Automation of Packaging Process
Automatic packing of hacksaw blades in SNAEurope (Lidköping)
Abstract

The design work that precedes the automation of a process is not an easy job. Each one of the variables and possible risks involved in process must be carefully considered before implement the final design as well the requirements in performance and cost. However automate a dangerous, inefficient or just uncomfortable task entails many benefits that make up for the long period of design process. A well automated line will benefit the production with quality, productivity and capacity among other profits. In this project the immediate objective is to automate the “SANDFLEX Hacksaw blades” packaging process in the plant that SNAEurope owns in Lidköping. Actually the packing is completely manual. One operator packs the blades into the boxes meanwhile one more operator loads and unloads the packing station with empty and full boxes respectively. The task is both, tiring and uncomfortable for the operators as well inefficient for the company since the production rate is limited.

Analyzing and observing carefully product and process, different theories and strategies to achieve the goal were developed. Three are the possible solutions to solve the problem, with different levels of automation and technologies. The robotic solution uses an articulated robot to perform all the tasks; the hybrid solution uses pneumatic devices to pack the blades and an articulated robot to support the station loading and unloading the boxes. Finally the pneumatic solution uses only pneumatic devices, which hold, open and close, push box and blades using airpower; a few sensors detect positions and states, since a PLC coordinates and controls all process. By means of discussing these solutions with the company’s engineers and workers, after a deep literature study and two test of performance, was it possible to select the most suitable solution to accomplish the packaging task. The pneumatic solution is cheap and simple, but at the same time robust and reliable. This design performs the packaging task efficiently and fast. And more important, the operator passes from pack manually the blades to monitor the process.
# TABLE OF CONTENTS

Description of the Company .................................................................1

1  PROBLEM BACKGROUND ......................................................................2
   1.1  DESCRIPTION OF THE PRODUCT .....................................................2
   1.2  DESCRIPTION OF THE PROCESS ..................................................5

2  PROBLEM DESCRIPTION .....................................................................10
   2.1  NEEDS OF AUTOMATION .................................................................10
   2.2  LIMITATIONS ...................................................................................11
   2.3  OBJECTIVES ....................................................................................11

3  LITERATURE REVIEW .....................................................................13
   3.1  PRODUCTION SYSTEM AND MANUFACTURING SYSTEMS .............13
   3.2  SINGLE STATION MANUFACTURING CELL ..................................15
   3.3  WHAT IS AUTOMATION? .................................................................16
   3.4  REASONS TO AUTOMATE ...............................................................17
   3.5  SELECTION CRITERIA ......................................................................18
   3.6  INDUSTRIAL ROBOTS .....................................................................19
   3.7  ROBOT SELECTION CRITERIA .........................................................19
   3.8  ACTUATORS .....................................................................................22
   3.9  SENSORS .......................................................................................23
   3.10 THE PLC .........................................................................................24

4  PROBLEM SOLUTION .......................................................................26
   4.1  SOLUTION 1: PNEUMATIC ...............................................................27
   4.2  SOLUTION 2: ROBOT .......................................................................30
   4.3  HYBRID SOLUTION .........................................................................34
   4.4  TABLE OF DEVICES BEING USED IN PROCESS ............................34
   4.5  COMPARISON OF DIFFERENT SOLUTIONS ....................................35
   4.6  SELECTION OF THE SUITABLE SOLUTION ......................................37

5  FINAL SOLUTION .............................................................................39
   5.1  EMPTY BOXES MAGAZINE .............................................................39
   5.2  FILLING STATION ...........................................................................41
   5.3  PUSHING OF SAW BLADES IN THE BOXES ..................................47
   5.4  FILLED BOX PALLETIZING TO WELDING STATION ......................52
   5.5  PROCESS AFTER AUTOMATION ......................................................53
   5.6  COMPONENTS SELECTION .............................................................55
   5.7  COMPONENTS LIST .........................................................................59
   5.8  TECHNICAL TEST ...........................................................................60

6  CONCLUSIONS ................................................................................67

7  REFERENCES .....................................................................................69
   7.1  BOOKS ..........................................................................................69
   7.2  PERSONAL CONTACTS .................................................................69
   7.3  WEBSITES .....................................................................................69
Description of the Company

SNA Europe is a part of Snap-on Incorporation which is a leading global manufacturer and distributor of tools and equipment for mechanics and technicians in most vehicle factories. Snap-on Inc. was found in 1920 and has a turnover of two billion USD. The number of employees is about 14000 with their main office in Kenosha, Wisconsin, USA.

SNA Europe Industries AB (joint-stock company) manufactures a wide range of tools such as wrenches, saws and files with the trademark Bahco. It is the world’s largest manufacturer of handsaws and saw blades, where the largest amount is manufactured in Europe. The products are known for good design and ergonomics. The company has its own representation in about forty countries and its own manufacturing in six countries, a turnover of three billion SEK and about 2500 employees, thereof 1000 in Sweden.

Saw blade manufacturing started in Lidköping about hundred years ago by the company “Lidköpings sågbladsfabrik”. In the 1980’s the company was purchased. Lidköping became a product centre with manufacturing of research and development of tools for Metal cutting and used the company name SANDVIK Metal Saws AB. The company was purchased by the American company Snap-on in 1999. At this time SANDVIK Metal Saws AB became BAHCO Metal Saws AB. 2006 BAHCO Metal Saws AB became SNA Europe and is now a part of SNAP-on Industries AB. The factory in Lidköping manufactures hack sawblades, power sawblades, sabre sawblades and rotating files. 250 people are employed in Lidköping [1]
1 PROBLEM BACKGROUND

1.1 Description of the Product

1.1.1 Hack saw blades: SANDFLEX®

The factory in Lidköping produces four different products, which are three different types of sawblades: hack sawblades, power sawblades, sabre sawblades; and the fourth product rotating files. However the Hacksaw blades SANDFLEX® BI-METAL, 3906 are the product star of the factory, it constitutes approximately the 60 percent of the total production of hacksaw blades with 75 million blades produced every year [1].

The blades SANDFLEX are produced in two different sizes as well different number of teeth and packages depending on the demands of the market:

- 250 mm long, 13 mm wide and 0.65 mm thick
- 300 mm long, 13 mm wide and 0.65 mm thick
- With 14, 18, 24 or 32 teeth per inch
- Packs of 100, 10, 5, 3 and 2 blades

The process to manufacture the saw blades is long and complex. It is accomplished in two different factories that SNAEurope owns in Lidköping. This manufacturing process is divided in two main processes:

1. Bi-metal workshop
2. Blade manufacturing workshop

*Bi-metal workshop:* The hack saw blades SANDFLEX are made using a special alloy called Bi-metal which gives to the blades a high degree of flexibility and at the same
time a great wear resistance. The Bi-metal manufacturing is done in the other plant that SNAEurope owns in Lidköping, and transported to Lidköping blade manufacture, the main plant. Both the materials used in the manufacture of the bi-metal and the processes done on it, are carefully kept in secret by the company. This Bi-metal is stored in coils; the first step of the blade manufacturing is to cut the coil to shape the saw blades.

Blade manufacturing workshop; The processes accomplished in the blade manufacturing workshop to obtain the SANDFLEX hacksaw blades are:

1. Cut to shape: The coils are unrolled and cut in different sizes and shapes depending on the product type. After it, they are separated in batches of the same type of product.
2. Grinding/Milling & Setting: The different teeth are cut and sharp
3. Heat treatment
4. Painting: The SANDFLEX hacksaw blades are painted using dip painting. Here they take its characteristic orange colour.
5. Marking: The blades are marked according with their characteristics: model, size and number of teeth.
6. Packaging: The blades are packed in boxes of 100, 10, 5, 3 and 2 blades. Every hour approximately (10 000) blades are marked and packed.
7. Storage: The blades are manufactured to fill the stocks in the markets, so the does not need to be stored. The maximum storage time is two days; afterwards the packages are shipped to the customers. The main markets for SANDFLEX are South-Asia and South-America. [1]
1.1.2 The package:
The most common packing of the SANDFLEX is the box of 100 blades which occupies the 80 percent of market of SANDFLEX hacksaw blades (Figure 1.1). These boxes are manufactured as well by SNAEurope, which receive them in containers of 350 boxes from other factory. These containers are opened and used directly in the packing process. The containers are stored near the packaging process and transported to it by a (wheelbarrow).

The box for 100 blades is 350mm long, 80mm wide and 25mm high, and made of hard plastic with a transparent cover. Inside the box five lanes separate the different stacks of blades meanwhile two levels can be filled. The weight of an empty box is 186 grams, whereas it is approximately 2 kilogram when it is full. Its frontal part has a lid of 80mm long which is opened by pulling up. Normally boxes are open before packing process. After it are closed completely and one security piece assures the integrity of product until it reaches the client.

Figure 1.1; The package of 100 SANDFLEX hacksaw blades
1.2 Description of the Process

To produce the rotating files a mass production system is used, meanwhile for the three different kinds of sawblades the manufacturing systems used are two: mass production system at the beginning of process, especially to produce the coils of bi-metal, and batch manufacturing system in the final part, where the differences between “models” of sawblades are higher. All three kinds of sawblades are part of the same “technologic group” and the differences between them are small, however some parts of the process are different depending on the requirements of each product, for example the shape and size, the material treatment, the paint or the packing is not the same between the hacksaw blades and the power sawblades. The first separation of sawblades according to their product type is done after the cutting to shape process and from the heat treatment. In next step of the production the blades are processed in batches.

This project is pointed to the last four steps of the manufacturing process, specifically in the packing process of the SANDFLEX hacksaw blades, the product with the production rate higher of the factory, and in the packages of 100 blades. The manufacturing system used in the marking and packing processes is batch manufacturing system.

The last steps of the hacksaw blades manufacturing process are:

1. Marking brand name on the product
2. Pack the Hacksaw blades in boxes of 100, 10, 5, 3 or 2 blades.
3. Closing and labelling of boxes
4. Storage

In the marking machine used to mark the SANDFLEX sawblades, 8 main batches can be defined: the blades of 300x13x0.65 with 14, 18, 24 or 32 teeth per inch and the blades of 250x13x0.65 with 14, 18, 24 or 32 teeth per inch. Each one of these batches is marked with a different layer depending on the characteristics of the blades. When one whole batch is marked, the cliché of the marking machine is changed, and the next batch is processed.

As well in the packaging of SANDFLEX sawblades five different packages are used. None of these processes is automated. However the SANDFLEX blades of 300x13x0.65 packed in the boxes of 100 are the product that manufactured more than 80 percent of the total production.

Both marking and packing stations can be defined as a Single Stations Manned Cells. In the case of the marking machine the process is semi-automated meanwhile the packing process is completely manual. It means that two operators run and control the process at these stations, operator B at the packing and operator A at both stations.
The sketch of machines stations how they are placed in machine hall is shown below in fig 1.2.

Figure 1.2; Machines current position in machine hall
1.2.1 Marking the saw blades

After painting process, the saw blades are placed in one wagon and moved to the marking machine to mark the brand name on them. One operator (A) put the unmarked blades in a magazine that adapts the blades for the marking process, turning all of them with their teeth in the same direction.

The magazine of the marking machine has the room for 1000 saw blades and the machine can process 250 blades per minute. Two wheels provided with magnets collects and places, one by one, the blades from the magazine to a conveyor which moves them into the marking machine (Figure 1.3).

The marking machine is composed by one cliché, one flexo and one paint rollers. The paint is taken from the paint roller by the cliché roller, which has on it the mark that will be printed on the blades. This paint is UV curable, and can be of 4 different colours. In this case it is blue. Then, the cliché prints the logo on the flexo, which marks the blades. Then the marked blades pass through an UV dryer for three seconds to dry the paint.

Finally the hacksaw blades are grouped in stacks of 10 and jointed with Sellotape.

Figure 1.3; Marking machine: 1) Magazine; 2) wagon with unmarked blades; 3) Marking machine
1.2.2 Packaging of saw blades

From the marking station saw blades move on a conveyor to the packing station where they are packed into plastic boxes. At the packing station there are two wagons—one for empty boxes and one for filled boxes. The position of the conveyor and wagons is shown in Fig 1.4.

Operator (B) fills the boxes manually with the marked blades. They collect empty boxes from one container placed at its left side, open the box lid, collect five stacks of blades from the conveyor and put them into the box. The blades have sharp teethes, the direction of teethes should be on the right hand side and the arrow on the blade should be visible. The same operator places the filled box in a wagon which is standing on the right hand side. When the container becomes empty, operator (A) replaces it with another container.

When the wagon becomes full with the filled boxes, operator (A) moves it to the next station, where the boxes will be closed.

Figure 1.4; Packing station
(1) Conveyor C1; (2) container of empty boxes; (3) Full boxes wagon.
1.2.3 Closing and labelling of the boxes

The operator A passes the full boxes from the packing station to the welding machine in a wagon with place for 210 boxes. The Welding process is fully automated and its purpose is to close the boxes. The welding machine has an arm with vacuum cups that collect 10 boxes from the wagon and places them on a conveyor. This conveyor transports the boxes to the welding station, which by using the ultrasound welds the boxes knobs and closes the box completely.

After welding, through a conveyor, the box passes to labelling process where the labels with the brand name and product characteristics are stuck on each box.

Finally a robot SCARA picks and places the boxes from the labelling station to one container with place for 203 boxes. These containers with full boxes are stored no longer than 2 days, when they are shipped. [1]


2 PROBLEM DESCRIPTION

2.1 Needs of Automation

After understanding the product and process, it is necessary to identify and define the lacks on them. The reasons to automate must be enough good to justify the spending time and money to find other solutions as well the affording of changes in the production line.

The main problems with the current process are: The long time spent in the packing process, the high production rate needed for the product, the repetitive and uncomfortable task for the worker and the needs of two workers in one station. These factors are deeply described below.

2.1.1 Cycle time

The total time required to complete packaging process without any interruption at production line is approximately two and a half hours [1]. In order to run continues production the operator should be able to pack two boxes in a minute. If the person fails to perform this operation then the production has to be stopped until it clears. By means of automate the process; the manufacturing lead time can be reduced. The machine will accomplish the packing operation without stops.

2.1.2 Production Rates

As well the SANDFLEX hacksaw blades are the main product produced in SNAEurope, and its increasing market makes necessary the implementation of an automated system able to achieve the required production rates. With the automation the production rate will be increased since the speed of the marking machine will pass from 216 blades/minute to 350 blades/minute.

2.1.3 Ergonomics

Although operator (A) does the most of the tasks in the process, ergonomically the task of operator (B) is complicated; here operator (B) should pick boxes and fill them with the blades and also put them in the wagon. When empty box wagon is almost empty operator B has to bend down to collect one box. When the filled boxes wagon is empty in the beginning operator B has to bend down to place the boxes. The approximate weight of one filled box is 2 kilogram, to fill one wagon it may take more than 2 hours.

2.1.4 Logistics

Actually two operators (A and B) are needed to complete the packaging process. The only task of operator (B) is to pack the blade stacks into the boxes, operator (A) is required to work on three different tasks at the same time like filling marking machine, filling empty boxes wagon and moving the full boxes wagon to the next station. Implementing an automated station, only one operator is required and the task is to monitor the packing process and to fill the marking machine.
2.2 Limitations

It is important to consider the limitations of this project since it helps to define the scope and goal. The requirements of the project must be fulfilled without overload the limitations, that are both technical and economical.

2.2.1 Economical

The initial investment of the project is limited by the company to 500 000:- SEK, which is the loose estimated to be recovered in less than one year.

2.2.2 Technical

The project is focused in the design of an automated or semi-automated system to pack the SANDFLEX hacksaw blades in boxes of 100 blades, specifically the 300x13x0.65 mm sized with 18 teeth, although the design must be able to handle variations in the length and number of teeth of blades. The package of 100 blades does not admit any variations. Since the marking process is not fully automated, it is not necessary to have a fully automated packing system as the same operator can handle with both processes. However the attention of the operator must be only required periodically, and in monitoring or supporting tasks.

The packing station must be removable since the marking machine is used to mark other kind of blades, which are packed manually. For the same reason it is possible to modify neither the marking machine nor the way in which the blades come from the marking machine. For example, the marking process cannot be stopped during package and the blades are coming in stacks of 10 blades taped by Sellotape.

2.3 OBJECTIVES

The goal of this project is to reduce manual handling after marking the hack saw blades, through the automation of the packaging process. This objective can be divided in sub objectives that help to solve better the problem.

Sub objectives

1. Move the empty boxes to the packing position: The objective is to find a way to move the empty boxes from the container where they are stored to the position where they are filled. The process should not be stopped to provide the station of empty boxes, the packaging must be continuous. This task can be automated or semi-automated because of the difficulty to collect the boxes from the container.

2. Holding and opening of the box: Assure all the conditions to make a reliable packaging process, as the holding and opening of the box, by means of defining the characteristics of the packing position.

3. Pack 100 saw blades per box: The box used in this project has capacity to contain 100 blades. The design must assure that all boxes are completely filled with 100 blades.
4. **Close the box after packing:** The next step in the process line is the closing of boxes by welding two knobs in the box. So the boxes must be completely closed before being moved to the next station. The box is completely closed when the closing plaques at both sides of it are holding the lid.

5. **Move full boxes to the next station:** The full boxes must be prepared to pass to the next station. It means, they must be in a wagon or container that let the operator move them, or they must pass directly to the Welding Station from the packing process.

6. **Define all possible risks involved in process:** It is fundamental to define all the possible risks of each one of the solutions suggested to perform the tasks mentioned before. If one of these problems admits more than one solution, one of them must be suggested, explaining the reasons.

The machine designed has to be able to:

1. **Be disconnected from the marking machine when other products are made:** The marking machine is used fundamental to mark the SANDFLEX sawblades, but is not the only product marked in this machine. At the same time the SANDFLEX product has five different packages considering as well the 100 blades package. During the time the Marking Machine is processing other product different to the SANDFLEX or packing the blades in other package, the “Packing Station” will be removed.

2. **Give a quick return of investment:** To be a profitable design for the company, the optimum payback is one year.

3. **Handle with variations in the product type:** The machine has to be able to pack all SANDFLEX types (300x13x0.65mm and 250x13x0.65mm with 14, 18, 24 and 32 teeth) in the package for 100 blades.
3 LITERATURE REVIEW

In order to understand the purpose of this project, first it is important to clarify the meaning of concepts as production systems, manufacturing systems and automation. Without understanding these concepts it is very difficult to realize the backgrounds of this project since the type of automation is deeply linked with the characteristics of the manufacturing system. The kinds of equipment to use, the quantity or variety of the products produced among other aspects are fundamental to consider before approach a project of automation.

3.1 Production system and manufacturing systems

Production system can be defined as “the collection of people, equipment, and procedures organized to accomplish the manufacturing operations of a company”. One very important part of the production system is the facilities, the part of the production system which includes the factory, the equipment (as production machines and tooling, material handling and inspection equipment as well the computer systems) and the way the equipment is organized. The way as the equipment is arranged and the worker to operate them is the manufacturing system, and can be referred to either a single machine or a whole production line. [2]

Two important factors that determine the type of manufacturing system: the product variety and the production quantity. The product variety refers to the number of different product designs or types that are produced; meanwhile the production quantity refers only to the number of products produced.

Based in the production quantity three groups can be defined: low, medium and high production (often called mass production). In turn each one of them has their own manufacturing systems divided according to the product variety.

3.1.1 Mass production

The products are produced in high quantities due to the high demand rate. The product variety is low and the equipments used are special purpose machines or dedicated machines, which are specialized in doing a specific task, with special tooling, since they are not required to produce anything else. The investment cost in equipment is high to ensure they operate effectively, but affordable due to the great quantities produced by the system: “the greater quantity, the more specialized the equipment can be” because it will be worthwhile [3]. The main disadvantage is the impossibility to introduce big variations in the product without a high investment to change the operation mode of the machines.
3.1.2 Medium production

Two different manufacturing systems can be used according with the product variety: **Batch production** when the product variety is high and **cellular manufacturing** when this variation is low. In batch production the products are made in groups considered similar in type. The equipment used in batch production is called general purpose equipment because is able to produce a wide range of different parts or products. After one machine processes one batch of products, it is changed to produce the next batch of products that can be different.

In cellular manufacturing, the difference between products manufactured is low and limited. It means “the cell specializes in the production of a given set of similar parts or products, according to the principles of group technology” [2]

A type of facilities and layout for different production levels is shown in figure 3.1.

3.1.3 Low production

Very small quantities are produced, but often they are specialized products. The equipment used is general purpose machines, which are combined with high skilled workers in manual tasks. Specialized equipment is not justified for low production rates. As the quantities produced of one product are small, it is compensated producing a wide range of products.

![Diagram](image-url)

*Figure 3.1; Types of facilities and layout for different levels [4]*
3.1.4 Flexible manufacturing systems
It is more than a simple manufacturing system as it can involve every part of the production system and can be overlaid across the other manufacturing systems. Although is not possible to give only one meaning for FMS, it can be defined as “A reprogrammable manufacturing system in its broadest sense, dealing with high level distributed data processing and automated material flow, using highly flexible, computer controlled material and information processors within an integrated, multi-layered feedback control architecture”.[29] The equipment used in FMS is very flexible to handle with high product variations, and its control system is very complex since it has to make decisions in real time. The advantages of FMS over the other manufacturing systems are many, for example the possibility of unattended operations, the ability to react in the case of changes either in product type or production capacity, capability and volume; and the capability to recover gracefully from malfunctions or breakdowns. However the investments costs are very high and in many cases FMS is not necessary, useful or profitable for a specific production or product. The appropriate production range where FMS is profitable is the mid-volume and mid-variety. [2]

3.1.5 Lean production
Can be defined as “An adaptation of mass production in which workers and workcells are made more flexible and efficient by adopting methods that reduce waste in all forms.” Although lean production is a very abstract concept, the basic idea is to improve all fields of the production system as operations (remove unnecessary processing steps, unnecessary transport and workers waiting), quality or product design, to make more efficient the process.

3.1.6 Agile Manufacturing
Involves much more than the manufacturing system. Basically consist in make the whole process system able to react to the continuous changes in the market, bringing new products as fast as possible and in this way improve the competitively of the company. [2]

3.2 Single Station Manufacturing Cell
When the manufacturing system is referred to a single machine, it is possible to talk about a Single Station. These single stations are the most common manufacturing system in industry and are divided in two different categories depending on the labours of the worker at the station: Single Station Manned Cell and Single Station Automated Cell.

3.2.1 Single Station Manned Cell
Can be either manually or semi-automated. In a manually operated station the work is done by the worker, which operates manually the machine or the tool, as well as does the loading and unloading operations; meanwhile in a semi-automated station the worker simply loads, unloads the machine and eventually changes the tools. In both cases the attendance of the operator is required although in the case of manual operation it is continuous. Some of the advantages of this manufacturing system are the low investment costs, the flexibility since is operated by a human and the simplicity.
### 3.2.2 Single Station Automated Cell
Unlike the Single Station Manned, for the Single Station Automated Cell the attention of the operator is only required periodically since it has the ability to operate unattended for extended periods of time. The main advantages obtained with the fully automation of one process is: labour cost reduction, product rates higher and usually is the first step to install an integrated multi-station automated system. [2]

### 3.3 What is Automation?
Nowadays the concept of automation is widely extended in the world of production systems and each day acquires major relevance.

The word automatic often is referred to processes that automatically do things. In this case automatically means without human assistance [5]. This term can be extended since actually in production systems the purpose of automation is wider, considering automation as a “technology in which a process or procedure is accomplished by means of programmed instructions usually combined with automatic feedback control to ensure the proper execution of the instructions” [6]. The basic elements of automation system are shown in figure 3.2.

Automation is not a new idea. Since the humanity develop the first basic mechanical devices, to perform or just help doing simple tasks, until now with our fully automated systems, automation has suffered several changes in its concept. The first attempt to use a machine to help the human was the wheel, invented nearly 3200 B.C. This simple device is still useful nowadays. Behind the invention of wheel some basic instruments were invented like the lever and winch (circa 600 B.C), cam (circa 1000 A.D), screw (1405 A.D) and gear among other. These basic devices in turn were improved and used to develop new machines, which were able to use the environment to power them. Wind, water and steam became the fuel of these machines instead of the manpower used before. Some examples of these new machines are the waterwheels, windmills and steam engines. The improvement continues using the power generated by these machines to operate other machinery as flour mills or railroad machinery.

The concept of autonomous control system was introduced with the feedback control (around 1785) and it, linked with the program instructions and the power source constitute the basic elements of automated systems.

![Figure 3.2; Elements of an Automated System [2]](image-url)
From 1800 the developments in automated systems went fast, some examples are the electrification (1881) and the mathematical theory of control systems (1930s and 1940s). However the great technological leap occurred with the arrival of the digital era. The first electronic digital computer (1946), the first numerical control machine tool (1952), digital computers were connected to machine tools (late 1960s and early 1970s), the first flexible manufacturing system (late 1960s), the first industrial robot (1961), the first PLC introduced in industry (1969) and the first personal computer (1978) among others constitute the base of the actual concept of automation: “a technology concerned with the application of mechanical, electronic, and computed-based systems to operate and control production.” [2]

Other advances were fundamental in the development of automated systems as the transistor (1948), integrated circuits (1960), the microprocessor (1971), the modern operating systems (Unix 1985, Windows 1985) and programming languages. [2]

### 3.4 Reasons to automate

One of the most attractive reasons to automate a process is the reduction in labour costs. Nowadays the investment in automation is still high, but economically justifiable to replace manual operations [2]. In spite of the relation between investments, running costs of the machine and labour savings is not always favourable and more considerations must be done. Not all processes are automatable, and humans are still fundamental in the manufacturing industry. Tasks that require manual dexterity, demands on hand-eye coordination, products with a high level of customary or changes in demand or product are easily done by humans. In general “humans are more flexible than any automated machine” [2].

Human have more advantages over machines than the ability to adapt the changes. Develop new solutions to problems, learn from experience or cope with abstract problems are examples of these advantages. So why to automate a production?

Some factors can influence the potential automation of a task or process. In the case of repetitive, uncomfortable or fatiguing jobs, the performance of a human worker depends highly of its physical, mental and mood conditions. A worker that is not in the best frame of mind for working, is tired or simply bored will not accomplish their job in the same way as a worker that is satisfied or motivated. Likewise in case of hostile environments or heavy operations the limitations of humans are obvious [7].

However machines accomplish their work with reliability, repeatability and accuracy along whole process. As well is known that machines have a great strong and power, can perform multiple tasks at the same time or perform simple computations quickly. The job of the worker passes from their participation in the process to a supervisory role, with the consequents advantages as safety and reduction of human error [2].

As well processes with a high product demand or/and high quality products will benefit more of automation. Production rates can be increased and manufacturing lead time be reduced since machines can accomplish the operation faster than humans and without
stops. The manufacturing process improves its quality as the machine achieves its task with uniformity and accuracy. [2]

As conclusion, although the idea to automate is attractive, automation is not always the most suitable option for all processes. It is important to consider afterwards the reasons and the ways to automate a certain process. As well to have a good understanding of process and identify the tasks possible to simplify and risks behind automation is fundamental to achieve a well automated process.

3.5 Selection Criteria

3.5.1 Flexibility
Flexibility is a concept that means able to change or be changed easily according to the situation [8]. In this context flexibility is focused on the design of packing process that the same design can be used to manufacture different types of product. As well it can be related with the ability of the design to be changed easily in the future to modify the process, product or production rate.

3.5.2 Reliability
In such case it can stated that the system is reliable if it will work well in the way you expect [8]. The design of proposed solutions should have to work well according to the requirements of the company and involve all the possible risks.

3.5.3 Accuracy
The ability of a measurement to match the actual value of the quantity being measured is known as accuracy. [9]. Here the accuracy context is the measure of how precise the design is. It means that the sawblades must be packed precisely without crashes of sticks. As well it can be referred to each one of the devices and its performances.

3.5.4 Robustness
Robust design generally means that the design is capable of functioning correctly, (or at the very minimum, not failing catastrophically) under a great many conditions. Also, it means that tolerances can be looser because “it can only be built one way” [9].

3.5.5 Maintenance
Maintenance means to keep a machine in good condition as well the work to repair it after a breakdown. Companies define their schedules for the maintenance of machines [10]. In many cases machine needs to stop for schedule maintenance and if its maintenance routine is complicated then it will take more time. The production stop is a lost of production, consequently it increase the production cost so while selecting the machines maintenance point is always a considerable. As well the life time and costs of spares are important.

3.5.6 Complexity
“Automation complexity refers to the number and connectivity of the information streams that the operator must monitor and maintain” [11]. The priority is to find the simplest solution to certain problem.
3.5.7 Safety
“A state in which or a place where you are safe and not in danger or at risk” [8].

3.5.8 Payback Time
The amount of time it takes to get back the sum of money originally invested on project is called the payback time. [8]. This is always important for companies while investing money on a project that how long it will take to return the invested amount and how long it will give benefit.

3.6 Industrial Robots
Nowadays the robot has become in a fundamental part of the manufacturing industry as it is one of the most flexible equipments presents in the industry. It can be defined as “a reprogrammable, multi-functional manipulator designed to move material, part, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.” [12] This ability to be re-programmed is the main reason that makes it appropriate for the most of tasks required in the factories. It can accomplish from a pick and place task to a welding, assembly, packing and more. [7]

However the investment in a robot is a high risk if their characteristics are not considered carefully. There are many different robots in the market and not all of them are suitable for a certain task. Industrial robots can be categorized in six types based on their mechanical structure:

1. Cartesian robot /Gantry robot
2. Cylindrical robot
3. Spherical/Polar robot
4. SCARA robot
5. Articulated robot
6. Parallel robot

From this division is possible to compare easily the main selection criteria to select the best robot for a certain application.

3.7 Robot selection Criteria
Many factors will determine which robot is best suited for a specific application. These include the axes of movement, work envelope, speed, load capability (payload), structural rigidity, repeatability and accuracy. [7] Each application requires some characteristics that make one robot more suitable than the others.

3.7.1 Workspace
It is the range of space that the robot can reach. It is defined by the maximum distance reachable by the end-effector at the end of the robot arm. [7]

3.7.2 Degrees of Freedom
The number of DOF that a manipulator possesses is the number of independent position variables that would have to be specified in order to locate all parts of the mechanism.
In other words, “the dimensions in which a manipulator can move are called its degrees of freedom.” [13]

3.7.3 Accuracy
Accuracy is the ability of a robot to go to the specified point in space defined in term of axis or coordinate system [14]. It is impossible to position a machine exactly.

3.7.4 Repeatability
The ability of a robot to return to the same spot again and again after that point has already been taught system [14]. Accuracy is absolute concept whereas repeatability is relative.

3.7.5 Pay Load
Robot payload is the weight a robot arm can lift. It includes the weight of the end of arm tooling. [7]

3.7.6 Speed
The amount of distance per unit time, at which the robot can move usually specified in meters per second. The speed is usually specified at a specific load or assuming that the robot is carrying a fixed weight. [7]
<table>
<thead>
<tr>
<th>Type of Robot</th>
<th>DOF</th>
<th>Work Space</th>
<th>Repeatability</th>
<th>Accuracy</th>
<th>Payload</th>
<th>Speed</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cartesian robot</td>
<td>4</td>
<td>Large (100 by 100 mm to 2000 by 2000 mm)</td>
<td>Very good</td>
<td>Good</td>
<td></td>
<td>Fast</td>
<td>Pick and place work Application of sealant Assembly operations Handling machine tools Arc welding</td>
</tr>
<tr>
<td>Cylindrical robot</td>
<td>3</td>
<td>Limited</td>
<td>Good</td>
<td>Fair</td>
<td>Large</td>
<td>Slow</td>
<td>Assembly operations Handling at machine tools Spot welding Handling at die-casting Machines</td>
</tr>
<tr>
<td>Spherical/Polar robot</td>
<td>3</td>
<td>Large</td>
<td>Fair</td>
<td>Fair</td>
<td>Large</td>
<td>Slow</td>
<td>Handling at machine tools Spot welding Die-casting Fettling machines Gas welding, Arc welding</td>
</tr>
<tr>
<td>SCARA robot</td>
<td>4</td>
<td>Limited</td>
<td>Good</td>
<td>Good</td>
<td>Large</td>
<td>Fast</td>
<td>Pick and place work Application of sealant Assembly operations Handling machine tools</td>
</tr>
<tr>
<td>Articulated robot</td>
<td>6</td>
<td>Large</td>
<td>Very good</td>
<td>Good</td>
<td>Large</td>
<td>Fast</td>
<td>Assembly operations Pick and place work Die-casting Fettling machines Gas welding Arc welding Spray painting.</td>
</tr>
<tr>
<td>Parallel robot</td>
<td>6</td>
<td>Limited</td>
<td>Good</td>
<td>Good</td>
<td></td>
<td>Fast</td>
<td>Mobile platform handling Cockpit flight simulators Robotic surgery</td>
</tr>
</tbody>
</table>

Ref [15]
3.8 Actuators

Cylinders are used more than any other device for taking the pressure or power in a fluid system and converting it into mechanical force. It produces a straight-line motion but this can be converted into a limited rotary motion [16]. A pneumatic or hydraulic cylinder simply converts fluid pressure into linear motion. Both having specific advantages and disadvantages. The two options can be regarded as competitive or possible alternatives. A basic difference between them is that the pneumatic cylinder working fluid exhausting to atmosphere since the cost of fluid is nil and hydraulic cylinders working fluid operate in a recirculation or closed loop that needs additional components. A comparison between pneumatic cylinders and hydraulic cylinders can make a good understanding of both types own benefits. [17]

Factors favouring Pneumatic cylinders

1. Low initial cost.
2. Low operating cost.
3. Low maintenance
4. High reliability
5. High operating speed
6. Simplicity of control
7. Operation in hazardous ambient
8. Operation at high temperature
9. Cleanliness of operation

Factors favouring Hydraulic cylinders

1. High output force.
2. High rigidity of the system
3. Good hold facility
4. Good synchronization possible
5. Positive feeds and precise control
6. Extremely high power amplification
7. Low noise level

Pneumatic system can often suitable for applications under which hydraulic system are basically unsuited. The big advantage of pneumatic system is very low operation cost comparatively other.

Generally pneumatic cylinders are of two types, single acting and double acting:

*Single Acting Cylinder:* In a single acting cylinder compressed air is fed only in one side. This cylinder can produce work only in one direction. The return movement of the piston can be a built in spring or an external force.

*Double Acting Cylinder:* In a double acting cylinder the compressed air moves the piston in two directions. They are particularly used when the piston is required to perform work not only on the advance movement but also on the return. [18]
3.8.1 Valves
Valves are components that control the direction, pressure or flow-rate of fluid or air with the purpose to control the actuators. [17]

3.9 Sensors
“In order to successfully automate a process, it is necessary to obtain information about its status. The sensors are the part of the control system which is responsible for collecting and preparing process status data and for passing it onto a processor”. [19] The different types of sensors are listed below.

3.9.1 Inductive proximity sensor
The inductive proximity sensors detect the presence or absence of metallic objects with an electronic noncontact sensor. They are used in place of limit switches for noncontact sensing. The range limit of a proximity sensor is up to 100 mm. The typical uses of inductive proximity sensors are: [19]
- Detection of rotating motion
- Zero-speed indication
- Fault condition Indication
- Speed regulation
- Product count and product selection

3.9.2 Capacitive proximity sensor
The capacitive proximity sensor detects objects based on their dielectric strength. Capacitive proximity sensors produce an electrostatic field. It can sense metal as well as non-metallic materials. The typical uses of capacitive proximity sensors are:
- Overflow limit.
- Dry tank
- Material presence

3.9.3 Ultrasonic sensors
Ultrasonic sensors enable the detection of different objects irrespective of colour and transparency. It gives analog output current or voltage that are proportional to the distance of the sensor from the target. It allows simple contact-less measurement. It can detect plastic, foils, level of liquid and can monitor transparent material.

3.9.4 Photoelectric sensors
Photoelectric sensing uses a beam of light to detect the presence or absence of an object. This technology is an ideal alternative to inductive proximity sensors when the required sensing distances are longer or when the item to be sensed is non-metal. [19]

3.9.5 Micro Switch
Micro switch is electric switch actuated by the physical motion of mechanical devices. The actuation of the switch typically causes an “on” or “off” action. It can be use to detect Presence or absence, where physical contact with an object is permissible. [20]
3.10 The PLC

A programmable logic controller (PLC) is a microcontroller based controller used in industry to control industrial processes. The PLC is designed for multiple inputs and output arrangements, which are used to communicate and control the devices such as sensors, cylinders or conveyors. Before the invention of PLC hard wired controllers were used to control the process that were composed of relays, timers, counter and etc. PLC eliminates the use of all these components and makes the control easier. PLC has several advantages instead having a conventional (relays, timer, counter) controller. [2]

1. Easy to makes changes in the program comparatively changing a hard wired control system.
2. Very high reliability as compare to the conventional controller
3. Easy to interface and communicate with computer system, remote monitoring and control via digital computer network is possible.
4. Can perform a large number of control functions
5. Compact in design; eliminate the use of big control panels.
6. Decrease the maintenance cost due to having less equipments.
7. Computational abilities allow more sophisticated control.
8. Troubleshooting aids make easier programming task easier and cause to reduce the down time.

3.10.1 Components of PLC

The basic components of a Programmable Logic Controller are power supply, central processing unit, memory, analogue I/O module, digital I/O module and programming device. A block diagram of components is figured down in Fig 3.3.

Power supply

Normally the vendor of PLC they provide a power supply unit that is actually a converter from 110 VAC or 220VAC to 24VDC. The low voltages are used to operate equipments. The power supplies often have a backup battery that will automatically switch on in case of external power supply failure.

Central Processing Unit

This part is called the heart of the PLC; it executes logical and sequencing functions and performs all arithmetic functions. The processor of a PLC is like a normal pc but facilitated with I/O transactions.

Memory Unit

Memory unit is connected with the processor, which contains the logical program, sequence and I/O operations. This is an application memory because the programme stored on it is described by the user. Most of the time a volatile memory is used in PLC but some vendors is also offering non-volatile.
Input/Output Module
This module provides the connection with the field equipments of the process. Input of the system can be like a push button, limit switch, sensor and the output of the plc can be an on/off signal or a value to control an actuator. The size of a PLC is rated of its I/O terminals. [2]
4 PROBLEM SOLUTION

The objective is to pass the packing process from a manually operated Single Station Manned Cell to a semi-automated Single Station Manned Cell or to a Single Station Automated Cell. It means the task of operator passes from do manually the operation to supervise the process.

The machine will pack only one type of product, the SANDFLEX sawblades since is the product more demanded to the factory. The production rate is high and the product variation is low, so the equipment used for this automation should be a special purpose machine, it means it is specialized in doing a specific task, in this case the packaging of the SANDFLEX blades in packs of 100 blades.

After a long design process, three solutions were developed to solve the problem. The different possible ways to pack the hacksaw blades are:

1. **Pneumatic solution:** Is a semi-automated Single Station Manned Cell since one operator is required to load the empty boxes to the station. Uses pneumatic devices to accomplish tasks as hold, open and close the box or push either sawblades or box. The process is controlled by a PLC, which coordinates the different devices as sensors, cylinders and conveyors. The sawblades handling is automatic by use of three conveyors that connect the different stations.

2. **Robotic solution:** Single Station Automated Cell where an articulated robot performs all the tasks of process: load, unload of boxes and packaging of blades. However the operator besides to monitor the process, replaces the container of empty boxes when it is empty and changes the full boxes wagon when it is full.

3. **Hybrid solution:** Using both pneumatic and robotic equipment is possible to have a robust design which combines the unattended operation with the flexibility and reliability of the robot. It is a Single Station Automated Cell with a robot playing a supporting role, just loading and unloading the boxes.

The concept of FMS is not possible to apply to this process since the product volume is high and the product variety low. As well the investment cost is limited, and a high reconfiguration of the manufacturing system is not feasible. The equipment involved in the manufacturing of sawblades is dedicated, as the case of the marking machine, specially designed to mark the SANDFLEX sawblades.
4.1 **Solution 1: Pneumatic**

The sketch of pneumatic solution is shown below in figure 4.1.

![Figure 4.1: Pneumatic solution](image)

After the marking process, saw blades come out from the marking machine with one specific orientation and in stacks of 10 saw blades jointed with Sellotape.

One conveyor (C1) moves the saw blades stacks from the marking machine to other conveyor (C2) placed just next to it. This second conveyor has the same orientation as the first one, however it is faster. This increment of speed is necessary to make longer the distance between the saw blade stacks on second conveyor. One obstacle at the end of C2 stops the blades at the packing position.

The packaging process is made by the Packing station, one removable table that contains the most of components necessaries to the packaging process like sensors, pneumatic devices and control.

Finally, after packing the saw blades in the boxes, another removable conveyor (C3) transports the full boxes to the welding machine.

The whole process is controlled by a PLC.
4.1.1 Packing station:

It is composed of two main parts: the empty boxes magazine and the filling station. The front view of packing station is shown below.

![Figure 4.2: Packing station front view](image)

4.1.1.1 Empty boxes magazine

Empty boxes are placed in one magazine designed for this task, with appropriate size and shape to put the boxes in it. This magazine has capacity to contain 20 boxes.

One reflective proximity sensor (S_1) positioned at one side of the magazine, notices if the magazine is empty. In this case, one light signals notifies operator that they have to fill the magazine.

A pneumatic cylinder (Cyl_1) is used to push the box out from the empty boxes magazine to the filling station, where the box is going to be filled. This cylinder does not push any empty box unless the filling station has no boxes on it. One micro switch (S_2) is used to detect the box presence at filling station.

4.1.1.2 Filling station

As soon as an empty box is positioned at the filling station, one cylinder (cylinder 4) is activated from the top to hold the box at packing position. Cylinder 3 is at one side of the box and its function is to push full box to conveyor 3. Three more cylinders (cylinder 5, cylinder 6 and cylinder 7) are used to open and close the box. Cylinder 5 keeps the lid open during filling process, cylinder 6 pushes the lid horizontally to bring it near to the cylinder 7, which pushes it down and closes the box completely.

4.1.1.3 Packaging of saw blades

At the end of conveyor 2 one obstacle stops the saw blades stacks. Five magnetic sensors placed along conveyor (MS_0, MS_1, MS_2, MS_3, MS_4) detect the presence of five stacks at packing position. When there are stacks at the packing position and at the same time there is an open empty box in the packing station, one cylinder (cylinder 2) pushes the saw blades stacks directly through a guide that leads them into the box.
4.1.1.4  After filling the box: Counter 0

Every time when cylinder 2 pushes saw blades stacks into a box, one counter (Counter0) initially at zero, increments its count. Once the count reaches 2, cylinder 2 sends a signal (Full_box) to cylinder 3 to push the filled box to the conveyor 3. Then Counter0 resets the count.

4.1.1.5  Conveyor 3 and Welding Machine

Conveyor 3 links packing station with the welding machine to make the process faster. With this purpose, welding machine is moved from its actual position to the front of the packing station and the marking machine. The distance between the packing station and the welding machine is approximately 2 meters.

As well conveyor 3 is used as a buffer between Packaging station and welding machine. In case welding station is stopped, packaging process continues until one reflective proximity sensor (S_3) placed at the end of the conveyor 3 detects that it is full. Both conveyors and packaging process will automatically stop to wait until welding station continues its work. The signal weld_state from welding station notices when the welding process is stopped or restarted.

A visual signal advices operator when conveyor 3 is full. The packaging process is stopped automatically until C3 is emptied.

4.1.2  Pros and cons of pneumatic solution

4.1.2.1  Pros

1. Packing station can be easily removed
2. Simple in design
3. Low cost maintenance
4. Easy to troubleshoot
5. Easy to implement
6. Low initial investment
7. Very safe
8. Availability of skilled labour is not an issue
9. Continuous process without any stop

4.1.2.2  Cons

1. Unattended operation is not possible
2. It is not fully automated solution it still need little human interaction
3. More noisy system due to cylinders extending and retracting operation
4. Difficult to adapt to new applications. Change in design is difficult
5. With the passage of time components performance will be affected
6. Production line needs to modify to implement this design
7. Limited control and accuracy (air is compressed)
4.2 Solution 2: Robot

After the marking process saw blades come out from the marking machine to the conveyor (C1), all with one specific orientation and in packs of 10 saw blades jointed with Sellotape.

As in the pneumatic solution, one second conveyor (C2) is placed just next to the conveyor (C1). This second conveyor is faster than conveyor (C1) with the only purpose of the making longer the distance between saw blade stacks.

Empty boxes received from vendor, packed in a big container with capacity of 350 boxes, putted in different orientation (Figure 4.3), which makes the collecting task complicated for the robot.

Figure 4.3: Position of boxes in empty boxes container
(1, 2) Horizontally; (3) vertically

To solve this problem the options are:

1. Changing the orientation of the boxes in the container: It is possible to ask the manufacturer of these boxes to change the specification of the boxes packaging according to the requirements of the project. Place the empty boxes in a magazine or wagon is another option but it requires manual work.
2. Using vision systems to detect the orientation of boxes: Although the vision detection is feasible due to the box characteristics, the investment costs are increased.

The most suitable option is to change the orientation of the boxes in the container since the manufacturer of the boxes is also SNAEurope.

![Diagram of Robotic Solution](image)

**Figure 4.4: Robotic solution**

### 4.2.1 Empty boxes

The robot collects an empty box from the container and places it on the filling magazine. During packaging process a counter (C_bx) indicates the robot which box to pick (box 0, box 1 ... box n). Every time the robot picks one box, the counter is incremented, as well when the robot is started this counter is reset. To collect an empty box from the wagon, the robot has to know the exact position of the box in the Workcell. These positions are recorded in the robot memory during the robot programming process, controlling the robot arm with the teach pendant directly in the Workcell (online programming).

To manipulate the boxes robot has a vacuum gripper. This is a suitable option to pick boxes due to boxes flat surface. Since boxes are placed side by side to each other, is
difficult to pick them with a mechanical gripper. The position of the robot is shown in figure 4.4.

4.2.2 Filling magazine

It is the place that holds the box during packing process and can be attached to the robot’s base or to conveyor (C3) base. It dimensions are a tenth of millimetres bigger than box and two flexible sticks keep the lid of box open during packaging process (Figure 4.5).

![Figure 4.5: Filling Magazine](image)

(1) Flexible sticks

4.2.3 Packaging of blades

To detect the saw blades stacks on the conveyor five magnetic sensors are placed along it. When all five sensors become active the robot grabs five saw blade stacks and packs them into the box. Counter 0 is used to know how many stacks have been putted into the box. First time it is zero and every time robot moves stacks into the box it increments the count. When counter 0 reaches 2, the counter is reset; robot closes the box and places it on conveyor (3), which links packing process with the welding machine.

To grip the hacksaw blades stacks the robot uses a magnetic gripper, the most suitable option due to the metallic material of blades.

Finally, as in pneumatic solution, conveyor (3) can be used as a buffer, stopping only when welding machine is stopped and conveyor (3) is full.
4.2.4  Pros and cons of robotic solution

4.2.4.1  Pros
1. Fully automated, no human interaction involved while running the process
2. Unattended operation is possible
3. Easy to make changes in production rate, volume and variation of product. Robot is reprogrammable
4. More accuracy and repeatability

4.2.4.2  Cons
1. Comparatively costly to implement this design. Initial investment very high
2. Complex kinematics
3. Two different grippers are used. More complex
4. Skilled labour required. Engineers and programmers
5. Other devices in process have to be in the same relative distance to robot to assure accuracy
6. Maintenance cost is high
7. High cost of spares
4.3 **Hybrid Solution**

Use the robot only for the task to pick and place the boxes with a vacuum gripper whereas for packaging process use the design of filling station explained in pneumatic solution's description, only removing cylinder 3. Robot takes and places the boxes as is described in robotic solution's description.

4.3.1 **Pros and cons of hybrid solution**

4.3.1.1 **Pros**
1. Unattended operation is possible. Fully automated
2. Only one gripper

4.3.1.2 **Cons**
1. Many of the problems of robotic and pneumatic solutions
2. Initial investment very high due to the use of a robot, a PLC, pneumatic devices, etc

As a different option, the robotic or hybrid solutions can be modified by using a vision system integrated with the robot to detect orientation and position of the boxes in the container, instead of the use of magazines, special containers or wagons. This solution makes easier and unattended the pick and place task, but is more complex to program and also more expensive than other solutions.

4.4 **Table of devices being used in process**

All devices mentioned along the three solutions are summarized in the table below, with their respective symbols and description:

<table>
<thead>
<tr>
<th>Device/ Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylinder 1 / Cyl_1</td>
<td>Cylinder 1 is used to push out empty box from empty boxes magazine</td>
</tr>
<tr>
<td>Cylinder 2 / Cyl_2</td>
<td>Cylinder 2 is used to push saw blades into the box</td>
</tr>
<tr>
<td>Cylinder 3 / Cyl_3</td>
<td>Cylinder 3 is used to push fill box next to conveyer 3</td>
</tr>
<tr>
<td>Cylinder 4 / Cyl_4</td>
<td>Cylinder 4 is used to fasten the box at filling station</td>
</tr>
<tr>
<td>Cylinder 5 / Cyl_5</td>
<td>Cylinder 5 is used to open the flap of box</td>
</tr>
<tr>
<td>Cylinder 6 / Cyl_6</td>
<td>Cylinder 6 is used to close the box horizontally</td>
</tr>
<tr>
<td>Cylinder 7 / Cyl_7</td>
<td>Cylinder 7 is used to close the box vertically</td>
</tr>
<tr>
<td>Conveyor 1 / C_1</td>
<td>Conveyor 1 brings out saw blades from Marking Machine</td>
</tr>
<tr>
<td>Conveyor 2 / C_2</td>
<td>Conveyor 2 is used to increase the distance between saw blades stacks</td>
</tr>
<tr>
<td>Conveyor 3 / C_3</td>
<td>Conveyor 3 is used to transport the filled box next to welding machine</td>
</tr>
<tr>
<td>Sensor 1 / S_1</td>
<td>Reflective proximity sensor to detect the status of empty boxes magazine</td>
</tr>
<tr>
<td>Sensor 2 / S_2</td>
<td>Micro-switch to detect the presence of box at filling station</td>
</tr>
<tr>
<td>Sensor 3 / S_3</td>
<td>Reflective proximity sensor to detect the status of conveyor 3 full or not</td>
</tr>
<tr>
<td>Inductive sensor 0</td>
<td>Inductive sensor 0 to detect the presence of blades stacks at filling station</td>
</tr>
<tr>
<td>MS_1</td>
<td>Inductive sensor 1 to detect the presence of blades stacks at filling station</td>
</tr>
<tr>
<td>MS_2</td>
<td>Inductive sensor 2 to detect the presence of blades stacks at filling station</td>
</tr>
<tr>
<td>MS_3</td>
<td>Inductive sensor 3 to detect the presence of blades stacks at filling station</td>
</tr>
<tr>
<td>MS_4</td>
<td>Inductive sensor 4 to detect the presence of blades stacks at filling station</td>
</tr>
</tbody>
</table>
4.5 Comparison of Different Solutions

Once defined the pros and cons for each one of the solutions, it is important to compare the solutions between them until select the most suitable solution for this task. In this sub chapter the selection criteria used to select the final solution are defined, describing the importance that they have in this specifically design.

4.5.1 Flexibility

Flexibility concept in manufacturing is usually related to the ability of system to adapt the changes in variety of product or in volume of production [3]. The hacksaw blades SANDFLEX occupy the major rate of production (80 percent) although some times the marking machine is used to mark other types of the blades. The station to pack saw blades has to be easily removable from the marking machine when other products are marked.

In this context pneumatic solution is flexible since it is composed by packing station and conveyors 2 and 3, all of them easily removable. However it cannot afford changes in product type or volume, which can be easily done in robotic solution by reprogramming the robot. On the other hand robot cannot be moved as easy as pneumatic solution due to its security stuff and the need of calibration.

4.5.2 Reliability

Both designs will perform satisfactorily the packaging process, even though robotic design has more risks involved in its operation. It is more sensible to change in details as calibration or defective jointing of stacks with the Sellotape.

4.5.3 Accuracy

The level of accuracy in manufacturing gives an idea about how precise one task or process is [3]. In terms of accuracy and repeatability, robot is the most suitable option due to its control system. As well pneumatic cylinders are well known to have limited control and accuracy because of the use of compressed air in their control [17].

However to perform the packaging process of the blades a very high accuracy and repeatability is not the main requirement since the tolerance is quite enough. The box lanes are 14.2 mm as the width of blades is 10mm, which means 4.2 mm of difference.

4.5.4 Robustness

Pneumatic and robotic solutions are very robust in design. In this design means all components can operate near or outside of their rated limits. [21]

4.5.5 Maintenance

Selecting the suitable solution maintenance is a considerable factor due to the cost, lost of time and troubles that can cause an inadequate routine maintenance. A routine of preventive maintenance well done extends the life of the equipment as well a good managed corrective maintenance routine prevents the long stops in production [22].
In the case of robots, the maintenance service is often offered by the vendor. It cost is approximately 15000SEK per year. The maintenance of pneumatic devices is done by the company’s maintenance personal. The approximate cost of the maintenance of the machine designed in this project is 8000SEK per year.

It is also important to consider the price and availability of the spares. In the case of cylinders, nowadays most of them are disposable and it is necessary to buy new devices in case of failure. On the other hand, robots are quite robust but its spares are also quite expensive. The approximate cost of robot spares is 10000 SEK per year. Compared with the money that company can spend in the pneumatic solution spares, 3000 SEK per year approximately, is greatly less [1].

4.5.6 **Complexity**

“Automation complexity refers to the number and connectivity of the information streams that the operator must monitor and maintain” [11]

The control system of a robot has to carry out with both the kinematics of the arm and the structure of the robot program [7], which requires a very complex control system which does hundred of mathematical operations in just a few milliseconds. On the other hand a pneumatic cylinder is a very simple device composed by mechanical parts and moved by compressed air.

4.5.7 **Safety**

It is very important to assess the risks involved in process and develop a safe design. “It is the clear moral and legal responsibility of a company or individual to identify any danger points in a facility and to provide appropriate safeguard” [7]

Although robots can free operators from the risks to work with machinery, the robot itself involves several risks for personal. The main difference between a robot and the traditional machinery is the big work envelope also the freedom of movement of its arm. This work envelope has to be well secured either with a fence or with a light curtain, as well restricted for personal during process. More safety precautions have to be taken to avoid hazards caused by robot. Safety training is also important. [7]

“Compressed air systems are capable of generating significant forces that power fast moving mechanisms. When things move fast and with great force, they become very dangerous. Pneumatically powered mechanisms can move at speeds that are too fast for humans to safely react to”. [23]

However the moveable parts of the pneumatic cylinders are easily coverable and with the use of light curtains and emergency stops the safety can increased.

4.5.8 **Payback**

Is one of the most important selection criteria for the company and in this project is a requirement to give a quick return of investment within one year.

\[
P = \text{Payback} = \frac{I}{(L - E)}
\]

\[
I = \text{Total investment}; \quad E = \text{Annual running costs}; \quad L = \text{Annual labours savings}[7]
\]
The approximate costs of a robot within the maintenance cost are [24]:

IRB 140: 300 000:-
IRB 340: 310 000:-
IRB 1600: 340 000:-
PickMaster: 100 000:- (Vision system)

I = Total investment = 300 000:-

E = Annual running cost of the robot = 25 000:-

L = Annual labours savings = 445 000:-

P = Payback = I / (L - E) = 0, 71

The approximate cost of a pneumatic installation is:

I = Total investment = 80 000:-

E = Annual running cost of the pneumatic installation = 8 000:-

L = Annual labours savings = 445 000:-

P = I / (L - E) = 1, 83

4.6 Selection of the suitable solution

The pneumatic is the solution that better adapts to the requirements of project regarding flexibility, payback, maintenance, complexity and safety. The robotic solution is more suitable regarding to reliability, accuracy and repeatability.

All the considerable points of the solutions have been discussed so far. By the comparing and contrasting the best solution to automate the packaging process is the Pneumatic Solution.
<table>
<thead>
<tr>
<th>SELECTION CRITERIA</th>
<th>PNEUMATIC</th>
<th>ROBOTIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexibility</td>
<td>Packing station can be easily removed to change the production line.</td>
<td>Robot can be removed easily to change the production line, but requires calibration every time before start process again.</td>
</tr>
<tr>
<td></td>
<td>Difficult to make changes in the final design of station.</td>
<td>Big possibility to expands production capacity in future, robot is easy to re-program</td>
</tr>
<tr>
<td></td>
<td>Difficult to expand production capacity in future.</td>
<td></td>
</tr>
<tr>
<td>Complexity</td>
<td>Simple design. Mechanically simple.</td>
<td>Complex and complicated to design and program, high level programmers and engineers required</td>
</tr>
<tr>
<td></td>
<td>Easy to program and simple to implement.</td>
<td>Employees will require training in programming and interacting with the new robotic equipment.</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Easy and low cost maintenance.</td>
<td>Maintenance cost is high.</td>
</tr>
<tr>
<td></td>
<td>Fail gradually with the time (wear and tear because of the use).</td>
<td>Specialized personal required for maintenance</td>
</tr>
<tr>
<td>Reliability</td>
<td>Accuracy and repeatability depends highly on environmental factors</td>
<td>Very good quality, accuracy and repeatability.</td>
</tr>
<tr>
<td></td>
<td>(components, temperature, etc).</td>
<td></td>
</tr>
<tr>
<td>Robustness</td>
<td>Their components can resist physical damage inherent in many manufacturing environments (vibrations, noise, etc).</td>
<td>High robustness.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Collisions have to be avoided.</td>
</tr>
<tr>
<td>Safety</td>
<td>High safety no dangerous tasks in station.</td>
<td>Workers are moved to supervisory roles, so they no longer have to perform dangerous applications in hazardous settings.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Robots presence can create some safety problems (possibility of collisions).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>These new dangers must be taken into consideration.</td>
</tr>
<tr>
<td>Cost/Payback</td>
<td>Costs of components are low. Skilled workers are not an issue but at least one operator is needed during the process running.</td>
<td>The initial investment of the robot is significant measure.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Training of employs takes time and money.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Specialized personal is required during design.</td>
</tr>
<tr>
<td>Level of automation</td>
<td>Human interaction needed. Unattended operation is not possible.</td>
<td>Fully automated.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unattended operation is possible.</td>
</tr>
<tr>
<td>Performance</td>
<td>Complicated design to guide saw blades into the boxes.</td>
<td>Very sensible in order to boxes orientation.</td>
</tr>
<tr>
<td></td>
<td>Noisy caused by cylinders operation.</td>
<td>Robot requires calibration before start process (Other devices have to be placed at the same relative distance to robot every time).</td>
</tr>
<tr>
<td></td>
<td>Operation in hazardous ambient.</td>
<td>Operation in hazardous ambient and high temperatures.</td>
</tr>
<tr>
<td>Floor space</td>
<td>Medium / small floor space required</td>
<td>Large floor space required (very long reach of robot needed).</td>
</tr>
<tr>
<td>requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>Fast speed.</td>
<td>Fast speed.</td>
</tr>
</tbody>
</table>
5 FINAL SOLUTION

To structure the design process the main task was divided in different sub-task, finding one or more solutions for each one of them. The sub-tasks defined for this process are:

1. How to provide empty boxes to the Packing Station
2. How to hold and open box during packing process
3. How to close the box
4. How to detect and push saw blades into the box
5. How to move the full boxes to Welding Station

How to provide empty boxes to the Packing Station

5.1 Empty Boxes Magazine

Empty boxes are placed in one magazine designed specifically to hold them during process as well to provide the Packing Station with empty boxes to fill. The magazine is a hollow box 90 mm wide and 350 mm long made of metallic material. It is a tenth of an mm bigger than the box to get free fall. The length of the magazine is 550 mm and it has capacity to store 20 boxes. The magazine can fill only from the top and a pneumatic cylinder (Cyl_1) is used to push the box out from the magazine to the packing position. This design is inspired in the magazines used in the laboratory of automation in Högskolan I Skövde (Figure 5.1).

![Figure 5.1: Magazine used in laboratory of automation, HIS](image)

(1) Magazine; (2) photoelectric sensor; (3) cylinder

Before the magazine becomes empty the operator has to fill the magazine, to solve this problem a photoelectric sensor (S_1) positioned at one side of magazine is used. When this sensor condition becomes true then it will send a signal to notify the operator to refill the magazine.

For safety precautions the magazine is designed to be open at both sides, if the box is not in the correct position operator can fix it manually from the outside (Figure 5.2). If the magazine is closed from both sides there are chances of collisions with the cylinder while changing the
position. An emergency stop on the Packing station stops the process at any time in case of accident.

In front, one space 30mm high lets the box pass through magazine.

Finally, if the orientation of the box at packing position is not correct the saw blades stacks can be pushed through the wrong side of the box and it can damage equipment and product, it also can give interruption in production line. There are two solutions to solve this problem:

1. As boxes have a hole in the frontal part as well in the lid, proximity or position sensor in the bottom of the magazine uses that hole to identify the position of the box. If the box is in the wrong position it gives a signal to the operator to change the position of the box.

2. Changing the design of the boxes, making a cut in one of their corners, also changing the magazine design; in this case the operator can fill only in one direction (Figure 5.3).
How to hold, open and close the box during process

5.2 Filling Station
The geometrical design of the filling station is wider in box size, its left side (from Conveyor 2) is occupied by the head of cylinder 3 whereas its right side is little steep. It has four pneumatic cylinders to fasten the box at exact position, to open and close the box lid. One micro switch is placed at the surface of the filling station to indicate box existence at filling station (Figure 5.4).

![Figure 5.4: Frontal view of Filling Station.
(1) Cylinder 3; (2) head of Cylinder 3; (3) Micro switch; (4) steep side](image)

As soon as the empty box is positioned at filling magazine, one cylinder (Cyl_4) which is located on the top will activate to fix the box in position. The decisive point here is the design of the cylinder head and the force required to push the box. The cylinder head should be slightly rough to have a good grip on the box. The required force calculation is based on two factors: how hard the cylinder (Cyl_2) pushes the saw blades into the box as well as the material strength of the box.

When cylinder (Cyl_1) pushes out the box from the magazine it will reach the guide face, from there the blades will be filled into the box. While pushing out the box from the magazine there two risks: it may stop behind the end contour or it may go a little ahead. Under this risk the contour point should not be flat it must be a little elevated and the cylinder (Cyl_1) will push the box slightly with its head.
How to open the box during process

Cylinder 5 is used to open the box lid. The thickness of lid is only 2mm so the task to open the lid with the cylinder head could be problematic. If there is a space between box and the cylinder head then it will not open the box. To make sure this position, the front of filling magazine has the same shape as the box front. The bottom part of the box from it lid part is shown in figure 5.6.

![Figure 5.6: To open the box is necessary to push the lid up (1). Since this distance is very short the contour frontal of Filling station has to follow the blue line (2)](image)

Other solutions to open the box:

Vacuum cup: To open the lid of box it needs to lift from the top. By using a vacuum cup it can pull and hold the flap during the filling of the blades. The vacuum cup is hanging down, freely moveable with a support attached with one cylinder that moves it back and forth (Figure 5.7). First time to open the box it is necessary a large force due to break the resistance of the lid, therefore a vacuum cup with a great power is necessary.
Other considerations:
Some times boxes are fully closed (Figure 5.6) and it’s not possible to open it with one cylinder by pushing the lid up. To open the knobs is necessary to press both of them strongly from the bottom.

Solution: In this case it is possible to push the knobs from the bottom using the filling station as plane surface and pushing the box strongly from the top. Since filling station has in its design two holes in the place where the knobs are, is necessary to push with cylinder 4 at the middle of the stroke length of cylinder 1. In this way, pushing the box frontal part at plane surface, the knobs will push upward and box will open immediately. Finally cylinder 4 is retracted and cylinder 1 continues pushing the box until the end of Filling Station.

To avoid damage of equipment or product, a good coordination between cylinder 1 and 4 is fundamental. Cylinder 1 is provided with three positioning sensors, one of them in the middle of its stroke length. When Cylinder 1 reaches this position, it stops (activating extension and retraction at same time), Cylinder 4 is extended and retracted, and finally Cylinder 1 continues with the extension.
How to close the box

Cylinder 6 and Cylinder 7 have the purpose to close the box. Cylinder 7 pushes the lid from the top against the surface of filling station, which is designed specially to help the process of closing the box. Cylinder 6 is extended to bring nearer the lid to the range of Cylinder 7., as shown in figure 5.8.

![Figure 5.8: Range of Cylinder 7](image)

![Figure 5.9: Lid of box: 1) Knobs; 2) Holes](image)
To close the box completely is necessary to pass the knobs placed on the lid through two holes placed in front of box (Figure 5.9). As well to small plates placed at both sides of box have to joint the frontal part of box with the lid. After filling process the two knobs are welded, and then to open the box is necessary to break the security flat piece in which the knobs are fused (Figure 5.10).

Filling Station and Cylinder 7 head are specially designed both to help the small plates at sides of box to hold the lid closed. The pressure of Cylinder 7 head is done on the plates whereas the surface of Filling Station holds a little upper the sides of box (Figures 5.11 and 5.12).
The surface of the Filling Station has two parts upper than the base that holds firmly the box bottom and applies pressure in the right place of box. The frontal part of this upper surface is long to hold and do not break the security piece when Cylinder 7 is pushing. Two holes permit the knobs pass through Filling Station.

Figure 5.12: Surface of Filling Station, frontal part. The upper surface holds both sides of box to help the plates pass. The holes (2) let the knobs of box pass.
How to detect and push saw blades into the box

5.3 Pushing of Saw Blades in the Boxes

The box can contain 100 blades, separated by lanes (20 blades in each lane) and placed in two levels (10 blades per lane per level). Saw blade stacks will be pushed into the box in groups of five -50 saw blades-, for each box it is necessary to fill them in two levels. The two levels and five lanes are shown in figure 5.13.

![Figure 5.13: Levels and lanes of box](image)

During the packing process (Cylinder 2 pushing stacks) more saw blades are coming on the conveyor. To make sure that Cylinder 2 will not push more than five stacks blades every time, they have to be enough spaced between them before reach the end of conveyor. A second conveyor faster than the first one is used to ensure that distance. When one stack passes from Conveyor 1 to Conveyor 2, due to the difference in speed, rapidly reaches the end increasing the distance with the incoming blades.

5.3.1 Detection of blades and design of guide:

Five inductive sensors are used to detect the presence of five hacksaw blades stacks on Conveyor 2 meanwhile one pneumatic cylinder is used to push the saw blades in to the boxes. These sensors are placed along the conveyor, at the end of it, with the same relative distance between them as the blades on the conveyor (10mm approximately). One obstacle at the end of the conveyor stops the stacks. When there are five stacks all sensors become active and Cylinder 2 pushes saw blades directly into the box through a guide, designed for this task.

When the blades enter into the box with an angle of approximately 10 degrees or more with respect to the lane’s orientation, they stick against box (Figure 5.14). To solve this problem a guide to lead stacks into the box is used. It gives the stacks the orientation and separation between them necessary to enter easily into the box. It can be made with metallic material and the length can be between 50 and 70 mm long. It consists of five lines of 14.2 mm each one and separators between them of 1.5 mm wide. As well the blades can be blocked in the guide. To avoid this trouble the central lanes of the guide must be shorter than the others [1], to give a little tolerance to the blades at the entrance into guide (Figure 5.15).
5.3.2 Design of Cylinder 2:
The Cylinder 2 has to push the blades until they reach the end of the box, otherwise the box will not close. To complete this task the head of Cylinder 2 has to pass through the guide. The head of cylinder 2 was designed in two different ways to push the blade stacks until the end of the box properly. The design description of each designed is described in detail under the headings of design 1 and design 2.

5.3.2.1 Design 1
The head of the cylinder is shown in figure 5.16. It consists on two separate rectangular parts; one attached directly to cylinder (1), the other is used to push the stacks (2). Both are 20 mm wide.
and 82 mm long. The saw blades ends are semi circled so the surface of block 2 is also partially circled (3) to facilitate the pushing process and to help make adequate the distance between stacks.
The blocks are jointed by five metallic bars 138 mm long and ringed with springs, called fingers (4), which cross from block 1 to block 2. They are fixed in block 1 and are free to move through block 2. Fingers are used to push the saw blades when the cylinder’s head is stopped by the guide (5). Supports by means of springs, return block 2 to its original position after it is pushed against guide.
Fingers are stick to block 2 and nuts in each one of the fingers ends, at the external side of block 2 prevents the both blocks to separate. To reduce the friction between moving parts as fingers and block 2, their material should be metallic or be well lubricated.

After magnetic sensors detect the presence of five stacks ready to be pushed, a box is at Packing Station and it is opened, Cylinder 2 is activated. Both block 1 and 2 starts to move pushing the saw blades through the guide to the box. When block 2 is stopped by the guide, Cylinder 2 continues pushing, and block 1 continues moving. The stacks still need to be pushed until to reach the end of the box, so fingers pass through block 2, through guide and push the saw blades until the end of the box. When Cylinder 2 retracts, the springs return block 2 to their initial position as well fingers [25].

To avoid that cylinder pushes more than five saw blades, it is very fast -less than 3 seconds between extension and retraction- to push saw blades and be back before more stacks come. As well the shape of its head is similar to an L with a long bar at its right side, which will stop the incoming stacks until cylinder is retracted.

### 5.3.2.2 Design 2

The second design of the cylinder head is a solid block which has six drilled lines three mm wide each (1). The lines are designed in such a way that the head can go through the guide to the face of the box and in this way blade stacks will reach to the end of slots place. It emulates guide shape but is the opposite. This design is shown in figure 5.17.

![Figure 5.17: Head of cylinder 2: Design 2](image)

(1) “Lines” to pass through guide; (2) semi circled surface to push the blades

The problem with this design is the accuracy of the cylinder. Common cylinders are not very precise and repeatable, their piston rod has a small bent during operation and it increases considerably with temperature, time of use and other external factors are difficult to control. Due
to this play, it is possible that the lines of head can stick with the guide. To prevent this problem the lines of cylinder head should be wider drilled. By mean of using the same manufacturing material for the guide and cylinder head friction can also reduced which is also an important cause in performance.

It is fundamental to use a cylinder with high accuracy, using drives with linear guide: slide, rod guides or precision piston rod guide.

Other Considerations:
Every time the Cylinder 2 pushes the saw blades stacks into the box, one counter, initially at zero, increments its count, once the count reaches 2, cylinder 3 will push filled box to the next station. Then the counter resets the count to zero.

To avoid possible false triggers of Cylinder 2, caused by metallic parts apart from saw blades that are placed near sensors or by surrounding electrical and magnetic noise that could activate the inductive sensors out of time, some considerations have been taken in design. Cylinder’s body is placed out of the range of sensors and sensors are blinded to limit their range only to its front. As well sensors are placed at distance enough between them to do not disturb each other with electromagnetic noise. Finally, actions of Cylinder 2 are restricted by programming of the PLC: it will be triggered only if there is a box at filling station, it is opened and five saw blades stacks are in position to be pushed.

Finally, two risks were finding during the test to prove the cylinders’ heads. First, the blades climb up the boxes lanes if the alignment between box and guide is not good. And if Cylinder 2 is too low with regards to conveyor; or it is too high, it will either crush against the conveyor or not push the blades properly. Therefore the alignment between Cylinder 2, guide and box has to be perfect, in straight line, or the possibilities of crashing between devices and parts are highly increased; and the high of Cylinder 2 is very important and has to be carefully calculated.

How to fill the two levels of box

To fill both levels the guide is placed higher than box in such a way that the first group of blades fall down freely meanwhile the second level is filled directly. However it is fundamental to push the saw blades until the end of box in both levels otherwise the box will not close. To push the stacks until the end of box in the first level, two options are considered:

1. Add one more cylinder (Cylinder 8) with cylindrical rod head. This cylinder will be placed perpendicular to the box. It will be extended during filling process. In this way first time when Cylinder 2 push the stacks, Cylinder 8 head will hold up the blade stacks while Cylinder 2 pushes them until the end of box.

2. To extend the bottom of head of Cylinder 2 little ahead. When Cylinder 2 pushes strongly the first group of stacks, because of the inertia, the blades continue jointed to the cylinder’s head until it stops. The blades have reached the end of box and fall down filling the first level.
How to move the full boxes to Welding Station

5.4 Filled Box Palletizing to Welding Station
The process line is modified in order to reduce time and cost by changing the location of the welding machine. This machine has moved in line of Marking machine and Packing station. To make connection between these two machines a conveyor (C3) is used.

The distance between Filling station and welding machine is approximately two meters and conveyer is not horizontal it is slightly steep. The conveyer has two different levels of height on both ends because the welding machine is 1200 mm above from the ground level meanwhile the Packing Station is 900mm high, same level of height as marking machine.

The welding machine is working faster than packing process; Conveyor 3 is also functioning as a buffer between Packing machine and Welding machine. When Welding process is stopped, the packing process can continue until Conveyor 3 is full, which is noticed by a photoelectric sensor placed at the end of Conveyor 3 on Welding machine side. Then both, Conveyor 3 and Packing station stop until Welding Machine is restarted again. One signal is used from welding machine to packing station for the welding machine status.

The conveyor is removable as it described earlier and it must be exactly same size as the distance between the Packing station and the Welding station. The speed will be calculated according to the speed of marking and packing process, but the distance between boxes in conveyor should not be more than 100mm to make a good use of Conveyor 3 as buffer. Both Conveyor 2 and 3 are belt conveyors 300mm wide to hold blades and boxes properly.
5.5 Process after automation

The position of the machines in machine hall after automation of packing process will be like figure 5.18. The summary of the packing process after automation is described below:

After marking process the hacksaw blades come from the Marking Machine on Conveyor 1 in stacks of 10 blades jointed. Next to Conveyor 1, a second conveyor faster than Conveyor 1 increases the distance between them. The stacks are stopped in the packing position by an obstacle placed at the end of Conveyor 2.

The Empty boxes are placed in Empty Boxes Magazine by operator A. This magazine has capacity of 20 boxes. When the magazine is almost empty (one box left) an alarm notices operator to fill magazine again. Cylinder 1 pushes an empty box from magazine when Packing Station is free.
Five inductive sensors detect the presence of five blade stacks at packing position. When this happens, if there is an open box in Packing Station, Cylinder 2 (design 2) is activated to push the stacks through a guide into the box.

Cylinder 4 is used to hold the box during filling process. As well Cylinder 5, 6 and 7 are used to open and close the box. Once the box is full Cylinder 3 pushes it to Conveyor 3 which moves it to Welding Station where the box is completely closed.
5.6 Components selection
To select the components for the design, a wide range of factors and criteria must be considered. These selection criteria for each one of the components are described below.

5.6.1 Actuators
The selection criteria to consider selecting the pneumatic cylinders are: the type (single or double acting), the stroke length and minimum cylinder bore diameter.

Generally pneumatic cylinders are of two types, single acting and double acting. Single acting cylinders are pressurized in one direction only, this normally being the outward stroke. A double acting cylinder merely has an additional port which makes it possible to pressurize either side of the piston alternatively. For a higher thrust and longer stroke the double acting cylinders are preferred. Air consumption is roughly doubled, compared with a single acting cylinder but this is seldom a significant factor. As well double acting cylinders are more controllable.

The selection of actuators is made according with ISO. These standards warrantee that cylinders and valves provided by different vendors have the same dimensions. This lets components to be easily interchangeable with components of other supplier made as well according ISO and makes easier calculations through tables provided by vendors.

All actuators and valves are supplied by Festo which is the vendor of pneumatic devices of SNAEurope in Sweden. Also all calculations are made using an air pressure of 6 bars.

The theoretical maximum thrust obtainable from an air cylinder is equal to the product of the air pressure and effective piston area. [17]

\[
F_{\text{Teor}} = 0.7854 \times D^2 \times P_e
\]

Outward stroke of double-acting cylinders: 
\[
F_{\text{Teor}} = 0.7854 \times (D^2 - d^2) \times P_e
\]

Outward stroke of double-acting cylinders: 
\[
F_{\text{Teor}} = 0.7854 \times D^2 \times P_e
\]


\[
D = \sqrt{N/0.7854}\text{ mm}
\]

Cylinder 1:
\[
F_{\text{Teor}} = 5N
\]
\[
5N = 0, 7854 \times D^2 \times 6\text{ bar}
\]
\[
D = \sqrt{N/0.7854}\text{ mm}
\]

For Cylinder 1 the minimum cylinder bore diameter is over \(\text{mm}\) mm

Valves:
All cylinders are activated by valves actuated electrically. The Pneumatic connection of cylinders 1 and 2 is G1/8, while cylinders 3, 4, 5, 6 and 7 have pneumatic connection M5. Cylinders 1 and 2 are actuated by valves 4/2 meanwhile cylinders 3, 4, 5, 6 and 7 by valves 5/2.
5.6.2 Selection of suitable Sensors

To monitor the presence of empty boxes in magazine, presence of box at filling station, presence of saw blades on Conveyor 2 and status of Conveyor 3, whether it is full or not it is necessary the use of sensors. These sensors are fundamental in the industrial applications since are the responsible to “touch”, “ear” and “see” the product and devices that interact with it. Without using sensors, it is impossible to know the current state of a process or a certain variable without the intervention of a human. To find appropriate sensor for each task is fundamental to look briefly on the type of sensors that can be used for each task and the characteristics that must be measured or detected.

Key points to be well thought-out while selecting the appropriate sensor for measuring or detecting are range, environment, accessibility, size, consistency, integration, output signal and etc [19]. The sensors selection strategy is evaluated by the thought of pros and cons and their uses. Uses are described in detail in table below.

5.6.2.1 Detection of empty boxes and filled boxes

The boxes are made of plastic material, for such material detection a photoelectric sensor can be used. In the assignment photoelectric sensor looks best choice since it is cheap as well enough reliable in this environment.

5.6.2.2 Detection of boxes at Conveyer No: 3 (Buffer)

The conveyer is also functioning as a buffer between Packing machine and Fusing machine so when it is full, conveyer and packing process needs to stop, to detect the buffer status whether full or not an inductive proximity sensor is erected on Fusing machine side end of the conveyer.

Retro-reflective sensor SOEG-RSP-Q30-PS-K-2L - 165330

Figure 5.19: Retro-reflective sensor [26]
5.6.2.3 Detection of saw blades

The saw blades are made of metallic material and for metals inductive proximity sensors are paramount choice, particularly when there is no contact between object and sensor. As the environment conditions in the area is very clean and free of magnetic field such type of sensor is the good option for detection of saw blades. The diameter of sensor head should be less than the diameter of saw blades because is directly related with the range of sensor.

Festo, SIEN-M8B-PS-S-L – 150387

![Inductive Proximity Sensor](image)

Figure 5.20: Inductive Proximity Sensor [27]

5.6.2.4 Detection of boxes at Filling station

The boxes are detected by contact on surface of filling station. A micro switch is very economical and reliable type of sensor for such simple application.

Micro switch SR-3-E-SW - 14797

![Micro Switch](image)

Figure 5.21: Micro Switch [28]

5.6.3 Programmable Logic Controller

To select the PLC used in process the selection criteria was the politic of the company, which is using PLCs provided by Siemens.

The requirements of the PLC used in the automation are: Two input modules with 16 digital inputs and two output modules with 16 digital outputs.

Model of PLC: SIMATIC S7-300 CPU 314C-2 DP
I/O modules: SM321 (16 X) and SM322 (16 X)
Power supply PS-307
<table>
<thead>
<tr>
<th>Type of sensor</th>
<th>Pros</th>
<th>Cons</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inductive</td>
<td>Small range (from some mm to 40 mm approximately) Long operational life. No contact sensor and no moving parts. Is possible to detect lightweight or small objects than can not be detected by mechanical limit switches. High switching rate.</td>
<td>Small range. It is dependant on size, shape and material of part. As well is affected by some environmental factors as temperature and surrounding electrical conditions. Hysteresis has to be considered.</td>
<td>Noncontact sensing of metallic objects</td>
</tr>
<tr>
<td>Capacitive</td>
<td>Same pros as inductive sensors. Greater sensing range than inductive sensors. Can detect metallic as well non-metallic objects.</td>
<td>Affected by moisture and humidity. Must have an extended range for effective sensing. It is dependant on size, shape and material of part.</td>
<td>Noncontact sensing of metallic and non-metallic objects</td>
</tr>
<tr>
<td>Photoelectrical</td>
<td>Big range (from some mm till 50 m approximately)</td>
<td>Very sensible to dirt, oil mist and other environmental factors. Low switching rate.</td>
<td>Noncontact sensing of presence or absence of an object.</td>
</tr>
<tr>
<td>Through beam</td>
<td>The longest range of the three operating modes of photoelectrical sensors. Provides high power at shorter range to penetrate steam, dirt or other contaminants.</td>
<td>Source and detector are positioned opposite each other. Alignment of source and detector must be accurate.</td>
<td></td>
</tr>
<tr>
<td>Proximity</td>
<td>Source and detector are installed at the same side of the object to be detected.</td>
<td>The optimum range is defined by the power of source.</td>
<td></td>
</tr>
<tr>
<td>Reflex</td>
<td>Source and detector are installed at the same side of the object to be detected. The best cost-performance ratio of the three methods.</td>
<td>The object to be detected must be less reflective than the retro-reflector.</td>
<td></td>
</tr>
<tr>
<td>Micro-switch</td>
<td>Easy to implement. Comparatively cheap.</td>
<td>Requires to contact Is subject to mechanical failure. MTBF low compared to Noncontact sensors. Speed of operation relatively slow.</td>
<td>Contact sensing of presence, e.g.: Limit switches.</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td>Medium sensing range. No contact sensor and no moving parts. Can detect speed or direction.</td>
<td>Rugged devices capable of operating in hostile environments. It reliability is limited by the shapes of surfaces and the density or consistency of the material.</td>
<td></td>
</tr>
</tbody>
</table>
## 5.7 Components List

<table>
<thead>
<tr>
<th>No.</th>
<th>Device</th>
<th>Model</th>
<th>Qty</th>
<th>Manufacturer</th>
<th>Unit Price</th>
<th>Price(SEK)</th>
<th>Identifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Photo electric sensor</td>
<td>SOEG-RSP-Q30-PS-K-2L – 165330</td>
<td>2</td>
<td>Festo</td>
<td>1100</td>
<td>2200</td>
<td>S1, S3</td>
</tr>
<tr>
<td>2</td>
<td>Inductive proximity sensor</td>
<td>SIEN-M8B-PS-S-L - 150387 (PNP)</td>
<td>5</td>
<td>Festo</td>
<td>750</td>
<td>3750</td>
<td>M0 to M4</td>
</tr>
<tr>
<td>3</td>
<td>Micro switch</td>
<td>SR-3-E-SW - 14797</td>
<td>1</td>
<td>Festo</td>
<td>525</td>
<td>525</td>
<td>S2</td>
</tr>
<tr>
<td>4</td>
<td>Round reflector</td>
<td>SOEZ-RFS-20 - 165363</td>
<td>2</td>
<td>Festo</td>
<td>25</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Power supply</td>
<td>PS-307</td>
<td>1</td>
<td>Siemens</td>
<td>1600</td>
<td>1600</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Digital Input module</td>
<td>SM321 (16 X )</td>
<td>2</td>
<td>Siemens</td>
<td>2350</td>
<td>4700</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Digital Output module</td>
<td>SM322 (16 X )</td>
<td>2</td>
<td>Siemens</td>
<td>3200</td>
<td>6400</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>CPU</td>
<td>SIMATIC S7-300 CPU 314C-2 DP</td>
<td>1</td>
<td>Siemens</td>
<td>16000</td>
<td>16000</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Pneumatic valve</td>
<td>JMF-4-1/8-4556</td>
<td>2</td>
<td>Festo</td>
<td>625</td>
<td>1250</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Pneumatic valve</td>
<td>CPE10-M1BH-5J-M5 – 196875</td>
<td>5</td>
<td>Festo</td>
<td>886</td>
<td>4430</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Pneumatic cylinder</td>
<td>DNCB-32-400-PPV-A - 532734</td>
<td>1</td>
<td>Festo</td>
<td>1540</td>
<td>1540</td>
<td>Cyl_1</td>
</tr>
<tr>
<td>13</td>
<td>Pneumatic cylinder</td>
<td>DNCB-32-80-PPV-A - 532727</td>
<td>2</td>
<td>Festo</td>
<td>1200</td>
<td>2400</td>
<td>Cyl_3, Cyl_7</td>
</tr>
<tr>
<td>14</td>
<td>Pneumatic cylinder</td>
<td>DSNU-8-50-P-A</td>
<td>2</td>
<td>Festo</td>
<td>320</td>
<td>640</td>
<td>Cyl_4, Cyl_6</td>
</tr>
<tr>
<td>15</td>
<td>Pneumatic cylinder</td>
<td>DNCB-32-25-PPV-A - 532724</td>
<td>1</td>
<td>Festo</td>
<td>1000</td>
<td>1000</td>
<td>Cyl_5</td>
</tr>
<tr>
<td>16</td>
<td>Accessories for pneumatic</td>
<td></td>
<td></td>
<td></td>
<td>5000</td>
<td>5000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>devices installation.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Accessories for electrical</td>
<td></td>
<td></td>
<td></td>
<td>5000</td>
<td>5000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>installation.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Conveyor</td>
<td></td>
<td>1</td>
<td></td>
<td>14500</td>
<td>14500</td>
<td>C2,C3</td>
</tr>
</tbody>
</table>

Total estimated cost of components is 72985 SEK.
5.8 **Technical Test**

To support the theories developed in the project two tests were made, one in University of Skövde and the second one in SNAEurope. Devices used in the test did not have the same characteristics as devices defined in the project, so performances were quite different.

The material used for the experiments consists:

- Diverse kind of cylinders with different stroke lengths and bore diameters.
- Electro valves 5/2 bi-stable.
- Limit switches.
- Pneumatic and electric material

Due to the scant number of components and the impossibility to actuate more than two cylinders at once, different sub-tasks of process were proved separately. Three sub-processes were tested, grip and open the box, push the saw blades through the guide and close the box.

5.8.1 **Objectives**

1. Test performance of the different models of guides and cylinder heads.
2. Find appropriate position of components in Packing station, as well find the suitable sequence of cylinder’s activation and deactivation, where and when should act each cylinder.
3. Prove which parts of process works properly and which needs to be re-designed.
4. Find new solutions and designs of station and components.
5. Find possible risks involved in process caused by pneumatic components.

![Figure 5.22: Tests in HIS and SNAEurope](image-url)
5.8.2 Grip and Open the box

First experiment was to grip and open the box. One cylinder of 50mm stroke length and 20mm diameter was used in test to grip the box, it represent Cylinder 4 in design. Its head was rounded and made by rubber. One cylinder of 140 mm stroke and 35 mm diameter was used to open the box lid up, it represent Cylinder 5 in design. Both cylinders were installed vertically. While Cylinder 4 gripped the box one picture of this test is shown below (Fig 5.23).

The sequence of activation of cylinders was: extend Cylinder 4 and grip the box, extend Cylinder 5 and open the lid, retract Cylinder 5 and retract Cylinder 4.

Results

− To grip the box a small stroke is enough
− The box is enough fixed with Cylinder 4, wherever it presses the box
− To hold the box stronger, Cylinder 4 head is made of a rough material or rubber. Rubber is preferred because it does not damage the box surface. As well Cylinders 4 and 1 continue extended during filling process
− Cylinder 5 opens properly the box, although its position should be well calibrated

Figure 5.23: Test 1: Gripping of box
5.8.3  Push saw blades into the box

A guided cylinder of 35mm bore diameter and 200mm stroke length was used. The cylinder’s stroke length was only 200mm and process requires 350mm, so the process was tested in two parts, first to observe how saw blades pass through the guide and later how cylinder’s heads pass through the guide. As well both designs of cylinders’ heads were used.

In first case the guide was fixed to the table at 350mm from cylinders head and saw blades were placed between the guide and the cylinder head (as shown in figure 5.24), when cylinder push saw blades, they pass through the guide directly into the box, but not until its end.
In second case, the distance between guide and cylinder was only 100mm, so saw blades were placed into the guide (as shown in figure 5.25) and the test show how the head of cylinder pass through the guide and push the blades until the end of box.

![Figure 5.25 Test 3: Cylinders heads](image)

**Results**

- With both cylinder head designs the saw blades are pushed into the guide. The design of the guide is good as well design of the frontal part of cylinders’ heads.
- The alignment between box and guide has to be exact, if not saw blades will crash against box. The box has to be well fixed by cylinders 1 and 4. As well the alignment between cylinder’s head and guide is important to avoid crashes between them.
- Both designs pass through guide and push saw blades until the end of box.

5.8.4  Close the box

Process to close the box was consisting on two cylinders, cylinder 6 and 7, one placed above the box horizontally, with its head pointing to the box lid. The other was vertically on the box lid. The main task was to find the suitable head for cylinder 7. The head has been designed to make pressure at both sides of box. The floor of filling station has an upper part to press as well the sides of box. A preview of closing the box is shown in figure 5.26.
The sequence of activation of cylinders was: Cylinder 6 +, Cylinder 7 +, Cylinder 6 – and finally Cylinder 7 -

Figure 5.26 Test 4: Close the box

Figure 5.27 Models used during test: Head of Cylinder 7 and surface of Filling Station
Results

- Both cylinders are enough to complete the task of closing the box
- Cylinder 7 do not retract immediately, it keeps in extended position for a small amount of time to assure the closing of box
- The designs of cylinder’s head and filling station’s floor are good enough to close well the box
- Cylinder has to press at centre of box lid. If it pushes more one side of lid, the other will not close properly.

5.8.5 Test Conclusions

- Real performance of design can not be proved with the provided equipments
- Two troubles appeared: cylinder 2 has to push the saw blades stacks until they reach the end of the box (Figure x.6, middle). The box has to be filled in two levels. For this reason, actually the guide is placed at a second level. It is not possible to push the first group of saw blades until the end of the box with the actual design. Cylinder’s head should be 1 or 2 mm upper than guide which as well should be upper than box filling the second level (Figure x.6, down).
- With the actual design of filling magazine, with two holes for the box knobs, it is not possible to push the box with cylinder 3 when it is full. The design of filling magazine has to be redefined
- If the alignment between box and guide is not good, the stacks climb up the lanes of box (Figure x.6, top)
- It is important in the final design to place all devices in appropriate position. To avoid collisions between them, their courses should not be crossed each other. A good coordination between activation and deactivation sequences is vital.
- In some cases the rotation of the cylinder has to be considered: cylinders 1, 2, 3, 5 and 7 have to be non-rotating cylinders, or have to have a kind of magazine or guide to avoid rotations. In cylinders 4 and 6 rotation is not a trouble.
- Both designs of guides work properly
- Both designs of cylinder’s heads are reliable
- The cylinder’s head design is important in the performance of cylinders. Depending of the task heads of cylinders is different. Their shape, size and material have specified in project.
Figure 5.28: Different pictures from test
6 CONCLUSIONS

Although the main task of this project was to automate the packaging of the SANDFLEX hack sawblades in SNAEurope, it involved more than only the automation. It was itself a continuous learning regarding the process that an engineer has to follow not only to design a machine but also to achieve a solution for a certain problem.

Unlike we believed at the beginning of project, the first step of the design process is not to start thinking about the possible solutions. Before it, a deep work of investigation must be done to provide the necessary knowledge to afford the project. Literature study gives the theoretical base; the deep understanding of process and product, by means of observation and experimentation, provides the practical one; and to comprehend the reasons to automate shows the lacks and needs of process. Also is fundamental to define well the problem. If the goal is not clear, how is it possible to find a solution?

Then is the right moment to give solutions. The easiest way to solve a big problem is to divide it in smaller problems and try to solve them. If the problem is how to pack a group of blades in a box, is better to think before separately about aspects as how to hold or open the box. To consider all the possible risks that can be involved in the process is not less important since the design must be robust, reliable and safe in any situation. By means of discussing the different solutions with the engineers and workers of the company the design becomes more and more robust since the experience accumulated by them, whom have been in real contact with the process and product, permits to consider new risks, problems and solutions that were not considered before. Finally, a process of selection based in comparing the advantages and disadvantages of each solution permits to decide which is the most suitable solutions for a certain problem.

As a final step, it is important to prove that the theories developed during the design process will work in the real process. Using either simulation techniques or technical tests the solution is proved as good or wrong. If it is wrong, the engineer has to go back and include the new troubles and risks to the design process; meanwhile if it is reliable, the final step is the implementation of it.

In this project the result was the design of a robust station capable to pack the sawblades without involves the operator in manual tasks. The operator just provides the station with empty boxes to obtain the final product at the end of the process line. All the possible risks involved in the process are considered in the design, which makes it reliable and safe, as well the advantages in productivity and efficiency are enormous. The low investment to implement it, the low maintenance and running costs makes this design profitable for the company as the payback is less than a year. The only lack in this design is the impossibility to assume large changes in production variety or production rate. However as the SANDFLEX is a product with a long life time due to its great market, it is a secondary aspect.
Finally, we consider important to appeal to the critical thinking skills of the engineers before accomplish an automation project. The reasons to automate should not be pointed in the profitability of project. Many other aspects must be considered and the advantages to have workers in the factory are still significant. The workers are the mind of the company, and their flexibility, intelligence and the great ability to learn from the experience are qualities that the machines difficulty will achieve. The real advantage of the machines is their capacity to help us achieving goals that we never thought to achieve, but they are only one more tool, never the pillars to hold the production system.
7 REFERENCES

7.1 Books
[7] Industrial Robot Applications; E. Appleton and D.J. Williams
[10] Intelligent Production Machines and Systems; By Duc T. Pham, Eldaw E. Eldukhri
[13] The robotics Premier by Maja J Mataric
[14] Robot and Manufacturing Automation by C. Ray Asfahl
[16] Fluid Power trouble shooting by Anton H. Hehn
[18] Principles and maintenance by S. R. majumdar
[21] Modelling safe operating Area in HW Description Languages, Leonid Goldgeisser
[22] Intelligent planning and dynamic scheduling of Flexible Manufacturing Cells and Systems by P.G. Ranky

7.2 Personal Contacts
[1] Samuel Englund, Production engineer; Andreas Bengtsson, Workshop Manager
SNAEurope, Personal contact
[24] Patrik Palsson, personal contact, ABB
[25] Torbjörn Andersson, Student Design Engineer HIS

7.3 Websites
[26] Figure source http://www.baumerelectric.com/be96.html?L=1
[27] Figure source http://sensor.baumerelectric.com/productnavigator/
[28] Figure source https://xdki.festo.com/xdki/data/doc_de/PDF/DE/ER-EL_DE.PDF
APPENDIX A

Figures and Sketches

Figure 1.1; The package of 100 SANDFLEX hacksaw blades
Figure 1.2; Machines current position in machine hall
Figure 1.3; Marking machine
Figure 1.4; Packing station
Figure 3.1; Types of facilities and layout for different levels
Figure 3.2; Elements of an Automated System
Figure 3.3; Components of a PLC
Figure 4.1: Pneumatic solution
Figure 4.2: Packing station front view
Figure 4.3: Position of boxes in empty boxes container
Figure 4.4: Robotic solution
Figure 4.5: Filling Magazine
Figure 5.1: Magazine used in laboratory of automation, HIS
Figure 5.2: Frontal and side views of Empty Boxes Magazine
Figure 5.3: Top view of Empty Boxes Magazine with a cut in one of its corner
Figure 5.4: Frontal view of Filling Station
Figure 5.5: Frontal view of box
Figure 5.6: Bottom view of box closing part
Figure 5.7: Lid opening with Vacuum cup
Figure 5.8: Range of Cylinder 7
Figure 5.9: Lid of box, Knobs, Holes
Figure 5.10: Bottom of box
Figure 5.11: Head of Cylinder 7
Figure 5.12: Surface of Filling Station
Figure 5.13: Levels and lanes of box
Figure 5.14: Blade stuck in entrance of the box
Figure 5.15: Top, front and side views of Guide
Figure 5.16: Head of cylinder 2, Design 1
Figure 5.17: Head of cylinder 2, Design 2
Figure 5.18: Machine Hall after automation
Figure 5.19: Retro-reflective sensor
Figure 5.20: Inductive Proximity Sensor
Figure 5.21: Micro Switch
Figure 5.22: Tests in HIS and SNAEurope
Figure 5.23: Test 1: Gripping of box
Figure 5.24 Test 2: Guide performance
Figure 5.25 Test 3: Cylinders Heads
Figure 5.26 Test 4: Close the box
Figure 5.27 Models of Cylinder 7 used during test
Figure 5.28 Different pictures from test
APPENDIX B

Flow Charts of the Final Solution
Start

Counter_0 = 0

Box at station? (S_2==1)
  Yes
  No
  Full box?
  No
  Yes

Extend cylinder_4 (grip the box)
  Cylinder_4 extended?
    No
    Yes

Extend cylinder_5 (Open the box)
  Cylinder_5 extended?
    No
    Yes

Packaging of saw blades
  Full box? Counter_0==2
    No
    Yes
    Retract cylinder_6
      Cylinder_6 retracted?
        No
        Yes
        Retract cylinder_4 (Release the box)
          Cylinder_4 retracted?
            No
            Yes
            Retract cylinder_3
              Cylinder_3 retracted?
                No
                Yes
                Extend cylinder_3
                  (Push the box to the next station)
                    Cylinder_3 extended?
                      No
                      Yes

Conveyor 3 is full? (S_3==1 AND Fuse_state==0)
  No
  Yes

Retract cylinder_7
  Cylinder_7 retracted?
    No
    Yes

End
Packaging of saw blades

Start

Box at filling station? (S_2==1)

Yes

Full box? Counter_0==2

Yes

No

Cyl_5 extended? (Box opened)

No

Yes

Saw blades at position? (MS_0 AND MS_1 AND MS_2 AND MS_3 AND MS_4)

No

Yes

Extend cylinder_2 (Push saw blades)

Cylinder_2 extended?

No

Yes

Retract cylinder_2

Counter_0 = Counter_0 + 1

Cylinder_2 retracted?

No

Yes

Empty boxes magazine

Start

Cylinder_1 retracted?

No

Yes

Magazine empty? (S_1==0)

Yes

Alarm: Magazine empty

No

Box at station? (S_2==1)

Yes

No

Extend cylinder_1 (Push the box)

Cylinder_1 extended?

No

Yes

Retract cylinder_1
APPENDIX B

PLC program and pneumatic schematic
PLC PROGRAM
The main task of PLC is to control the 7 cylinders used in process as well all input signals from sensors and buttons. The program is divided in 7 sub-programs; each one controls a part of process:

<table>
<thead>
<tr>
<th>Sub-SFC</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>G0</td>
<td>Movement of conveyor 2</td>
</tr>
<tr>
<td>G10</td>
<td>Movement of conveyor 3</td>
</tr>
<tr>
<td>G20</td>
<td>Empty boxes magazine</td>
</tr>
<tr>
<td>G30</td>
<td>Empty boxes magazine alarm</td>
</tr>
<tr>
<td>G40</td>
<td>Filling station</td>
</tr>
<tr>
<td>G60</td>
<td>Packaging of blades</td>
</tr>
<tr>
<td>G70</td>
<td>Pause</td>
</tr>
<tr>
<td>G100</td>
<td>Emergency stop</td>
</tr>
</tbody>
</table>

**G0: Conveyor 2**
When start is pressed, conveyor 2 runs until stop is pressed.

**G10: Conveyor 3**
When start is activated, conveyor 3 runs until stop is pressed. If fuse machine is stopped and S3 is true (conveyor 3 is full), conveyor 3 stops and an alarm/light is activated to notifies operator. When fuse machine is on, conveyor 3 continues until stop is pressed.

**G20: Empty boxes magazine**
At the moment at start is pushed, cylinder 1 is retracted. If there is no box at filling station (S2 = false), cylinder 1 pushes one empty box from empty boxes magazine to filling station. It continues extended until box is full and cylinder 7 has closed the box. The second branch in SFC is for the case when empty boxes magazine is almost empty (S1 = true), cylinder 1 has to push the last box to filling station.

**G30: Empty boxes magazine alarm**
At any moment during process it is possible to know when empty boxes magazine is nearly empty, S1 checks continuously if there are two or more boxes in magazine. If in magazine is only one empty box, an alarm (emptymagazine) notifies operator that they have to fill magazine again.

**G40: Filling station**
as soon as start is pressed all cylinders (cylinder 3, 4, 5, 6 and 7) are retracted until cylinder 1 pushes an empty box in filling station (cyll1 and S2). Following step is to grip the box and open it (extend cylinder 4 and cylinder 5) until it is full (step 64: Fullbox = 1). Next the box is closed (cylinder 5 retracted, cylinder 6 and 7 extended), released (cylinder 6 and 7 retracted, cylinder 4 retracted) and pushed to next station (cylinder 3 extended and retracted). Fullbox counter is reseted.

**G60: Packaging of blades**
Once start is activated, cylinder 2 is retracted and counter 0 reset. When all inductive sensors are true and there is a box in filling station, opened and gripped (step 43), cylinder 2 is extended to push the first group to saw blades into box. Counter is incremented. After retract cylinder 2 there are two possibilities: counter 0 < 2 (box not filled completely) or counter 0 = 2 (full box). In the first case, cylinder 2 is activated when more saw blades are detected and the counter is incremented again. In second case, Fullbox signal is set to one, counter reset and cylinder 2 retracted until next cycle.
G70: Pause
Stop button acts as a pause. When it is pushed, the current tasks continue until they are completed and then whole process is paused. When start is pressed, process continues from the same task where it was.

G100: Emergency stop
When emergency stop button is pressed, immediately step 101 forces the SFCs G0, G10, G20, G40, G60 and G70 to go to their first step (step 0, step 10, step 20, step 40, step 60 and step 70 respectively) and wait until Estop is released and start button is pressed again. After an emergency stop, all process starts from the beginning.

Table of inputs and outputs
The output modules addresses are between 00 and 1F. As well the input modules addresses come from 20 until 3F. The input and output signals used in program are described in the following table:
<table>
<thead>
<tr>
<th>Address</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>%C0</td>
<td>counter</td>
<td>When it is 2 means the box is full.</td>
</tr>
<tr>
<td>%I20</td>
<td>start</td>
<td>Starts process</td>
</tr>
<tr>
<td>%I21</td>
<td>stop</td>
<td>Stop process. The task that is being done is finished before stop process. When start is pressed again, process continues from it was.</td>
</tr>
<tr>
<td>%I22</td>
<td>Estop</td>
<td>Emergency stop. Stops immediately all tasks. When start is pressed again, process restarts from the beginning.</td>
</tr>
<tr>
<td>%I23</td>
<td>S1</td>
<td>Sensor 1. Checks if empty boxes magazine is almost empty. It is true when there is only one box to be processed.</td>
</tr>
<tr>
<td>%I24</td>
<td>S2</td>
<td>Sensor 2. Detects the presence of box at filling station.</td>
</tr>
<tr>
<td>%I25</td>
<td>S3</td>
<td>Sensor 3. Detects the presence of box at the end of conveyor 3.</td>
</tr>
<tr>
<td>%I26</td>
<td>MS</td>
<td>Inductive sensors. They are five in total and detect the presence of saw blades on conveyor 2.</td>
</tr>
<tr>
<td>%I27</td>
<td>Fusestate</td>
<td>If it is true, fuse machine is stopped.</td>
</tr>
<tr>
<td>%I30</td>
<td>Cyli10</td>
<td>Position sensor. Cylinder 1 is retracted.</td>
</tr>
<tr>
<td>%I31</td>
<td>Cyli11</td>
<td>Position sensor. Cylinder 1 is extended.</td>
</tr>
<tr>
<td>%I32</td>
<td>Cyli20</td>
<td>Cylinder 2 is retracted.</td>
</tr>
<tr>
<td>%I33</td>
<td>Cyli21</td>
<td>Cylinder 2 is extended.</td>
</tr>
<tr>
<td>%I34</td>
<td>Cyli30</td>
<td>Cylinder 3 is retracted.</td>
</tr>
<tr>
<td>%I35</td>
<td>Cyli31</td>
<td>Cylinder 3 is extended.</td>
</tr>
<tr>
<td>%I36</td>
<td>Cyli40</td>
<td>Cylinder 4 is retracted.</td>
</tr>
<tr>
<td>%I37</td>
<td>Cyli41</td>
<td>Cylinder 4 is extended.</td>
</tr>
<tr>
<td>%I38</td>
<td>Cyli50</td>
<td>Cylinder 5 is retracted.</td>
</tr>
<tr>
<td>%I39</td>
<td>Cyli51</td>
<td>Cylinder 5 is extended.</td>
</tr>
<tr>
<td>%I3A</td>
<td>Cyli60</td>
<td>Cylinder 6 is retracted.</td>
</tr>
<tr>
<td>%I3B</td>
<td>Cyli61</td>
<td>Cylinder 6 is extended.</td>
</tr>
<tr>
<td>%I3C</td>
<td>Cyli70</td>
<td>Cylinder 7 is retracted.</td>
</tr>
<tr>
<td>%I3D</td>
<td>Cyli71</td>
<td>Cylinder 7 is extended.</td>
</tr>
<tr>
<td>%M0</td>
<td>Fullbox</td>
<td>Fullbox=1: The box at filling station is full.</td>
</tr>
<tr>
<td>%Q00</td>
<td>Conveyor2</td>
<td>Activates motor of conveyor 2.</td>
</tr>
<tr>
<td>%Q01</td>
<td>Conveyor3</td>
<td>Activates motor of conveyor 3.</td>
</tr>
<tr>
<td>%Q02</td>
<td>Conv3fullsignal</td>
<td>Light/Alarm. Notices conveyor 3 is full and fuse machine is stopped.</td>
</tr>
<tr>
<td>%Q03</td>
<td>Emergencystop</td>
<td>Light/Alarm. When emergency stop button is pressed an alarm notices operator.</td>
</tr>
<tr>
<td>%Q04</td>
<td>emptymagazine</td>
<td>Light/Alarm. Notices when empty boxes magazine is almost empty.</td>
</tr>
<tr>
<td>%Q11</td>
<td>Extcyl1</td>
<td>Actuates on valve 1 to extend cylinder 1.</td>
</tr>
<tr>
<td>%Q12</td>
<td>Retrcyl1</td>
<td>Actuates on valve 1 to retract cylinder 1.</td>
</tr>
<tr>
<td>%Q13</td>
<td>Extcyl2</td>
<td>Extends cylinder 2.</td>
</tr>
<tr>
<td>%Q14</td>
<td>Retrcyl2</td>
<td>Retracts cylinder 2.</td>
</tr>
<tr>
<td>%Q15</td>
<td>Extcyl3</td>
<td>Extends cylinder 3.</td>
</tr>
<tr>
<td>%Q16</td>
<td>Retrcyl3</td>
<td>Retracts cylinder 3.</td>
</tr>
<tr>
<td>%Q17</td>
<td>Extcyl4</td>
<td>Extends cylinder 4.</td>
</tr>
<tr>
<td>%Q18</td>
<td>Retrcyl4</td>
<td>Retracts cylinder 4.</td>
</tr>
<tr>
<td>%Q19</td>
<td>Extcyl5</td>
<td>Extends cylinder 5.</td>
</tr>
<tr>
<td>%Q1A</td>
<td>Retrcyl5</td>
<td>Retracts cylinder 5.</td>
</tr>
<tr>
<td>%Q1B</td>
<td>Extcyl6</td>
<td>Extends cylinder 6.</td>
</tr>
<tr>
<td>%Q1C</td>
<td>Retrcyl6</td>
<td>Retracts cylinder 6.</td>
</tr>
<tr>
<td>%Q1D</td>
<td>Extcyl7</td>
<td>Extends cylinder 7.</td>
</tr>
<tr>
<td>%Q1E</td>
<td>Retrcyl7</td>
<td>Retracts cylinder 7.</td>
</tr>
<tr>
<td>%T32</td>
<td>Temp32</td>
<td>Temporizer 32.</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>-----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Cyl_1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyl_2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyl_3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyl_4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyl_5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyl_6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyl_7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>p</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylH1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylH0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylE0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylE1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylE0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylE1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylH0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylH1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylE0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylE1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylH0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylH1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylE0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylE1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylH0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylH1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylE0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cylE1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TIMING DIAGRAM OF CYLINDERS
PURE PNEUMATIC SCHEMA

Start  S_2  MS  Full_box
**APPENDIX D**

**Datasheets**

**Cylinder 1: DNBC-32-400-PPV-A - 532734**

<table>
<thead>
<tr>
<th>Feature</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroke</td>
<td>400 mm</td>
</tr>
<tr>
<td>Piston diameter</td>
<td>32 mm</td>
</tr>
<tr>
<td>Piston rod thread</td>
<td>M10x1,25</td>
</tr>
<tr>
<td>Cushioning</td>
<td>PPV: Pneumatic cushioning adjustable at both ends</td>
</tr>
<tr>
<td>Assembly position</td>
<td>Any</td>
</tr>
<tr>
<td>Conforms to standard</td>
<td>ISO 15552 (previously also VDMA 24652, ISO 6431, NF E49 003.1, UNI 10290)</td>
</tr>
<tr>
<td>Piston-rod end</td>
<td>Male thread</td>
</tr>
<tr>
<td>Piston</td>
<td>Profile barrel</td>
</tr>
<tr>
<td>Profile barrel</td>
<td>For proximity sensor</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>0.6 - 12 bar</td>
</tr>
<tr>
<td>Mode of operation</td>
<td>double-acting</td>
</tr>
<tr>
<td>Operating medium</td>
<td>Dried compressed air, lubricated or unlubricated</td>
</tr>
<tr>
<td>Corrosion resistance classification CRC</td>
<td>2</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>-20 - 80 °C</td>
</tr>
<tr>
<td>Impact energy in end positions</td>
<td>0.4 J</td>
</tr>
<tr>
<td>Cushioning length</td>
<td>20 mm</td>
</tr>
<tr>
<td>Theoretical force at 6 bar, return stroke</td>
<td>415 N</td>
</tr>
<tr>
<td>Theoretical force at 6 bar, advance stroke</td>
<td>483 N</td>
</tr>
<tr>
<td>Moving mass with 0 mm stroke</td>
<td>108 g</td>
</tr>
<tr>
<td>Additional weight per 10 mm stroke</td>
<td>27 g</td>
</tr>
<tr>
<td>Basic weight for 0 mm stroke</td>
<td>460 g</td>
</tr>
<tr>
<td>Additional mass factor per 10 mm of stroke</td>
<td>9 g</td>
</tr>
<tr>
<td>Mounting type</td>
<td>with internal (female) thread</td>
</tr>
<tr>
<td>Pneumatic connection</td>
<td>G1/8</td>
</tr>
<tr>
<td>Materials information for cover</td>
<td>Aluminium die cast coated</td>
</tr>
<tr>
<td>Materials information for seals</td>
<td>TPE-U( PU)</td>
</tr>
<tr>
<td>Materials information for piston rod</td>
<td>High alloy steel</td>
</tr>
<tr>
<td>Materials information for cylinder barrel</td>
<td>Wrought Aluminium alloy</td>
</tr>
</tbody>
</table>

Ref: [www.festo.com](http://www.festo.com)
**Cylinder 3 and 7** DNCB-32-80-PPV-A - 532727

<table>
<thead>
<tr>
<th>Feature</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroke</td>
<td>80 mm</td>
</tr>
<tr>
<td>Piston diameter</td>
<td>32 mm</td>
</tr>
<tr>
<td>Piston rod thread</td>
<td>M10x1.25</td>
</tr>
<tr>
<td>Cushioning</td>
<td>PPV: Pneumatic cushioning adjustable at both ends</td>
</tr>
<tr>
<td>Assembly position</td>
<td>Any</td>
</tr>
<tr>
<td>Conforms to standard</td>
<td>ISO 15552 (previously also VDMA 24652, ISO 6431, NF E49 003.1, UNI 10290)</td>
</tr>
<tr>
<td>Piston-rod end</td>
<td>Male thread</td>
</tr>
<tr>
<td>Design structure</td>
<td>Piston rod</td>
</tr>
<tr>
<td>Position detection</td>
<td>Profile barrel</td>
</tr>
<tr>
<td>Variants</td>
<td>For proximity sensor</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>Single-ended piston rod</td>
</tr>
<tr>
<td>Mode of operation</td>
<td>0.6 - 12 bar</td>
</tr>
<tr>
<td>Operating medium</td>
<td>double-acting</td>
</tr>
<tr>
<td>Corrosion resistance classification CRC</td>
<td>Dried compressed air, lubricated or unlubricated</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>2</td>
</tr>
<tr>
<td>Impact energy in end positions</td>
<td>-20 - 80 °C</td>
</tr>
<tr>
<td>Cushioning length</td>
<td>0.4 J</td>
</tr>
<tr>
<td>Theoretical force at 6 bar, return stroke</td>
<td>20 mm</td>
</tr>
<tr>
<td>Theoretical force at 6 bar, advance stroke</td>
<td>415 N</td>
</tr>
<tr>
<td>Moving mass with 0 mm stroke</td>
<td>483 N</td>
</tr>
<tr>
<td>Additional weight per 10 mm stroke</td>
<td>108 g</td>
</tr>
<tr>
<td>Basic weight for 0 mm stroke</td>
<td>27 g</td>
</tr>
<tr>
<td>Additional mass factor per 10 mm of stroke</td>
<td>460 g</td>
</tr>
<tr>
<td>Mounting type</td>
<td>9 g</td>
</tr>
<tr>
<td>Pneumatic connection</td>
<td>with internal (female) thread</td>
</tr>
<tr>
<td>Materials information for cover</td>
<td>with accessories</td>
</tr>
<tr>
<td>Materials information for seals</td>
<td>G1/8</td>
</tr>
<tr>
<td>Materials information for piston rod</td>
<td>Aluminium die cast coated</td>
</tr>
<tr>
<td>Materials information for cylinder barrel</td>
<td>TPE-U(PU)</td>
</tr>
<tr>
<td>Ref: <a href="http://www.festo.com">www.festo.com</a></td>
<td>High alloy steel</td>
</tr>
<tr>
<td></td>
<td>Wrought Aluminium alloy</td>
</tr>
</tbody>
</table>
## Cylinder 4 and 6 DSNU-8-50-P-A

<table>
<thead>
<tr>
<th>Feature</th>
<th>values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroke</td>
<td>50 mm</td>
</tr>
<tr>
<td>Piston diameter</td>
<td>8 mm</td>
</tr>
<tr>
<td>Piston rod thread</td>
<td>M4</td>
</tr>
<tr>
<td>Cushioning</td>
<td>P: Flexible cushioning rings/plates at both ends</td>
</tr>
<tr>
<td>Assembly position</td>
<td>Any</td>
</tr>
<tr>
<td>Conforms to standard</td>
<td>CETOP RP 52 P</td>
</tr>
<tr>
<td>ISO 6432</td>
<td>Male thread</td>
</tr>
<tr>
<td>Piston-rod end</td>
<td>Piston</td>
</tr>
<tr>
<td>Design structure</td>
<td>Piston rod</td>
</tr>
<tr>
<td>Position detection</td>
<td>For proximity sensor</td>
</tr>
<tr>
<td>Variants</td>
<td>Single-ended piston rod</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>1.5 - 10 bar</td>
</tr>
<tr>
<td>Mode of operation</td>
<td>double-acting</td>
</tr>
<tr>
<td>Operating medium</td>
<td>Dried compressed air, lubricated or unlubricated</td>
</tr>
<tr>
<td>Corrosion resistance classification</td>
<td>2</td>
</tr>
<tr>
<td>CRC</td>
<td>-20 - 80 °C</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>Germanischer Lloyd</td>
</tr>
<tr>
<td>Authorisation</td>
<td>0.03 J</td>
</tr>
<tr>
<td>Impact energy in end positions</td>
<td>23 N</td>
</tr>
<tr>
<td>Theoretical force at 6 bar, return stroke</td>
<td>30 N</td>
</tr>
<tr>
<td>Theoretical force at 6 bar, advance stroke</td>
<td>7.5 g</td>
</tr>
<tr>
<td>Moving mass with 0 mm stroke</td>
<td>2.4 g</td>
</tr>
<tr>
<td>Additional weight per 10 mm stroke</td>
<td>34.6 g</td>
</tr>
<tr>
<td>Basic weight for 0 mm stroke</td>
<td>1 g</td>
</tr>
<tr>
<td>Additional mass factor per 10 mm of stroke</td>
<td>with accessories</td>
</tr>
<tr>
<td>Mounting type</td>
<td>M5</td>
</tr>
<tr>
<td>Pneumatic connection</td>
<td>Wrought Aluminium alloy neutral anodisation</td>
</tr>
<tr>
<td>Materials information for cover</td>
<td>NBR</td>
</tr>
<tr>
<td>Materials information for seals</td>
<td>TPE-U(PU)</td>
</tr>
<tr>
<td>Materials information for piston rod</td>
<td>High alloy steel, non-corrosive</td>
</tr>
<tr>
<td>Materials information for cylinder barrel</td>
<td>High alloy steel, non-corrosive</td>
</tr>
</tbody>
</table>

Ref: [www.festo.com](http://www.festo.com)
**Cylinder 5** DNCB-32-25-PPV-A – 532724

<table>
<thead>
<tr>
<th>Feature</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroke</td>
<td>25 mm</td>
</tr>
<tr>
<td>Piston diameter</td>
<td>32 mm</td>
</tr>
<tr>
<td>Piston rod thread</td>
<td>M10x1.25</td>
</tr>
<tr>
<td>Cushioning</td>
<td>PPV: Pneumatic cushioning adjustable at both ends</td>
</tr>
<tr>
<td>Assembly position</td>
<td>Any</td>
</tr>
<tr>
<td>Conforms to standard</td>
<td>ISO 15552 (previously also VDMA 24652, ISO 6431, NF E49 003.1, UNI 10290)</td>
</tr>
<tr>
<td>Piston-rod end</td>
<td>Male thread</td>
</tr>
<tr>
<td>Design structure</td>
<td>Piston jet, male thread, piston rod, profile barrel</td>
</tr>
<tr>
<td>Position detection</td>
<td>For proximity sensor</td>
</tr>
<tr>
<td>Variants</td>
<td>Single-ended piston rod</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>0.6 - 12 bar</td>
</tr>
<tr>
<td>Mode of operation</td>
<td>double-acting</td>
</tr>
<tr>
<td>Operating medium</td>
<td>Dried compressed air, lubricated or un lubricated</td>
</tr>
<tr>
<td>Corrosion resistance classification</td>
<td>2</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>-20 - 80 °C</td>
</tr>
<tr>
<td>Impact energy in end positions</td>
<td>0.4 J</td>
</tr>
<tr>
<td>Cushioning length</td>
<td>20 mm</td>
</tr>
<tr>
<td>Theoretical force at 6 bar, return stroke</td>
<td>415 N</td>
</tr>
<tr>
<td>Theoretical force at 6 bar, advance stroke</td>
<td>483 N</td>
</tr>
<tr>
<td>Moving mass with 0 mm stroke</td>
<td>108 g</td>
</tr>
<tr>
<td>Additional weight per 10 mm stroke</td>
<td>27 g</td>
</tr>
<tr>
<td>Basic weight for 0 mm stroke</td>
<td>460 g</td>
</tr>
<tr>
<td>Additional mass factor per 10 mm of stroke</td>
<td>9 g</td>
</tr>
<tr>
<td>Mounting type</td>
<td>with internal (female) thread</td>
</tr>
<tr>
<td>Pneumatic connection</td>
<td>G1/8</td>
</tr>
<tr>
<td>Materials information for cover</td>
<td>Aluminium die cast coated</td>
</tr>
<tr>
<td>Materials information for seals</td>
<td>TPE-U(NU)</td>
</tr>
<tr>
<td>Materials information for piston rod</td>
<td>High alloy steel</td>
</tr>
<tr>
<td>Materials information for cylinder barrel</td>
<td>Wrought Aluminium alloy</td>
</tr>
</tbody>
</table>

Ref: [www.festo.com](http://www.festo.com)

**Cylinder 2** DFM-20-400-B-PPV-A-GF or DFM-20-400-B-PPV-A-KF  
Festo: [https://xdki.festo.com/xdki/data/doc_engb/PDF/EN/DFM_EN.PDF](https://xdki.festo.com/xdki/data/doc_engb/PDF/EN/DFM_EN.PDF)

**Inductive Proximity Sensor** SIEN-M8B-PS-S-L - 150387 (PNP)  
http://www.festo.com/INetDomino/files_01/894-912.pdf

**Retro reflective Sensor**: SOEG-RSP-Q30-PS-K-2L – 165330  
http://www.festo.com/INetDomino/files_01/275842d.pdf
SIMATIC S7-300 CPU 314C-2 DP
APPENDIX E

Electrical and technical Drawings