

FINAL DEGREE PROJECT

Industrial Electronics and Automatic Engineering

**ENHANCEMENT AND AUTOMATION OF A LOGISTIC
PROCESS**



Volume I

Memory – Articles and conditions

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Abstract

The main goal of the following project is the familiarization of the student with the logistical environment. This way it's pretended that the student, through a real preparation process and by visiting the company several times, will have to be capable of making a full study that allow the correct automation and, lately, to offer the project as a solution to the enterprise.

Also, measures and calculations will be taken and it will be used information that will contribute to upgrade the logistical environment of the warehouse with the mentioned automation.

Resumen

El presente trabajo tiene como objetivo la familiarización del estudiante con el entorno logístico. De esta manera, se pretende que a partir de un proceso real de preparación el estudiante sea capaz, mediante sucesivas visitas a la empresa, de llevar a cabo un estudio completo que permita su correcta automatización y se pueda, finalmente, ofrecer como solución a la empresa.

Asimismo, se tomarán medidas, se realizarán cálculos y se usará demás información que contribuirá a mejorar el entorno logístico del almacén con dicha automatización.

Resum

El present treball té com a objectiu la familiarització de l'estudiant amb l'entorn logístic. D'aquesta manera, es pretén que a partir d'un procés real de preparació l'estudiant sigui capaç, mitjançant successives visites a l'empresa, de portar a terme un estudi complet que permeti la seva correcta automatització i es pugui, finalment, oferir com a solució a l'empresa.

Tanmateix, es prendran mesures, es faran càlculs i s'utilitzarà altra informació que contribuirà a millorar l'entorn logístic del magatzem amb l'esmentada automatització.

1.- Introduction

With the constant demand nowadays of producing more and faster, humans become less efficient at industrial processes. Machines have proven themselves more than capable of substitute us in these tasks that might be considered dull, repetitive, dangerous or dirty.¹

This Final Degree Project is borned with the motivation of learning more about Automatics. In the *Control Industrial i Automatització* subject (CIA) a piece of this world was seen but, as the career is also about Electronics, it hasn't appeared the opportunity to go deeper in this field. This is why as the Final Project Degree (*Treball de Final de Grau*, TFG) choosing time was coming closer, having the great chance (and luck) to visit a real industrial process, has brought me to take the decision of finally doing this Final Project.

A bit about logistics

In this Final Degree Project it is going to be talked about logistics, so it is really important that it is understood how the studied process works. So, what is logistics?

There are multiple definitions, for instance, Wikipedia says: "*Logistics is the set of necessary media and methods to carry out the organization of a company, or a service, especially of distribution*".

In other searched webs it can be found similar definitions that confirm what has just been said. In *Economía Simple*, for example: "*The logistic concept includes all the operations carried through so an article gets to the consumer from the raw material to other phases like the production place*".

In *Definición de*, it is found a definition more focused on the organization and services of a logistic company: "*It's the set of media and methods that allow carrying out the organization of a company or a service.*"

¹ Note: 4D's of robotics: Dull, dirty, dangerous and dear.



Although logistics is a word taken from the military environment, it is understood today as a business term and it refers to, as Promonegocios points out:

“The possible flow of resources that a company will need to the realization of its activities and the set of operations and tasks related to finished products sending to a consumption or use point”.

It's pretty clear that all these definitions make reference to the distribution of a product that a customer needs, so a notion can be sensed about what exactly logistics is and by doing so it can developed our own definition:

“Logistics is the set of operations that allow a costumer or client to get a product thanks to a company that has previously stored it and distributed it”.

This definition is more related to what a logistic company does, which is exactly the point of this assignment.



2.- Scope of the project

As for the scope of the project the following items are the main goal of it:

- Study and comprehension of a real industrial process within a logistic company.
- Study of the process automation and searching for possible solutions.
- Presentation of the final solution to the company for its implementation.

3.- Description of a company

In this chapter it is going to be explained a bit of the company, ID Logistics. More detailed information (where does it come from, its origins, etc.) can be found at the Appendix document.

Here, it will be made a brief description of the warehouse in which the study of the process (and its automation) has been done.



Fig. 3.0.- IDL's logo. Source [Google images].

3.1.- Location

To be more specific, the center in which the field work has been done it is located in La Granada (P.C. 08792), a small village in Catalonia, Spain.

The facility is located outside La Granada town, at the industrial park next to Alt Penedés Street. Coordinates are $41^{\circ} 22' 29.09''$ / $1^{\circ} 43' 50.48''$.



Fig. 3.1.- Location of IDL in La Granada. Source [1].

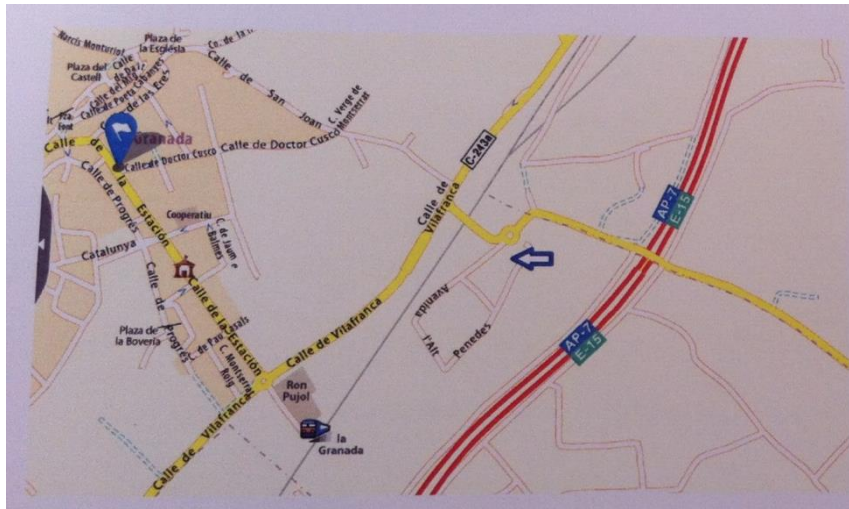


Fig. 3.2.- Map of IDL's location. Source [1].

3.2.- The warehouse

It is proceeded now to describe the warehouse where it has been worked and has full interest in this project. The figure below shows a schematic of the facility:

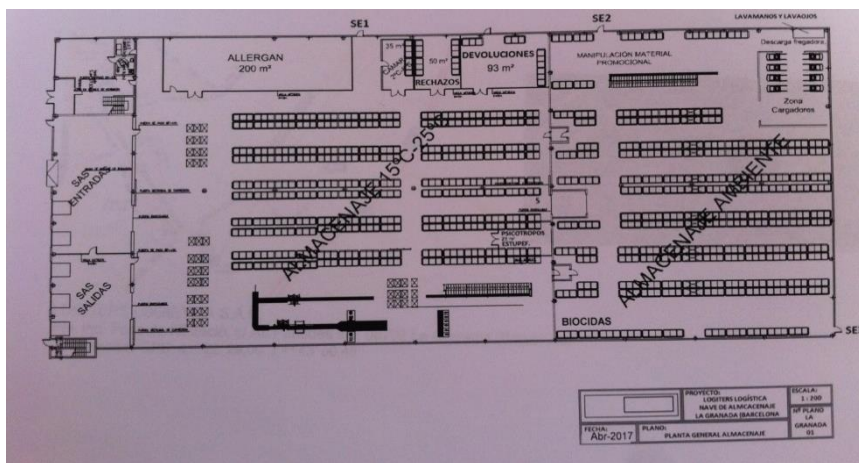


Fig. 3.3.- Map of the industrial ship at IDL (top view). Scale: 1:200. Source [2].

As the map is too large to be explained in just one picture, it is going to be splitted in different figures and detailed for a bigger comprehension.

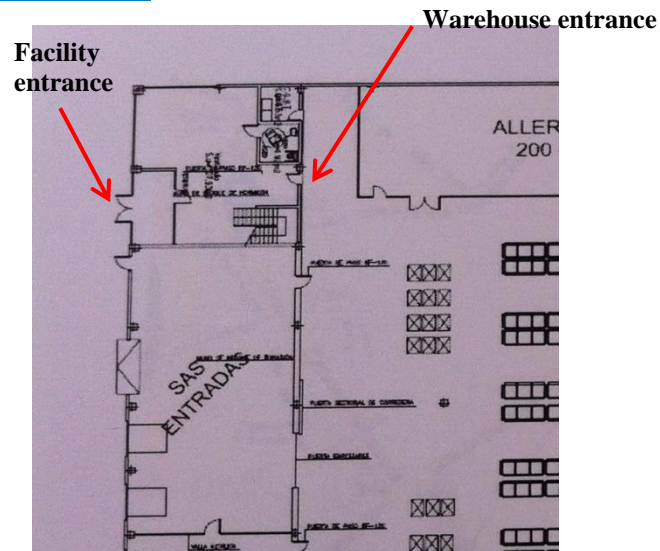


Fig. 3.4.- Company and warehouse entrances. Detail of figure 2.3 (top view). Scale: 1:200 (edited). Source [2].



Fig. 3.5.- General view of the warehouse. Source [own].

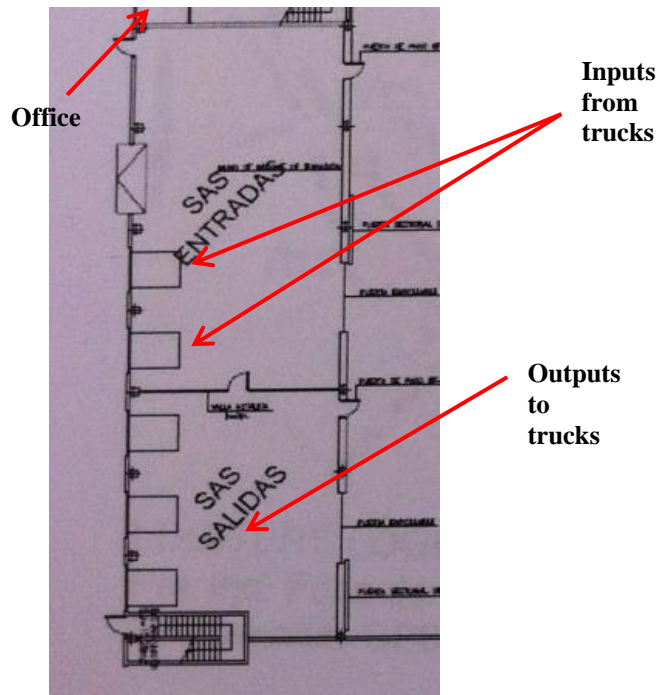


Fig. 3.6.- Inputs and outputs of the warehouse. Detail of figure 2.3 (top view). Scale: 1:200 (edited). Source [2].



Fig. 3.7.- Inputs of the warehouse [edited]. Source [own].

As it can be seen in figure 3.8, inputs and outputs are segregated by a gate. This is done to prevent any mistake when loading or downloading the trucks by the company personnel.

The space of the room is used to leave the commodities while they aren't taken to the appropriate racks, normally grouped by clients or companies although that depends of the work or command demand.



Fig. 3.8.- Outputs of the warehouse (edited). Source [own].

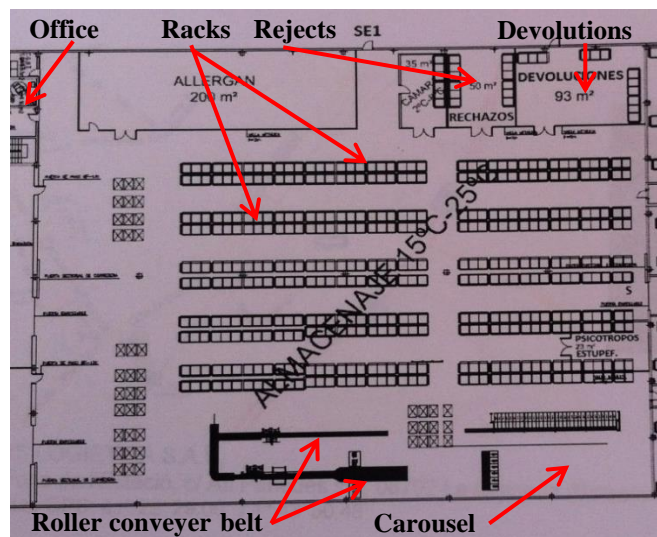


Fig. 3.9.- Acclimatized warehouse. Detail of figure 2.3. (top view). Scale: 1:200 (edited). Source [2].



Fig. 3.10.- View of the roller conveyer belts seen from the carousel emplacement. Source [own].

4.- Description of the process

In this chapter it is going to be explained all the preparing process and how orders are prepared. This is necessary to understand the further automation. More interesting information about how other stages of the process work can be found in the Appendix document.

4.1.- The carousel

It's important to talk about this component, given the fact that it is an essential part of this project. What it is intended to automatize is what comes after this process. The proposal is to add an automatic conveyor belt next to the workbench where the orders of the carousel are done. In chapter 6, all the components and different elements are going to be presented along the process while in chapter 7 calculations will determine all the necessary parameters (weight, speed, power...).



Fig. 4.1.- Perspective of the carousel. Source [own].



Fig. 4.2.- Work bench of the carousel. Source [own].

Now, how does the carousel work? The process goes as follows:

1. First, the operator opens with the computer a program called CS-LOG, a tool that is connected with “the system”, which is the main software that controls all the informatics in the warehouse. The system will give the operator the orders to prepare. The person in charge of the carousel enters with his/her own username and password.

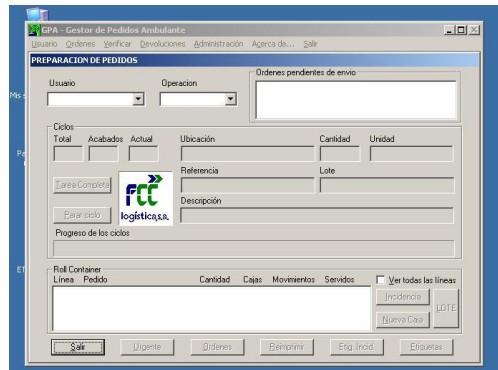


Fig. 4.3.- Interface of the program. Preparation of commands. Source [own].

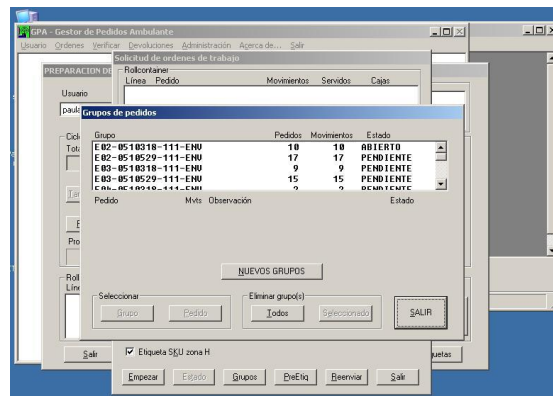


Fig. 4.4.- Interface of the program. Preparation groups selection. Source [own].

2. Once the group is selected, to start preparing, the “Empezar” button will be clicked and the carousel will automatically start to work. It will turn and stop where it detects that the reference (product) needed for the order is stored. In the frontal panel, three displays can be seen: the first one indicates the height at which the product is stored and the location (where), the quantity (how much). The second one will indicate the batch needed to be served and the third one the reference of the product (what).



Fig. 4.5.- Frontal panel of product command. Source [own].

3. The product is taken and the confirmation button (yellow button at the frontal panel) is pressed to indicate that it has been removed. As soon as the carousel gets the confirmation signal it will automatically start to turn to search for the next order.
4. The product is taken to the corresponding slot at the workbench (indication is printed in each slot at the table) and it is confirmed (by pressing again another yellow button at the table slot) that that product is there.
5. If the command is not over, the worker will get the next reference that the carousel will have already prepared. If not, a “*Fin*” sign will appear in the slot panel. Then, a box will be grabbed and the product will be placed inside.
6. Once this is done, a ticket will be provided by the labeling machine and it will be placed in one of the box’s wings. After that, the box is pushed to the other side of the workbench.

All this information gets summarized in the following diagram, which describes the human-machine interaction. The steps carried out by the operator are marked with a pictogram:

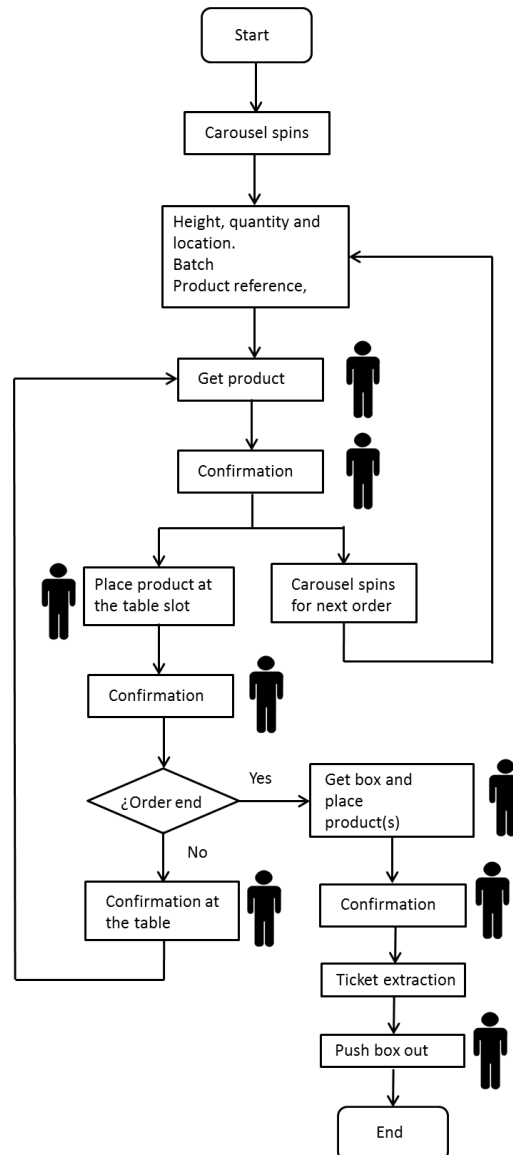


Fig. 4.6- Block diagram of the carousel functioning. Source [own].

4.2.- Verification

When the boxes are in the roller belt, they proceed to be verified manually. With the packing list, it is confirmed that the product is the one in the list. If it's not, a warning is made to the person that prepared the order.



Fig. 4.7.- A regular box at the belt for being verified [edited]. Source [own].

Now, once verified, in the CSLOG the option “*Salidas*” → “*Confirmación Propuesta extracción carrusel*” is chosen: the code of the label is read and F10 is pressed to confirm. A new window will emerge and will ask how many boxes there are for the command. Number is introduced, F10 again to confirm and automatically it is going to be received as many labels as boxes there are. After this, it is proceed to stick the labels² outside the boxes.

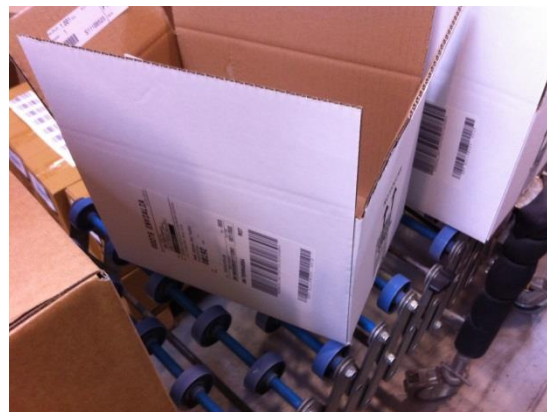


Fig. 4.8.- Box with the sending label stuck. Source [own].

A red label will be placed with the “*Contains delivery note*” text to indicate that the paper describing the group composition³ is there.

² Note: This label is the same one that the machine gave us. It is the sending label, different from the other one read at the beginning of the process, which is the one gotten from the carousel or the picking zone.

³ Note: The groups are distinguished in the line by sticking a red dot at the beginning of each one. This way, a group starts with the box marked with the red dot and ends one box before the next red dot.



Fig. 4.9.- Box with the delivery note attached [edited]. Source [own].



Fig. 4.10.- Box with the red label of delivery note stuck.[edited]. Source [own].

Filling and sealing of the box

To prevent the content of any damage, the box is filled with air bags and sealed. This is done with all the groups. Once finished, the pallet is prepared. To do this, the responsible will go to the computer at the table, next to the finalization zone.

In the GTA software, the route will be selected according to the product demand. Usually, a group always goes in the same pallet, avoiding the loss of some units than if it was splitted.

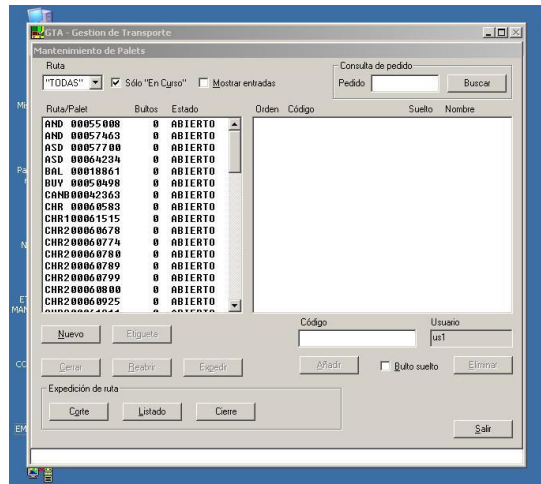


Fig. 4.11.- Interface showing the different routes. Source [own].

Once the route is selected, the option “*Etiqueta*” will be chosen. This will create a label for the pallet that is going to be the label route.

The box’s code bar is read and next, the route label that was just created. This way every box that is read is going to be related to that pallet it is wanted to make.

When the pallet is completed, it needs to be closed. The option “*Cerrar*” will be selected → “*Confirmar*”.

Now it will be selected the option “*Expedir*” → “*Corte*” (that will put the pallet in the marked route before) → “*Cierre*” (the pallet will disappear of the list, meaning it’s done).

Finalized

When the pallet has reached some height, it is sent to a rotating machine that will wrap the pallet with a plastic film, to compact the boxes and avoid them to fall. After that, the route label will be stacked outside the plastic film so when arrives to destiny it can be read without any trouble.

Once finished, a pallet control sheet (fig. 4.30) will be grabbed and filled in the corresponding fields with the required information.



5.- Objectives

In the light of the above, the main goal of this project is to automate the preparing process of ID Logistics (La Granada warehouse) where necessary. For that purpose, the proposal for the enhancement of the warehouse is the following:

- An automatic conveyor belt instead of a manual roller belt.
- An automatic box rejection system.
- An automatic labeling machine at the conveyor belt.
- An automatic sealing system for the box expedition.
- A program for the PLC that controls the conveyor's movement and all its elements.

In chapter 7, calculations will determine the requirements of the necessary components and chapter 8 will introduce these selected components.

6.- Automation proposal

6.1.- Process' working

In this chapter it is going to be explained the proposal for the upgrade of the preparing process. This is only going to be for the client A conveyor belt⁴. In figure 6.1, shown below, it can be seen the schematic for the automation proposal, which consists in multi-type conveyor belts, detectors, a diverter and two automatic machines: the labeling machine and the sealing machine, to close the box. The filling machine is semi-automatic.

Figure 6.1 shows a schematic of a possible solution to the already existing problem, where:

- BD-BD7 are presence detectors (implemented by photocells), as well as D1, D2, AD, AD1, SD and SD1.
- CR is a code bar reader or a scanner.
- EVD is a diverter that will push boxes to the reject conveyor belt.
- W1-W6 are wedges that will activate to stop the boxes.
- In the case of the belt to be full, motor 1 will stop in order to allow the other belts to move on and clear the way.

Needless to say boxes will come from workbench attached to the carousel (indicated with red arrows) and from the front of it. The belt in front of the verification control is the rejection belt, for those orders that have a missing product or have been compromised along the way. The worker will check the product with a packing list and if the product is not correct will activate a diverter that will guide the box to the rejection belt.

Along the process, some palletization areas have been set out to ease the work to the employers. There is one at the end of track, another at the rejection belt and a last one between the rejection belt and the first conveyor for the incoming carts.⁵

⁴ Note: It is important to know that the center has various clients, but for the proposal only one is going to be analyzed.

⁵ Note: Carts are used in the picking process. If the reader is interested, it can be checked at the Appendix document.



Attached to the curve it can be seen another curve. This will be a guide that will help the box to orientate for the scanner.

Also, to optimize energetic resources, if the belt is active during 5 minutes and does not detect any box, it will automatically shut down.

In figure 3.10 it was seen that there are at least 3 conveyors at the warehouse (one per client) and yet this project only sets out one. This is due to the fact that the automation of the process should be capable of unite different clients' orders in a single belt, simplifying the work at the warehouse.

In figures 6.2 and 6.3 it is going to be seen, via GRAFCET, all the automation process.

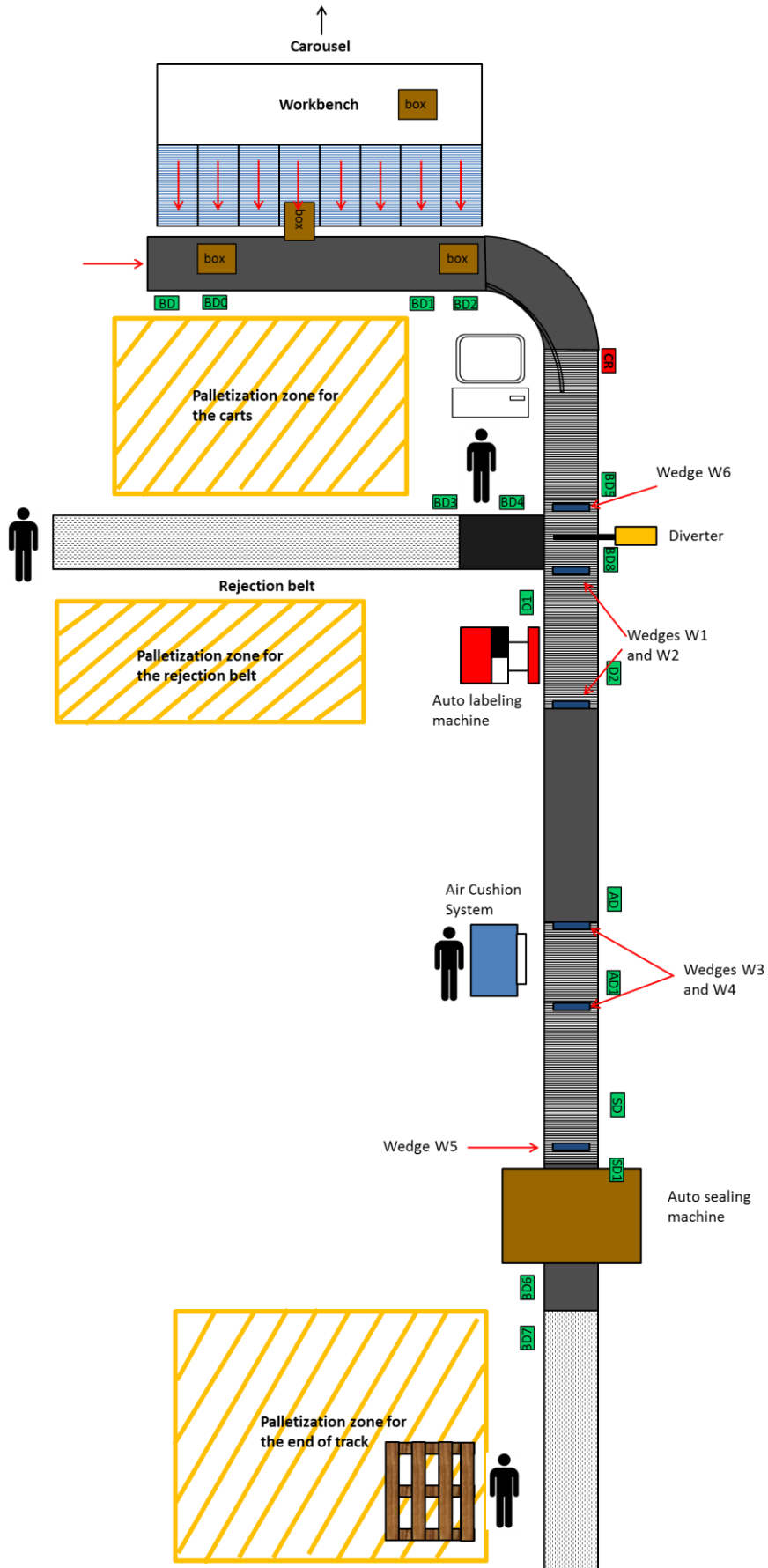


Fig. 6.1.- Proposal of automation at the preparing process. Source [own].

The process will work this way:

- Boxes will enter at the first conveyor belt as they are expelled from the workbench or if they're entered from the picking process. Sensor pairs BD-BD0 and BD1-BD2 will detect the presence of boxes in the belt.
- After section 2 (the curve) a code bar reader will know which kind of box is running in the belt in order to warn the verification operator, that will have the packing list prepared to check the box.
- When a box is detected in BD5, the first wedge will rise up to cut off the boxes circulation. Then, BD8 detects box presence and wedge 6 will rise to prevent any other box to interfere with the verification process. The verification operator will determine with the packing list if that box will be able to continue its natural way or if it has to be rejected.
- After that, when D1 detects presence, wedge 2 is activated. When the box gets to where D2 is waiting for detection, wedge 1 will rise up again so there are no more boxes at the labeling process.
- Once completed the labeling, boxes advance to the next stage. When AD detects presence, wedge 4 activates and when it reaches AD1, so does wedge 3. This way, the box it is wanted to fill with air bags gets isolated. After the person in charge of filling the box confirms that the stage is over, activates a signal by using a button and the wedges deactivate to leave the box to free run.
- When the operation is completed, next step is the sealing machine. The sealing machine is an independent one, so it has its own signals. Basically, as soon as it detects a box, it closes with a mechanical arm the short sides of the box and with a couple of plastic wings it closes the long sides of the box's cover.

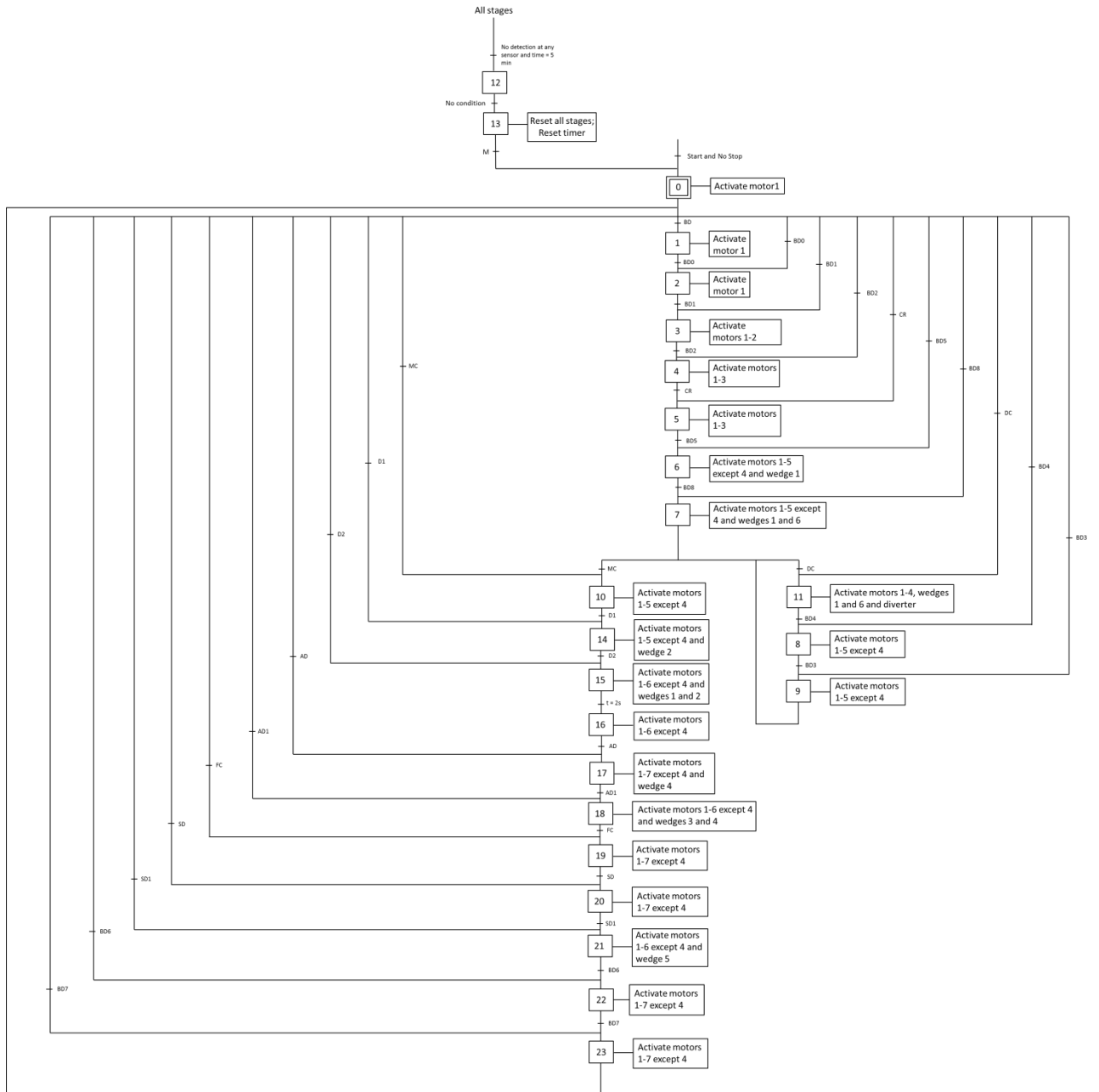


Fig. 6.2.- First level GRAFCET of the conveyor process. Source [own].

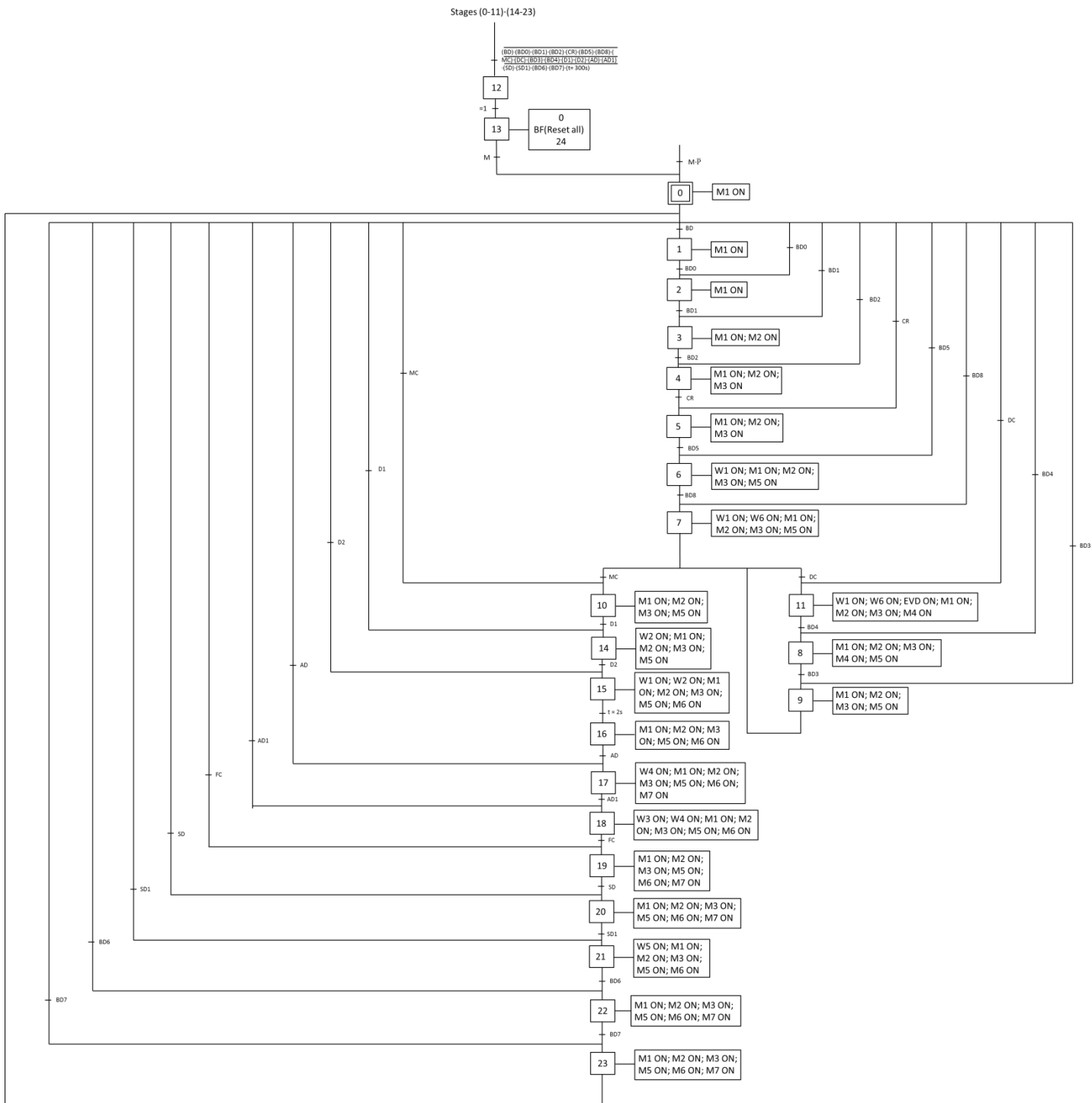


Fig. 6.3.- Second level GRAFCET of the conveyor process. Source [own].

6.2.- Detailed 3D model

Although it may be considered an Appendix's sub-section, it feels right to add some 3D model images created with SolidWorks® in order to simulate in a real scale the conveyor's dimensions and the looks like of it.

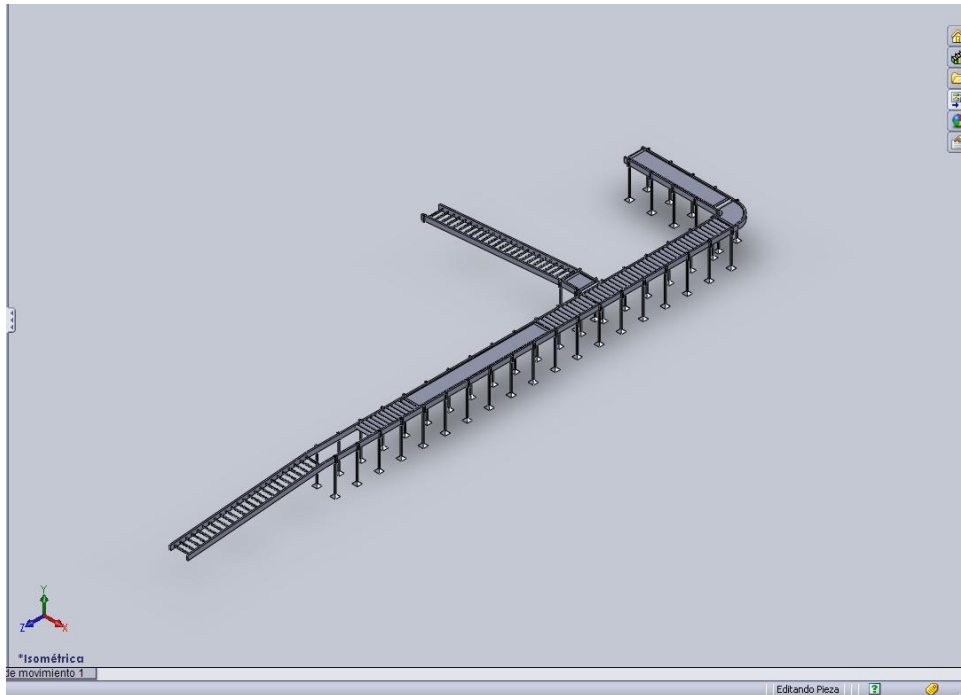


Fig. 6.4.-3D model made with SolidWorks®. Source [own].

It is important to remark here that no measures will be given in this chapter. The corresponding conveyor's measures can be found in the Schematics document. All the mechanical schematics have been done using this tool, thanks to the property that SolidWorks offers by creating drawings from the created 3D model.

In figure 6.5 it can be found a detail of the carousel workbench attached to the line, which is exactly how it is pretended to work.

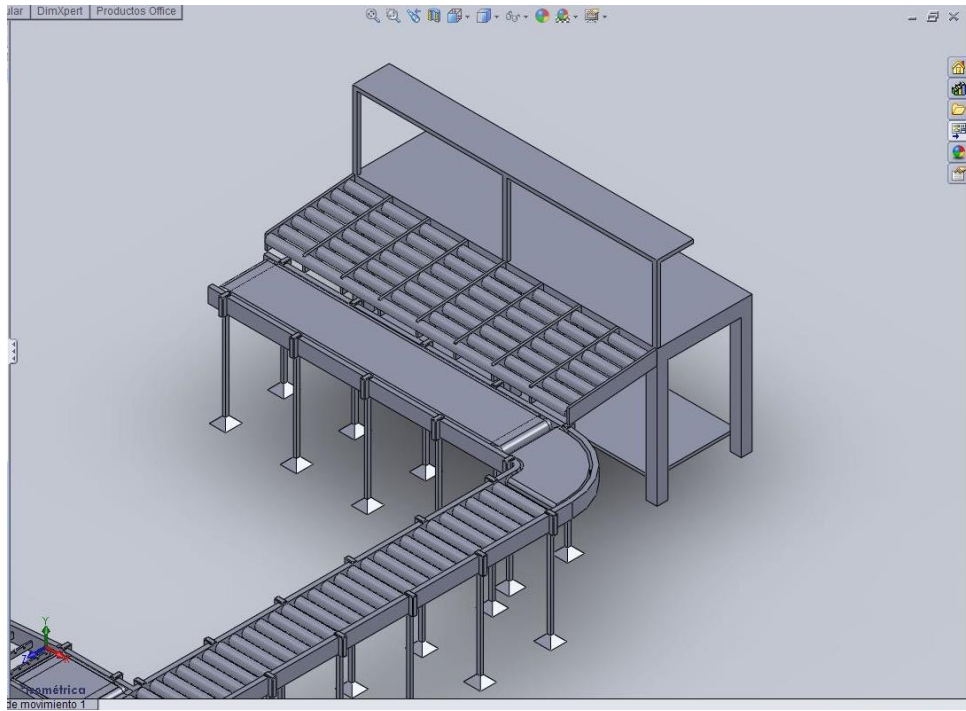


Fig. 6.5.-Detail of workbench made with SolidWorks®. Source [own].

7.- Calculations for the process' automation

For calculating the all the parameters that are going to be determinant for the project, it is going to be started with the conveyor belt, one of the most important components.

7.1.- Conveyor belt

As previously said, the conveyor belt will consist on a motorized one, with both roller belt and the conventional band type, depending on the section (see figure 7.1.).

Now, one of the most important parameters to consider it is going to be the weight that the belt will have to endure.

Based on actual information about the orders received by the company between 2016 and 2018 it has been seen that the maximum weight per box is 15.5 Kg. This deduction is explained next.

In figure 3.9 it could be seen that the map scale is 1:200. This means that the usable area where the orders are completed, which is the one intended to be automated, is of 24.96 m² (12 x 2.08 m).

Measuring the workbench where the boxes prepared in the carousel are dispatched, it has been estimated that its length is 2.08 m. This gives the conveyor belt a total length of 15.08 m.

Before any calculation for the motors is done, though, it is necessary to split the conveyor in different sections (every section will have its own motor and its own conveyor type). For example, those sections where transportation is only needed will have a common conveyor type, whereas when the box is needed to be stopped to do any operation the conveyor will be roller belt type.

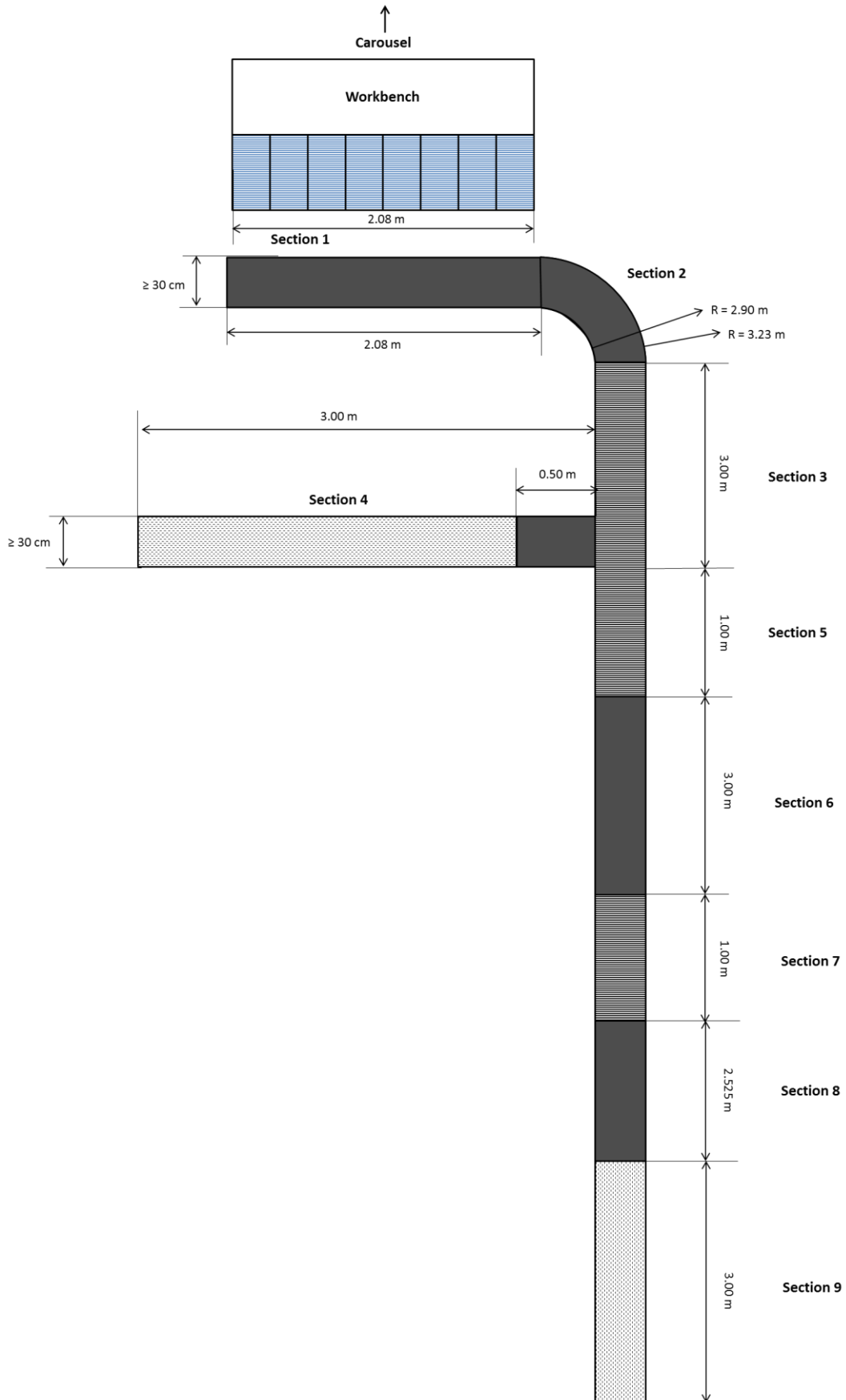


Fig. 7.1.- Diagram of measures for the conveyor belt (not in scale). Source [own].

Table 7.2.- Different sections of the conveyor.

| Section | Type | Length | Description |
|-----------|----------------------|----------|---|
| Section 1 | Band | 2.08 m | From the beginning to the curve |
| Section 2 | Band | ≈ 1.00 m | Curve |
| Section 3 | Roller | 3.00 m | From curve to rejection belt |
| Section 4 | Band | 0.50 m | Rejection belt. |
| | Free-roller | 3.00 m | Rejection belt. |
| Section 5 | Roller | 1.00 m | Automatic labeling machine. |
| Section 6 | Band | 3.00 m | From labeling machine to filling machine. |
| Section 7 | Roller | 1.00 m | From filling machine to sealing machine. |
| Section 8 | Unknown ⁶ | 2,525 m | Sealing machine process. |
| Section 9 | Free-roller | 3.00 m | From sealing machine to the end. |

On figures 7.2 and 7.3 it is going to see how the maximum weight of the boxes was extracted from the excel sheet of commands between the 2016 and 2018 period.

⁶ Note: Section 8 corresponds to the sealing machine process. This machine, as it will be seen in chapter 8, has its own conveyor belt, which is why this section won't have a motor, because it is already integrated in the case sealer.

| A | B | C | D | E | F | G | H | I | J | K |
|------------------|-----------------|-------------------|-------------------|--------------------|--------------------|--------|-----------|----------------|-------------|----------------|
| Código de client | Número de pedid | Fecha de estado d | Fecha de estado m | Fecha de estado añ | Código destinatari | Ruta | Referenci | Cantidad Pedid | Un venta Pe | Un venta Volum |
| 1 | 111 | S11061163 | 1 | 2 | 16 | C10054 | ENV | 7 | | 0,00453 |
| 2 | 111 | S11061163 | 1 | 2 | 16 | C10054 | ENV | 7 | | 0,00453 |
| 3 | 111 | S11061165 | 1 | 2 | 16 | C10005 | ENV | 6 | | 0,00012 |
| 4 | 111 | S11061166 | 1 | 2 | 16 | C24257 | PROF | 6 | | 0,00016 |
| 5 | 111 | S11061167 | 1 | 2 | 16 | C24257 | PROF | 5 | | 0,0001 |
| 6 | 111 | S11061167 | 1 | 2 | 16 | C24257 | PROF | 5 | | 0,0001 |
| 7 | 111 | S11061167 | 1 | 2 | 16 | C24257 | PROF | 5 | | 0,00011 |
| 8 | 111 | S11061167 | 1 | 2 | 16 | C24257 | PROF | 5 | | 0,00084 |
| 9 | 111 | S11061167 | 1 | 2 | 16 | C24257 | PROF | 5 | | 0,00033 |
| 10 | 111 | S11061167 | 1 | 2 | 16 | C24257 | PROF | 5 | | 0,00008 |
| 11 | 111 | S11061167 | 1 | 2 | 16 | C24257 | PROF | 5 | | 0,0001 |
| 12 | 111 | S11061167 | 1 | 2 | 16 | C24257 | PROF | 5 | | 0,00021 |
| 13 | 111 | S11061167 | 1 | 2 | 16 | C24257 | PROF | 6 | | 0,00028 |
| 14 | 111 | S11061167 | 1 | 2 | 16 | C24257 | PROF | 6 | | 0,00032 |
| 15 | 111 | S11061167 | 1 | 2 | 16 | C24257 | PROF | 6 | | 0,00016 |
| 16 | 111 | S11061168 | 1 | 2 | 16 | C25996 | SOU | 6 | | 0,00016 |
| 17 | 111 | S11061169 | 1 | 2 | 16 | C16350 | OLM | 6 | | 0,00016 |
| 18 | 111 | S11061170 | 1 | 2 | 16 | C11785 | ENV | 7 | | 0,00404 |
| 19 | 111 | S11061172 | 1 | 2 | 16 | C26984 | ENV | 6 | | 0,00016 |
| 20 | 111 | S11061172 | 1 | 2 | 16 | C26984 | ENV | 6 | | 0,00016 |
| 21 | 111 | S11061173 | 1 | 2 | 16 | C26699 | ENV | 317 | 1 | 0,394 |
| 22 | 111 | S11061173 | 1 | 2 | 16 | C26699 | ENV | 501 | 64 | 0,06 |
| 23 | 111 | S11061174 | 1 | 2 | 16 | C25678 | ENV | 619 | 1 | 0,36 |
| 24 | 111 | S11061175 | 1 | 2 | 16 | C25551 | MAND | 619 | 4 | 0,36 |
| 25 | 111 | S11061177 | 1 | 2 | 16 | C14314 | ENV | 619 | 1 | 0,36 |
| 26 | 111 | S11061178 | 1 | 2 | 16 | C16030 | ENV | 619 | 15 | 0,36 |
| 27 | 111 | S11061179 | 1 | 2 | 16 | C15989 | ENV | 619 | 2 | 0,36 |
| 28 | 111 | S11061184 | 1 | 2 | 16 | C17019 | ENV | 619 | 1 | 0,36 |
| 29 | 111 | S11061186 | 1 | 2 | 16 | C17747 | ENV | 619 | 4 | 0,36 |
| 30 | 111 | S11061188 | 1 | 2 | 16 | C25996 | ENV | 619 | 1 | 0,36 |
| 31 | 111 | S11061189 | 1 | 2 | 16 | C16030 | ENV | 619 | 5 | 0,36 |
| 32 | 111 | S11061190 | 1 | 2 | 16 | C16030 | ENV | 619 | 5 | 0,36 |
| 33 | 111 | S11061191 | 1 | 2 | 16 | C16030 | ENV | 619 | 10 | 0,36 |
| 34 | 111 | S11061194 | 1 | 2 | 16 | C17277 | ENV | 619 | 12 | 0,36 |
| 35 | 111 | S11061199 | 1 | 2 | 16 | C13560 | ENV | 619 | 6 | 0,00016 |

Fig. 7.2- Orders list from 2016 filtered by weight. Source [3].

In the mentioned period, it has been observed that for every year the maximum weight for each command is 15.5 Kg. A 19 Kg approx. order was found. If the quantity column is observed in figure 7.3 there is a 48 unit value. It means that more than one box was prepared for that order. This is why this weight data is ignored.

| A | B | C | D | E | F | G | H | I |
|------------------|-----------------|-------------------|-------------------|--------------------|--------------------|--------|-----------|----------------|
| Código de client | Número de pedid | Fecha de estado d | Fecha de estado m | Fecha de estado añ | Código destinatari | Ruta | Referenci | Cantidad Pedid |
| 194 | 111 | S11105417 | 2 | 1 | 18 | C14953 | ENV | 542 |
| 195 | 111 | S11105417 | 2 | 1 | 18 | C14953 | ENV | 542 |
| 18943 | | | | | | | | |
| 18944 | | | | | | | | |
| 18945 | | | | | | | | |
| 18946 | | | | | | | | |
| 18947 | | | | | | | | |

Fig. 7.3.- A common order at the warehouse. Source [3].

Now, for the belt to move without any trouble, it is going to be considered a 30% of extra weight per box, a 20% of safety margin weight and a 10% for the cardboard box itself:

$$15.5 \text{ Kg} \cdot 1.3 = 20.15 \text{ Kg} \quad [1]$$

Considering that in the company 2,000 orders are monthly made, and a month has 20 working days, it can easily be extracted that 100 orders (average) are done in a normal day.

There is only going to be two parts maintaining the already existing roller belt (non-motorized) with a 2° inclination: 3 m of the rejection belt and 3 m at the end of the belt. This is to ensure that a rejected box reaches the end of track, it doesn't get smashed by other boxes and to avoid it to graze against the moving conveyor, while with a non-motorized one, it doesn't happen.

Having in mind that length, if it is wanted a box to make all the circuit in a determined time (2 min, for example), the speed of the conveyor belt can be calculated:

$$x = v \cdot t \quad [1]$$

$$15.08m = v \cdot 120s$$

$$v = \frac{15.08m}{120s} = 0.12567 \text{ m/s}$$

Which is a speed of 12.57 cm/s or 7.54 m/min⁷.

Now, each box has a maximum length of 550 mm (an extra margin of 50 mm is going to be added). If a simple calculus is done, it can be estimated the maximum number of boxes per section:

$$N.\text{boxes} = \frac{\text{Section length}}{\text{box length}} \quad [2]$$

$$N.\text{boxes} = \frac{3 \text{ m}}{0.6} = 5 \text{ boxes}$$

$$N.\text{boxes} = \frac{2.08 \text{ m}}{0.6} = 3.46 \approx 3 \text{ boxes}$$

$$N.\text{boxes} = \frac{1 \text{ m}}{0.6} = 1.67 \approx 1 \text{ box}$$

⁷ Note: This is an estimation. Total time of a box going through the conveyor could change (especially in the manual processes). However, the speed wouldn't change too much.

Total boxes in the conveyor at the same time: $3 + 1 + 5 + 5 + 1 + 5 + 1 + 1 + 5 = 27$ boxes. To round this quantity and to add another security margin (just in case) 30 boxes will be considered simultaneously on the conveyor.

7.2.- Motors

With all these data, weight, length, number of boxes, and speed it can be now calculated the power of the conveyor's motor. Considering equation [3] from source [6]:

$$P = \frac{9.81 \cdot Q \cdot v \cdot \mu}{60 \cdot \rho} \quad [3]$$

Where:

Q = Load (Kg; it depends of the conveyor's section).

v = 7.54 m/min

μ = 0.2 (coefficient for translation).

ρ = 0.6 (default value).

As exposed before, the belt will have 9 sections, but as there are only going to be 1, 3 or 5 boxes in each one, the calculus is the following:

$$P = \frac{9.81 \cdot 20.15 \cdot 1 \cdot 7.54 \cdot 0.2}{60 \cdot 0.6} = 8.28 \text{ W}$$

$$P = \frac{9.81 \cdot 20.15 \cdot 3 \cdot 7.54 \cdot 0.2}{60 \cdot 0.6} = 24.84 \text{ W}$$

$$P = \frac{9.81 \cdot 20.15 \cdot 5 \cdot 7.54 \cdot 0.2}{60 \cdot 0.6} = 41.40 \text{ W}$$

This means a 0.05 KW (at least) motor is needed. Consulting AEG's catalog, the most similar is a 2-pole 90 W motor or a 4-pole 60 W motor.

| Tipo | kW | HP | min ⁻¹ | M _N Nm | EFF2 η | | | cos φ | I _N | | I _d /I _N | M _d /M _N | M ₂ /M _N | M ₄ /M _N | J 10 ³ kgm ² | kg | |
|--|----|--------------------|--------------------|----------------------|--------|------|------|-------|----------------|----------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|---------------------------------------|------|------|
| | | | | | 50% | 75% | 100% | | 400V | 380-420V | | | | | | | |
| 3000 min⁻¹ (2 polos) | | | | | | | | | | | | | | | | | |
| AM 56Z AA | 2 | 0.09 | 0.12 | 2810 | 0.3 | 49 | 53 | 59 | 0.67 | 0.35 | 0.40 | 3.9 | 3.8 | 3.8 | 3.9 | 0.09 | 3.4 |
| AM 56Z BA | 2 | 0.12 | 0.16 | 2800 | 0.4 | 51 | 56 | 62 | 0.68 | 0.40 | 0.45 | 3.5 | 3.4 | 3.4 | 3.5 | 0.1 | 3.5 |
| AM 63Z AA | 2 | 0.18 | 0.25 | 2790 | 0.6 | 54 | 58 | 63 | 0.73 | 0.60 | 0.65 | 3.7 | 3.0 | 3.0 | 3.1 | 0.14 | 3.6 |
| AM 63Z BA | 2 | 0.25 | 0.33 | 2790 | 0.9 | 57 | 62 | 68 | 0.70 | 0.80 | 0.75 | 4.5 | 3.2 | 3.2 | 3.3 | 0.17 | 4.1 |
| AM 63Z CA | 2* | 0.37 ¹⁾ | 0.50 ¹⁾ | 2800 | 1.3 | 54 | 58 | 65 | 0.70 | 1.20 | 1.25 | 4.6 | 3.4 | 3.3 | 3.4 | 0.20 | 4.4 |
| AM 71Z AA | 2 | 0.37 | 0.50 | 2820 | 1.3 | 58 | 64 | 70 | 0.78 | 1.0 | 1.2 | 4.7 | 3.6 | 3.4 | 3.6 | 0.36 | 5.8 |
| AM 71Z BA | 2 | 0.55 | 0.75 | 2830 | 1.9 | 57 | 64 | 71 | 0.77 | 1.5 | 1.6 | 4.8 | 3.2 | 3.1 | 3.3 | 0.42 | 6.2 |
| AM 71Z CA | 2* | 0.75 ¹⁾ | 1.0 ¹⁾ | 2800 | 2.6 | 60 | 67 | 74 | 0.77 | 1.9 | 2.0 | 5.2 | 3.1 | 3.2 | 3.1 | 0.61 | 7.2 |
| AM 80Z AA | 2 | 0.75 | 1.0 | 2840 | 2.5 | 67.7 | 73.0 | 74.5 | 0.78 | 1.9 | 2.0 | 5.0 | 2.8 | 2.8 | 2.9 | 0.75 | 8.4 |
| AM 80Z BA | 2 | 1.1 | 1.5 | 2810 | 3.7 | 74.3 | 77.3 | 77.6 | 0.82 | 2.5 | 2.6 | 4.6 | 2.4 | 2.8 | 2.9 | 0.89 | 9.5 |
| AM 80Z CA | 2* | 1.5 ¹⁾ | 2.0 ¹⁾ | 2825 | 5.1 | 76.5 | 79.4 | 79.1 | 0.83 | 3.3 | 3.4 | 5.0 | 2.9 | 3.0 | 3.3 | 1.05 | 11.1 |

Fig. 7.4.- AEG's 2-pole motor catalog. Source [25].

It can be seen as it has a power of 90 W, 2,810 rpm (due to sliding it isn't 3,000) and an output torque of 0.3.

To calculate the reduction needed for each pole motor, the speed in rpm is divided by the theoretical speed of the conveyor.

$$2P: 3,000/7.54 = 397.88 \rightarrow 1:400$$

$$4P: 1,500/7.54 = 198.93 \rightarrow 1:200$$

$$6P: 1,000/7.54 = 132.63 \rightarrow 1:135$$

$$8P: 750/7.54 = 99.47 \rightarrow 1:100$$

$$10P: 600/7.54 = 79.58 \rightarrow 1:80$$

$$12P: 500/7.54 = 66.31 \rightarrow 1:70$$

In the case of the 2-pole motor, $0.3 \cdot 400 = 120$ Nm output torque. If a 4-pole was chosen:

| Tipo | kW | HP | min ⁻¹ | M _N Nm | EFF2 η | | | cos φ | I _N | | I _d /I _N | M _d /M _N | M ₂ /M _N | M ₄ /M _N | J 10 ³ kgm ² | kg | |
|--|----|--------------------|--------------------|----------------------|--------|------|------|-------|----------------|----------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|---------------------------------------|------|------|
| | | | | | 50% | 75% | 100% | | 400V | 380-420V | | | | | | | |
| 1500 min⁻¹ (4 polos) | | | | | | | | | | | | | | | | | |
| AM 56Z AA | 4 | 0.06 | 0.08 | 1300 | 0.4 | 42 | 44 | 48 | 0.70 | 0.28 | 0.32 | 2.6 | 2.1 | 2.0 | 2.1 | 0.14 | 2.7 |
| AM 56Z BA | 4 | 0.09 | 0.12 | 1330 | 0.6 | 43 | 47 | 51 | 0.74 | 0.35 | 0.40 | 2.5 | 2.2 | 2.1 | 2.2 | 0.16 | 2.9 |
| AM 63Z AA | 4 | 0.12 | 0.16 | 1350 | 0.8 | 46 | 50 | 57 | 0.65 | 0.50 | 0.55 | 2.4 | 2.0 | 1.9 | 2.0 | 0.25 | 3.3 |
| AM 63Z BA | 4 | 0.18 | 0.25 | 1330 | 1.3 | 47 | 50 | 58 | 0.70 | 0.65 | 0.70 | 2.3 | 1.9 | 1.8 | 1.9 | 0.27 | 4.1 |
| AM 63Z CA | 4* | 0.25 | 0.33 | 1360 | 1.8 | 49 | 52.5 | 58 | 0.74 | 0.85 | 0.90 | 2.7 | 2.2 | 2.0 | 2.1 | 0.30 | 4.2 |
| AM 71Z AA | 4 | 0.25 | 0.33 | 1340 | 1.8 | 55 | 59 | 64 | 0.66 | 0.9 | 1.00 | 3.2 | 1.9 | 1.8 | 2.0 | 0.70 | 5.7 |
| AM 71Z BA | 4 | 0.37 | 0.50 | 1370 | 2.6 | 60 | 63 | 67 | 0.67 | 1.2 | 1.25 | 3.3 | 2.2 | 2.1 | 2.2 | 0.82 | 6.0 |
| AM 71Z CA | 4* | 0.55 ¹⁾ | 0.75 ¹⁾ | 1380 | 3.8 | 61 | 64 | 69 | 0.68 | 1.7 | 1.80 | 3.6 | 2.4 | 2.3 | 2.4 | 0.95 | 7.3 |
| AM 80Z AA | 4 | 0.55 | 0.75 | 1400 | 3.8 | 67.0 | 69.0 | 70.0 | 0.72 | 1.6 | 1.7 | 3.6 | 2.6 | 2.5 | 2.6 | 1.58 | 8.2 |
| AM 80Z BA | 4 | 0.75 | 1.0 | 1410 | 5.1 | 62.5 | 69.0 | 70.6 | 0.71 | 2.2 | 2.3 | 4.4 | 2.8 | 2.3 | 2.8 | 2.00 | 9.3 |
| AM 80Z CA | 4* | 1.1 ¹⁾ | 1.5 ¹⁾ | 1385 | 7.6 | 74.1 | 76.4 | 75.9 | 0.77 | 2.8 | 2.9 | 4.4 | 2.5 | 2.5 | 2.6 | 2.41 | 10.6 |

Fig. 7.5.- AEG's 4-pole motor catalog. Source [25].

It is seen that the output torque is 0.6 Nm. Multiplied for the reduction ratio (200) it returns a 120 Nm value output torque, same as before.

As a motor has to be chosen, and the maximum power required for the conveyor is 50 W (approx.) the model AM 56Z BA of 4 poles could be a candidate because it has plenty power for all the conveyor's sections and it is the one with an acceptable torque and speed without increasing the price too much due to it. The reducers, then, will be cheaper as well.

7.3.- Wedges and Diverter

Wedges

The pneumatic cylinder placed between rollers at the conveyors will have to raise a barrier that will stop the box. This cylinder will have to be strong enough to lift this barrier. Considering a standard steel sheet of the following dimensions:

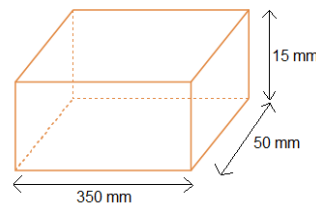


Fig. 7.6.- Steel barrier for the conveyor. Source [Google Images; edited].

Now, steel has a $7,850 \text{ Kg/m}^3$ density. Calculating its volume and using the density formula, its mass can be extracted:

$$V = 15 \cdot 50 \cdot 350 = 262500 \text{ mm}^3 = 2.625 \cdot 10^{-5} \text{ m}^3$$

$$\rho = \frac{m}{V} \quad [4]$$

$$m = V \cdot \rho$$

$$m = 2.625 \cdot 10^{-5} \cdot 7,850 = 0.206 \text{ Kg}$$

For safety reasons, mass will be approximated to 0.21 Kg. So its weight will be of:

$$P = m \cdot g \quad [5]$$

$$P = 0.21 \cdot 9.81 = 2.06 \text{ N}$$

If it is calculated now the force made by the cylinder with the formula:

$$F_{cyl.} = \pi \cdot \frac{D^2 [mm^2]}{4} \cdot \frac{P [bar]}{10} \quad [6]$$

As it is already known the minimum force that the cylinder has to do in order to lift the barrier, diameter will be isolated in order to know the cylinder dimensions.

$$D = \sqrt{\frac{F_{cyl.} \cdot 40}{\pi \cdot P}}$$

Elaborating a table with Excel for various pressures it can return the required diameter to lift the barrier.

Table 7.3.- Obtained diameter for the barrier application ($F = 2.06 \text{ N}$).

| P [bar] | D (mm ²) |
|---------|----------------------|
| 1 | 5,12 |
| 2 | 3,62 |
| 3 | 2,96 |
| 4 | 2,56 |
| 5 | 2,29 |
| 6 | 2,09 |
| 7 | 1,94 |
| 8 | 1,81 |
| 9 | 1,71 |
| 10 | 1,62 |
| 11 | 1,54 |
| 12 | 1,48 |

For higher forces, the needed diameter is bigger too.

Table 7.4.- Obtained diameter for the barrier application ($F = 3 \text{ N}$ and 5 N).

| P [bar] | D (mm ²), F = 3 N | D (mm ²), F = 5 N |
|---------|-------------------------------|-------------------------------|
| 1 | 6,18 | 7,98 |
| 2 | 4,37 | 5,64 |
| 3 | 3,57 | 4,61 |
| 4 | 3,09 | 3,99 |
| 5 | 2,76 | 3,57 |
| 6 | 2,52 | 3,26 |
| 7 | 2,34 | 3,02 |
| 8 | 2,19 | 2,82 |
| 9 | 2,06 | 2,66 |
| 10 | 1,95 | 2,52 |
| 11 | 1,86 | 2,41 |

| | | |
|----|------|------|
| 12 | 1,78 | 2,30 |
|----|------|------|

For safety reasons, again, a 5 N force will be considered in order to make the cylinder stronger.

The working pressure for the installation, once seen chapter 8 (pneumatic components) will be around 6 bar.

Diverter

Here it is going to be estimated the force needed to push a box to the rejection belt and the selected component will be seen in next chapter. If a 20.15 kg box is considered, which is the needed force to reject it?

First let's set up the scenario. The box placed in the verification zone will be stopped as long as necessary for its checking. Once it is confirmed that that box has to be rejected the worker will activate the pedal valve and divert the box.

The situation is the following:

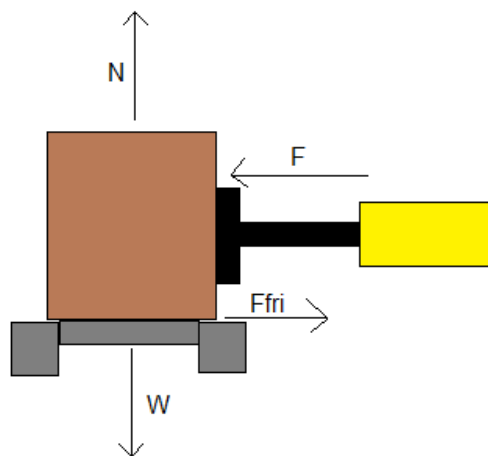


Fig. 7.7.- Dynamics situation of the rejected box. Source [own].

Now for the known values:

N = It's the normal.

F = The needed force to reject a box.

F_{fri} = It's the friction force that opposites movement.

W = Weight.

The equation to solve that defines the system:

$$F - F_{fri} = m \cdot a \quad [7]$$

Isolating the variable that wants to be found:

$$F = m \cdot a + F_{fri}$$

$$F_{fri} = \mu \cdot N \quad [8]$$

Now, the normal is a known parameter because it equals the weight. What it is unknown it's the friction coefficient. As no cardboard-steel coefficient has been found, the leather-steel ($\mu=0.6$) will be used to make a proper estimation. Considering that the box is made of cardboard and not leather, it would be considered $\mu=0.5$.

However a detail rests before anything else is calculated. This coefficient is considered in case of both surfaces being completely in contact. But it is not the case, because the box will be on a roller conveyor belt, which means it won't have a total surface contact. It can be estimated, that half of the box won't make any contact and that means a reduction of the friction coefficient to its half. Then $\mu=0.25$.

Having set up this parameter it can now be calculated the friction force, according to eq. [8]:

$$F_{fri} = \mu \cdot m \cdot g$$

$$F_{fri} = 0.25 \cdot 20.15 \cdot 9.81 = 49.42 \text{ N}$$

And returning to the main problem at equation [7]:

$$F = 20.15 \cdot a + 49.42$$

See that there are two unknown variables: F and a . If a little acceleration is considered, let's say between 0 and 1 m/s^2 , the maximum and minimum forces that would result would be:

$$F = 20.15 \cdot 0 + 49.42$$

$$F = 49.42 \text{ N}$$

$$F = 20.15 \cdot 1 + 49.42$$



$$F = 69.57 N$$

So, for a middle point a force of 60 N (approx.) would be needed.

8.- Components' selection

8.1.- Conveyor's sections

The selected company for the conveyor's modules installation will be Cintasa, an enterprise located at Zaragoza, a Spanish city in the Aragón Autonomic Community (CA).

This company has been kind enough to answer at the request of a budget for the conveyor's modules. This is why, at the Charter document, the reader will see the estimated price of the belt's sections based on this budget.

Figure 8.3 shows a band section for the belt. As it can be seen, the high can be regulated and it includes the proper motor to move it. Having in mind that the order would be from IDL to Cintasa, the motor could be replaced for the one in chapter 8.2.



Fig. 8.1.- Cintasa conveyor section. Source [28].

The roller belt is manufactured for different lengths and widths. Cintasa also offers its installation and maintenance, providing a global solution to the problem and searching always the customer's satisfaction.

8.2.- Motors and reducers

Motors

It wasn't chosen any AEG motor because the catalog has been used merely to investigate the power required for the conveyor belt to move. Searching for the proposed model at chapter 7, it returned to the same catalog.

The motor finally selected for the conveyor movement is the model BN series from BONFIGLIOLI manufacturer, which can be found at its web page. The good thing about this series is that has a large variety of powers (from 60 W to 30 kW) and it can be found for a different number of poles combination.

On the figure below it can be seen the selected motor:

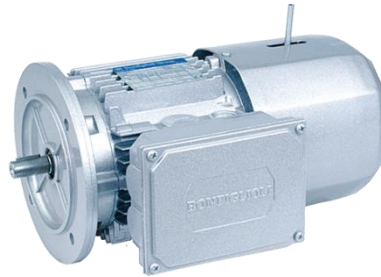


Fig. 8.2.- BN series AC motor from Bonfiglioli. Source [32].

As the power needed for the conveyor was 50 W (approx.) the BN63A model will be chosen. This motor delivers 120 W, which is more than enough for the desired application and can work at 4 poles (which is the wanted speed) besides other pole numbers.

Table 8.1.- Features of BN series AC motor.

| | |
|----------------------------|--|
| kW rating (4 pole) | 0.06 kW ... 30 kW |
| Frame Sizes | 56A ... 200L |
| Pole Numbers | 2, 4, 6, 8, 2/4, 2/6, 2/8, 2/12, 4/6, 4/8 |
| Mounting Options | Foot IM B3 Flange IM B5 and IM B14 |
| Operation | 50 Hz and 60 Hz |
| Compliance | 2006/95/EC (LVD) and 2004/108/EC (EMC) |
| Inverter Duty | All frame sizes |
| Housing | Cast aluminum |
| Main Brake Features | DC and AC supply Faster Brake Engage/Disengage through Electronically Controlled AC/DC Rectifier type SB, NBR, SBR (options) |
| Main Options | Thermistors and |

| | |
|--|---|
| | thermostates sensors Separate supply forced ventilation Line driver and push-pull incremental encoder CSA and UL approved design |
|--|---|

Reducers

The reducer chosen is the S 40 because it gives 125 Nm at its output and let's remember that the wanted output torque was 120 Nm, which is pretty close. Figure 8.2 shows the model:



Fig. 8.3.- S series motorreducer from Bonfiglioli. Source [33].

The good thing about this reducer is that it is totally compatible with the AC motor (along with other Bonfiglioli products) chosen for the conveyor application.

Table 8.2.- Features of S series motorreducer.

| | |
|---|--|
| Torque Range | 21 Nm... 200 Nm |
| Mechanical Rating (n1= 1400 min-1) | 0,12 ... 11,6 kW |
| Gear ratios | 1,4 ... 13,1 |
| Output Configuration | Foot and Flange mount |
| Input Configurations | IEC-normalized Motor Adaptors Solid Input Shaft |
| Applicable AC motors | Integral motors and Brake motors - M series/ME |

| | |
|----------------------------|---|
| | <p>series IEC-normalized Motors and Brake motors - BN series/BE series Single and Dual Speed Motors</p> |
| Main Brake Features | <p>DC and AC supply Faster Brake Engage/Disengage through Electronically Controlled AC/DC Rectifier type SB, NBR, SBR (options)</p> |
| Main Motor Options | <p>Thermistors and Thermostats sensor Separate Supply Forced Ventilation Line Driver and Push- Pull Incremental Encoder</p> |

Frequency variator

In order of the motors to turn backwards in case an emergency stop was ordered, a frequency variator is needed. This device will make the motor to turn backwards a little bit before cutting its voltage supply. This will be done to avoid fingers to get caught at the roller conveyor belt sections.

The selected model, thus, it is the SINAMICS V20 from SIEMENS. It can be connected to the triphasic web (400 V) to control the motors seen before.



Fig. 8.4.- SINAMICS V20 frequency variator . Source [Google Images].

Table 8.3.- Features of the frequency variator.

| | |
|---|--|
| Voltage | 1AC 230V: 1AC 200V ... 240V (-10% ... +10%) 3AC 480V: 3AC 380V ... 480V (-15% ... +10%) |
| Maximum output voltage | 100% of input voltage |
| Supply frequency | 50 / 60 Hz |
| Line supply type | TN, TT, TT earthed line, IT |
| Power range | 1AC 230V 0.12 ... 3.0 kW (1/6 ... 4 hp) 3 AC 480V 0.37 ... 30 kW (1/2 ... 40 hp) |
| cos ϕ / Power factor | $\geq 0.95 / 0.72$ |
| Overload capability | up to 15 kW: High Overload (HO): 150% I_H for 60 s within a cycle time of 300 s from 18.5 kW: Low Overload (LO): 110% I_L for 60 s within a cycle time of 300 s High Overload (HO): 150% I_H for 60 s within a cycle time of 300 s |
| Output frequency | 0 ... 550 Hz resolution: 0.01 Hz |
| Efficiency factor | 98% |
| Control modes | Voltage / frequency control mode: linear V/f, square law V/f, multi-point V/f Flux current control mode: FCC |

The connection diagram to the PLC and to the motors is shown in figure 8.5.:

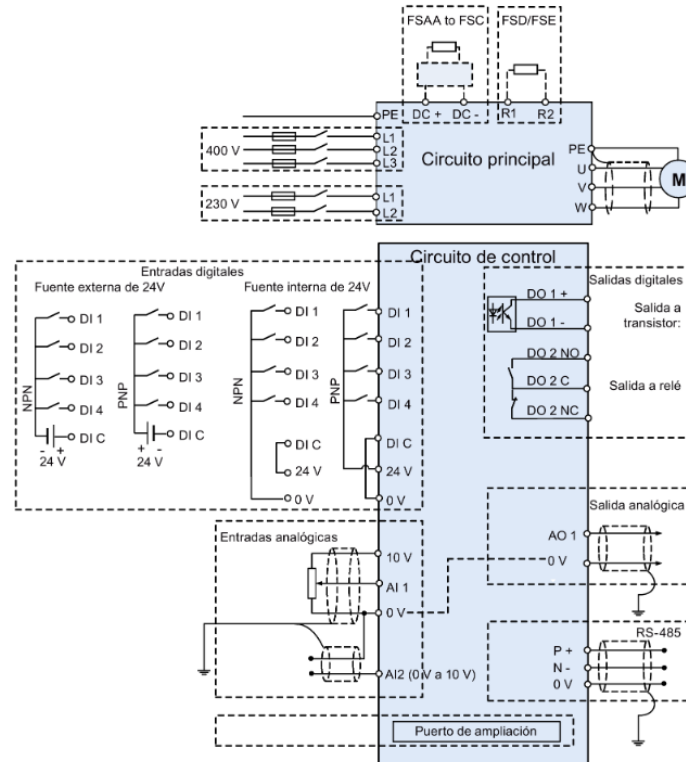


Fig. 8.5.- SINAMICS V20 connection diagram . Source [55].

On the main circuit it can be seen that the frequency variator will be connected to the tri-phase web (400 V) by using L1, L2 and L3. Outputs U, V and W will be connected to the corresponding motor.

The used inputs will be the digital ones (analogic inputs won't be used for this application) that will be controlled by the PLC. According to its programming it will set on the corresponding output in order to move the motor forward or backwards.

As it is desired the motor to work at two different speeds (normal speed and reverse speed) the selected operating mode for the frequency variator is the 2nd mode (Cn002).

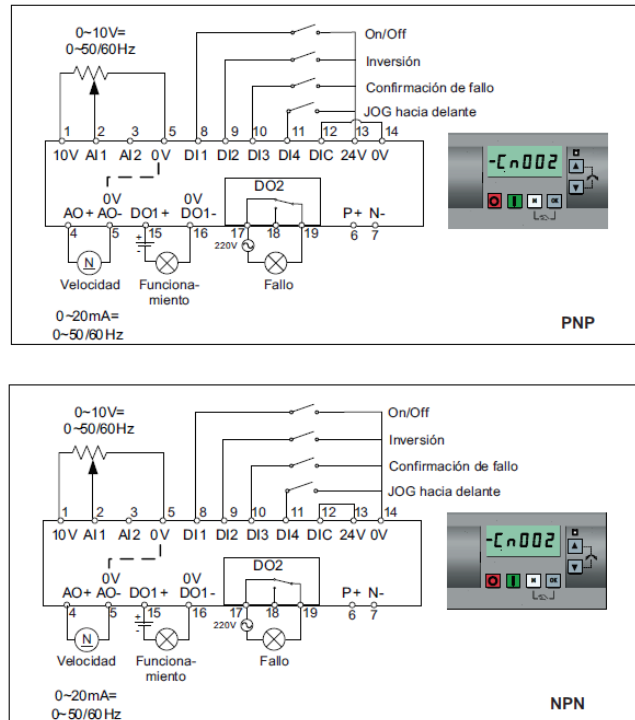


Fig. 8.6.- SINAMICS V20 control circuit diagram corresponding to working configuration n. 3 . Source [55].

As there are seven motors to be controlled at the installation, there will be needed seven frequency variators.

8.3.- PLC

The main component of the project is the CPU from SIEMENS, the SIMATIC S7-1200, which is the one used in the programming and lab testing.



Fig. 8.7.- Siemens CPU 1214C - 6ES7214-1AG40-0XB0. Source [44].

To control the frequency variator, as 5 digital inputs of the PLC are required for each one, expansion modules will be needed in order to control the rest of them as well as the rest of the outputs: barriers, the rejection belt diverter...

As it will be seen in the Schematics document, an 8 digital input/8 digital output module and a 16 digital output module will be needed. Figure 8.8 show these expansion modules.



Fig. 8.8.- a) Siemens SM 1223 DC/RLY - 6ES7223-1PH32-0XB0 (8 DI/8 DO).
b) Siemens SM 1222 - 6ES7222-1HH32-0XB0 (16DO). Source [44].

8.4.- Sensors

Photocells

For the detectors it is going to be selected the CY-192B-Z-Y from Panasonic. This sensor, shown in next figure, has the following characteristics:



Fig. 8.9.- CY-192B-Z-Y optical sensor from Panasonic. Source [19].

Table 8.3.- Features of the Panasonic sensor.

| | |
|------------------------------|----------------------------|
| Sensing method | Retroreflective |
| Sensing distance | 4 m |
| Source voltage | 12 ~ 24 V |
| Response time | 1 ms |
| Output configuration | NPN- open collector |
| Connection method | Connector, M12 |
| Protection grade | IP67 |
| Cable length | - |
| Illumination source | Infrared |
| Operating temperature | -25 °C ~ 55 °C |

Given the fact that a photocell is intended to be placed at the conveyor, a reflector will be needed. For thus, it has been selected the one in figure 7.7.:



Fig. 8.10.- 50 x 50 mm reflector from Panasonic. Source [19].

Scanner

The selected model for the code bar scanner placed at the curve of the conveyor is the DS5100 from Datalogic.



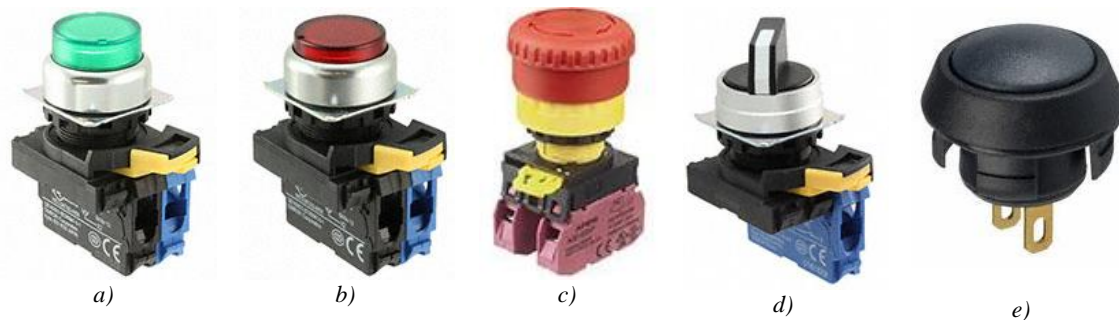
Fig. 8.11.- DS5100 code bar scanner from Datalogic. Source [45].

As well as the photocells it operates at 24 V DC.

8.4.- Other components

8.4.1.- Switches

The chosen switches are mainly from Omron manufacturer. They all have IP65 or IP66 protection indexes which make them practically immune to ambient conditions inside the warehouse.



*Fig. 8.12.- a) Start switch. Source [19].
b) Stop switch. Source [19].
c) Switch for the emergency stop. Source [19].
d) Selector switch for the keypads. Source [19].
e) Switch for the rearm and motors at the keypad. Source [19].*

The emergency stop switch will block itself once pressed and it can only be unblocked by turning it, which adds an extra security margin of deactivate it by mistake.

These switches will be placed at the keypads controlling the whole installation.

8.4.2.- Lights and LEDs

This is the red light that will indicate when the belt has reached its full capacity. It will be placed at the end of track and when active, all the motors will have to turn off in order to force the employers to clear the conveyor from boxes and continue its normal activity. It has an IP54 protection which is for water streams and dust.



Fig. 8.13.- Red light for the exit conveyor belt. Source [19].

Table 8.4.- Features of the red light.

| | |
|------------------------------|-----------------------|
| Manufacturer | Hammond Manufacturing |
| Series | PBR |
| Piece status | Active |
| Type | Optical element |
| Number of batteries | 1 |
| Lamp type | LED |
| Color clear | Red |
| Function | Blinking |
| Source voltage | 24 VCC |
| Protection grade | IP54 |
| Operating temperature | -25 °C ~ 45 °C |

The LEDs selected for the keypad are the following. The keypad design can be found in chapter 10.



Figure 8.14- Selected LEDs for the keypads design.. Source [19].

Their function is basically to indicate which sensors have detected presence signal on the conveyor.

8.4.3.- Pneumatic components

Air compressor

As there are components that need an air supply, as well as electrical, an air compressor will be installed in order to provide these machines this air supply. Specifically, the selected model is the LZ 7-10 from manufacturer AtlasCopco.

As the most restrictive machine (the labeling machine) demands a 5 cfm (2.36 l/s) of air flow, the LZ 7-10 is the perfect one for the application. It delivers until 11 l/s, so it is over the threshold. The electrical connection will be at 400 V and the power motor is between 0.55 kW and 1.5 kW.



Fig. 8.15.- LZ 7-10 air compressor Source [54].

To follow the normative, the air compressor will have to be installed outside the warehouse due to the noise it might generate. Also its connection to the tri-phase grid will be aside from the one of the motors and the sealing machine.

Valve island

To activate the barriers of the installation, electrovalves will be needed. However, if a valve island is installed, the final composition is more compact and the connection cable length is significantly reduced.



Fig. 8.16.- Pneumatic pedal valve. Source [36].

The valve island selected, the Micro-Moduflex V series from Parker manufacturer has 10 valves modules, connection to the PLC and can be programmed for 4/2 valves, 3/2 NO, 3/2 NC and 4/2 EC. It delivers a maximum air flow of 4.58 l/s, which guarantees that if the compressor provides a 2.53 l/s, the valve island will operate properly. The working pressure is between -0.9 and 8 bar, also the desired working pressure rank for the installation.

Pneumatic cylinders

The chosen pneumatic cylinder is a simple effect cylinder model AEN-16-25-I-P-A-25K8 from manufacturer FESTO. This model will be used as well for the barriers/wedges as for the diverter. As it was seen in chapter 7, a force of 60 N approx. was needed to reject a box and the cylinder offers, in advance, 88 N which is more than enough to move the box.⁸

It also provides more than enough force to lift the barrier's weight seen at calculations' chapter.

⁸ Note: A piece of rubber of a bigger area than the pneumatic cylinder is recommended to be attached to it in order to minimize the impact of the piston rod on the cardboard and avoid the box's breaking.



Figure 8.17.- Pneumatic cylinder AEN-16-25-I-P-A-25K8 model⁹ from Festo. Source [35].

Its technical characteristics:

Table 8.5.- Features of the pneumatic cylinder.

| | |
|--|---|
| Shift | 1 ... 25 mm |
| Piston diameter | 16 mm |
| Based in normative | ISO 21287 |
| Damping | P: damping for elastical block/sheet at both sides |
| Construction | Piston Piston rod Outlined tube |
| Working pressure | 1,5 ... 10 bar |
| Working modes | simple effect compression traction |
| Fluid | Compressed air according to ISO 8573-1:2010 [7:4:4] |
| Clase de resistencia a la corrosión KBK | 2 – moderate corrosion risk |
| Environmental temperature | -20 ... 120 °C |
| Theoretical force with 6 bar, backwards | 58 N |

⁹ Note: image may not correspond to the mentioned model.

| | |
|---|--|
| Theoretical force with 6 bar, advance | 88 N |
| Masa mòvil con carrera de 0 mm Moving mass with 0 mm shift | 15 g |
| Extra weight for 10 mm shift | 14 g |
| Basic weight with 0 mm shift | 79 g |
| Extra mass for 10 mm shift | 4 g |
| Fixing type | To choose: With through drill with interior thread with accessories |
| Pneumatic connection | M5 |
| Material indication | Conforming to RoHS |

As it can be seen, the selected component satisfies the imposed conditions set up at chapter 7.

Diverter valve

For the diverter, a pneumatic valve has been chosen. To be a bit more specific, a pedal valve has been selected because if the verification responsible is working manually in the line, it will be easier to reject a box by pressing a pedal rather than pushing every box.



Fig. 8.18.- Pneumatic pedal valve. Source [31].

Technical features:

- Reference: OP52M4.
- Size: 1/4 ".
- Type: 5 way 2 positions monostable, with protective cover.
- Working pressure: 0 - 8.83 bar.
- Effective diameter flow: 12 mm².
- Valve material: Metal.
- Housing material: Polycarbonate.
- Color blue.

8.5.- Automatic machines

8.5.1.- Labeling machine

The advantage of the KPA 400 labelling machine, from Ketan Automated Equipment INC is that it can be attached next to the conveyor belt and as the boxes go through the belt, it will print on them.

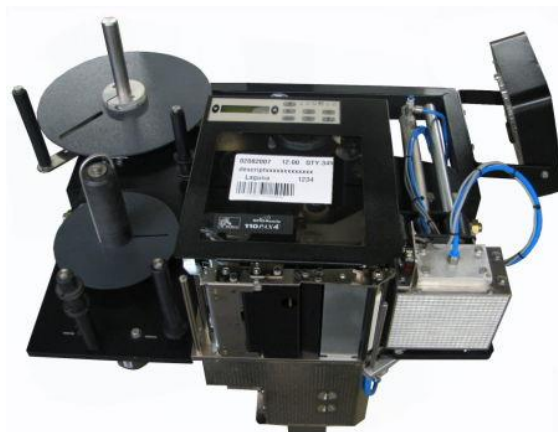


Figure 8.19.- Labeling machine. Source [30].

It needs 5.5 bar pressure of dry air to work and 2.36 l/s of air flow.

8.5.2.- Filling machine

The filling machine chosen for the project is the AirWave1, from Flöter. This type of machine is currently being used at the warehouse and it has a speed 8-10 m/min.



Figure 8.20.- Filling machine. Source [40].

This isn't actually an automatic machine, given the fact that it only produces air bags but it doesn't put them in the boxes. For that, human intervention is needed, which is why it can be considered semi-automatic, like the carousel. However, it is included in this chapter, because it is a machine of the packaging process, just like the other ones.

Firstly another machine was going to be chosen, the PRO PACK R Cushion System but it was a problem for the cable section calculus as well for the fact that another component has to be selected, given the fact that the machine supply was at 120 V, not at 230 V.

8.5.3.- Sealing machine

For the sealing machine it is selected the model CS-Random of the manufacturer Lantech. This election is due to the fact that it has been seen the effectivity of this machine in another IDL's warehouse and it is the model with less boxes per minute ratio (12 boxes/min). As every box in the process will remain in the conveyor for at least 2 minutes, it is the right choice.

The working procedure is clear: once the box enters at the machine, an arm closes the interior wings of the box while a couple of plastic blades (of the machine) close the exterior ones. After that, the tape is stacked on the top using the own box's inertia.



Figure 8.21.- Sealing machine. Source [24].

8.6.- Energy consumption

This sub-section will intend to justify the elements consumption in order to calculate the next stage, the cables section. Consulting the bibliography of the different components that are part of the installation we have the following breakdown:

Table 8.6.- Energy consumption from the different elements of the conveyor.

| Element | Volts (V) | Current (I) | Watts (W) | Quantity | TOTAL |
|-----------------------|-----------|-------------|-----------|----------|-------------------|
| Motor | 400 | 0,3 | 120 | 7 | 840 |
| Photocells | 24 | 0,035 | 0,84 | 17 | 14,28 |
| Switch | 24 | 10 | 240 | 1 | 240 |
| AC/DC converter | 230 | | 60 | 1 | 60 |
| PLC | 24 | 0,4 | 9,6 | 1 | 9,6 |
| PLC expansion modules | 24 | 0,185 | 4,44 | 4 | 17,76 |
| Air compressor | 400 | | 5500 | 1 | 5500 |
| Electrovalves | 24 | 0,042 | 1,008 | 1 | 1,008 |
| Sealing machine | 400 | 0,95 | 380 | 1 | 380 |
| Filling machine | 230 | 3,28 | 756 | 1 | 756 |
| Labeling machine | 220 | 10 | 2200 | 1 | 2200 |
| TOTAL | | | | | 10,018.648 |

As it can be seen the total power consumption of the installation would be approximately of 10 kW maximum.

8.7.- Cable section calculus

Based on sub-section 8.6, it will be tried here to select the different cables section according to the power consumption of the components.

- For monophasic lines,

$$S = \frac{2\rho LI}{\Delta V} \quad [9]$$

- For monophasic alternating current lines,

$$S = \frac{2\rho LI \cdot \cos \varphi}{\Delta V} \quad [10]$$

- For triphasic alternating current lines,

$$S = \frac{\sqrt{3}\rho LI \cdot \cos \varphi}{\Delta V} \quad [11]$$

Where:

- ΔV is the voltage drop (in this case 5% as it is neither a housing installation nor a streetlight project).
- $\cos \varphi$ is the active power factor. It will be considered of 0.8.
- L is the cable length (m). It will be considered always of 20 m.¹⁰
- ρ is the copper resistivity ($1.724138 \cdot 10^{-2} \Omega \text{mm}^2/\text{m}$).

From eq. [9]:

¹⁰ Note: This length is taken so the selected cable can reach all the installation without any trouble and if there is any left over, it will be stored for any reparation/maintenance issue.

$$S = \frac{2 \cdot 1.724138 \cdot 10^{-2} \cdot 20 \cdot 0.035}{0.05} = 0.48 \text{ mm}^2$$

As there are no cables of this section, the most similar from above in the scale is the one of 0.5 mm² section cable. Figure 8.22 shows the selected cable from RS components.



Figure 8.22- Section cable for the signal inputs (24 V). Source [20].

This cable of 0.5 mm² section and 3 cores can stand a 2.5 A current, 440 V and has a PVC cover. This will be the cable used for the PLC signals.

From eq. [10]:

$$S = \frac{2 \cdot 1.724138 \cdot 10^{-2} \cdot 20 \cdot 10 \cdot 0.8}{0.05} = 110.34 \text{ mm}^2$$

This result clearly it is not right. The current is taken 10 A because at table 8.7 it was seen that the labeling machine needs more current than the filling machine. Now, although the calculation is correct, the result clearly is shocking because its lack of logic. How can it be that the needed section for a triphasic cable is of 4 mm² and yet, for a monophasic system (in CA) the section is bigger?

If an estimation was made taking the middle point of both sections, the result would be a section of 2.25 mm², which makes much more sense. The general rule is 1 mm² for 1 kW. Taking the closer rank in the scale the cable chosen would be the shown in figure 8.23 a):

| Sección del cable | Intensidad máxima | Potencia máxima en 12 Vcc | Potencia máxima en 24 Vcc | Potencia máxima en 48 Vcc | Potencia máxima en 220 Vac |
|---------------------|-------------------|---------------------------|---------------------------|---------------------------|----------------------------|
| 1,5 mm ² | 11 A | 132 W | 264 W | 528 W | 2.420 W |
| 2,5 mm ² | 15 A | 180 W | 360 W | 720 W | 3.300 W |
| 4 mm ² | 20 A | 240 W | 480 W | 960 W | 4.400 W |
| 6 mm ² | 25 A | 300 W | 600 W | 1.200 W | 5.500 W |
| 10 mm ² | 34 A | 408 W | 816 W | 1.632 W | 7.480 W |
| 16 mm ² | 45 A | 540 W | 1.080 W | 2.160 W | 9.900 W |
| 25 mm ² | 59 A | 708 W | 1.416 W | 2.832 W | 12.980 W |

a)



b)

Fig 23 a) Table relating the power in CA with the cable section. Source [41].

b) 2.5 mm² cable section. Source [39].

Figure 23.b) also shows the chosen color for the cables.

From eq. [11]:

$$S = \frac{\sqrt{3} \cdot 1.724138 \cdot 10^{-2} \cdot 20 \cdot 0.3 \cdot 0.8}{0.05} = 2.86 \text{ mm}^2$$

For catalog issues, this section will have to be of 4 mm².

The following image shows the cables chosen to connect the different triphasic elements of the installation. According to the cable color code (source [38]), the green-yellow one is for earth, the red, brown and black are for phase and the blue for the neutral.

This combination will be used for the motors, the sealing machine and the air compressor.

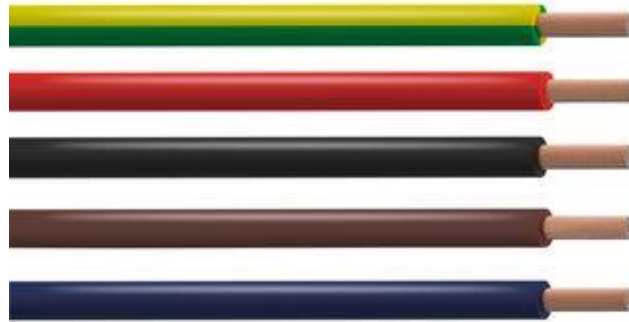


Figure 8.24- Section cable for the triphasic elements (400 V). Source [39].

8.8.- Electric web components

Converter

The AC/DC converter chosen has the following characteristics. The converter has to take the 230 V of the electrical web and transform them to the 24 V the sensors along with some switches. With a 60 W power it is more than enough to bear the demanded loads.



Figure 8.25- AC/DC converter from Red Lion Controls. Source [19].

Table 8.7.- Features of the AC/DC converter.

| | |
|---------------------------|------------------------------|
| Manufacturer | Red Lion Controls |
| Series | PSDR |
| Piece state | Active |
| Type | Locked |
| No. de outputs | 1 |
| Supply Voltage | 100 ~ 120 VCA, 220 ~ 240 VCA |
| Voltage - Output 1 | 24 V |
| Voltage - Output 2 | - |
| Voltage - Output 3 | - |
| Voltage - Output 4 | - |

| | |
|------------------------------|---|
| Output current (max) | 2.5 A |
| Power (W) | 60 W |
| Applications | ITE (Commercial) |
| Voltage - Insulation | 4kV |
| Efficiency | 89.7% |
| Operation temperature | -10 °C ~ 70 °C (with power decrease) |
| Characteristics | Adjustable output, compatible con entrada de CC, IP20, load share |
| Mounting type | Riel DIN |
| Size / Measures | 3.58" L x 1.77" A x 2.95" H (91.0 mm x 45.0 mm x 75.0 mm) |
| Minimum required load | - |
| Approbations | CE, cULus |

Protections

In order to prevent any damage to the installation due to overvoltage or others, some protections are needed to be added.

For the 220 V line (which comprehends the air cushion machine and the sealing machine), the circuit breaker chosen is:



Figure 8.26- EUC2P16C circuit breaker of 230 V, 16 A, 2 poles. Source [39].

To protect the 400 V line where the motors and the sealing machine are connected to, the following circuit breaker will cut the connection.



Figure 8.27- FAZ-C13/3 circuit breaker of 400 V, 13A, 3 poles. Source [39].

The protection switch connected (PIA) to the Emergency stop button is the shown in figure 8.28:



Figure 8.28- DILA-XHI22 power switch of 415 V, 6 A, 4 poles. Source [39].

Also, to protect the installation against any current escape, it will be placed a differential switch next to the PIA:



Figure 8.29- A9R21463 differential switch of 63 A, 30 mA sensitivity, 4 poles. Source [46].

Electrical cupboard

In order of having all the electrical components safe, a protection cupboard needs to be installed next to the conveyor. The cupboard specifications will be detailed in the Schematics document. In figure 8.30 a sample of how this cupboard would look is shown:

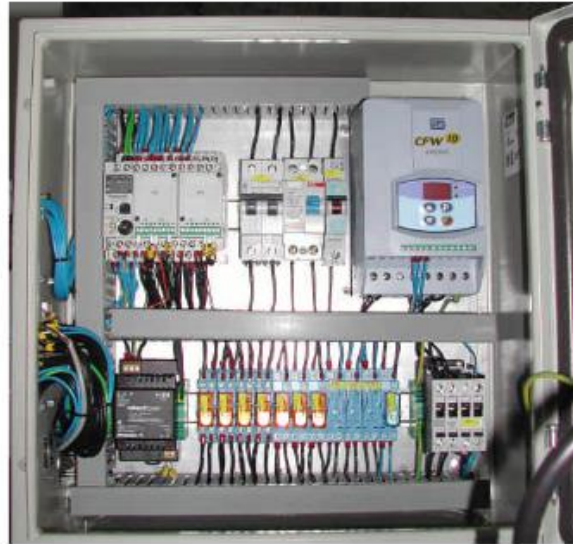


Figure 8.30- Electrical cupboard shown as sample. Source [43].

The used cupboard could be from the following measures: 609.6 mm L, 297.18 mm W, 914.4 mm H.



Figure 8.31- Electrical cupboard for the components' distribution. Source [19].



An electric cupboard of such characteristics could be placed near the conveyor installation. The cupboard has an IP66 degree code protection and it is from Panduit Corp manufacturer.

9.- Applied normative

In this chapter there will be mentioned all the normative consulted in order to make the project's calculus. The following are just a few:

- Restriction of Hazardous Substances Compliant (RoHS).
- Electro-technical Low Voltage Regulation (“*Reglamento Electrotécnico para Baja Tensión*”; REBT).
- Other regulations used:
 - Pneumatic regulations:
 - ISO 21287.
 - ISO 8573-1:2010 [7:4:4].
 - ISO 8573-1.
 - ISO 12238.
 - Electrical normative:
 - 2006/95/EC (LVD).
 - 2004/108/EC (EMC).
 - EN 60 529, NEMA4 (IP degree protection).

10.- The program

Here it is introduced the core of the whole project. Within this chapter it is going to be exposed the software programming that will be in the PLC and will control the installation.

First of all, looking at the GRAFCET previously made in chapter 6, an association table with the inputs and outputs of the PLC is necessary to be done. To make it easier, inputs and outputs have been grouped depending to their connection to the PLC or to an expansion module.

PLC

Table 10.1.- Inputs of the PLC.

| Inputs | | |
|--------|------|-----------------------------------|
| M | I0.0 | Start |
| BD | I0.1 | Box detector |
| BD0 | I0.2 | Box detector |
| BD1 | I0.3 | Box detector |
| BD2 | I0.4 | Box detector |
| CR | I0.5 | Code bar reader |
| BD5 | I0.6 | Box detector |
| BD8 | I0.7 | Box detector |
| MC | I1.0 | Manual confirmation |
| DC | I1.1 | Divert confirmation |
| BD4 | I1.2 | Rejection belt detector |
| BD3 | I1.3 | Rejection belt detector |
| D1 | I1.4 | Box detector for labeling machine |
| D2 | I1.5 | Box detector for labeling machine |

Table 10.2.- Outputs of the PLC.

| Outputs | | |
|---------|------|----------------------------|
| M1_b1 | Q0.0 | Bit 1 from section 1 motor |
| M1_b2 | Q0.1 | Bit 2 from section 1 motor |
| M1_b3 | Q0.2 | Bit 3 from section 1 motor |
| M1_b4 | Q0.3 | Bit 4 from section 1 motor |
| M2_b1 | Q0.4 | Bit 1 from section 2 motor |
| M2_b2 | Q0.5 | Bit 2 from section 2 motor |
| M2_b3 | Q0.6 | Bit 3 from section 2 motor |
| M2_b4 | Q0.7 | Bit 4 from section 2 motor |
| M3_b1 | Q1.0 | Bit 1 from section 3 motor |
| M3_b2 | Q1.1 | Bit 2 from section 3 motor |
| M3_b3 | Q1.2 | Bit 3 from section 3 motor |
| M3_b4 | Q1.3 | Bit 4 from section 3 motor |

| | | |
|----|------|---------|
| W1 | Q1.4 | Wedge 1 |
| W2 | Q1.5 | Wedge 2 |

As the PLC only disposes of 14 digital inputs, for the rest it will be needed expansion modules:

1st expansion module

The first expansion module, as it was told before and can be seen in the schematics document, consists on an 8/8 digital inputs and outputs device.

Table 10.3.- Inputs of the first expansion module.

| Inputs | | |
|--------|------|----------------------------------|
| AD | I0.0 | Box detector for filling machine |
| AD1 | I0.1 | Box detector for filling machine |
| FC | I0.2 | Filling confirmation |
| SD | I0.3 | Box detector for sealing machine |
| SD1 | I0.4 | Box detector for sealing machine |
| BD6 | I0.5 | Box detector |
| BD7 | I0.6 | Box detector |
| P | I0.7 | Stop |

Table 10.4.- Outputs of the first expansion module.

| Outputs | | |
|---------|------|----------------------------|
| M4_b1 | Q0.0 | Bit 1 from section 4 motor |
| M4_b2 | Q0.1 | Bit 2 from section 4 motor |
| M4_b3 | Q0.2 | Bit 3 from section 4 motor |
| M4_b4 | Q0.3 | Bit 4 from section 4 motor |
| M5_b1 | Q0.4 | Bit 1 from section 5 motor |
| M5_b2 | Q0.5 | Bit 2 from section 5 motor |
| M5_b3 | Q0.6 | Bit 3 from section 5 motor |
| M5_b4 | Q0.7 | Bit 4 from section 5 motor |

2nd expansion module

This expansion module only needs to set on the outputs of the KOP programming inside the PLC. This is why a 16 digital output module has been selected.

Table 10.5.- Outputs of the second expansion module.

| Outputs | | |
|---------|------|----------------------------|
| M6_b1 | Q0.0 | Bit 1 from section 6 motor |
| M6_b2 | Q0.1 | Bit 2 from section 6 motor |
| M6_b3 | Q0.2 | Bit 3 from section 6 motor |
| M6_b4 | Q0.3 | Bit 4 from section 6 motor |
| M7_b1 | Q0.4 | Bit 1 from section 7 motor |

| | | |
|-----------|------|----------------------------|
| M7_b2 | Q0.5 | Bit 2 from section 7 motor |
| M7_b3 | Q0.6 | Bit 3 from section 7 motor |
| M7_b4 | Q0.7 | Bit 4 from section 7 motor |
| W3 | Q1.0 | |
| W4 | Q1.1 | |
| W5 | Q1.2 | |
| W6 | Q1.3 | |
| EVD | Q1.4 | |
| Red light | Q1.5 | Full conveyor's red light |

Finally, the marks related to the GRAFCET stages that will be used in the programming:

Table 10.6.- GRAFCET stages.

| Stages/Phases | | |
|---------------|------|----------|
| ET 0 | M0.0 | Stage 0 |
| ET 1 | M0.1 | Stage 1 |
| ET 2 | M0.2 | Stage 2 |
| ET 3 | M0.3 | Stage 3 |
| ET 4 | M0.4 | Stage 4 |
| ET 5 | M0.5 | Stage 5 |
| ET 6 | M0.6 | Stage 6 |
| ET 7 | M0.7 | Stage 7 |
| ET 8 | M1.0 | Stage 8 |
| ET 9 | M1.1 | Stage 9 |
| ET 10 | M1.2 | Stage 10 |
| ET 11 | M1.3 | Stage 11 |
| ET 12 | M1.4 | Stage 12 |
| ET 13 | M1.5 | Stage 13 |
| ET 14 | M1.6 | Stage 14 |
| ET 15 | M1.7 | Stage 15 |
| ET 16 | M2.0 | Stage 16 |
| ET 17 | M2.1 | Stage 17 |
| ET 18 | M2.2 | Stage 18 |
| ET 19 | M2.3 | Stage 19 |
| ET 20 | M2.4 | Stage 20 |
| ET 21 | M2.5 | Stage 21 |
| ET 22 | M2.6 | Stage 22 |
| ET 23 | M2.7 | Stage 23 |

These tables have suffered modifications due to the length of the program: with the lab resources, the program is too large to be executed by a single PLC. Extension modules would be required. In order to solve this issue, the GRAFCET has been cut back to 13

stages instead of the original 27. The inputs and outputs, of course, are likewise reduced.

In addition, the reduced program does not contemplate the possibility of controlling the motors via the frequency variator but to activate them as if they were connected to a relay.

So, for the final presentation a part of the program is needed to be demonstrated to show how the automation proposal would work. The GRAFCET used for that purpose:

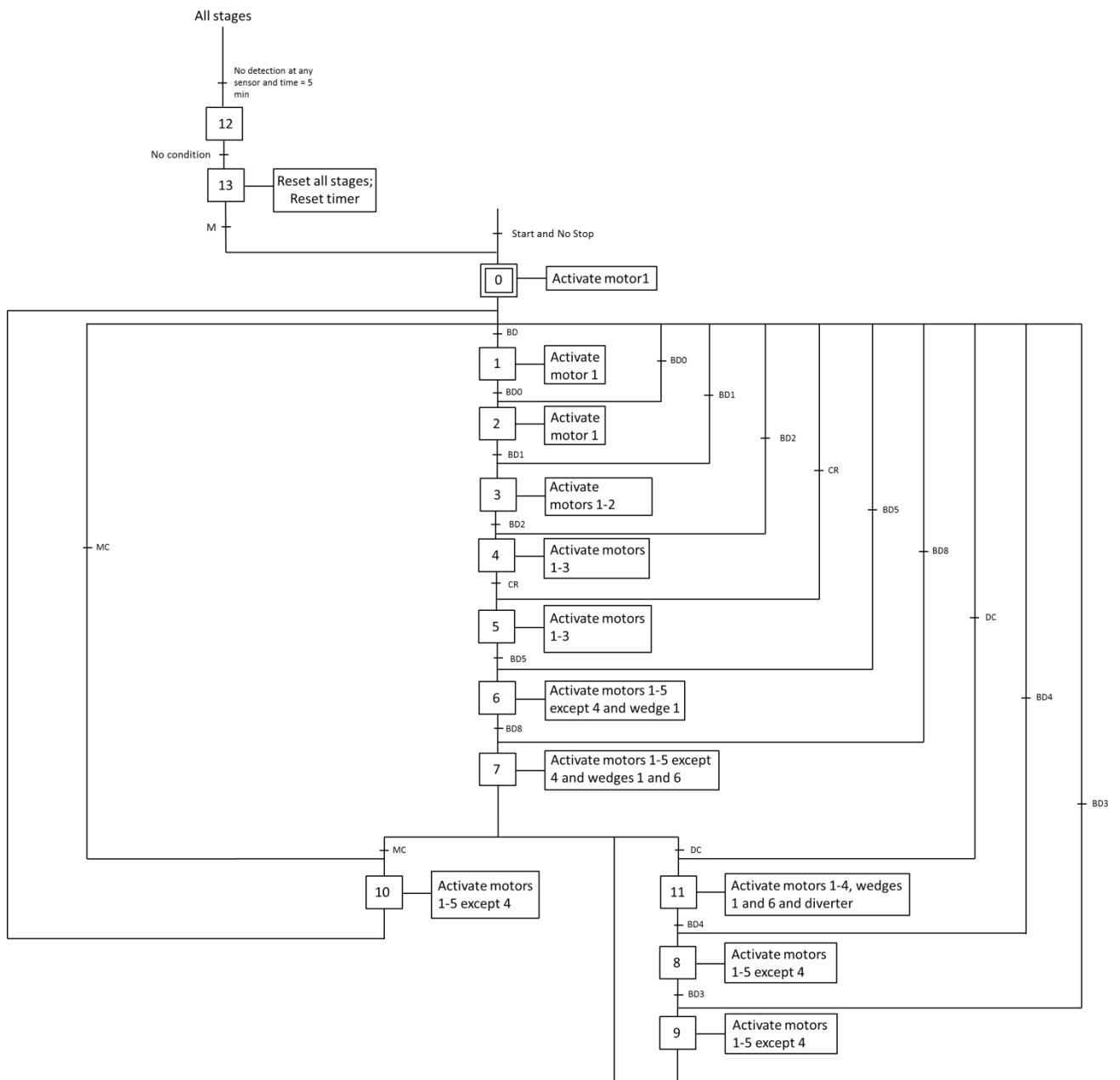


Figure 10.1.- 1st level GRAFCET for the final presentation. Source [own].

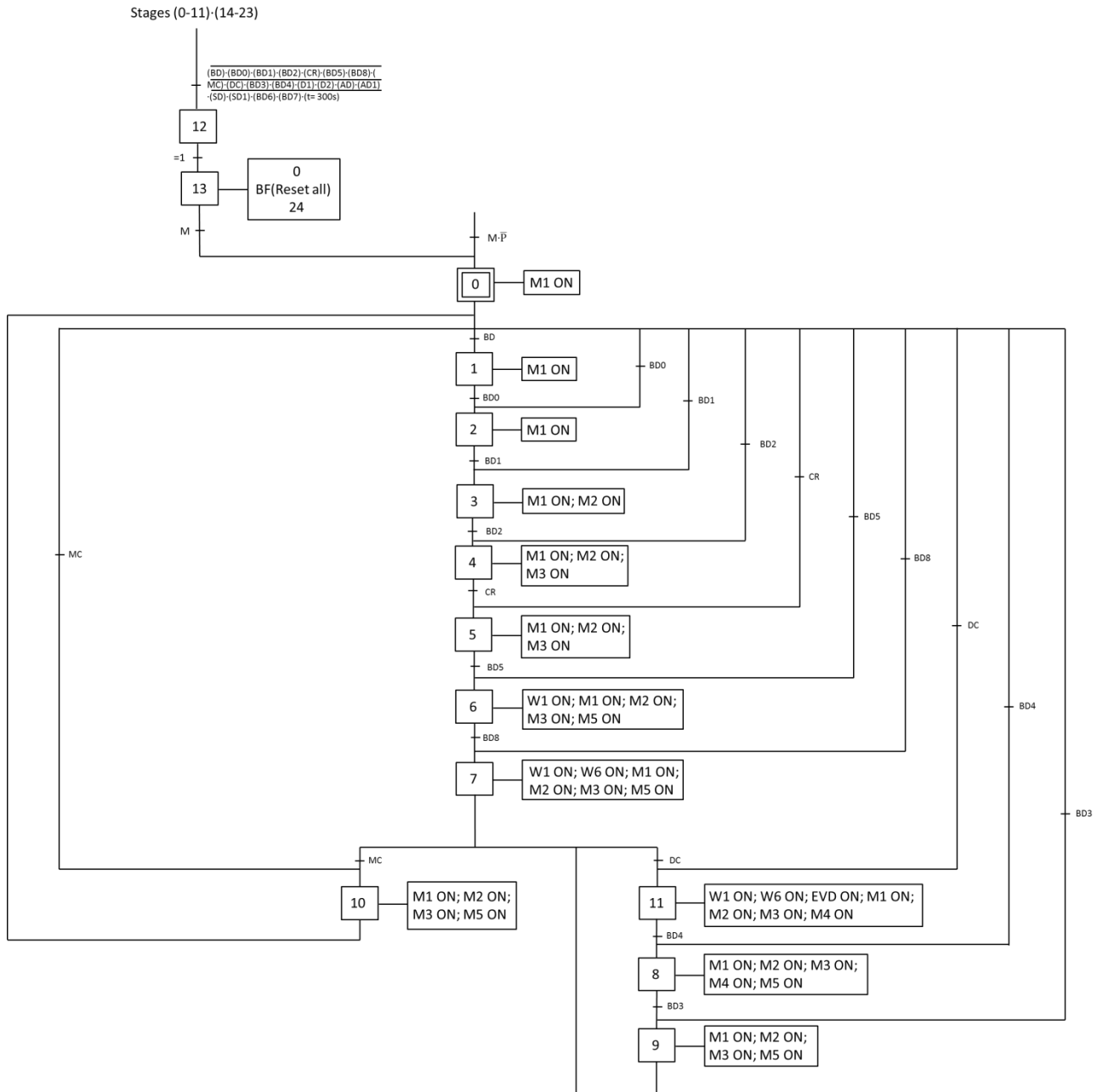


Figure 10.2.- 2nd level GRAFCET for the final presentation. Source [own].

And the tables once reduced for the final presentation of the project:

Table 10.4.- Inputs of the PLC.

| Inputs | | |
|--------|------|-----------------|
| M | I0.0 | Start |
| BD | I0.1 | Box detector |
| BD0 | I0.2 | Box detector |
| BD1 | I0.3 | Box detector |
| BD2 | I0.4 | Box detector |
| CR | I0.5 | Code bar reader |
| BD5 | I0.6 | Box detector |

| | | |
|-----|------|-------------------------|
| BD8 | I0.7 | Box detector |
| MC | I1.0 | Manual confirmation |
| DC | I1.1 | Divert confirmation |
| BD4 | I1.2 | Rejection belt detector |
| BD3 | I1.3 | Rejection belt detector |
| P | I1.4 | Stop |
| - | I1.5 | (Not used) |

Table 10.5.- Outputs of the PLC.

| Outputs | | |
|---------|------|-----------------------------|
| M1 | Q0.0 | Section 1 motor |
| M2 | Q0.1 | Section 2 motor |
| M3 | Q0.2 | Section 3 motor |
| M4 | Q0.3 | Section 4 motor |
| M5 | Q0.4 | Section 5 motor |
| W1 | Q0.5 | Wedge 1 |
| W6 | Q0.6 | Wedge 6 |
| EVD | Q0.7 | Diverter for rejection belt |

Table 10.6.- GRAFCET stages.

| Stages/Phases | | |
|---------------|------|----------|
| ET 0 | M0.0 | Stage 0 |
| ET 1 | M0.1 | Stage 1 |
| ET 2 | M0.2 | Stage 2 |
| ET 3 | M0.3 | Stage 3 |
| ET 4 | M0.4 | Stage 4 |
| ET 5 | M0.5 | Stage 5 |
| ET 6 | M0.6 | Stage 6 |
| ET 7 | M0.7 | Stage 7 |
| ET 8 | M1.0 | Stage 8 |
| ET 9 | M1.1 | Stage 9 |
| ET 10 | M1.2 | Stage 10 |
| ET 11 | M1.3 | Stage 11 |
| ET 12 | M1.4 | Stage 12 |
| ET 13 | M1.5 | Stage 13 |

Both KOPs, the full software solution and the implemented for the final presentation can be found in the Appendix document.

Now, a brief detailed explanation of how the code works and how it was reached this solution.

The algorithm is divided in 4 parts:

- Main structure: Basically it consists on the body or structure seen in the GRAFCET diagrams showed in chapter 6.
- Special cases: How the belt has to respond in case that two or more input signals are activated. It will always give a higher priority to the most critical case.
- Others: timers, Stop, Ecological Stop...
- Outputs: The motors and wedges control.

Before beginning, it is important to say that the programming is done in Ladder logic, a.k.a KOP. This structure is the one followed all along this project. The tool used to charge the program for its testing at the PLC has been the TIA portal (2013 version). This software was previously used in the CIA subject, back at second grade year.

10.1.- Main structure

For the program's body some segments can be shown, for example:¹¹

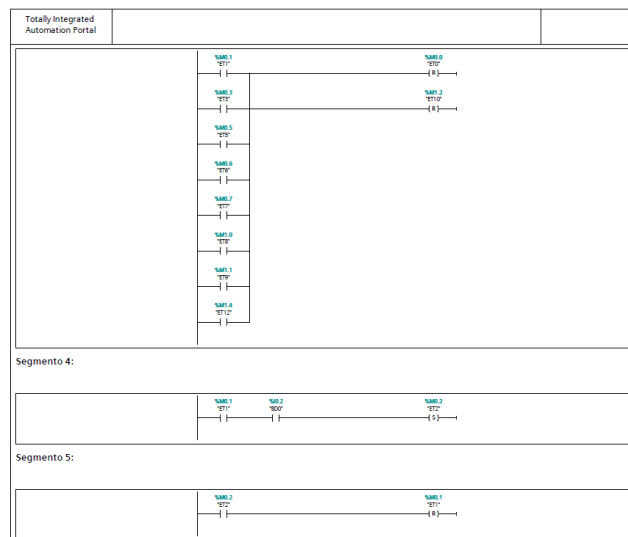


Figure 10.3.- Segments 3-5 of the KOP diagram. It is seen the reset for stage 0 (initial step) and the development of stage 1 and its reset when stage 2 begins. Source [own].

These lines correspond to the next GRAFCET instructions:

¹¹ Note: Important! All the program's segments shown will be from the final presentation file.

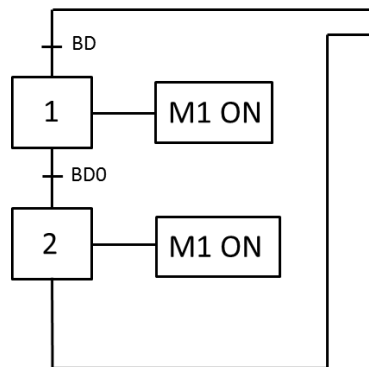


Figure 10.4.- 2nd level GRAFCET corresponding to figure 9.1.

10.2.- Block programming

In last section it was seen the main program, that means, the normal functioning mode. But what happens when it is activated another GRAFCET that controls, for example, the emergency stop of the system?

The following diagram, extracted from the “*Guide d’Etudes des Modes de Marches et d’Arrêts*”¹² (GEMMA) explains the relation between the different blocks. These blocks are classified in different categories:

- F blocks: The normal functioning blocks
- A blocks: The waiting/stop modes
- D blocks: the defects modes. These modes are for example, exceptions that may occur, like the emergency stop.

Figure 10.5 shows this diagram logic:

¹² Note: Starts and Stops Modes Study Guide

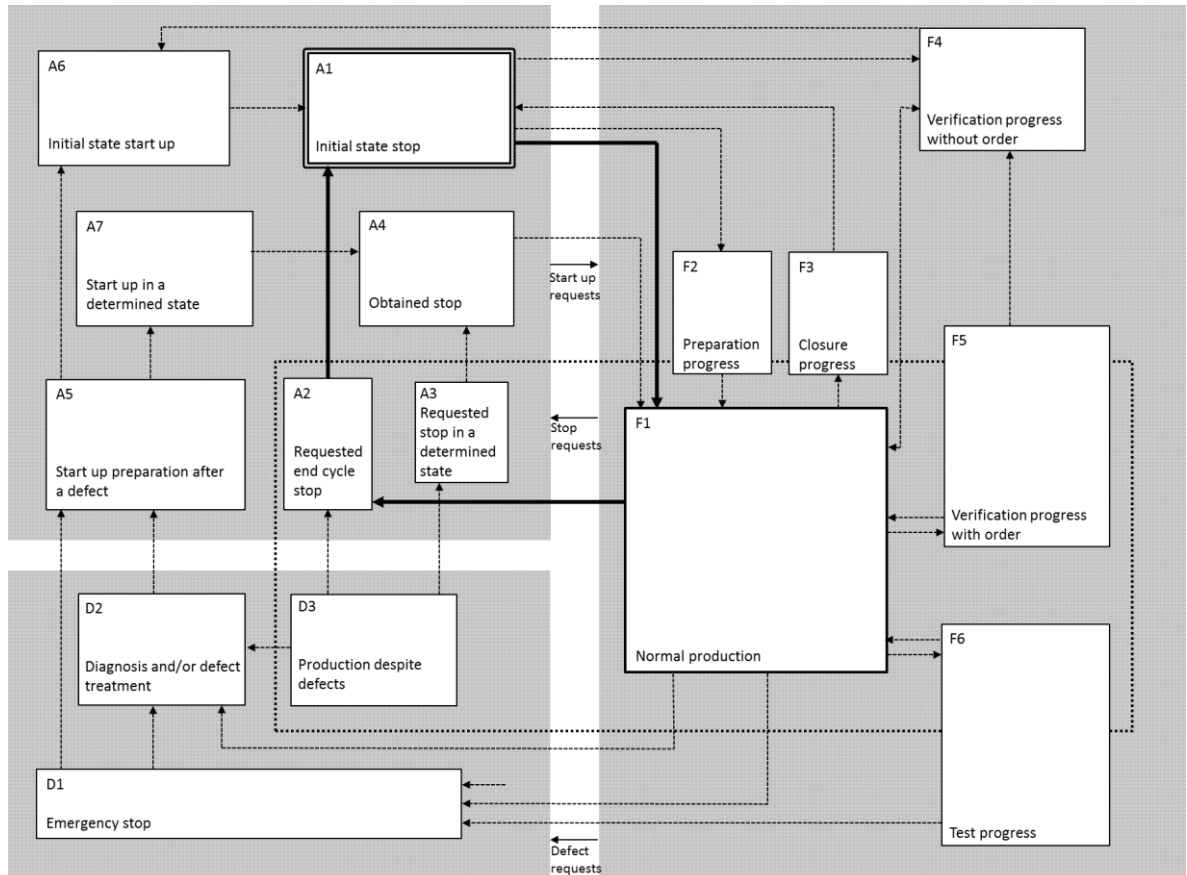


Figure 10.5.- GEMMA graphic for the different machine modes. Source [10.A].

If a block is not used by a machine it simply gets crossed out. The following diagram (based on the GRAFCETs but following the GEMMA guide directives) shows the interaction between the blocks used for the conveyor belt.

Below there are the segments used for the special conditions that allow jumping one stage to another given, for example, the order of emergency stop. The used stages for the conveyor belt and all the installation are shown in next figure:

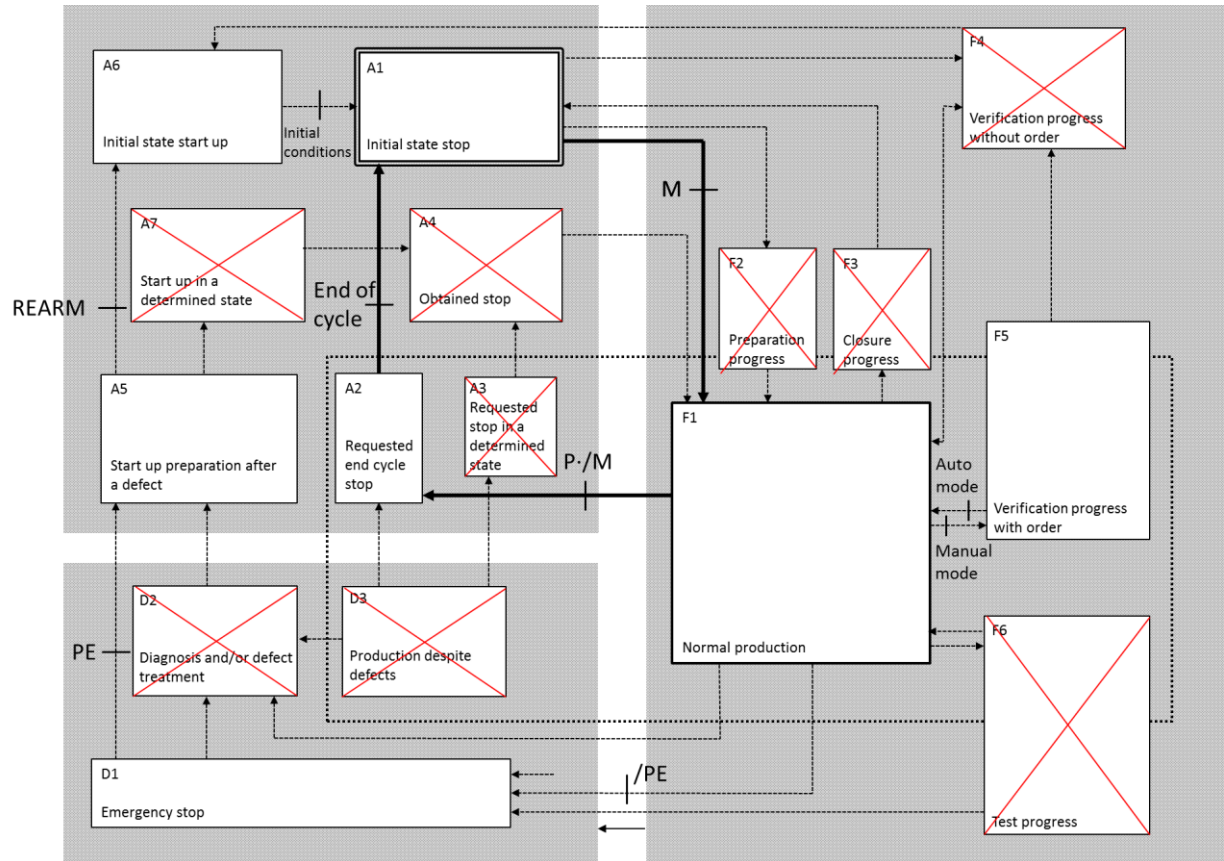


Figure 10.6.- GEMMA graphic for the machine design. Source [10.A; edited].

As a summary the figure could be seen as something like this:

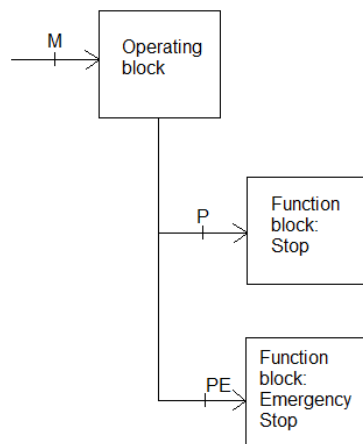


Figure 10.7.- Diagram of figure block programming. Source [own].

Calling sequence

When the program is running on its normal production mode (F1) and a special condition A like the Stop or Ecological stop is given, it will automatically jumps to the A or D modes. An example of the calling sequence can be seen next:

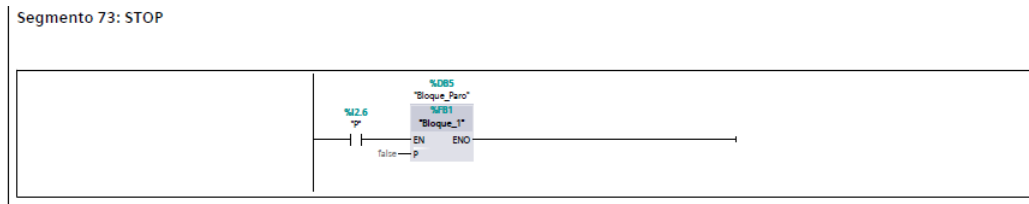


Figure 10.8.- Calling sequence for the stop order. Source [own].

And the function block will respond by doing whatever it has been programmed to do. In this case, the stop order shuts down the motors, resets everything and goes back to initial stage once the start instruction is set again:

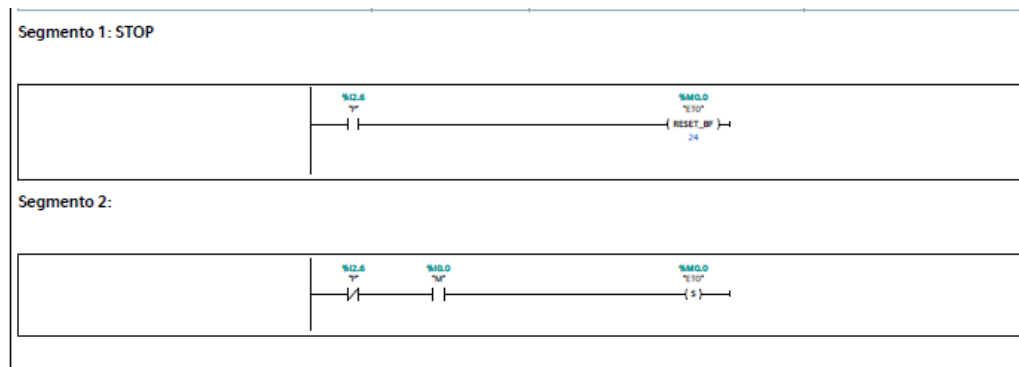


Figure 10.9.- Stop function block. Source [own].

10.3.- Special cases

It is important how this part was made, because it has been probably one of the most difficult in terms of boarding it. In the Appendix document it can be seen at the headboard of some segments the following text: “*Special case CAT. 2-3*”, for example. Moving on to explain it:

As it is known for now, there are a lot of input signals that control the conveyor’s functioning. What happens when two or more signals are activated simultaneously? The answer is clear: the belt will have to respond in consequence, and this means it will always give priority to the signal coming downstream. This way, it is guaranteed that a box at the end of the track does not get ignored while a new one arrives.

Now, going back to the mentioned text: it means special case (because two or more inputs could be activated) and “CAT” it is the abbreviation for category because a set out like table 9.7 was made:

Table 10.7.- Categories for the input sensors.

| Sensor \ Cat. | 1 | 2 | 3 | 4 | 5 |
|---------------|---|---|---|---|---|
| BD | | | | | |
| BD0 | | | | | |
| BD1 | | | | | |
| BD2 | | | | | |
| CR | | | | | |
| BD5 | | | | | |
| BD8 | | | | | |
| MC | | | | | |
| DC | | | | | |
| BD4 | | | | | |
| BD3 | | | | | |

This table basically consists on way to organize the information so it can be understood how to proceed with the special cases. The sensors shown were classified in categories based on how many motors they controlled. This way, category 1 includes all sensors which next stage will activate only one motor and so on.

Having said this, an example of the situation:

Segmento 33: Special case CAT. 1-5

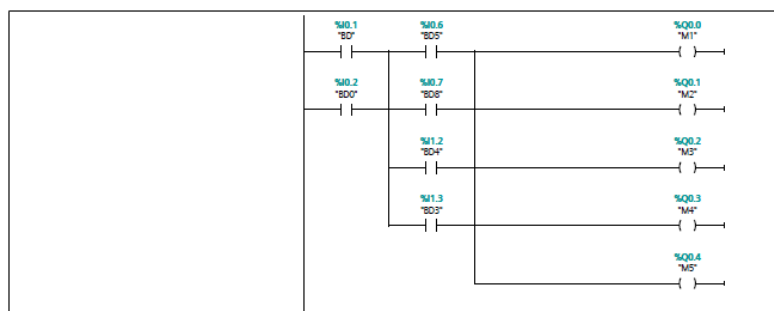


Figure 10.10.- Special case CAT. 1-5. Source [own].

This segment in concrete is a logical AND between sensors (BD or BD0) and (BD5 or BD8 or BD4 or BD3). If the condition is satisfied by one way or another motors 1 to 5 will activate.

This way, as previously said, it is guaranteed that the conveyor gives priority to all the boxes on it, but especially to the critical cases in which more than one signal is on at the same time.

10.4.- Others

The others section includes the timers set up, the stop, the emergency stop, etc. All this can be seen at the Appendix document and won't be exposed here. It will, although, be explained what it is called the ecological stop, which has been the hardest thing to do.

So the reader to know, an ecological stop it is a stop like the general stop or the emergency stop with the exception that it is not manually executed. In this case, the ecological stop activates if it does not detect any activity within 5 minutes.

This allows the installation to shut down in case of human mistake (e.g. someone left it turned on or if a long pause is produced) and save some energy.

The segment that controls the ecological stop:

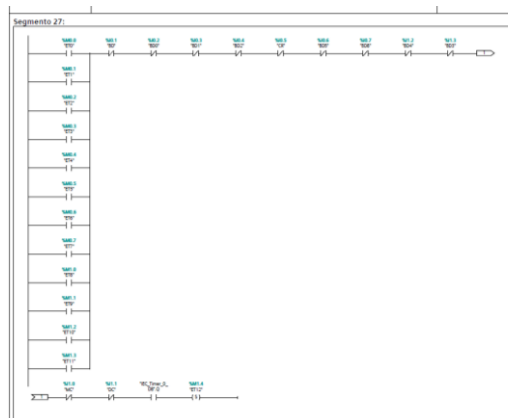


Figure 10.11.- 27th segment of the KOP: ecological stop. Source [own].

The corresponding GRAFCET sequence:

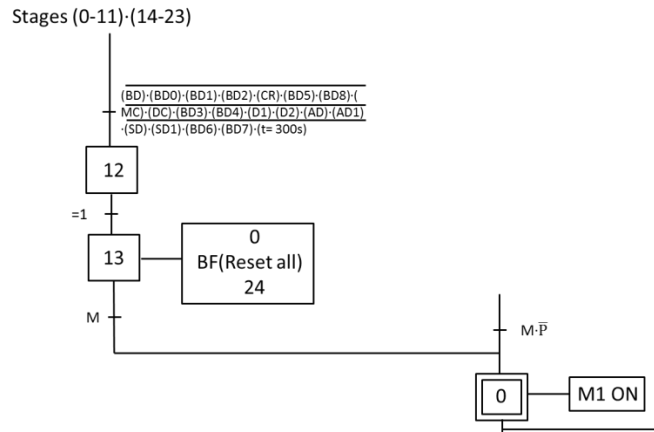


Figure 10.12.- 2nd level GRAFCET of the ecological stop. Stages 12 and 13. Source [own].

Coming from any stage of the GRAFCET, if no rising flank is detected from any sensor after a counter of 5 minutes, it will automatically enter stage 12 (which will shut down all the conveyor's motors) and right away stage 13 that will reset all stages and the 5 minutes timer. After this, if the start button is pressed, the system will reboot at the beginning (stage 0).

An important mention: for the lab tests, the ecological stop timer has been set up for 10 seconds. This has been done to avoid a waiting waste of time for each test. Although this parameter has not been changed for the captures presented it can be quickly reconfigured again.

10.5.- Outputs

The outputs section is the one in charge of controlling all the motors, wedges and the diverter of the conveyor. Simply it consists on assigning these outputs the corresponding stages that activate them.

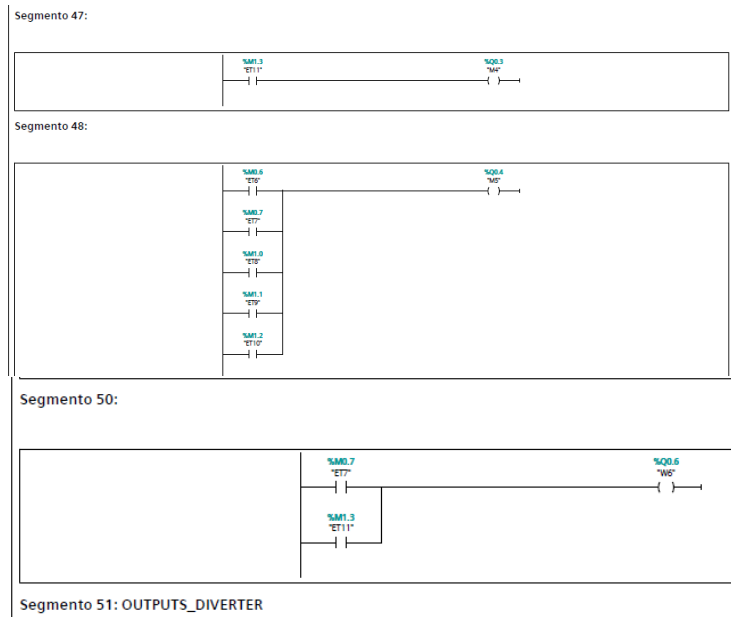


Figure 10.13.- Motor 4 & 5 and wedge 6 activation stages. Source [own].

10.6.- Keypads design

In the light of the above point, a keypad must be designed in order to have the conveyor controlled in all moment. For that, the following figures, show how many and a possible design of these keypads. Aside of the main keypad, it can be seen at the right of the images the buttons that control each section. To reduce the number of keypads (and the people manipulating it; let's remember that only 4 people will be working at the conveyor at the same time) the motors have been grouped in pairs.

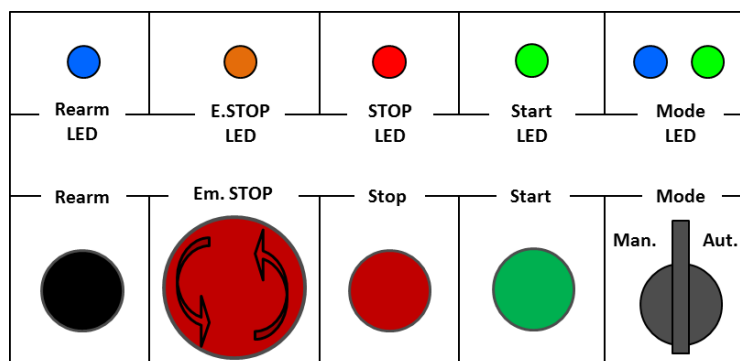


Figure 10.14.-Main keypad. Source [own].

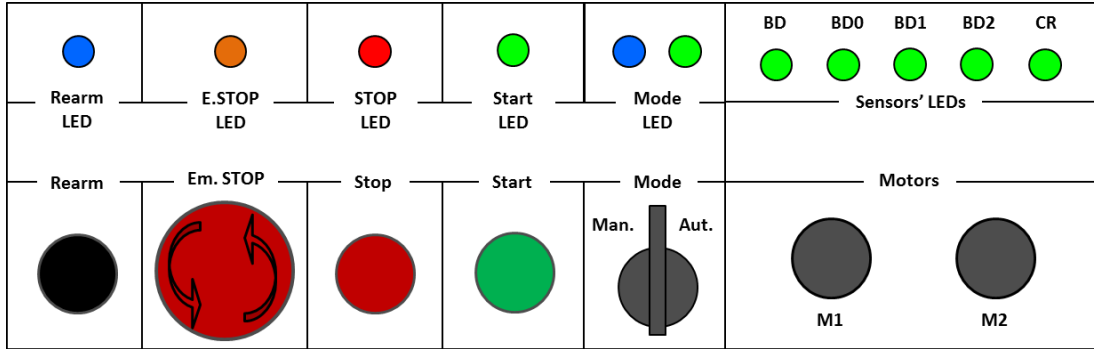


Figure 10.15.-Keypad for conveyor's sections 1 and 2. Source [own].

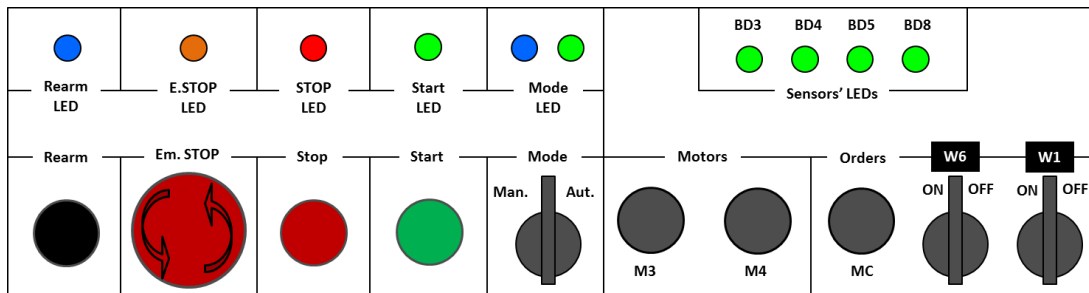


Figure 10.16.-Keypad for conveyor's sections 3 and 4. Source [own].

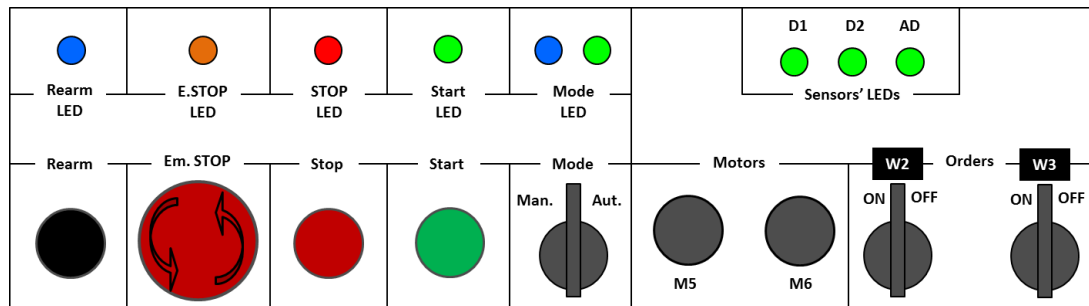


Figure 10.17.-Keypad for conveyor's sections 5 and 6. Source [own].

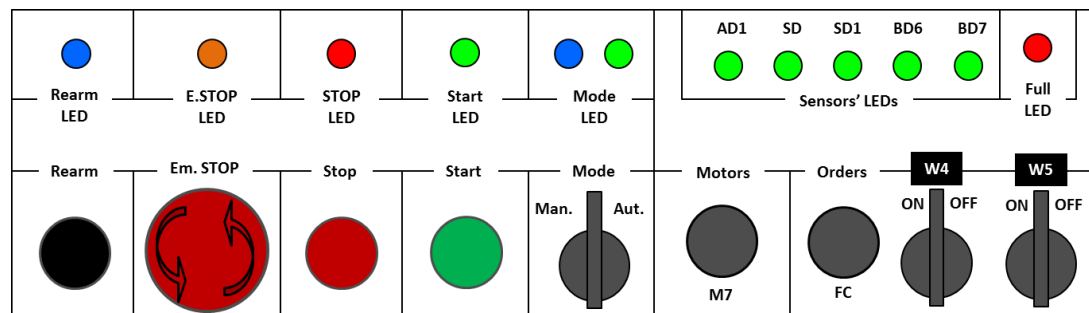


Figure 10.18.-Keypad for conveyor's sections 7, 8 and 9. Source [own].

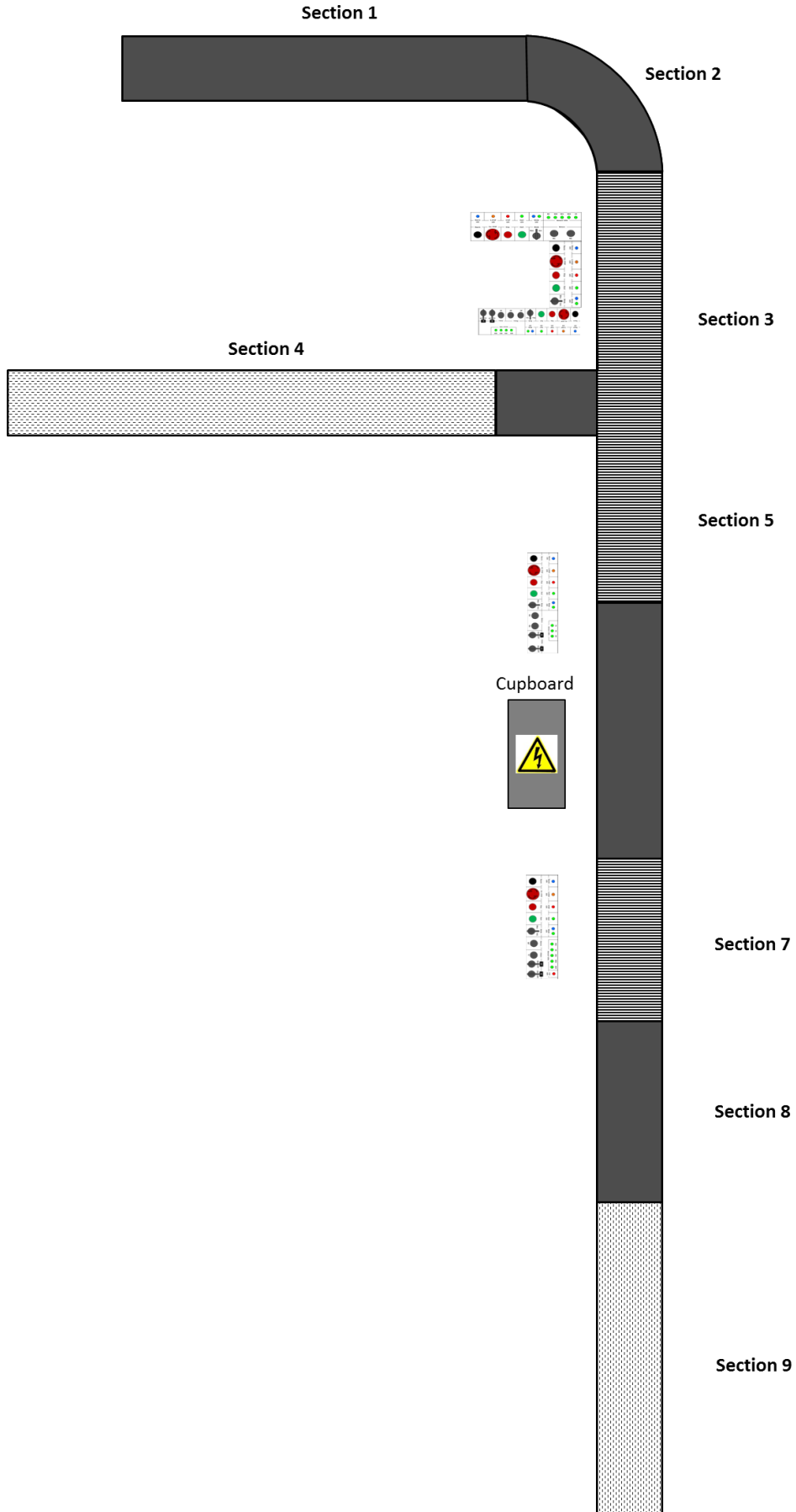


Figure 10.19.-Keypads and manoeuvre cupboard distribution on the conveyor's map. Source [own].

11.- Conclusions

11.1.- General comments

As a way of summary, the work developed has been satisfactory. The most remarkable facts or goals of the project have been:

- Understanding how a logistic warehouse operates¹³ and all the methodologies used in each department.

This is definitely one of the most important items because without having studied the mechanics of the logistic process it would have been impossible to carry out the automation of this project. It is indispensable to understand the needs of the warehouse to bring in an actual solution.

- Automation proposal.

Probably, one of the easiest points because it consists on the creative part. One can imagine the warehouse operating fully automatic but the reality is another one. There are a lot of things that were supposed to be included in the main project but have been totally unviable, like for example, a robotic arm at the end of the rejection belt and the main track. This would have probably reduced significantly the warehouse personnel but it also would have been too expensive for the company to buy it.

- Feasibility of the automation proposal.

Like said before, here is where the creative part crashes with reality. There a sum of sets that has been impossible to include due to costs issues, practicality, viability, etc. These were included as part of the original objective list of the project but were rejected. The summary is the following:

- An automatic verification system: Totally out of the scope of this project. It would have implied a whole project inside this one and nowadays, technology is not developed enough so that a computer knows the content of a box by simply taking a look at it.
- A robot attached to the shelves to deliver product: This idea was one the favorites because it was thought to be a human-machine interaction like

¹³ Note: This has also been increased thanks to the curricular practice at IDL in Castellar del Vallès.

the one in the carousel. It would have saved a lot of time to the workers in preparing orders but in the end, it is not feasible for various reasons: The first one is that it would be needed a continuous shelf and the warehouse has different ones. Either changing the whole structure of storage or add a robot in each one implies to spend too much money, resources, productivity or time, which is not a desirable thing and also totally unviable.

- An upgrade for the traceability system: Again, another project inside the actual one. Not only it wouldn't have been an extremely hard task that would have required more time than the given for this project, but also, it would have had a lack of interest for the coursed specialty. If the matter of discussion was Informatics Engineering, of course, it would have been a valid project because it would have implied reinforcement and a deep into C programming. But as a matter of practicability in the field of Industrial Automation and Electronic Engineering it would have been, as said before, a lack of interest because what it is wanted to solve is an already existing industrial automation problem, not a informatics-logistical one.

- Design and programming the actual solution

One of the most difficult parts of the project not by the difficulty of itself but because:

- The constant changing and adapting of the solution to the problem, each one closer to the final stage but it has implied changes on the GRAFCET and the KOP.
- The availability of the necessary tools: The lab, being at college, implies a displacement by the student. Working by the morning and also the needs of the CIA and RIVC students of the lab, have made this stage one of the most complicated.

- The schematics and different figures

One of the stages that have needed most of the attention, care and careful. Having the class notes of the CIA subject at hand surely has made things easier but it does not end there. There are extras, like the GEMMA graphic, the connection diagrams and the

wiring plan that have not been studied or done in any previous subject, which is why they have been suppressed to continuous reviews by the professor and manager of the project. To him the gratitude of the author in this matter and in all the queries that have taken place along this semester.

- The budget document

This is the first time a real budget is done so that an already existing company buys the idea presented on it. As there is no experience in this field, and it does not have a single solution (or it could be said a single formal presentation format) it has been not easy to elaborate.

- The writing and redaction of the documents

One of the things this project has also contributed on is in the development and perfectionism of the author at communicating in a not-native language. Of course, given the internationality of English nowadays it is not a problem, but it implies an extra difficulty it surely can be appreciated. Personally, the student is satisfied with this experience because it has helped him continuing learning and practicing in this area.

- The format, extension and presentation style

Truly this is the first time the author faces a real project of huge dimensions. The fact of presenting not one, but different documents and the necessity of classifying the information for each one of them really makes one worry about the extension of the document and the presentation format. Having in mind that the memory document needs to be 100 pages long (not less or more) if information is really well synthesized adds a lot of complication because the resulting extension will never be the required and it might mean the failure of the Final Career Project.

- The presentation of the project

Finally, the zenith of the project done is the final presentation in front of a jury. It cannot be talked about it in here because its defense will be after the delivery of this document and in consequence, facts cannot come ahead of time.

But (and there is always a but) what it can be said is that for the final presentation the GRAFCET and KOP have been modified (that means, cut back). As there are used so

many inputs and outputs, an extension PLC module is needed to prove that the actual program really works. Given the fact that university does not provide these modules, the program needs to be significantly reduced for the demonstration. Of course, it can be checked in the Appendix document that the full program appears and it should work in the proper hardware but as the available conditions are others it has emerged the need of adapting it to an existing solution.

11.2.- Conclusions

After the project is finished, and having said all the previous in section 8.1, it is stated that:

- The Final Degree Project has been a window to the labor world and also a way of approaching university concepts to the upgrade of an existing logistical process.
- The worked competencies which are the ones of the main career as well as the third language have been come to terms with and surpassed in order to deliver this Final Project.
- The program has been a challenge for the constant changing of the problem's considering. At the beginning, it was programmed all the GRAFCET and, of course, it didn't work. Then a little test with a simple example diagram was done with a successful result. Since there, the programming was performed sequentially, adding little parts and testing them before going on the next stage, splitting the problem, as every good engineer does.
- The constant checking and improving of the memory document has become a problem by the time of the final delivery was coming closer. One is conscious that a good job is perfectly carried out by the correct execution of its parts, but the presentation has to be as good as the product (or service) intended to be sold.

- The proposed solution might seem simple but it is effective and there is no doubt of the program's toughness. It is taught at colleges that engineering has to offer adapted solutions and the one presented in this project is not only a customized proposal at the looks of industrial engineering, but also an optimized solution for the logistic process that seeks, of course, the client's satisfaction.
- As for the objectives it can be said that all of them have been complimented (except for the said in section 11.1) because it was all components searching and automatic machines. Needless to say that for all of that, a lot of searching has been done, in order to manage all the possibilities and try to obtain the best solution. The conception of the line and how it works are genuine ideas as well as their execution via the PLC program.
- The product searching has also been a little bit chaotic, given the fact that determined components, such as the wedges/barriers or the pedal valve have been tricky to find. In these cases the project tutor's help has been invaluable.

11.3.- Possible upgrades

In this chapter it is going to be treated all the possible upgrades that could be done to complement the main project but, for time reasons, cannot have been implemented or designed as originally it was thought. Some of them are:

- A palletization system for the end of track and for the rejection belt.
 It could consist on a crane that lifted the loads (boxes in this case). For that purpose it could have its end finished in a suction pad that grabbed the box by the sealing tape.
 This way, boxes could be automatically lifted and moved to the palletization zone next to the belt.
- A sorter at the end of the main track that would classify the different boxes. This way, their lately palletization depending on the route or client would be easier. Right now, this is being carried out manually.

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