Automated packaging station design for circular saws

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Master Dissertation

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Master's Degree in Mechanical Engineering

September 2023

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"Research is to see what everybody else has seen, and think what nobody has thought"

Albert Szent-Gyorgyi

Resumo

Esta dissertação retrata o desenvolvimento de um projeto realizado na indústria de serras circulares com o intuito de desenvolver uma nova estação de embalamento para o setor de embalamento de serras circulares na empresa Frezite.

O projeto focou-se em três grandes objetivos, integração do processo de embalamento com o processo de gravação, analisar e desenvolver um sistema de armazenamento de embalagens a integrar na nova estação, incluindo a escolha e especificação de componentes.

A fábrica não possuía nenhum tipo de embalamento automático, obrigando assim a um conhecimento profundo das embalagens e as diferentes etapas envolvidas no processo de embalamento de forma a perceber o seu funcionamento e as suas especificações tendo sido fundamental o tempo passado no chão de fábrica.

Após uma análise inicial dos vários processos envolvidos no fabrico e embalamento das serras circulares, analisaram-se alternativas disponíveis de embalamento automático. Estas soluções não satisfaziam os requisitos pretendidos pelo que se optou pelo desenvolvimento de uma solução particular para uma estação de embalamento de serras circulares.

Estudaram-se várias soluções tendo em conta a especificação das séries de serras circulares a considerar, a integração com a estação de gravação, a disponibilidade de espaço e integração com os sistemas de transporte e locais de armazenamento. A solução proposta tem em conta duas variantes, tendo sido projetada com base na identificação e escolha dos vários elementos de atuação para as várias etapas de manipulação envolvidas.

Um dos elementos principais é um robô industrial, que se desloca num eixo horizontal, sendo utilizado alternadamente para a função de manipulação das serras na estação de gravação e na manipulação das serras e embalagens na estação de embalamento. São ainda utilizados vários elementos de atuação pneumática e elétrica para as restantes funções de embalamento e transporte das serras embaladas. A solução proposta inclui a escolha e especificação dos vários componentes.

Abstract

This dissertation covers the development of a project carried out in the circular saw industry with the aim of developing a new packaging station for the circular saw packaging sector in the company Frezite.

The project focused on three main objectives, integration of the packaging process with the engraving process, analyzing and developing a packaging storage system to be integrated in the new station, including the choice and specification of components.

The factory did not have any type of automatic packaging, thus requiring a thorough knowledge of the packaging and the different stages involved in the packaging process in order to understand its operation and its specifications, with the time spent on the factory floor being essential.

After an initial analysis of the various processes involved in the manufacture and packaging of circular saws, available alternatives for automatic packaging were analyzed. These solutions did not satisfy the intended requirements, so it was decided to develop a particular solution for a circular saw packing station.

Several solutions were studied taking into account the specification of the series of circular saws to be considered, integration with the engraving station, space availability and integration with transport systems and storage locations. The proposed solution takes into account two variants, having been designed based on the identification and choice of the various actuation elements for the various manipulation steps involved.

One of the main elements is an industrial robot, which moves along a horizontal axis, being used alternately for handling saws at the engraving station and handling saws and packages at the packaging station. Various pneumatic and electrical elements are also used for the remaining functions of packaging and transporting the packed saws. The proposed solution includes the choice and specification of the various components.

Acknowledgements

I would like to begin by expressing my gratitude to my parents and sibling for their unwavering support not only during this dissertation but also throughout my academic career. They have shaped who I am today and serve as my true role models.

To my friends for their ability to inspire me and convince me that anything is possible with dedication and effort.

To my dissertation's supervisor Prof. Manuel Romano Barbosa for all the help and support during the development of this project.

To Frezite for the opportunity given and all the trust deposited in me. In special to Eng. Paulo Neves, Eng. Fernando Figueiredo and Eng. Pedro Ferreira for all the support, availability and interest shown during the project.

To all Frezite collaborators with whom I had contact for their kindness, which facilitated my integration in the company.

To all my sincere thanks.

Index

Abbreviations and symbols

AOI – Automatic Object Identification

AGV - Automatic Guided Vehicles

CBN - Cubic Boron Nitride

EAC – External Axis Controller

HDPE – High density Polyethylene

HMI – Human Machine Interface

PCD - Polycrystalline Diamond

VCI - Vapor Corrosion Inhibitor

Index Figure

Index Table

1 Introduction

This chapter outlines the inspirations behind the creation of this dissertation as well as a quick overview of the project's goals and envisaged outcomes. Also, a brief overview of the company where the work was developed is given, along with the methodology used in the project's various phases.

1.1 Context and motivation

This project was carried out in a industrial environment, more specifically in Frezite Group. The Frezite Group is a portuguese multinational company that specializes in the manufacturing and distribution of cutting tools, woodworking tools, and high-precision machining solutions (Frezite).

Over the years, the Frezite Group has expanded its operations to over 25 countries, with subsidiaries and partners located in Europe, Asia, Africa, and the Americas. The company serves a wide range of industries, including aerospace, automotive, construction, furniture, and medical equipment.

The Frezite Group's product portfolio includes carbide and diamond cutting tools, solid carbide drills and end mills, polycrystalline diamond (PCD) and cubic boron nitride (CBN) tools, saw blades and router bits for woodworking, and high-precision machining. The company is known for its innovation, research and development, and state-of-the-art production facilities, which allow it to provide high-quality and reliable products to its customers.

The company has implemented various environmental and social initiatives, including the use of renewable energy, waste reduction, and employee training and development programs.

My interest in doing my dissertation in Frezite stems from the company's status as a market leader with a strong reputation for innovation and quality. Some of the most recent awards and recognitions that Frezite Group has received are: The Walter’s Global Process Championship: Financial, Quality, Environment, Health, and Safety (QEHS) in 2022; The Green Project Award 2020; The PME (pequenas e médias empresas) Líder 2019; The Innovation Award 2018.

1.2 Objectives

Over the years, Frezite has endeavored to improve the quality and productivity of the circular saws production process while placing less emphasis on the final process of packaging the saws. Prior to a few years ago, the packaging process was able to satisfy orders requests; however, as the company grew, the packaging process's responsiveness was unable to keep up, giving birth to the need to improve this process. This dissertation attempts to enhance this process by developing an automated packaging line for circular saws. The focal point in the development of the solution will be to increase delivery capacity and decrease delivery time.

As the company evolved over the years, so did the saw engraving process, which went from a single manual engraving system to an automatic one while maintaining a manual engraving system, due to wide range of saw sizes. The new packaging line proposed in this dissertation has as one of its requirements the integration of the engraving process with the packaging process, resulting in the creation of a station that combines these previously distinct processes.

The focus of this dissertation will be on the following four objectives:

- Analysis of alternative saw and packaging handling system;
- Integration of the packaging process with the engraving process;
- Analysis and design a package storage system to integrate in the new station;
- Define and specify the components for the new station.

The pursuit of theses objectives will be guided by initial analysis and evaluation of the current system and taking into consideration the company directions and support all along the process.

1.3 Methodology

With the dissertation's objective being the creation of a new packaging station for the company Frezite, it was necessary to first gain knowledge of the processes involved in the creation of a circular saw, packaging, and engraving. After a thorough examination of the various processes involved and a debate within Frezite, the initial objective of the creation of the new automatic packaging station, was of working with saws of diameters between 160 and 520 mm. Later on, however, the new packing station was expanded to include engraving, with the intention of integrating these two processes and working on the same variety of saws, but the engraving process being capable to engrave saws of any size.

With this in mind, research was conducted on the various packaging processes currently available on the market. During the research process, information available from packaging exhibition fairs were taken into consideration as they showcase the most recent and innovative packaging ideas on the market.

With a clearer idea of the different types of packaging automation solutions used, it was proposed by Frezite in a meeting with a partner company which Frezite often uses to implement automation solutions, to determine whether it would be possible to improve the operational capacity of the packaging process, as well as to guarantee good communication between the engraving and the packaging process. In addition, another parameter to take into account was to reuse the engraving robot for manipulation in the packaging process. As a result of these discussions, a new range of work was defined for the packaging process, which now included saws with a diameter between 115 and 520 mm.

With all the decisions taken in relation to the final objectives, the development of several layouts was carried out, which were later presented to Frezite. In the development of the different layouts there were some difficulties in relation to the packaging process to be used due to the great diversity of sizes of the saws to be worked on, as well as in the development of the storage buffers.

Experimental tests were performed to evaluate the capability of the robot to manipulate the carton packages within the planned designed enviroment. Experimental teste were also used to evaluate the limiting forces the carton packages could withstand in order to validate the proposed holding actuation solutions.

During my dissertation at Frezite, I was also required to design a new manual packaging table that combines the engraving and packaging processes; the design was approved and the table was implemented.

1.4 Dissertation structure

In addition to this first chapter the dissertation includes four more chapters:

- chapter 2, where a full and detailed characterization of the processes involved in the production of saws is conducted. It will also be studied and analyzed the existing solutions available in the market in order to critically evaluate opportunities for improvement and finalizing with a synthesis and critical interpretation of the system to be developed.
- chapter 3, presents an analysis of alternative solutions for the packing station, among which a selected solution will be detailed designed and proposed.
- chapter 4, presents an implementation plan for the new packaging station.
- chapter 5, concludes with the main achievements of the work developed and suggestion for future developments.

2 Current state of the production process of circular saws

This chapter begins with an overview of the circular saw manufacturing process, followed by a detailed description of the processes up until packaging and the packaging procedure itself. After gaining a comprehension of the processes involved, we will describe the current problems associated with the packaging process and its surrounding processes, as well as how to evaluate potential market-ready solutions.

2.1 Circular saw production process and factory layout

Figure 1 is a flowchart that represents the various steps involved in the production of circular saw blades. Nine sub-processes are involved, from the initial plate cutting to the final graving and packaging.

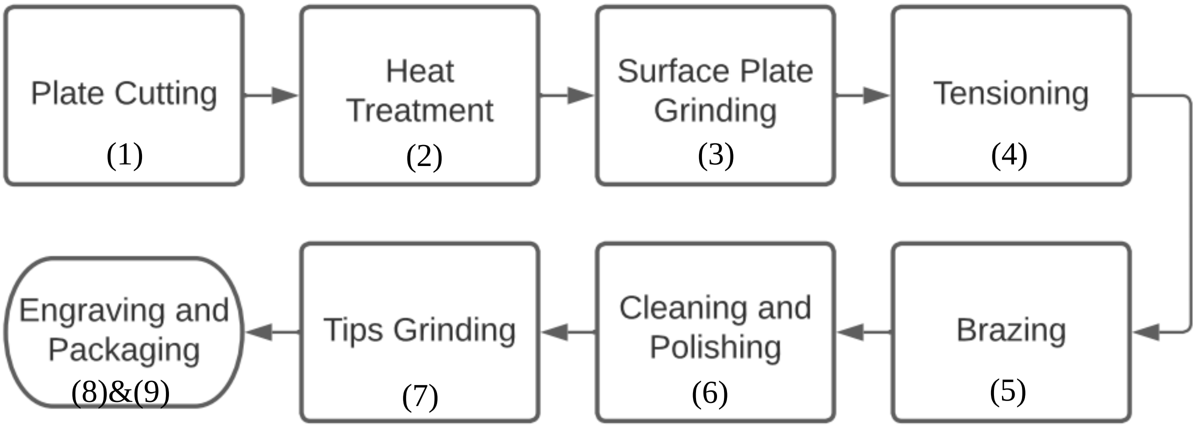


Figure 1 – Flowchart of the circular saw blades production process

In the initial step, the body is cut using a laser cutting process. Utilizing 2D laser cutting machine to melt or vaporize the material, laser cutting creates a clean and precise cut of the saw tooths in a circular shape periphery from a steel sheet as seen in Figure 2. Laser cutting has several advantages, including high precision, rapid cutting speed, and the ability to cut intricate and intricately detailed shapes. In the case of circular saw cutting, the laser machine would be configured according to the saw's dimensions and specifications. The laser would be precisely positioned, and the saw material would be cut in a controlled manner, without affecting the material's mechanical properties.

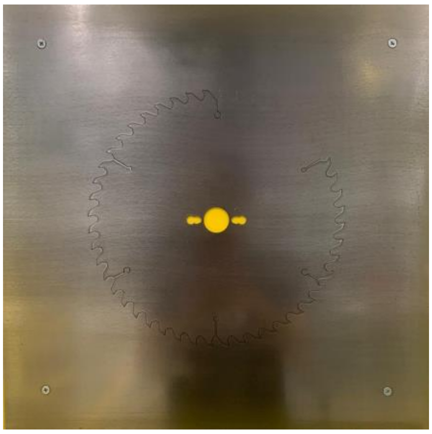


Figure 2 - Plate cutting

Figure 3 - Heat treatment

The second step (Figure 3) involves the heat treatment tempering, a common method for improving the mechanical properties of a wide range of materials, including the metals used in circular saws. The process begins by stacking the saws between two bases, and depending on which oven the saws will be placed in, the saws are either compensated or not. This is because one of the ovens already incorporates a press. Compression is crucial because it prevents the saw from deforming due to temperature differences.

The third step is where the surface plate grinding is performed (Figure 4). Surface plate grinding is a process used to ensure the flatness and accuracy of a surface plate. To grind a surface plate, a grinding machine is used to remove material from the surface of the plate, creating a flat and smooth surface. The plate is placed on the grinding machine and the grinding wheel is moved back and forth across the surface of the plate until the desired flatness and smoothness is achieved. During the grinding process, the plate is frequently checked for flatness and accuracy using precision measuring instruments such as dial indicators and surface gauges. This process ensures that the body of the saws has the right final dimensions.

Figure 4 - Surface plate grinding

Figure 5 - Tensioning

Step four is known as tensioning, and it plays a crucial role because saws have a resonant frequency very close to their working speed, which can lead to saw fractures and a poor cut. The tensioning process consists of making circular engravings around the saw, as it can be seen in Figure 5, causing the resonant frequencies to increase and enhancing the saws functionality.

After the tensioning process is complete, the saws move on to the brazing process. Brazing is a technique for joining materials that entails fusing a filler material, such as a weld metal or alloy, to join two pieces of base metal. Brazing is a low-temperature soldering process that typically occurs at temperatures below the base metal's melting point. During this procedure, the saws' teeth are attached, show in Figure 6. This process is performed automatically by machines for standard saws, but manually for saws with dimensions outside the standard range. During the brazing procedure, it is essential to ensure that the filler material completely fills the space between the base metal pieces, thereby forming a joint that is both strong and durable.

Figure 6 - Brazing

The sixth step, Figure 7, is to clean and polish the saws. This procedure begins with sandblasting or laser blasting to remove any residue left by the brazing process. The object is then polished to achieve the desired aesthetic.

The process of sharpening teeth, Figure 8, occurs in step 7. The process of sharpening is the act of sharpening a tool or sharp object to increase its effectiveness and efficiency in use. At this stage, the geometries and types of sharpening for the saw teeth are finished.

Step 8 and 9 concludes the process by engraving and packaging the product, Figure 9. Engraving is a process of carving a design or text onto a hard surface such as metal, wood, or stone using tools such as chisels or lasers. The engraving process is for functional purposes such as creating serial numbers or identification codes on industrial parts. This step is not only applicable to saws that are produced by Frezite itself but also to the saws that are bought from other companies.

Figure 7 - Cleaning and polishing

Figure 8 - Tips grinding

Figure 9 - Engraving and packaging

For a better comprehension of the company's workspace, Figure 10 depicts a perspective of the circular saw factory's layout, which in addition to the various processes previous identified in Figure 1 it also presents other associated processes such as storage and transports systems.

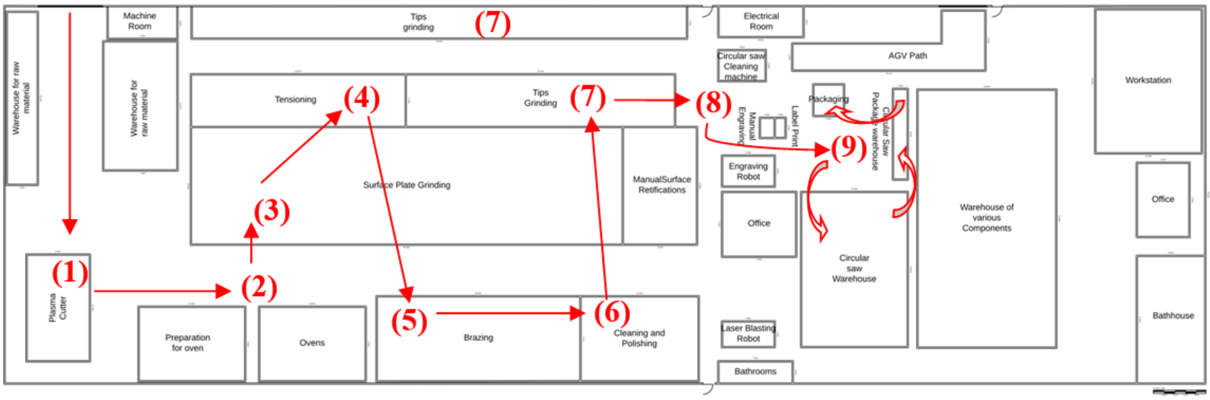


Figure 10 - Circular saw factory layout

Figure 11 displays the space of the engraving and packaging step of the circular saw production process in greater detail so that the workspace can be better comprehended. Above the office space in this image is the circular saw warehouse made of 5 rows and 4 columns, where the manufactured saws and the bought saws are stored. On the left side of the offices, two engraving stations for saws can be observed. One station corresponds to the automated engraving process that encompasses a robot, while the manual engraving station is located to the left of the robot. Adjacent to the manual engraving station is the labeling process, which prints the labels used in the packaging process. In the upper portion of the space in Figure 11, the packaging to be used for the circular saw packaging process is stored. The packaging process, consisting of a table and a strapping machine, is situated in the middle of the area between the labeling process and the storage of the products. In the upper left quadrant of the figure, one can also see a portion of the path followed by an AGV. There can also be seen the location of 4 computers (PC) used in the packaging, label printing, manual engraving and automatic engraving stations.

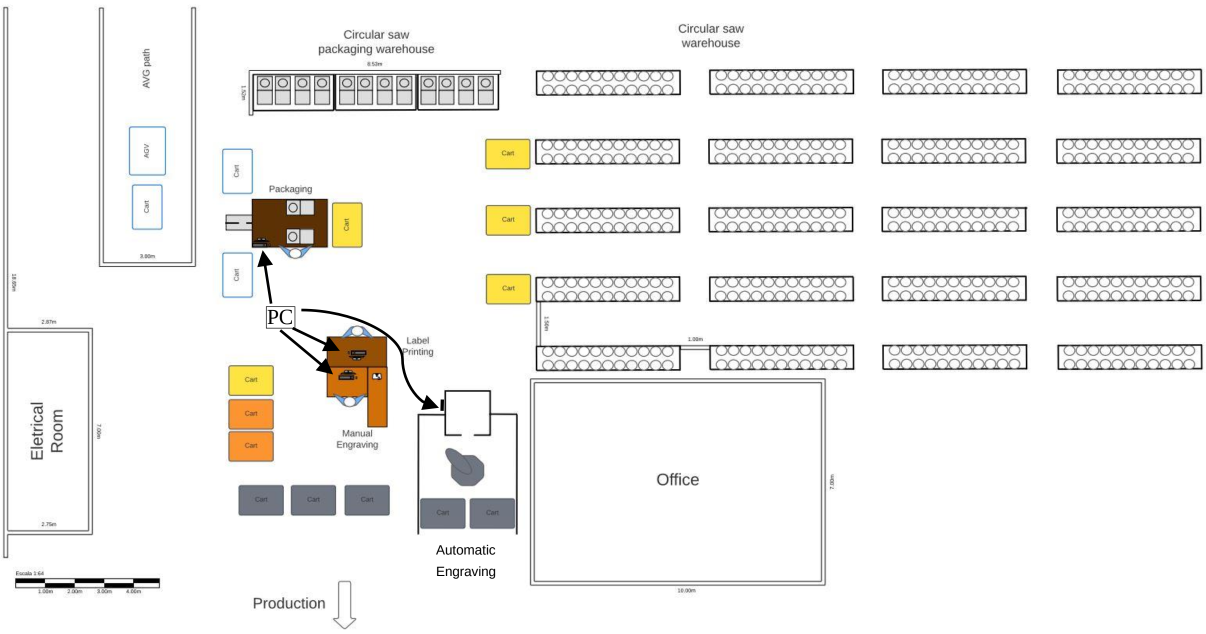


Figure 11 - Layout of the engraving and packaging stage of the circular saw production

2.2 Sequence of operations for engraving and packaging orders

To get a better understanding of the processes involved in the engraving and packaging sequence that will be presented in the following subchapters, Figure 13 represents the overall sequence of operation, and the Figure 12 represents all the software applications used.

The *Kardex Power Pick System* is an automated storage and retrieval software designed to improve the efficiency and accuracy of order fulfillment in warehouses and distribution centers (“Kardex Power Pick System” 2023). The *Triagem* software was developed by Frezite to monitor the logistical aspects of the circular saw production process. When a saw moves from one stage to another, it must be indicated that it has already completed the previous stage, so the *Triagem* software can be used to determine its current production status. In the Triagem software the is also a subprogram destined to print the desired labels to be used. *Gravauto* is also a program created by Frezite that contains a database of possible engravings to be engraved on circular saws. This software has a subprogram called Barcode that reads the barcodes, and we determine which destination is the engraving going to happen, if it’s in the manual engraving or the automatic engraving. If the automatic engraving is selected the subprogram Sequence is opened and it’s added to a sequence of operation. The *MagicMark,* provides access to all available functions and enables users to control the laser and laser peripherals for the engraving of the saws (“Magic Mark” 2023).

As shown in Figure 11 there are 4 pcs present in the engraving and packaging step, three pcs are equipped with all the software applications (Kardex Power Pick, Triagem, Gravauto, Magic Mark) presented in Figure 12 and the pc near the automatic engraving robot is the only one that is just equipped with the Gravauto and Magic Mark software’s.

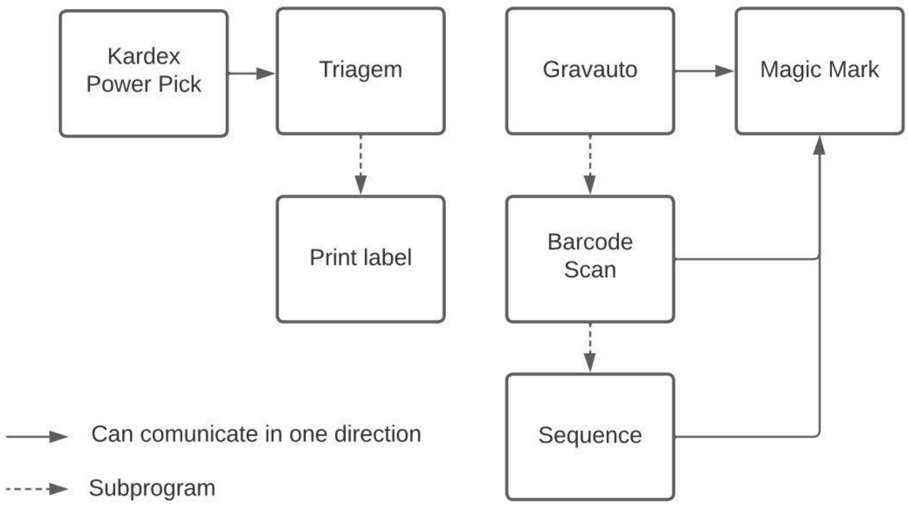


Figure 12 - Software’s used in the engraving and packaging step

In order to initialize the engraving and packaging process a order for saws must be made, with an order made an operator starts to print the sheet order and then scans the saws orders to verify if the saws are in stock or not. After verifying the saws are in stock the operator then prints the labels of each type of saw and picks the saws from the warehouse with a cart. When collecting the saws, they can take different paths: one is the saws that need to go to the production process to make small adjustments, other may have to be engraved and some saws may already be engraved and go directly to the packaging process. After the packaging process the packaged saws are placed in carts that are coupled to an AGV that transports the packages to the distribution warehouse.

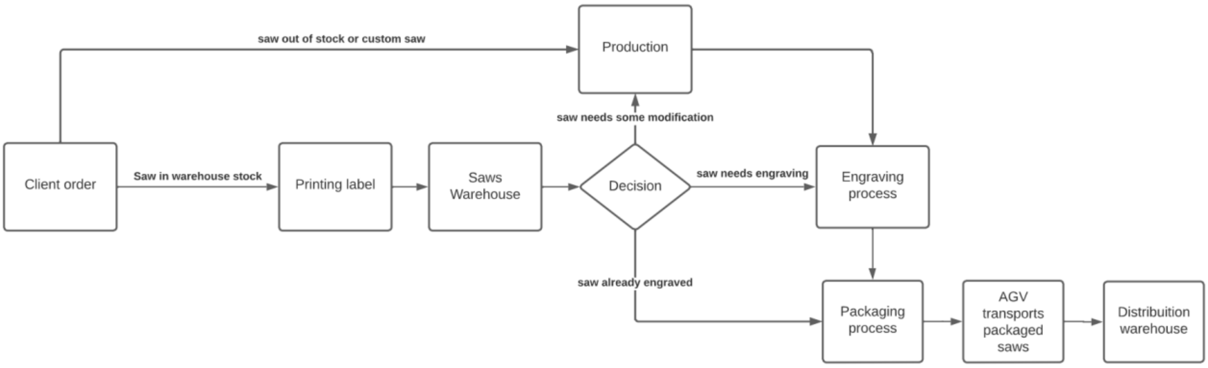


Figure 13 - Engraving and packaging sequence of operation

2.3 Collecting saws from the storage facility

This subchapter will describe the complete process for collecting circular saws in the warehouse, from collecting out to the packaging process. In this procedure, two distinct software applications are used: the *Kardex Power Pick System* (“Kardex Power Pick System” 2023) and *Triagem*.

The flowchart in Figure 14 is used to gain a greater understanding of the cycle of operations involved in the process being described. The flowchart uses different geometries, the rectangles represent a process, the diamonds represent decisions, the inclined rectangles represent data and the cylinders represents databases.

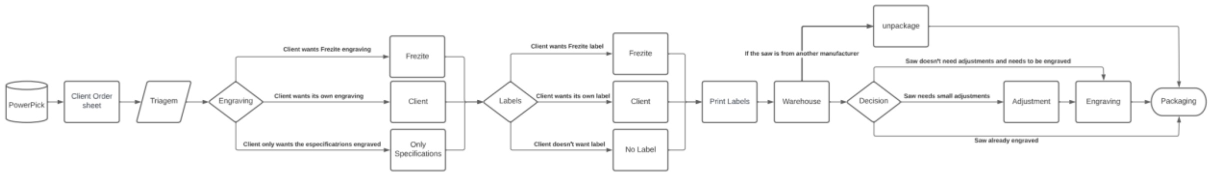


Figure 14 - Flowchart of storage warehouse picking process

Accessible through a computer, the *PowerPick* software allows users to visualize submitted orders along with the following information fields: main order, movement, description, lines, seller, customer name, and date of creation. After selecting the desired order, the relevant client order sheet is printed. After printing, the *PowerPick* software must be informed that the order is being processed, which removes the order from the order manifest.

With the client order list withdrawal from the software *Kardex Power Pick System* as illustrated in Figure 15, it is possible to examine the saws ordered by the customer, along with the type of saw and its location, the type of material, the quantity, the order number, and the barcodes for each type of saw ordered.

Pedido: Client name ./Balcão Trofa

15/02/2023 13:30

Line	Pick/Put-Location	Material	Qty	Conf	Encomenda	Encomenda
1	Serras Circulares01-005/00-01/01	866.250.060.30	1.00		0202307210	
2	Serras Circulares01-025/01-01/01	871.125.024.20	1.00		0202307210	
3	Serras Circulares01-015/04-01/01	864.250.080.30	5.00		0202307210	

Figure 15 - Client order list

In the Print Labels subprogram of the *Triagem* software, shown in Figure 16, the barcode of the customer's order sheet can be read to determine whether or not the customer desires a label on the package and the type of engraving. In general, when printing labels, the same number of labels are printed as the number of saws to be packaged, plus one for the customer's name. In instances where the customer desires their own labels on the shipments, there's an option on the program that prints the labels with the customer's reference.

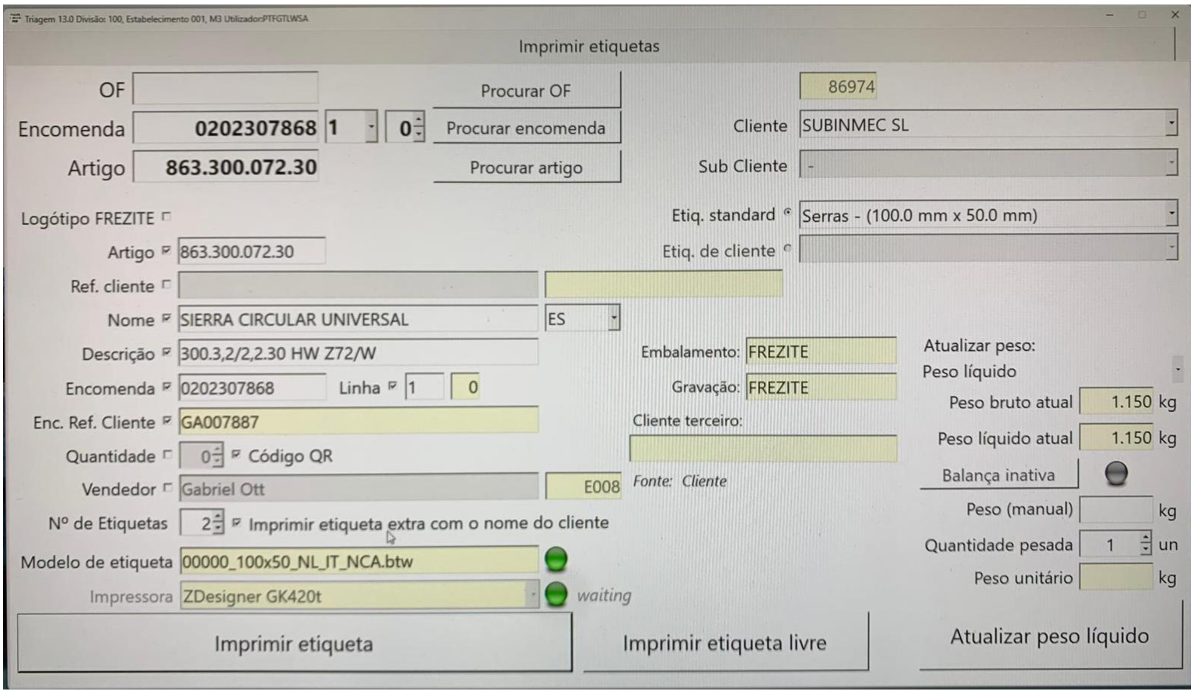


Figure 16 - Print labels subprogram from Triagem

For better organization in the collection of saws in the warehouse, the labels are grouped by saw size as they are being printed, so it will be simpler to place the saws in the appropriate trolleys when the collection is carried out.

When printing the labels for the stock saws that must be engraved, they are marked differently to aid in both the engraving process and the collection of the saws. If there are no notes or markings on the labels, the purchaser desires the Frezite marking and the saw specifications. If in the labels the customer's name is highlighted, it indicates that the customer desires their own marking on the saw. When the labels contain the customer's name followed by the phrase "dimensions only," these are saws for which the customer desires only the specifications to be engraved. In the event that the customer does not desire a label on his order, three distinct labels are printed. A label with the customer's name, a label with the quantity ordered and a notation that no labels are to be placed on the containers, and a label with the standard reference for when the engraving process begins.

If the customer desires his own engraving, he must order at least five units; otherwise, Frezite refuses and only engraves the saw's specifications.

Once the appropriate labels have been printed, we must recheck the customer's order document to determine the warehouse location of the saws as illustrated in Figure 17.

For example: circular saws 01-017/02-01/01, the information 017/02 indicates that the saw is located in section 17 and row 17.2, while the information 01/01 indicates the date of the registration in day/month format. If in the information of the location where the saw is located the number 99 appears, it means that is out of stock.

Figure 17 - Circular saw warehouse arrangement

On the right side of the shelves (example: number 6) in the warehouse are saws that already have Frezite engraving and the dimensions engraved, while on the left side of the shelves (example: number 11) are saws that require engraving. If the order is for saws that Frezite purchases from other companies, they must be removed from their packaging and, if the customer desires, engraved before being placed in the packaging process.

Two distinct varieties of stock manual carts are available. A low-profile cart visible in Figure 18, where a large number of saws to be engraved are stacked loaded and moved to a robot to perform engravings. The other cart, which may contain two or four stacks visible in Figure 19, is used to collect saws for manual engraving or for adjustments to be made to the saws. The cart containing the *to-be-modified* saws is returned to the production process and then conveyed directly to the packaging or engraving processes. When saws are destined for manual engraving, they are placed solely on the upper shelves of the cart so that manual marking makes it simpler and more obvious to determine which saws have been engraved. When the cart is loaded into the packaging process, there is no differentiation between its upper and lower portions. During collection, the appropriate labels are placed on top of each complete order, making it easier to distinguish the type of box to be used during the packaging process.

Figure 18 - Low profile cart

Figure 19 - Stack cart

2.4 Engraving process

The process of circular saw engraving is depicted in Figure 20. In this flowchart, there are 3 distinct software used: the first is *Gravauto*; the second is *MagicMark*; and the third is *Triagem* software.

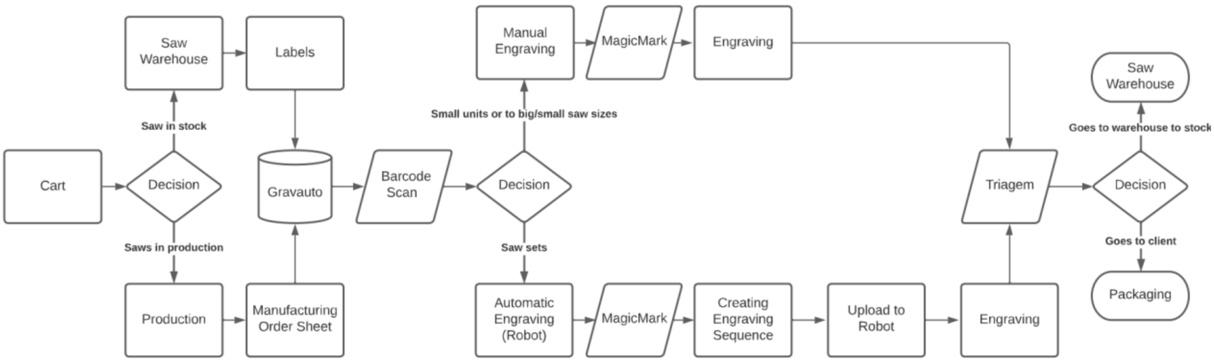


Figure 20 - Flowchart of the engraving process

The engraving process begins with the selection of the type of cart, whether carts from the production line or carts from the warehouse. These are distinguishable due to the different geometries of the carts: some have two or four shelves (Figure 19); others are the production carts, exclusive from the production line, with a very distinctive geometry, similar to an exhibitor they can be seen in Figure 21; and lastly, the low profile carts are exclusive to robot feeding (Figure 18). Occasionally, however, customer-required modifications to saws necessitate the use of warehouse section carts, making it visually more difficult to distinguish what comes from the warehouse and what comes from production.

If the saws to be engraved come from the production line, they include a cover containing the saw's technical sheet and a sheet with the manufacturing order; if they come from the warehouse section, they include the labels described in the warehouse process.

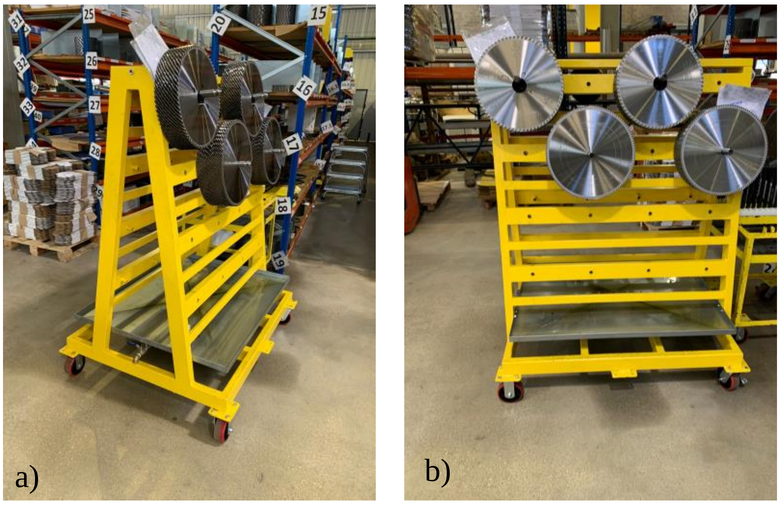


Figure 21 - Display cart a) side view b) front view

Within the *Gravauto* software shown in Figure 22, a barcode related to a manufacturing order can be scanned from the manufacturing order sheet or the labels. This software presents two fields, the “layout” where we select the name that the customer wants to engrave on the saw, and the "*Tipo de artigo*" where several options, such as *Gravação OF*, *Serras*, *Serras Plus*, can be selected. After selecting the "*Tipo de artigo*" field, the specifications are displayed and can be edited if desired. After defining what we wish to engrave on the saw, we select the create a *txt file* option (“*Criar Ficheiro TXT*”) and copy the manufacturing order (“*Ordem de fabrico*”) to *Barcode scan*, a subprogram of the *Gravauto* software, where we select the destination of the engraving, if it’s for the automatic or manual engraving.

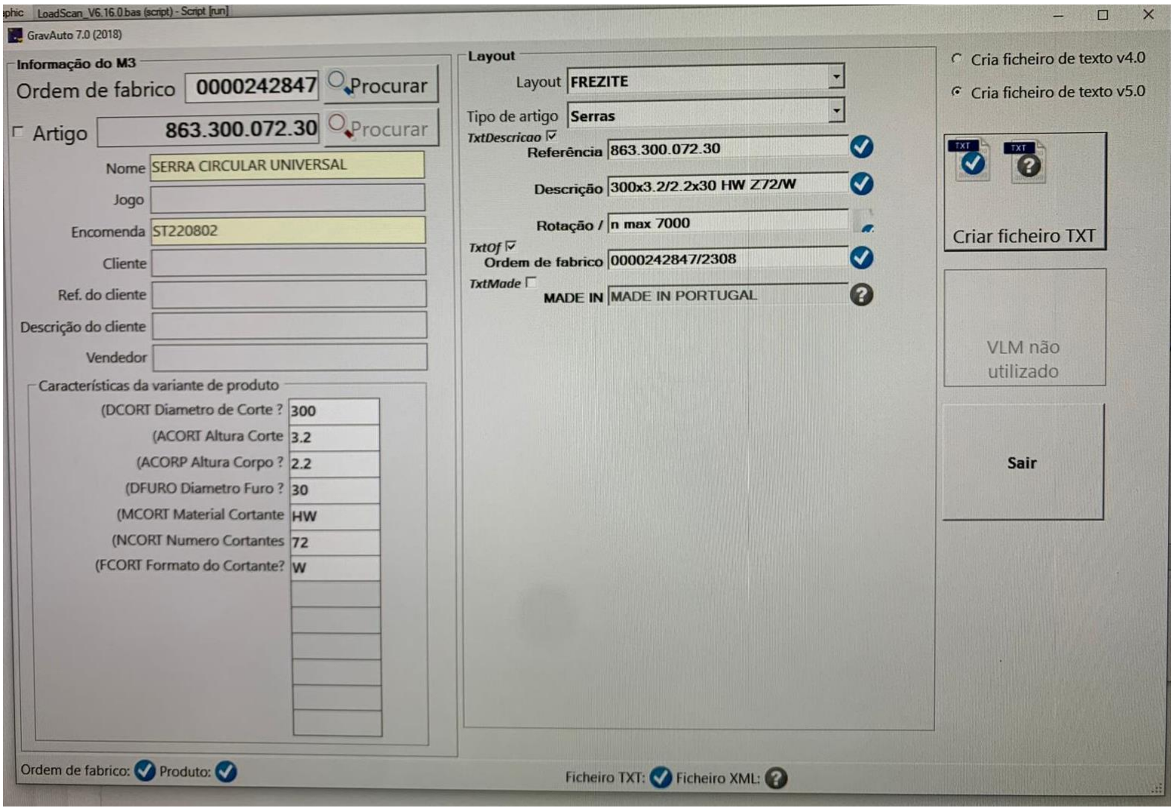


Figure 22 - Gravauto software for a 300 mm diameter saw

When the manufacturing order is copied to the *Barcode scan* subprogram and its destination is selected, it communicates with the *MagicMark* software, where a representation of the saw and the previously selected engraving can be viewed. It is feasible to modify the logo positioning parameters and specifications within the *MagicMark* software in order to obtain a good engraving. The file containing the manufacturing order number is then stored so that it can be retrieved without having to be modified again.

If the information is manually engraved, the operator places the adequate base for the saw beneath the engraving machine and then secures the saw's central opening to the base. From there, you can select an option within the *MagicMark* software that allows you to observe the logo and specifications to be engraved on the saw using the engraving machine. This view can be of the entire set or of each individual component. Once the engraving positions have been defined, simply select the "Mark" option to conduct the engraving. This sequence is illustrated in Figure 23.

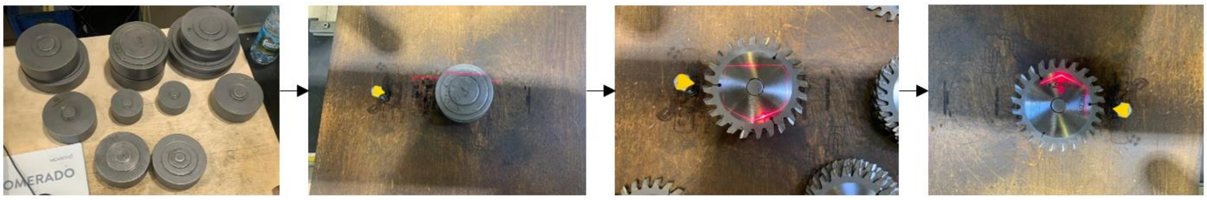


Figure 23 - Manual engraving sequence

If the destination is automatic engraving, a engraving sequence must be created and defined. This is accomplished using the "*Sequence*" interface accessible via the *Barcode scan* subprogram shown in Figure 24. In this window, the sequence corresponding to the intended wheelbarrow is configured via two parameters, one with the label "*pins*" where the number of pins on the cart is specified, and the second parameter "*number of layouts*" where the number of various saws in the cart is specified. Then we must import and organize the saved saw configurations from the *MagicMark* software. Ultimately, the sequences must be uploaded to the robot's computer.

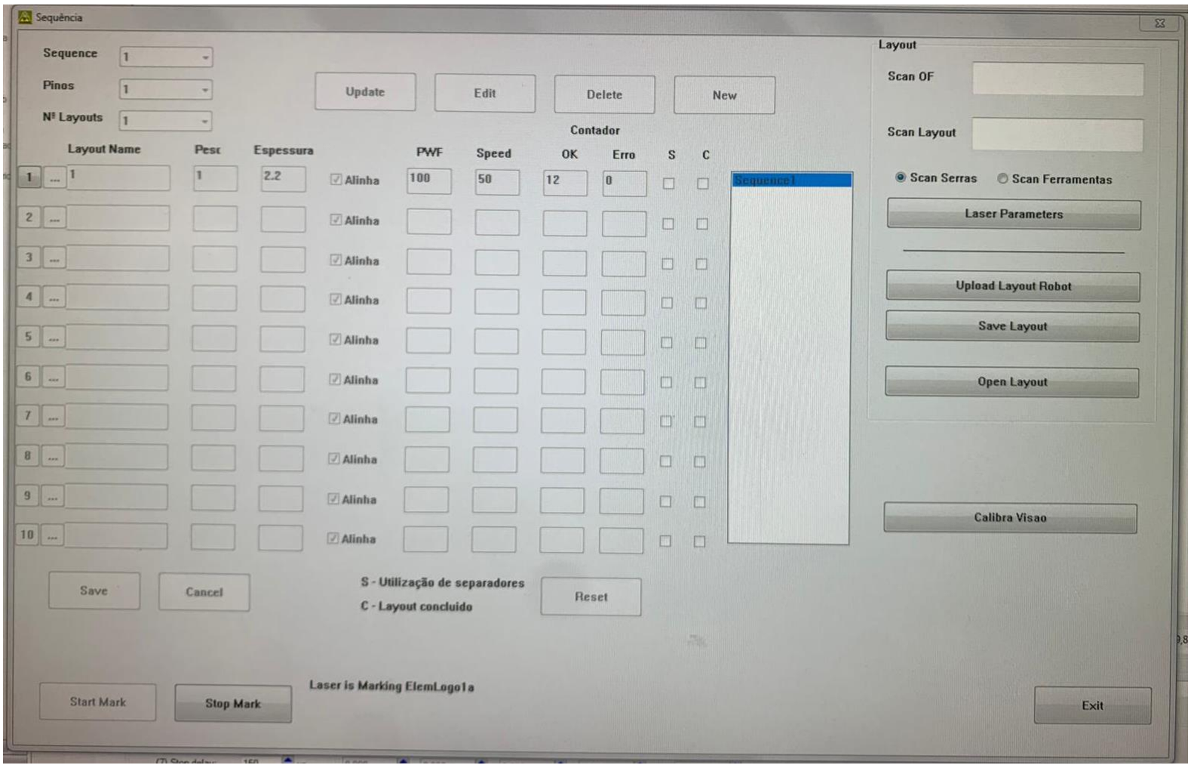


Figure 24 - Sequence interface

Placing the intended cart on the robot's left side station and an empty cart identical to the one on the left in the right die station, which will be loaded with the previously programmed saws. Selecting the desired sequence on the robot's computer and tapping the START button initiates the engraving process.

The robot gripper shown in Figure 25, is composed of three suction cups, six holding magnets of varying intensity, an inductive sensor and a capacitive sensor. The robot then begins by checking the heights of the three stations: the rejection station, then the unloading station, and finally the loading station, where it grabs and transports a saw to the entrance of a chamber where it is check that the saw is in the gripper or not. If there is a saw, the procedure continues. If there is a separator made of plastic, it is dropped into a box.

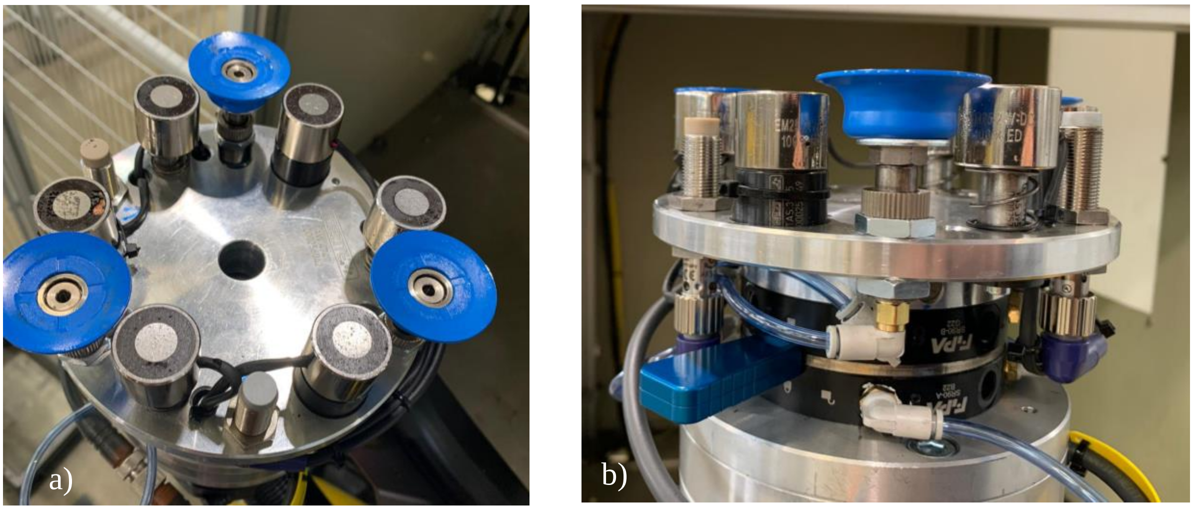


Figure 25 - Robot gripper a) top view b) side view

After confirming that there is a saw in the gripper, the robot moves the saw into a camera, where a photograph is taken, and a vision system compares the saw's shape, position, and centering to the one previously selected. The vision system images displays can be seen in Figure 26. With this vision system, it is possible to indicate to the robot the necessary adjustments for positioning the saw to be transported to the engraving area, thereby ensuring that the engraving is placed in the correct location on the saw. If the saw observed differs from the one specified, it will not be engraved and will be deposited in the rejected area. After everything has been determined, the saw is engraved and then transferred to the unloading cart.

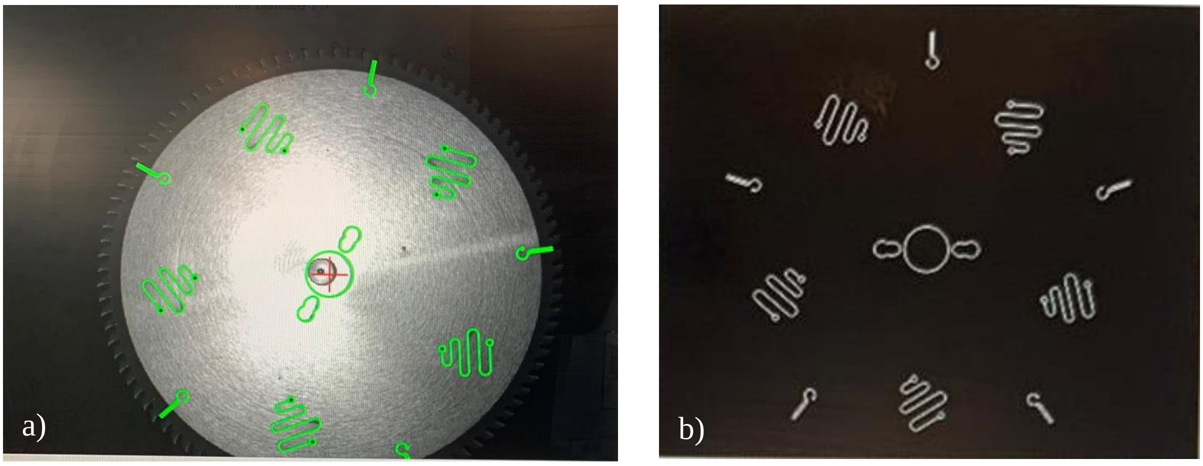


Figure 26 - Vision system a) captured image of the circular saw to be engraved and its features by the vision system; b) circular saw feature reference

After manual or automatic engraving, it is necessary to access the *Triagem* software and change the saws from state 60 to state 90, which signifies that the saws transition from the engraving-pending state to the engraving-completed state. With this, there are two possible destinations for the saws: the warehouse where they will be stored, or the packaging process itself.

2.5 Existing manual packaging process

Figure 27 depicts a flowchart of the sequence of operations for the manual packaging process.

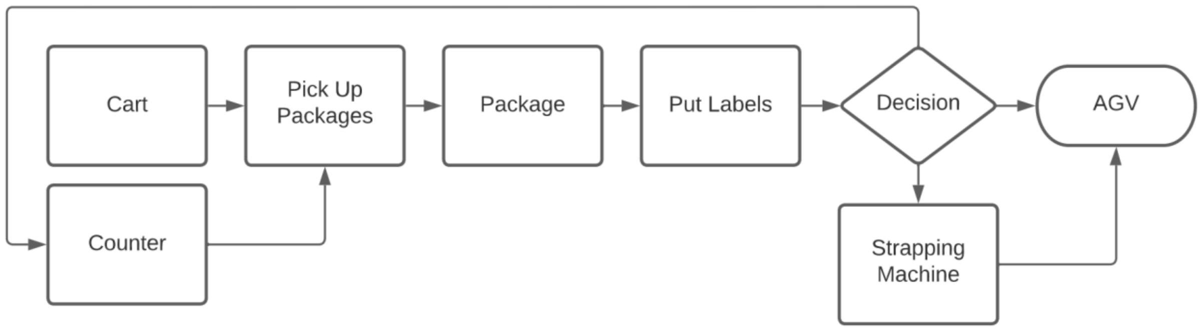


Figure 27 - Flowchart of the manual packaging process

When an order is placed at the counter, the packaging sequences are halted and priority is given to the order placed at the counter. After packaging, this order is brought to the counter to be delivered to the customer.

The existing packaging process is performed exclusively manually. This process begins by choosing a cart in which the saws are ready to be packaged. After the corresponding packages are fetched, this process is carried out with the labels that were previously put available on the cart, as they show the diameter of the saw and the type of packaging to be used.

Packaging varies based on the type of saw tooth material. For saws with carbide teeth, white or yellow cardboard boxes are used, whereas wooden boxes are utilized for saws with polycrystalline diamond teeth. There are a few exceptions, such as larger than 800 mm saws, which are placed in wooden boxes regardless of the material of their teeth. The yellow boxes are reserved for saws with Frezite engraving, while the white boxes are for all other engravings.

During the process of collecting the packages, it is necessary to keep in mind that some packages have the capacity to store multiple sizes of saws in the same package, which is made possible by pre-defined diameter spacers within the package.

The saws are individually packaged, beginning with placing a package on the table, then opening the flaps, if any, and finally removing the diameter spacers, if any and necessary. After the saw is placed inside the packaging using a hand magnet and covered with a vapor corrosion inhibitor (VCI) paper and closing the flaps. Then, the upper portion of the package is closed, lifted and fold down to the surface that will perform the wedging in the package's slot. Finally place the folded surface in the slot to complete the packaging. The packing sequence is displayed in the Figure 28.

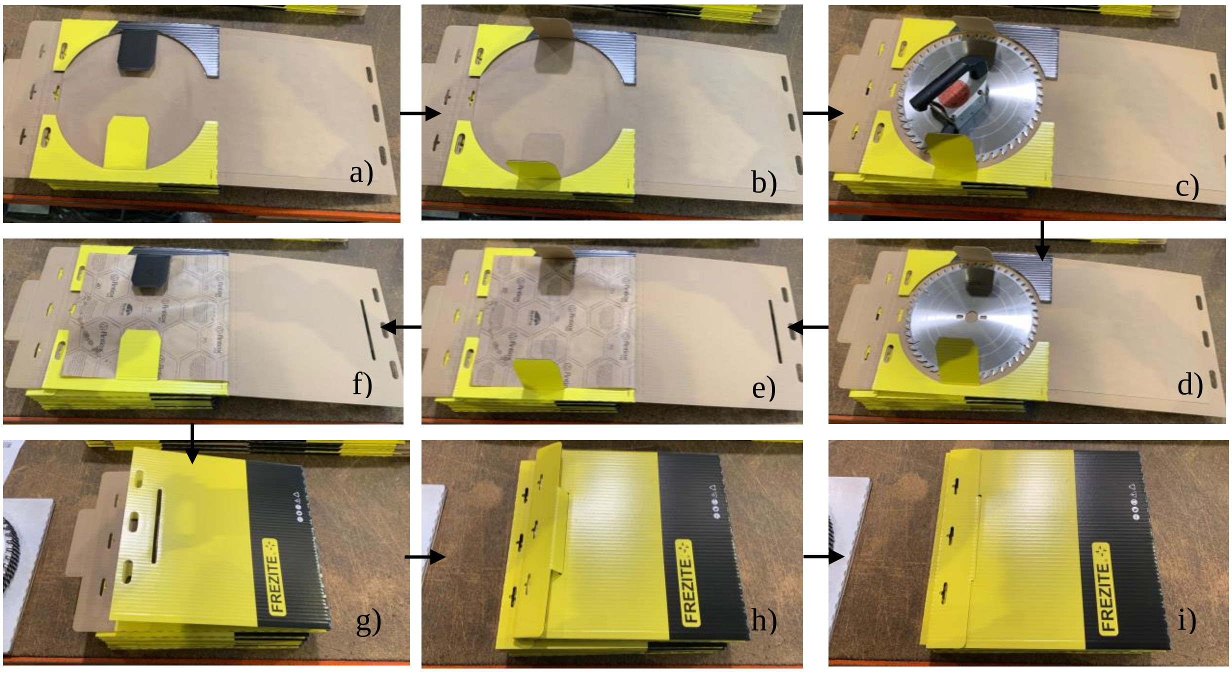
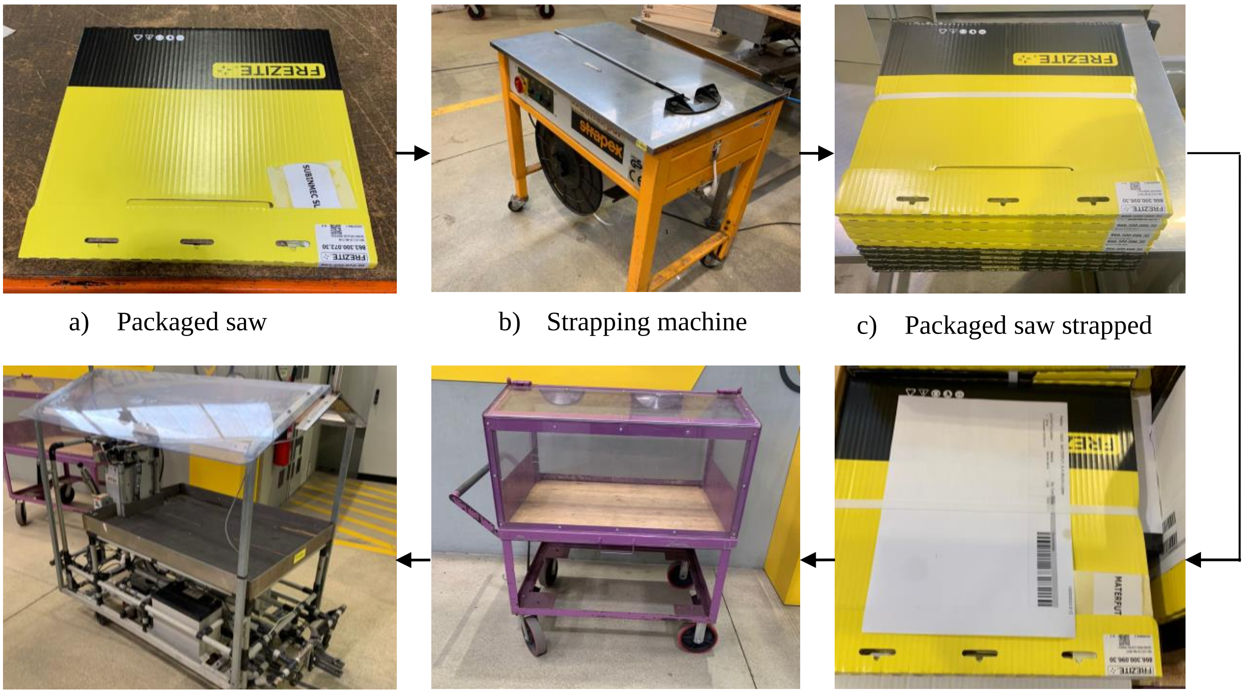


Figure 28 - Packaging sequence

After the saws are packaged, depending on the customer's request, the appropriate labels are placed or not, as described in the process of collecting saws from the warehouse. Depending on the size of the saw being packaged, a strapping machine is utilized to strengthen the packaging. This machine is also used to group similar-sized saws, as illustrated in Figure 29.

The packages are then loaded onto carts that can be connected to be pulled by an AGV, which transports the finished packages to the distribution warehouse, in another building, from which they will be shipped to customers. When placing orders in the AGV carts, labels containing the customer's name and order sheet are placed on top of each order to improve shipping process organization. The AGV is guided by a single magnetic tape that connects the distribution warehouse and the packaging and engraving space.



a) Packaged saw
b) Strapping machine
c) Packaged saw strapped
d) Order sheet places in the strapped packages
e) Cart that couples to AGV
f) AGV

Figure 29 - Strapping and transport sequence

2.6 Time duration analysis of the processes in the current system

After gaining a greater understanding of the involved processes, an analysis was taken to identify the main restrictions associated with the engraving and packaging process. To do so a graph for the most popular saw is presented in Figure 30 with the different task times for an order of 30 saws with 300 mm of diameter.

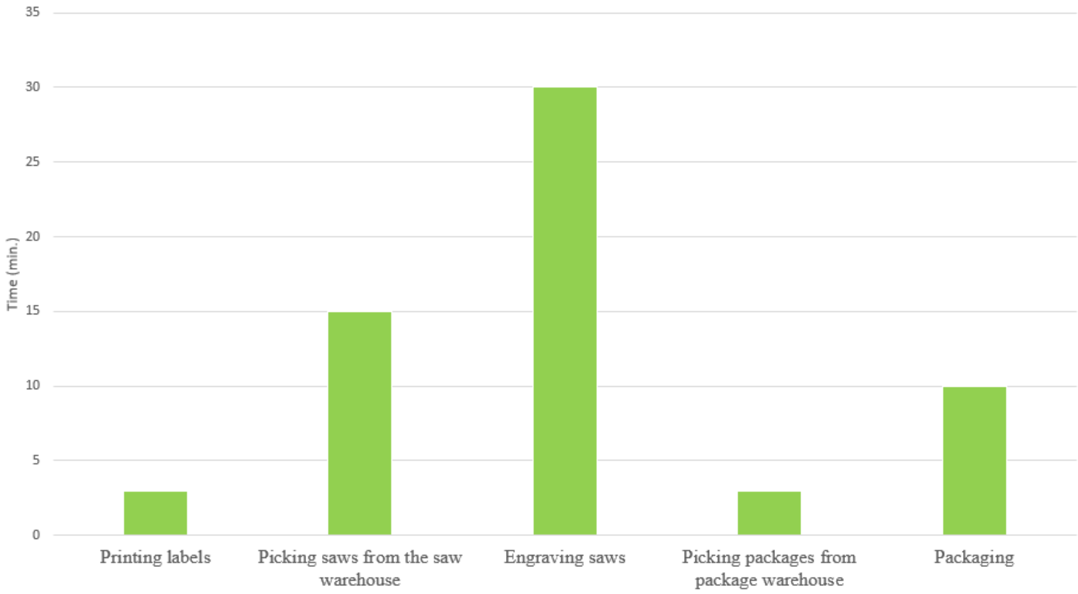


Figure 30 - Task times in the engraving and packaging process

The process of engraving and packaging is made by two operators, one operates exclusively in the engraving process and the other operator is responsible for the other tasks. Depending on the size of the saw the time durations of the operations may vary, especially the saw picking, the engraving process and the packaging process.

The time durations presented in Figure 30 were recorded separately and not in a continuous operation sequence due to the engraving process taking longer and not being able to keep up with the speed of the rest of the previous tasks. Further details regarding the specific types of packages and engraving times will be provided in the subsequent chapter. The average operator packaging time was measured using a stopwatch and its times can be seen in table 1.

Table 1 - Operators packaging time

Diameter (mm)	Time (s)	Strapping
216	12	No
250	16	No
300	20	No
380	26	No
400	25	No
420	26	No
450	27	No
560	44	Yes
600	65	Yes

2.7 Market-ready solutions for automated packaging stations

In order to evaluate whether the automated solutions existing in the market could be considered for the circular saws packaging station, a thorough search was made using mostly information on the web. The information found was mostly related to carton boxes but not for the specific case of circular saws. After an initial overview the main sources used were exhibition events and magazines related to the packaging industry ("Packaging World" 2023) ("PACK EXPO TRADE SHOWS" 2023). In common with the standard carton packages formats (Figure 31), the packages used in circular saws have various bending/folding movements and surfaces, as well as specific closing ears. In addition to the manipulation of the base unfolded cartons, removing or inserting separation materials, these movements must be performed in a defined sequence (Figure 28). Regarding the equipment surveyed, all of them have the objective of responding to a specific type of application, which is food packaging. Some of the machines described also satisfy the need for packaging pharmaceutical, cosmetic and beverage products.

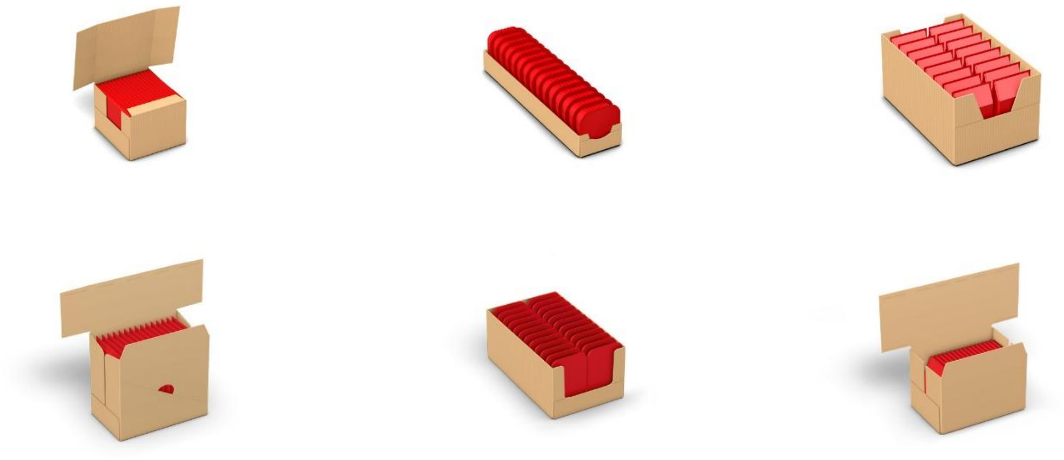


Figure 31 - Standard package formats (“SOMIC Packaging” 2023)

Consequently, finding a direct usable solution proved impossible, as the packaging used for saws in Frezite exhibited a significantly different format and Frezite's packaging is typically sealed with a jam, whereas standard packaging is typically sealed with an adhesive product. Neverthless a few automated solutions were identified and are presented next.

Through the Packaging World magazine, a few packaging companies were encountered, such as A-B-C Packaging Machine Corp. and Schubert, showcasing their innovative ideas for automatic packaging (“A-B-C Packaging Machine Corporation” 2023) (“Schubert” 2023).

The Case Erector Model 400 by A-B-C Packing Machine Corp. displayed in Figure 32 is a machine designed to automatically form and seal corrugated cardboard cases and can handle a range of case sizes, from small to large. The case erector uses vacuum technology to pick up and erect cases from a magazine, and then folds the bottom flaps and seals them with adhesive tape or hot melt glue. The machine is built with heavy-duty construction and is designed for high-speed (“A-B-C Packaging Machine Corporation Case Erector | Model 400” 2023).

Figure 32 - A-B-C packaging machine corp. model 400 (“A-B-C Packaging Machine Corporation Case Erector | Model 400” 2023)

Schubert is also a company that specializes in packaging solutions. All components in the Schubert modular system are designed to be compatible with each other and can be combined multiple times to create highly efficient packaging solutions.

The Lightline Cartonpacker showcased in Figure 33 is a compact machine designed to handle a variety of packaging types, including cartons, trays, and wrap-around cases. The machine is equipped with advanced automation technology that ensures precise product placement and efficient packaging processes. One of the key features of the Schubert Lightline Cartonpacker is its flexibility. The machine can be quickly and easily reconfigured to accommodate different product sizes and packaging types, like packaging pharmaceutical, cosmetic and beverage products ("Schubert Lightline Cartonpacker" 2023).

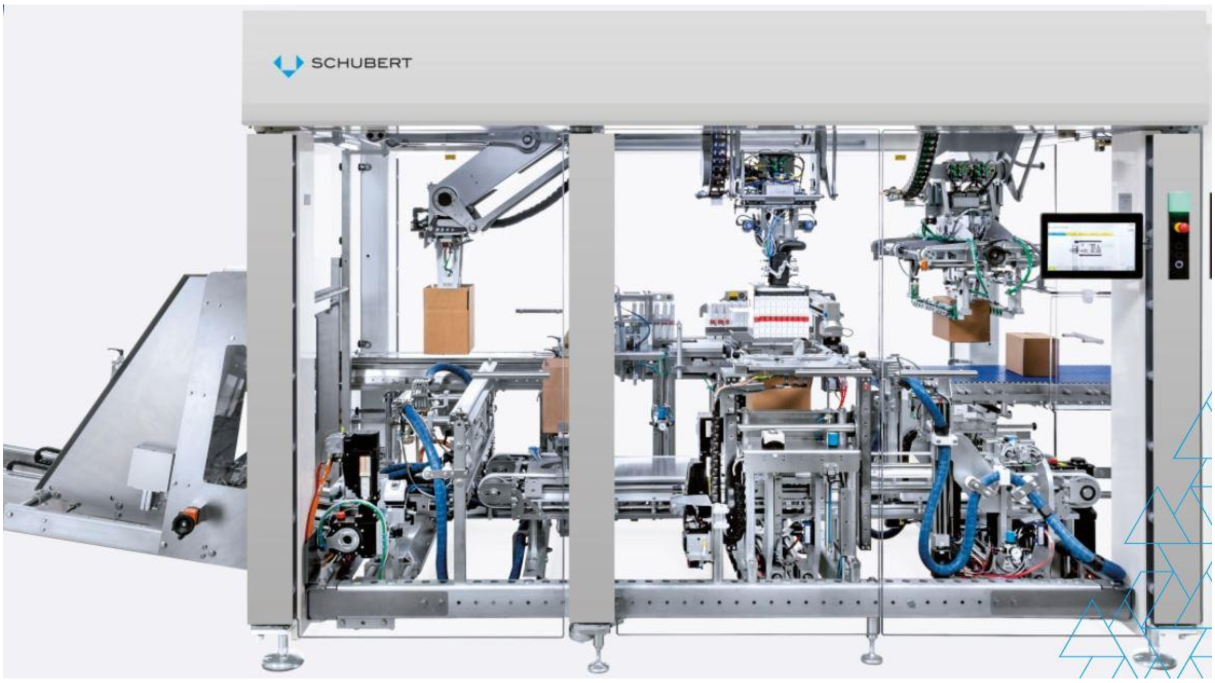


Figure 33 - Schubert lightline cartonpacker ("Schubert Lightline Cartonpacker" 2023)

Despite the fact that these machines do not apply for the packaging process of circular saws due to the various geometries of the boxes and the packaging process itself, these innovative machines have inventive solutions to the handling regarding the feeding of packages.

Through the exhibition EXPO Pack (PACK EXPO TRADE SHOWS 2023) it was possible to identify several companies dedicated to automated packaging systems. The Aagard company and the SOMIC company were highlighted among the others due to their ideas for handling the packaging closing process ("Aagard" 2023) ("SOMIC Packaging" 2023).

The Aagard Inspire Wrap Around Case Packer presented in Figure 34 is an automated packaging machine designed to efficiently pack products into cases. It is specifically designed to handle wrap-around style cases, which are formed around the product and then sealed, providing a secure and tight fit. It is capable of handling a wide range of product sizes and configurations, making it a versatile solution for a variety of packaging needs ("Aagard Inspire Wrap Around" 2023).

Figure 34 - Aagard inspire wrap around (“Aagard Inspire Wrap Around” 2023)

SOMIC Ready Pack is a packaging system developed by SOMIC Group that is designed to provide a flexible and efficient packaging solution for a wide range of products. This system is particularly well-suited for the food and beverage industry, but it can be used to package many other types of products as well. This compact system can be viewed in Figure 35. The system is highly flexible, which allows it to handle a variety of product types, sizes, and shapes, such as meat, poultry, fish, and baked goods. (“SOMIC ReadyPack” 2023).

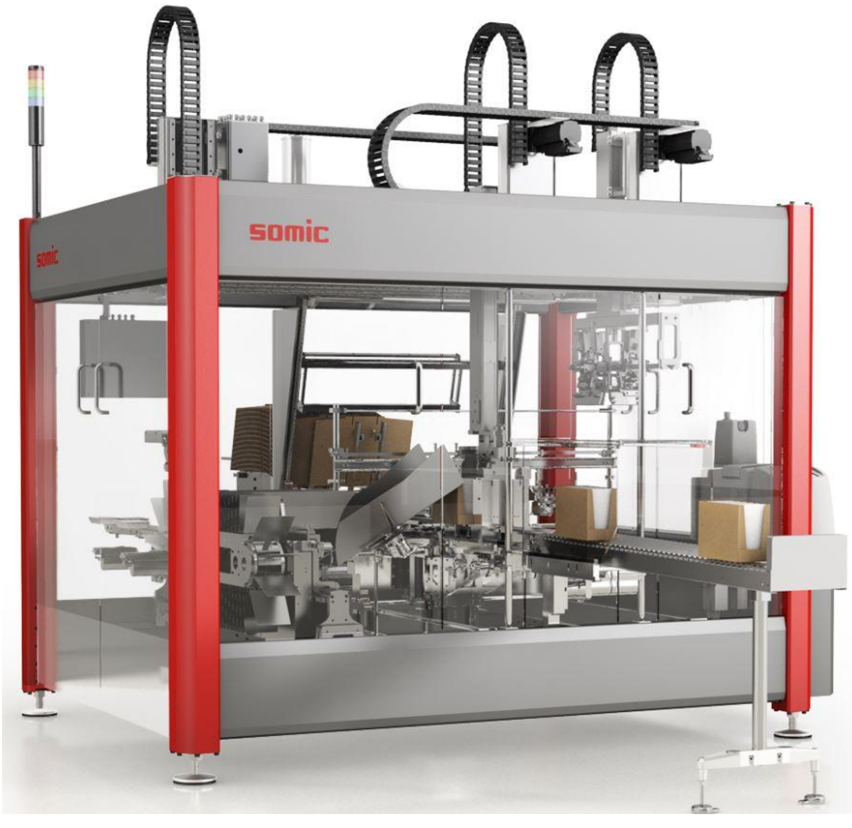


Figure 35 - SOMIC ReadyPack (“SOMIC ReadyPack” 2023)

To explore potential solutions to incorporate the lable printing process in the new station, the magazine Packing World was consulted, which showcases a range of offerings from different companies. The table top series labeling machine from All-Fill presented in Figure 36 stood out due to its simplicity and simple integration into a packaging line. All-Fill manufactures a wide variety of table top labeling machinery. These machines are particularly ideal for containers and products with unique shapes that might pose handling challenges. These labeling systems are highly recommended for startups, first-time buyers, and operations with limited floor space, providing an excellent solution for their specific needs (“All-Fill” 2023) (“All-Fill Table Top Series” 2023).

Figure 36 - All-Fill table top series (“All-Fill Table Top Series” 2023)

One of the biggest impasses encountered with these machines is the type of packaging used by these machines, these being standard packaging, as seen in Figure 31. The labeling process, as opposed to the packaging process, was significantly more beneficial, leading to the possibility of a direct implementation in the packaging process.

3 Detailed specification of the problem and proposed solutions

This chapter begins by characterizing in detail the orders for saws to identify the quantities, varieties and packages involved, allowing for a greater understanding of the requirements for the proposed packaging process solutions.

After gaining an understanding of the quantities involved in the packaging process, an analysis of the engraving process was conducted to determine the various engraving times, as well as the pick and place movement times. Following this, an assessment of the possible manipulation limitations imposed by the saws weight and sizes are evaluated.

After analyzing the characteristics of the saws, the sequence of operations performed in the new station is described, including the mode of saw conveyance, both in the saw's feeding system for the engraving process and the transition from the engraving process to the packaging process.

In conclusion, various layout options for the new packaging station are presented and discussed.

3.1 Identification of the requirements to be considered for the new station

For the design of the new station, it is important to take into account several parameters such as the number and frequency of saws that are normally ordered, the different formats and sizes of the packages, the different types of engraving and corresponding times and the procedure for maneuvering the saws.

Table 2 provides information on the quantities of saws ordered per day according to their diameter sizes. Due to the extensive diversity of saw sizes, the table is divided into various range sizes for easier reading and comprehension. The diameters displayed in Table 2 are standard sizes, with a few exceptions involving saws that are custom-made per customer request.

Table 2 – Orders of saws per day by various diameters

Diameter range size (mm)	Number Saw/Day	Diameter range size (mm)	Number Saw/Day
45≤D≤100	12	**371≤D≤400**	46
101≤D≤115	4	**401≤D≤430**	4
116≤D≤140	43	**431≤D≤450**	29
141≤D≤170	28	**451≤D≤480**	9
171≤D≤200	45	**481≤D≤500**	15
201≤D≤230	24	**501≤D≤580**	10
231≤D≤260	69	**581≤D≤680**	8
261≤D≤290	12	**681≤D≤720**	2
291≤D≤300	145	**721≤D≤790**	1
301≤D≤320	21	**791≤D≤800**	1
321≤D≤340	9	**801≤D≤950**	1
341≤D≤370	97	**Total**	635

Due to the broad variety of saw sizes manufactured, the design of the new station will prioritize the most popular saws, with the goal of fulfilling at least 90% of the orders. So the plan is to design a station that can accommodate saws with diameters between 115 and 520 millimeters. The smaller saws were discarded from the start because their packaging was not only distinct in shape but also in material. Similarly, saws larger than 520 mm were dismissed because their packaging also possessed a unique shape.

With the plan of work already defined, the different packages were evaluated. Frezite initially used 12 different types of carton packages to accommodate saws ranging in diameter from 115 mm to 800 mm. This is possible because some packages contain diameter spacers. The diameter spacers although allowing for a bigger range of sizes in one package, sometimes can be difficult to remove and can damage the package, so Frezite decided to increase the variety of box sizes from 12 to 17, making the manual packaging process faster. With the new implementation of the packaging line, it will no longer be necessary to constantly remove these diameter spacers, making the process less complex and faster. If it is necessary to remove the diameter spacers from the new packages on the new packaging line, these spacers will be removed manually before the packages are fed into the system.

In Tables 3 and 4 the various characteristics of the packages are displayed according to their respective range sizes.

Table 3 - Old packaging range sizes

	Reference			**Package**	
	White Package	**Frezite**	**Diameter range size (mm)**	**Tabs**	**Diameter Spacers**
1	EM52.03	EM52.12	115≤D≤185	Without	With
2	EM52.04	EM52.13	190≤D≤235	Without	With
3	EM52.05	EM52.14	240≤D≤260	With	Without
4	EM52.06	EM52.15	265≤D≤315	With	Without
5	EM52.07	EM52.16	320≤D≤360	With	Without
6	EM52.08	EM52.17	365≤D≤435	With	With
7	EM52.09	EM52.18	440≤D≤520	With	With
8	EM52.11	-	520≤D≤575	Without	With
9	EM52.02	-	575≤D≤675	Without	With
10	EM52.10	-	675≤D≤720	Without	With
11	EM52.22	-	720≤D≤760	Without	With
12	EM52.23	-	760≤D≤800	Without	With

Table 4 - New packaging range sizes

		Package	
	Diameter range size (mm)	**Tabs**	**Diameter Limiters**
1	**115<D<141**	Without	Without
2	**140<D<171**	Without	Without
3	**170<D<201**	With	Without
4	**200<D<231**	With	Without
5	**230<D<290**	With	With
6	**290<D<301**	With	Without
7	**301<D<340**	With	With
8	**340<D<366**	With	Without
9	**365<D<426**	With	With
10	**425<D<451**	With	Without
11	**450<D<481**	With	Without
12	**450<D<501**	With	Without
13	**500<D<576**	Without	Without
14	**575<D<676**	Without	Without
15	**675<D<721**	Without	Without
16	**720<D<761**	Without	Without
17	**760<D<801**	Without	Without

Another parameter to take into account for the design of the new station is the engraving times of the circular saws. The amount of time required to engrave a saw depends on a number of factors, including the design to be engraved, the dimensions of the saw, and the type of saw material.

As indicated in the previous chapter, when ordering a saw, the customer can specify what he wants engraved on it, such as the specifications of the saw, the specifications plus the customer's logo, or the specifications of the saws with the Frezite logo, among other options.

The relationship between the size of the saw and the size of the engraving is also an important parameter to consider, as the size of the engraving varies depending on the size of the saw, with smaller saws having smaller engravings and larger saws having larger engravings.

Finally, the two type of saw material will vary the engraving speed, with this last point having the most impact in terms of time, as can be seen in Table 5.

In Table 5, we can see engraving durations for various saw sizes, with engraving and material type variations identified by engraving speed: 1200 mm/s is the engraving speed for oxidized saws, while 400 mm/s is the engraving speed for conventional saws.

The engraving times were obtained through the *MagicMark* software, which provides the time of engraving in real time, resulting in smaller estimation errors than when using a manual stopwatch. However, engraving durations for identical engravings varied by approximately 1 second.

Table 5 - Engraving times vs diameters vs materials engraving speed

Diameter (mm)	Engraving	Engraving Speed (mm/s)	Time (s)
120	Ref. + Logo (Frezite)	400	24
120	Ref. + Logo (Frezite)	1200	13
160	Esp. + Logo (Frezite)	400	35
160	Esp. + Logo (Frezite)	1200	16
210	Esp. + Logo (Frezite+Termo)	400	57
210	Esp. + Logo (Frezite+Termo)	1200	29
300	Esp. + Logo (Frezite)	400	52
300	Esp. + Logo (Frezite)	1200	32
350	Esp. + Logo (Frezite)	400	63
350	Esp. + Logo (Frezite)	1200	30
500	Esp. + Logo (Frezite)	400	77
500	Esp. + Logo (Frezite)	1200	34
500	Esp. + Logo (Frezite + Dinosaw)	400	86
500	Esp. + Logo (Frezite + Dinosaw)	1200	35

As disclosed in the subchapter on market-ready solutions, the purpose of this new station is to integrate the new packaging line with the engraving process. As part of the process integration, a robot will be responsible for transporting the engraved saws from the engraving process to the packaging process. Therefore, the robot must be able to manipulate saws of various weights and sizes.

The Fanuc M-10iD/16S robot depicted in Figure 37, which is already used in the automated engraving process, is a good choice because it can pick up to 16 kg, which is sufficient to pick up all Frezite saws in the intended work range. Due to its six rotating axes, this robot is also able to reach a distance of 1103 mm, allowing for excellent maneuverability of saws during transport between stations.

Regarding the gripper, it must be able to grab and hold circular saws of various weights and sizes. Due to its six holding magnets and three suction cups, the grip depicted in Figure 25 is a suitable option for picking up saws with a diameter ranging from 115 to 600 mm, as it had already been specified for that.

Figure 37 - Fanuc M10iD/16S (“Fanuc M-10iD/16S” 2023)

Since the robot to be implemented in the new station is already the one already in use, a study was conducted of the robot movement time. This study was carried out with the purpose of gaining an idea of the time spent in the movement of pick and place, so it can be taken into account when picking the components involving the new station, making it more efficient.

The loading and unloading time of the robot was measured using a chronometer for a 300 mm diameter saw and engraving Frezite logo plus specifications at a speed of 400 mm/s. This diameter and engraving was chosen since it is the best selling saw, leading to 15 recorded times being conducted. The count of recorded instances was 15, corresponding to the quantity of saws that required engraving for the order placed during the recording period. The robot's recorded movements encompassed descending to retrieve the saw from the cart of unengraved saws, ascending and rotating to align the saw within the engraving chamber, and subsequently rotating and descending to carefully position the saw onto the cart of engraved saws.

With the full operation times recorded, we need to remove the engraving time already validated in Table 5, to obtain an average loading and unloading time of the movement without engraving. This is done due to the fact that during the automatic engraving process the robot uses itself as a table to position the saw in the engraving stage and in the new station that won't be the case. The timed values and consequently the values of the robot operation movement time without the engraving time for a 300 mm diameter saw are displayed in Table 6.

Table 6 - Load and unload robot cycle times for engraving speed of 400 mm/s for the 300 mm diameter saw

	Load to unload	
	Total Time (s)	**Movement Time (s)**
	67.44	15.44
	68.10	16.10
	67.52	15.52
	68.15	16.15
	68.04	16.04
	68.70	16.70
	67.46	15.46
	68.02	16.02
	67.57	15.57
	67.49	15.49
	68.20	16.20
	68.12	16.12
	67.55	15.55
	68.20	16.20
	68.07	16.07
Average	-	15.91

The new station will have a new system to position the saws in the engraving stage, this will be made possible with a 2-axis table. Comprising a longitudinal axis and a rotary axis, the 2-axis table will be responsible for supplying the saw to the engraver and rotating the saw to the precise location for engraving. This option was chosen to give the Fanuc robot greater versatility during the time of the engraving process, as well as the ability to perform manual engraving if necessary.

3.2 Proposed approch to the new packaging station

In order to create the new design of the new station, it was necessary to take into account the main constraints such as the sequence of operations, location, layout and some operating requirements.

The objective of the new station is to integrate all the steps mentioned in chapter 2. With this the engraving process, the packaging and the distribution process must be present in the new station. Regarding the location, this station will be implemented in the engraving and packaging section of the saw warehouse next to the AGV path in order to obtain a better work flow, with regard to the process of distribution and collection of material for the operation of the new station. Another parameter to take into account is the organization of the processes, which must follow a sequence. Initially, it was thought of using an assembly line layout, where the processes were aligned in a single line. However the space it would occupy would not be adequate for the implementation space. Thus, it was decided to try to combine the processes in a U-shape type layout. Finally, some requirements that had to be kept in mind for the development of this new station, were the engraving process having the capacity to engrave all ranges of saws available at Frezite, taking into account the reuse of some equipment, such as the low profile cart and its docking station, the engraving machine, the vision system, the robot and its gripper. Another requirement for designing the new station was the packaging process, having the capability to pack a wide range of saw sizes and be able to work 24 hours a day.

With all this in mind the sequence of operations of the new station will be described, so that when the new station design is proposed, the possible solutions will be taken into consideration. Figures 38 and 39 help with an improved comprehension of the operation sequence.

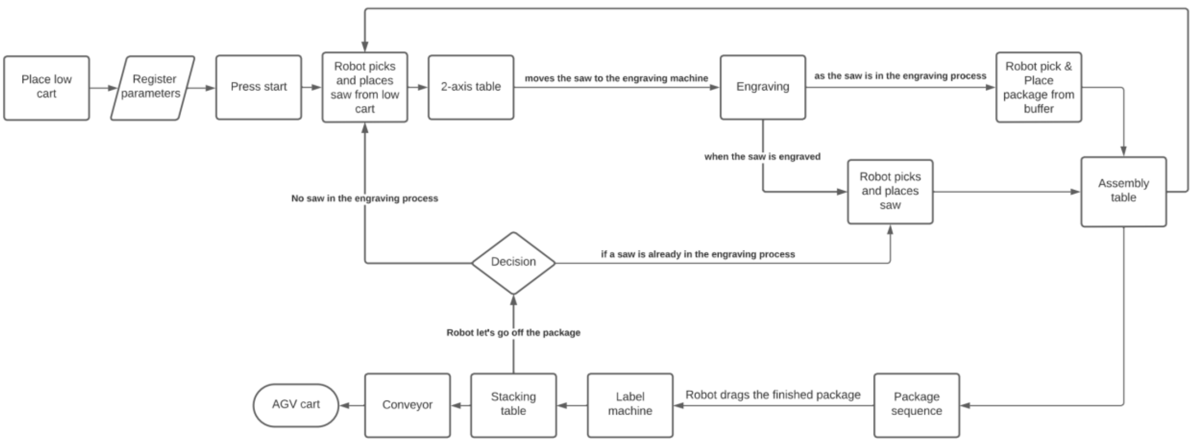


Figure 38 - Sequence of operation of the new station

An operator initiates the sequence of operations by placing a low cart with saws on a dock, similar to the stations used in the automatic engraving process. The operator then registers in the computer all the parameters to be considered for the sequence of operations in the station, including the type of engraving to be performed and the type of label. Once the parameters have been registered, the robot starts by picking up a saw from the cart and moves it to the feeding table of the engraving process, as it can be seen in the path movement 1 in Figure 39. This feeding system consists of a table with two components, one longitudinal and one rotary. Depending on the size of the saw, the longitudinal axis will allow positioning from the receiving and exiting location to the precise location for saw engraving. The rotation axis will have the function of orienting the saw so that engraving is always performed in a desired location.

While the saw is being engraved, the robot loads the packaging process with the appropriate carton packaging, path movement 2 displayed in Figure 39. After completing the engraving, the two-axis table moves to the exiting position where the robot takes the engraved saw and places it on top of the packaging already in the initial location of the packaging table, path 3 in Figure 39. With the saw in the packaging, the packaging process is carried out, while the robot returns to place a new saw in the engraving process. Once the packaging process is complete, the robot moves horizontally, using its supporting linear axis, the finished package through an automatic label printing machine that places the appropriate label on the package, until it reaches a stackable table that groups the same type of packages in height, path movement displayed in Figure 39. Then the packages are pushed through a pushing system and reach a strapping machine where they are grouped and transported to a conveyor that moves the packages to the desired location where a worker will pick and place the packages in a cart. If there is only one package of the same type, it passes the strapping process ahead and goes directly to the distribution area. In an alternative design the strapping process may not be required, meaning that this may not exist at the packing station itself.

Figure 39 provides an overview of the first layout created, with the different components identified. Some components of this layout will be carried over to the next layouts, such as the low cart and low cart dock station, the computer and its support, the structure of the engraving process, the robot model and finally the labeling machine.

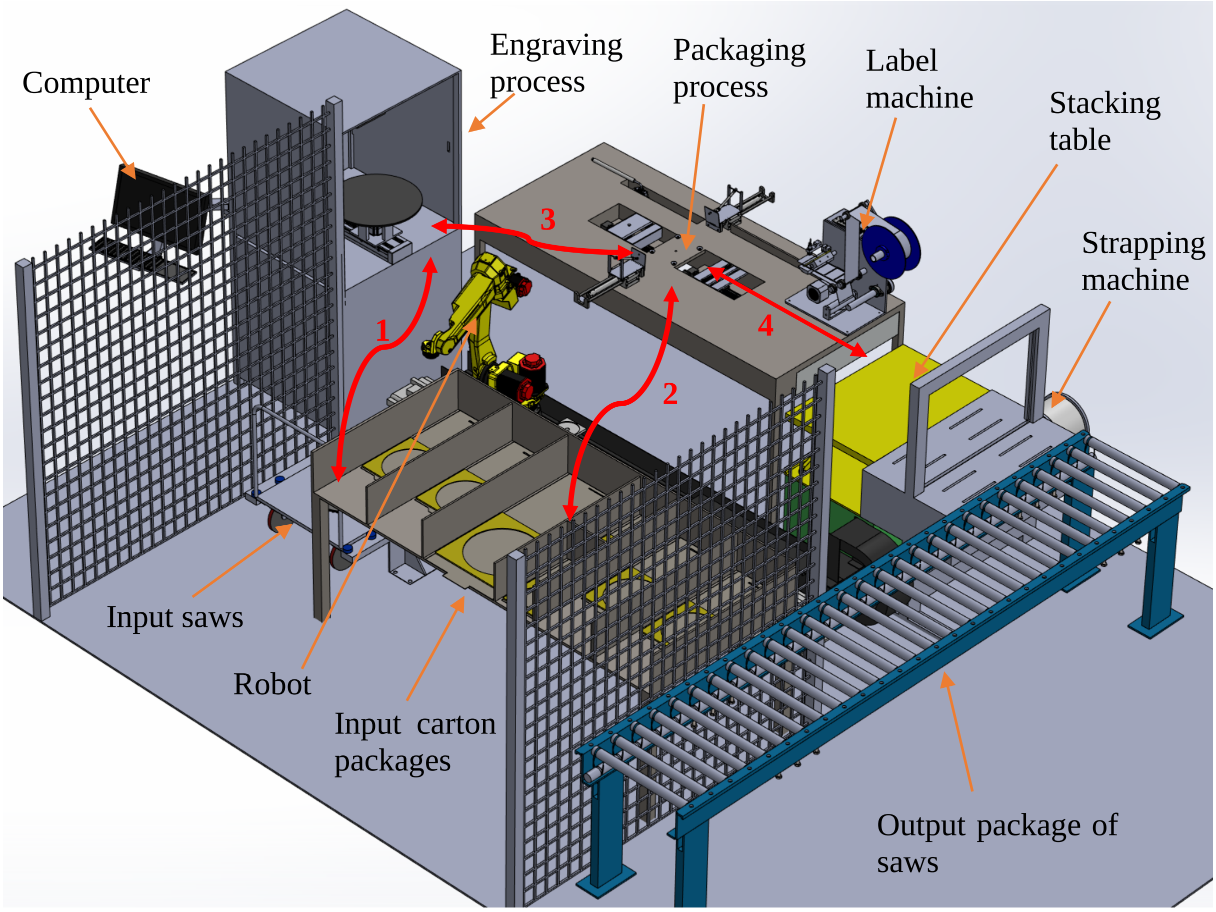


Figure 39 – Overall view of layout 1

The engraving process illustrated in Figure 40 is composed of 3 main components, a two-axis positioning table already mentioned above, an engraving machine that will have the purpose of engraving the saws and finally a vision system represented by a camera that will make it possible to verify that the saw to be engraved is the correct one, as well as indicate the suitable engraving location on the saw. Both the engraving machine and the vision system are currently in use in the automated engraving process.

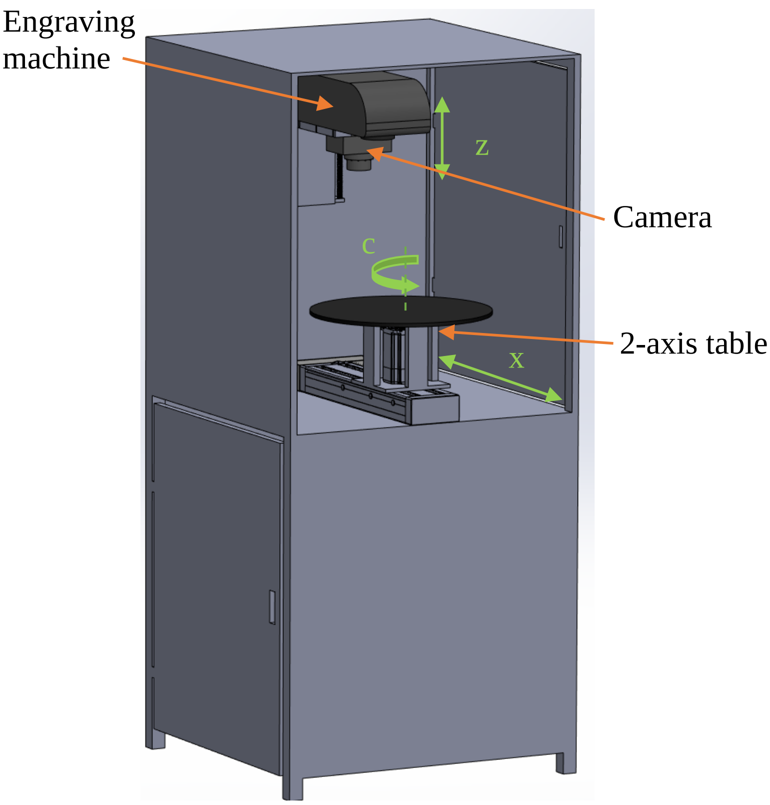


Figure 40 - Engraving process

Due to the diversity of packages possibly used, this design places an emphasis on the process of arranging the unfolded carton packages. The storage table proposed and designed shown in Figure 41 can accommodate up to 250 unfolded packages in total, for the configuration illustrated in the figure, this includes having 4 slots for packages that can accommodate saws from 240 to 360 mm in diameter, 2 slots for packages that can accommodate saws from 115 to 240 mm in diameter and 1 slot for the bigger packages that can accommodate saws from 360 to 520 mm in diameter. This number of packages does not cover the capacity required for a typical day's work, as there is a great deal of variety; however, it was designed to be able to fulfill half of the orders for the most frequently requested circular saws. The table is inclined at a 5 degree angle to facilitate the placement of packages and ensure that they do not slide off the buffer and are always in the same location, as well as to improve the robot's ability to collect packages. This storage table in not configurable and is manually loaded by an operator.

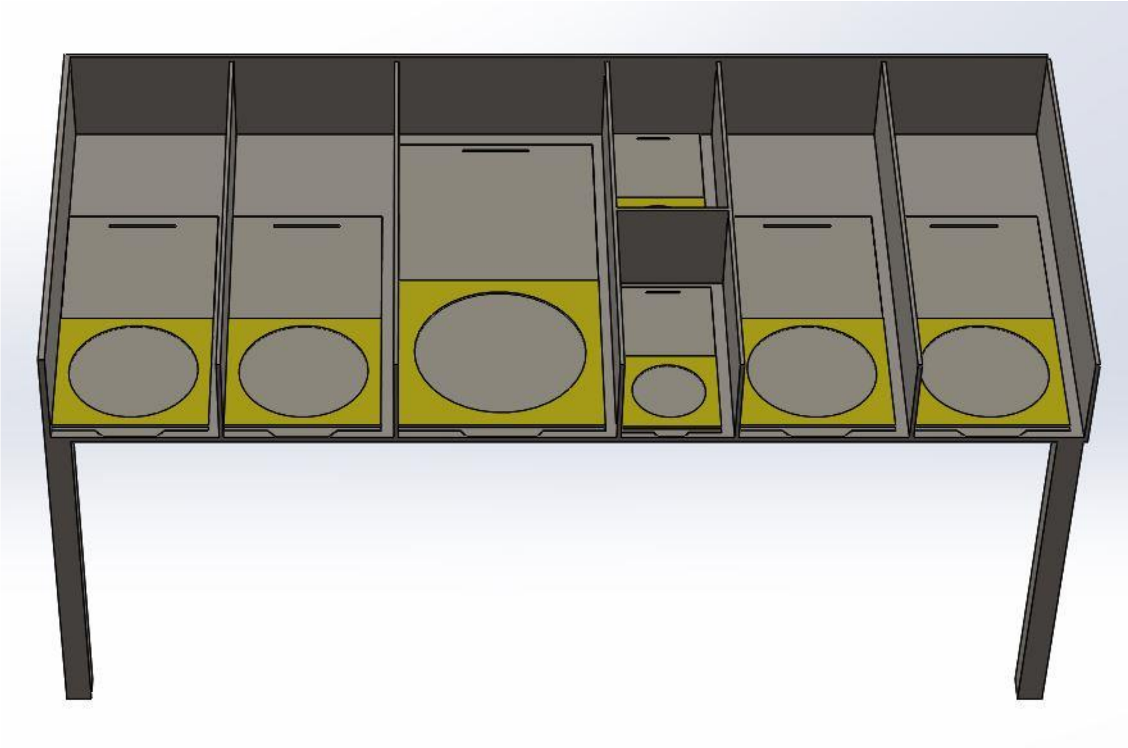


Figure 41 – Input storage of cartons packages

With the same importance placed on the design of the input cartons packages, the assemble table and its packaging system is a crucial design element, as it must be able to accommodate the various sizes of packaging and ensure quick and efficient packaging. Figure 42 illustrates the assembly table as well as the packaging system conceived and designed to fulfill the main packaging movements (i.e bending, folding, closing). Figure 42 depicts a guiding wall, the purpose of which is to place the package in the correct position after it has been completely packaged, so that when it travels through the labeling machine, the label is always placed in the correct location. In the table's design, a rectangular area was envisioned at the table's center to place and secure the utilized packages. This area features a central point intended to serve as a reference for, facilitating the correct placement of both the package and subsequently the saw within it.

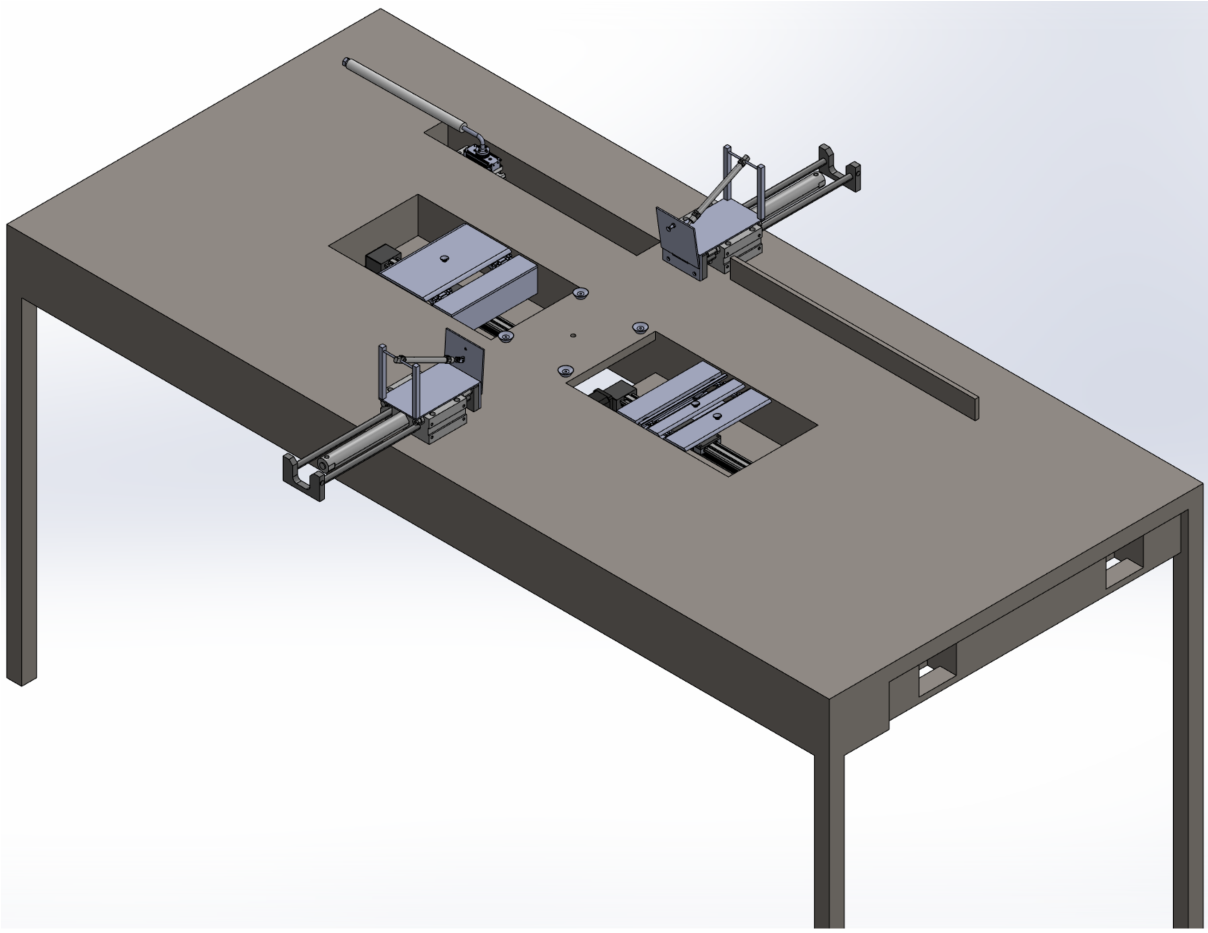


Figure 42 - Packaging table

To facilitate comprehension of the packaging system, Figures 43, 44, and 45 present its three main components.

The lower handling system shown in Figure 43 is intended to close the packages by folding the two halves. One half is intended to close the larger part of the packaging which, through its groove, allows the joining of both package parts and the other half is intended to carry out the folding of the smaller part of the packaging which, when aligned with the groove in the larger part of the package allows closing and sealing the package. This system contains of two linear guides that have the purpose of moving the folding system to the exact place of operation depending on the package used.

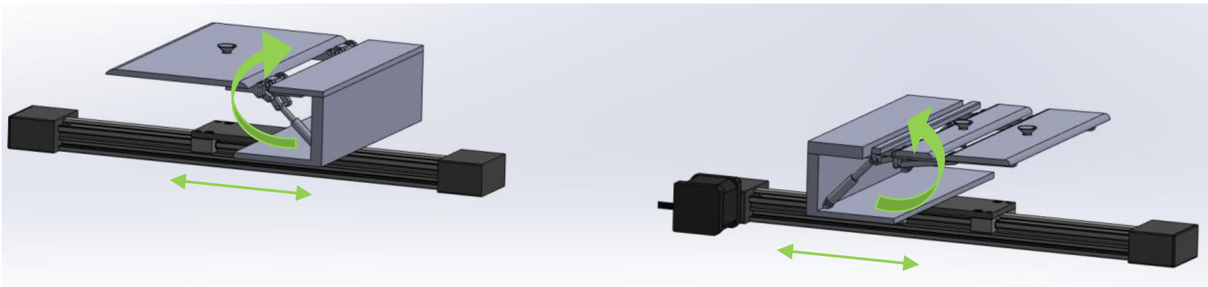


Figure 43 - Lower handling system

Figure 44 represents a rubber paper roll mechanism whose function is to ensure the position of the Vapor Corrosion Inhibitor (VCI) paper in the correct position after the saw has been placed in the package. This mechanism is composed of two pneumatic actuators: one designed to move the system dependent on the package (linear actuator), while the other is designed to position the arm roller to the works position (angular actuator).

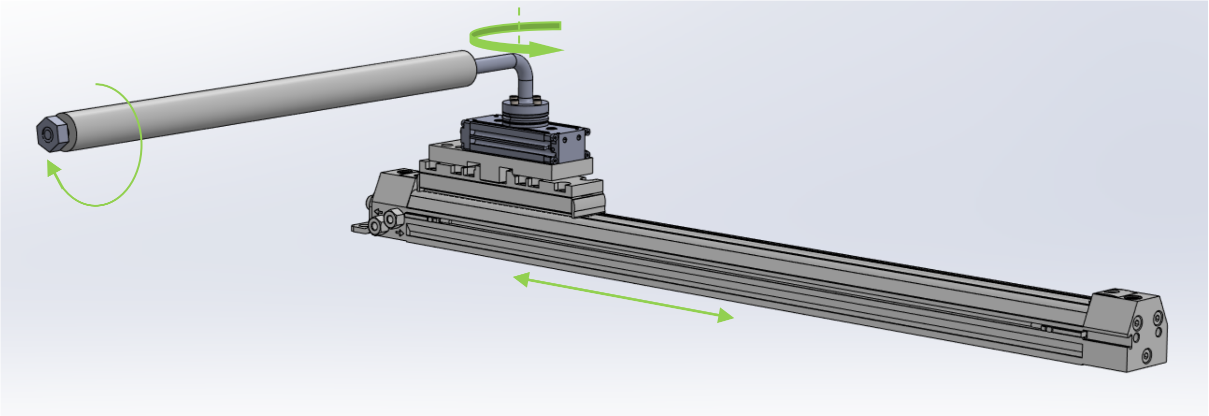


Figure 44 - Roller mechanism

The tab handling system shown in Figure 45 has the purpose to lift and lower the flaps of the packaging, so that the saws can be placed in the packaging and also secure the VCI paper on to the saw. The mechanism consists of a pair of pneumatic cylinders: one designed to position the system depending on the package, while the other functions to raise and lower the flaps, assisted by a suction cup to secure the flaps in place.

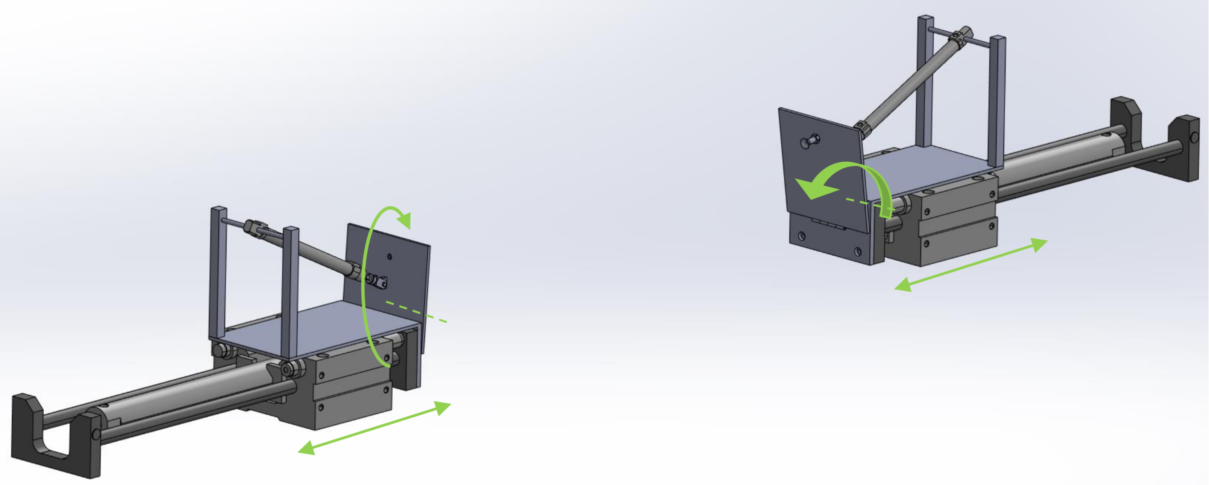
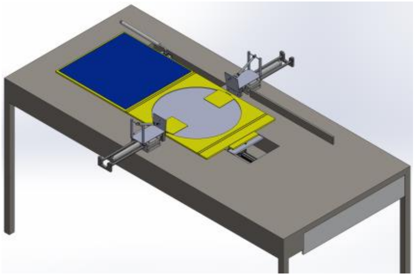
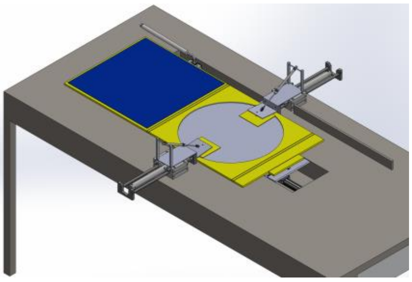


Figure 45 - Tab handling system

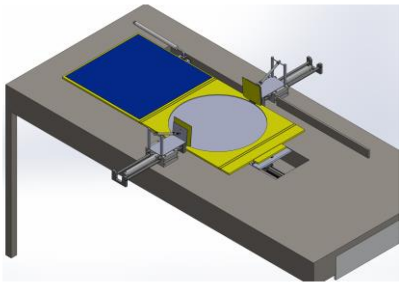
To better understand the process of the handling system, a sequence of operations is displayed in Figure 46.



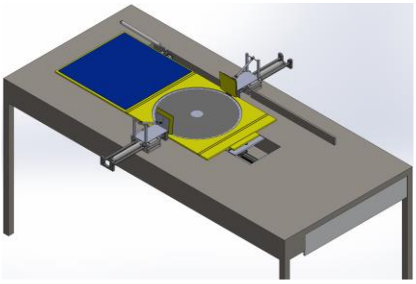
a) Placement of the package



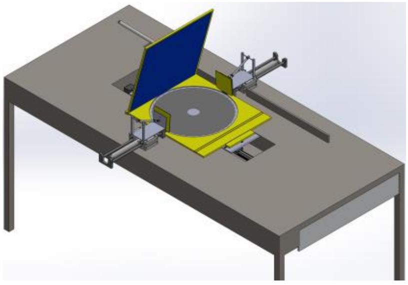
b) Tab handling system goes to position



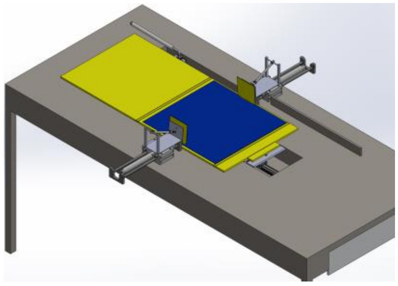
c) Pick up tabs



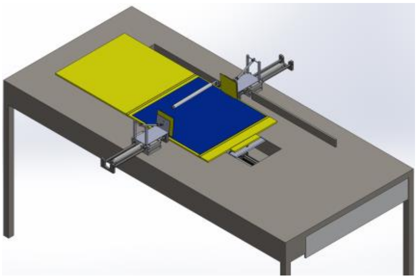
d) Saw placement



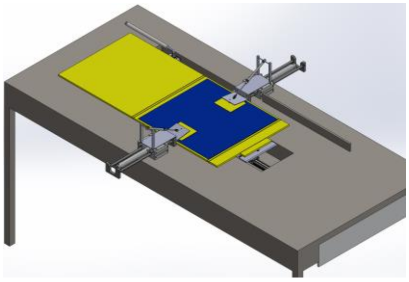
e) Lift one side of the package to let the vci paper down



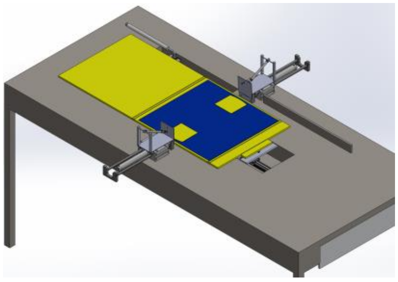
f) Vci paper placed layed down



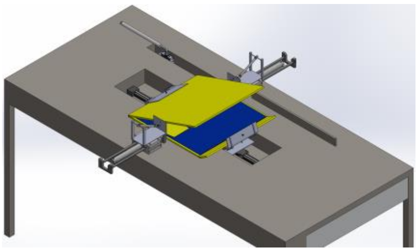
g) Roller mechanism ensures vci paper is placed correctly



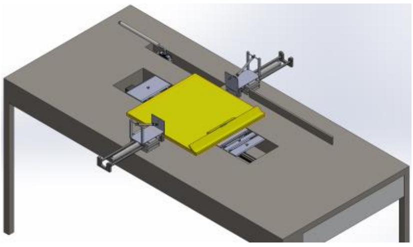
h) Tabs goes down



i) Tab handling system reset position



j) Closing package



k) Finished package

Figure 46 - Sequence of packaging operations

With the packaging system visualized, a method was idealized to vertically arrange the packages so that they could be strapped on the strapping machine if necessary. Figure 47 represents an electro-hydraulic lift table that can be programmed for establishing the number of stacked packages.

In order to be able to transfer the grouped packages from the stacking table to the strapping machine, a push system was designed that could be mounted within the packaging table in order to optimize space. This system is composed of two pneumatic cylinders and a metal plate, as can be seen in Figure 48.

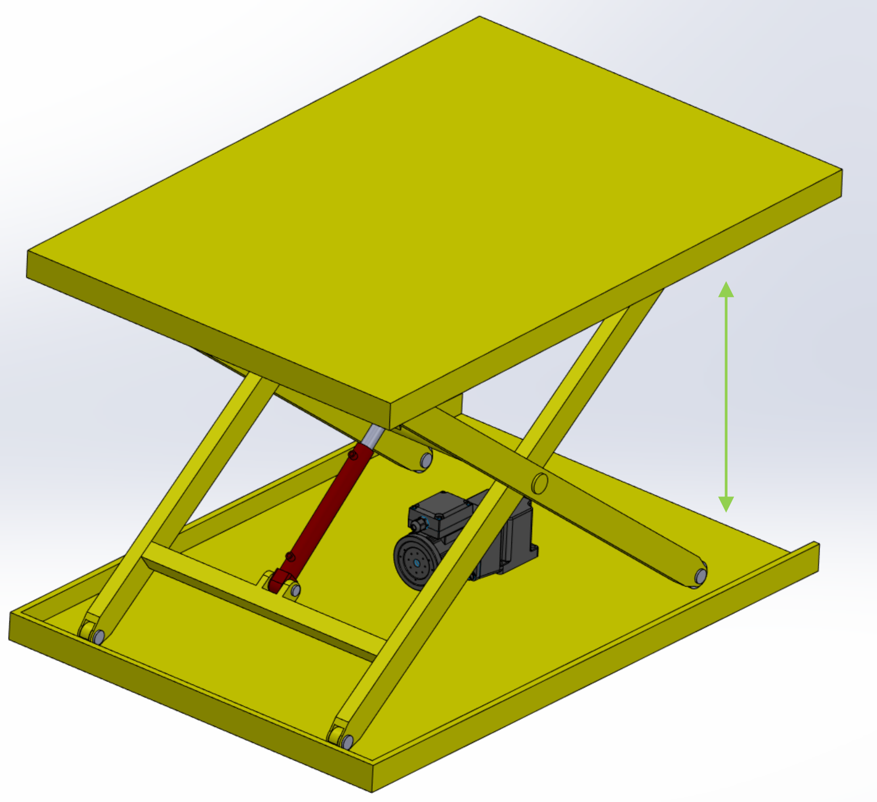


Figure 47 - Stacking table

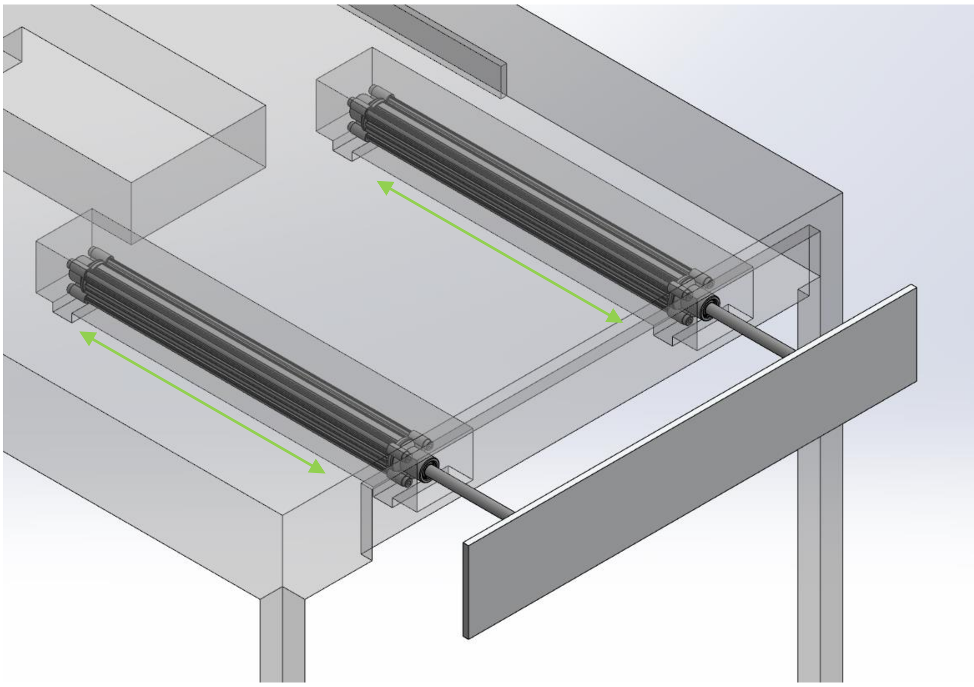


Figure 48 – Packaging push system

The distribution area is made up of a roller conveyor that has the purpose of transporting by gravity the finished packages to be manually removed to a cart, afterwards transported by an AGV to the distribution warehouse. This conveyor can be visualized in Figure 49.

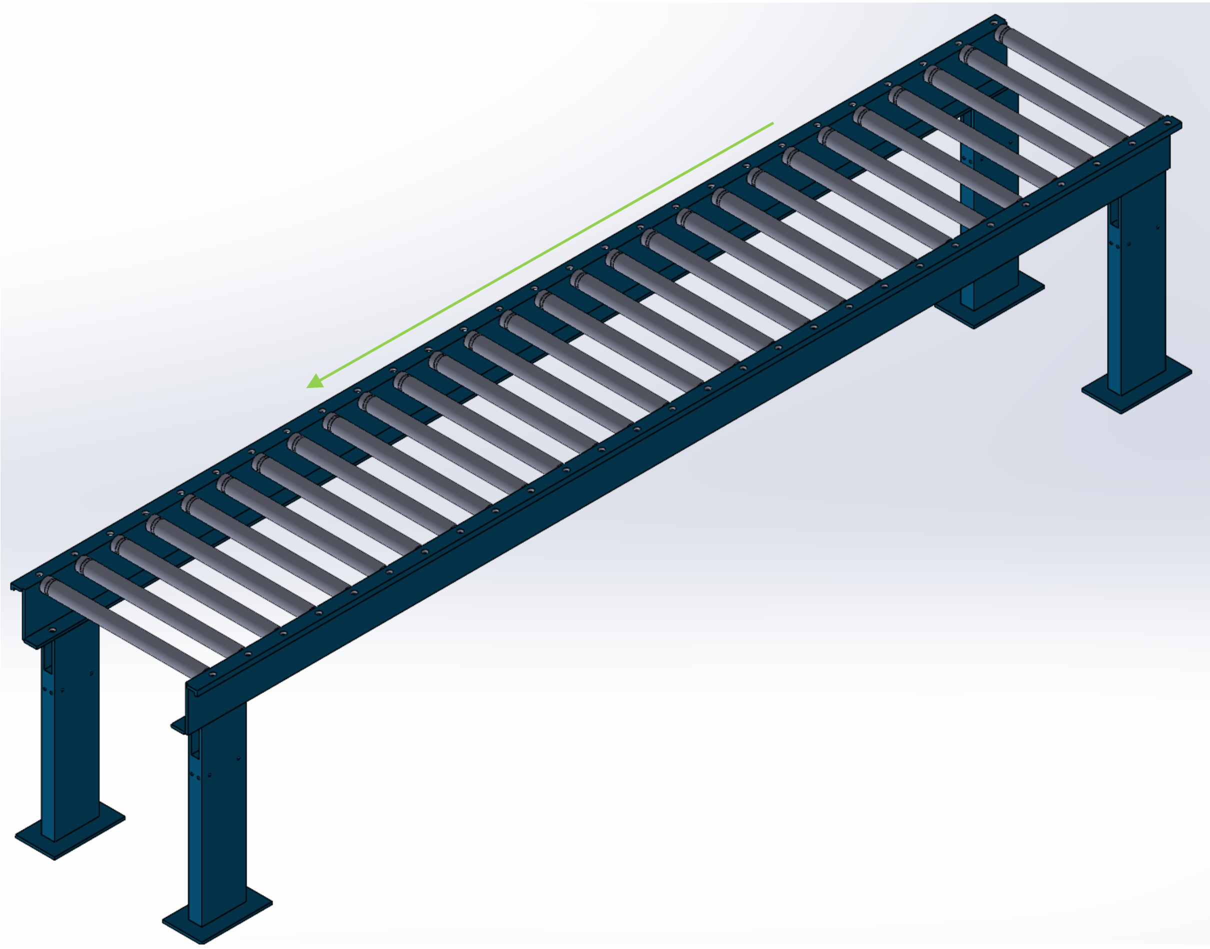


Figure 49 - Roller conveyor

After developing the first layout, an alternative design was developed in order to reduce the space occupied and improve the distribution process. This new design emerged from the elimination of the strapping machine and the necessity for support the loading stacked packages onto the carts. The new design can be observed in Figure 50.

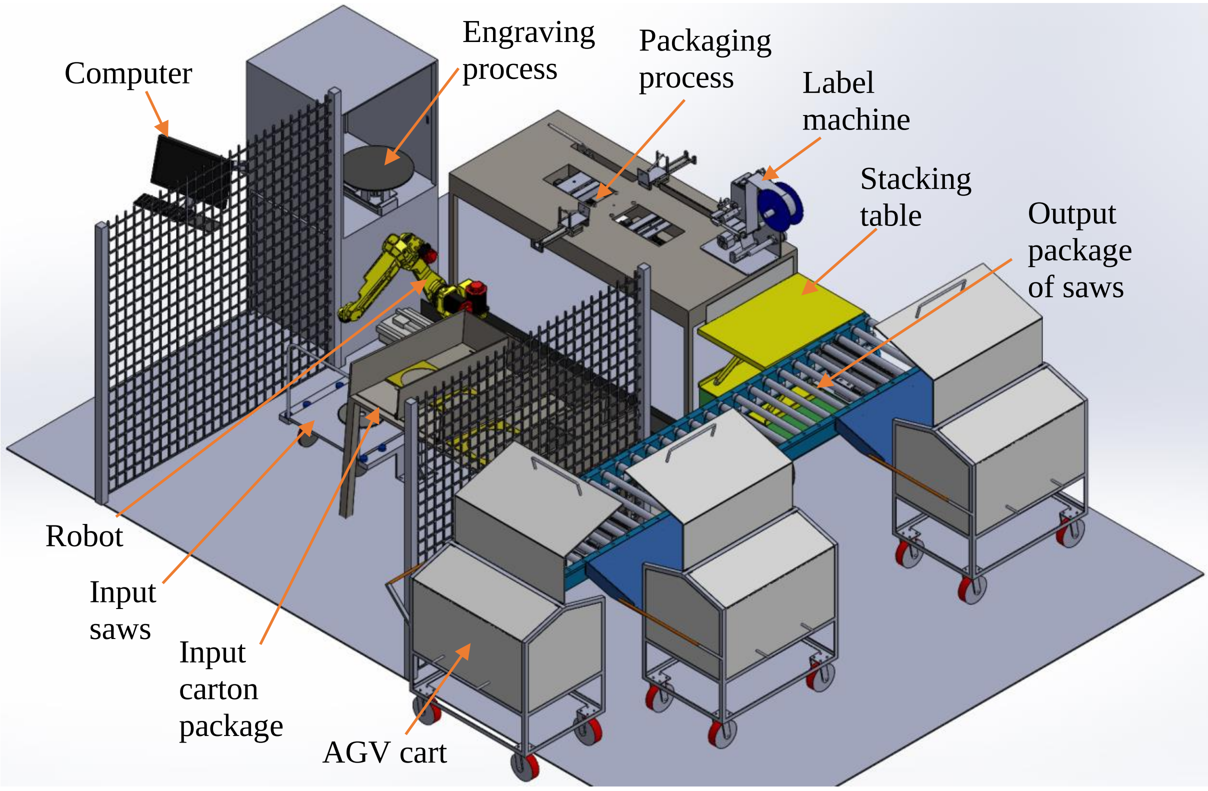


Figure 50 – Overall view of layout 2

With the reduction of the space the input carton package was also reduced, resulting in the previously defined objective of attempting to provide half of the most frequently used package required for a day's work is no longer feasible. Therefore, it was crucial to establish new operational goals for the new input carton package, being decided to attempt to supply the quantity of packaging necessary for the execution of one cart at a time. For this to be feasible, it was necessary to know that the cart's maximum capacity, which stands at 100 saws. As space is limited in the design of the new storage table, a solution was devised that allows the table's dimensions to be adjusted to accommodate all necessary packages, regardless of their size. This was accomplished by the use of shelves that slide in two grooves and a spring and pin system to secure the shelves in the desired position. Under this changes, a worker will be required to supply the input carton package with new packaging every time a new cart is positioned at the station. It is possible to visualize the new input carton package from Figure 51.

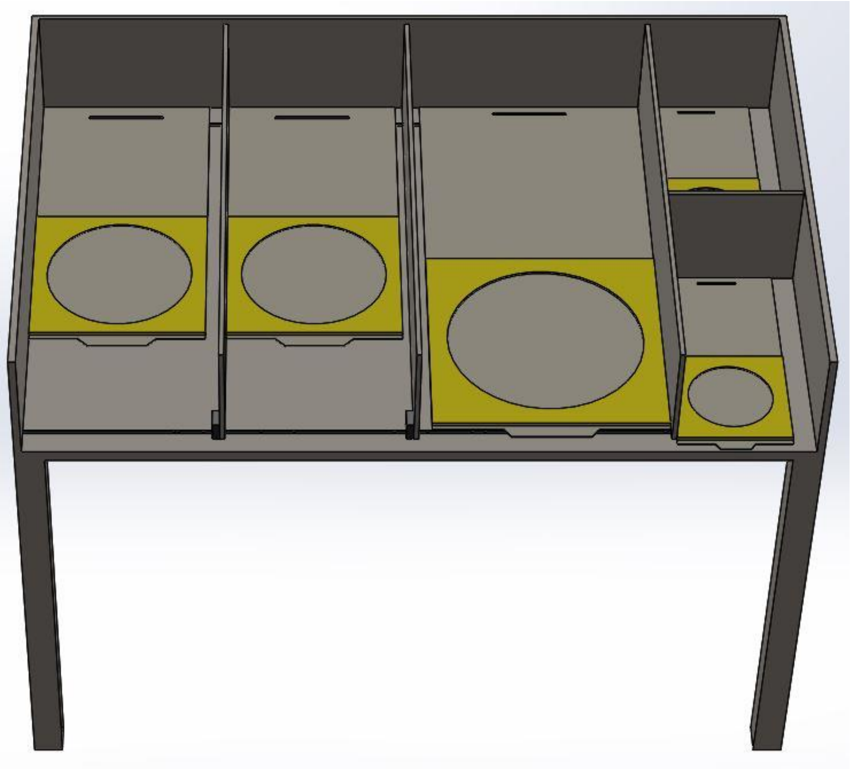


Figure 51 – Smaller input carton package

With the new input carton package defined we can move into the output package of saws. The output is composed of a motorized roller conveyor with modular transfer units displayed with more clarity in Figure 52.

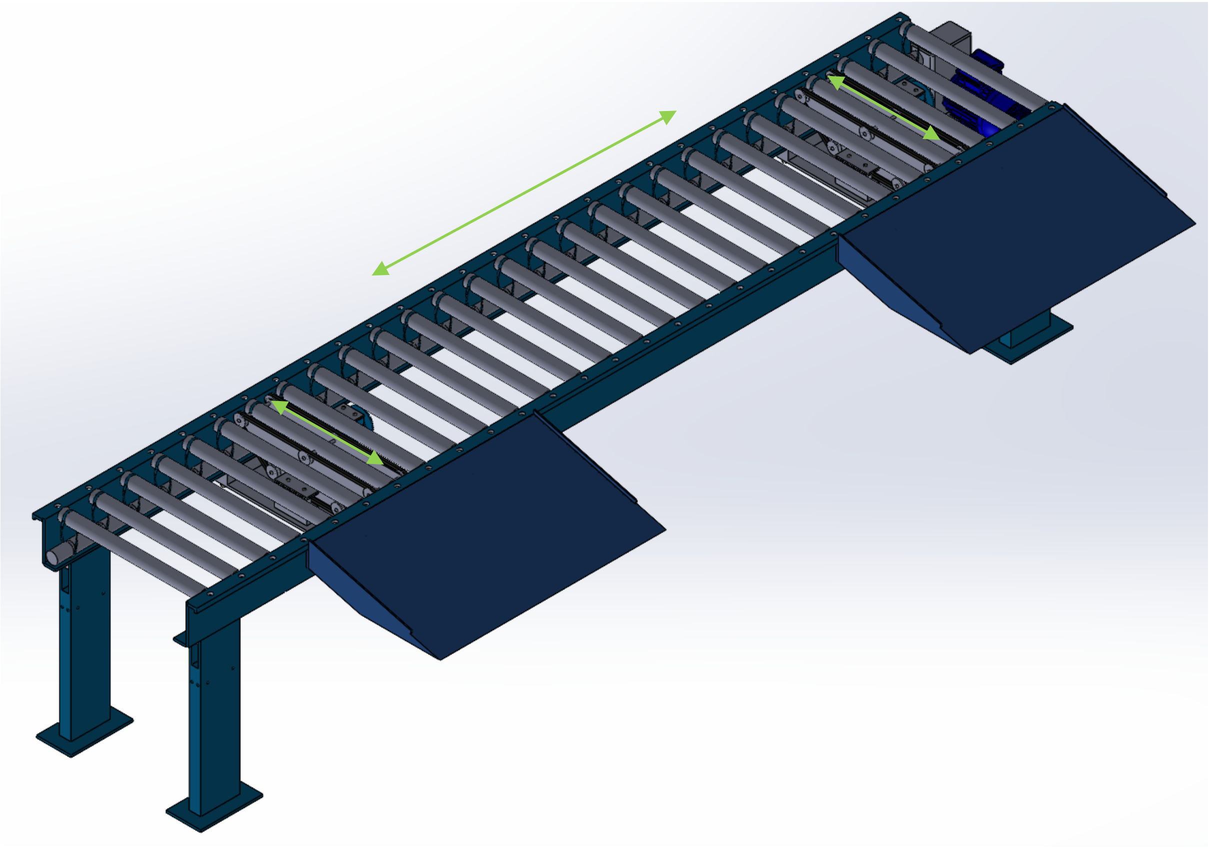


Figure 52 - Distribution conveyor

The roller conveyor was designed with the intention of grouping multiple carts so that distribution can be performed in a variety of ways, such as, each cart being loaded with each order or loaded until the cart is full or even loaded with a specific quantity of packaging, among other possibilities. One prerequisite for the implementation was the capability to manage the weight of stacked packages, alongside the capacity to accommodate varying package sizes. The conveyor consists of three components: The first is a motorized roller conveyor that drives the packages through a linear path visible in Figure 53. This type of conveyor was chosen due to having the possibility to incorporate different modules, one of them being the transfer unit.

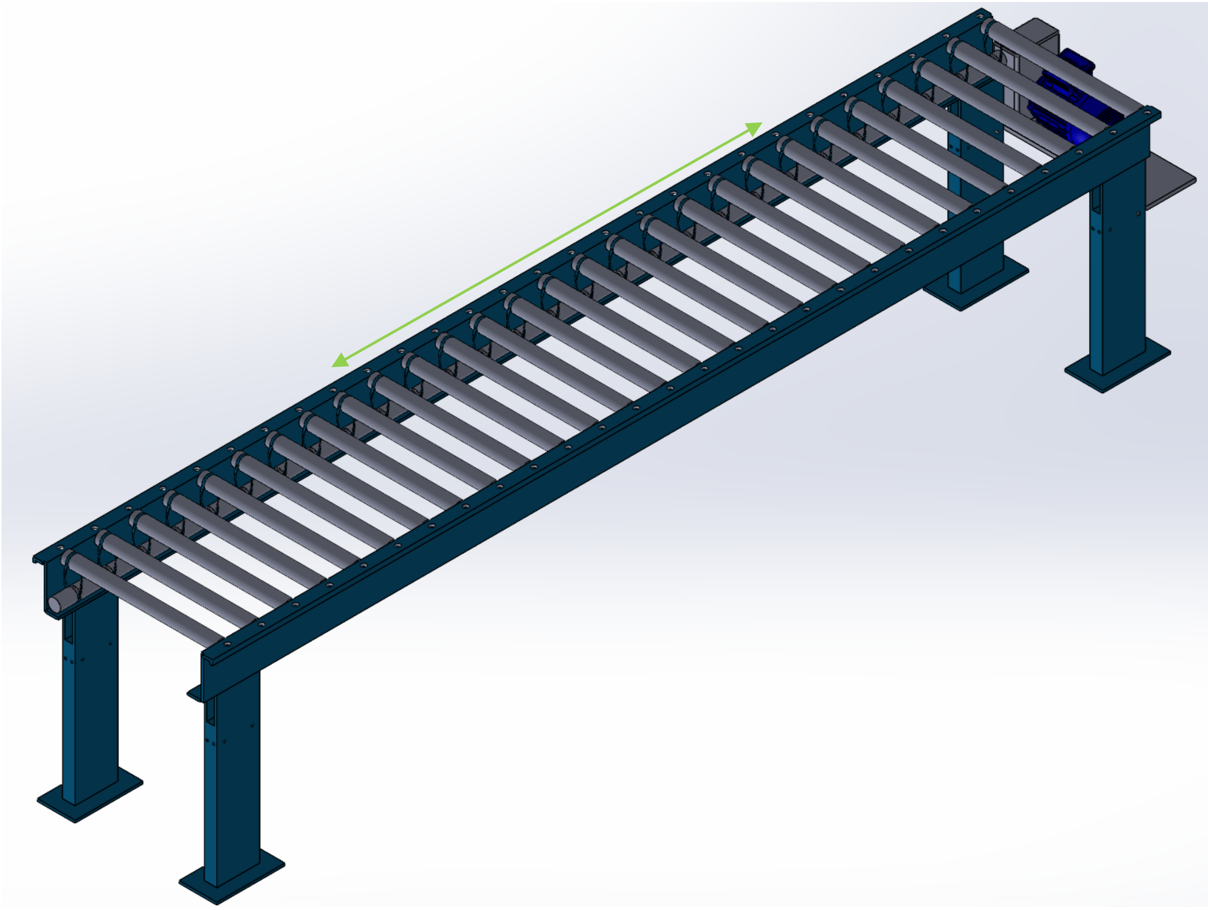


Figure 53 - Roller conveyor

The second component are two chain transfer conveyors that drive the packages in the transverse direction of the roller conveyor in order to move the packages to the desired cart and the third component consists of a pair of ramps designed to enable the smooth sliding of packages onto the carts, thereby streamlining the process of loading packages by workers. The second and third component can be visualized in Figures 54 and 55.

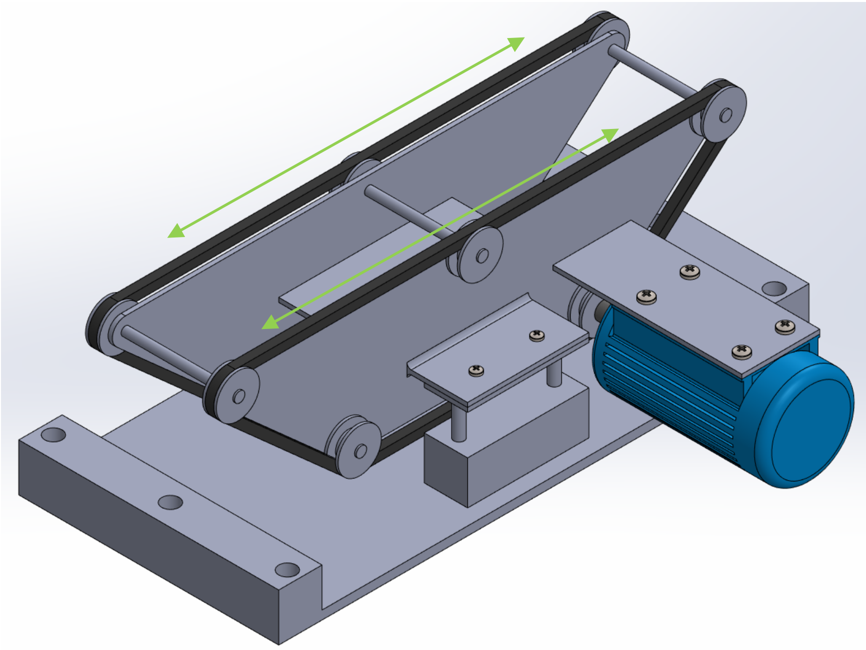


Figure 54 - Chain Transfer Unit

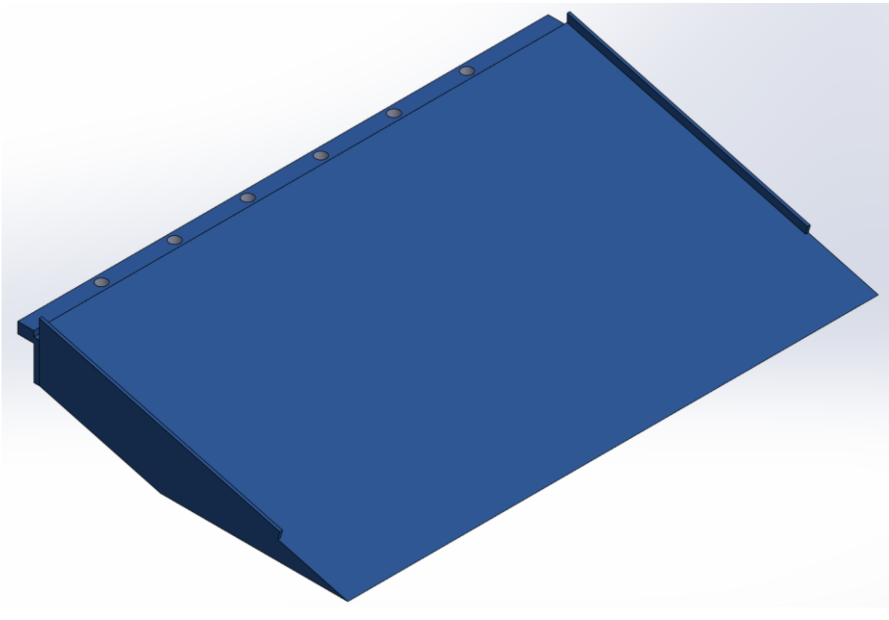
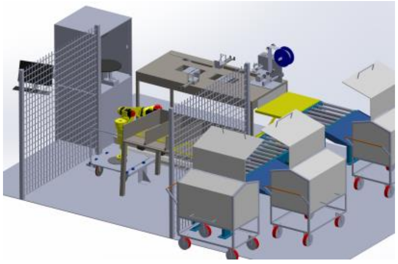
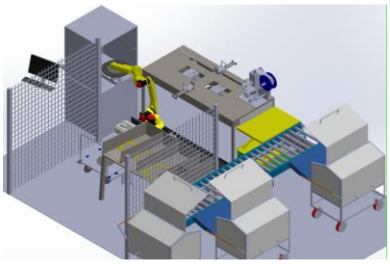


Figure 55 – Ramp

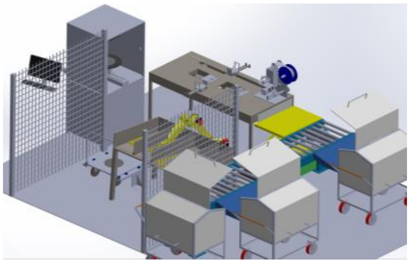
A motion model is presented through the sequence of images in Figure 56 to better illustrate the conceptual solution proposed. To prove that the proposed solution is feasible, the picked layout will be detailed in greater depth in the following chapter.



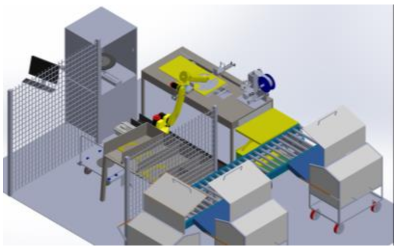
a) Pick up saw



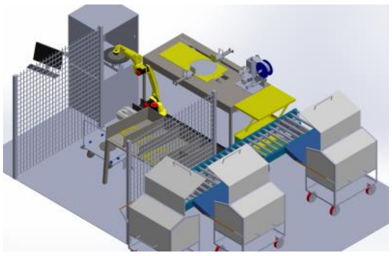
b) Place saw in the 2-axis table



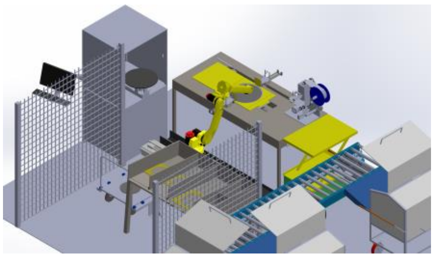
c) Engraving saw and pick package from buffer



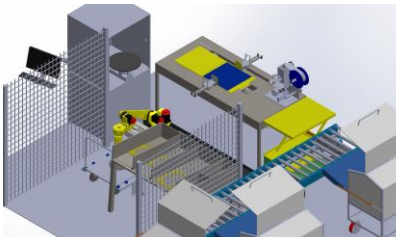
d) Place package in assembly table



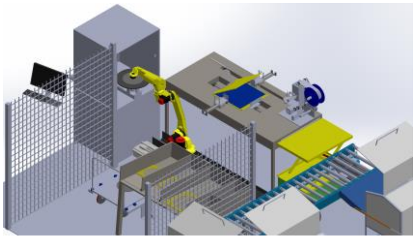
e) Pick saw engraved saw



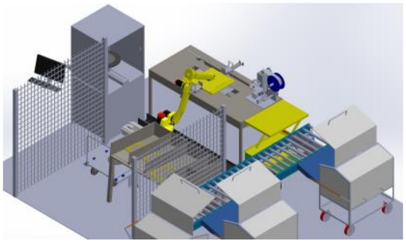
f) Place engraved saw in package



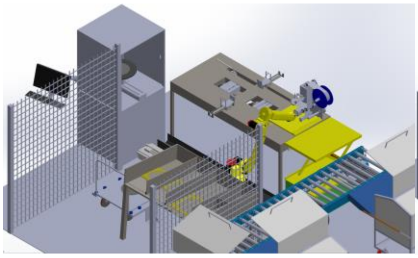
g) Packaging operation and pick up new saw



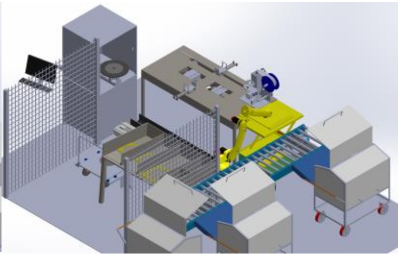
h) Place saw in the 2-axis table



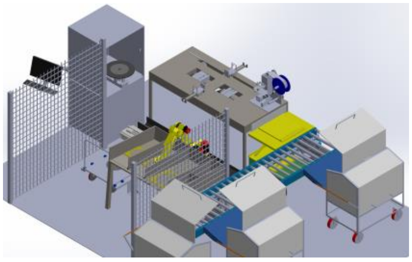
i) Grab and drag completed package



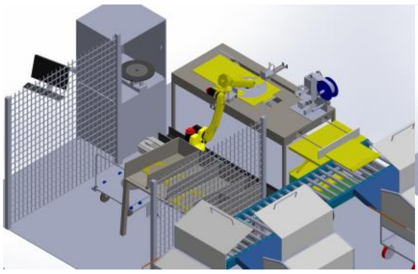
j) Drag package through label machine



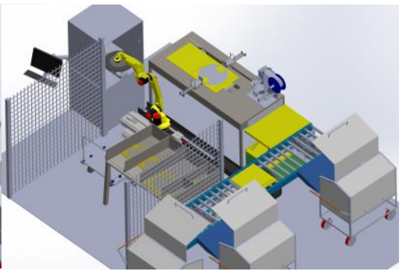
k) Release package in stacking table



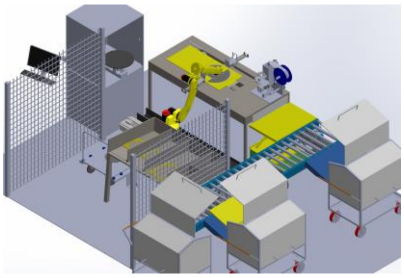
l) Stacking table descend and pick new package



m) Pushing system activation



n) Transport package to destined cart and pick up the engraved saw



o) Place engraved saw in package and package enters cart

Figure 56 - Sequence of operation of the new station

4 Detailed description of the proposed design

In this chapter, we dive deeper into the layout 2 proposed in the previous chapter, describing its features in greater detail. Specifically, we will present the main components and their unique properties, that includes sizing and selecting the actuators, the different electric motors, gearboxes, drivers, and controllers.

4.1 Select and specify the components of the engraving process

After defining the design, it is necessary to select the components that will be used in the various processes of the new station to be implemented. Beginning with the engraving process, this process consists of a 2-axis table, a vision system, and an engraving machine as it was illustrated previously in Figure 37.

The components of the two-axis table will be purchased from the company Qualas group, which provided the specifications for the mechanical components and external axis controller (EAC) of the two-axis table (“Qualas Group” 2023).

The 2-axis table consists of two distinct components: a horizontal linear axis that transports a saw from the location where it is fed, through a vision system, where it pauses momentarily, and then to the engraving location, where the saw is engraved, and back to the initial location after the engraving has been performed. The second component is a rotating axis that rotates a base where the saws are placed. This axis is designed to rotate the saw to the desired engraving location, allowing saws of the same series to be engraved in the same location.

The selection of an electric motor for a given application depends on various parameters and is normally an iterative process. The various considerations and requirements include the values of the loads, torques, speed values involved, the type of movements and velocity profiles, the accuracy of positioning and velocity, the type of operation cycle, among others. In the following cases a simplified analysis was considered in order to verify if the concept design proposals presented previously can be pursuit. A review of the actuators sizing will be necessary at a detailed design stage, if an implementation decision is made.

Regarding the rotary actuator axis of the positioning table, a step motor selection can be justified because it enables good accuracy in position in an open loop control mode, and therefore this was the decision taken. To verify the loads/torques involved, the materials of the table, the velocity profiles and other movement requirements were established as presented in Table 7.

The main sizing criteria for step motors is for the torque load to be well below (ie. safety factor of 2) the motor´s torque/speed curves at the maximum desired speed, and to limit the load to motor inertia ratio (ie. 10). The motor will directly drive the table.

Table 7 - Specifications for the rotary axis

Table	
Diameter	500 mm
Thickness	6 mm
Density	2800 kg/m^3 (Aluminum)
Mass	3.2 Kg
Drive shaft dimensions	
Diameter	20 mm
Length	100 mm
Density	7900 kg/m^3 (Steel)
Mass	0.25 Kg
Maximum Load	
Diameter	1000 mm
Thickness	3 mm
Mass	30 kg
Table support bearing	
Friction coefficient	0.015
Distance from the table center to the supporting mechanism	200 mm
Operating conditions for a triangular velocity profile	
Stopping accuracy	1º
Positioning distance	30º
Acceleration/deceleration time	0.5 s
Holding time	60 s
Safety factor	2

After having the various specifications defined, using the equation 4.1 we determine the operation speed.

$$\Theta = 1/2 \cdot w \cdot t_1 \tag{4.1}$$

Where:

Θ, is the positioning distance
w, is the maximum angular velocity, considering a triangular velocity profile
t_1, is the acceleration time

With the maximum angular velocity being 1.047 radians per second, the moment of inertia and torque can be calculated using equations 4.2 to 4.6 (Richard G.Budynas and Keith Nisbett 2011).

$$J_t = 1/8 \cdot m_t \cdot D_t^2 \tag{4.2}$$

Where:

J_t, is the table inertia
m_t, is the table mass
D_t, is the table diameter

$$J_L = J_t + J_s + J_I \tag{4.3}$$

Where:

J_L, is the total inertia
J_s, is the drive shaft load inertia
J_I, is the load inertia

$$T_A = J_L \cdot \alpha \tag{4.4}$$

Where:

T_A, is the acceleration torque
A, is the angular acceleration

$$T_L = g \cdot m_{total} \cdot \mu \cdot l \cdot (1/\eta \cdot 0.01) \tag{4.5}$$

Where:

T_L, is the load torque
μ, is the friction coefficient of the table support bearings
l, is the distance from the table center to the table support bearings
η, is the system efficiency

$$T = (T_A + T_L) \cdot \text{ Safety Factor} \tag{4.6}$$

Where:

T, is the total torque reference to select the motor

Based on the given data (Table 7) and the following equations the resulting values are presented in Table 8.

Table 8 - Result values for sizing rotary axis

Inertia values	
Table inertia	0.1031 kgm^2
Drive shaft load inertia	1.2409x10^{-5} kgm^2
Load inertia	3.750 kgm^2
Total inertia	3.853 kgm^2
Torque values	
Acceleration torque	8.070 Nm
Load torque	1.152 Nm
Total torque	18.44 Nm

To size the motor, we must also know the inertia ratio to be considered and the gear ratio if needed, to do so the equation 4.7 is used. In consideration of motor frame size 85, the reference value of 10 for the inertia ratio was taken into account. This value was sourced from Oriental Motor's motor selection tips for appropriately sizing motors (“Oriental motors” 2023).

$$\text{Inertia ratio} \geq J_L / (J_o \cdot i^2) \quad (4.7)$$

Where:

J_o, is the motor inertia
i, is the gear ratio

With all the requirements presented, the selected RM 3R3M stepping motor form R.T.A. could not satisfy the requirements, so the PD085-BAD040 planetary gearbox from planetroll was selected (“R.T.A.” 2023) (“Planetroll” 2023). The calculations were redone with the gearbox and presented in Table 9.

Table 9 - Result values for sizing rotary axis with gearbox

Inertia values	
Table inertia	0.1031 kgm^2
Drive shaft load inertia	1.2409×10^{-5} kgm^2
Load inertia	3.750 kgm^2
Total inertia	3.853 kgm^2
Torque values	
Acceleration torque	8.183 Nm
Load torque	1.152 Nm
Total torque	18.67 Nm

The driver selected for the motor is the 230 Vac X-PLUS which was recommended by the motor manufacturer. The specifications of the motor, gearbox and driver can be seen in more detail in appendix A.

After the rotary axis components have been selected the linear axis motor could be sized. The selected *linear unit LES 6* model made by isel consists of four Ø 12 h6 steel shafts encased in an aluminum housing measuring 990 mm in length, 150 mm in width, and 75 mm in height (“Isel” 2023). This linear axis was selected due to having the capabilities to support the torque momentums and forces and offers high precision and accuracy in positioning with a repeatability of ± 0.02 mm.

In the same approach as the rotary axis, some specifications need to be presented before calculating the inertia and torque required for the motor. Table 10 shows the specifications taken into account.

Table 10 - Specifications for sizing the linear axis

Load	
Motor plus gearbox mass	6.7 kg
Saw mass	30 kg
Table mass	3.2 kg
Table support volume	5.346×10^{-4} m^3
Friction coefficient of the guide	0.015
Ball/Lead screw specifications	
Diameter	10 mm
Total length	590 mm
Pitch	4 mm/rev
Efficiency	85 %
Density	7900 kg/m^3 (steel)
Mechanism placement horizontal	
Mechanism angle	0º
Operating conditions	
Positioning distance	400 mm
Positioning time	3 s
Stopping time	60 s
Acceleration/deceleration time	0.5 s
Stopping accuracy	0.02 mm
Safety factor	2

With the sequence of equations 4.8 to 4.17 we obtain a total torque of 4.92×10^{-2} Nm, a root mean squared torque of 5.39×10^{-3} Nm, a total inertia of 2.56×10^{-5} $Kg \cdot m^2$ and a required speed of 3000 rpm.

$$J_W = m_W \cdot (P_B/2\pi)^2 \tag{4.8}$$

Where:

J_W, is the total load inertia
m_W, is the total load mass
P_B, is the pitch

$$J_B = (\pi/32) \cdot \rho \cdot L_B \cdot (D_B)^4 \tag{4.9}$$

Where:

J_B, is the ball screw inertia
L_B, is the total length
D_B, is the ball screw diameter

$$J_k = J_w + J_B \tag{4.10}$$

Where:

J_k, is the total inertia

$$w = (L/(t_0\text{-}t_1))\cdot(60/P_B) \tag{4.11}$$

Where:

L, is the positioning distance
t_0, is the positioning time

$$T_A = (1.2\cdot J_k)\cdot(w/(9.55\cdot t_1)) \tag{4.12}$$

Where:

T_A, is the acceleration torque

$$F = F_a+(m_w\cdot 9.81)\cdot(\text{sen}\alpha+\mu\cdot\cos\alpha) \tag{4.13}$$

Where:

F, is the total force
F_a, is the external force
A, is the mechanism angle

$$T_L = (((F\cdot P_B)/2\pi)\cdot 1.1+T_B)\cdot(1/(\eta\cdot 0.01)) \tag{4.14}$$

Where:

T_L, is the load torque
T_B, is the breakaway torque of the screw

$$T = (T_A + T_L)\cdot\text{Safety Factor} \tag{4.15}$$

Where:

T, is the total torque

$$T_{rms} = \sqrt{(((T_A+T_L)^2\cdot t_1 + T_L^2\cdot(t_0 - 2\cdot t_1) + (T_A - T_L)^2\cdot t_1) / (t_0 + t_s))}\cdot(\text{Safety Factor}) \tag{4.16}$$

Where:

T_{rms}, is the root mean squared torque
T_s, is the stopping time

$$\Delta\Theta = \Delta l\cdot(360\,/\,P_B) \tag{4.17}$$

Where:

$\Delta\Theta$, is the required stopping accuracy
Δl, is the stopping accuracy

For the electric motor of the linear axis it was selected the option of the axis manufacturer, the direct drive motors suggested by the *linear unit LES 6*, the EC 60TM 400W 48V servo motor was selected due to satisfying all the requirements. The linear unit and the motor can be seen in more detail in appendix A.

The EAC controller shown in Figure 57 is a dedicated controller for controlling and operating two linear axes, consisting of a control panel and an emergency button located on the front of the controller, and four interfaces and the power switch on the rear. The interfaces are composed of two dedicated connectors for the X and Z axis, an interface for the PC via a usb port, and an interface for the emergency system. Through Figure 58 it’s possible to visualize the placement of the operating elements. Controlling the position of the components is performed from the computer using the MagicMark engraving software; however, it is also possible to move the components using the controller's control panel interface.

Figure 57 - External axis controller (“ACI Laser marking solutions” 2023)

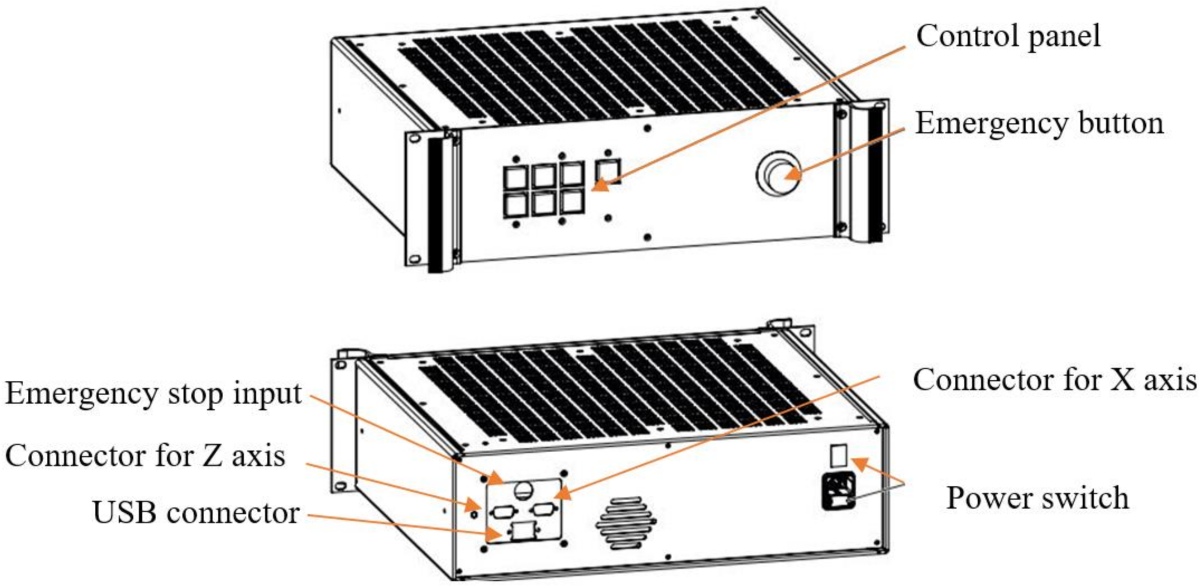


Figure 58 - EAC operating elements (“ACI Laser marking solutions” 2023)

Along with the EAC controller and the two-axis table, the Qualas company also provides the engraving machine. The machine in question is the DFL Ventus Marker that has the ability to engrave different materials, as can be seen in Figure 59. This solution corresponds to the currently used in the manual and automatic existing engraving systems and therefore it was selected as well for the new station.

Metal	
Temper the metal	●
Engrave metal	●
Remove metal	●
Plastic	
Foam plastic	●
Carbonize plastic	○
Engrave plastic	–
Laser foil	
Foil removal	●
Foil color cover	●
Glass	–
Ceramics	○
Wood, paper, leather	–

– not suitable ○ well suited ● very suitable

Figure 59 - DFL Ventus Marker and its working materials (“ACI Laser marking solutions” 2023)

This machine offers variable pulse widths for use in a variety of applications, and its exceptional beam quality produces excellent marking results. The laser beam is deflected using a special mirror system in order to engrave the component. With the capability to separate the body from the head, it is possible to integrate into tighter places and give a more subtle and elegant look (“ACI Laser marking solutions” 2023).

The DFL Ventus Marker is a machine with exceptional low energy consumption, with the Economy Fiber model having an energy consumption of up to 20 W and the Business Fiber model having a variable energy consumption of up to 70 W, allowing for greater material versatility. This machine is connected to a computer via a USB port and can engrave text, graphics, codes (barcodes, data matrix codes), serial numbers, and logos on workpieces using *MagicMark* engraving software.

Regarding the vision system to be utilized, the Automatic Object Identification (AOI) machine from the company ACI will be chosen due to its easy compatibility with the previously chosen components and its wide range of application possibilities. The vision system is illustrated in Figure 60 (“ACI Laser marking solutions” 2023).

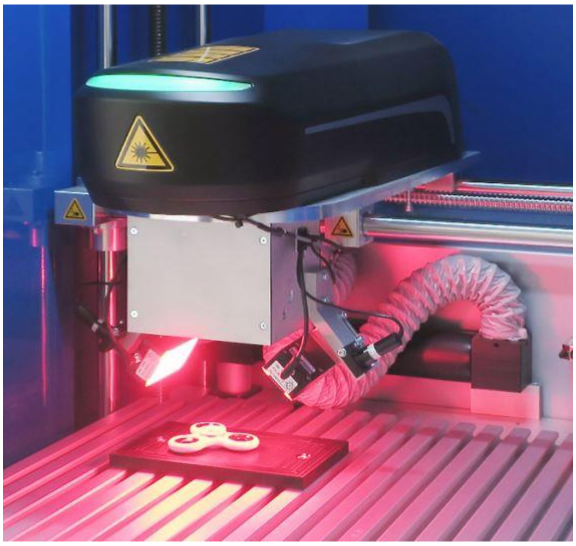


Figure 60 - AOI with DFL Ventus Marker

AOI is a sophisticated vision system capable of verifying the position and rotational position of a part, as well as verifying if a part is present, detecting and identifying the type of part. The AOI system is suitable for marking small components with high positioning tolerance and marking large components with a high level of accuracy, detecting special edges and contours. The technical specifications of the AOI system are based on the specific requirements of the customer and the geometric properties of the object to be marked.

Image area and markup area are defined according to job requirements and object size. System resolutions vary depending on the size of the image field and the optics used. Typically, resolutions between 20 μm/pixel for image sizes of 20 x 20 mm and 80 μm/pixel for image sizes of 110 x 110 mm can be achieved.

For the implementation of all the selected components, a structure was designed, which can be visualized in Figure 61. This structure was sized with two requirements in mind. The first is that it must be able to accommodate all the selected elements, ensuring the conditions necessary to achieve adequate performance and it must be able to accommodate the entire spectrum of saws sold by Frezite. The second requirement is the capacity to manually insert a saw into the engraving system when necessary.

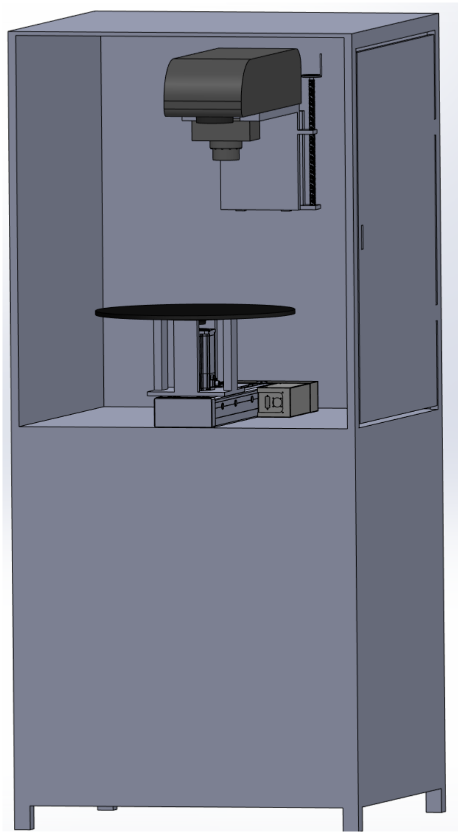


Figure 61 – Engraving station structure with components

To meet the first requirement, a parallelepiped-shaped booth measuring 1200x1200x2000 mm was designed, with the engraving machine and vision system located in the upper area placed in support with vertical adjustment, as shown in Figure 62, and the 2-axis table system located in the mid-height zone. To satisfy the second requirement, a door with a securing mechanism was installed in the upper portion of the booth, opposite the computer peripherals. The structure also includes a cabin in the lower area, in which the engraving process control equipment and robot control equipment are housed for protection against dust and potential accidents. The designed booth is composed of HMBS Profile Columns from Festo to make it simple to assemble and modify as needed (“Festo” 2023).

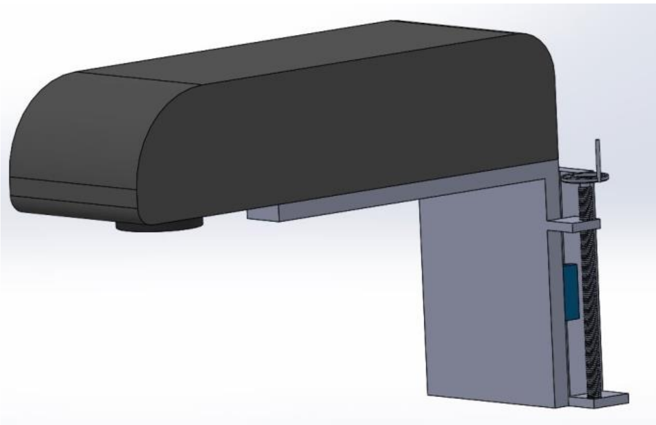


Figure 62 - Engraving machine holder design

4.2 Manipulating robot and associated componets

As mentioned in chapter 3, a Fanuc M10iD/16S robot will be used to transport the saws through the different processes of the new station with the gripper from Figure 25. This robot was chosen due to its main features and because it is already used in the current system its ability to handle quickly and accurately, its compactness and ability to reach narrow spaces, ability to pick up parts up to 16 kg and a reach of 1103 mm. Its working area and dimensions, can be seen in Figure 63.

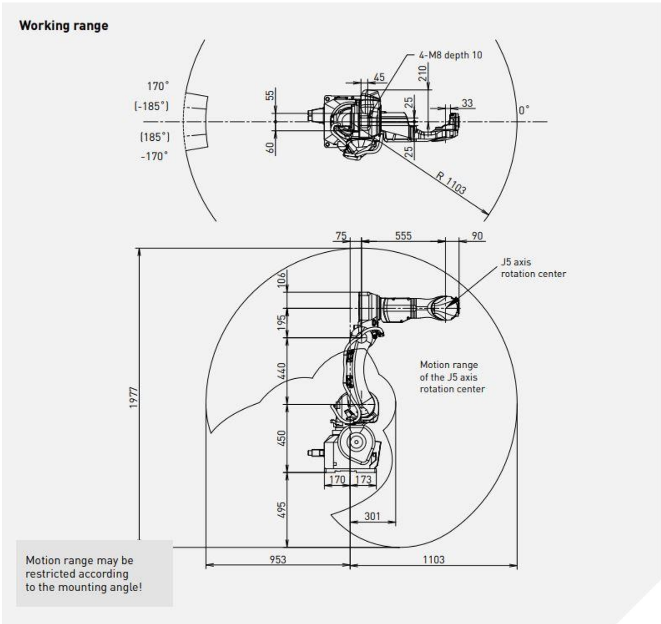


Figure 63 - Fanuc M10i/16S working range (“Fanuc M-10iD/16S” 2023)

The controller selected to operate the M10i/16S robot was the new R-30iB Plus controller, recommended by Fanuc. This controller comes with a new iHMI (Human Machine Interface) interface for easier setup, also providing a full connectivity via an Ethernet network, allowing an easy connection to connect robots, remote computers and other hardware. From Figures 64 and 65 it is possible to visualize the controller and the HMI.

Figure 64 - Fanuc R-30iB Plus (“Fanuc” 2023)

Figure 65 - Fanuc R-30iB Plus HMI (“Fanuc” 2023)

To enable the robot to move through the different working places of the new station a linear 7th axis was incorporated.

In the search for an existing axis on the market, the company Güdel was selected which offers a wide variety of linear tracks for robots (“Güdel” 2023). From the Güdel company website, in the linear tracks for robot section, it’s possible to select the desired manufacturer and the robot for the linear track implementation. After entering the data for the robot in question, several solutions are presented. For the selection of the axis to be used, a first analysis was carried out of the necessary work requirements, presented in Table 11.

Table 11 - Linear axis operating requirements

Operating conditions	
Saw weight	117.72 N
Robot weight	1373.40 N
Gripper weight	39.24 N
Total weight	1530.36 N
Robot max reach	1103 mm
Total moment applied by the robot	1688 Nm
Angular velocity	1.047 rad/s
Stroke length	2500 mm

Since there is no specification on the weight of each part of the robot, the whole 140 kg of the robot was considered in the calculation for the total torque moment. With all this in mind the TMF-1 linear track type was chosen due to its capabilities to support the different momentums and speed, as shown in Table 12 and Figure 66.

Table 12 - TMF-1 operating conditions for articulated robot (“Güdel” 2023)

Operating conditions	
Max payload	3000 N
Velocity	180 m/min
Acceleration	8 m/s^2
Acceleration time	0.38 s
Precision	±0.02 mm
Axis length capability	100 m
Lifetime	10^7 m

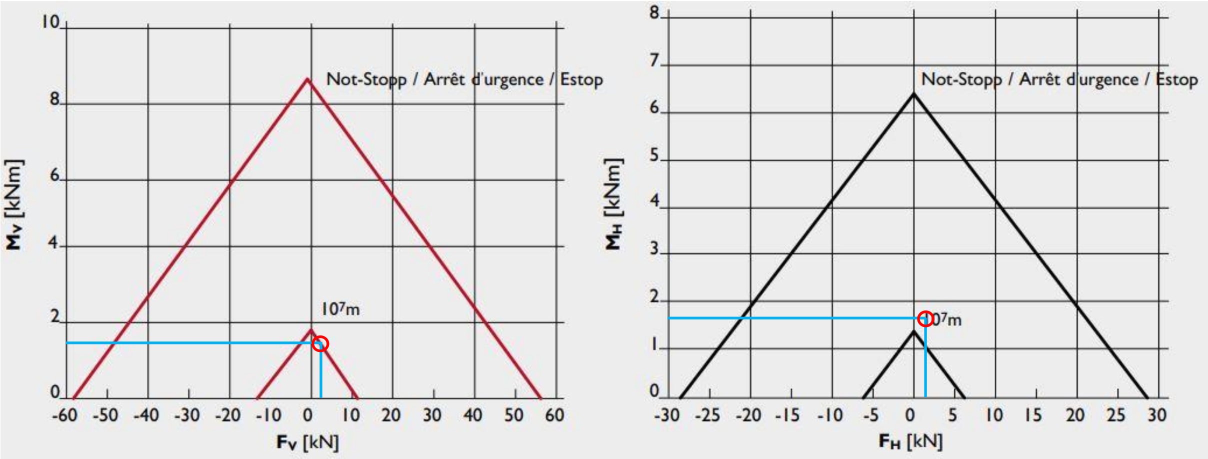


Figure 66 - Recommended base values for linear axis sizing (M_V, F_V, M_H, F_H) lifetime 10^7 m ("Güdel" 2023)

The TMF-1 linear track is a versatile modular drive axes equipped with a rack-and-pinion drive system. It is specifically designed for a range of applications including welding, plasma-arc cutting, packaging, and more. Once the operating conditions have been verified, the next step is to select a motor that can effectively drive the linear track. The linear track provides the specifications of a motor and two different types of gearboxes to choose from, as can be seen in more detail in Table 13.

Table 13 - Motor specifications for different gearboxes ("Güdel" 2023)

	Angle gearbox	Planetary gearbox
Size of Güdel gearbox type	HPG 060	NRH 100
Gearbox ratio	4	5
Axis travel per motor revolution	40 mm	40 mm
Motor speed	4500 min^{-1}	4500 min^{-1}
Stall torque	1.5 Nm	1.3 Nm
Max torque	27.7 Nm	23.3 Nm
Red. Inertia of axis	1.8×10^{-2} kgm^2	1.8×10^{-2} kgm^2

Both gearboxes and the motor are a viable option since the operation requirements designed for this linear track is much higher than the robot in use. The total lengths of the TMF-1 to be used can be calculated through the dimensions sheet presented in the appendix A, as well as through the website when configuring the CAD file to exported by inserting the stroke length of 2400 mm and it calculates the effective stroke being 2400 mm and the effective axis length being 3000 mm.

The manipulation of the carton boxes can pose problems due to the flexibility of cartons in the initial extended form and the different sizes. Because the same model robot is available currently, various motion tests were performed that validated the proposed design for transferring the carton boxes to the packaging table.

4.3 Select and specify the different components of the packaging process

After defining the engraving procedure and the robot systems, we can proceed to the packaging process. The designed packaging process includes a 2200x1000x1000 mm table, a packaging handling system, and an automatic labeling machine. This table is depicted in greater detail in Figure 67 and its dimensions, associated to the subcomponents, in Figure 68.

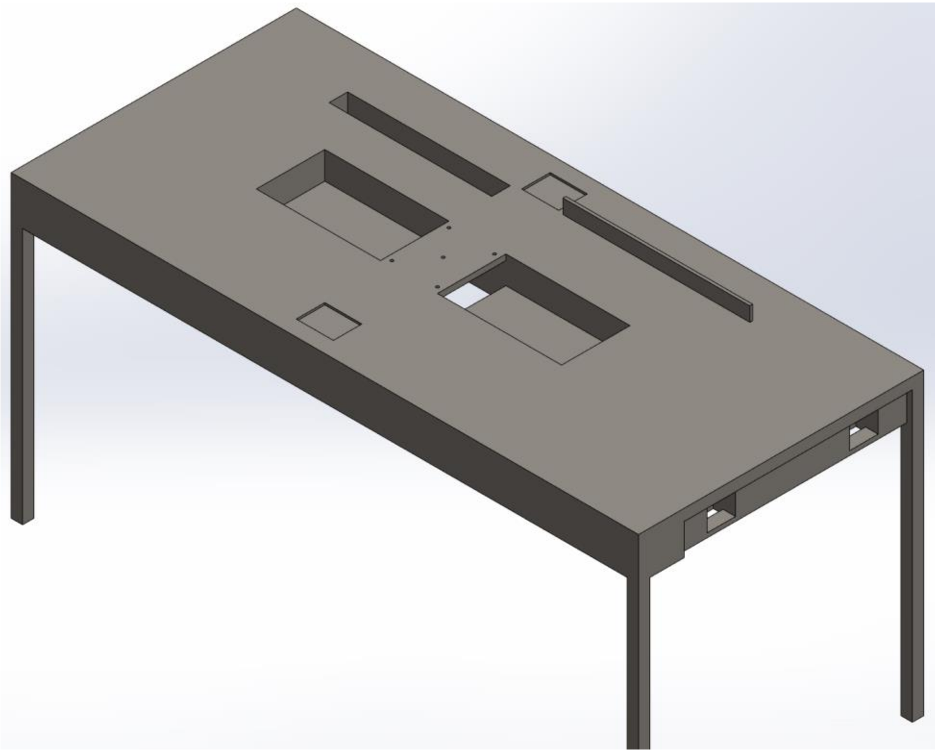


Figure 67 - Packaging table

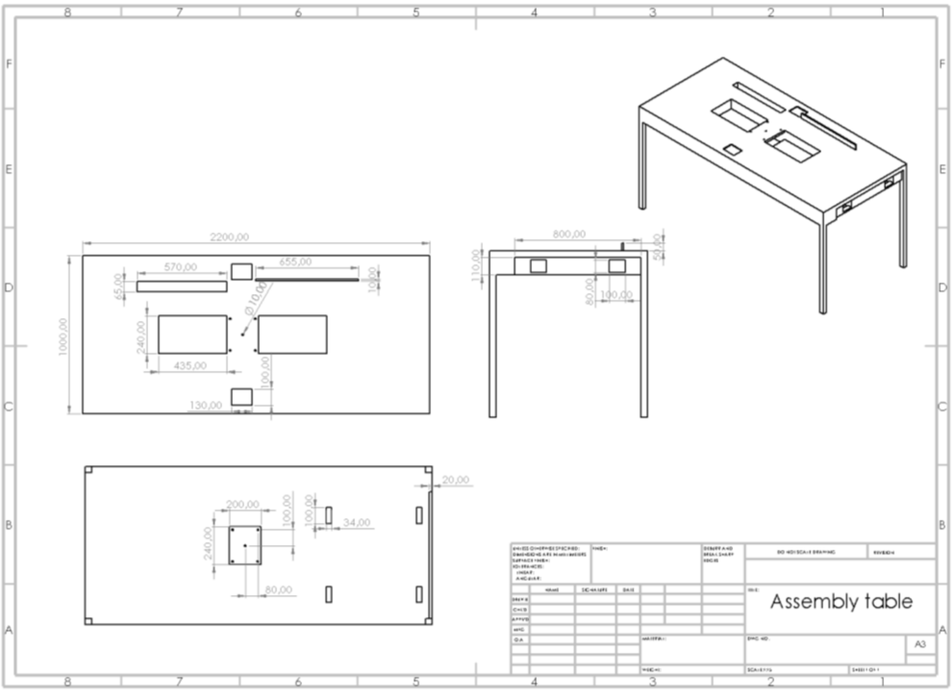


Figure 68 – Size of the packaging table elements

This packaging table has a central area of 240x200 mm designated for placing the carton packages to be used in the packaging process. This area features a central point with a diameter of 10 mm intended to serve as a reference for the point of concentricity, facilitating the placement of both the package and subsequently the saw within it. Within this region, additional four holes are present, strategically housing suction cups that secure the packages in place, guaranteeing their stability throughout the packaging process. The suction cups proposed are the AVENTICS series FSR from the company Emerson as illustrated in Figure 69 (“Emerson” 2023).

Figure 69 - AVENTICS series FSR (“Emerson” 2023)

Along the length of the table is a 655x10x50 mm backstop whose purpose is to guide packages into the strapping machine. The five openings on the top of the table indicate the locations of the guide systems and respective mechanisms of the packaging system's various components. The two 435x240x96 mm gaps are for the lower handling system, whereas the two 130x100x7 mm gaps are for the tab handling system and last the 570x65x80 mm opening is for the roller system. The two openings on the side of the table with 100x80x700 mm, as well as the four 100x34x20 mm are intended for the pneumatic cylinders of the pushing system.

The handling system consists of three parts: one that handles the carton package closure, another that handles the package flaps, and a third that ensures the placement of the VCI paper.

The handling system for closing the packaging displayed in Figures 70 and 71 is where the folding of the packaging takes place. This mechanism's motion is realized by four pneumatic linear actuators, two actuators for each part.

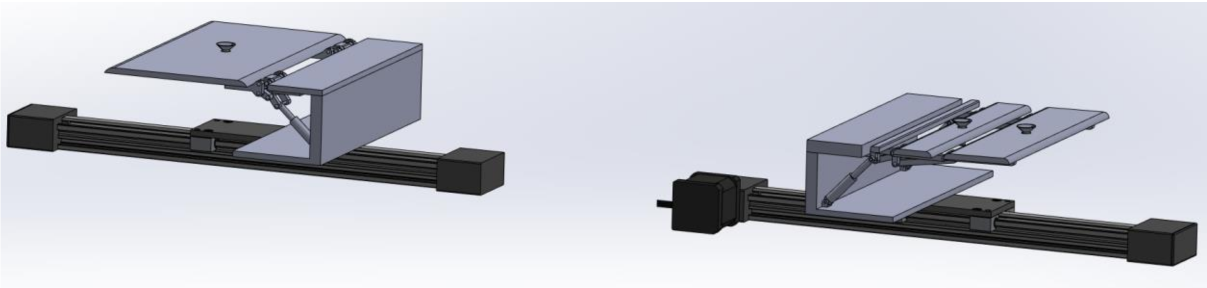


Figure 70 - Lower handling system parts initial position

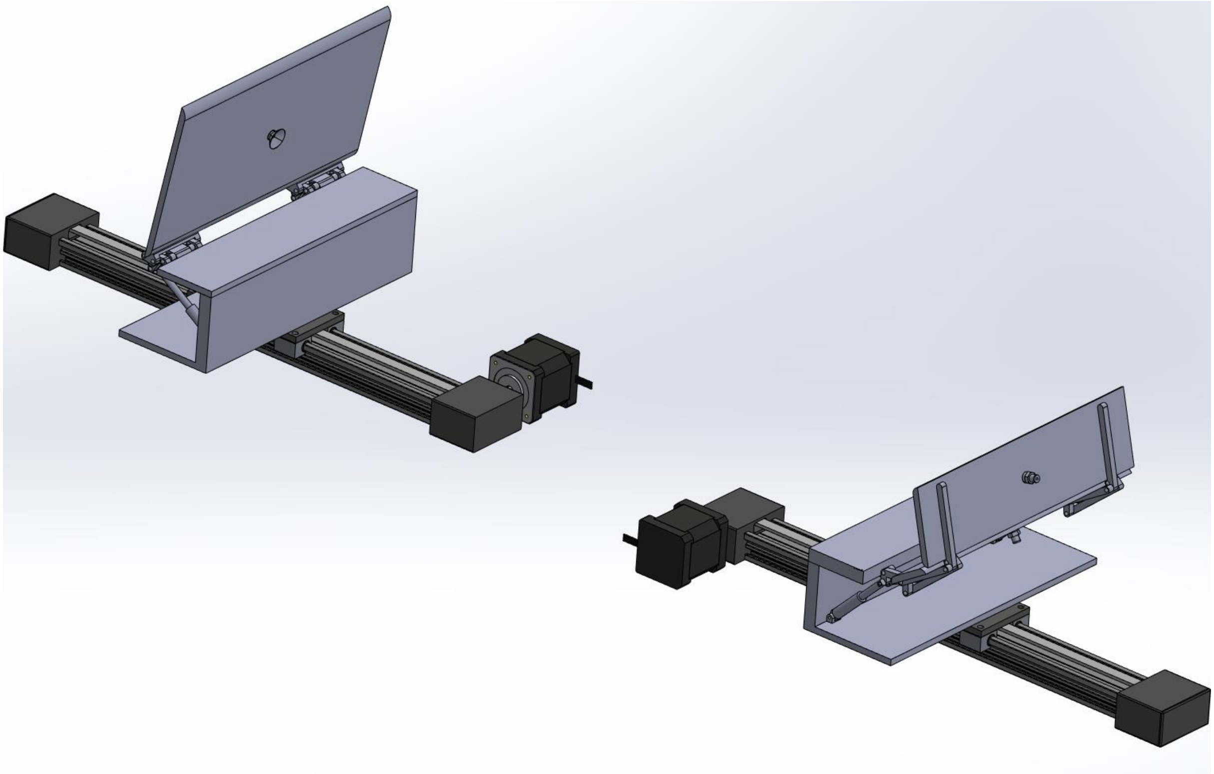


Figure 71 - Lower handling system parts operating position

Mini cylinder actuators from Emerson's AVENTICS ICM series were selected for folding the larger portion of the package due to the size of their stroke and the force they must overcome to complete the movement. The actuators are illustrated in Figure 72.

Figure 72 - Aventics series ICM (“Emerson” 2023)

The calculation of the force to be overcome by the actuator was carried out through the theoretical weight of the handling components. Disregarding the weight of the packaging card and considering that the mechanism is manufactured in F10 steel, it is feasible to obtain an approximate weight based on the volume of the mechanism components. With the approximate volume of the handling components used in the bigger portion of the folding mechanism being 0.2 dm^3 and with the material’s density of 7.84 kg/dm^3, we arrive at a mass of approximately 1.57 kg, which corresponds to a theoretical weight of approximately 15.7 N.

Following the same reasoning, the same actuators were chosen to fold the other portion of the mechanism. Using the same type of material and a volume of 0.16 dm^3, we arrive at a theoretical weight of 12.3 N.

The specifications of the selected actuators can be seen from Table 14.

Table 14 - Aventics series ICM specifications (“Emerson” 2023)

Standard	**ISO 6432**
Piston Ø	8 mm
Stroke	80 mm
Piston force in retraction	24 N
Piston force in extension	32 N
Ambient temperature min./max.	-20 ... 70 ºC
Operating pressure min./max.	2 ... 10 bar
Weight	0.05 kg

To move the folding mechanism through the different necessary positions, a system of linear guides actuator was utilized.

Similar to the Aventics series ICM, a force capacity of each guide needs to be determined. To calculate the force, the theoretical weight of all handling components and the mini cylinder actuators needed to be taken into account. All components involved in the handling system were considered manufactured in F10 steel. So, with the total volume of the components used in the larger section of the folding mechanism added to 0.5 dm^3, resulting in a total mass of approximately 3.92 kg. Additionally, factoring in the mass of each mini cylinder, which is 0.05 kg, the total theoretical weight that the guide should support is determined to be 39.24 N.

The selection process for the linear guides and their components was carried out using the Igus electric linear guide configuration system available on their website (“Igus” 2023).

Based on the specified weight, the required stroke length of 250 mm, and the desired speed of 0.5 m/s, the drylin ZLW-0630-eco was chosen as the appropriate option. The linear guide is presented in Figure 73 and in Table 15 presents various characteristics of the chosen linear guide.

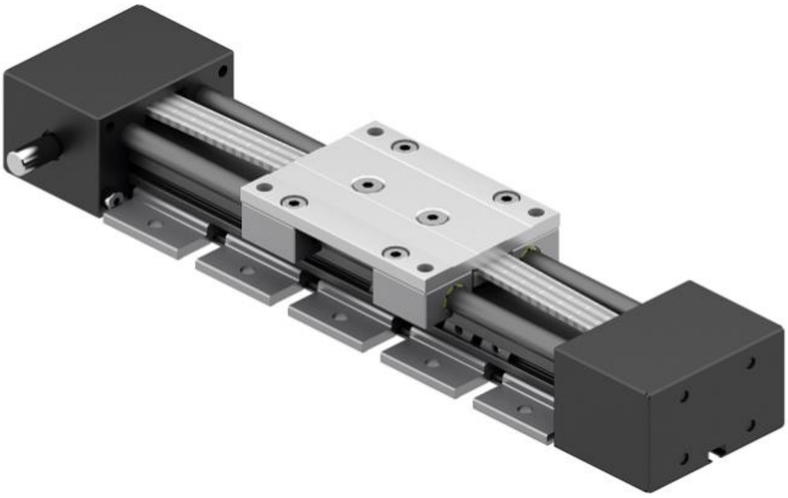


Figure 73 - Drylin ZLW-0630-eco (“Igus” 2023)

Table 15 - ZLW-0630-eco specifications (“Igus” 2023)

Series	**ZLW**
Belt driven	HTD 3M
Maximum load	80 N
Max torque of grip	0.4 Nm
Stroke	250 mm
Max speed	1 m/s

Igus recommended using the NEMA 17 stepper motor and the drylin D1 controller to provide the necessary power and control for this linear guide actuator in the specified application. The stepper motor can be seen in Figure 74 and its specifications in table 16. The drylin controller can be seen in Figure 75.

Figure 74 - NEMA 17 (“Igus” 2023)

Table 16 - NEMA 17 specifications (“Igus” 2023)

Series	**NEMA 17**

Voltage	48 V
Holding torque	0.5 Nm
Motor flange	42 mm
Nominal current	1.8 A

Figure 75 - Drylin D1 (“Igus” 2023)

The upper mechanism illustrated in Figure 76, is a system designed to manipulate the package's flaps, made up of two suction cups, two pneumatic cylinders and two pneumatic cylinders with guide rods.

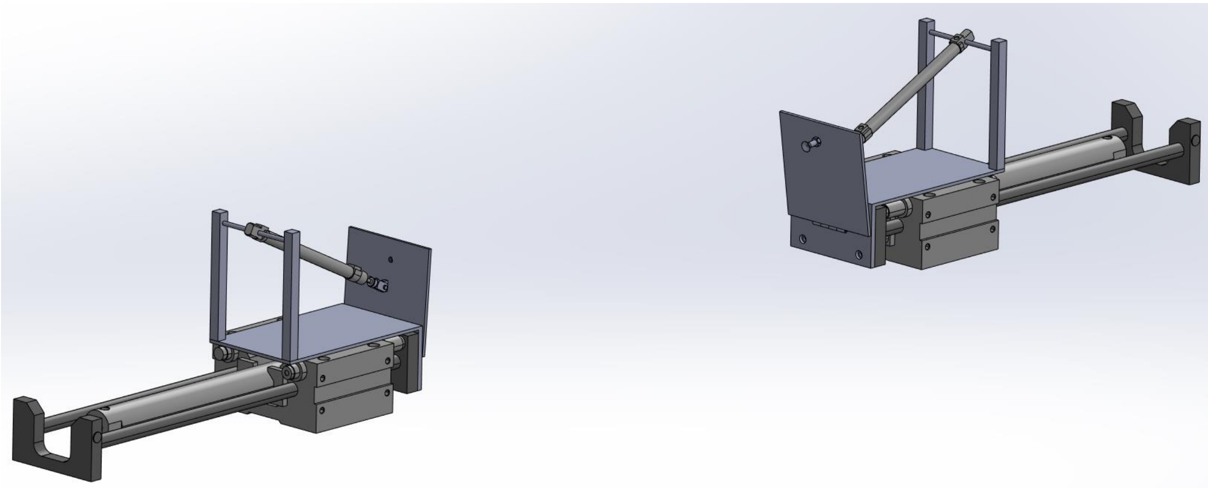


Figure 76 - Tab handling system

The suction cups and pneumatic cylinders were selected from Emerson's website; the cylinders are the AVENTICS MNI series, the suction cup is the AVENTICS SGN series, and the cylinders with guided rods are the SMC series MGG with end lock. The respective components are shown in the Figures 77, 78, and 79.

Figure 77 - AVENTICS series SGN (“Emerson” 2023)

Figure 78 - AVENTICS series MNI (“Emerson” 2023)

Figure 79 – SMC series MGG (“Emerson” 2023)

The SGN series suction cup was chosen because it is specified to work with soft and sensitive surfaces such as flaps. The suction cups selected have an external diameter of 16 mm, a suction force of 8 N and a weight of 0.004 kg.

To enable the vertical motion of the flap’s mechanism, the AVENTICS MNI cylinder was proposed. This cylinder was selected to for its stroke length of 100 mm and its small size. The force needed to operate the vertical motion is very small due to the weight of the components that it must operate. The flap where the suction cup is attached will be considered made out of F10 steel, as well as the rest of the fabricated components. With the flap having a volume of 0.03 dm^3 and the density of the material being 7.84 kg/dm^3, we arrive at a weight of 0.24 kg, so the cylinder must be able to produce at least 2.3 N with the weight of the suction cup. Table 17 provides additional specifications for the cylinder, allowing for a comprehensive view of its details.

Table 17 - AVENTICS series MNI specification ("Emerson" 2023)

Series	**MNI**
Piston Ø	10 mm
Stroke	100mm
Piston force in retraction	42 N
Piston force in extension	49 N
Weight	0.082 Kg
Operating pressure min./max.	1 ... 10 bar

To ensure the functionality of the flap manipulation mechanism across all package sizes, the MGG series cylinder was incorporated. This cylinder is equipped with an end lock type system, which prevents any positional shifts while the MNI series cylinder is active. Notably, the MGG series stands out for its dimensions, substantial lateral load capacity, and effective torsion protection. Detailed specifications for the MGG series cylinder can be found in the provided Table 18.

Table 18 - SMC series MGG specification ("Emerson" 2023)

Series	**MGG-P24**
Piston Ø	25 mm
Stroke	250 mm
Spring force in retraction	16 N
Spring force in extension	7 N
Weight	4 Kg
Operating pressure min./max.	1.5 ... 10 bar

To control the limiting positioning of the cylinder, to account for different boxes sizes, a pressure reduced valve was used, pneumatic circuit in Figure 80, that allows for the cylinder advancing position be stopped upon contacting the carton box surface.

To verify the maximum force, and therefore the possible combination of cylinder diameter sizes and operating pressure, that the carton packages can withstand without unacceptable deformation laboratory experiments were performed (Figure 81). For the experiments it were used a 12 mm diameter and a 25 mm diameter cylinders (Tables 19 and 20). It was verified that up to approximately 2.7 bar with a 25 mm bore size (i.e a force of 132.23 N), the packages do not suffer deformations. The experimental setup and the pneumatic circuit proposed are illustrated in Figures 80 and 81.

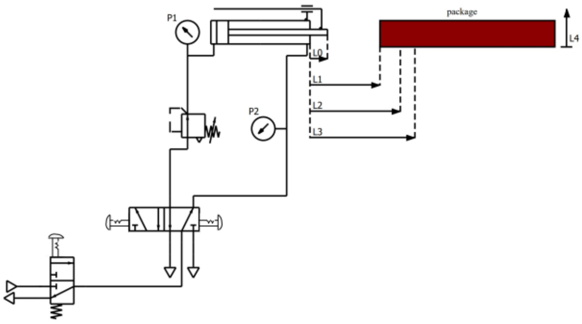


Figure 80 - Pneumatic circuit diagram

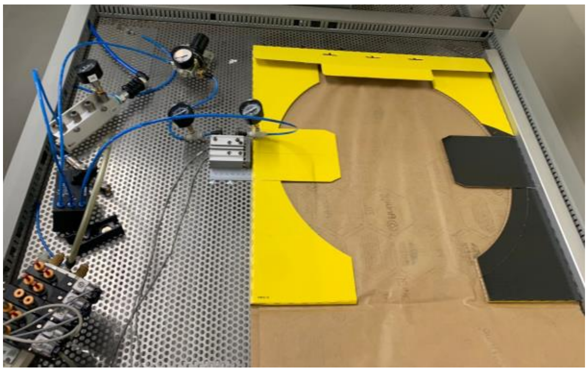


Figure 81 - Experimental setup

Table 19 and 20 shows the recorded deformations for the package EM52.18 observed throughout the different experiments. The EM52.18 was selected because it represented the package displaying the more pronounced deformations that were observed. The L2 position (Figure 80) represents the position of the cylinder when the pressure is activated, while the L3 (Figure 80) represents the position of the cylinder when the force is applied for a time of 5 min.

Table 19 - Recorded deformations for a 12 mm bore size

P1 (bar)	P2 (bar)	Visual deformation	L0 (mm)	L1 (mm)	L2 (mm)	L3 (mm)	L4 (mm)
0	0	No	70	76	76	-	0
1	0	No	70	76	76	-	0
2	0	No	70	76	76	-	0
3	0	No	70	76	77	-	0
4	0	No	70	76	77	-	0
5	0	No	70	76	78	-	0
6	0	No	70	76	78	78	0

Table 20 - Recorded deformations for a 25 mm bore size

P1 (bar)	P2 (bar)	Visual deformation	L0 (mm)	L1 (mm)	L2 (mm)	L3 (mm)	L4 (mm)
0	0	No	68	77	77	-	0
1	0	No	68	77	78	-	0
2	0	No	68	77	79	-	0
3	0	Yes	68	77	108	-	75

Finally, the part intended for ensuring the placement of the VCI paper will be carried out using the mechanism illustrated in Figure 82.

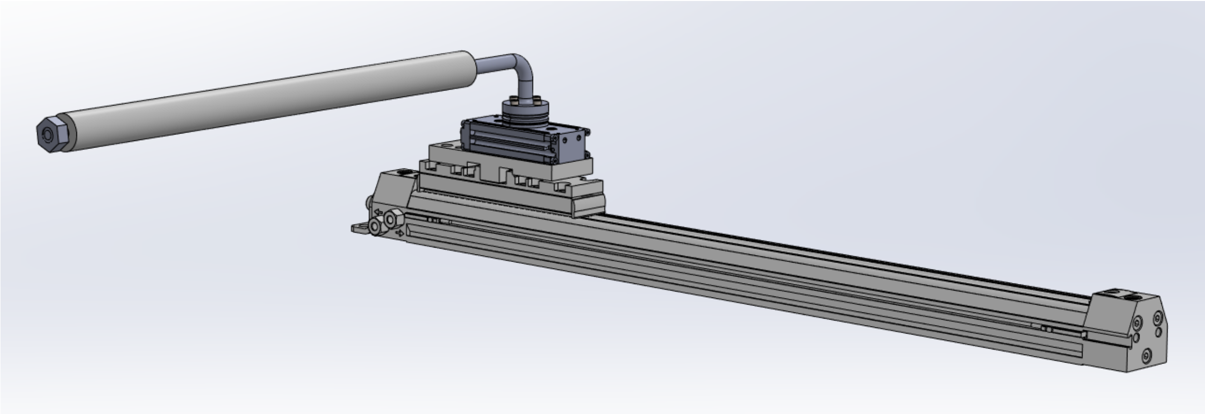


Figure 82 - Roller mechanism

In order to be able to position the packages and implement the handling system of closing the package without interference, a pneumatic rotary actuator is used to rotate the roller system out of the carton positioning surface. The actuator chosen for this task was the AVENTICS series RCM-SE, which can be seen from Figure 83 and its specifications from Table 21.

Figure 83 - AVENTICS series RCM-SE (“Emerson” 2023)

Table 21 - AVENTICS series RCM-SE specifications (“Emerson” 2023)

Series	**RCM-SE**
Ø	6 mm
Rotation angle min./max.	0 ... 90 º
Bearing axial load max.	170 N
Bearing radial load max.	170 N
Ambient temperature min./max.	5 ... 60 °C
Operating pressure min./max.	2 ... 8 bar

The roller chosen for operation is made of high-density polyethylene (HDPE) and has a dimension of 20 mm in diameter, 300 mm in length and a mass of 100 grams. The polyethylene compound was chosen due to its wide use and can be formulated for hard, tough, high-performance parts such as wheels and rollers, or soft shock absorbing applications such as impact absorbing pads and pads. The roller can be seen in Figure 84.

Figure 84 - HDPE Roller

As the sizes of the packages vary, it is not possible have this system in a fixed position, so a rod less cylinder was chosen to move the roller mechanism along the possible work positions. The pneumatic cylinder proposed is an AVENTICS of the RTC series and can be seen in Figure 85. This cylinder was selected due to its reduced size, the capability of handling the forces applied in the movement, having the required stroke of 350 mm and the fact that a position sensor could already be incorporated. The specifications of the cylinder chosen are presented in Table 22.

Figure 85 - AVENTICS series RTC (“Emerson” 2023)

Table 22 - AVENTICS series RTC specifications (“Emerson” 2023)

Series	**RTC-CG**
Piston Ø	25 mm
Stroke	400 mm
Piston force	309 N
Max speed	2 m/s
Weight	1.64 Kg
Operating pressure min./max.	2 ... 8 bar

4.4 Select and specify the different components of the distribuition process

The distribution process is composed of 3 primary components, the first one being the conveyor, the second one is the scissor lift table and the third one is the packaging push system.

The conveyor is the first component to be determined, and the following requirements were considered: being able to handle all the different packaging sizes, being capable of handling a mass of 50 kg and be modular.

The conveyor that verified all the requirements was the lineshaft roller conveyor XU90 from Monk Conveyors as it can be seen in Figure 86 (“Monk conveyors” 2023).

Figure 86 - Lineshaft roller conveyor XU90 (“Monk conveyors” 2023)

This conveyor is suitable for very small products with 225 mm product length, has a standard width of 612 mm, a 3 m fully assemble length standard with the capability of more length on request, a drive capacity of 12 kg per roller, a 0.37 kW geared motor drive unit from SEW Eurodrive and is capable of having different components attached, like a chain transfer unit.

The chain transfer unit that will be used will be the twin chain transfer unit that has the capability of handling 50kg, with a maximum of 15 operations per minute and a width of 612 mm. This unit rises and falls via a single pneumatic cylinder and is driven via sprockets on the main lineshaft. This chain unit can also be configured to be triple chain, making it capable of handling 100 kg with the rest of the specifications being identical to the twin chain but needs a second pneumatic cylinder for the rise and fall of unit. The transfer unit can be seen in Figure 87.

Figure 87 - Chain transfer unit (“Monk conveyors” 2023)

After the conveyor is fully defined the scissor lift table can be specified. The scissor lift will have to be able to handle 100 kg to future secure the triple chain transfer if it’s used, have the dimensions to handle all the packaging and the lift stroke to ensure the height differences between the assemble table and the roller conveyor. The TR 501 single scissor lift from Edmolift was chosen due to checking all the requirements, like its size of 900x700 mm, being capable of handling a capacity of 500 kg, as well as having a lift stroke of 600 mm and being capable to accommodate a large variety of accessories (“Edmolift” 2023). The TR 501 is illustrated in Figure 88.

Figure 88 – TR 501 scissor lift (“Edmolift” 2023)

For the packaging pushing system, it will consist of two pneumatic cylinders that are secured within the assembly table and attached to a pushing plate. To calculate the force required for each cylinder, the pushing plate was considered to be made of the steel F10. With the pushing plate having a volume of 1.16 dm^3 and the density of the steel being 7.84 kg/dm^3, the mass of the pushing plate come to 9.09 kg. Considering that the total mass of a stack packaged is 100 kg and the mass of the pushing plate, we come to a total of 109.09 kg, that corresponds to approximately 1070.17 N.

The AVENTICS series PRA shown in Figure 89 was selected and its specifications can be seen in table 23.

Figure 89 - AVENTICS series PRA (“Emerson” 2023)

Table 23 - AVENTICS series PRA specifications (“Emerson” 2023)

Series	**PRA**
Piston Ø	40 mm
Stroke	500 mm
Piston force in retraction	660 N
Piston force in extension	790 N
Weight	2.25 Kg
Operating pressure min./max.	1.5 ... 10 bar

5 Conclusion and future works

In this dissertation, the conception and design of an automatic packaging station for circular saws was carried out, which includes the engraving process, the packaging process and the distribution process. The solutions proposed are able to satisfy the main objectives proposed by the company, namely increase packaging capacity through an automated system. Moreover the solutions optimize the existing layout and, as desired by the company allow for incorporation of already used equipments and systems, such as the engraving systems and the manipulating robot.

The concept design is validated through the specification of various components existing in the market. For the manipulation and packaging operations experiments were performed that validate the manipulation of empty cartons by the robot, as well as establishing a pneumatic solution to adapt securing the carton boxes of various sizes in an expedite way.

Therefore the proposed solutions can be a basis from which a detailed implementation specification can be pursuit and further explored. That can be dependent on future decisions of the company regarding the definition of the carton features and sizes according to new requirements.

The proposed design was modeled in CAD software (SolidWorks), based on real designs of components available on the market and also with components developed for the packaging process, which allowed for validation in the implantation of some components. The proposed station allows visibility and access to all the processes involved, fulfilling the determined objectives in which the equipment's are inserted.

Regarding the possibility of carrying out future work, the following developments are suggested:

- Analysis of the incorporation of protection and security systems, for example through the application of photoelectric barriers in the material loading area, security barriers around the station and magnetic sensors with interlocking for the doors of the engraving structure;
- Experimental validation of selected components;
- Establish the control system architecture and software implementation of the various components of the new station;
- Analyze the integration of the new station with the various software applications currently in use for logistics purposes of the circular saw processing.

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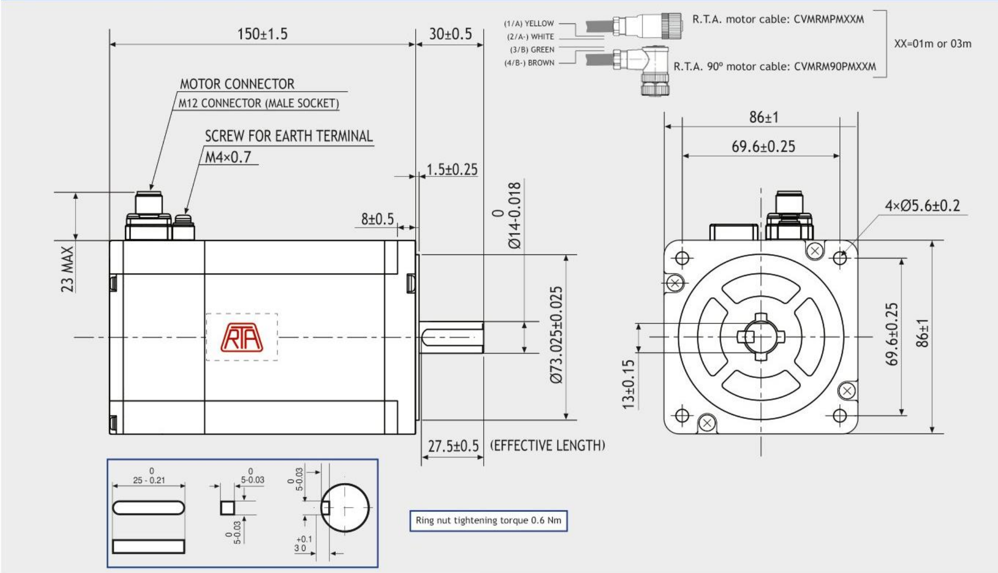
APPENDIX A:

RM 3R3M

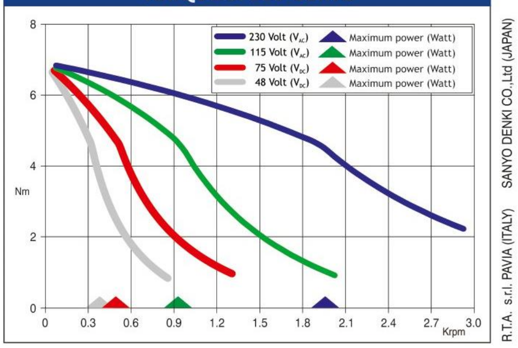
Dimensions (Unit:mm)

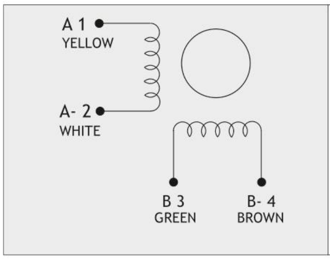


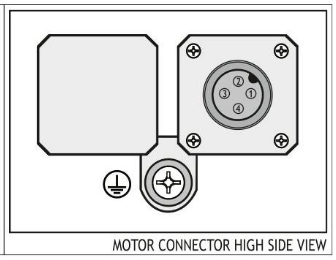
FEATURES

MODEL		RM 3R3M
BASIC STEP ANGLE		1.8 ± 0.09°
BIPOLAR CURRENT	(Amp)	4
RESISTANCE	(Ohm)	1
INDUCTANCE	(mH)	7.9
BIPOLAR HOLDING TORQUE	(Ncm)	920
ROTOR INERTIA	(Kgm ^{2} x 10 $^{-7}$)	4500
THEORETICAL ACCELERATION	(rad x sec. $^{-2}$)	20500
BACK E.M.F.	(V/Krpm)	241
MASS	(Kg)	4.2
INTERNATIONAL STANDARDS		UL, CSA, CE, RoHS
INSULATION VOLTAGE	(V)	250 V_{AC} (350 V_{DC})
PROTECTION DEGREE - INSULATION CLASS		IP 54 - CLASS F
LEADS CODE		V

TORQUE/SPEED CURVE







Suggested R.T.A. drive series: 230 Vac X-PLUS

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27020 Marcignago (PV) (Italy)
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Pune 411026 (India)
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PD 085

Tabelle 8 table 8

Untersetzung / ratio	Getriebestufen / number of gear stages	Abtriebsnenn-drehmoment / nominal output torque	Beschleunigungs-moment* / accelerating torque*	NOT-AUS Drehmoment** / emergency stop torque**	Massenträgheits-moment / moment of inertia	
i		T_{2N}	T_{2B}*	T_{2NOT}**	Hohlwelle ø14 / hollow shaft ø14	Hohlwelle ø19 / hollow shaft ø19
		Nm	Nm	Nm	kgcm²	
3	1	35	70	105	0,67	1,62
4	**1**	**45**	**88**	135	0,49	1,44
5	**1**	**45**	**90**	135	0,43	1,36
7	**1**	**43**	**86**	129	0,37	1,30
10	**1**	**35**	**70**	105	0,34	1,27
16	**2**	**55**	**98**	165	0,48	1,42
20	**2**	**55**	**98**	165	0,42	1,35
25	**2**	**58**	**105**	174	0,42	1,35
28	**2**	**55**	**98**	165	0,37	1,29
35	**2**	**58**	**105**	174	0,37	1,29
40	**2**	**55**	**98**	165	0,34	1,26
50	**2**	**58**	**105**	174	0,34	1,26
70	**2**	**50**	**90**	150	0,34	1,26
100	**2**	**35**	**70**	105	0,34	1,20
120	3	55	100	165	0,34	1,20
160	3	55	100	165	0,34	1,26
200	3	58	105	174	0,34	1,26
250	3	58	110	174	0,34	1,26
350	3	58	110	174	0,34	1,26
500	3	58	110	174	0,34	1,26
700	3	50	95	150	0,34	1,26
1.000	3	35	70	105	0,34	1,26

Die Abtriebsdrehmomente beziehen sich auf eine Lebensdauer von 20.000 h, Nenn-Eingangsdrehzahl, Betriebsfaktor 1 und Betriebsart S1 für elektrische Maschinen.

* Maximal 1.000 Zyklen pro Stunde. T_{2B}-Anteil an der Gesamtlaufzeit < 5 %.

** Maximal 1.000-mal während der Getriebelebensdauer zulässig.

Fett gedruckte Untersetzungen sind Bestandteil der Vorzugsreihe R1.
Dünn gedruckte Untersetzungen sind Bestandteil der Nebenreihe R2.
Achtung: Lieferzeit auf Anfrage bei Bestellung aus Nebenreihe R2.

The output torques refer to a service life of 20,000 h, nominal input speed, service factor 1 and operating mode S1 for electrical machines.

* Up to a maximum of 1000 cycles per hour. T_{2B} portion of the total running time < 5 %.

** Up to a maximum of 1000 times permissible during gearbox lifetime.

Reduction ratios **printed in bold** are components of the standard series R1.
Reduction ratios printed in plain are components of the non-standard series R2.
Attention: delivery time on request for purchase orders of non-standard series R2.

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▸ DETAILINFORMATIONEN / LEISTUNGSWERTE
▸ DETAILED INFORMATION / POWER VALUES

Planetroll the driving power

PD 085

Tabelle 9 ◂ ▸ table 9

Getriebestufen	number of gear stages		1	2	3
Verdrehspiel	torsional backlash	arcmin	10	15	20
Verdrehsteifigkeit	torsional rigidity	Nm/arcmin	4,8	6	5,5
Wirkungsgrad bei Volllast	efficiency with full load	%	96	94	90
Gewicht ca.	approximate weight	kg	2,6	3,5	4
Maximal zulässige Radialkraft	max. permissible radial load	N	1.770		
Maximal zulässige Axialkraft	max. permissible axial load	N	2.180		
Nenn-Eingangsdrehzahl	rated input speed	min^{-1}/rpm	3.000		
Max. Eingangsdrehzahl	max. input speed	min^{-1}/rpm	5.000		
Schmierung	lubrication		Lebensdauer-Fettschmierung lifetime grease lubrication		
Betriebstemperatur*** Gehäuse-Oberflächentemperatur	operating temperature*** housing surface temperature	°C	-25 bis +90 / kurzzeitig +120 -25 to +90 / short-time +120		
Einbaulage	mounting position		beliebig / any		
Schutzart	protective system		IP 64		
Schallemission****	running noise****	dB(A)	≤ 70		
Lebensdauer	service life	h	20.000		
Anzugsmoment für die Klemmschraube M5	tightening torque for clamping screw M5	Nm	8,3	Hohlwelle Ø14 / hollow shaft Ø14	
Anzugsmoment für die Klemmschraube M8	tightening torque for clamping screw M8	Nm	43,0	Hohlwelle Ø19 / hollow shaft Ø19	
Flanschgenauigkeit	flange tolerance		DIN 42955-N		
Getriebe-Oberfläche	gear surface	Gehäuse pulverbeschichtet RAL3020. Flansche aus Aluminium. Housing powder coated RAL3020. Flanges out of aluminium.			

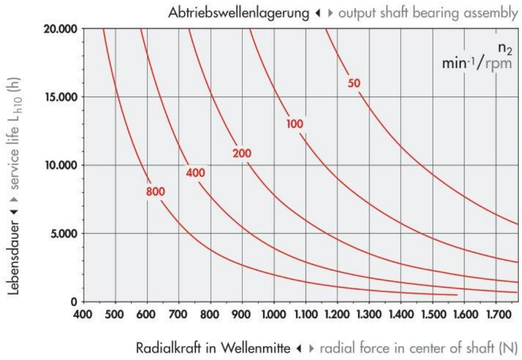
*** **Achtung!** Werden die Getriebe mit der maximal zulässigen Eingangsdrehzahl betrieben oder kommen Motoren mit hoher Wärmeentwicklung zur Verwendung, dann ist sicherzustellen, dass die zulässige Betriebstemperatur des Getriebes nicht überschritten wird.

**** Ermittelt bei 1m Abstand und Nenn-Eingangsdrehzahl, ohne Last.

*** **Attention!** If the gears are operated with the maximum permissible input speed, or if motors are used with high generation of heat, then it is to be guaranteed that the permissible operating temperature of the gear is not exceeded.

**** Determined at a distance of 1m and rated input speed, without load.

Diagramm 3 ◂ ▸ diagram 3



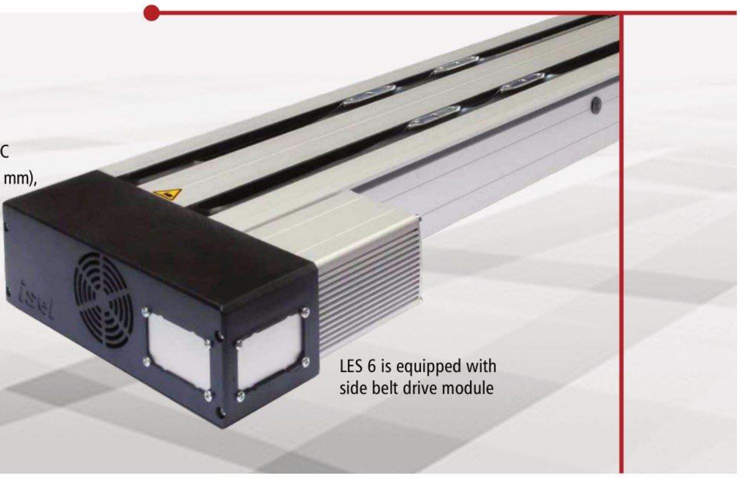
n_2 = Abtriebsdrehzahl ◂ ▸ n_2 = output speed

13

LINEAR UNITS

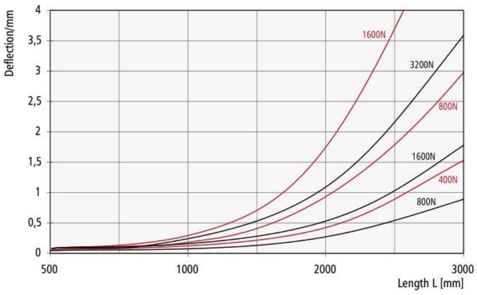
Linear unit is equipped with spindle drive LES 6

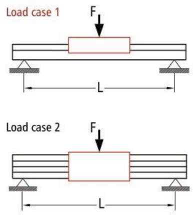
- Aluminum shaft mounting profile W 150 x H 75 mm, naturally anodized
- Clamping surface and underside of milled profile
- Equipped with 4 precision steel shafts Ø 12 h6, material Cf53, and hardness 60 ± 2 HRC
- Aluminum shaft slide WS 5/70 or 2 x WS 5/70 (L 70 mm), adjustable without clearance, centered Lubrication
- Ball screw drive equipped with 2.5 / 4 / 5 / 10 / 20 mm gradient
- Profile sealing equipped with abrasion-resistant sealing lips
- Die-cast aluminum endplates
- Equipped with 2 limit and/or reference switches, with a repeat accuracy of ± 0.02 mm
- Sealed angular contact ball placed inside of the drive steel flange



LES 6 is equipped with side belt drive module

Deflection





Options

- Black anodized aluminum profile
- Electromagnetic brake located inside the motor module or as extension of the drive spindle
- Steel slide
- End limit switch equipped with mounting-kit (see accessories)

Upon request

- Length measurement system
- Bellows cover
- Assembly on the left side of the motor module

Technical data

Aluminum profile LES 6	
Moment of inertia $_{Ix}$	707,100 cm^4
Moment of inertia $_{Iy}$	212,200 cm^4
Center of gravity (see dimensional drawing)	32,78 mm
Area	30,07 cm^2
Material	AlMgSiO, 5F22
Anodizing	E6/EV1
Weight with steel shafts	11.4 kg/m
Weight with both steel shafts and spindles	12.8 kg/m

No load torques [Ncm]

Torque (1/min)	Spindle gradient				
	2.5	4	5	10	20
500	17	17	18	20	21
1,500	20	20	22	24	25
3,000	24	25	26	26	30

Order key

234 XXX 0XXX

Profile lengths (L1)*

E:G: 029 = 290 mm (min.)
299 = 2,990 mm (max.)

Drive

6 = Preparation of direct drive module
7 = Preparation of belt drive module

Linear guide slide

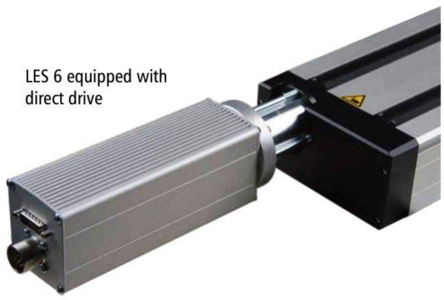
0 = 2 slides 70 mm
1 = 2 slides 200 mm
2 = 4 slides 70 mm

Ball screw drive

0 = without
1 = gradient 2.5 mm
2 = gradient 4 mm
3 = gradient 5 mm
4 = gradient 10 mm
5 = gradient 20 mm
6 = gradient 20 mm (equipped with return of the ball)

*The data is shortened by the last digit. Ordering standard profile lengths can be done in 100 mm increments.

LES 6 equipped with direct drive



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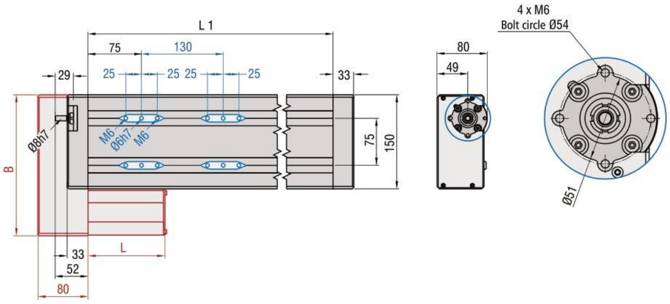
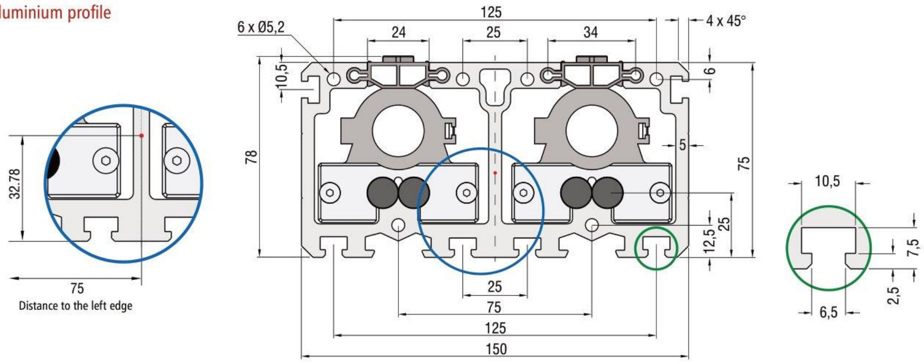
Dimensional drawing

Length of stroke
with 2 x WS 5/70 = L1 -150 mm
with 4 x WS 5/70 = L1 -280 mm

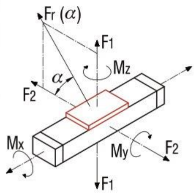


Aluminium profile



$$F_r(\alpha) = \frac{F_2}{\cos\alpha}$$

$$F_r(\alpha) = \frac{F_1}{\sin\alpha}$$



Load data

LES 6 with two WS 5/70	
C_0	5153 N
C	2319 N
F_1 static	4401 N
F_1 dynamic	1981 N
F_2 static	5153 N
F_2 dynamic	2319 N
M_x static	212 Nm
M_y static	164 Nm
M_z static	192 Nm
M_x dynamic	95 Nm
M_y dynamic	74 Nm
M_z dynamic	87 Nm

LES 6 with four WS 5/70	
C_0	6606 N
C	3746 N
F_1 static	5642 N
F_1 dynamic	3198 N
F_2 static	6606 N
F_2 dynamic	3746 N
M_x static	212 Nm
M_y static	367 Nm
M_z static	429 Nm
M_x dynamic	120 Nm
M_y dynamic	208 Nm
M_z dynamic	243 Nm

permissible spindle speeds

LES 6	Spindle gradient p [mm]	2.5	4	5	10	20
Profile length L [mm]	maximum permissible Spindle speed n perm. [1/min]	maximum permissible Feed speed v perm. [mm/s]				
490	4,000	167	267	333	667	1333
990	3,000	125	200	250	500	1000
1,390	1,500	63	100	125	250	500
1,490*	3,000	125	200	250	500	1000
1,990*	1,650	69	110	138	275	550
2,490*	1,050	44	70	88	175	350
2,990*	750	31	50	63	125	250

*equipped with spindle support

isel® From Components to Systems

EC-SERVO MOTORS
with brushless drive

EC 60 TM 400W 48V

- brushless
- small & compact
- maintenance-free
- Protection IP65

ORDERING DATA

EC 60 TM 400W 48V
Part no. **474400 0048**

EC 60 TM 400W 48V with brake
Part no. **474400 1048**

CHARACTERISTICS

- permanently energized 3-phase synchronous motor
- incremental position encoder / encoder integrated in the motor - supply 5VDC, RS422, tracks A, / A, B, / B, Z, / Z,
- integrated commutator signals U, V, W - 5V PUSH / PULL
- applications: positioning controls, CNC controls
- optionally with holding brake
- recommended control electronics: single axis controller MC 1-20 and drive controller iMD 20

BASIC INDEX	
Working time	continue
Thermal endurance class	class F
Dielectric voltage withstand	AC1500V 1min
Insulation resistance	DC500V 100M Ω
Ambient temperature	0 ~ +40°C
Ambient humidity	20 ~ 80% without condensation
Vibration class	V15
Connection way	direct connection
Motor mounting	flange
Excitation way	permanent magnet
Degree of protection	whole sealing, self cooling, IP 65 (except the pass-through parts of the axle)
Direction of rotation	anticlockwise rotation from the side of axle stretch end

TEST CONDITION

1. The motor is installes on a 200 x 200 x 20 mm aluminium panel horizontally, with a 25°C and free-flowing air environment.
2. Adopt interference fitting, unlimeted inertia loading are imposed on the extension part of the motor axle.
3. Typical error of the standard value is less the 10%.

BASIC PARAMETERS	without brake	with brake
Rated power [W]	400	
Pole number	8	
Rated voltage [V AC]	48	
Rated speed [rpm]	3000	
Max. speed [rpm]	5000	
Rated torque [N.m]	1.27	
Peak torque [N.m]	3.8	
Rated current [A]	10.25	
Peak current [A]	31.8	
Line counter EMF coefficient [mV / rpm]	7	
Torque coefficient [N.m / A]	0.128	
Moment of inertia of the rotor [kg.m^2.10^{-4}]	0.342	
Line resistance [Ω]	0.27 @ 25°C	
Line inductance [mH]	0.67 @ 1 kHz, 1 V	
Rated voltage of the brake [V]	n/a	24
Rated power of the brake [W]	n/a	7.5
Holding torque of the brake [N.m]	n/a	1.3
Moment of inertia of the brake [kg.m^2.10^{-4}]	n/a	0.0117
Weight [kg]	1.7	2.4

Measuring system	sensor	Inremental, ABZ+uvw, 2500 PPR
	supply voltage	5V DC +/- 5%
	current consumption	I max = 110 mA

EC 60 TM 400W 48V

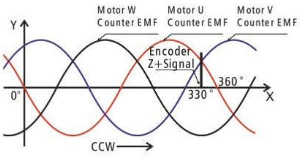
PIN ASSIGNMENT

Power Line					with brake	
Color	yellow-green	red	blue	black	brown	white
Signal	FG	U	V	W	Br+	Br-

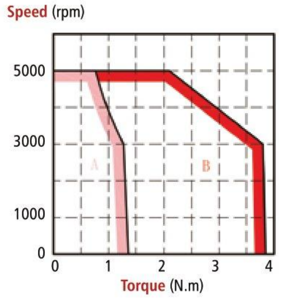
Encoder Line												
PIN No.	1	2	3	4	5	6	7	8	9	10	11	12
Signal	Shield	Gnd	Vcc 5V	A+	A-	B+	B-	Z+	Z-	Hall U	Hall V	Hall W
Connector: JST PHR-12, PH-Serie												

CHARACTERISTICS CURVES

RELATIONSHIP between Encoder Zero and Motor Phase Position:

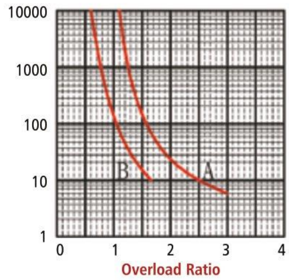


TORQUE – SPEED:



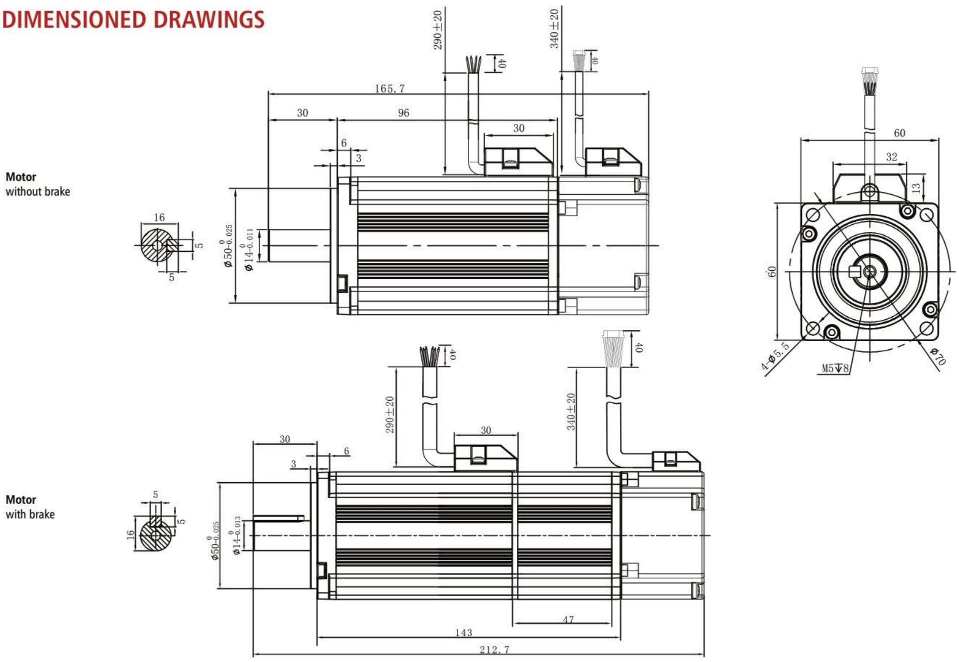
A: Continous Duty Zone, B: Intermittent Duty Zone

OVERLOAD:



A: 3000 rpm, B: 5000 rpm

DIMENSIONED DRAWINGS



Technical specifications subjects to change.

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