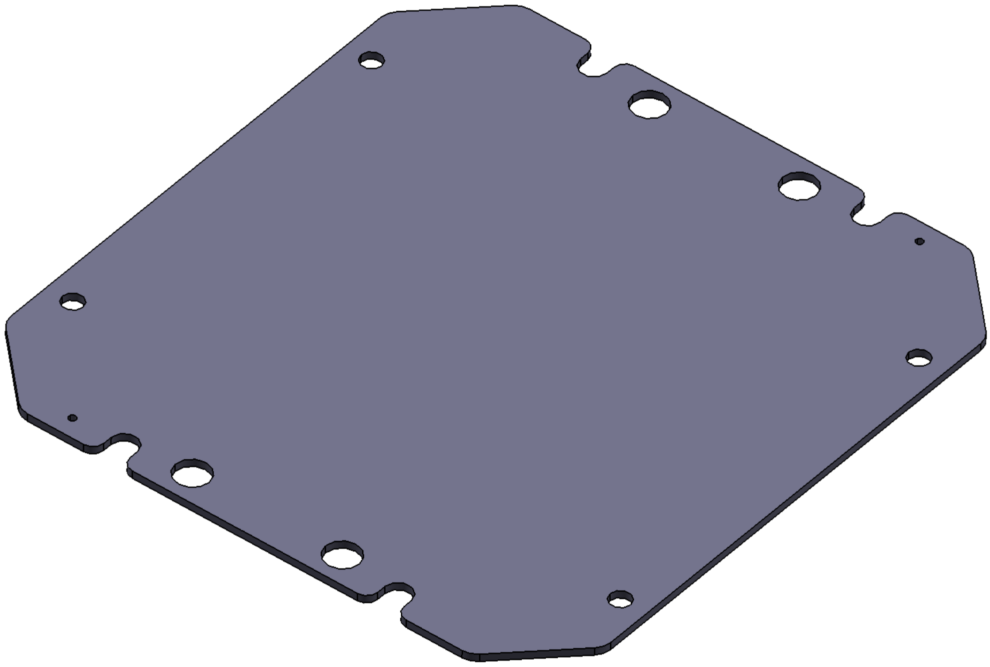


Figure 27. *Drawing platform*

Others constraints gives the drawing platform some more peculiarities. There are two small holes for the positioning pins. These holes have a diameter of 3 mm. The function of them is to assemble the positioning pins. The finality of the positioning pins is described in point 4.5.6.

The four holes which their diameter is 5.5 mm are made to fix the piece with the base. The other four holes which have a 10 mm diameter are necessary for the frame fixation system. This system has four magnets, they are installed in the plastic structure, but they need to attract the frame, which will be over the drawing platform, so to increase the power of the magnets it is recommend to avoid interposing anything between the frame and the magnets.

The four slots are calculated so that the robot can pick up the frame. Using the measures of the gripper the design was realized. The measures are increased because there is a margin, it is due to the pallet that does not always stop at the same point, it has a ±1 mm precision in the perpendicular direction to the conveyor belt, so this data was used to decide the dimension of the slot. In figure 27, the relationship between the free area and the gripper is depicted.

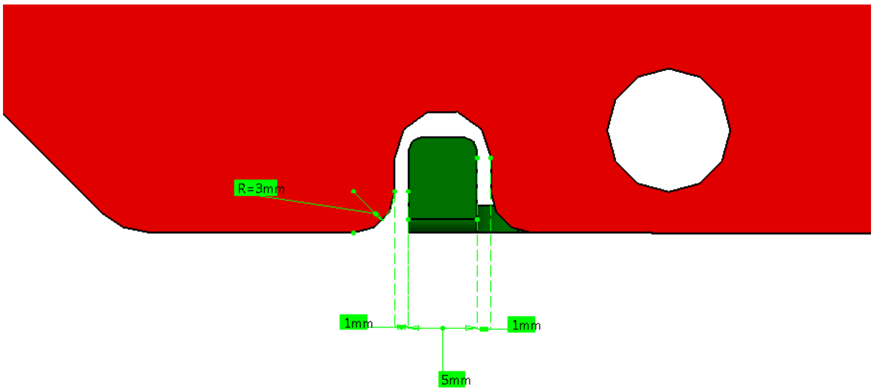


Figure 28. *Slot and gripper in detail*

Thanks to this margin the gripper can take the frame avoiding crashes. The purposes of having edge fillets in the slot are two; the first one is a functional feature, because with that shape it makes the entrance easier. The other is to get a better appearance, so the edges must always be smoothed. The aim of that is to give a better quality sensation. For the touching of sharp edges is not pleasant.

4.6.3 Plastic structure

When it is known that the dimension to increase is the height, and the base will be kept without changes, a new piece is required. The main parameters to define are: size, shape, material and how fit this piece with the other components as a whole.

The first step to define the component is determining the main requirements, those are plotted in the next list.

1. Maximizing the pallet volume for the attachment of new devices.
2. Support the drawing platform.
3. Make it possible using the new gripper.

Let us now look to how the material for this piece was chosen. There were two big options, the first is to manufacture it in metallic material and the other one is to use plastic material. Manufacturing it in metallic material was dismissed for several disadvantages such as, more expensive, more difficult to manufacture, it is heavier and so on. Perhaps the main problem is that metallic material can create interferences on the behaviour of the new devices, so **Faraday Cage** could be created as it was explained in the point 4.3.2 when the accelerometer was tested. In fact when the FMEA is done, table 12, one recommended action is use plastic for some components.

Table 12. *FMEA for Wireless signal*

Item/ function	Potential Failure mode	Potential Failure effect	S	Potential Cause(s)	O	D	RPN
Wireless Signal	The accelerometer cannot send the signal properly	There is no information about acceleration and turning of the pallet	3	It is produced by the Faraday Cage	9	8	160

Item/ function	Recommended actions	New S	New O	New D	New RPN
Wireless Signal	Use plastic material to avoid the Faraday Cage	3	1	8	24

Using plastic also avoided other possible problems, the forces caused between magnets and magnetic material, in case of that the metallic material was magnetic one. Moreover, the plastic machining is faster than metallic machining.

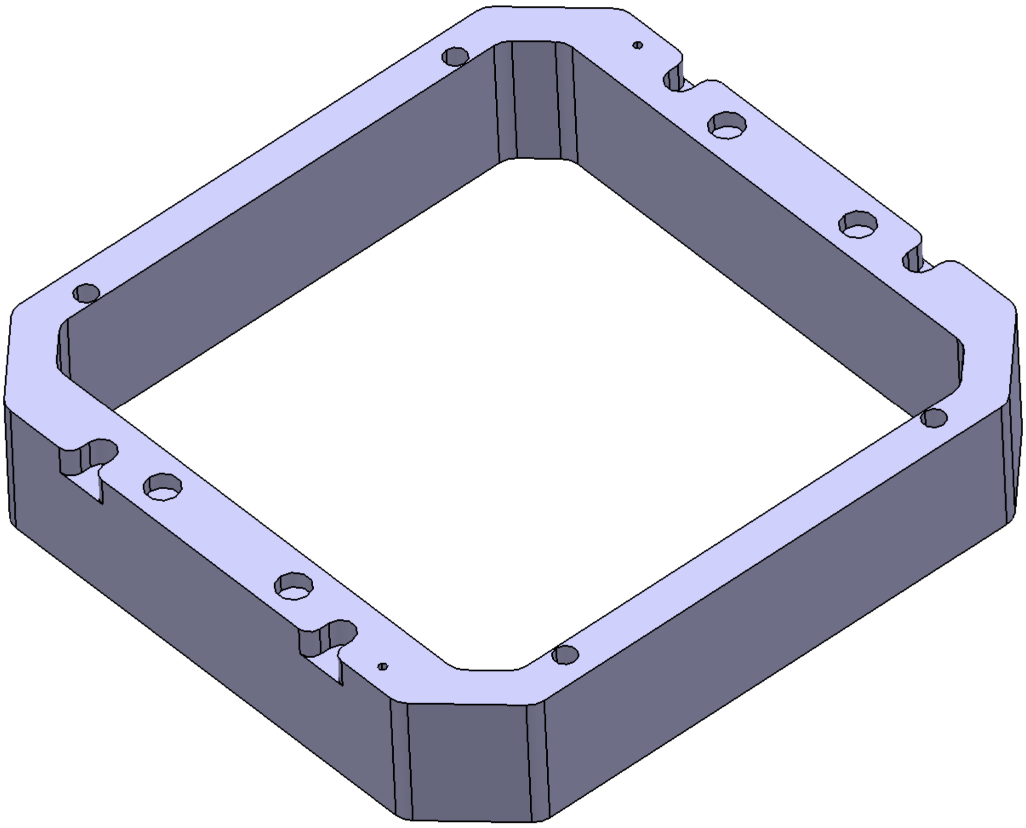


Figure 29. *Plastic structure*

The plastic structure is the result of a combination of several components. It is assembled over the base, so the bottom surface is flat. On the top we put drawing platform, so the upper surface is also flat but some extra holes and slots are needed. In figure 28 can be seen its appearance.

The four slots are indispensable so that the gripper can take the frame. Its dimensions are the same as the drawing platform, except the depth. It is 5 mm, it is due to the necessity of 3 mm by the gripper to pick up the frame. The thickness of the gripper is 2mm, so in total we need a 5 mm gap at least. The drawing platform is 2 mm thickness, so the safety margin is about 2 mm. The graphical explanation is depicted in figure 29, in which the dimensions previously named can be seen.

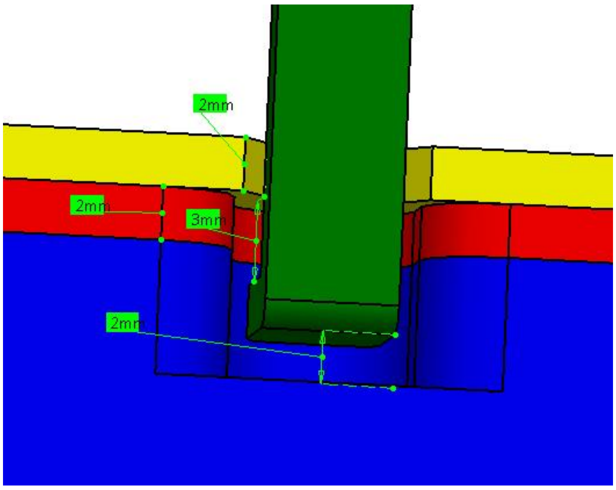


Figure 30. *Plastic structure*

There are four blind holes, used to put the magnets in charge of fixing the frame to the drawing platform. It avoids the movement of the paper over the drawing platform. The diameter of the magnets is 9 mm, and their height is 5 mm. The magnets are fixed to the hole thanks to interference fit, so the blind hole has 8 mm diameter. The depth is 5 mm. In addition some glue can be used to do the union stronger.

The two small holes are for placing the positioning pins, their dimensions are Ø3 x 10. Positioning pins are used to site the frame in correct localization, preventing that human interface can move it. They are fixed by interference fit, as well as magnets. These holes have 2.5 mm diameter and their depth are 6 mm approximately.

The remaining four holes are used to fix the drawing platform with the base through the plastic structure. The screws are M5 x 50, so the holes are clearance and their diameter is 5.5 mm.

The exterior dimensions in the plastic structure are the same as the drawing platform. We get a continuous assembly, without edges. The appearance is better using that type of design. The thickness of the plastic structure could be 10 mm in all walls, but to ensure bigger surface for the magnets not all of them will be 10 mm. Two walls, where the magnets are assembled, will have greater thickness, they are 15 mm.

The final goal of this new design is to implement new electronic devices, thus the height of the pallet is modified. The question now could be the next, *which is the required height?*

The answer is achieved making a dimensional analysis of all pallet components. In figure 30 the dimensions of the main pallet parts are depicted, (Only in the Z axis). The final height is the total sum of all components. The result is 41 mm. Whether we use the conveyor belt as reference plane for the measures, the 10 mm of the bearings are not taken into account for calculations. Thereby the reference plane is the bottom part of the base, so the height, in this case, would be 31 mm instead 41 mm. From now on the reference plane (it is depicted in figure 30) will be used.

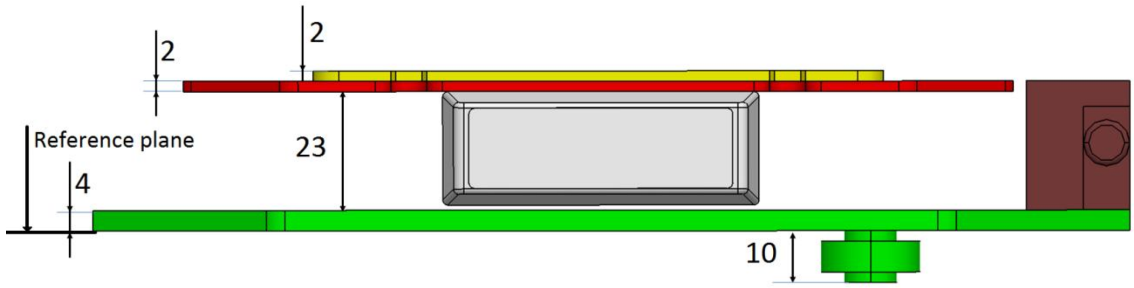


Figure 31. *Main dimensions in Z axis*

One aim is to maximize the volume inside the pallet, thereby it is interesting to do the plastic component as high as possible. The constraint, in this case, is acquired from the physical elements which are in the manufacturing line. Measuring some components gives us the maximum height. It is 46 mm (from the reference plane), 5 mm is the safety margin, so total high is 41 mm. The final plastic structure is 33mm in its Z axis. To do easier the measures it can be observed in figure 31, where final dimensions are delimited.

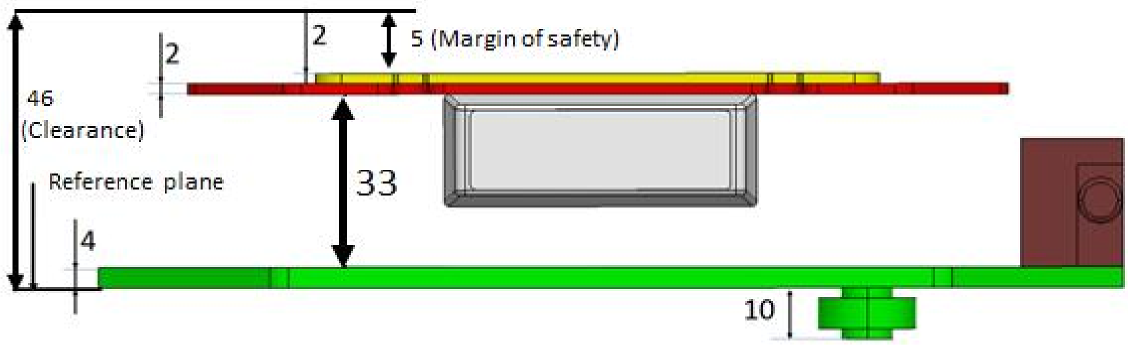


Figure 32. *Final measures in Z axis*

4.6.4 Frame

Over the drawing platform is the paper. Obviously, it is the element on which the robots draw. When the robot is drawing there are two forces, one is perpendicular to the sheet plane and the second force is in the sheet plane. The drawing platform supports the first force. To hold the paper in its place and avoiding its movements due to the second force it is necessary to have a piece. It is the frame, it supports the second force thanks to the friction force. It is known that friction force depends on two variables, friction coefficient and normal force. The friction force satisfices the next equation:

$$F_f \leq \mu F_n$$

Where F_f is the friction force, μ is the friction coefficient and F_n is the normal force. This equation becomes in equality when the two body in contact are in situation of imminent motion or in motion. In the first case the friction coefficient is coefficient of static friction and in the second case is coefficient of kinetic friction. Fulfilling the next inequality:

$$\mu_s \geq \mu_k$$

Where μ_s is coefficient of static friction and μ_k is coefficient of kinematic friction.

The set (frame, paper and drawing platform) must work in static conditions. It is due that the paper cannot move while the pallet is moving around the line. The coefficient of static friction depends on roughness of the surface of the components. Papers roughness is defined for paper type used. The drawing platform cannot be rough, because the robots will draw over it. The only part to increase the coefficient is the frame, so it has a rough surface finish.

On the other hand, the second component of the equation, the normal force can be increased with different ways. The most efficient solution is using magnets. Their features are explained in the next subchapter.

The shape of the frame is really straightforward. The frame must get adapted to the paper shape. It is a standard size, particularly ISO A6, so its measures are 105 x 148. Free space to draw is 140 x 96. These and other dimensions, such as contact area between frame and paper or total size of the frame are in figure 32.

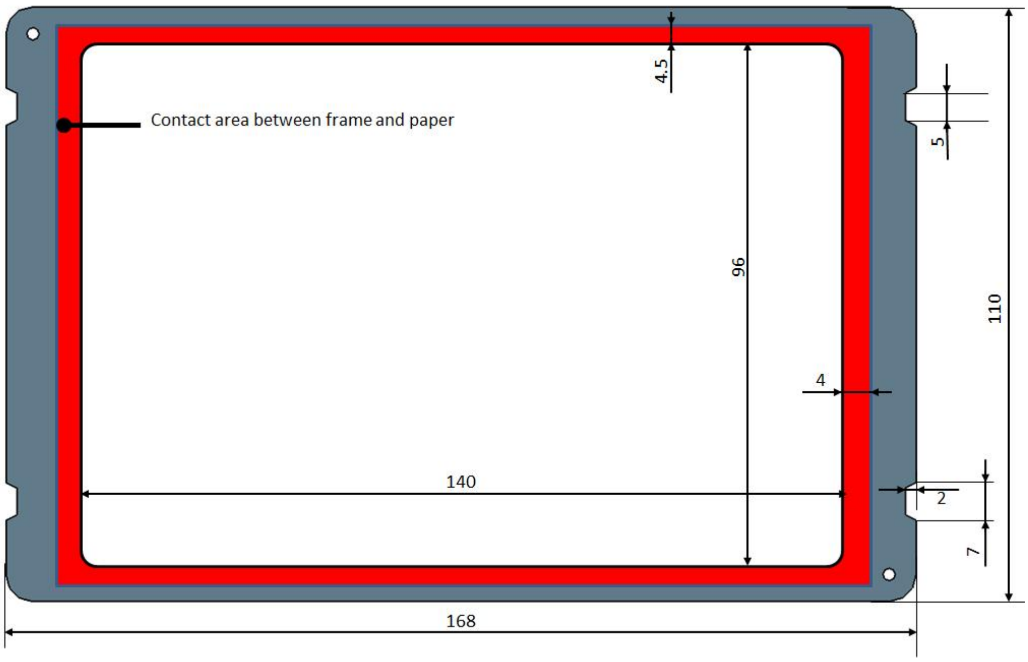


Figure 33. *Main dimensions of the frame*

The four slots are to achieve an “auto-positioning” when the pallet is in the stopper of the main cell. When the pallets are in that stopper their positioning accuracy is ±0.5mm. The tolerance of the slots is ±1, that way the robot can work, because it can place the pallet in the exact point. The two small holes are for positioning system of the frame. It is explained in the point 4.5.6.

At that point we have the geometric parameters. To choose the material is the next step. Thanks to FMEA which is in table 13, we can define the main features for the material. There are already three defined requirements, roughness, magnetic and strength. A magnetic metal is the best solution, it fulfils with all requirements.

Last but not least important is the thickness. It must be as small as possible, but the frame cannot bend when the robot is taking it, because if the frame bends it could move the paper, and it will fall. With a thickness of 2 mm the frame will not bend, so that is the final dimension.

__Table 13.__ FMEA of the frame

Item/ function	Potential Failure mode	Potential Failure effect	S	Potential Cause(s)	O	D	RPN
Frame	The plastic frame is broken	The robot cannot take the paper	6	A worker breaks the frame putting it manually	5	4	120
		The paper is moved when the robot is drawing	4		7	6	168
		The robot cannot take the frame	9		3	5	135

Item/ function	Recommended actions	Potential Failure effect	New S	New O	New D	New RPN
Frame	A frame more solid	The robot cannot take the paper	6	2	4	48
		The paper is moved when the robot is drawing	4	3	6	72
		The robot cannot take the frame	9	1	5	45

4.6.5 Fixation system

In the previous subchapter was said why the magnets are necessary. They are used to increase the normal force. Basically there are two kinds of magnets, ferrite magnets and neodymium magnets. In table 14 some features are depicted.

__Table 14.__ Features of two types of magnets

	Neodymium magnet	Ferrite magnet
Power	High. About six times more than ferrite magnets.	Low.
Composition	Alloy of neodymium, iron and boron.	Ceramic material with iron (III) oxides.
Necessary size	Small.	Big.
Protective coating	Yes. They have a high corrosion.	No.

The pallet has electronic device and, probably, in the future it will have more electronic devices, so putting small magnets is interesting. They will be placed as far as possible from the reserved space for the electronic devices. Neodymium magnets are the best option, because we can place them further and we need less or smaller magnets.

The next questions are: *how many magnets do we need?* And *which is their size?* The answers have a big relationship, so that they will be solved as one. The force required was calculated empirically. The ideal number of magnets looks like to be four, because the gripper will remove the frame taking it for four points. Thereby the four magnets will be in nearby four points where the griper concentrates the strain. It will minimize the bending moment and torque.

Once it is known the number of magnets and their type, we just need to know their shape to choose the size. The commercial magnets are sold in three shapes, disk, ring and blocks. The ring shape is not appropriate because it is not compact. The other two options are similar. The disk magnets has two small advantages, the cylindrical holes are easier manufacture than rectangular pocketing. The second advantage is that the magnets will be fixed to the plastic piece by interference fit, these kinds of unions works better in cylindrical pieces than rectangular or square pieces.

Now all parameters have been defined, except its size, but it is given for the remain constraints. This results in a magnet with these measures Ø9 x 5. In figure 33 can be seen the magnets used.

Figure 34. *Disk magnets[Supermagnete 2011]*

4.6.6 Positioning method

The frame must be in the exact point for a proper working. The main problem placing the frame in its position is when it is manually inserted. If a person puts the frame it will not be in the exact spot of its original emplacement, because humans do not have capability for setting pieces with a high accuracy. This problem is commented in table 15, it is part of FMEA where the need of a positioning system has been quantified.

Table 15. *FMEA of the positioning system*

Item/ function	Potential Failure mode	Potential Failure effect	S	Potential Cause(s)	O	D	RPN
Positioning system	The frame pressures only in some points but not on all paper	The paper is moved while the robot is drawing	4	The frame is not correctly positioned. The robot puts it in a wrong position	4	7	112
				The frame is not correctly positioned. Someone moved it	7	5	140

Item/ function	Recommended actions	Potential Cause(s)	New S	New O	New D	New RPN
Positioning system	Put pins in the pallet, so the frame cannot be moved by people and the robot puts the frame in the exact position	The frame is not correctly positioned. The robot puts it in a wrong position	4	2	7	56
		The frame is not correctly positioned. Someone moved it	4	2	3	24

The solution is inserting two pins, in opposite corners of the frame. Two pins are enough to remove all the degrees of freedom. The pins dimensions are Ø 3 x 10, but from the drawing platform the pin just protrudes 2 mm, in order to keep the upper part of the pin in the same plane as the frames upper part, getting a nice appearance. Figure 34 shows the pin assembled in the pallet.

Figure 35. *Positioning pin in detail*

4.7 Design of the robot gripper

Once it is known how the pallet is, we will explain how the robot gripper in charge of manipulating the frame was designed and its features. Actually the robot gripper and the pallet were designed at the same time, but to a better understanding of the set (robot gripper and pallet), first the main pallet features where explained and now the same thing with the robots gripper will be done. The FMEA of table 16 proves the need of improving the put/remove system of the frame. In the old system, the robots gripper took the frame thanks to four screws that are installed, but these created some problems.

Table 16. *FMEA of the system for put/remove the frame*

Item/ function	Potential Failure mode	Potential Failure effect	S	Potential Cause(s)	O	D	RPN
The screws to pick up the frame	The grippers of the robot cannot work properly	The robot cannot take the frame	9	The screw is not in the correct position	5	3	135
				The screw falls	3	3	81
		The robot breaks the frame	10	The screw is not in the correct position	4	3	120
				The screw falls	3	3	90
		The robot can take the frame but cannot take the paper	6	The screw is not in the correct position	3	6	108
				The screw falls	2	6	72
	The drawing robot cannot work properly	The robot does a bad picture	4	The drawing robot hit the screw	3	8	96
		The robot does a bad picture	4	The screw hit some piece of the manufacturing line	3	9	108
		The robot draws outside of the drawing area	6		2	6	72

Item/ function	Recommended actions	Potential Failure effect	New S	New O	New D	New RPN
The screws to pick up the frame	New system to pick up the frame without screws	The robot cannot take the frame	9	2	4	72
		The robot breaks the frame	10	1	3	30
		The robot can take the frame but cannot take the paper	6	2	6	72
		The robot does a bad picture	4	2	9	72
		The robot draws outside of the drawing area	6	1	6	36

4.7.1 Initial proposed solution

In order to achieve a good robot gripper the first step is defining the system to hold the frame. It can be a pneumatic or a hydraulic system. In this case the line is totally pneumatic, so to use a hydraulic component will involve introducing a new system and many components. It would be really expensive. Furthermore in this kind of robots and for this kind of operation the force which the pneumatic cylinder can offer is not required. The next list shows advantages of pneumatic effectors for our system.

- Power source is installed.
- They can work at high speed.
- It has a low noise level.
- Pneumatic systems have lower cost components.
- It does not need liquids to work.

- Pneumatic systems are more respectful with environment. (They do not use oils).
- Components size is smaller.
- **There are no pneumatic components in the line.**

The present system to pick up the frame works moving the nails of the end-effector in one direction. This causes that sometimes the gripper cannot remove the frame. It can be due, basically, due to two movements. The pallet can be moved, in only one direction, because the gripper whether the screws are not in the correct position. For the same reason sometimes instead of moving the pallet, the gripper just moves the frame. To get a better comprehension, the explanation in figure 35 represents the possible frame and pallets movements when the gripper nails collide with screws.

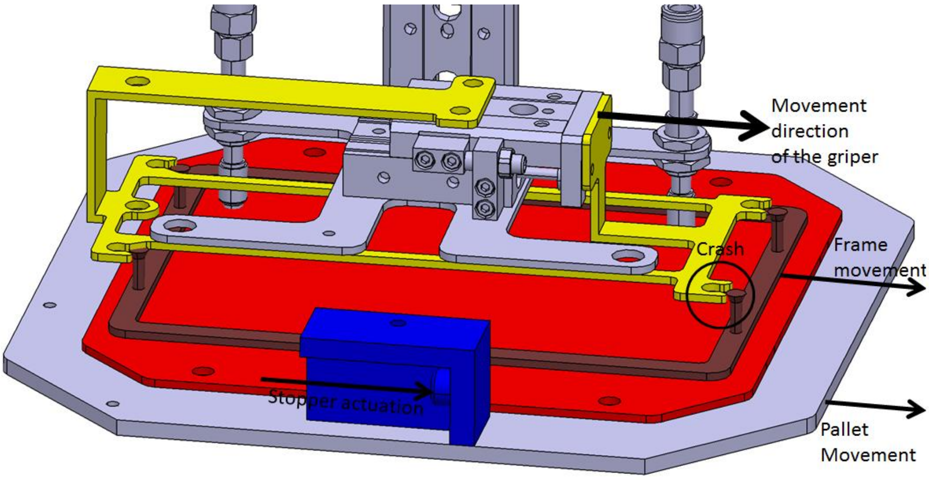


Figure 36. *Direction movements when the gripper collides with the screws*

The frames movement is avoided with the new positioning system, the two positioning pins. However the pallets movement can still be a problem. The first solution proposed to solve this issue was reusing the same main structure and the same pneumatic slide table. In figure 36 is depicted the robot gripper close.

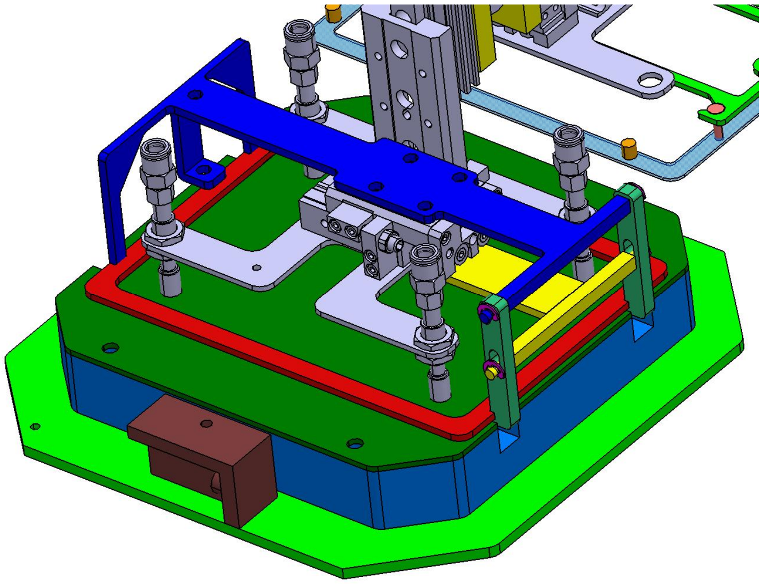


Figure 37. *First solution for robot gripper*

Observing figure 37 we can know easily how the gripper works. The blue piece is fixed to the mobile part of the pneumatic component, whereas the yellow part is assembled on the static part of the gripper, thereby it remains in the same position when the slide table move the blue component. The two green pieces have a “L” shape, to take the frame right side. They rotate using the axis of the cylindrical part of the yellow piece as axis of rotation. This system uses four circlips, they need a small clearance to work. Analysing that clearance and how it affects to the accuracy we determinate that the accuracy in this robot gripper is less than the robots accuracy needed to work properly. So that the robots gripper proposed here is not valid and it is necessary to find another solution.

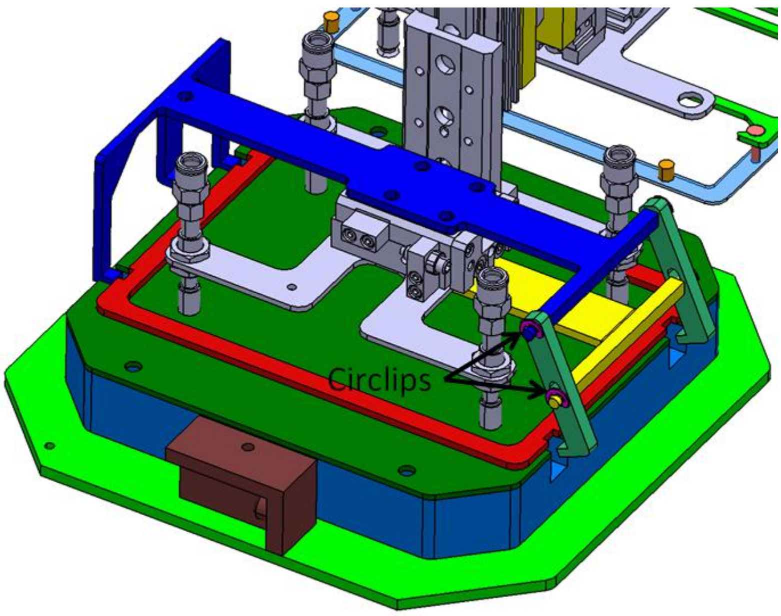


Figure 38. *Open robot gripper*

4.7.2 Final solution

With the aim of getting more accuracy, we tried to get the mobile pieces to be driven by pneumatic end-effectors, thus avoiding the use of intermediate mechanisms. The approach to this problem was, achieving more accuracy by designing as simple as possible. This means to reduce the number of pieces used and to make them straightforward. Nonetheless the new design requires two slide tables instead of one to move the gripper nails.

Except the main rod all components are new or their position is different. The separator is now bigger, it is for decreasing the bending moment in the vertical slide table and in the suction plate. The main forces which create this moment are:

- Components weight
- Magnetic forces caused for the magnet when the robot is taking/removing the frame.

The distance between the vertical end effector and center of mass is just 12 mm. Thereby the elastic deformation in the suction pads is lower. It allows more accuracy, because the strain is less.

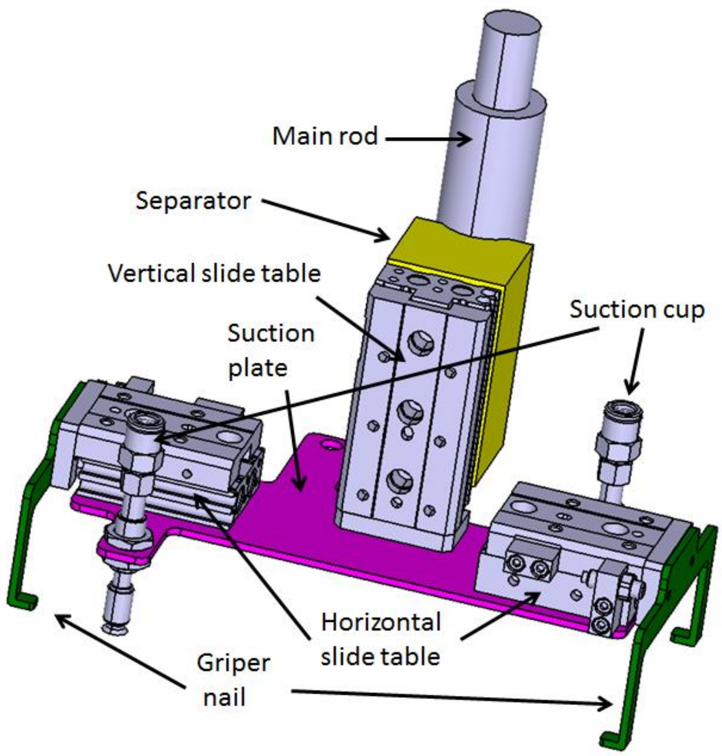


Figure 39. *Components of the robot gripper*

In figure 38 the components of the new gripper are indicated. The two suction pads are destined to hold the paper when the robot is moving. Their model is ZPT 7009 from SMC. They have a vertical vacuum entry with buffer. The buffer stroke is 5 mm, it allows to take/remove the paper easily.

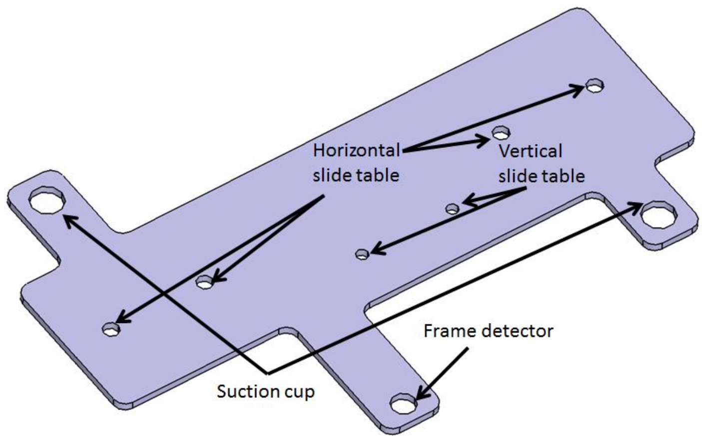


Figure 40. *Suction plate*

Figure 39 is the suction plate, all holes have the name of each component that is assembled in them. It has a thickness that ensures a small flexion, it contributes to keep the high accuracy.

The support has two big holes for the suction cups, they have a diameter of 8 mm. The holes for the suction cups and the hole for the frame sensor are in some kind of "finger". The reason is that they need to be in those exact points. The hole for the frame sensor must be in the vertical of the frame for its detection. Its diameter is 6 mm. The holes for suctions cups are in two points that allows the robot to move fast keeping the paper secure.

The horizontal end effectors are fixed to the suction plate from theirs base. It determines the size of the holes; in this case their diameter is 4 mm. However the size of the vertical end effectors holes is 3mm.

The Nail gripper has a simple design as the rest of the components. It is symmetric respect to the vertical axis. In the central part has a reinforcement, it is to support the strain when it is supporting a bending moment. The reinforcement shape is determinate for the end effector, both have the same contour. The two holes which are placed in the middle of the reinforcement have a diameter of 3 mm.

The contact area with the frame it is depicted in figure 40. It is 5 x 5 mm (black area) and 5x2 (red area). The nails hold the frame in four points, so total area in contact is 140 mm^2. It is sufficiently consistent to work. The thickness is constant and its value is 2 mm.

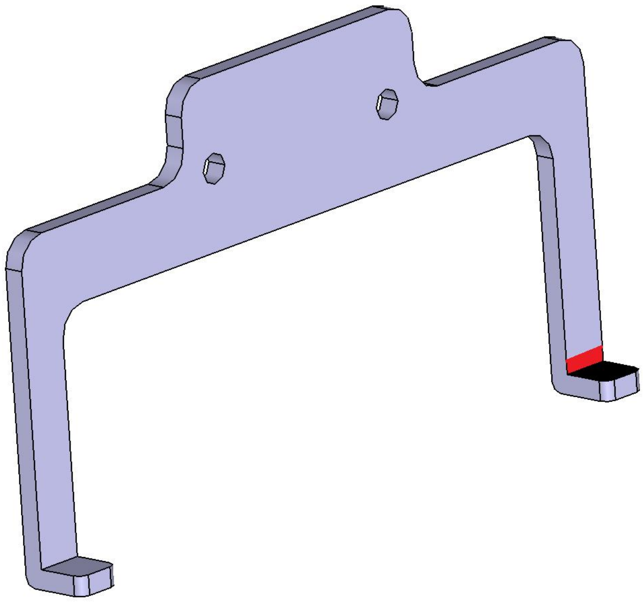


Figure 41. *Nail of the robot gripper*

Probably the most important components are the end effectors. The two suction plates of the vertical slide table need to operate at the same time. The reason for this behaviour was explained in section 2.2 of this thesis. Due to the fact of having two vertical slide tables, the gripper can have one suction plate in the upper position and the other one in the lower position. This allows the suction pads, placed in the lower suction plate, to grab the frame. In the meantime, the other suction plate is in the upper position, avoiding a possible crash of the grabbed frame with the pallet or the feed tray.

The vertical cylinder has a second function, it is a safety role. Whether the robot collides with some element when it is moving in the Z axis, the end effector will absorb the crash, the maximum margin is its stroke. It conditions directly the end effector selection. In this case the necessary stroke to fulfil safety requirements is 30 mm.

To select the model we analysed the using conditions, getting the requirements for the vertical slide table. They can be summarized as follows:

- Stroke 30 mm.
- Compact size.
- High accuracy.
- Low weight.
- Position sensing.

In the market there are two main options with those characteristics. The first option is a mini slide from Festo (model SLT-6-30-P-A), the second option is a SMC product, (model MXS6-30-A93VLS). In the small comparative of the table 17 we can see their features.

Table 17. *Comparison between Festo and SMC mini slides*

Features	**Festo (model SLT-6-30-P-A),**	**SMC (model MXS-6-30-A93VLS**
Stroke (mm)	30	30
Size (mm)	73 x 35 x 20	68 x 41.5 x 20
Weight (g)	210	147.5
Piston diameter (mm)	6	6
Operating pressure (MPa)	0.15 - 0.7	0.15 - 0.7
Theoretical force at 0,6 MPa, advance stroke (N)	34	34
Theoretical force at 0,6 MPa, return stroke (N)	25	25

The comparison shows the main data; almost all technical features are identical. The SMC model is a little bit lighter and the line is assembled with SMC slides, so the SMC model has been installed in the gripper. Figure 41shows the selected model.

Figure 42. *Slide table SMC MXS-6-30*

The two end effectors which are placed in each suction plate share the requirements of the previous list, excepting the stroke, in this opportunity it is 10 mm instead 30 mm. If we build a new comparative table, similar to table 16, it gives us just one difference, the weight again. The horizontal slide tables are SMC MXS-6-10-A93LS.

4.7.3 Gripper implementation

Once that the design and manufacturing are done we proceed to assemble the gripper. The most difficult components to install are the horizontal slides, because they require also a pneumatic assembly. Figure 42 shows the pneumatic actuation of horizontal slide tables. There is a 5/2 solenoid valve, which selects the state of the both slides.

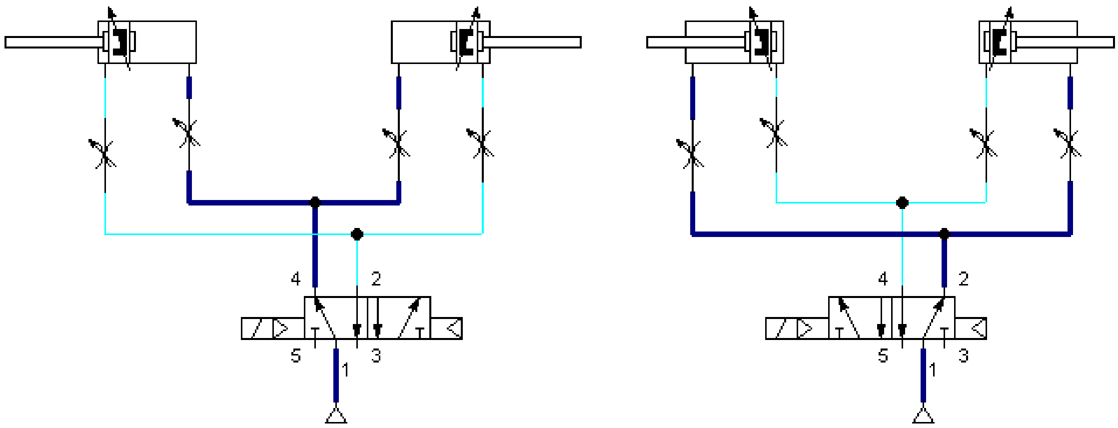


Figure 43. *Pneumatic schema for horizontal end effectors*

When the pneumatic and electrical connections are ready we need to reprogram the robot in cell 1. It is made using a mix programing, it means that teach mode and point to point mode are used to reprogram the robot. We define the points thanks to teach pendant. The points to define are the next:

1. Take/leave the frame and the paper sheet on the pallet with gripper 1.
2. Take/leave the frame and the paper sheet on the pallet with gripper 2.
3. Leave the drawing on finished drawing tray with gripper 1.
4. Leave the drawing on finished drawing tray with gripper 2.
5. Take a new blank sheet from tray with gripper 1.
6. Take a new blank sheet from tray with gripper 2.

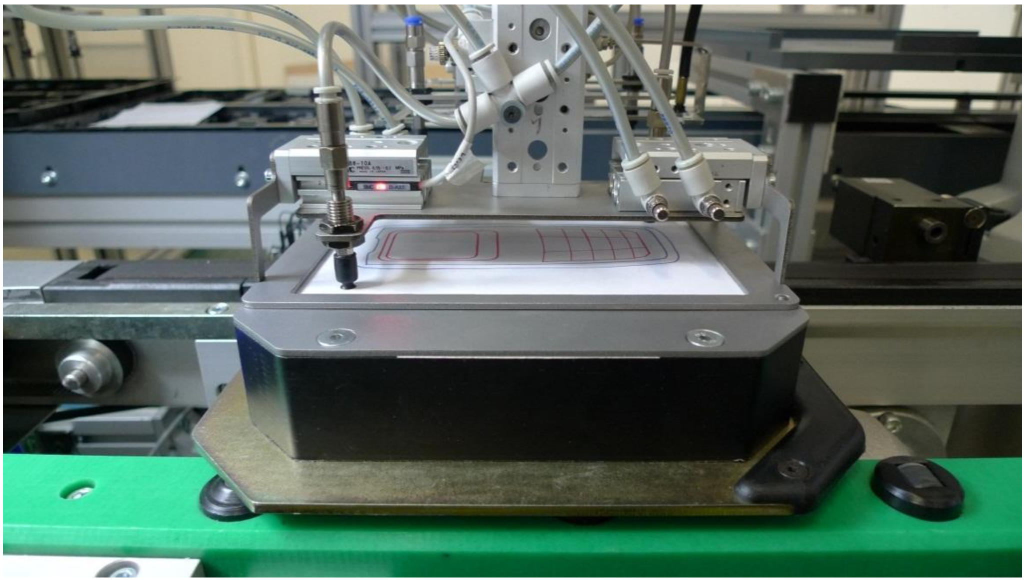


Figure 44. *Programing robot by teach mode*

Once that the points are gotten by teach mode, such as figure 43, we define the paths thanks to a point to point mode. The methodology to achieve the final trajectory is memorizing the next steps: first point, actuation 1, path, second point, actuation 2. This sequence is repeated for each movement. The actuations are simples, open/close the end effectors, and activate/deactivate the suction pads. The robot program follows the flowchart. It is depicted in figure 44. In it is represented just a half operation, because the other half is the same but changing actions in gripper 1 for actuations in gripper 2 and vice versa. The drawing robots are reprogrammed too, but in this case it is easier, because it is only necessary to change the drawing plane. In other words, we need to increase the Z axis 33 mm when the robot is drawing, and all other parameters are constants.

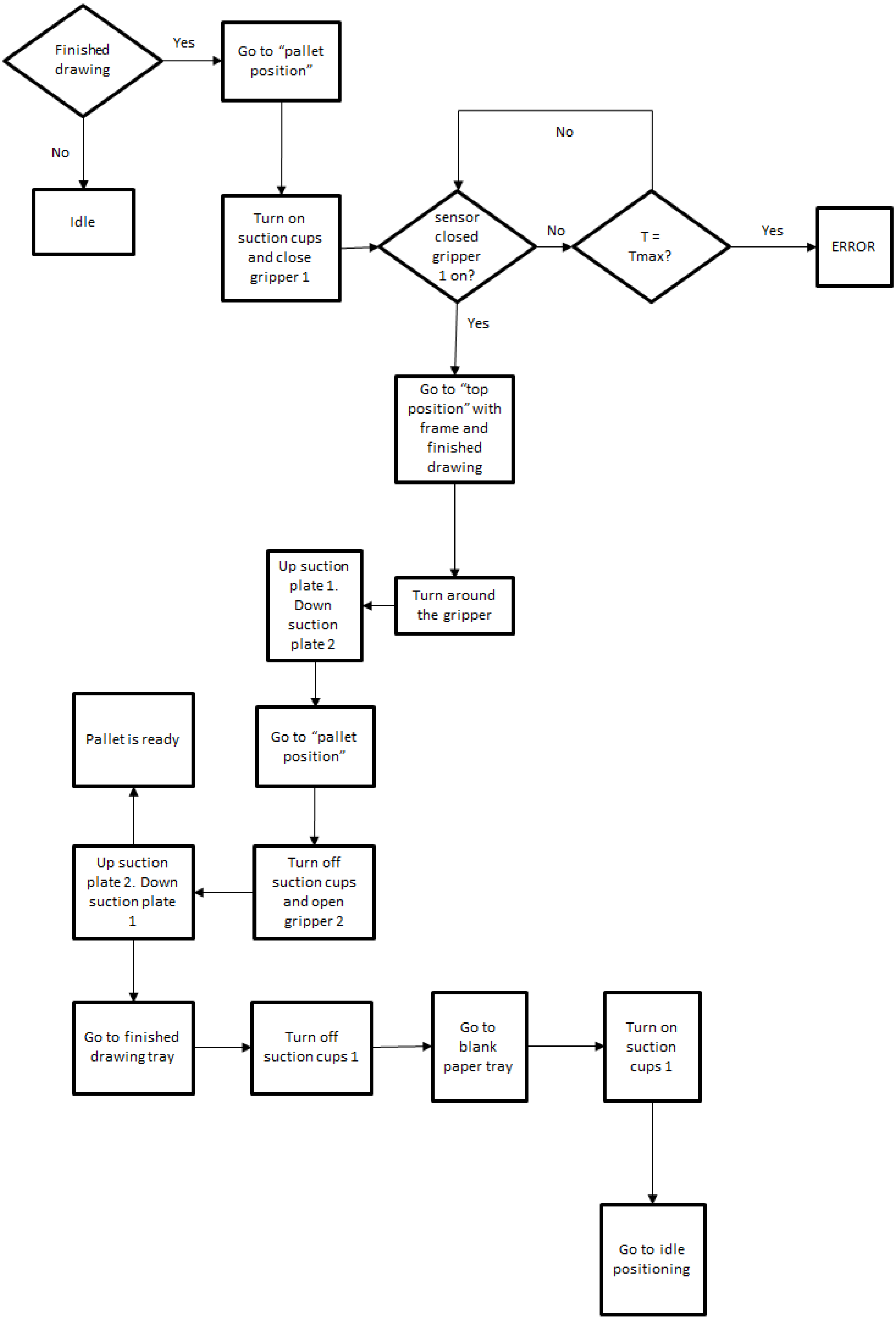


Figure 45. *Flowchart of loading/unloading operation*

4.8 Extra components.

The manufacturing line needs some components to install the new NFC readers. Its position in the line is between two profiles of the conveyor belt. Thereby it is placed in a safety position, where it is out of reach of involute knocks from people.

There are twelve NFC readers, one for each workcell. All of them are attached to an aluminium profile thanks to steel brackets. Eight of them share the same brackets, but the four which are placed in the corners need another kind of brackets. In figure 45 are the design for two brackets.

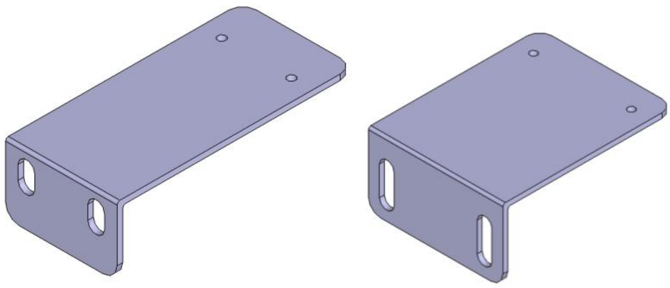


Figure 46. *On left side, the bracket for corners. On right, side, bracket for remain cells*

Moreover in two corners there is a metallic piece to drive the pallet in that point. It is a problem for the reader for two reasons.

1. They create interference in the communication between NFC reader and RFID tag. (The pieces are metallic).
2. The distance between reader and tag is high. It is due to their thickness, it is 20 mm.

Figure 46 shows the design for these pieces. Thanks to it, it is easy to understand how the two problems are avoided. The pieces are manufactured in plastic material, so there are not interferences. To solve the second question the thickness is reduced in 10 mm. allowing placing the reader nearer to the tag, thus giving a better reading.

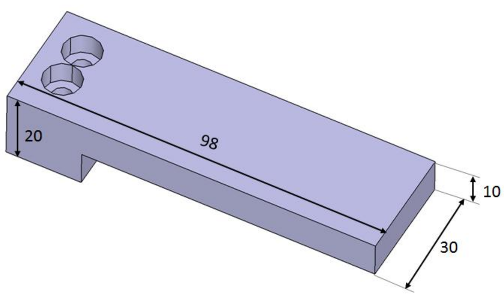


Figure 47. *Coupling piece for the corners*

5. CONCLUSIONS AND FUTURE WORK

Improving an existing system has an extra task, which is getting to know the system first. In fact the first steps were aimed to know how the line and the main components worked. The acquisition stage needs time and people who can explain which elements can or cannot be replaced, moved, changed and so on.

Particularly in this manufacturing line are several researchers working at the same time, so a small change can suppose a big problem for another person. The members of the research team have to communicate every innovation to each other, in any other case the projects are doomed to failure. In addition the group works in tasks as diverse as software development, installing new systems, designing new components, changing the control and so on.

Fortunately some team members had worked previously in similar situations, it avoided causing problems and interferences between projects. Thanks to having the line modelled completely in CATIA it was not necessary to disassemble any component. This is a great advantage because this way the members who needed to test their improvements in the line could do it. Moreover the Fastory line has had some presentations where it had to work properly during the time this Thesis was done.

On the other hand while we were working in the design we were looking for a realistic model, a realistic solution. That means having in mind several points:

- Easy to manufacture
- Not too expensive
- Quick to assembly
- Easy to integrate
- Functional

The introduction of the pallet and the gripper in the line was delayed until the first tests were mandatory. It had the aim to create the minimum interferences with other on-going projects. Thanks to CATIA the geometrical constraints were checked virtually.

The original idea was to modify just the pallet, but it was impossible because the line has many elements which interfere with the pallet in some point of it. When the components of the pallet began to be modified we realized the robots would need a new programing. Later with the improvements made in the pallet a new gripper for the loading/unloading station was required. This has happened in a small manufacturing line, so instead a small line if we had a big manufacturing line the modifications would be much more and they could be really expensive and require a lot of time.

Thanks to the modifications some goals were achieved. We respected the requirements for the precious system and accomplished on top of that these features:

- Accuracy.
- Robustness.
- Repeatability.
- Easy integration.
- Possibility of placing the frame manually.
- Installation of the new devices.

These improvements are obtained through the design and choosing the materials. Other goals were developed thanks to the implementation of the new devices, (Inico´s accelerometer and NFC system). For this last, other researcher is working in new software called APIS (Advanced Pallet Information System). This allows knowing some valuable information such as position, path times, turns, when the pallet is placed/removed manually in the line and so on. It gives to the line asset-aware capabilities. With software information it is possible to solve the bottleneck better.

A future work apart from the work carried out in this Thesis could be introducing an identification system for the frame. It means to place a barcode, RFID, reference number or something similar on the frame. In the griper install a reader. This way we could identify the frames, because they are not associated to the pallets, it is due to their changing in each place/remove operation. If we can identify the frame we can associate the time of place/remove the frame and to detect whether some frames have problems or not.

Other possible implementation could be the installation of new devices. Using the free space, this is under the drawing platform. With the last problems suffered with the Nuclear, installing a sensor able to detect the radiation could be a great idea. This way the products which have a high level of radiation can be separated from the production. Its application is really interesting for countries with nuclear power problems, but it is also interesting for countries that import raw material, products, food and so on, from regions affected with radioactive contamination.

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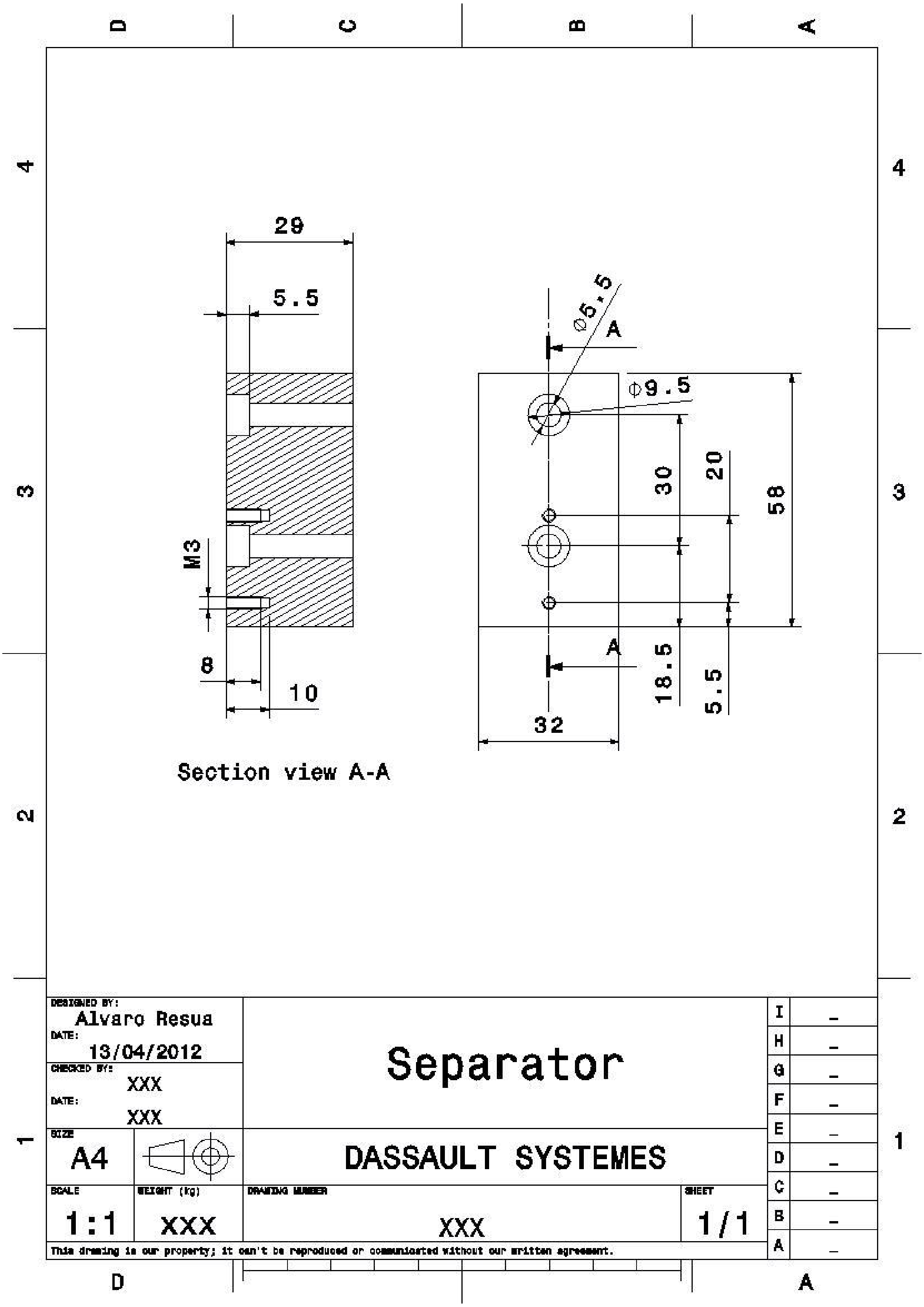
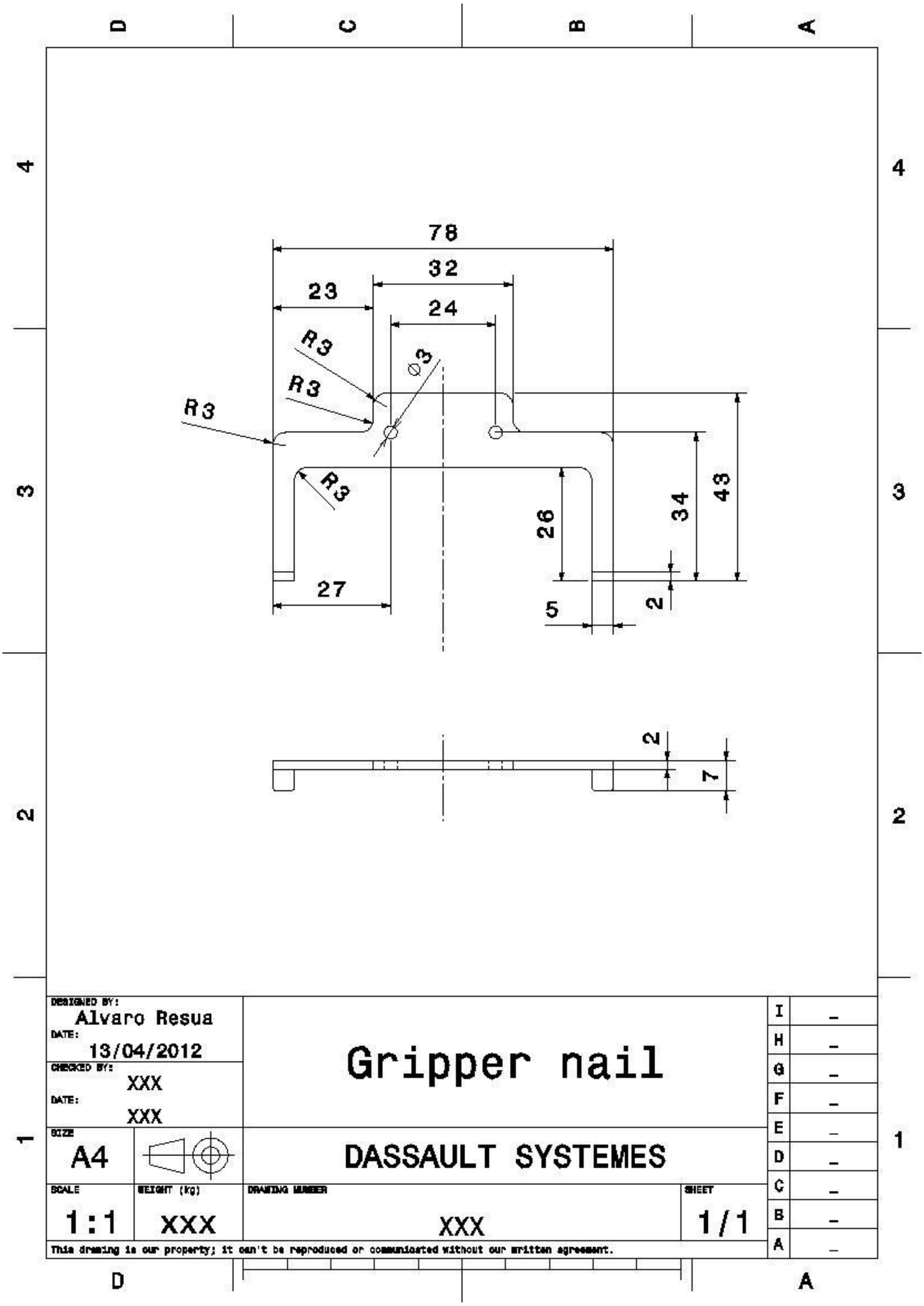
APPENDIX 1. TECHINCAL DRAWINGS

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32
23
24
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R3
R3
Ø3
R3
26
34
43
27
5
2
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7
DESIGNED BY:
Alvaro Resua
DATE:
13/04/2012
CHECKED BY:
XXX
DATE:
XXX
SIZE
A4
Gripper nail
DASSAULT SYSTEMES
SCALE
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WEIGHT (kg)
XXX
DRAWING NUMBER
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SHEET
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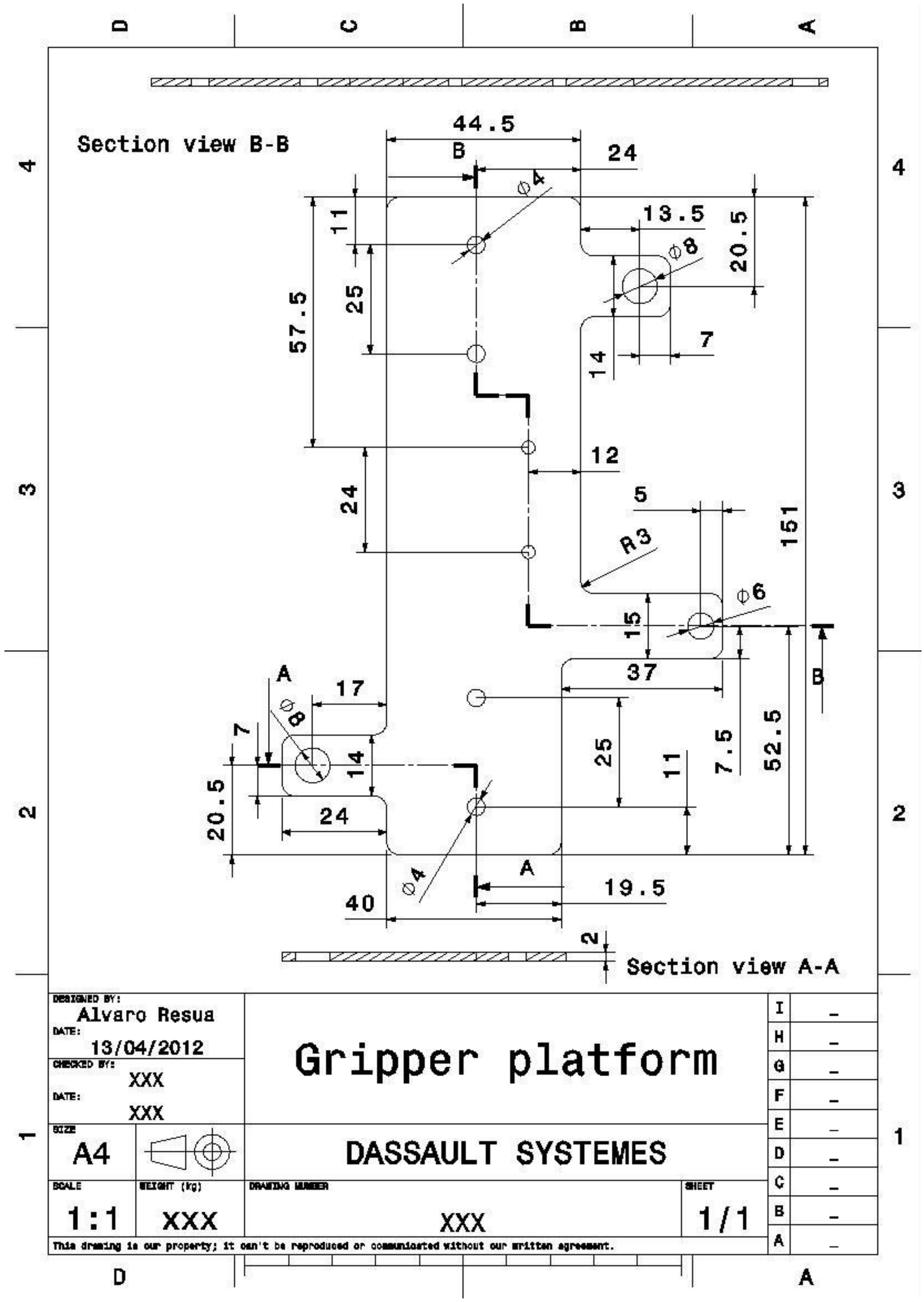
Section view B-B
Section view A-A
44.5
24
13.5
20.5
57.5
25
11
14
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15
37
17
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Gripper platform
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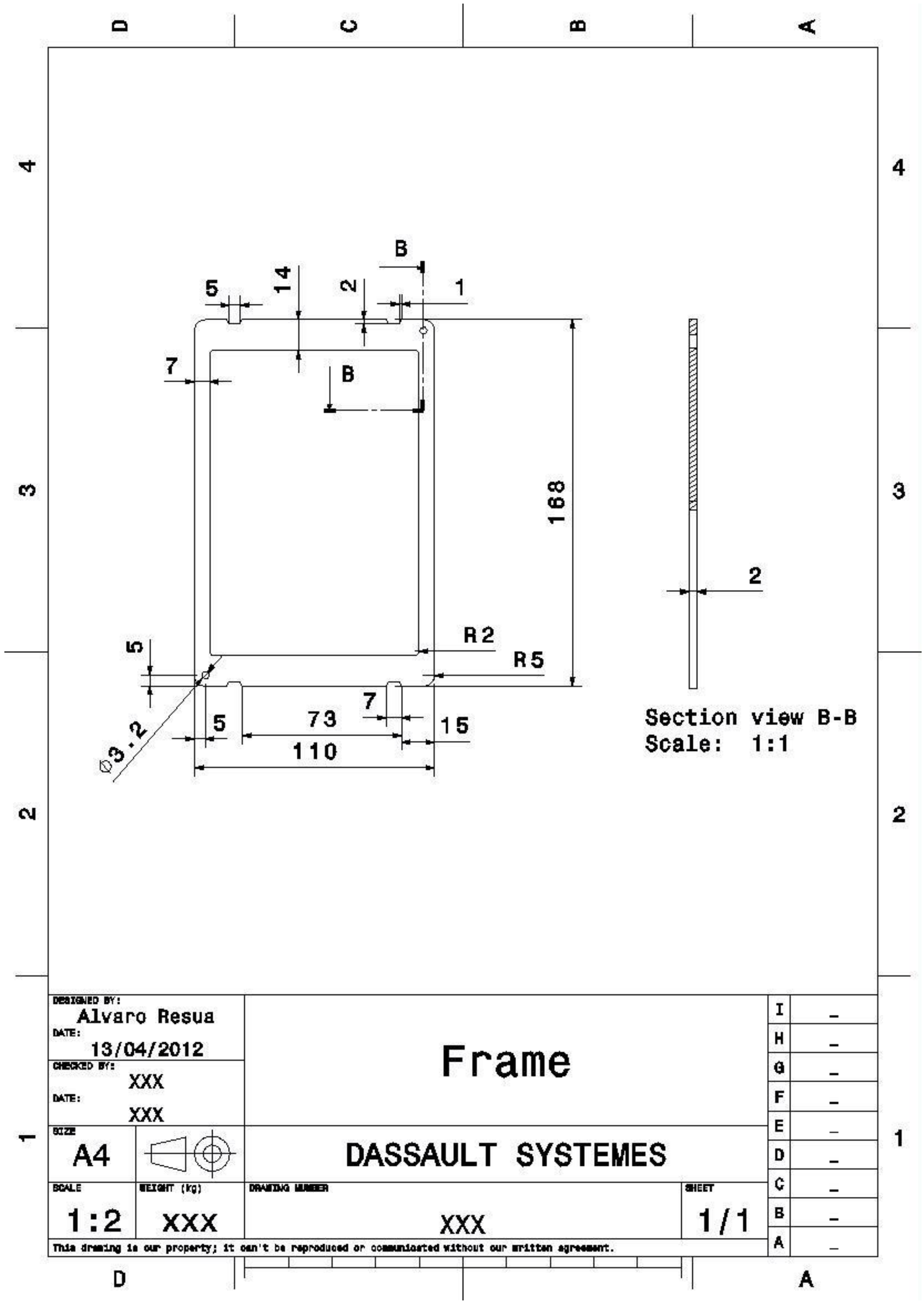
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Section view B-B
Scale: 1:1
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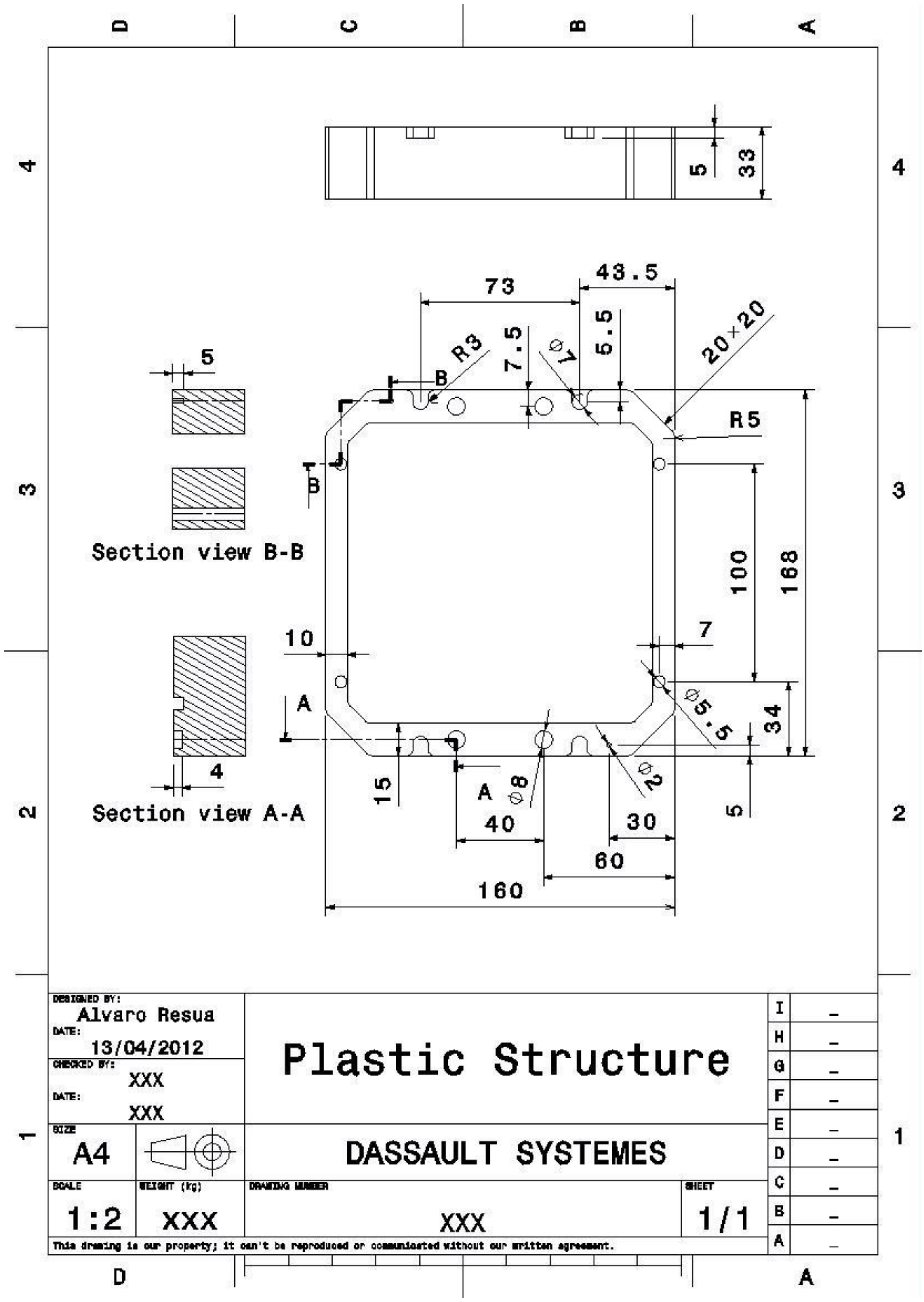
Section view B-B
Section view A-A
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20×20
R5
100
168
10
7
Ø5.5
34
15
Ø8
Ø2
40
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60
160
5
33
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DESIGNED BY:
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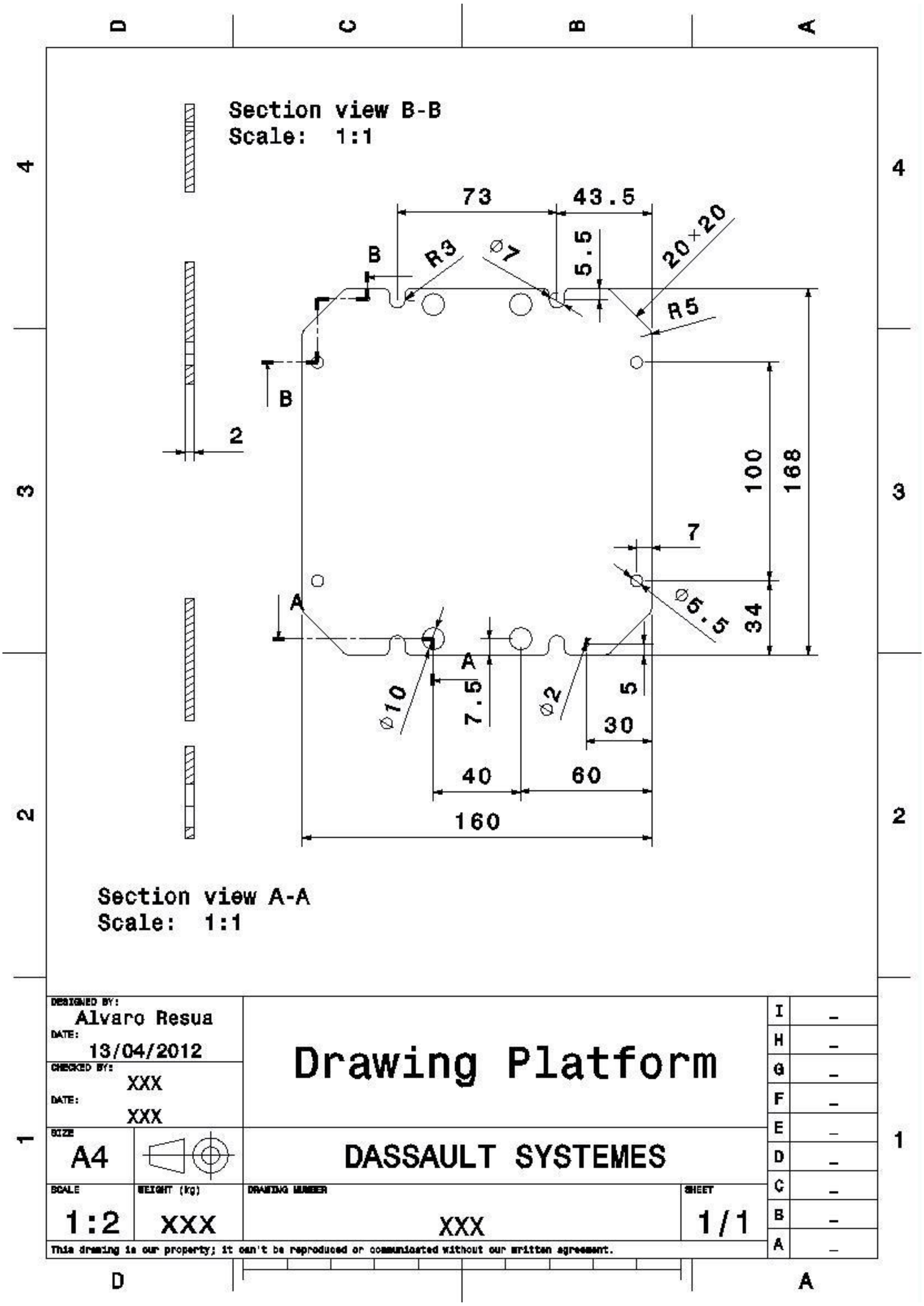

Section view B-B
Scale: 1:1
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5.5
20×20
R5
B
B
2
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168
7
⌀5.5
34
A
A
⌀10
7.5
⌀2
5
30
40
60
160
Section view A-A
Scale: 1:1
DESIGNED BY:
Alvaro Resua
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13/04/2012
CHECKED BY:
XXX
DATE:
XXX
Drawing Platform
SIZE
A4
DASSAULT SYSTEMES
SCALE
1:2
WEIGHT (kg)
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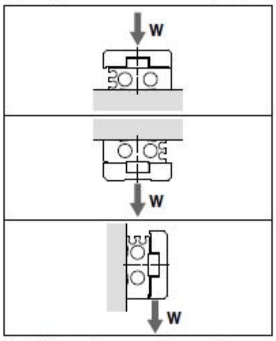
APPENDIX 2. CYLINDERS INFORMATION

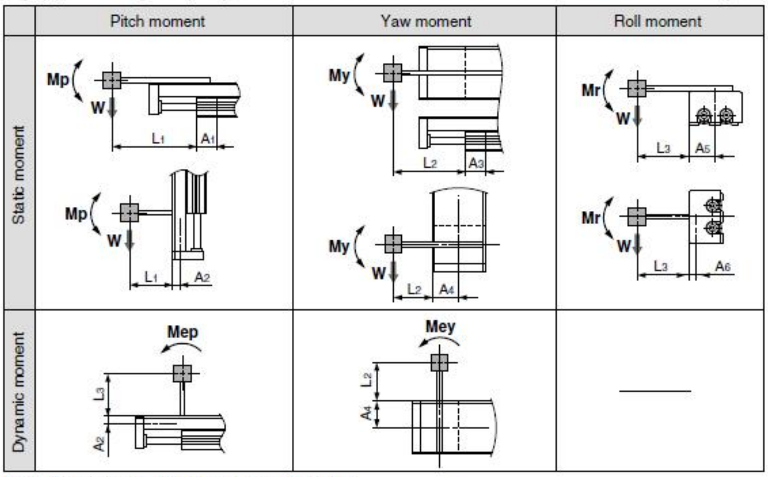
Air Slide Table *Series MXS*

Fig. (1) Load Mass: W (kg)



Note) There is no need to consider this load factor in the case of using perpendicularly in a vertical position.

Fig. (2) Overhang: Ln (mm), Correction Value of Moment Center Position Distance: An (mm)



Note) Static moment: Moment generated by gravity
Dynamic moment: Moment generated by impact when colliding with stopper

Fig. (3) Workpiece Mounting Coefficient: K

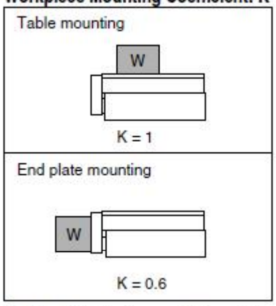


Table (1) Maximum Allowable Kinetic Energy: Emax (J)

Model	Allowable kinetic energy	
	Rubber bumper	Shock absorber
MXS6	0.018	—
MXS8	0.027	0.054
MXS12	0.055	0.11
MXS16	0.11	0.22
MXS20	0.16	0.32
MXS25	0.24	0.48

Graph (1) Allowable Load Mass Coefficient: β

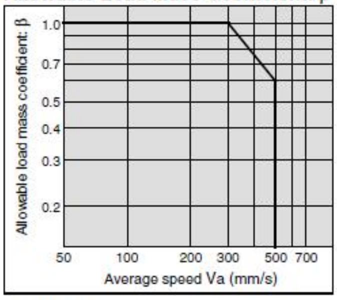


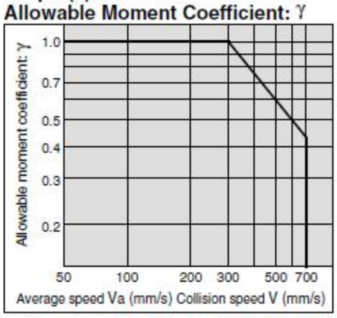
Table (2) Maximum Allowable Load Mass: Wmax (kg)

Model	Maximum allowable load mass
MXS6	0.6
MXS8	1
MXS12	2
MXS16	4
MXS20	6
MXS25	9

Table (3) Correction Value of Moment Center Position Distance : An (mm)

Model	Correction value of moment center position distance (Refer to Figure 2.)					
	A_1	A_2	A_3	A_4	A_5	A_6
MXS6	11	6	13	16	16	6
MXS8	11	7.5	13	20	20	7.5
MXS12	24	8.5	26	25	25	8.5
MXS16	27	10	30	31	31	10
MXS20	34	14.5	36	38	38	14.5
MXS25	42	19	44	46	46	19

Graph (2) Allowable Moment Coefficient: γ



Note) Use the average speed when calculating static moment.
Use the collision speed when calculating dynamic moment.

Table (4) Maximum Allowable Moment: Mmax (N·m)

Model	Stroke (mm)								
	10	20	30	40	50	75	100	125	150
MXS6	0.7	1.0	1.2	1.2	1.2	—	—	—	—
MXS8	2.0	2.0	2.8	3.6	4.2	4.2	—	—	—
MXS12	4.2	4.2	4.2	5.8	7.0	10.0	10.0	—	—
MXS16	11.3	11.3	11.3	11.3	15.9	25.0	34.1	34.1	—
MXS20	19.4	19.4	19.4	19.4	27.2	35.0	50.5	50.5	50.5
MXS25	30.6	30.6	30.6	30.6	42.8	55.1	67.3	67.3	67.3

Symbol

Symbol	Definition	Unit
An (n = 1 to 6)	Correction value of moment center position distance	mm
E	Kinetic energy	J
Ea	Allowable kinetic energy	J
Emax	Max. allowable kinetic energy	J
Ln (n = 1 to 3)	Overhang	mm
M (Mp, My, Mr)	Static moment (Pitch, Yaw, Roll)	N·m
Ma (Map, May, Mar)	Allowable static moment (Pitch, Yaw, Roll)	N·m
Me (Mep, Mey)	Dynamic moment (Pitch, Yaw)	N·m
Mea (Meap, Meay)	Allowable dynamic moment (Pitch, Yaw)	N·m
Mmax (Mpmax, Mymax, Mrmax)	Max. allowable moment (Pitch, Yaw, Roll)	N·m
V	Collision speed	mm/s

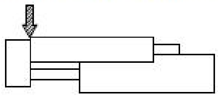
Symbol	Definition	Unit
Va	Average speed	mm/s
W	Load mass	kg
Wa	Allowable load mass	kg
We	Mass equivalent to impact	kg
Wmax	Max. allowable load mass	kg
α	Load factor	—
β	Allowable load mass coefficient	—
γ	Allowable moment coefficient	—
δ	Damper coefficient	—
K	Workpiece mounting coefficient	—

Series MXS

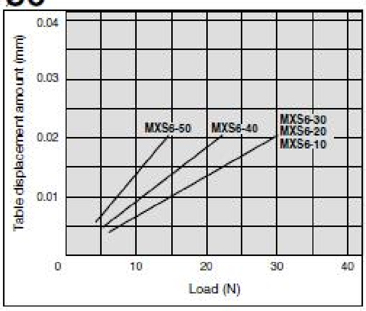
Table Deflection (Reference Values)

Table displacement due to pitch moment load

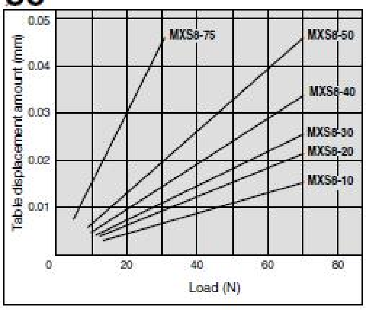
Table displacement when loads are applied to the section marked with the arrow at the full stroke.



ø6



ø8



ø12

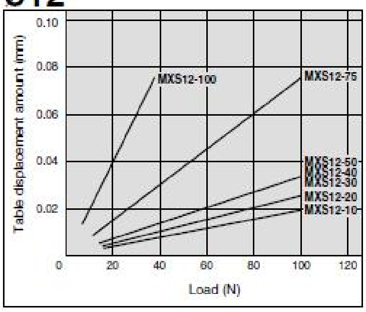
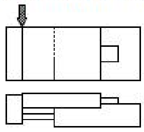
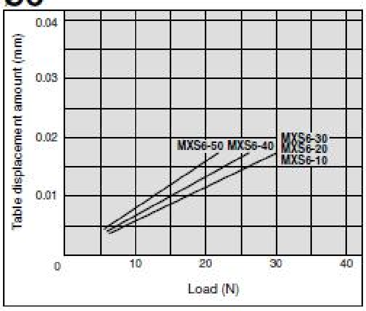


Table displacement due to yaw moment load

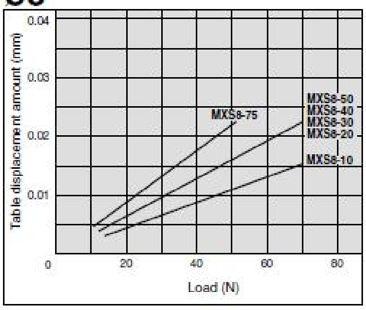
Table displacement when loads are applied to the section marked with the arrow at the full stroke.



ø6



ø8



ø12

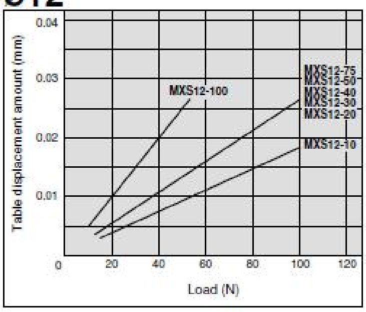
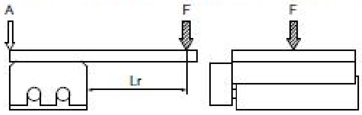
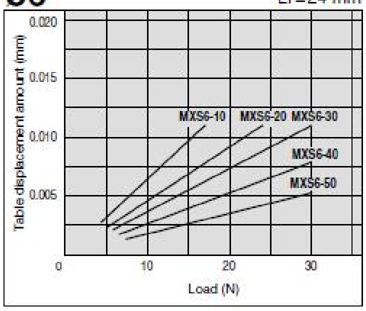


Table displacement due to roll moment load

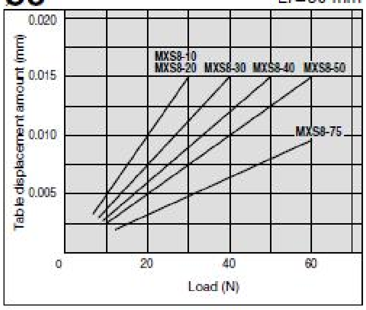
Table displacement of section A when loads are applied to the section F with the slide table retracted.



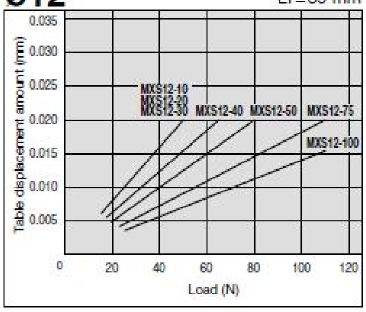
ø6 Lr=24 mm



ø8 Lr=50 mm



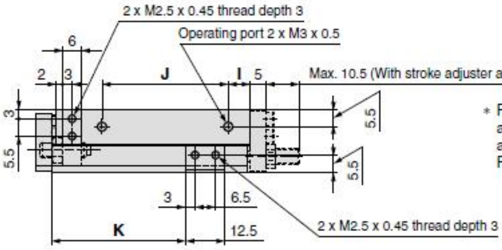
ø12 Lr=65 mm



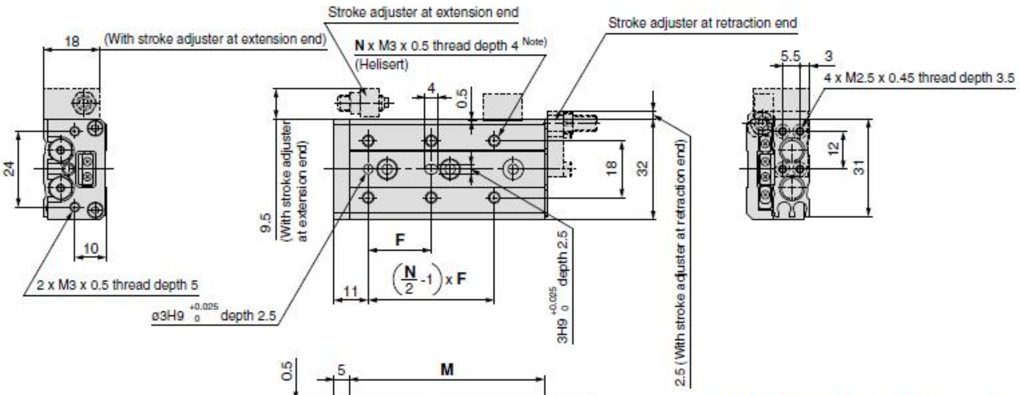
Series **MXS**

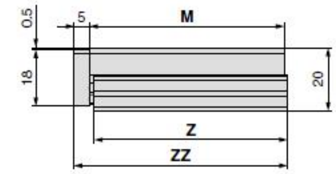
Dimensions: MXS6

Basic style

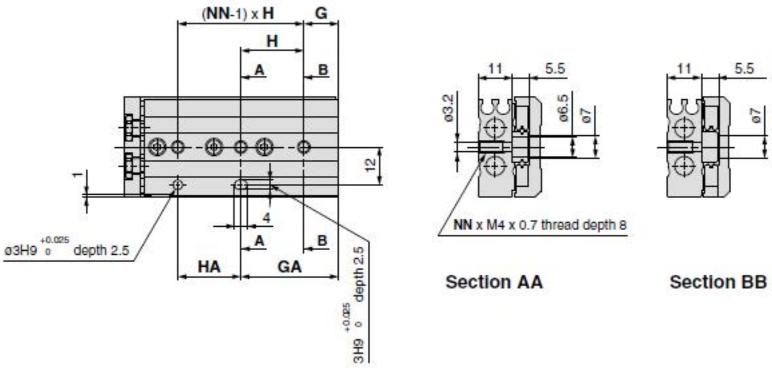


∗ For detailed dimensions on stroke adjusters, refer to the options available with adjusters.
Rubber stopper (Refer to page 70.)





Note) If long bolts are used, they can touch the guide block and cause malfunction, etc.
Refer to the Specific Product Precautions.



(mm)

Model	F	N	G	H	NN	GA	HA	I	J	K	M	Z	ZZ
MXS6-10	20	4	6	25	2	11	20	10	17	22.5	42	41.5	48
MXS6-20	30	4	6	35	2	21	20	10	27	32.5	52	51.5	58
MXS6-30	20	6	11	20	3	31	20	7	40	42.5	62	61.5	68
MXS6-40	28	6	13	30	3	43	30	19	50	52.5	84	83.5	90
MXS6-50	38	6	17	24	4	41	48	25	60	62.5	100	99.5	106

Specifications

Bore size (mm)	6	8	12	16	20	25
Piping port size	M3 x 0.5	M5 x 0.8			Rc 1/8, NPT 1/8, G 1/8	
Fluid	Air					
Action	Double acting					
Operating pressure	0.15 to 0.7 MPa					
Proof pressure	1.05 MPa					
Ambient and fluid temperature	–10 to 60°C					
Piston speed	50 to 500 mm/s					
Cushion	Rubber bumper (Standard, With stroke adjuster) Shock absorber (Optional)					
Lubrication	Non-lube					
Auto switch (Optional)	Reed auto switch (2-wire, 3-wire) Solid state auto switch (2-wire, 3-wire) 2-color indication solid state auto switch (2-wire, 3-wire)					
Stroke length tolerance	$^{+1}_{0}$ mm					

Made to Order
(For details, refer to pages 1955 to 2021.)

Symbol	Specifications
-X7	PTFE grease
-X9	Grease for food
-X11	Adjusting bolt, long specification (Adjustment range: 15 mm)
-X12	Adjusting bolt, long specification (Adjustment range: 25 mm)
-X33	Without built-in auto switch magnet
-X39	Fluororubber seal
-X42	Anti-corrosive specifications for guide unit
-X45	EPDM seal

For clean room specifications, refer to "Pneumatic Clean Series" catalog.

Option

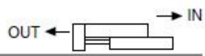
Adjuster options	With stroke adjuster	Extension end (AS)	Stroke adjustment range 0 to 5 mm
		Retraction end (AT)	
		Adjuster on both ends (A)	
	With shock absorber	Extension end (BS)	W/ shock absorber is not available with the MXS6 series.
		Retraction end (BT)	
		Absorber on both ends (B)	
Functional options	With buffer (F)		W/ end lock is not available with the MXS6 series.
	With end lock (R)		
	Axial piping type (P)		

* For details of adjuster and functional option, refer to "Optional Specifications" on pages 70 to 73.

Standard Stroke

Model	Standard stroke (mm)
MXS6	10, 20, 30, 40, 50
MXS8	10, 20, 30, 40, 50, 75
MXS12	10, 20, 30, 40, 50, 75, 100
MXS16	10, 20, 30, 40, 50, 75, 100, 125
MXS20	10, 20, 30, 40, 50, 75, 100, 125, 150
MXS25	10, 20, 30, 40, 50, 75, 100, 125, 150

Theoretical Output



The dual rod ensures an output twice that of existing cylinders. (N)

Bore size (mm)	Rod size (mm)	Operating direction	Piston area (mm^2)	Operating pressure (MPa) 0.2	0.3	0.4	0.5	0.6	0.7
6	3	OUT	57	11	17	23	29	34	40
		IN	42	8	13	17	21	25	29
8	4	OUT	101	20	30	40	51	61	71
		IN	75	15	23	30	38	45	53
12	6	OUT	226	45	68	90	113	136	158
		IN	170	34	51	68	85	102	119
16	8	OUT	402	80	121	161	201	241	281
		IN	302	60	91	121	151	181	211
20	10	OUT	628	126	188	251	314	377	440
		IN	471	94	141	188	236	283	330
25	12	OUT	982	196	295	393	491	589	687
		IN	756	151	227	302	378	454	529

Note) Theoretical output (N) = Pressure (MPa) x Piston area (mm^2)

Mass

(g)

Model	Standard stroke (mm) 10	20	30	40	50	75	100	125	150	Adjuster option: Rubber stopper, Extension end	Rubber stopper, Retraction end	Shock absorber, Extension end	Shock absorber, Retraction end	Functional option: With buffer	With end lock	Axial piping type S: Stroke (mm)
MXS6 (L)	80	100	115	155	180	—	—	—	—	10	5	—	—	30	—	13+0.15S
MXS8 (L)	150	160	190	235	285	410	—	—	—	15	9	35	45	40	40	26+0.17S
MXS12 (L)	325	325	325	385	480	660	890	—	—	30	20	50	60	80	90	43+0.21S
MXS16 (L)	570	570	580	640	760	1090	1370	1700	—	50	30	80	105	120	160	55+0.21S
MXS20 (L)	960	980	1010	1100	1250	1630	2150	2670	3190	100	71	170	205	140	310	150+0.45S
MXS25 (L)	1660	1680	1690	1840	2090	2650	3270	4140	4710	150	125	215	300	240	540	220+0.45S

MXH
MXU
MXS
MXQ
MXF
MXW
MXJ
MXP
MXY
MTS
D-□
-X□
Individual -X□

APPENDIX 3. FMEA

Item/function	Potential Failure mode	Potential Failure effect	S	Potential Cause(s)	O	D	RPN	Recommended actions	New S	New O	New D	New RPN
RFID tags	The RFID reader cannot read the RFID tag	It is not possible to identify the pallet	4	There are interferences caused by metallic materials	8	5	160	Use RFID tags which can work within metallic materials	4	1	5	20
Frame	The plastic frame is broken	The robot cannot take the paper	6	A worker breaks the frame putting it manually	5	4	120	A frame more solid	6	2	4	48
		The paper is moved when the robot is drawing	4		7	6	168		4	3	6	72
		The robot cannot take the frame	9		3	5	135		9	1	5	45
Wireless Signal	The accelerometer cannot send the signal properly	There is no information about acceleration and turning of the pallet	3	It is produced by the Faraday Cage	9	8	160	Use plastic material to avoid the Faraday Cage	3	1	8	24
Positioning system	The frame pressures only in some points but not on all paper	The paper is moved while the robot is drawing	4	The frame is not correctly positioned. The robot puts it in a wrong position	4	7	112	Put pins in the pallet, so the frame cannot be moved by people and the robot puts the frame in the exact position	4	2	7	56
				The frame is not correctly positioned. Someone moved it	7	5	140		4	2	3	24

Item/function	Potential Failure mode	Potential Failure effect	S	Potential Cause(s)	O	D	RPN	Recommended actions	New S	New O	New D	New RPN
The screws to pick up the frame	The grippers of the robot cannot work properly	The robot cannot take the frame	9	The screw is not in the correct position	5	3	135	New system to pick up the frame without screws	9	2	4	72
				The screw falls	3	3	81					
		The robot breaks the frame	10	The screw is not in the correct position	4	3	120		10	1	3	30
				The screw falls	3	3	90					
		The robot can take the frame but cannot take the paper	6	The screw is not in the correct position	3	6	108		6	2	6	72
				The screw falls	2	6	72					
	The drawing robot cannot work properly	The robot does a bad picture	4	The drawing robot hit the screw	3	8	96		4	2	9	72
		The robot does a bad picture	4	The screw hit some piece of the manufacturing line	3	9	108					
		The robot draws outside of the drawing area	6		2	6	24		6	1	6	36