YRKESHÖGSKOLAN NOVIA

Design and Automation

Vacuum transport system for the eye drop medicine filling process.

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Abstract

The pharmaceutical industry imposes strict requirements on maintaining clean and sterile production environments, as outlined by the International Organization for Standardization (ISO). This necessitates the adherence to ISO standards not only within cleanrooms but also during the transportation of materials. However, the current methods of material transportation often lack automation and often present challenges and inefficiencies. This thesis aims to design and automate a Vacuum Transport System as an alternative to conventional material transport in the pharmaceutical industry. The focus is on the eye drop medicine bottling process, which requires high levels of cleanliness to ensure the safety and efficacy of the medication.

A brief study of the pharmaceutical industry requirements in the related aspects and an extensive overview of the industrial standards for proper design provide the foundation for this project. A system prototype is created by developing designs conforming to industrial standards, assembling 3D models for visualization, and designing a PLC program for standard operation. The prototype obtained is calculated to have an approximate material cost of 44.344,93 €.

The results demonstrate the successful achievement of project objectives and fill the gap in the available technical information regarding vacuum transport systems in the pharmaceutical industry. Although aerodynamic calculations and component sizing are not included due to the aim to provide an adaptable solution. This thesis provides a solid foundation for future implementations. Future research opportunities include conducting comprehensive aerodynamic analyses, detailed component sizing, and the development of a simulation server for production process integration.

Language: English
Key Words: Vacuum Transport, Pharmaceutical Industry, Process Design, Pneumatics, Automation

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1 Introduction

Many restrictions and requirements need to be met in the pharmaceutical industry production processes in order to prevent any alien particle found in the productive environment to compromise the sterility of the product. The International Organization for Standardization (ISO, www.iso.org) defines in the ISO 14644:2015 (Labsom, 2022), the specifications of requirements that the cleanrooms need to meet in these particular production environments. The ISO regulations must be complied with to develop manufacturing activities and are very strict in the pharmaceutical industry.

All these requirements not only need to be complied with inside the cleanrooms themselves but also everything that gets in needs to be completely clean according to the ISO standards, which includes people and any material. This implies that every material that enters the cleanroom needs to guarantee a certain degree of sterility, including the raw materials used for fabrication, which can sometimes make logistics complicated. The transportation of these in the specified conditions from the material reception area to the production one is usually an issue and needs to be clearly defined by the process engineers whether it is produced in the same factory or purchased to an external producer.

The author having worked as a consultant in Engineering and Automation has a range of experience in cleanroom automated production environments and often got to witness how the machine feeding of the raw material process was the less automated one. This process is normally handled by persons who need to be wearing special clothes and carrying big amounts of material that can lead to personal injuries, material loss or even production stops. Another common solution is the use of conveyor systems that have significant limitations in long distances and have significant volumes while maintenance and proper cleaning are difficult in these specific conditions.

However, the author also had the chance to witness material transportation of granulated products, powder products, animal food, and even some pharmaceutical applications of vacuum transportation, which is, by energy consumption, more expensive than conventional transportation methods but might have some other advantages over them as well.

In this thesis the author will act independently to design and automate a Vacuum Transport System for raw material transport for the feeding process of the main production one. For doing so, the eye-drop medicine bottling process was decided to be a good process to emulate as three different pieces (bottles, dosifiers, and caps) would need to be transported from the reception area to the feeder of the production machine.

The eye-drop medicine bottling process requires even higher levels of cleanliness to ensure the safety and effectiveness of the medication as the eye is a highly sensitive and delicate organ that is easily susceptible to infection and irritation (Arakelians, 2023). Contamination of eye-drop medication can lead to serious complications such as corneal ulcers, conjunctivitis, and even blindness. Additionally, eye-drop medication typically contains preservatives and other chemicals that can react with contaminants (Marino, 2018), resulting in a change in the medication's composition, efficacy, and safety, being this the reason why it is indicated to throw away any eye-drop medicine after certain time from opening.

1.1 Aims and objectives

The aim of this thesis is to design and automate a vacuum transport system as an effective alternative to conventional transport in pharmaceutical industrial production.

To achieve this aim, the following objectives are defined:

- Develop designs that conform to industrial standards for the electrical, pneumatical and process systems.
- Design 3D models of the important elements to give the client visual inputs of the prototype.
- Create a PLC program as a standard sequence for operation in the designed system.

The purpose of this thesis is to provide a general enough prototype to be easily adapted in different production processes and to be a prototype that could be presented to a potential client.

1.2 Document structure

Section 2 provides the required background and theoretical framework of the necessary previous concepts that are needed to be clear before starting to work on the design of the system. Section 3 focuses on the process design according to the standards stated in the previous section. Subsequently, section 4 states the design of the pneumatical system while section 5 discusses the electrical one according to the process and pneumatic designs so that the system is coherent. Section 6 reflects the automation sequence of the whole system. The results achieved are reflected along section 7 and discussed through section 8. Finally, the conclusions are provided in section 9.

2 Theoretical framework

This section provides a critical foundation for the development of the system in the future stages of this thesis by establishing the concepts, theories, and principles that underpin the topic discussed. The ISO cleanroom standards are defined in 2.1 so that the requirements to be met and the relevance of the solution to provide is clear. Subsequently, section 2.2 provides the foundation, the concepts, and the tools that need to be clear before starting to develop and design the process and a similar approach is made with pneumatic control, electric knowledge for industrial installations, and PLC automation concepts in the following sections, 2.3, 2.4 and 2.5.

2.1 ISO 14644

The International Organization for Standardization (ISO, www.iso.org) is a non-governmental organization that develops and publishes international standards for various industries and sectors. These standards provide a framework of best practices and guidelines that help organizations improve their products, services, and operations, as well as enhance their overall efficiency, safety, and sustainability.

Following ISO standards is not required by any law (Davoren, 2013); however, ISO standards are recognized in many industries. Furthermore, ISO certification conjures up an image that the business adheres to certain quality measures when developing and producing products and services.

As pharmaceutical products are critical to well-being, the industry is highly regulated and has strict procedures to follow (NQA, 2023), although compliance with ISO standard may not be compulsory, not doing so can severely impact a company's ability to operate, compete, and meet the regulatory and customer requirements.

Therefore, most of the pharmaceutical companies choose to comply with these standards as a way to ensure product quality, safety, and efficacy (beSlick, 2021), as well as to enhance their competitiveness and reputation in the marketplace.

Concerning this thesis, as the project would imply modifications of a cleanroom environment, and possibly some additions to it, it is necessary to check the ISO requirements to take them into account along with the development and design of the prototype.

ISO 14644 is a series of international standards that stablish requirements and guidelines for cleanrooms and associated controlled environments. The ISO14644-1:2015 standard provides a framework for determining the level of air cleanliness required for a given application, based on the concentration particles between 0.1 and 5 micrometers.

ISO 14644-1:2015 does not specifically mention pneumatic systems, which are meant to be used in the prototype of the system, as it is focused on the classification of air cleanliness in cleanrooms. However, it is important to note that pneumatic systems can have significant impact on the level of air cleanliness in a cleanroom.

Contaminants such as oil, moisture, and particles can be introduced into the cleanroom environment through pneumatic systems (Palkowitsh, 2019). Therefore, it is important to ensure that pneumatic systems used in cleanrooms are designed, installed, and maintained in accordance with relevant standards and guidelines such as the ISO 8573 for compressed air quality.

Another important issue in cleanroom environments defined by the ISO 14644, is the guidance provided on the selection of materials used in cleanrooms, including considerations such as chemical resistance, ease of cleaning, and compatibility with the intended application. The standard recommends that materials used in cleanrooms be selected based on their ability to minimize particle shedding, chemical off-gassing, and contamination, and that the materials should be easy to clean and maintain.

Stainless steel is considered to comply with these requirements, and it is often specified in ISO standards related to cleanrooms and associated to controlled environments, as it is the case in 14644-9:2015 where it is included in the classification for surface cleanliness by particle concentration, and in the ISO 14698 for biocontamination control.

Based on the findings of this section, it can be concluded that for the following stages of this thesis, it is important to consider the compressed air quality, reduce as much as possible the amount of elements inside the cleanroom so that the risk is reduced and fewer elements need to comply with the standards. If certain elements must be present within the cleanroom, the material selection must be made with utmost care and consideration, in accordance with the requirements.

2.2 Process design

Process design is a critical phase in the development of any system, as it lays the foundation for how the system will operate and perform its intended functions (Pisano, 1996). In simple terms, process design refers to the creation of a roadmap that outlines the series of steps and actions that must be taken to achieve a specific outcome. It involves defining the inputs, outputs and transformations that take place within the system as well as the resources, tools, and technologies required to support these processes.

According to Johnson (2020), effective process design and documentation ensures that a system runs efficiently, effectively, and in line with the desired outcomes, and proper documentation of the design will result into future advantages in term of maintenance and process success.

2.2.1 Definition of the needs of the project

To understand the implication of the design in the bottling process of eye drop medicine, it is important to learn about the bottling process itself. To do so, two very clarifying videos would be advisable to visualize in the following links: UPMACH bottling machine and Maharshi Udyog machine. Even though the processes are different, the same use of vacuum transport can be provided to both.

The process consists in the empty eye dropper bottles being transported by the conveying mechanism to the rotary table positioning mechanism of the filling machine, also called feeding bowl:

Figure 1- Example of feeding bowl (Source: www.autodev.com)

This kind of machine allows to be fed with big amounts of material and is capable to sort it out so that only the pieces in an appropriate position will get to the inside of the process line. After that, bottles will be cleaned by an air washing system and will enter a large rotary table where they will be filled.

After filling, the rotary table will transport the filled bottles to the next station, where the dosifier tips will be located in the neck of the bottles. In a similar way as in the bottle feeding, there is a feeding machine that will provide the dosifiers only when they are in the correct position to enter the process.

The dosifiers are introduced in the bottles' and, in a similar way as in the previous step, the bottle caps are screwed in the top of the bottles finalizing the process and obtaining sealed medicine bottles ready to package.

This thesis focuses on providing an alternative system of transporting the material to the feeding bowls as the one in Figure 1, so that the inconvenience of the conveying systems can be avoided.

In general, pharmaceutical factories do not produce their own plastic components for filling with medicine (Connors, 2021). Instead, they typically purchase these components from specialized manufacturers who specialize in producing high-quality plastic components for the pharmaceutical industry and adhere to current Good Manufacturing Practices (GMP).

As pharmaceutical factories may not focus on one only production process, the material receiving area can be located far from the point where this material is needed. Moreover, this material arrives to the factories complying to very strict quality control measures and standards, and any bad handling of the material could result in its refusal and throwing it away.

Adequate material handling often involves trained personnel wearing specific clothing, who empty bags into conveyors or hoppers, or even carrying to the feeders with the associated risk of injury (Busch Vacuum Solutions, 2023). Over time, these processes have been modernized, and conveying systems have been developed to transport the materials efficiently. However, these systems require significant space, and pieces may become stuck, requiring constant cleaning tasks.

For this reason, although being a higher energy-demanding transport system (Sothis, 2023), vacuum transport is gaining popularity in the pharmaceutical industry as it provides a possibility to transport material through pipes, which occupy less space, and in a sterile medium as vacuum consists in the absence of air.

In the further stages of this thesis, a vacuum transport system will be designed to transport material from the collection point to each feeding point of the bottling machine. Little to none technical information is found online about these processes as the companies that provide these solutions have very strict confidentiality policies.

The objective of this thesis is to provide a general system so that it can work as a reference for other projects with similar necessities in similar situations by adapting in accordance. Therefore, no distances, diameters, and pump powers will be defined as these characteristics strongly depend on the requirements of every specific case.

In fact, significant success would be achieved if these undefined factors are the only ones needed to define once the design is finished, meaning that the design can work as a standard to adapt to multiple processes with little modifications while maintaining the core provided in this thesis.

2.2.2 ISA 5

The International Society of Automation (ISA) 5 Instrumentation Norm is a set of standards and practices that define the symbols, identification codes, and graphic symbols used in process control instrumentation and automation. The norm provides a common language for engineers, technicians, and operators to communicate and interpret instrumentation and control information in a consistent and unambiguous manner. It is widely used in various industries to ensure safe, efficient, and reliable operation of the process.

The ISA 5 norm encompasses various aspects of instrumentation, including process measurement and control, signal transmission, alarm, and safety systems. It provides a standard framework for designing, implementing, and maintaining instrumentation and control systems.

Some aspects defined in the ISA 5 norm will be used in this thesis to define the process design according to the international standards in industry.

ISA-S5.1:

ISA S5.1 norm mainly focuses on standardizing codes and symbols for instrumentation and control diagrams. For doing so, easy geometrical figures are used, and an identification letter system is developed within the 5.1 norm.

Geometrical figures are used to represent measuring and control functions in the process as well as devices and systems. The most used ones and most significant for the requirements of this project are circles.

Circles are used to indicate the presence of an instrument or as a descriptive element. When positioned perpendicular and in contact with the process pipe, it will act as an instrument presence indicator, as in the example provided in the following figure:

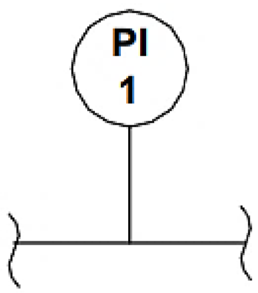


Figure 2- Circle as an instrument presence indicator (Source: ISA-S5.1)

When the circle is used to provide information about another element, it is located in an inclined position and the line pointing to the element will not be in contact with the element. As seen in this example:

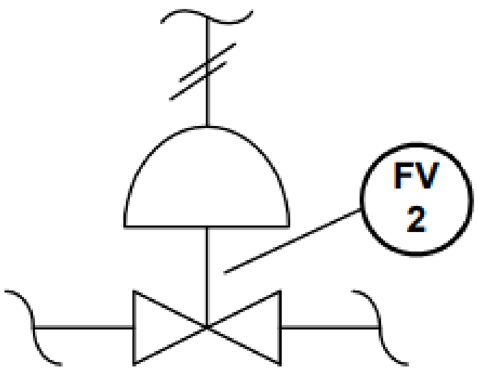


Figure 3- Circle as a descriptive element (Source: ISA-S5.1)

If the element is located in field, the circle will maintain the same aspect as in the previous figures. However, if it is located in a control panel and is easily accessible to the operator, then a solid horizontal line will divide in half the circle.

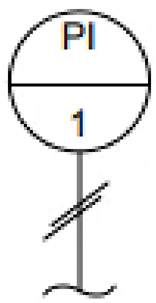


Figure 4- Element located in a control panel (Source: ISA-S5.1)

In case the element is located in a control panel, but it is not visible for the operator, the circle will be divided by a discontinuous horizontal line.

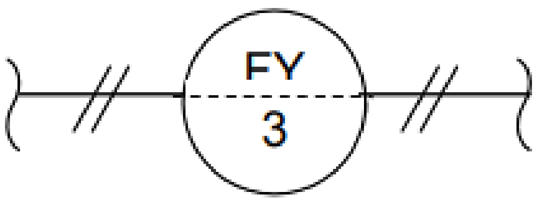
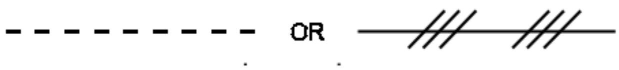
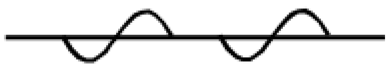
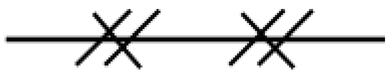


Figure 5- Element located in a not visible control panel (Source: ISA-S5.1)

A line symbolism is also defined in ISA 5.1 and is crucial to differentiate the different piping systems that can be found in a process design diagram. The different identification elements are defined in the following table.

Table 1- Line symbolism (Source: ISA-S5.1)

INSTRUMENT SUPPLY OR CONNECTION TO PROCESS	
UNDEFINED SIGNAL	
PNEUMATIC SIGNAL	
ELECTRIC SIGNAL	
HYDRAULIC SIGNAL	
CAPILLARY TUBE	
ELECTROMAGNETIC OR SONIC SIGNAL (GUIDED)	
ELECTROMAGNETIC OR SONIC SIGNAL (NOT GUIDED)	
INTERNAL SYSTEM LINK (SOFTWARE OR DATA LINK)	
MECHANICAL LINK	
PNEUMATIC BINARY SIGNAL	
ELECTRIC BINARY SIGNAL	

The ISA -S.1 document specifically states that in the cases where two options are available, user’s choice will prevail. However, consistency needs to be applied once a decision is taken.

The following abbreviations are suggested to denote the types of power supply:

- AS-> Air Supply
    - IA-> Instrumentation Air
    - PA-> Plant Air
- ES-> Electric Supply
- GS-> Gas Supply
- HS-> Hydraulic Supply
- NS-> Nitrogen Supply
- SS-> Steam Supply
- WS-> Water Supply

The supply level should be added to the instrument supply line, e.g., AS-6 bar, as a 6-bar air supply.

Once the symbolism standards are clear, it is necessary to define the letter system designed to describe elements of a process so that they can be tagged in a clear, effective, and standardized way. To do so, a functional identification standard is defined in ISA S5.1 and it consists in:

- Letters assignations stablished in Table 2, including one first letter (designating the measured or initiating variable) and one or more succeeding-letters (identifying the functions performed).
- Functional identification of an instrument is made according to the function and not to the construction.
- In an instrument loop, the first letter of the functional identification is selected according to the measured or initiating variable, and not according to the manipulated variable.
- Succeeding letters designate readout or passive functions and/or output functions.
- Modifying letters may also be used to modify a first letter or succeeding letters, if used, modifying letters are interposed immediately following the letters they modify.

- The total number of letters within one group should not exceed four and all letters should be upper case.

Table 2- Identification letters for instrumentation (Source: ISA-S5.1)

	FIRST-LETTER (4)		SUCCEEDING-LETTERS (3)		
	MEASURED OR INITIATING VARIABLE	MODIFIER	READOUT OR PASSIVE FUNCTION	OUTPUT FUNCTION	MODIFIER
A	Analysis (5,19)		Alarm		
B	Burner, Combustion		User's Choice (1)	User's Choice (1)	User's Choice (1)
C	User's Choice (1)			Control (13)	
D	User's Choice (1)	Differential (4)			
E	Voltage		Sensor (Primary Element)		
F	Flow Rate	Ratio (Fraction) (4)			
G	User's Choice (1)		Glass, Viewing Device (9)		
H	Hand				High (7, 15, 16)
I	Current (Electrical)		Indicate (10)		
J	Power	Scan (7)			
K	Time, Time Schedule	Time Rate of Change (4, 21)		Control Station (22)	
L	Level		Light (11)		Low (7, 15, 16)
M	User's Choice (1)	Momentary (4)			Middle, Intermediate (7,15)
N	User's Choice (1)		User's Choice (1)	User's Choice (1)	User's Choice (1)
O	User's Choice (1)		Orifice, Restriction		
P	Pressure, Vacuum		Point (Test) Connection		
Q	Quantity	Integrate, Totalize (4)			
R	Radiation		Record (17)		
S	Speed, Frequency	Safety (8)		Switch (13)	
T	Temperature			Transmit (18)	
U	Multivariable (6)		Multifunction (12)	Multifunction (12)	Multifunction (12)
V	Vibration, Mechanical Analysis (19)			Valve, Damper, Louver (13)	
W	Weight, Force		Well		
X	Unclassified (2)	X Axis	Unclassified (2)	Unclassified (2)	Unclassified (2)
Y	Event, State or Presence (20)	Y Axis		Relay, Compute, Convert (13, 14, 18)	
Z	Position, Dimension	Z Axis		Driver, Actuator, Unclassified Final Control Element	

Some examples of this naming system could be:

- LIC -> Level indicator and controller.
- TDI -> Differential temperature indicator.

- PDIC-> Pressure differential indicator and controller.
- FV-> Flow valve.

ISA-S5.4:

The ISA-S5.4 standard is created as an extension of the communications defined by ISA-S5.1 and the definitions of that standard therefore apply. The purpose of ISA-S5.4 standard is to provide a guide for the preparation and use of instrument loop diagrams in the design, construction, startup, operation, maintenance, and modification of instrumentation systems.

It also helps in understanding instrument loop diagrams and improves communication between technical and non-technical personnel, managers, designers, builders, operators, and maintenance personnel.

The norm defines the instrument loop diagram as a composite representation of instrument loop information, which must contain all associated electrical and piping connections and should contain all the information needed to accommodate the intended uses. The minimum requirements stated by ISA that affect the Process and Instrumentation Diagram (P&ID) development of this project are as follows:

- Identification of the loop and loop components shown on the P&ID according to the standards specified in ISA-S5.1 norm.
- Energy sources of devices, such as electrical power, air supply, and hydraulic fluid supply. Identify voltage, pressure, and other applicable requirements.
- Process lines and equipment sufficient to describe the process side of the loop and provide clarity of control action. Include what is being measured and what is being controlled.

Examples and other specific guidelines given in the ISA-S5.4 document provide enough information to be able to generate the P&ID that will represent the process diagram of this project.

2.2.3 Safety measures

Industrial safety is a multi-disciplinary approach to developing and ensuring compliance with regulatory agencies, safe working practices, and maintaining the health and well-being of those employed in a particular occupation or workplace (University of California, 2022). Strategies to accomplish these goals maintain strong focus on injury prevention through hazard identification, prevention and controls, and engineering modifications.

According to Mark (2017), a designer must consider the potential risks and work to reduce them during the entire design phase through careful choices about materials, manufacturing processes, method of use, and additional safety features whether requires by law or otherwise.

Safety measures are considered in the further stages of this thesis according to the regulations and the standards established. As the process is fully automated and does not involve human interaction, an industrial engineer would recognize that only minimal safety requirements are necessary. The operations mainly involve opening and closing valves, and the only potential risk arises during the maintenance and repair activities in the event of valve malfunction. Therefore, there is an optional safety method that has been deemed to be appropriate for the application. The LOTO system.

The LOTO system stands for Lock Out Tag Out (University of Virginia, 2021), which is a safety procedure used in various industries to ensure that machinery or equipment is properly shut down and cannot be inadvertently restarted during maintenance, cleaning, or repair activities.

The LOTO system involves the use of locks and tags to secure equipment and prevent unauthorized operation. Before the maintenance or repair work begins (Wermac, 2023), the authorized person will apply a lock and a tag to the equipment to isolate it from its energy source, such as electricity and compressed air in the case of this thesis.

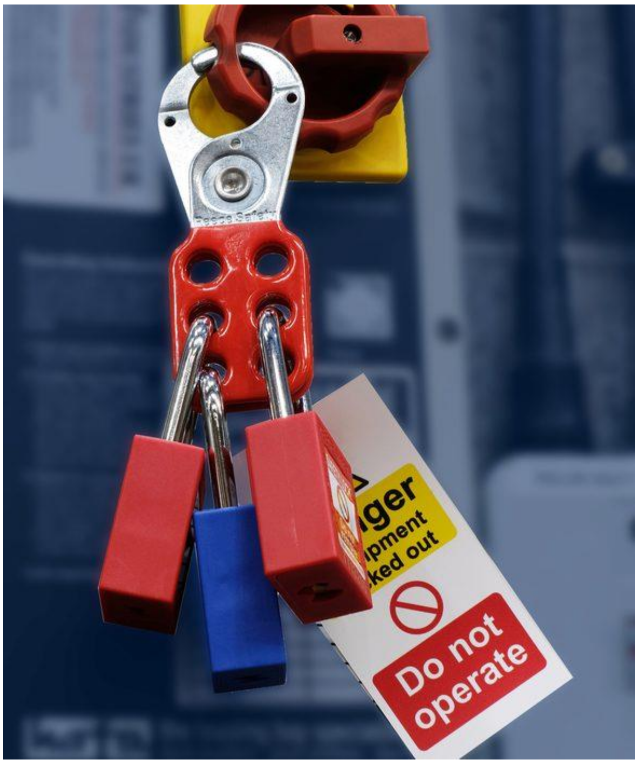


Figure 6- Lock Out Tag Out Illustration (Source: www.hsimagazine.com)

As seen in the previous figure, the lock and tag provide a visual signal that the equipment is under maintenance or repair and should not be operated. Only the authorized person who applied the lock and tag can remove them completing the maintenance task and ensuring that it is safe to operate the equipment again. If another maintenance work is carried on parallelly, the first operator will not be able to energize the machine because another lock and tag will be located in the source power.

This system is an essential safety measure and prevents accidents and injuries caused by inadvertent startup of equipment during maintenance or repair work (Safeopedia, 2014). It is usually a task for the risk management department of every company to define the use of this kind of systems, however, the design of the energy sourced elements of this thesis is provided with LOTO compatible elements so that it is easier to implement.

2.3 Pneumatics

The use of pneumatic systems is fundamental for the control system of the flow valves in the process. Compressed air is one of the most used energy sources in industrial processes due to its safety, quickness, and its ease to implement in any process (Interempresas, 2017). The most common uses for these systems are actioning machinery and valve controlling, which is the case to be considered in this process.

To be able to work with these systems, it is important to have a good knowledge of how compressed air works and how the systems need to be treated before their use in the industry.

2.3.1 Fundamentals

According to the National Geographic Society (2022), the Earth's atmosphere is composed of about 78 percent nitrogen and 21 percent oxygen as major components, and other gases in a minor percentage as carbon dioxide, argon, hydrogen... as well as water vapor and other materials in suspension. This particular topic is important to take into account as, for example, an industrial area will have a bigger number of particles in suspension than others, and this fact will define the quality of the air that will be compressed and used in the posterior stages.

The air pressure prevailing on the Earth's surface is called atmospheric pressure. This pressure is also called relative pressure and it is used as a reference. When working above the reference pressure it will be referred to as overpressure, and below it, will be called vacuum.

<u>Compressed air preparation:</u>

To guarantee the reliability and efficiency of a pneumatic system, the air supplied to the system must be of sufficient quality. For that, it is important to first realize that in, approximately, one cubic meter of air in an industrial area, according to Festo Automation (2021) this amount of elements can be found:

- Over 180 million dust particles
- Over 50g of H_2O (Water)
- Over 0,03 mg of oils
- Various chemicals such as lead, cadmium...

All these elements will be compressed and get into the system and must be taken into account if the three goals for proper air quality are to be accomplished, which according to Heney (2016) consist in:

- Proper pressure (constant)

  Not being able to achieve constant pressure in the system will result in premature wear of the components, undesired vibrations in the machine, lack of force in the operations of the application, air leaks, and poor performance in the production process.

- Dry Air

  Condensate water in the system will cause corrosion, low speed, blockage in the condensate outlets, and would sweep off the original grease of the components causing premature wear of the joints.

- Clean Air

  Excessive particles in the system will cause premature wear of components which would lead to pressure fluctuations and would result in general system malfunction. Important to avoid using oil in a system that does not require oil by manufacturer specification. Pneumatical elements are manufactured with an original grease that is meant to last all the life expectancy. The usage of oil will sweep off this grease and will require continuity.

Air compressor:

When working with pneumatic systems, the first step is to compress the air to a desired overpressure value so that it can be used for a later application. There are many different types of compressors, and the choice will depend on the application. Note that compressed air is not free, there is significant waste in air compressing (Chicago Pneumatic, 2017), that is why it is very important to avoid leaks in the system or bad dimensioning that would make our compressor work more than desired.

Air reservoir:

In order to stabilize the compressed air, an air accumulator/reservoir needs to be installed right after the compressor. The air reservoir will balance the pressure oscillations when extracting air from the system and when the pressure falls to a determined value, the compressor will return to compress air until the desired value (Advanced Pneumatic Industries, 2019). This way, the compressor will not have to be in continuous operation.

The fact that the air reservoirs' area is relatively big causes a cooling effect in the compressed air, which results in water condensation that will lay at the bottom of the accumulator and will need to be drained regularly (Air Supplies, 2014). The parts of a usual air reservoir are seen in the following figure:

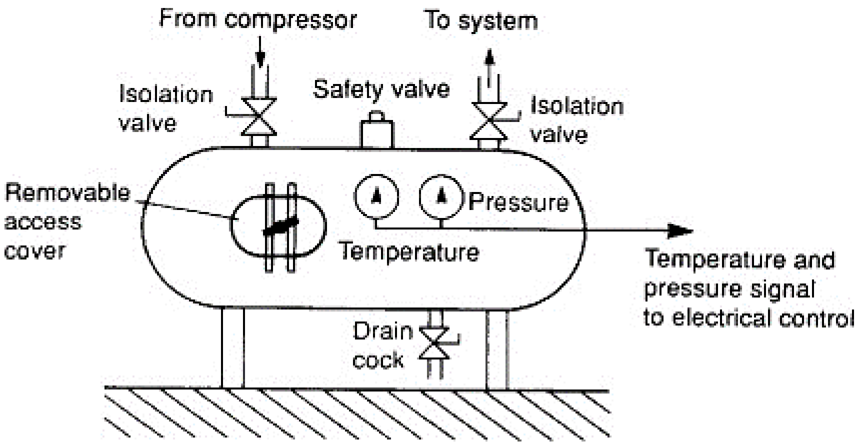


Figure 7- Air receiver components (Source: www.sciencedirect.com)

As seen in the previous figure, the air receivers are equipped with isolation and safety valves that will prevent unwanted dangerous situations and also count with pressure and temperature indicators which are of significant importance for maintenance staff to check the proper operation of the system or even introducing monitoring systems so that the behaviour of the system is registered and flaws can be detected (Compressed Air Technology, 2018).

Air drying:

The humidity (water vapor) enters the network through the air sucked by the compressor. By compressing the air taken in, an increase in its temperature is produced up to 70ºC to 85ºC and the humidity percentage grows to 100% (Festo Automation, 2021). As commented previously, when the compressed air enters the air reservoir, the temperature drops to the environmental temperature causing the condensation of a significant quantity of water, however, the air humidity percentage is still 100% (Guelker, 2015). Therefore, it is very important to reduce the excess humidity so that when the air is used and it expands and consequently suffers another temperature drop, it won't condensate again causing corrosion in the components (Atlas Copco., 2020).

This is solved by installing dryers after the air reservoir, but it is of vital importance that they are properly dimensioned for the system and possible future additions (Grupo Indutorres, 2019).

2.3.2 Required knowledge for proper design

The preceding sections will not receive further elaboration in this document, as it is assumed that factories possess the necessary infrastructure, which is essential for proper pneumatic systems. Nevertheless, it was deemed appropriate to provide an overview, as many issues in pneumatic systems stem from this area.

In the following sections, more specific contents will be displayed so that they are clear before applying them to the project.

Air quality:

The presence of pollutants such as particles, humidity, or oils significantly reduces the efficiency of the pneumatic components and can cause process inefficiencies, leaks in actuators or valves, and time delays in the working cycles. It is of crucial importance to properly define the air quality needed according to the application.

The definition of the level of quality required according to the application is established by ISO 8573-1:2010 (2010) and is divided into three aspects, which will be classified by three numbers separated by a double-dot in the format of "X:X:X", each of them meaning according to their position:

1. Determines the number of solid particles. Specifying a requirement of minimum filtering.

2. Determines the condensates permitted. Specifying a requirement of minimum drying.

3. Determines the oil content in the air. Specifying a requirement of filtering or even completely forbids it in the application.

The values corresponding to each number follow the parameters indicated in ISO 8573-1:2010 and seen in the following figure:

ISO 8573-1:2010	Solid particles				Water		Oil
	Max. number of particles per m³			Mass concentration	Pressure dew point	Liquid	Total oil content (liquid, aerosol and vapour)
	0.1 ... 0.5 µm	0.5 ... 1 µm	1 ... 5 µm	mg/m³	°C	g/m³	mg/m³
0	In accordance with specifications by the device user, stricter requirements than Class 1						
1	≤ 20,000	≤ 400	≤ 10	–	≤ –70	–	0.01
2	≤ 400,000	≤ 6,000	≤ 100	–	≤ –40	–	0.1
3	–	≤ 90,000	≤ 1,000	–	≤ –20	–	1
4	–	–	≤ 10,000	–	≤ +3	–	5
5	–	–	≤ 100,000	–	≤ +7	–	–
6	–	–	–	≤ 5	≤ +10	–	–
7	–	–	–	5 ... 10	–	≤ 0.5	–
8	–	–	–	–	–	0.5 ... 5	–
9	–	–	–	–	–	5 ... 10	–
X	–	–	–	› 10	–	›10	›10

Figure 8- ISO 8573-1:2010 Air quality standards. (Source: www.festo.com)

In most cases, compressed air is used as pilot air, for example, to control valves, cylinders and grippers. For this type of application, contamination only needs to be removed from the compressed air to protect the pneumatic components against corrosion and excessive wear. Class 7:4:4 would be enough in this case.

As mentioned in the ISO 14644 section, significantly higher levels of purity are required when compressed air is used as process air, e.g., for blowing out molds, or when it comes directly into contact with food. However, this is usually limited to specific locations. Decentralized compressed air preparation, as close as possible to the consuming device, would be advisable then so that only the required amount of air is prepared to the higher purity level, thus resulting in energy and economic savings. The proximity of compressed air preparation to the consuming device also minimizes the danger of recontamination of highly purified air in the piping network, for instance with rust particles.

When compressed air is used for transporting, mixing, blowing, or any other action that results in direct contact with food or pharma products, then the following compressed air quality classification in accordance with ISO 8573-1:2010 applies: 1:4:1.

This aspect is important to be considered when designing the pneumatic system as any component located inside the cleanroom will need to be fed with specifically filtered air to comply with the ISO requirements.

Service units:

The different functions of compressed air conditioning as filtering, pressure regulating, and lubricating (only if needed), can be carried out by individual elements, however, it is common and appropriate to integrate these functions into single operating units, the service units. These units are placed before every pneumatic installation, meaning that the pneumatic system to be designed in this project will need its own.

Festo (www.festo.com) pneumatic elements will be used mostly in this thesis as the product range is known to the author as well as the software programs that allow to handle these products, which are also available for the author.

- **Switch-on / shut-off manual valve:**
  Normally the first valve to be placed at the connection point between the general network and the equipment to be fed.

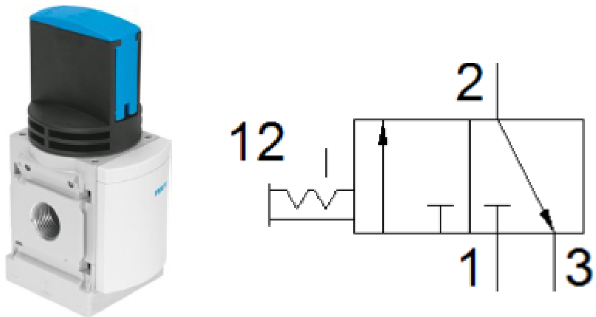


Figure 9- Manual Valve (Source: Festo Quick Search)

This valve is a 3/2 valve that allows the operator to manually let pressurized air get inside the system or empty it so that maintenance and repair tasks can be carried on with no pressure in the system. This system is lockable so that LOTO policies are applicable.

- **Switch-on / shut-off electric valve:**
  This valve consists of the same physical concept as the previous one.

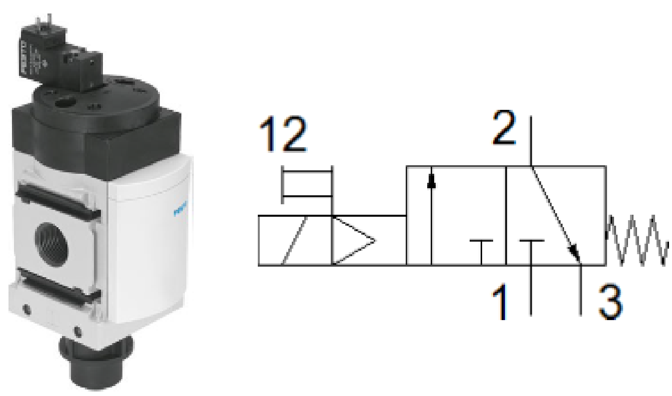


Figure 10- Electric Valve (Source: Festo Quick Search)

Depending on the working position, it can let air flow or discharge the system. The main difference is that it is electrically driven. This allows the automation of this action by PLC control and the incorporation of security functions.

In the following figure, the concept of the two previous valves is easily seen.

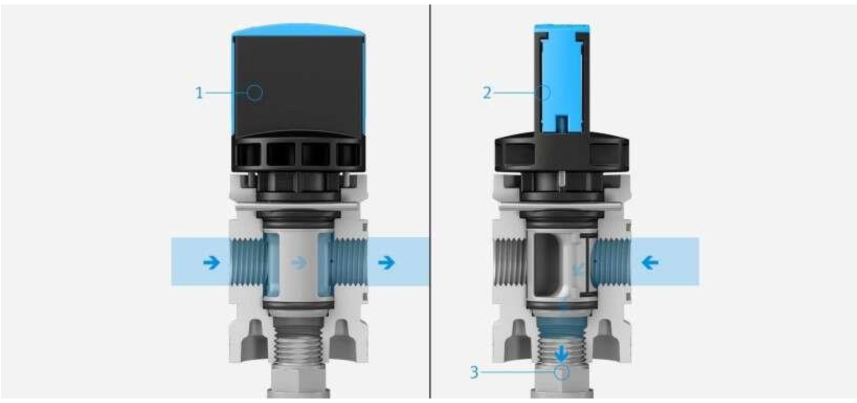


Figure 11- Switch-on / Shut-off Valves (Source: www.festo.com/gb/)

These valves are crucial for security in pneumatic installations as they must depressurize the system as fast as possible to avoid hazardous situations. That is why in the cases that are considered appropriate, they are equipped with larger exhaust ports, the electric ones can have redundant channels, and even specific safety models exist to provide lower reaction times.

- **Pressure Regulator:**

One of the most important valves is the pressure regulator. While the compressor will normally compress air up to 10 or 12 bar, the standard working pressure for most pneumatic elements is 6 bar, meaning that proper regulation needs to be done before the network air enters the system.

The working pressure is regulated by turning a knob. With the help of a manometer or pressure sensor, the pressure can be adjusted if necessary.

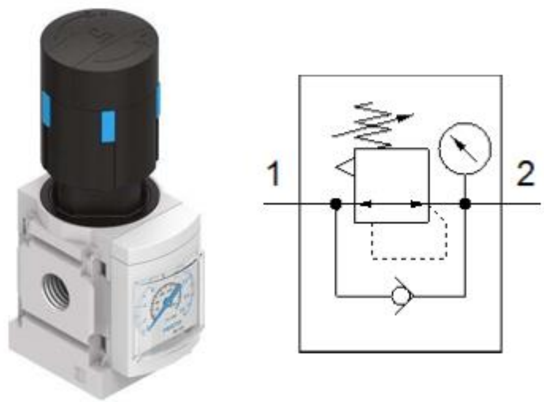


Figure 12- Pressure Regulator (Source: Festo Quick Search)

This element can be locked so that no unauthorized personnel can manipulate the working pressure of the system.

- **Filters:**

The filters chosen for our system will define the level of air filtering achieved according to ISO 8573-1:2010 and will guarantee a certain degree of air purity and cleanness.

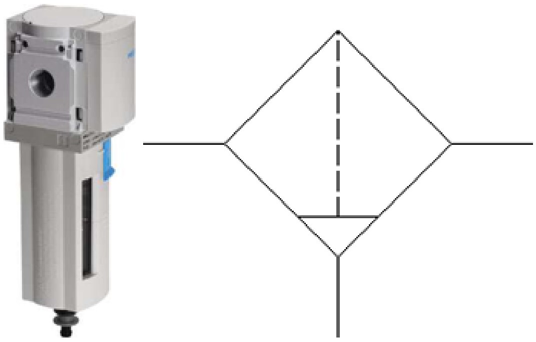


Figure 13- Air filter (Source: Festo Quick Search)

The working principle for these filters is related to cyclone separators. The pressurized air enters the filter and passes through a baffle that creates a vortex, since the density of the moisture is higher than the one of compressed air, the moisture will hit the bowl wall due to centrifugal force of the vortex. The moisture then flows into the bowl where it is drained either manually or automatically. When the compressed air leaves the regulator, it passes through a physical filter that will prevent solid particles above a certain size to pass. This process is easily recognized in the following figure:

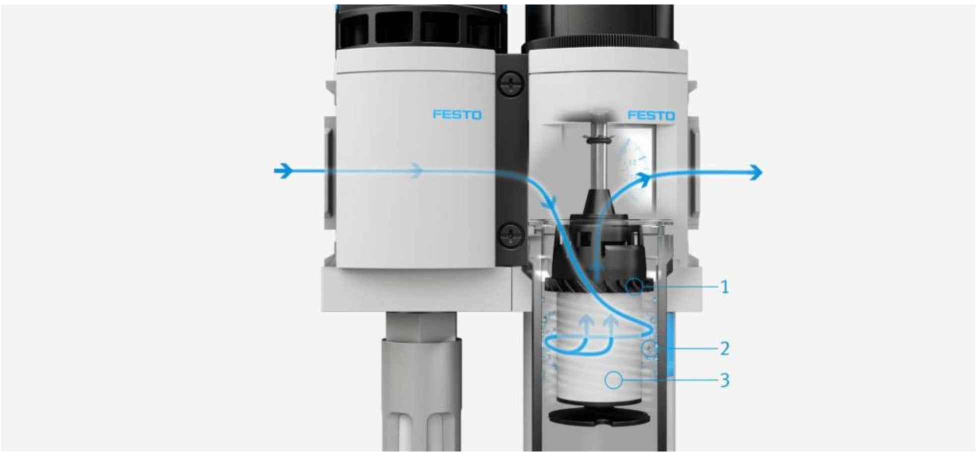


Figure 14- Filters working principle (Source: www.festo.com/gb/)

The standard physical filtration levels are of 40 μm and 5 μm. The 40 μm one meets the minimum quality class 7:4:4 in accordance with ISO 8573-1:2010. However, higher levels of filtration are achievable if micron and submicron filters are added in cascade after the standard ones so that higher requirements of air quality can be met.

It is usual that the pressure regulator and the first filter of a service unit are mounted together resulting in room and economic savings as seen in the following figure:

Figure 15- Filter regulator example (Source: Festo Quick search)

Once all the significant service unit elements are known, it is possible to design the following elements of the pneumatic system.

Pneumatic valves:

In pneumatics symbology, every position of a valve is represented by means of a square. The number of squares defines the number of possible positions of the valve and the lines inside define the airflow and its direction. Blocked connections are represented by perpendicular lines and the inputs and outputs of airflow are represented by lines outside the square representing the valve. In the following Figure, some examples of valves are represented so that they can be easily understood.

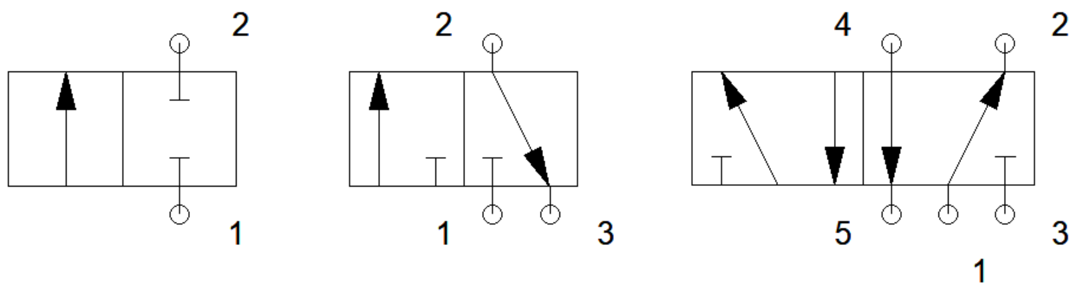


Figure 16- Pneumatic valves examples (Source: Fluidsim)

By considering the example valves it is easily observable that the supply port is defined by number 1 and the possible working ports are defined by the pair numbers. The other odd numbers always refer to the exhausts of the air already used in the system.

The most commonly used valves are presented so that they can be recognized in the future:

- **2/2 Valve:** Normally used as flow valves, they only have two positions, and they can be used for stopping or letting the air flow through them.

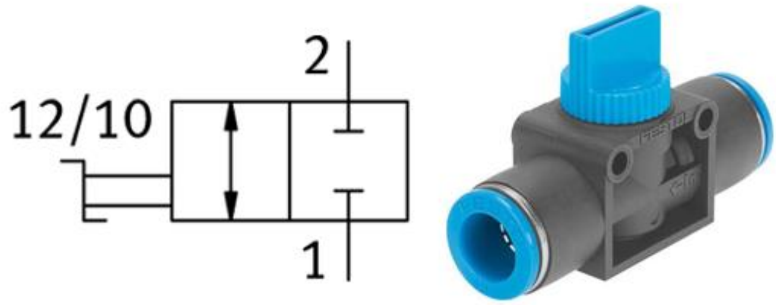


Figure 17- 2/2 Valve (Source: Festo Quick Search)

- **3/2 Valve:** Normally used as flow valves at closed systems and for handling simple-acting cylinders because due to their 3 ways, the airflow can go in two different directions and while it will pressurize the system in the open position, it will work as an exhaust in the closed one.

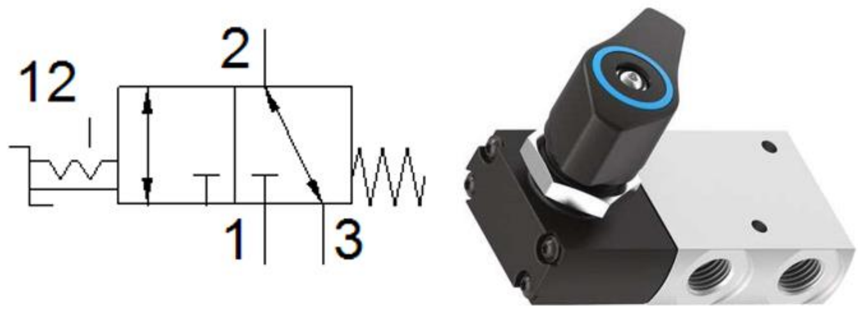


Figure 18- 3/2 Valve (Source: Festo Quick Search)

The previous valves have been presented as specific models actioned mechanically for a better and easier understanding of the concept, the most common way of controlling pneumatical valves is electrically.

- **5/2 Valve:** Most used type of valve. Used to control many different actuators, double-acting cylinders, rodless cylinders, grippers, rotary actuators… This type of valve allows controlling movement in both directions.

5/2 Valves can be monostable or bistable, the main difference is that monostable ones have a rest state which they will come back to after being triggered, and bistable ones will stay in the last position they were triggered and will not go back to the other position until the next input asking for so.

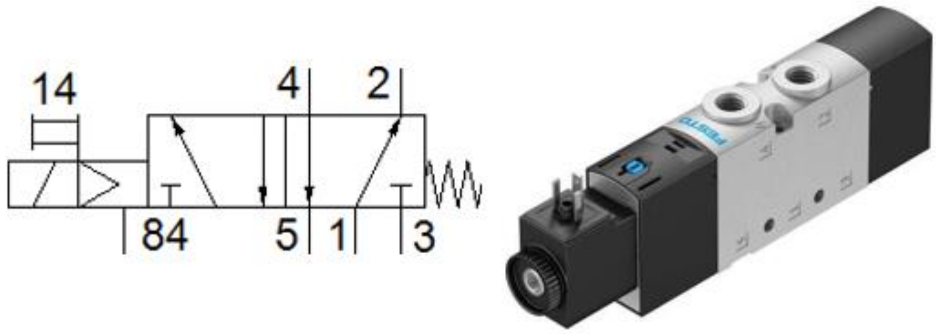


Figure 19- 5/2 Monostable Valve (Source: Festo Quick Search)

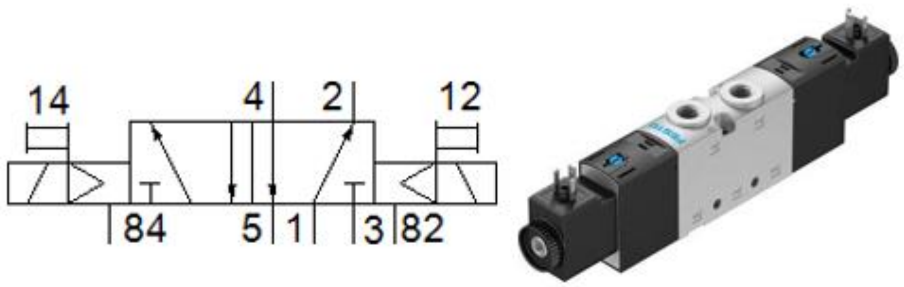


Figure 20- 5/2 Bistable Valve (Source: Festo Quick Search)

Other types of valves could be discussed; however, it has been considered that they will have no application in this specific project, therefore they will be omitted.

2.4 Electric design aspects

Electric circuits are an essential component of industrial environments, powering the machines and equipment that are used in manufacturing, production, and other industrial processes (Headrome, 2019). Properly designed electric circuits are critical for ensuring the safe and efficient operation of these systems, as well as minimizing the risk of equipment damage, downtime, and other costly issues.

From power distribution to control systems, a well-designed electric circuit can improve reliability, reduce energy consumption, and enhance the overall performance of an industrial operation (London Training Excellence, 2023). In this section, the principal elements and symbols of a proper electric design are presented and described so that they are properly known in the further stages of the thesis.

2.4.1 Safety and power distribution elements

Isolator panel switch:

An isolator panel switch is an electrical device used to isolate a particular circuit or piece of equipment from the power supply. It is essentially a switch that physically separates the equipment from the power source by breaking the electrical connection between the two (GRL Fuse, 2022). This prevents any unwanted electrical current from flowing into the equipment, which can protect it from damage or prevent electrical incidents.

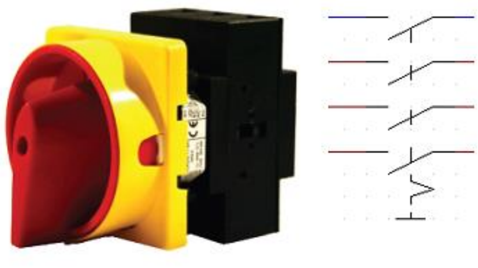


Figure 21- Isolator panel switch (Source: es.rs-online.com)

The isolator panel switch consists of a mechanical knob that can be rotated. When it is switched to the "off" position, the contacts of the switch are opened, ensuring that the equipment is completely disconnected from the power supply. This element is significantly important in electrical cabinets, as it allows isolation for maintenance operations and is compatible with the "Lock Out, Tag Out" system for greater safety in case somebody is working in the line, and someone tries to turn the system on.

Differential switch:

A differential switch, also known as residual current device (RCD), is an electrical safety device that detects any imbalance in the flow of electric current between the live and neutral wires of a circuit (One Elec, 2023). It is designed to protect people from electric shocks and prevent fires caused by faulty wiring or appliances.

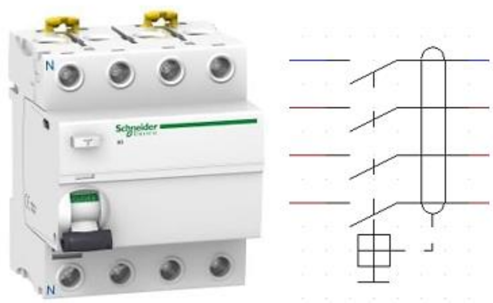


Figure 22- 3-phase differential switch (Source: www.one-elec.com)

A differential switch works by constantly monitoring the current flowing through the live and neutral wires of the circuit. If there is any difference between the amount of current flowing through the two wires, it implies that some of the current is scaping from the circuit and is potentially flowing through a person or a fault in the system. When this happens, the differential switch detects the imbalance and trips, cutting off the power supply to the circuit.

According to the Finnish National Electrotechnical Standardization Association (SESKO) (2020), in their report analyzing the fatal electrical accidents in Finland from 1980 to 2019, 37% of all fatalities in the period could probably have been prevented if the circuit had been protected with a residual current device, which is now mandatory in new installations.

Monophase differential switches are a common sight in household fuse boards. However, in industrial settings, three-phase differential switches such as the one illustrated in Figure 22, are also prevalent since three-phase components can also present faults or imbalances and can cause significant damage to equipment and pose a safety hazard to workers.

Electric circuit breaker:

An electric circuit breaker is a safety device that automatically interrupts the flow of electricity in an electrical circuit when it detects an excessive current (Eaton, 2023), thus protecting the electrical system and its components from damage caused by overloading, short circuits, or other electrical faults.

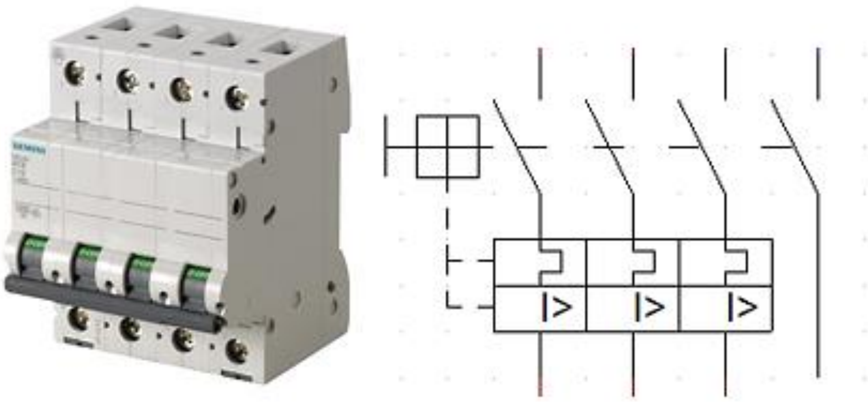


Figure 23- 3-Phase Circuit breaker (Source: www.automation.siemens.com)

Circuit breakers consist of a switch mechanism and a tripping mechanism. The switch mechanism allows to manually stop the electricity flow through the circuit and isolate it, while the tripping mechanism is activated when the current exceeds a certain level (Harris & Homer, 2002), causing the switch to open and interrupt the flow of electricity.

Circuit breakers are widely used in residential, commercial, and industrial settings to protect electrical systems and equipment from damage (ABB US., 2018), reduce the risk of electrical fires, and ensure the safety of people working with or around the electrical system.

24-Volt Power Supply:

A 24-volt power supply is an electrical device that converts incoming AC voltage (in this case) to a stable, regulated 24-volt DC output (Shahjahan, 2021). It consists of a transformer to step down the voltage, a diode rectifier to convert to pulsating voltage, and a voltage regulator and filter capacitors that ensure the constant 24-volt output.

The circuit and the elements mentioned are identifiable in the following example figure:

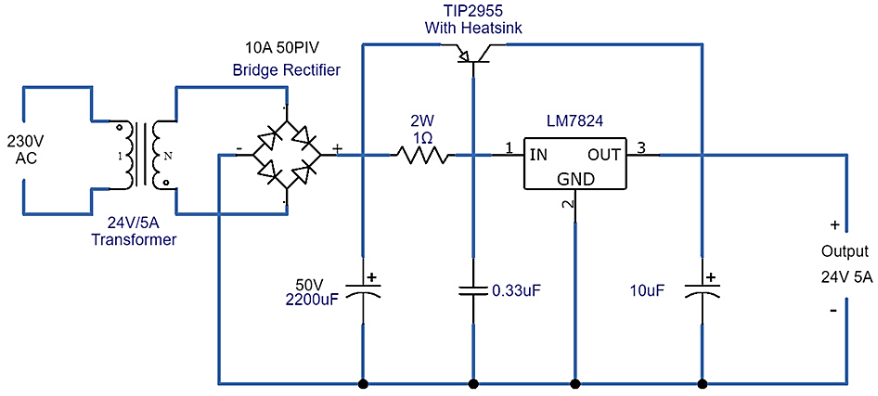


Figure 24- 24 volt power supply (Source: www.circuits-diy.com)

This element is used to provide electrical supply to control elements, which work with 24 volts as they are mainly used for sending signals of activation or deactivation of the elements that control the power-demanding elements that need more voltage, as motors (Manufacturing.net, 2003). Using 24 volt as control voltage has some advantages, as the increment in reliability by being able to protect circuits against short circuits, a reduction of the size of the components due to the lack of special requirements that bigger elements have, and a safer environment for the operator as there is no potential for personnel injury with the limited power of these systems.

An industrial model example and its electrical sign are identifiable in the following figure:

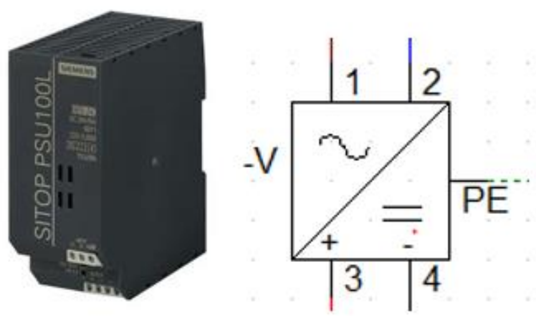


Figure 25- 24-Volt Power Supply (Source: www.automation.siemens.com)

This element is used in further stages of this thesis to supply the control elements of the system.

2.4.2 Control elements

<u>Programable Logic Controller (PLC):</u>

A Programable Logic Controller (PLC) is a type of industrial computer system used to control and automate manufacturing processes, machinery, and other complex systems (Cristensen, 2022). PLCs are designed to withstand harsh industrial environments and operate reliably and efficiently for extended periods of time.

Figure 26- PLC and I/O modules in cabinet. (Source: www.logimatic.com)

This element is supplied by the 24-volt supply unit and provides the outputs according to the programmed sequence to achieve the proves automation. This element's features are furtherly developed in 2.5 section of this thesis.

<u>Variable Frequency Drive:</u>

A variable frequency drive (VFD) is an electronic device that controls the speed and torque of an electric motor by varying the frequency and voltage of the power supplied to the motor (Hartman, 2014). Variable frequency drives are used in a wide range of industrial applications, such as conveyor systems, fans, and pumps (Danfoss, 2023). They offer several advantages over traditional control methods as significant reduction of the energy consumption, improved process control, and extended motor lives as they also provide soft starting and stopping of the motors, which reduces mechanical stresses on the equipment.

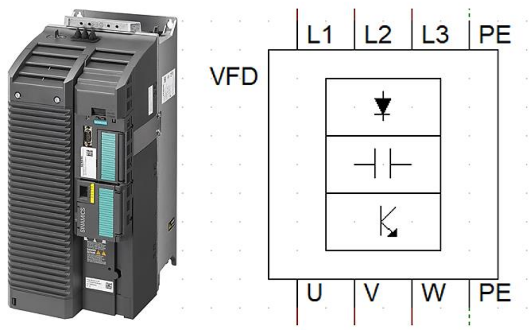


Figure 27- Variable frequency drive example (Source: www.drivesandautomation.com/)

2.4.3 Electrically driven elements

Vacuum pump motor:

A vacuum pump is a mechanical device used to remove air and other gasses from a system to create vacuum (Zelle, 2021). The pump works busing a mechanism to generate a low-pressure zone that causes gas molecules to move from the system into the pump.

Figure 28- Vacuum pump example (Source: www.buschvacuum.com)

The pumps are usually powered by electricity and controlled by VFDs so that the amount of vacuum generated, and the power consumed is set according to the desires of the design.

Solenoid coils:

A solenoid coil is a component used to control the commutation of the electro valve itself. The coil is an electromagnetic device that generates a magnetic field when an electric current is passed through it (The Engineering Mindset, 2019). This magnetic field is used to control the opening and closing of a valve.

Figure 29- Solenoid Coil (Source: Festo Quick Search)

The application of solenoid coils in pneumatic control operation is widely spread as it allows to control the flow of the air by electrical signals (Electricsolenoidvalves.com, 2021). These coils standard operating voltages are 12-24 V in DC, and 24-110-220-230 V in AC at 50-60 HZ frequency (STC Valve, 2016). However, the most common are 24 V DC and 230V AC.

Signaling column:

Signaling columns are important in industry because they provide a visual indication of the status of the machine or process (Siemens, 2023). This is particularly important in industrial settings where machinery and processes can be complex, and it can be difficult for workers to monitor them at all times.

Figure 30- Signaling column example (Source: mall.industry.siemens.com)

Signaling columns typically consist of a tower of lights of different colors, with each color representing a different status or condition. For example, green might indicate normal operation, yellow might indicate warning or error, and red might indicate emergency stop or shutdown, and might also activate an acoustic alarm.

Using signaling columns facilitates the workers to quickly identify the status of a machine or process from a distance, without having to physically inspect it (Rodavigo.net, 2023). Resulting in safety, reduced downtime, and an increase of efficiency in industrial settings.

2.5 Programable Logic Controller (PLC)

Programable Logic Controllers are specialized computer-based control systems that are used in industrial settings to automate and control machinery and processes (Mortenson, 2020). A PLC typically consists of a Central Processing Unit (CPU), which is the brain of the system and the element that is responsible of executing the program logic and controls the Input/Output (I/O) modules, which allow the PLC to interface with sensors, actuators, and other devices in the industrial process.

PLCs are used in a wide range of industrial applications, including manufacturing, process control and transportation (Inductive Automation, 2020). They are particularly well-suited for applications that involve repetitive, high-speed, or hazardous tasks, as they can operate continuously and reliably without human intervention.

In the following sections, the Ladder Logic is introduced and explained as the main programming language for PLC operation, and subsequently, communication protocols are also explained.

2.5.1 Ladder Logic

Ladder Logic is a graphical programming language commonly used in PLCs and other industrial control systems (Chaudhari, 2020). It was originally developed to mimic the look and feel of a relay-based control system but has since evolved to include a wide range of functions and capabilities.

In Ladder Logic, the program is represented as a series of “rungs” that run horizontally across the screen. Each rung represents separate instruction or operation, and is made up of two vertical “rails” that represent the power supply and the ground, and the actual rung that runs horizontally between the rails as seen in the following figure:

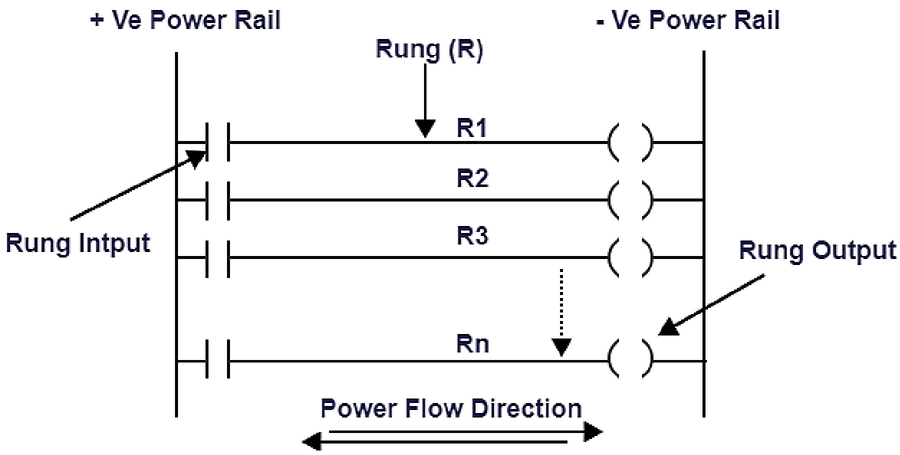


Figure 31- Rung and Rail in PLC (Source: dipslab.com)

Within each rung, there can be a number of different instructions, such as timers, counters, comparisons and logic operations. The basic logic expressions can be arranged to form AND, OR, and NOT logic operations by implementing normally open/closed contacts and series/parallel connections (Steven, 2018). These instructions, combined with the inputs, outputs, and internal variables, end up conforming a Ladder Logic Diagram, as the one in the following diagram:

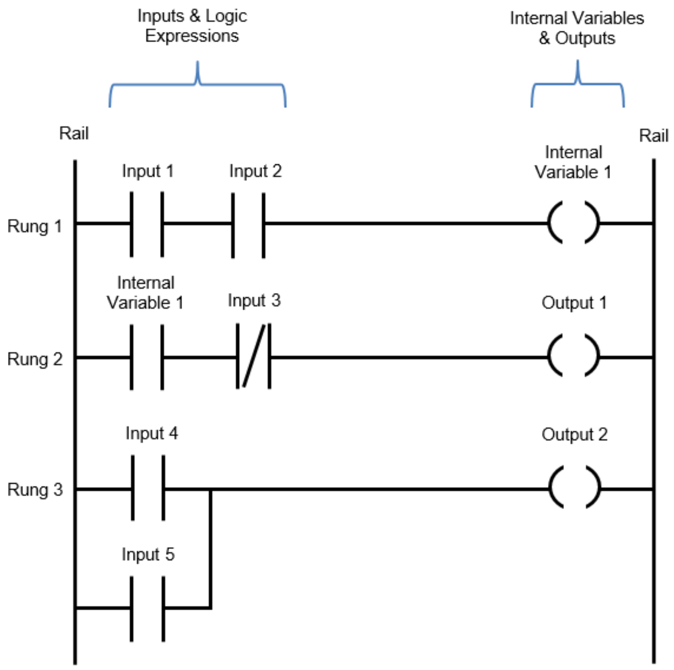


Figure 32- Ladder logic diagram (Source: ladderlogicworld.com)

Every PLC manufacturer has different ladder logic programming rules when it comes to building the logical expressions contained within a rung. However, according to Electricalvolt.com (2022) there are some basic rules that all PLC manufacturers use for ladder logic programming.

- A PLC scans each rung in the ladder diagram from the left hand side to the right hand side and from the top to the bottom.
- The PLC runs in a repeated cyclic manner where the inputs are monitored, the rung logic evaluated and then the state of the outputs are executed. The scan time is expressed in milliseconds (ms).
- The logic state of the outputs is evaluated as the program scans through the rungs. But they are only updated at the very end of each PLC scan, simultaneously.
- There must be at least one input or logic expression at the start of each rung.
- There must be at least one output at the end of each rung.

- An input, output, or logic expression can be used more than once in the ladder diagram. The same tag name and address is used to label it if used more than once.

In order for the PLC to process the Ladder Logic rungs, each symbol needs to be allocated to a variable name weather it is an input, output or internal data (Liam, 2020). There are three essential elements that must be defined when declaring a variable and one optional element:

1. **Variable Name:** The name must be unique and is used to make the ladder logic easily readable by human beings. There are length and specific character restrictions.

2. **Address:** The address can either be an Input, Output, or System memory address. The address nomenclature is dependent on the PLC manufacturer.

3. **Data Type:** The data type used will depend on the symbol being used and the programming operation required. Defining a variable as BOOL means that it has a binary value, an INT means it has a whole number value and a REAL or FLOAT, means it has a number value with decimal points.

4. **Comment:** Adding comments is not compulsory, however, it is highly recommendable to use them continuously to describe the variables, and code rungs to make the code clear for future changes or readable for other programmers.

2.5.2 Point- to-point connections and communication protocols

When it comes to receiving signals from sensors at the PLC input cards or sending output signals to the actuators of the system, there are two main systems used (Struck, 2023). Point-to-point connections and communication protocols.

Point-to-point connections, also known as direct connections, refer to the type of connection between two devices that are connected without any intermediate devices or networks. The signal is transmitted in one end of a wire and the information is received at the other end.

Communication protocols in industry are sets of rules and standards that define how devices and systems communicate with each other over a network or bus (Canet, 2020). They specify how data is transmitted, received, and interpreted, while providing a common language for different devices to exchange information.

In industrial settings, communication protocols are used to facilitate the exchange of data between devices and systems, such as sensors, actuators, PLCs, Human Machine Interfaces

(HMIs), and Supervisory Control and Data Acquisition (SCADA) systems. According to Nagda (2022), some common communication protocols used in industrial settings include:

- Modbus: Popular protocol used for communication between devices over a serial network, often used in PLCs, HMIs, and SCADA systems.
- Ethernet/IP: A protocol that allows devices to communicate over an Ethernet network, often used in advanced control systems and machine vision applications.
- PROFIBUS: A protocol used for communication between devices in industrial automation and process control systems.

Communication protocols play a critical role in industrial automation (Murrelektronik Ltd, 2019), as they ensure that devices and system can communicate effectively and work together seamlessly. By standardizing the way devices communicate, communication protocols help to reduce errors and increase reliability, while enabling more advanced automation and control applications.

As an overview, point-to-point connections and communication protocols are two different methods of connecting devices and systems in industrial automation. Each method offers its own set of advantages and limitations, which should be carefully considered when selecting the most appropriate solution for a specific application.

One of the main advantages of point-to-point connections is simplicity. Direct connections between two devices are often simpler to set up and maintain than more complex configurations that use communication protocols, while being less expensive as it consists in connecting two cables.

Point-to-point connections are also often more secure than networks, as there are fewer points of entry for unauthorized access. Additionally, point-to-point connections often have lower latency, making them ideal for real-time applications.

In the other hand, communication protocols provide a standardized way for devices and systems to communicate with each other, enabling devices from different manufacturers to work together, allowing greater flexibility in system design. Communication protocols also support large-scale industrial automation systems with many devices and complex networks, providing flexible and scalable ways to add new devices, which tends to be complex in big point-to-pint structures where the amount of wires grows exponentially.

Moreover, communication protocols are designed to be fault-tolerant, meaning that they can recover from communication errors or failures. Additionally, communication protocols are often optimized for efficiency, allowing for faster and more reliable data transmission.

3 Process design

In this section, all the aspects related to the process design are developed and stated so that they are clear for any trained personnel to be able to replicate it and materialize if necessary. By the end of this section, the reader will have thorough understanding of the system's operation and the elements composing it, the tagging system, and the justification of the parts selection.

In section 3.1, the Process and Instrumentation Diagram (P&ID) is developed and explained deeply. Subsequently, the tagging system used is explained and the criteria is provided in section 3.2, while in section 3.3 the elements selected are showcased.

3.1 Process and Instrumentation Diagram (P&ID)

As mentioned in the early stages of this document, a P&ID is a graphical representation of the system's components and their interconnections. It provides comprehensive overview of the system's equipment, piping, and instrumentation, and their specification.

The purpose of this P&ID is to facilitate a clear understanding of the process system being designed within this thesis and its operation. It enables visual representation of the various components, the structure of the system, and approximate locations. At the same time, representing the process idea in a diagram has allowed for the identification of potential issues, and modifications that resulted in an improved process system.

The figure in the following page is meant to be a valuable communication tool between the process engineers, operators, programmers, and maintenance personnel that may be involved in the materialization of the project, enabling effective collaboration as the elements are defined and tagged.

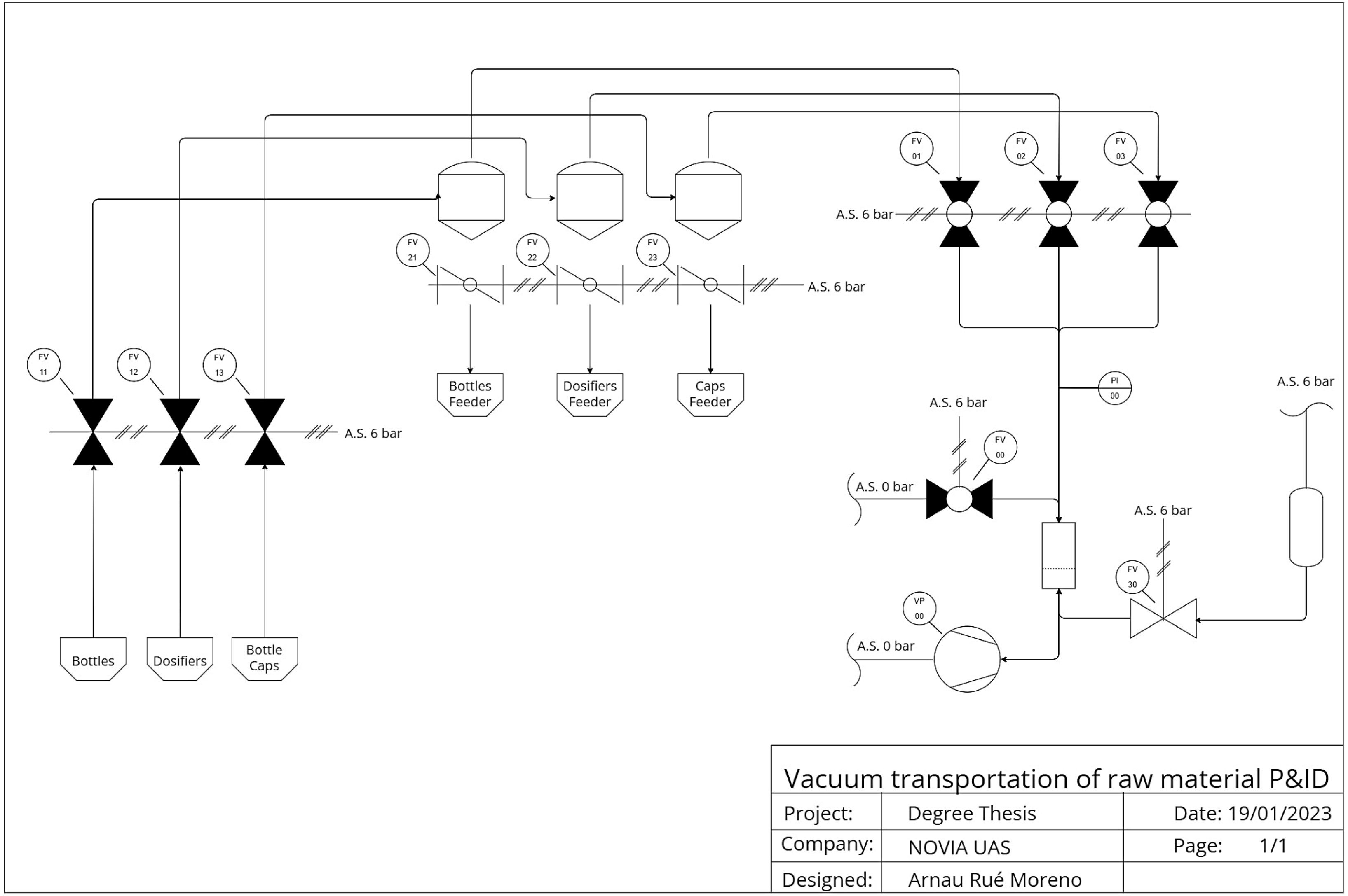


Figure 33- P&ID scheme for the Vacuum transport system (Author's own)

The process structure is defined by the author in the previous figure where the valves represented link to:

- **Ball Valves:**
  Type of valve used to control the flow of fluids or gases through pipelines. They work by using a ball-shaped disk with a hole in the center that rotates inside the valve body so that when the hole is aligned with the direction of flow, the material can pass through the valve.

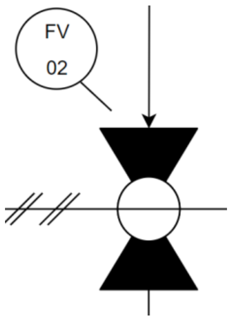


Figure 34- Ball Valve in P&ID (Author's own)

Ball valves are common in process industry because of their reliability, durability, and ease of operation. They have been chosen for that part of the process because they are a cheap and reliable way to fully open or close the air flow. And they will not be in direct contact with the material, which would not be a suitable situation for these valves due to their constructive principles.

- **Pinch Valves:**
  Type of valve used to control flow of material through pipelines. They consist of a flexible tube or sleeve that is pinched or compressed by a mechanism, actuator, or by compressed air in this case. When the sleeve is pinched, the flow of material is stopped, when it is released, the flow resumes.

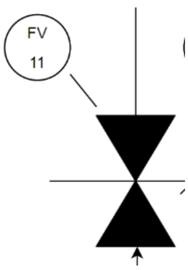


Figure 35- Pinch Valve in P&ID (Source: Author's own)

Pinch valves are commonly used in process applications as they are known for their reliability, simplicity, and low maintenance requirements. They have been chosen for the application as they can easily stop the aspiration of material and allows the separate areas and choose where vacuum is needed for aspiration in every moment. This valve is often used in applications where contamination or purity of the product is a concern, and that makes pinch valves more suitable for that area of the process than ball valves, as there will be direct contact in that area.

- **Butterfly Valves:**
  Type of valve used to control the flow of fluids or gases through a pipeline. They work by using a plate with a pivoting axis that rotates 90 degrees to control the flow. When the plate is turned parallel to the direction of flow, the material can pass through the valve, and when it is rotated perpendicular, the material is blocked and will not pass through.

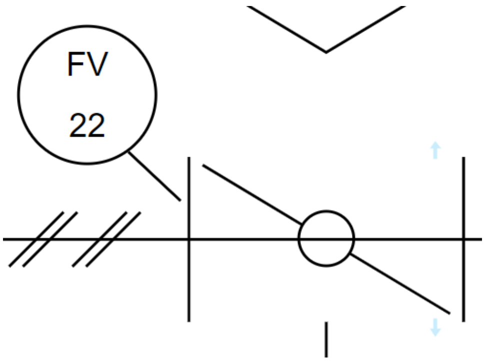


Figure 36- Butterfly Valve in P&ID (Author's own)

This particular type of valve has been chosen for the application as it is very suitable for a gravity drop in the discharge point at the desired moment.

- **Pneumatic rapid exhaust valve:**
  Type of valve is used to quickly release compressed air from a system. The specifics of this valve are furtherly explained in the following stages of this project.

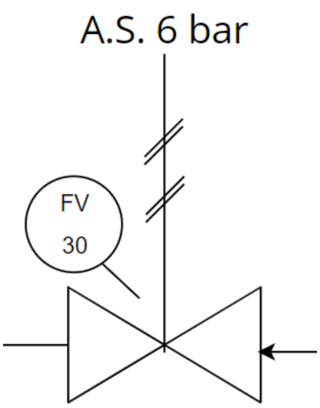


Figure 37- Pneumatic rapid exhaust valve (Author's own)

Once all valves' functionalities have been identified and discussed, it is possible to discuss the process as it was designed and provide step-by-step explanations so that the process is clearly defined.

In the first stage of the process, in the lower right part of the P&ID in Figure 33, the vacuum pump generating system is found:

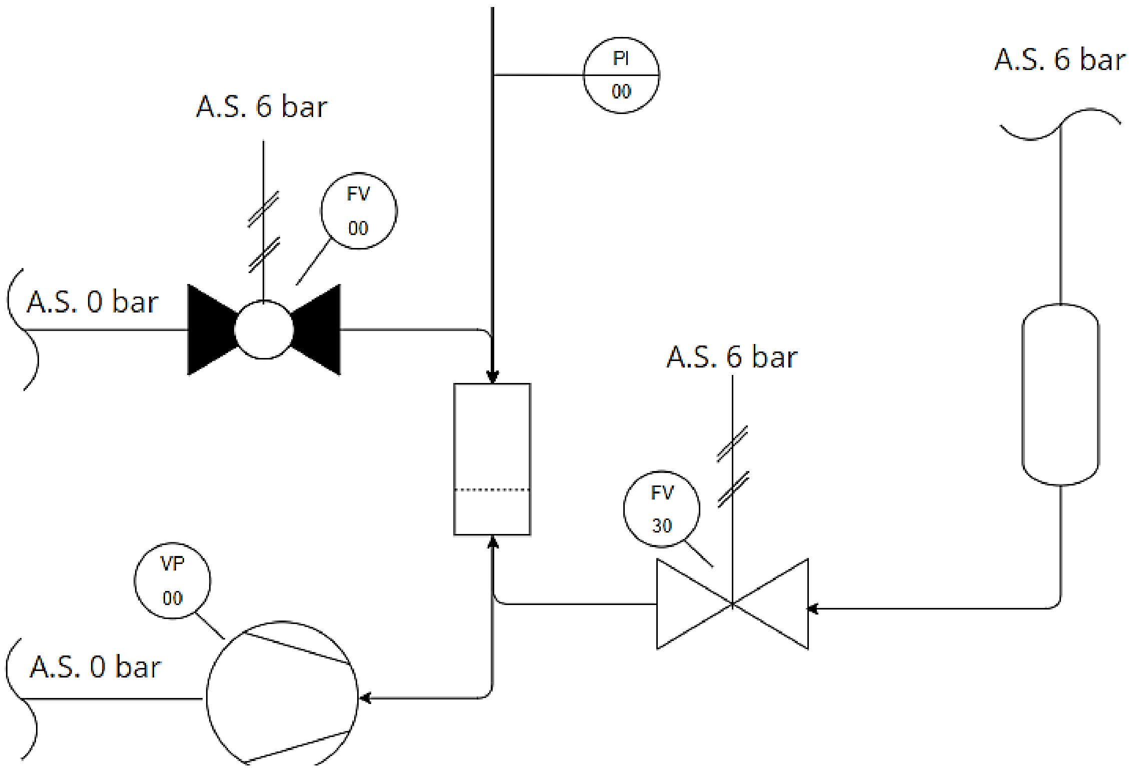


Figure 38- Vacuum management system (Author's own)

The first important element to identify is the vacuum pump tagged as VP-00, which mission will be to remove air from the closed system generating a pressure drop inside the system comparing to the atmospheric pressure around it.

As the idea is that the production area works continuously, and starting and stopping the pump every time a material translation needs to be done would result into important levels of energy consumption, the pump will work uninterruptedly. When no operation is needed, the FV-00 ball valve will act as a relieve valve and will be open so that the pump can recirculate air working in its lowest consumption operation mode. At the moment that vacuum generation is required, the relieve valve ball valve will close and then vacuum will be generated so that it can be used in the further stages of the process.

The squared shape in between the relieve valve and the pump represents a particle filter according to ISA-S5.1 and will prevent external dust from outside the system to enter the pump and cause any harm. Apart from protecting the pump, this filter generates a need of maintenance, cleaning, and supervision. To automate this process, a filter cleaning system has been designed and can be observed in the right part of the previous figure.

An air reservoir is filled with an enough pressurized air quantity so that, when the pump is switched off for any reason as maintenance or productions stops, all the mount of air will be liberated at a high speed thanks to the pneumatic quick exhaust valve FV-30 and the air will impact to the inside of the filter, propelling the dust particles to the outside through the relieve valve.

Once the vacuum generation part of the system is discussed, the following stage can be explained and seen as follows:

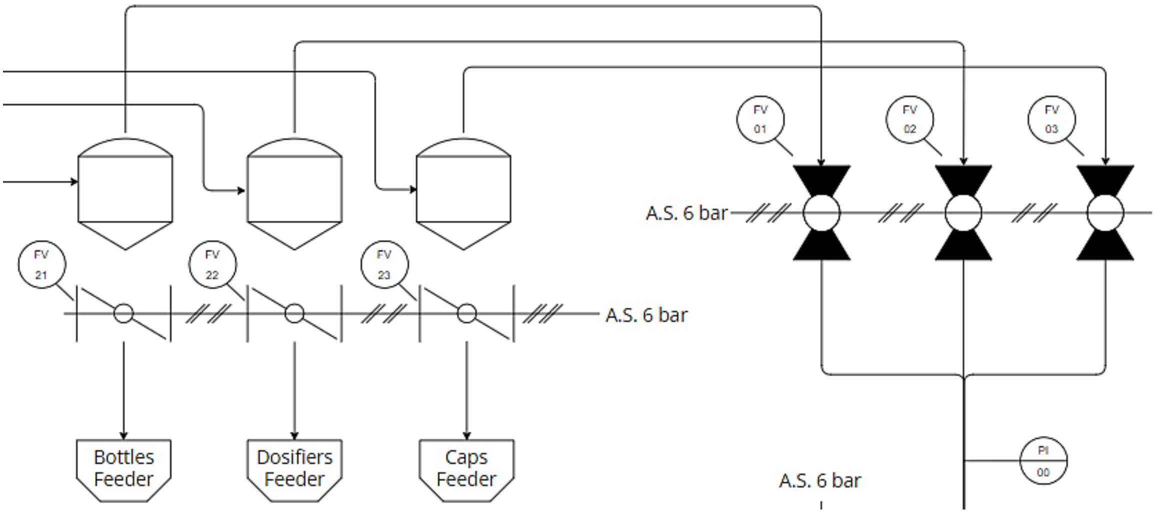


Figure 39- Material choice area (Author's own)

In this stage, the system will allow to select which element will be transported to its respective tank. Once the signal of material need is given to the PLC, the relieve valve will close, the pump will change to working operation mode as configured and the vacuum will be generated before the three ball valves seen in the right of the figure.

Once the indicated vacuum level is reached and given by the vacuum meter PI-00, the respective ball valve will open allowing the suction of material to the tanks. While this happens, the respective butterfly valve will be closed and sealed so that vacuum can be generated and the transported material does not fall when it arrives to the tank. To make it simple and safe, only one material can be transported at the time.

The collection tanks which will be located in another room at a certain distance, are separated by the pinch valves as seen in the following figure:

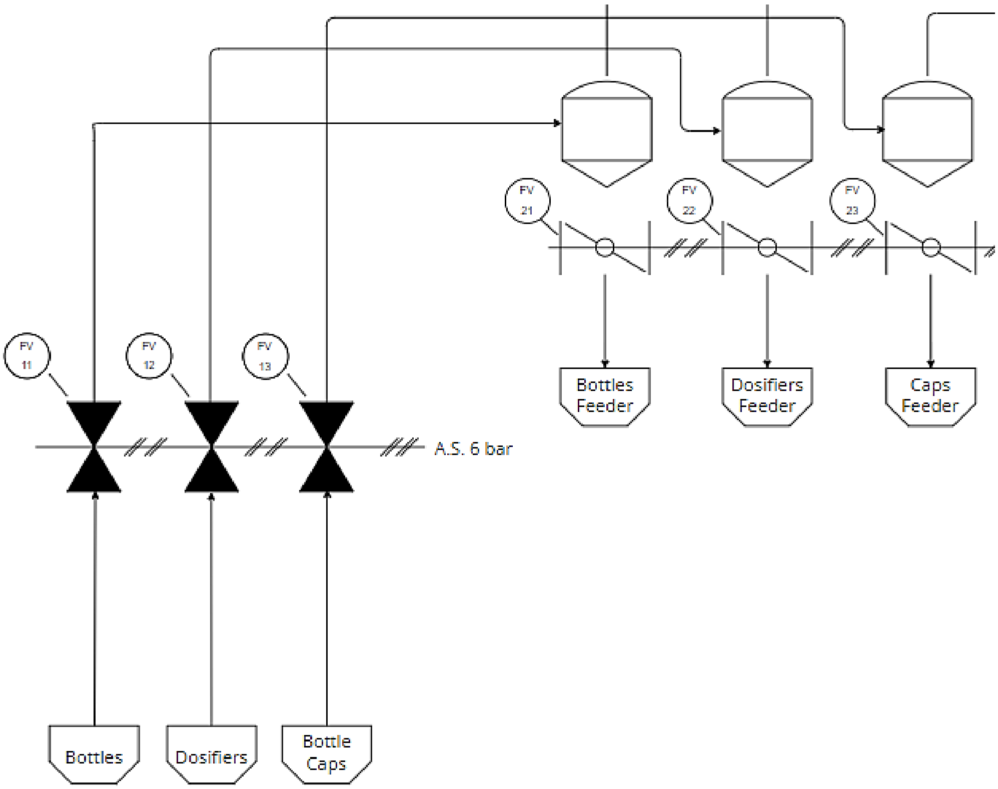


Figure 40- Collection point to tanks transport (Author's own)

The pinch valves will be the last to open, and that will happen when proper vacuum levels are reached in the previous stages. Once they open, the material will be transported by means of vacuum to the tanks, which will contain it until deployment is requested from the feeder. Before that happens, vacuum should be shut off so that the butterfly valves can open, and the material can drop by gravity to the feeder of the following machine.

The specifics about the procedures and the order of the sequences will be furtherly developed in the automation stage of this document.

3.2 Tagging system

Tagging elements in industry applications is significantly important for the process success. Proper tagging enables efficient inventory management and helps maintenance management tracking while it provides identification standards to be able to communicate with ease without previously knowing the elements (Safeopedia, 2018).

The following table stablishes the standards defined in this project, which mainly concern valves as no other elements appear multiple times:

Table 3- Tagging standards for valves (Author's own)

Type of Valve:	Id	Valve Number:	Id
Ball Valve	0	General	0
Pinch Valve	1	Bottles	1
Butterfly Valve	2	Dosifiers	2
Pneumatic Valve	3	Caps	3

In this case, as there are no standards from a factory to follow, the system was designed so that every element would be described according to the ISA-S5.1 letter system, and the numeration would correspond to the type of valve in the first number, and the valve location in the second number.

Examples:

- FV-12 -> Pinch valve in the dosifiers line.
- FV-30 -> Pneumatic valve in the general line.
- FV-01 -> Ball valve in bottles line.
- VP-00 -> Vacuum pump.

This identification system can be modified and expanded according to the needs and changes in the system but works as a reference and it is important that all the documentation is updated as these tags will appear in all the technical documentation as the process design, electrical and pneumatic circuits, and the PLC programming.

3.3 Elements selection

As mentioned in the early stages of this document, the purpose of this thesis is to provide a general enough prototype to be easily adapted in different production processes and to be a prototype that could be presented to a potential client. To illustrate how the process can be implemented, a set of example elements have been selected. Please note that these elements are not intended to be prescriptive, but rather to demonstrate the adaptability of the approach to a variety of scenarios.

The focus of this section is on selecting the right elements for the job rather than prescribing fixed values that may not be appropriate in every situation. The examples provided here are intended to serve as a starting point for those looking to implement the process, however, the specific values of power, diameter, distance… need to be studied and selected accordingly with the needs of each different scenario.

One of the key elements in the process is the selection of an appropriate vacuum pump.

Vacuum pump:

For the selection of the vacuum pump, the Busch Vacuum solutions brand (www.buschvacuum.com) has been considered appropriate as it has been a very useful source through the learning process on vacuum transportation system and has proved to provide reliable information and a very intuitive interface when it comes to components choices.

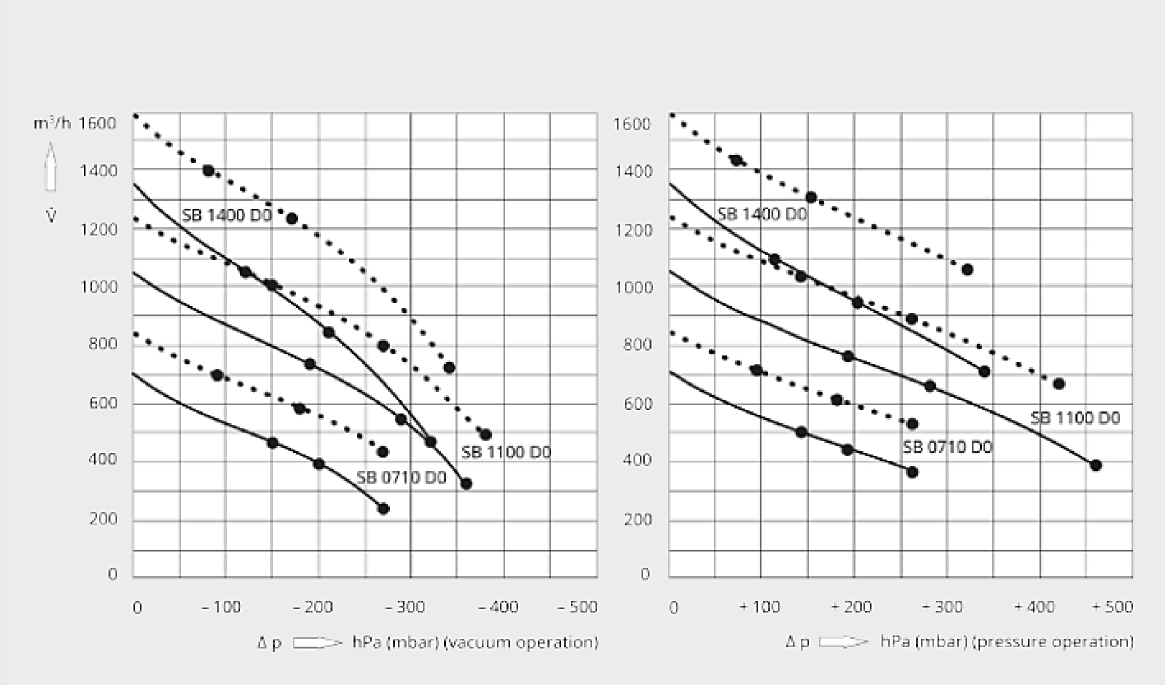
As the specific requirements of the system are unknown, a vacuum pump capable of working in different ranges and with enough capabilities has been chosen. The SAMOS series. According to BUSCH (2023), the SAMOS side channel blowers are the ideal vacuum pumps if the working range is wide as they are ones that can achieve the maximum differential pressure, by achieving up to -400 mbar of vacuum while providing volume flows from 40 to 260 m^3/h.

Figure 41- SAMOS pump (Source: www.buschvacuum.com)

This pump is classified as a side channel blower. Side channel blowers work by using a high-speed impeller that rotates within casing. The impeller has blades that trap the air between the blades and the casing as it rotates (Sjerp & Jongeneel, 2023). The air is then compressed and forced out of the impeller, where it is directed into a side channel, which redirects the airflow back to the impeller. This process creates a continuous cycle of compression and expansion that allows to generate big differential pressures and high-volume flows as desired in this application.

An important factor to consider when dimensioning the system and in the automation process, is to take into account the information provided by the manufacturer in the datasheet available in Appendix 2.1.

Table 4- Pumping speed/Volume flow correlation (Source: www.buschvacuum.com)



The previous table is significantly relevant in the pump choice once the aerodynamical study is carried on and the volume flow and vacuum values are selected for the specific system requirements, as these values are the once defining the pump choice.

Another important table, which is not available for this thesis as it is reserved information for customers according to BUSCH (2023), is the correlation between the motor velocity and power and the vacuum generation.

The curves presented in those tables are essential for programming the operating sequence as it is possible to find an appropriate resting point in which the pump is still working but in a reduced regime and consuming the minimum energy possible without switching off, and to define the velocity in which the pump is fully working at the set point. By providing these values, the variable frequency drive can be configured so that the process is optimized.

Storage tanks & butterfly valve:

In order to store the material when it is ready to discharge to the machine feeder until the order is sent, storing tanks need to be located above the cleanroom so that the material can fall by gravity. In this case, an existing device has been found that provides a solution for the needs of the project. AR-Vacuum (ar-vacuum.com) is a company that provides solutions for vacuum applications, from grippers, to suction caps, and vacuum generators.

A very interesting product for the application has been found, which is the one seen in the following figure, a storage tank that includes a butterfly valve, resulting into a very convenient product for this specific application:

Figure 42- Storage tank & butterfly valve (Source: ar-vacuum.com)

The material inlet is the pipe located in the middle of the tank, and the air outlet is the pipe in the superior part. The outlet is very properly designed as there are multiple filters located that avoid the possibility of saturation of the air outlet once the material arrives to the tank.

Figure 43- Outlet filters (Source: ar-vacuum.com)

There are different sizes available, meaning that the model choice can be adapted according to the dimensions of the material, and the accumulation capacity of the machine feeder.

According to the datasheet provided in Appendix 2.2, the construction material of all the elements is in AISI 316 L, stainless steel, as it is meant to be suitable wit food and pharmaceutical products. Making this product totally valid for the application.

Pinch valves:

The pinch valves are essential in this project as they allow to control the flow of material once the vacuum is generated in the line. The VARVMANG series of AR has been considered suitable for the application as it is also compliant with the requirements to meet as the interior of the valve is meant to be in touch with pharma material.

Figure 44- AR-Vacuum Pinch valve (Source: ar-vacuum.com)

There are also different sizes available, so it can be adapted to the specifications of the system once it is dimensioned.

Ball valves:

For the ball valve selection, FESTO (www.festo.com) VZBC ball valves series has been considered appropriate for the application.

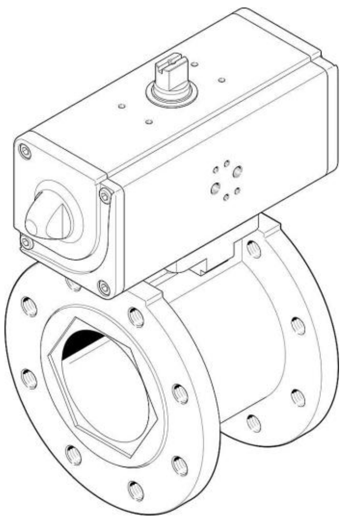


Figure 45- FESTO Ball valve (Source: FESTO Quick Search)

The pinion and rack system is used as principal mechanism of this valve. The valve stem is attached to a pinion gear, which engages with a rack gear. The pinion gear is driven by a pneumatic actuator, which rotates the pinion gear and moves the valve in a linear direction.

As the pinion gear rotates, the rack gear moves along its axis, which in turn moves the valve stem opening and closing the valve.

According to the datasheet available in Appendix 2.4, it is suitable for air flow applications, and the construction material is stainless steel. Apart from that, additional positioners can be added in case feedback is required for safety reasons or to fulfill the desire for major automation of the system.

Filter blowing system:

As mentioned in the previous section, the filter blowing system in charge of cleaning the pump filter once the pump stops, is composed by an air reservoir, and a rapid exhaust pneumatic valve. The selected rapid exhaust valve is the SEU-1/4 FESTO product:

Figure 46- Rapid exhaust valve (Source: Festo Quick Search)

This element's function is to let air flow through it in direction to the air reservoir with no effects and at the moment that the pneumatic valve commutes and there is no pressure in its input, the air stored in the air reservoir is exhausted as fast as possible. The exhaust of this valve is meant to be facing the pump's filter so that the air removes the possible dust remaining.

According to the datasheet available in Appendix 2.5, this valve has standard flow rates of 2300 l/min, which is a very high speed for the pressurized air in the reservoir to impact the pump's filter. The FESTO CRVZS-2, two-liter air reservoir has been selected as suitable for this application:

Figure 47- FESTO 2-liter air reservoir (Source: Festo Quick Search)

4 Pneumatics system design

In this section, all the aspects related to the pneumatics system are developed and stated so that they are clear for any trained personnel to be able to replicate it and materialize it if necessary. By the end of this section, the reader will have a thorough understanding of the procedures used, the justification of the parts selection made for this specific application and will be able to identify all the elements contained in a pneumatic cabinet. In section 4.1 the pneumatic scheme is explained step-by-step. Subsequently, in section 4.2, the adequate elements are chosen according to the needs of the project, and finally, in 4.3, the pneumatic cabinet design is justified and illustrated with 3D modelling.

4.1 Pneumatic scheme

Fluidsim (www.art-systems/fluidsim/) simulation software is used to create a pneumatic scheme by using the industrial standard symbolism so that anyone with previous knowledge on the area can properly identify the elements of the system and their function.

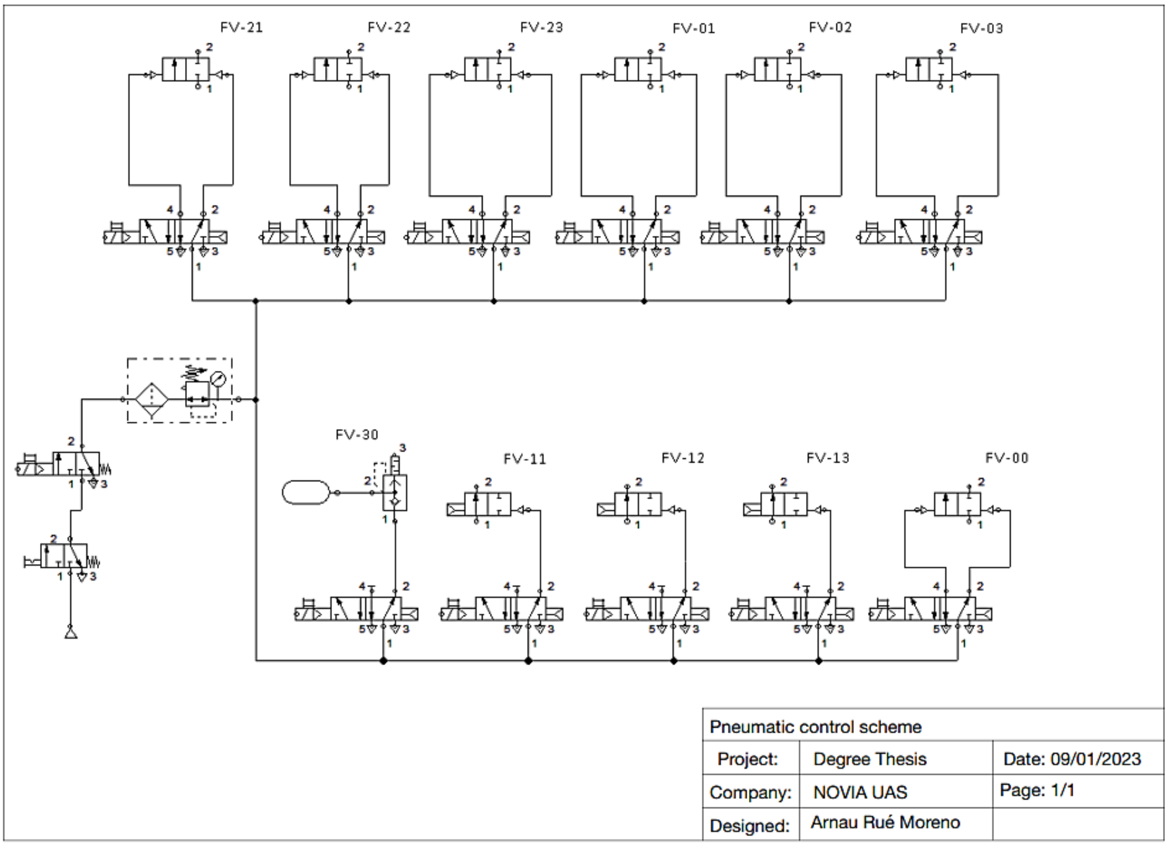


Figure 48- Pneumatic Scheme (Author's own)

To begin with, the service unit is represented and composed by a manual switch-on / turn-off valve that allows to empty the system for maintenance or repair purposes, an electric switch-on / turn-off valve that allows to control the same operation electrically from the PLC control or from the emergency stop buttons, and the filter regulator unit that will guarantee that the air entering the system is in the required conditions.

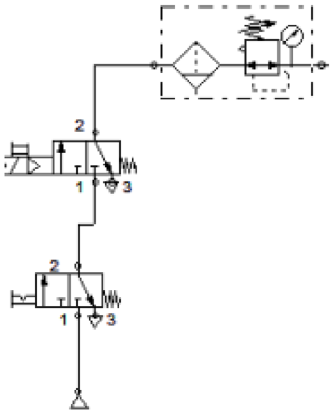


Figure 49- Service unit (Author's own)

The valves represented at the top are the ones piloting the ball valves in the process.

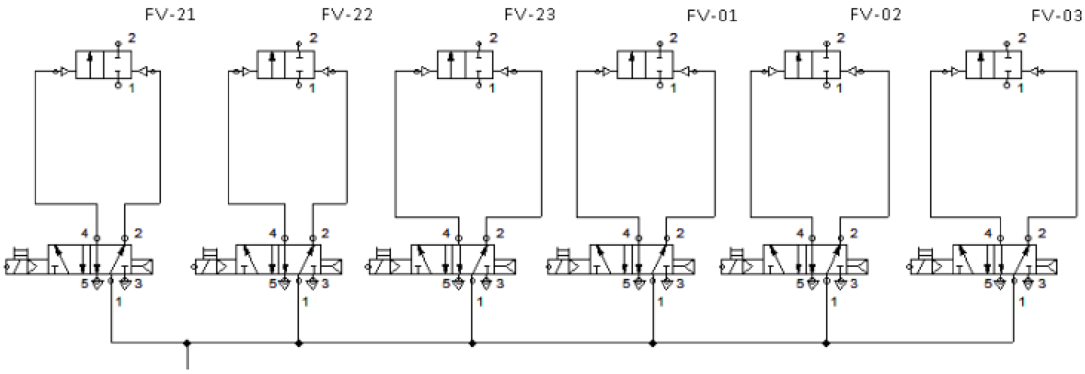


Figure 50- Control valves for ball process valves (Author's own)

The pneumatic valves consist in monostable 5/2 valves that allow to pilot the ball valves when an electric signal is sent to them. They return to their rest position (closed) once the signal is off thanks to the pneumatic spring.

Pneumatic spring instead of physical spring is chosen because physic strings are exposed to constant wear and a malfunction can lead to a valve not returning to the initial position. The pneumatic spring system redirects air from the air supply that will return the valve to the rest position once the coil is not acting anymore. The relief valve named FV-00 is also piloted this way (found in the bottom right).

In the case of the pinch valves, a decision is made in favor of standardization and even though they could be controlled by 3/2 valves, that would mean including a different valve of a similar price and another replacement piece to have in stock. That is why it is decided to operate with 5/2 monostable valves, which allows to have a unique reference and product in the system, and just by adding a stopper in one of the outputs, they can easily be converted to 3/2 operating valves.

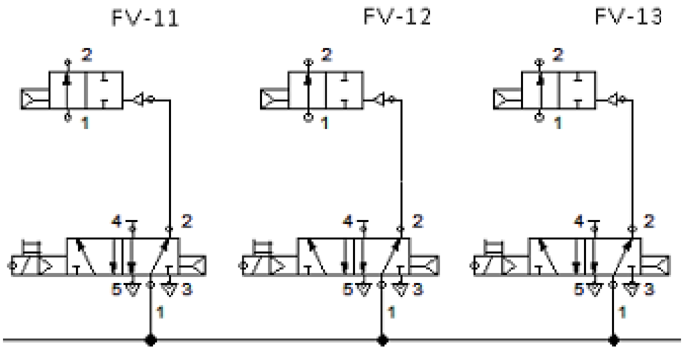


Figure 51- 5/2 valves converted into 3/2 (Author's own)

The pinch valves have been represented by 2/2 valves, which by definition fit to their function, and will be closed when pressurized air compresses the way (rest position) and will return to open position when the valves are piloted and atmospheric air makes the pinch valve return to the open position.

Finally, the last elements refer to the filter cleaning system explained in the process design section and seen in Figure 38. The idea is to be able to make a powerful air blow to the filter to eliminate any particle that could harm the pump after long time exposition. To do so, a 5/2 monostable valve has been chosen for the same reason as in the previous case. And after, the following configuration has been ideated:

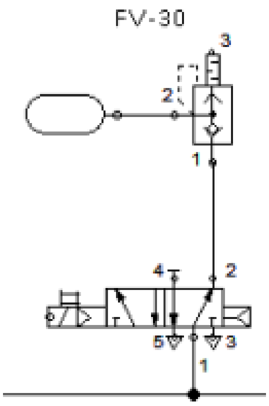


Figure 52- Filter cleaning system (Author's own)

The valve located after the 5/2 valve is a rapid exhaust valve, which, as explained in the previous section, will let air flow through it in direction to the air reservoir with no effects allowing the air accumulation, once the pneumatic valve is commuted and there is no pressure in the rapid exhaust valve, all the air will be exhausted in the direction of the filter.

4.2 Parts selection

As previously stated, the majority of pneumatic components utilized in this project will be Festo products. These products are familiar to the author and their technical information is easily available and is provided in the annexes of this thesis.

Based on the pneumatic scheme presented in Figure 48, the initial requisite component for the pneumatic control system is a service unit comprising of a manual and an electric switch-on/shut-off valves, followed by an appropriate filter-regulator that meets the system requirements.

To define the system filtering requirements, it is crucial to identify the valves that are potentially directly involved with the process and are susceptible to compressed air leaks that affect to the product sterility.

Two options are considered here. The first option is to apply maximum filtering requirements to all filtered air that enters the system, which would ensure the highest air quality throughout the system at risk of air recontamination in the piping system, as discussed in Section 2.3.2. This is particularly important since distances to the applications where the requirements need to be met can be significant. Moreover, using the same air for all elements increases the risk of contamination due to grease loss from one malfunctioning element, which is implicitly higher as the number of elements grows.

The second option is to identify the elements that specifically need to be supplied with the highest air quality requirements and incorporate appropriate filters only in those cases. While this strategy would guarantee optimal air quality in the targeted areas, it would introduce additional complexities than desired to the system and entail a considerable increase in the project's budget.

As neither of the preceding options appears to be sufficiently persuasive, it is deemed convenient to review the Piping and Instrumentation Diagram (P&ID) depicted in Figure 33 and examine the potential alternatives that may be advisable.

By examining the figure, it is possible to identify that the elements that pose a heightened risk of contaminating the cleanroom air are those in close proximity to the material transport elements, namely FV-11, FV-12, FV-13 (the first pinch valves that are located near the material charging points) and FV-21, FV-22, FV-23 (the butterfly valves situated directly above the machine feeders and in direct contact with the product).

However, it should be noted that these elements do not necessarily need to be located within the cleanroom, as the product can be conveyed through pipes either inside or outside of the respective cleanrooms, with the opening and closing of these valves being irrelevant to their location.

Obtaining this final distribution:

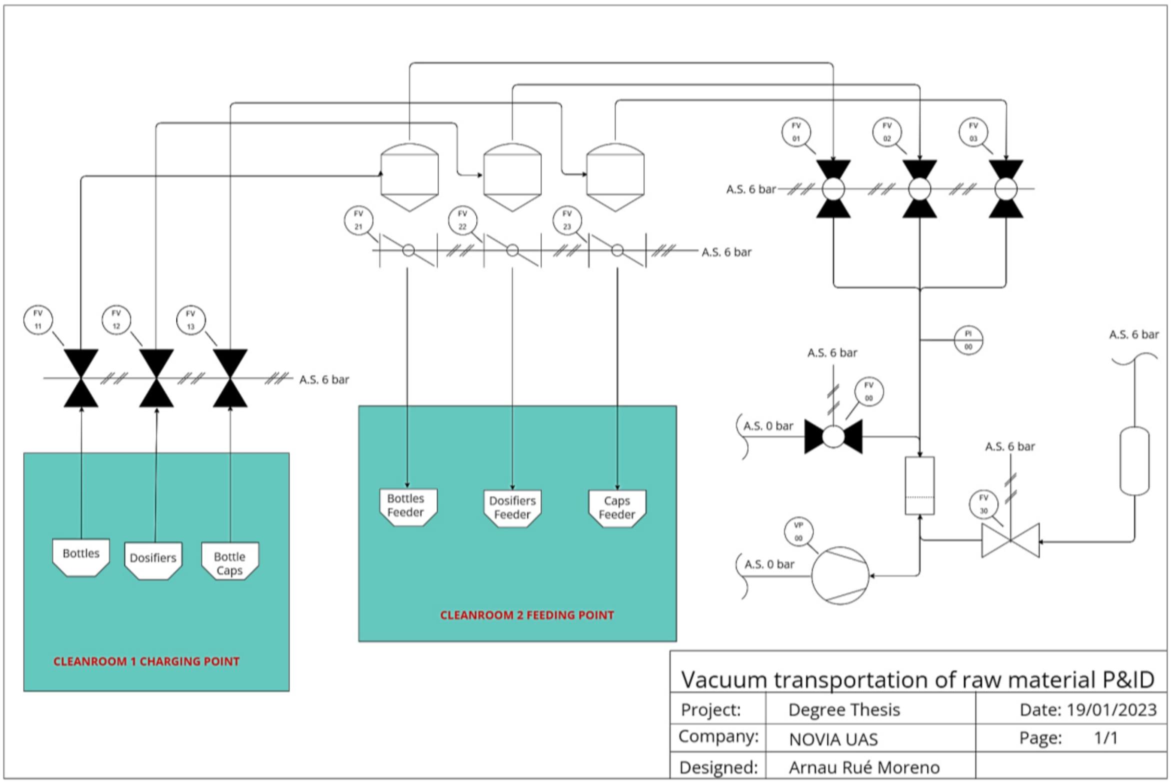


Figure 53- P&ID scheme, valves out of the cleanroom (Author's own)

The possibility to do this, allows to ignore the cleanroom air requirements for the design of the pneumatic system, implying into a lower money expense and a lower pollution risk on the cleanroom air. This decision also allows the centralization of all pneumatic valves into a single valve terminal. Although centralizing the pneumatic valves would require longer pneumatic pipes to connect the piloting valves to the process valves, resulting in lower response velocities and increased air consumption, it has been determined that centralizing the pneumatic control components in a single cabinet is preferable in terms of system maintenance and control if such an option is available.

Once the air filtering requirements are clear, it is possible to carry on and choose the parts desired for the system. The Festo Quick Search tool (www.festo.com) is utilized to select the pneumatic elements for the system, as it offers intuitive means of searching for the company’s range of products and is equipped with several software programs that help to choose the best fit for each application.

Within Festo’s product range, there are mainly two service unit series that are potentially suitable for the application: the MSB4 and the MSB6 series. The primary difference between these two series lies in their size and air flow limitations, which are detailed in Appendix 3.1.

In order to determine the characteristics that the service unit needs to provide, it is necessary to dimension the valves terminal, as it will dictate the requirements of the system.

Referring to the pneumatic diagram shown in Figure 48, eleven monostable electro valves are needed in the control system. Typically, a maximum of ten electro valves is recommended for valve terminals due to potential air flow limitations. However, since only a maximum of three valves will be in operation simultaneously and velocity is not a critical requirement of the system, the use of eleven electro valves will not pose an issue in this case.

Festo produces two main series of electro valve terminals, namely the VTUS and the VTUG series:

Figure 54- VTUS-25 electro valve terminal (Source: Festo Quick Search)

This terminal is composed by VUVS valves that are universal valves known for their durability, low cost and their lack of performance limitations. They offer high flow rates and are suitable for a broad range of applications. The electrical handling can only be managed by point-to-point connections, no communication protocols are available for this series.

On the other hand, the VTUG:

Figure 55- VTUG electro valve terminal (Source: Festo Quick Search)

This terminal is composed by VUVG valves that are compact universal valves that offer a combination of high flow and a compact design. This terminal allows communication with PLC by different protocols.

The durability and robustness of the VTUS terminal are not deemed to be critical factors since the valves are not intended to be exposed to harsh conditions. On the other hand, the ability to communicate the terminal to the PLC through desired protocols, as well as the size of the VTUG terminal are important factors to consider as they facilitate the cabinet design and mounting tasks. Therefore, a VTUG terminal will be utilized for the design.

By utilizing the dimensioning software programs provided by Festo Quicksearch, the following valve terminal has been assembled: VTUG-18-MSD-B1T-25V20-G38L-DTR-G14S-11PL+HM1

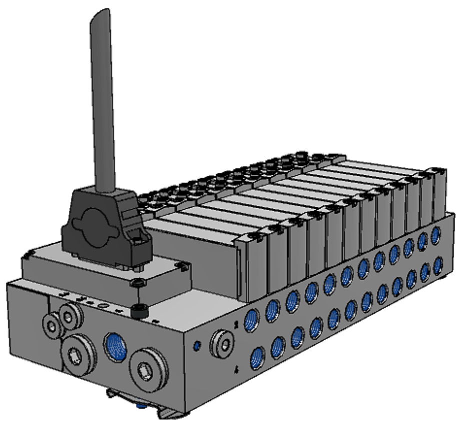


Figure 56- Valve terminal VTUG-18-MSD-B1T-25V20-G38L-DTR-G14S-11PL+HM1 (Source: Festo Quick Search)

The valve terminal has the following characteristics:

Table 5- VTUG terminal general data (Source: Festo Quick Search)

General data	
Size	18 Size 18
Valve control	M Multi-pin
Valve type	B Sub-base valve
Nominal operating voltage	1 24 V DC
Manual override	T Manual override push-in/detenting
Pressure supply connection	G38 G3/8
Compressed air supply port location	L Left
Exhaust port	DT Thread
Exhaust port location	R Right
Valve connection	G14 G1/4
Type of push-in connector	S Screwed
Type of multi-pin connection	SD Sub-D plug
Number of pins	25 pins
Pin allocation	V20 For 12 double-solenoid or 24 single-solenoid valves

The largest size of the valve terminal model was chosen due to its high standard nominal flow rate of 1200 l/m, which is the highest among the available options as documented in

Appendix 3.2. Although velocity is not a critical factor in this project, the need to cover long distances requires high nominal flow rate to ensure faster responses in the system.

Although an interface adaptable for field bus communications would be the preferred option for control, as in this project the material will not be available and the automation aspect will be designed, a multi-pin connection is a more convenient option for simulation purposes.

As it is possible to see in Figure 56 there are 12 positions in the valve terminal. That is because the terminal consists of 11 monostable valves and one empty position left in case it is needed in the future or for maintenance needs.

Once the valve terminal is dimensioned and its nominal flow rate requirements have been determined, the service unit can be properly sized and selected. Recalling the information provided in Appendix 3.2 and the assumption that a maximum of three electro valves will be commuted at the same time in the worst case, it is clear that the MS6 series from Festo meets the requirements as it can provide 3600 l/m and the worst-case scenario would imply the same exact consumption. It is worth noting that in applications that require velocity or precision, this would be unadvisable as it is convenient to have some margin between the needs of the terminal and the flow rate provided by the service unit. However, as discussed previously, in this particular case, this will not be a problem.

About the filtering requirements, from the VUVG valves datasheet available in Appendix 3.2, the air quality requirements go according to what is specified in the following figure:

Operating medium	Compressed air as per ISO 8573-1:2010 [7:4:4]

Figure 57- Air quality requirements for VUVG valves (Source: www.festo.com)

According to the ISO standards discussed in the previous stages of this thesis, this level of filtering can be reached using a 40 µm filter.

The configuration of the service unit will be composed by a manual and an automatic switch-on/shut-off valves and a filter regulator module. With the help of Festo Quick Search the following unit has been assembled: MSB6-1/2:C4:D4:J126-WP

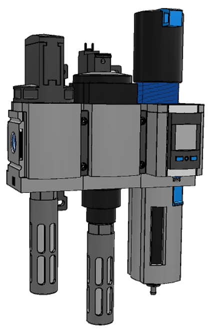


Figure 58- Service unit MSB6-1/2:C4:D4:J126-WP (Source: Festo Quick Search)

This configuration has the following characteristics:

Table 6- MS6 Service unit data (Source: Festo Quick Search)

General data	
Size	6
Pneumatic connection	1/2 Internal thread G1/2
Mounting type	WP Mounting bracket standard design

Service unit 1	
Service unit equipment position	EM1 On-off valve, manual
Variant	S Standard (metal)
Silencer	S Silencer

Service unit 2	
Service unit equipment position	EE On-off valve, electrical
Variant	S Standard (metal)
Supply voltage	V24 24 V DC, MS4: 14 bar, MS6: 18 bar, MS4/6 Polymer: 7 bar, MS12: 16 bar
Silencer	S Silencer

Service unit 3	
Service unit equipment position	LFR Filter regulator
Variant	S Standard (metal)
Pressure regulation range	D7 0,5 ... 12 bar
Degree of filtration	E 40 µm
Bowl	R Plastic bowl with plastic bowl guard
Condensate drain	V Fully automatic
Pressure gauge alternatives	AD12 Pressure sensor with LCD display, M8 plug, 4-pin, IO-Link®, PNP, NPN, 0...10 V, 1...5 V, 4...20 mA
Lockability	AS Lockable using accessories

The nomenclature of the previous table refers to the following figure:

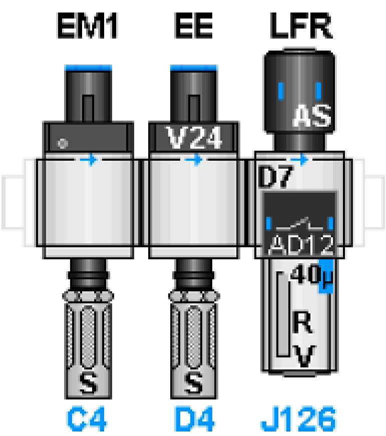


Figure 59- MS6 Service unit nomenclature (Source: Festo Quick Search)

4.3 Pneumatic cabinet design

In this section a pneumatic cabinet is designed so that it can contain all pneumatic control elements and can be located in an accessible position in order to provide easy access to the maintenance crew, but close enough to the application point to shorten the distances to cover.

In industrial applications, it is not uncommon to have electric and pneumatic components housed within the same cabinet, and this remains a valid option. However, in this case, it has been deemed appropriate to separate these elements into two distinct cabinets. This decision is due, in part, to a will of keeping electrical cabinets separate from pneumatical ones for safety reasons when such a possibility is available. Furthermore, this separation allows for greater accessibility of the programmable logic controller (PLC) by positioning it in a more readily accessible location, such as a process control room, where local access is easily achieved in cases where remote access may not be possible.

For the cabinet selection, IDE brand cabinets (ide.es) were selected to be suitable for the project. Having the author worked with different brands, such as Schneider (www.se.com) and others that may provide a higher quality, they are accompanied by considerably higher prices. The desire of decreasing the costs of the project in elements that are not deemed to be critical and do not require the highest quality, has defined the final choice for the first mentioned brand.

There are no material requirements as the cabinet is meant to be located outside the cleanroom, the standard material is chosen and the proper measures are selected according to FESTO elements' datasheets and IDE cabinets' datasheets. The proper size is considered to be, in millimeters: 400x600x200. Being the IDE reference: GN406020. Datasheet available in Appendix 5.1.

The 3D model of the model is available on IDE's official webpage and will be used to assemble all the pieces in a 3D AutoCad (web.autocad.com) design.

The initial aspect of the cabinet is seen in the following figures:

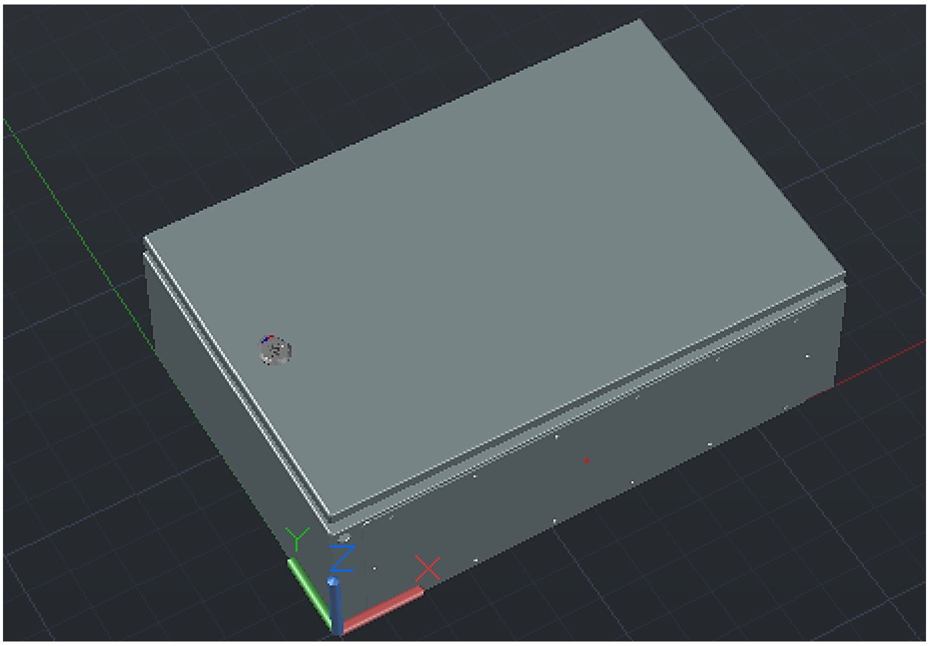


Figure 60- IDE GN406020 isometric view in AutoCad (Author's own)

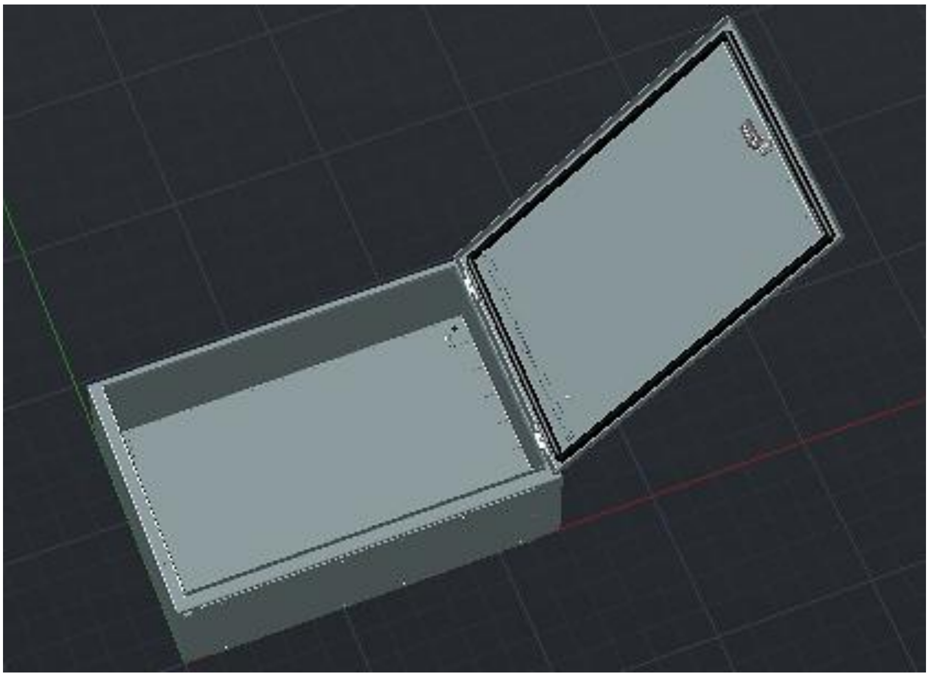


Figure 61- IDE GN406020 isometric view with open door (Author's own)

Once the cabinet file is available, it is needed to obtain all the material's files that will be part of the pneumatic cabinet so that it can be assembled. Other than the valves terminal and the service unit, other materials are needed to properly assemble a pneumatic cabinet.

Air leaks are one of the most significant threats to pneumatic systems (Rowse, 2019), which occur mainly in connections between the different parts of a system or in the piping when it is degraded by harsh conditions. Users normally consider that connections and fittings for pneumatic components are considerably expensive comparing to their functionality and tend to save by using different brands fittings while using high quality brand components. This normally results in air leaks and money losses through energy consumption.

In high quality brands, these components are specifically designed to work perfectly with their own components, therefore, mixing components with other brands is not advisable.

In the case of this project, Festo fittings and hoses will be used as follows:

<u>Push-in bulkhead connectors</u>:

Used to provide a secure, leak-proof connection between two tubes that pass through a panel. They offer a convenient way to quickly and easily connect or disconnect pneumatic lines.

Figure 62- Push-in bulkhead connector (Source: Festo Quick Search)

In the design, a 12 mm Ø bulkhead connector will be used to let the air supply enter from the service unit to the valve terminal, and twenty-four 8 mm Ø bulkhead connectors will be used for the valves' connections and 2 more for the common exhaust to the exterior of the cabinet.

<u>Push-in/threaded fittings:</u>

Provided with the same push-in system to easily connect and disconnect the pneumatic lines, this fitting allows connections from the pneumatic lines to the components' threaded bodies and guarantees proper sealing.

Figure 63- Push-in/threaded fitting (Source: Festo Quick Search)

This type of fitting will be used to connect the valves outputs to the lines that will connect to the bulkhead connectors that lead to outside the cabinet, twenty-four of them will be needed with a G1/4 thread to 8 mm Ø pipe connection.

Push-in/threaded L-fittings:

With the same working system as the straight fitting this fitting allows connections in an L shape, avoiding curvatures that could damage the pneumatic hose.

Figure 64- Pus-in/threaded L-fitting (Source: Festo Quicks Search)

Two G1/2 to 12 mm Ø will be used to for the input and output of the service unit, a G3/8 to 12 mm Ø for the valve terminal input, and two G1/4 to 8 mm Ø will be used to conduct the exhaust outputs to the outside of the cabinet.

PUN-H tubing:

In order to make all the proper connections, Festo's plastic tubing PUN-H will be used. It consists of a polyurethane tube that has a great resistance to microbes and hydrolysis, the two main factors of pipes degradation after temperature.

Figure 65- PUN-H Pipe (Source: Festo Quick Search)

Different colors will be used in the cabinet assembly. Black will be associated with pressurized tubes and blue to not pressurized tubes. Of course, this will change when the system is operating, but it is a useful method for maintenance crew to check correct operation, identification when following pipes or to carry out fast changes in the line.

Exhaust fitting:

Exhaust fittings are important to allow a safe discharge of the used air preventing at the same time non-filtered air to enter the system. In the case of this project, the valve terminal has two common exhausts for all the valves.

It is very important to conduct this air to the outside of the cabinet, otherwise the cabinet could pressurize and explode if the air was supplied continuously and there was no outlet. Even if the cabinet was not sealed, not conducting the air to the outside of the cabinet would result into grease and dust accumulation inside it. To avoid this and prevent air from the outside to enter the cabinet, an UC-QS fitting will be used:

Figure 66- UC-QS fitting (Source: Festo Quick Search)

This fitting is connected to the bulkhead connector and lets air flow to the outside while preventing dust to get in. The white color allows noticing the need to change for a new one once it is dirty, which means that the proper air flow is prevented by dust.

Additional elements:

Apart from the pneumatic components, the cabinet includes other components that need to be taken into account. In this case not many electrical cables need to be conducted inside the cabinet, but it is usual to have a channel profile that allows to conduct cables in an organized way as the one seen in the following figure:

Figure 67- C channel profile (Source: www.indiamart.com)

Other than that, a cable gland will also be needed so that the multipin cable that will provide signals to the valve terminals is properly fixed to the cabinet:

Figure 68- Cable gland (Source: fi.rsdelivers.com)

These materials 3D files will be retrieved from www.traceparts.com, a webpage with multiple industrial elements 3D files available. Once all the files are achieved organized and imported to the AutoCad software, the following design is created:

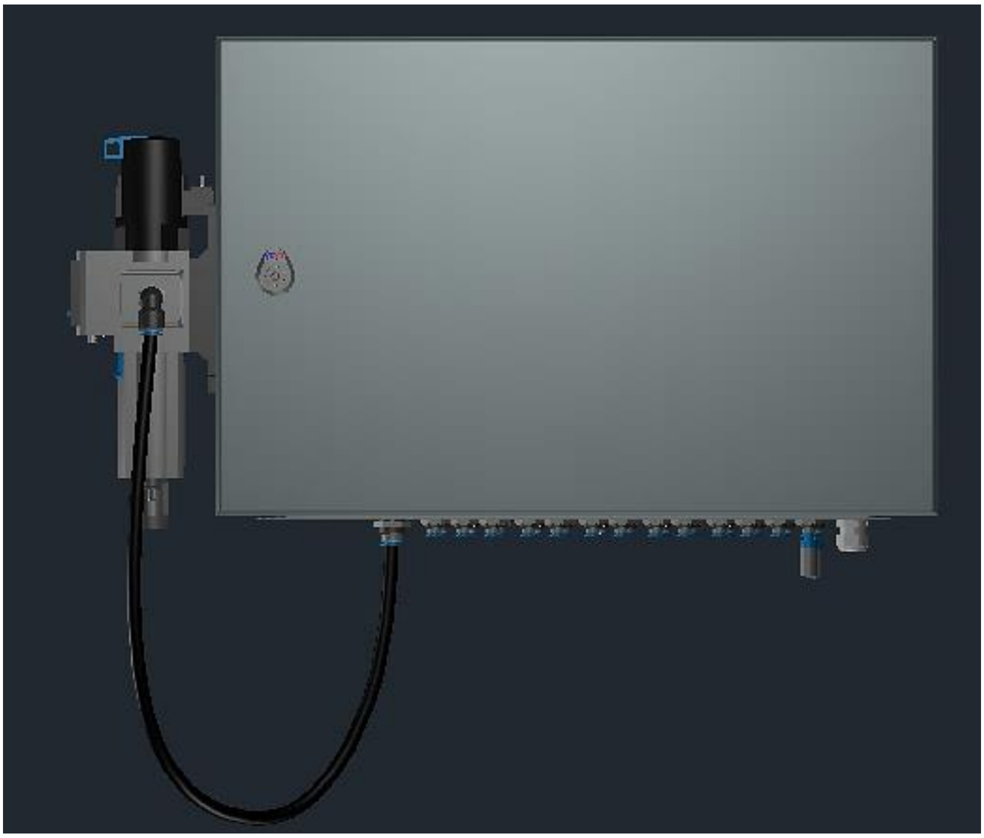


Figure 69- Front view closed cabinet (Author's own)

The previous figure represents the front view of the cabinet, in the way that would normally be seen once installed. It is possible to see the service unit in the left, the pressurized tube entering the cabinet and the bulkhead fittings as well as the exhaust fittings and the cable gland in the lower part.

A lateral view is shown in the following figure.

Figure 70- Lateral view closed cabinet (Author's Own)

The service unit is located at the outside of the cabinet, allowing anyone to cut the air supply in case of emergency. In this case there is no danger of manipulation of the system as the pressure regulator is lockable. Additionally, the switch-on/shit-off valve can be locked according to the LOTO system so that safe maintenance operation is guaranteed in the pneumatic components.

When the door is open, the view is as follows:

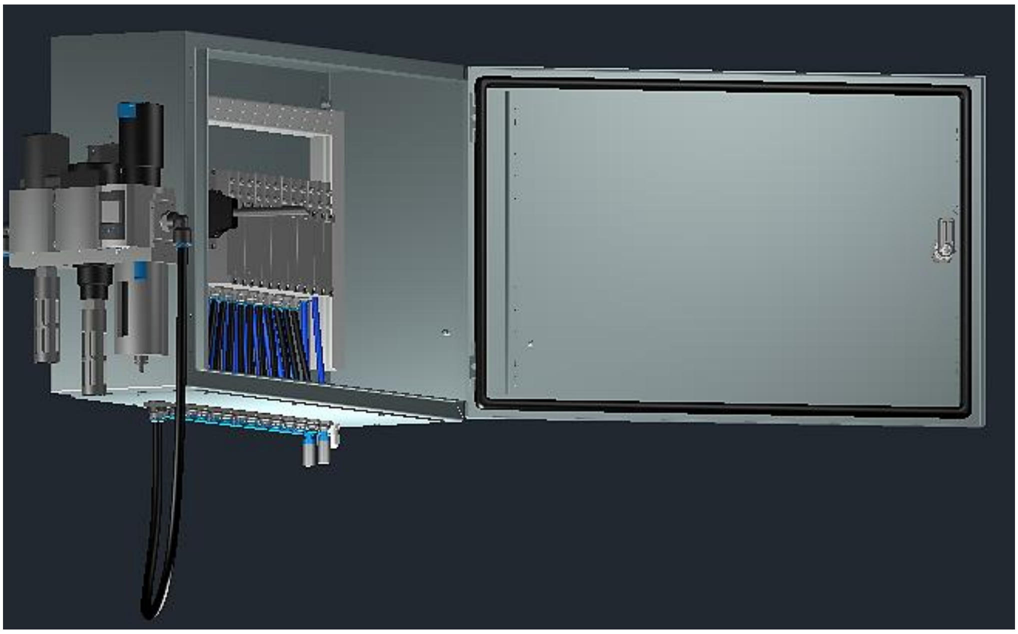


Figure 71- Isometric lateral view open cabinet (Author's own)

This design provides protection from the potential environmental hazards for the proper operation of the valves, while prevents unauthorized manipulation as only the maintenance crew responsible of the cabinet should have a key.

A rendered point of view with all the visible elements is provided in the following figure. Note the piping consideration about the initially pressurized pipes and the exhaust air conduction to the outside of the cabinet.

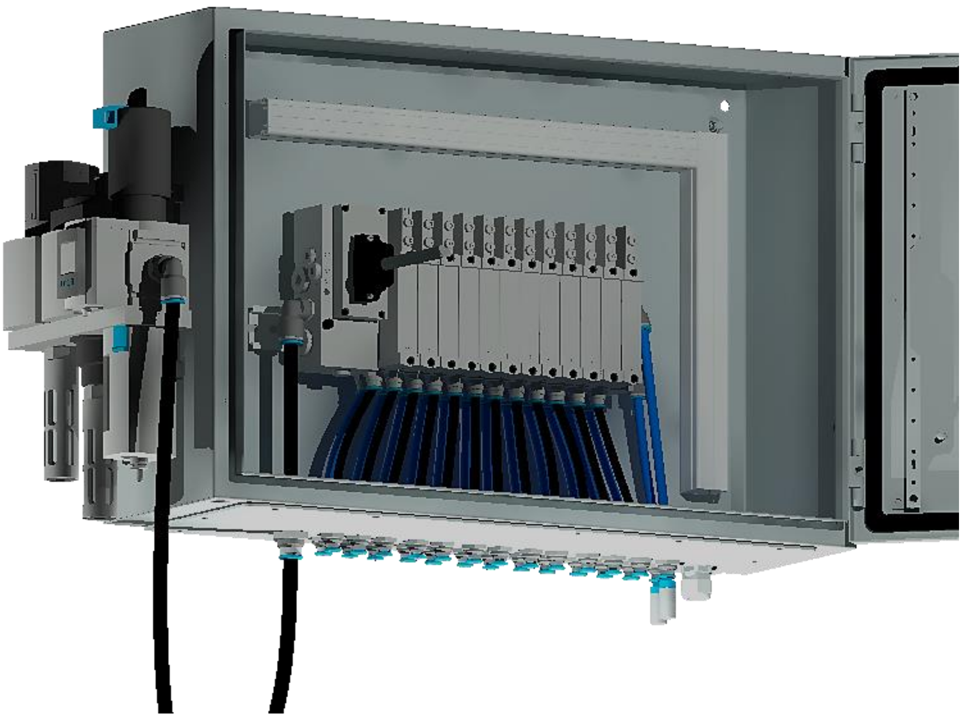


Figure 72- Rendered view open cabinet (Author's own)

With this, the pneumatic 3D design of the cabinet is finalized successfully as a presentable and realistic model has been achieved complying with the industry standards. Further piping tasks should be carried out later to connect to the corresponding valves.

5 Electrical system design

In this section, all the aspects referring to the electrical system design are covered. In section 5.1, the schemes from the general electricity supply to the PLC input and output assignation are provided. Subsequently, in section 5.2, the parts selected for the application are presented and discussed. Finally, the 3D model of the electric cabinet is provided in section 5.3.

5.1 Electrical system schemes

Cade Simu (cade-simu.com/) free simulation software is used to create the electric schemes of the electric system by using the industrial standard symbolism so that anyone with previous knowledge on the area can properly identify the elements of the system and understand their function.

5.1.1 Terminal block system

Before the schemes are designed, a terminal block system has to be stablished so that the design provides clear instructions, and it is possible to identify the elements in a cabinet by following the electrical scheme.

Terminal blocks are an essential component in electric cabinets as they provide a secure and organized way to connect electrical wires and cables (c3controls, 2016). Terminal blocks are typically made of a durable insulating material and have metal connectors that allow wires to be connected.

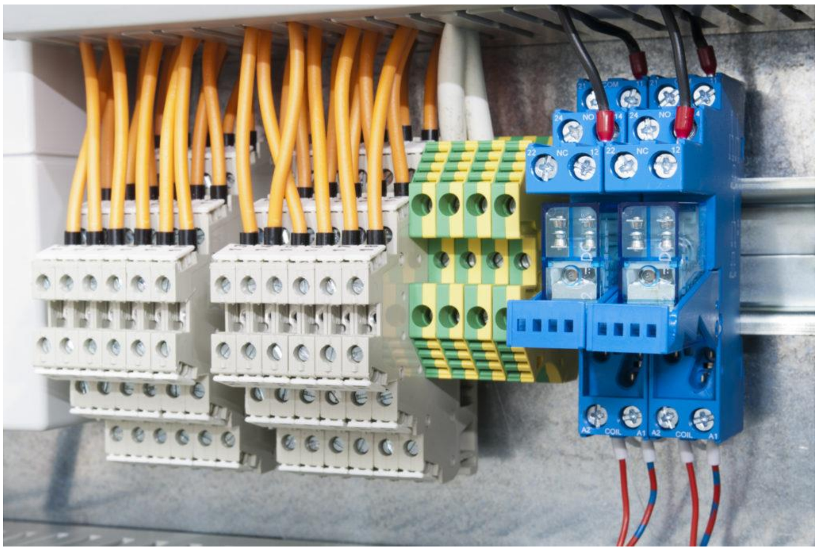


Figure 73- Example of terminal blocks in a cabinet (Source: www.designworldonline.com)

One of the main benefits of using terminal blocks is that they simplify the wiring process and make it easier to troubleshoot and maintain electrical systems (Eitel, 2020), as they allow to neatly organize and label the wires, which helps to prevent errors and makes it easier to identify specific wires when necessary.

To properly identify every terminal, the following system is created:

- All the terminals will be identified with a "T" as first letter.
- After the "T", the first character refers to the group it belongs (groups stated later). The first character is followed by a dot.
- After that, another number defines the number of the terminal in the group, counting from left to right.
- Additionally, for further clarity and comprehension of the schemes, the wires will be identified with the same system by adding a letter A when the wire is connected to the upper port of the terminal, and a letter B if it is the lower port.

The groups are defined as follows:

- T1 -> Terminals for power lines entering the cabinet.
- T2-> Terminals for the motor connections.
- T3->Terminals for the PLC inputs, outputs, power supply…

Then, for example, the T3.3A terminal block corresponds to the third terminal of the ones assigned to the PLC, in its lower connection.

The following list provides the assignation of the terminal blocks:

- T1 -> Terminals for power lines entering the cabinet.
  - T1.1 -> 1st Phase
  - T1.2 -> 2nd Phase
  - T1.3-> 3rd Phase
  - T1.4 -> Neutral.
  - T1.5 -> Ground
  - T1.6 -> Ground

  - T1.7 -> Ground
  - T1.8 -> Ground
- T2 -> Terminals for the motor connections.
  - T2.1 -> U Terminal
  - T2.2 -> V Terminal
  - T2.3 -> W Terminal
  - T2.4 -> Ground Terminal
- T3 -> Terminals for the PLC inputs, outputs, power supply…
  - T3.1 -> 24 V
  - T3.2- > 24 V
  - T3.3 -> 24 V
  - T3.4 -> 0 V
  - T3.5 -> 0 V
  - T3.6 -> 0 V
  - T3.7 -> I0.0
  - T3.8 -> I0.1
  - T3.9 -> I0.2
  - T3.10 -> I0.3
  - T3.11-> I0.4
  - T3.12 -> I0.5
  - T3.13 -> I0.6
  - T3.14 -> I0.7
  - T3.15 -> I1.0
  - T3.16 -> I1.1
  - T3.17 -> I1.2
  - T3.18 -> I1.3
  - T3.19-> I1.4
  - T3.20 -> I1.5
  - T3.21 -> I1.6
  - T3.22 -> I1.7
  - T3.23 -> Q0.0
  - T3.24 -> Q0.1
  - T3.25 -> Q0.2
  - T3.26 -> Q0.3
  - T3.27 -> Q0.4
  - T3.28 -> Q0.5
  - T3.29 -> Q0.6
  - T3.30 -> Q0.7
  - T3.31 -> Q1.0
  - T3.32 -> Q1.1
  - T3.33 -> Q1.2
  - T3.34 -> Q1.3
  - T3.35 -> Q1.4
  - T3.36 -> Q1.5
  - T3.37 -> Q1.6
  - T3.38 -> Q1.7
  - T3.39 -> Empty

5.1.2 General electric supply circuit

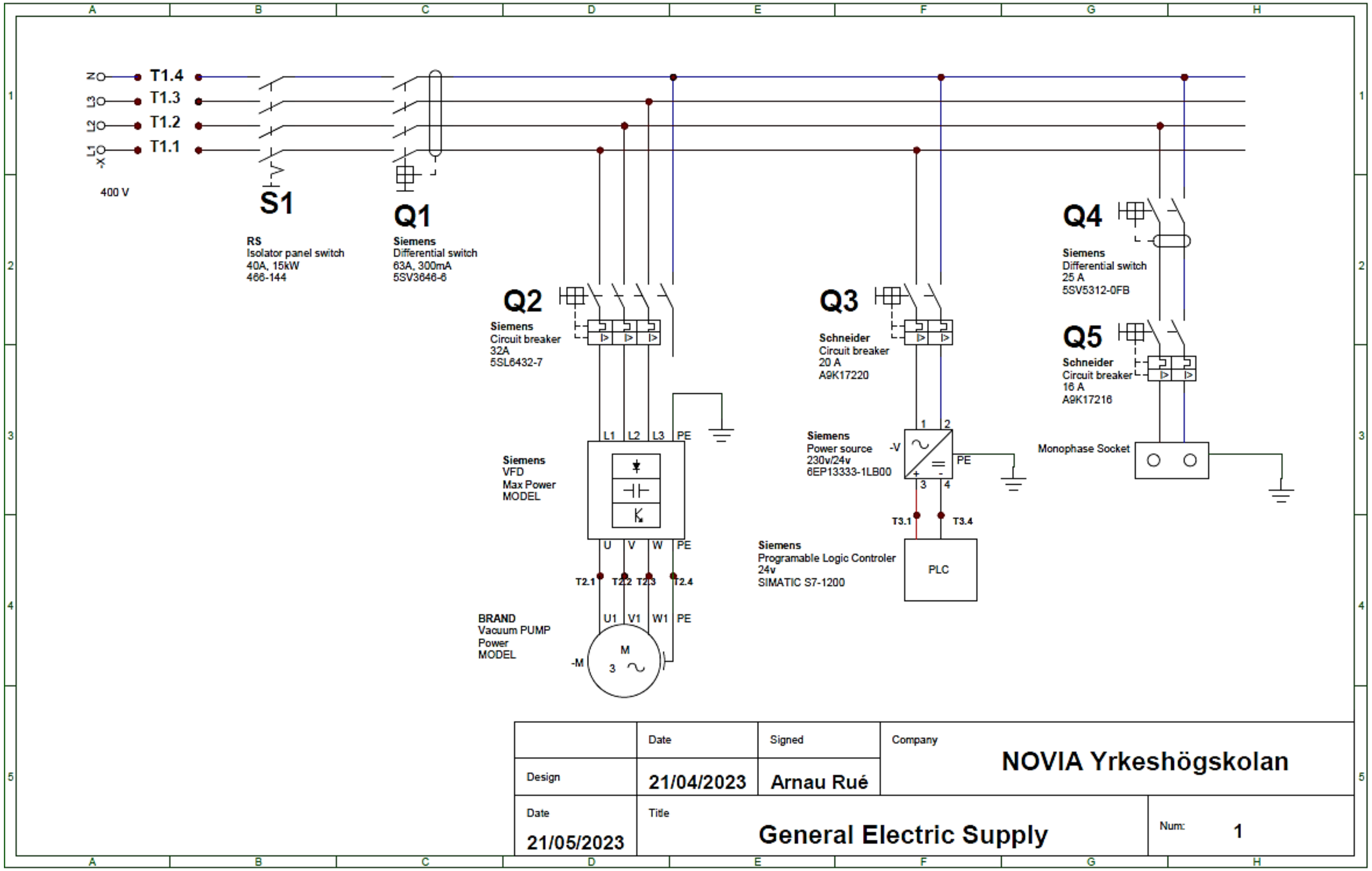


Figure 74- General electric supply circuit (Author's own)

As it is observable at the top of the previous figure, a 3-phase electricity line needs to be available at the location that the electric cabinet will be mounted. This 3-phase line will enter to the cabinet and will be connected to the isolator switch (S1) so that the cabinet can be isolated from the electric power whenever it is needed.

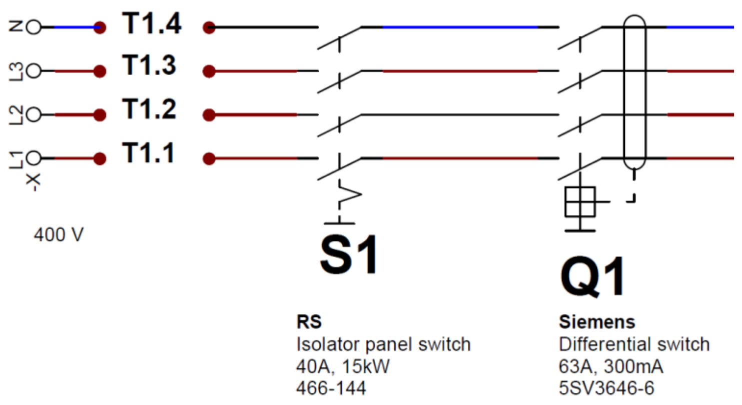


Figure 75- 3-phase line arriving to the cabinet (Author's own)

After the isolator switch, the wires will be connected to the differential switch (Q1) that will cut the current flow in the event that there is more than 300 mA current leak in the system.

After the isolation and protection elements, the system is divided in 3 main branches as observable in Figure 74. The first one, contains the main power element of the system, which is the pump's motor.

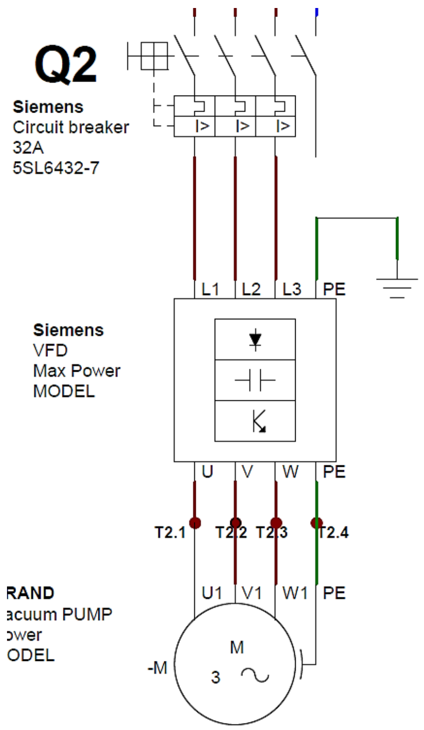


Figure 76- 1st Branch in the General Electric Supply circuit (Author's own)

In this branch, a 3-phase circuit breaker (Q2) is located to protect the system from overheating and short circuits, after that, the VFD is found connected to the motor, so that it can control the speed and power according to the requirements of the process.

The second branch provides electricity supply to the PLC.

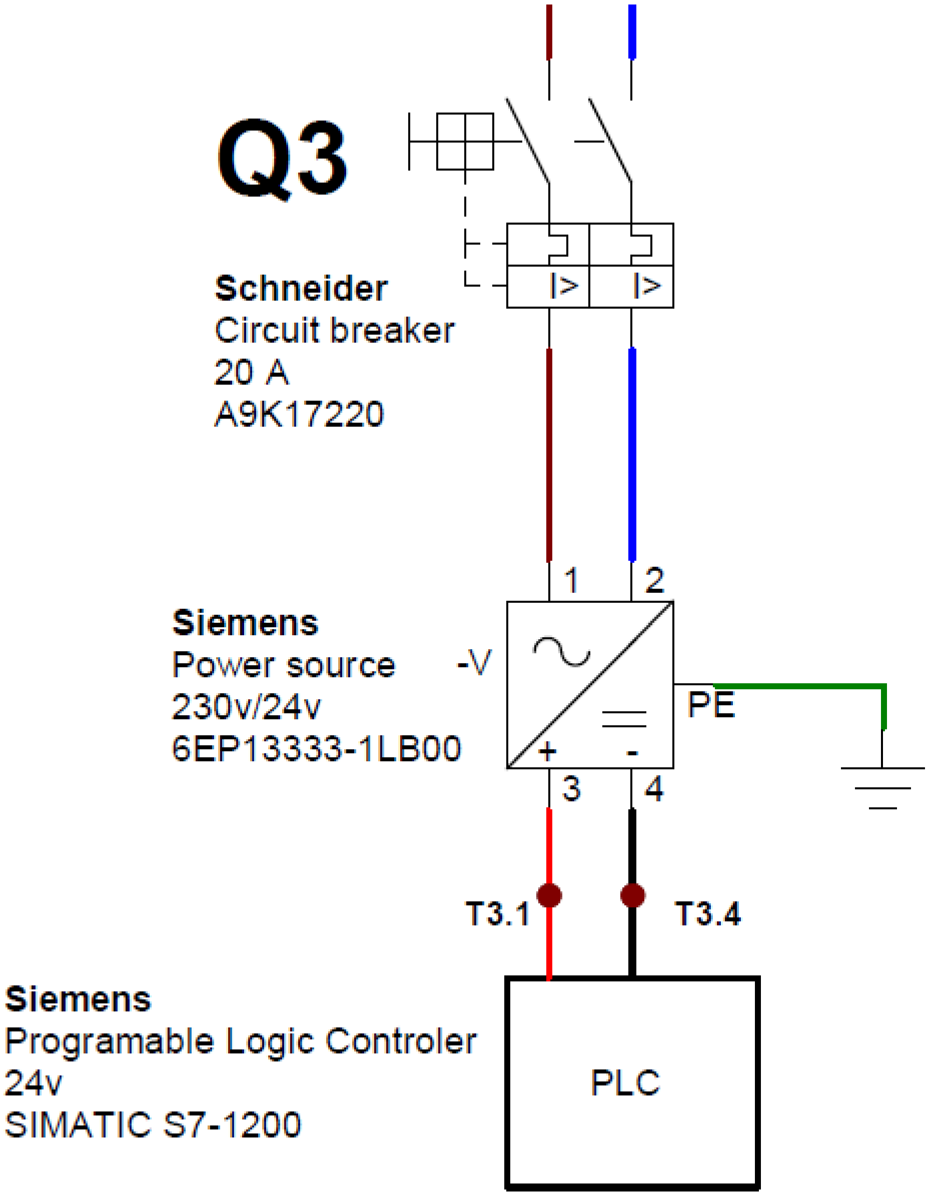


Figure 77- 2nd Branch in the General Electric Supply circuit (Author's own)

A monophasic circuit breaker (Q3) is located before the elements to protect the installation, after that, a 230 V AC to 24 V DC power supply provides 24 V to the PLC so that it can operate correctly.

The third branch provides an access to 230 V AC power supply so that, in the event that any maintenance operation needs to be done in the cabinet or local reprograming of the PLC is required, the maintenance crew can connect the tools or laptops if needed.

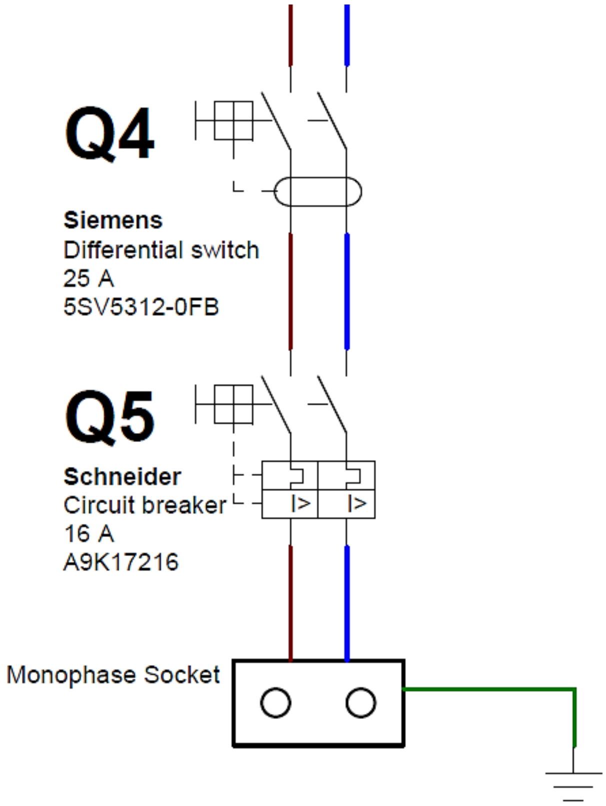


Figure 78- 3rd Branch in the General Electric Supply circuit (Author's own)

A monophasic differential switch (Q4) is installed in this branch, as there is a potential risk of personal damage in this case, the 30 mA tripping value is an standard for personal safety and in case of discharge, it would be perceptible for humans but wouldn't have fatal results (Ambegoda, 2022). The comparison with the effects of a 300 mA discharge is visible in the following figure:

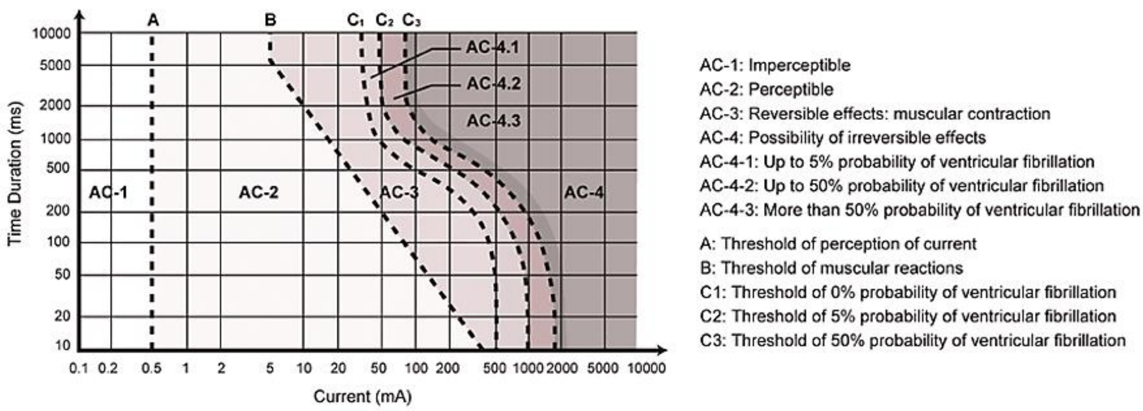


Figure 79- Time/Current correlation and consequences in case of electric shock (Source: kikblox.com)

It is clearly visible that there are significant time differences between fatal consequences when using 30 mA or 300 mA differential switches, that is the justification for installing the ones with 30 mA tripping values in the locations where there is potential human contact while operating.

After the differential switch, a 16 A circuit breaker (Q5) is installed as sockets are not supposed to provide more than that intensity, protecting then the elements connected to the line. Finally, the socket where the tools or laptops will be connected is located in the cabinet.

5.1.3 PLC input/output schemes

After designing the general electric supply circuit, it is necessary to define the inputs and outputs of the PLC and the terminals in which they will be connected. This is a crucial step in the design as these schemes will be used by both the person designing the automation program and the person building the electric cabinet. Any mistake in the design of these schemes can result in delays in the project as they are difficult to detect, and more than one area is involved in it.

In the first input module of the PLC, the main digital input signals are defined:

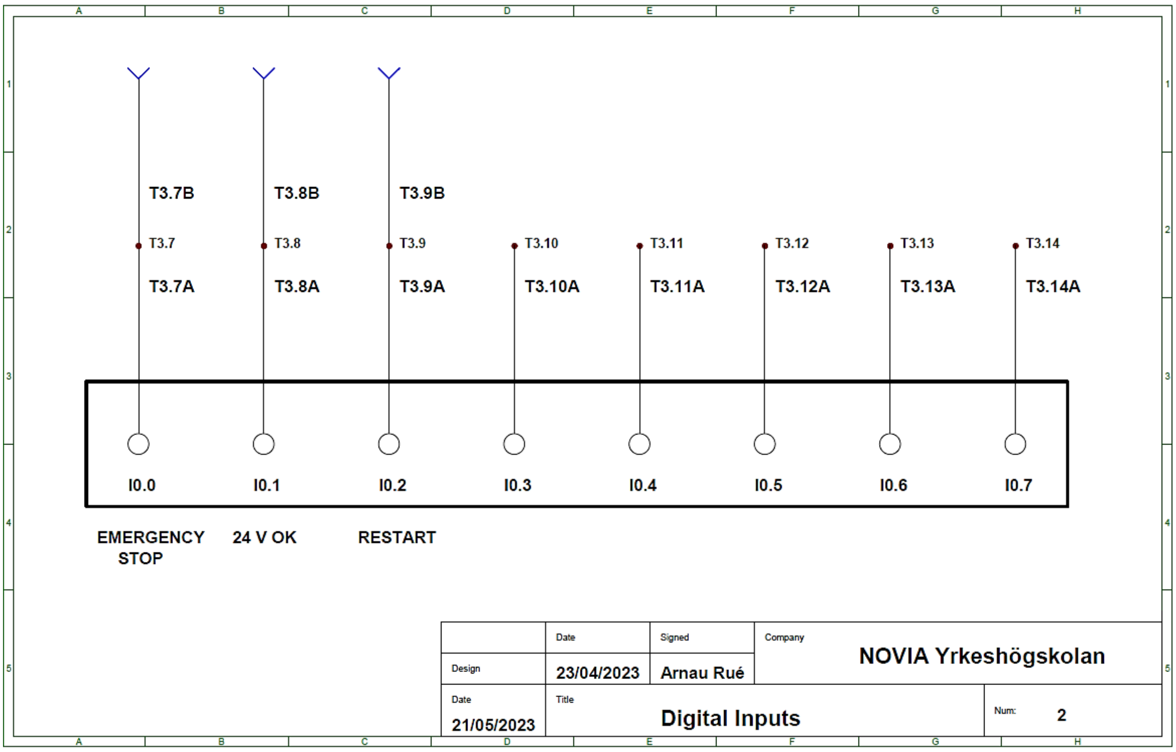


Figure 80- PLC Digital Inputs scheme (Author's own)

In this case, only the emergency stop signal, the components check, and the restart signal are the only digital inputs defined. If the sequence is operated according to the levels of material in the hoppers, sensors input signals could also be provided as digital inputs. Also, if there is a will of monitoring the valves, it would be possible to add a positioner input for each valve so that it is possible to check if the valves are in the position they are supposed to be. These cases are not considered in this application as it is intended to provide a basic setting with the ability to add all the previously mentioned features if it is desired.

Then, the analogic inputs are defined for the second module:

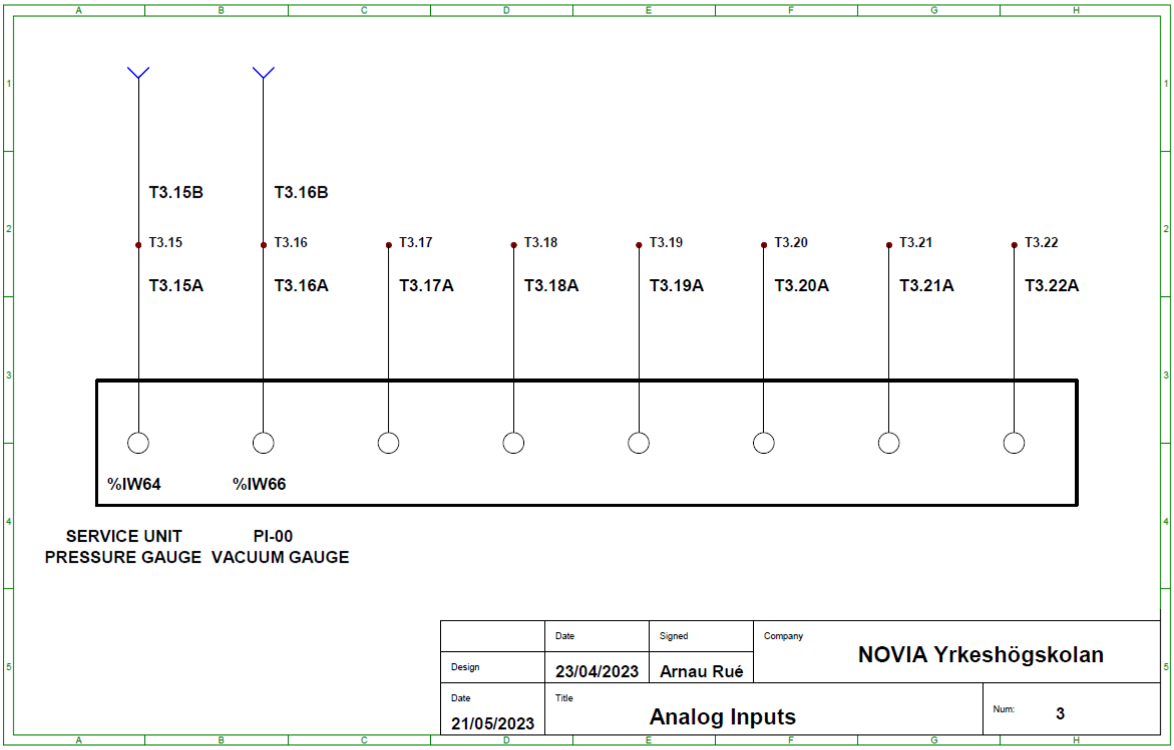


Figure 81- PLC Analog Inputs scheme (Author's own)

Again, only the minimum elements for proper operation are defined in the scheme. These elements are the service unit pressure gauge, which provides the pressure value and allows to monitor problems or faults in the pneumatic system, and the PI-00 vacuum gauge, that allows to stablish a threshold of vacuum to achieve before opening the next valves in the material suction operation. In this case, additional elements as temperature sensors for the motor and other pressure and vacuum gauges could be included in the free inputs.

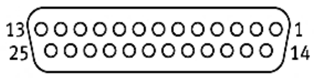
Once all the inputs are declared, the same thing needs to be done with the outputs. As it was stablished in the process design, all the elements to control are mainly pneumatic electro valves, which can be controlled by digital outputs. The only different element would be the VFD in the event that the selected one was controlled by an analogical signal, however, when possible, the control of the variable frequency drive is preferred to be by communication protocols. Therefore, no analogic output modules are needed in this design.

Before declaring all the digital outputs, it is important to define the correlation between the digital outputs and the solenoid valves they are activating. Recalling to Table 5, where the valve terminal is selected and the connection method is defined as multi-pin connector, it is important to define the color correlation from the multi-pin connector to the terminals so that the instructions for the installation are clear.

From the connector's datasheet available in Appendix 3.3, the following table with the colors and terminals association is retrieved.

Table 7- Pin-wire color association (Source: Festo.com)

Circuitry (socket view)



Open end, 15-core		Open end, 25-core	
Pin	Wire colour[1)]	Pin	Wire colour[1)]
1	WH	1	WH
2	BN	2	BN
3	GN	3	GN
4	YE	4	YE
5	GY	5	GY
6	PK	6	PK
7	BU	7	BU
8	RD	8	RD
9	BK	9	BK
10	VT	10	VT
11	GY PK	11	GY PK
12	RD BU	12	RD BU
13	–	13	GN WH
14	–	14	BN GN
15	–	15	YE WH
16	–	16	BN YE
17	–	17	GY WH
18	–	18	BN GY
19	–	19	WH PK
20	–	20	BN PK
21	–	21	BU WH[2)]
22	–	22	BN BU[2)]
23	GN WH	23	RD WH[2)]
24	BN GN	24	BN RD[2)]
25	YE WH	25	BK WH[2)]

Once the pin-wire color correlation is known, it is possible to create the digital output schemes stablishing the wire correlation to the outputs for further understanding.

Apart from the Digital Outputs related to the valves terminal, another solenoid valve needs to be activated, which is the electric valve in the service unit, and four additional signals are added, corresponding to green, yellow, and red lights to visually indicate the state of the process, and a sound alarm signal to alert the personnel in case of emergency.

The assignation of the digital outputs is observable in the two following figures:

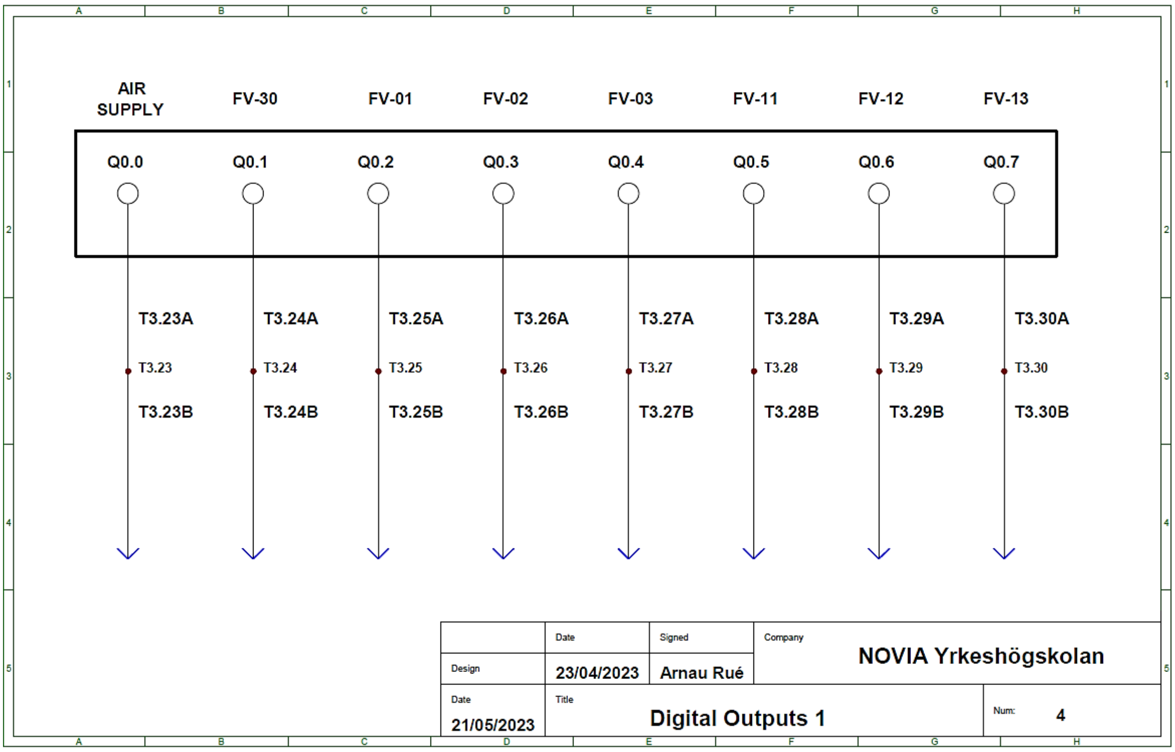


Figure 82- PLC Digital Outputs scheme (Author's own)

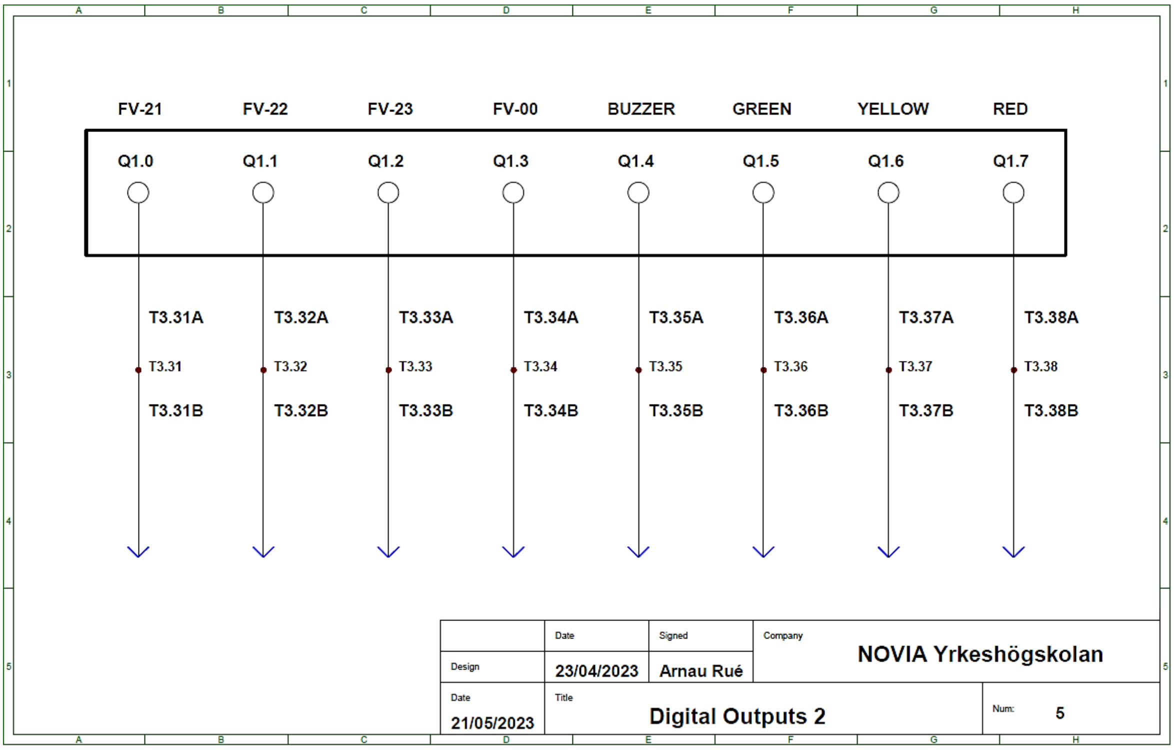


Figure 83- PLC Digital Outputs 2 scheme (Author's own)

Once all the electric schemes are completed, it is possible select the materials and proceed to build a working electric cabinet to materialize the designs.

5.2 Parts selection

Unlike in the parts selection of the pneumatic components, there is no brand preferences in the electrical components' choice. The main criteria when selecting the components in this case is prioritizing the approximate values that can fit general applications of the system and selecting well-known brands to ensure the availability of technical documentation and avoid stock problems.

The only previously fixed parameter is the PLC, which is provided by Novia UAS, and consists of a SIMATIC S7-1200 Siemens (www.siemens.com) PLC.

Programable Logic Controller (PLC):

The Simatic S-1200 is a programable logic controller developed by Siemens, which is used to control and automate industrial processes. This PLC has many features that make it ideal for automation tasks (Siemens, 2023), including high-speed counter and pulse output functions, integrated PID controllers, and the ability to perform mathematical and logical operations.

Figure 84- Simatic S7-1200 PLC (Source: www.siemens.com)

The programming language used in S7-1200 is ladder logic, which is graphical representation of the logic circuits used to control the system. The PLC programming is developed in the latest sections of this document.

According to the manufacturer's information provided in Appendix 4.1, the S7-1200 CPU 1215C, input and output channels are already integrated. DIa and DIb are two digital input channels that are used to connect sensors, switches, or other digital devices to the S7-1200. These inputs are compatible with a wide range of signals, including 24V DC, 120V AC, and 230V AC. Each input channel has its own LED indicator to show the status of the input signal.

In the same way, DQa and DQb are two digital output channels that are used to control external devices such as motors, valves, or relays. These outputs are also compatible with the same range of signals and include the LED indicator to show the status of the output. In the event that more inputs or output channels are needed, they can be added with additional input/output modules. All these integrated inputs and outputs are configurable and programmable through TIA Portal software.

This PLC is way above of the needs of this project, as no PID controllers are needed nor mathematical operations, however, it has been deemed appropriate to work with it as it is a very extended PLC in the automation industry and may be the standard selection in many factories. In fact, as seen in Figures 84 and 85, there are 16 defined digital outputs in the system, however, in the S7-1200, there are only 10 digital output signals available, meaning that an additional output module needs to be used.

Additional DO module:

In order to add 8 digital outputs to the S7-1200 Siemens PLC, the SM 1222 digital output module has been selected. The SM 1222 module provides 8 digital outputs, each rated at 24V DC, it is compatible with the S7-1200 PLC and can easily be integrated into the existing setup.

Figure 85- SM1222 -6ES7222-1BF32-0XB0 (Source: www.automation.siemens.com)

The SM 1122 module is configured via TIA Portal Software and then connected to the S7-1200 PLC via PROFIBUS or PROFINET interface. Once it is connected, it can be used to control external devices as solenoid valves in this case.

Variable Frequency Drive (VFD):

To select a proper VFD according to the system requirements, it is highly recommended to use the SIEMENS product configurator (mall.industry.siemens.com), this configurators provides the chance to introduce the characteristics of the system and returns the most suitable products available for the specific values given. The SINAMICS 6SL3210-1PC25-4UL0 is suggested by the configuration tool:

Figure 86- Siemens VFD (Source: mall.industry.siemens.com)

In this case, an approximate value of the pump power was guessed to be around 15 kW, so that the size of the product obtained would be taken into account for the cabinet selection in the next section.

24-Volt Power Supply:

In order to provide power to the PLC, the power supply module chosen for the application is the Siemens 6EP13333-1LB00.

Figure 87- 6EP1333-1LB00 Siemens 24-volt power supply (Source: www.automation.siemens.com/)

This power supply module converts a monophasic 230 V AC input into a 24 V DC stable output, it also provides a digital output as operation check that can be sent to the PLC for safety reasons. Further information available in Appendix 4.4.

Differential Switches:

According to the design in Figure 74, two differential switches are needed. A 3-phase one and a monophasic one. For the 3-phase line, a Siemens 5SV3646-6 4-pole switch has been chosen (Q1). As reflected in Appendix 4.5, this differential switch supports intensities under 63 A, it is suitable for 400 V AC lines, and has a triggering value of 300 mA.

Figure 88- 5SV3646-6 and 5SV5312-0FB differential switches (Source: www.automation.siemens.com)

In the case of the differential switch installed before the socket (Q4), visible in the circuit provided in Figure 78. The monophasic differential switch 5SV5312-0FB is selected, which according to the datasheet available in Appendix 4.6, allows a maximum of 25 Amperes through it, and has a tripping value of 30 mA, which makes it appropriate for safety reasons as the application has possible risk of human interaction.

Circuit breakers:

Three circuit breakers are installed in the system according to the circuit in Figure 74, one per each branch. The first one (Q2), is a 5SL6432-7, a Siemens 4-pole circuit breaker that supports 32 Amperes through it according to the datasheet provided in Appendix 4.7.

Figure 89- Siemens 4-pole and Schneider 2- pole circuit breakers (Source: www.siemens.com & www.se.com)

To protect the 24-volt power supply and the PLC and the monophasic socket branches, Schneider circuit breakers (Q3 & Q5) are installed in them both. They are the same product, with the difference that Q3 supports until 20 Amperes through, and the second one supports until 16 Amperes. The references are A9K17220 and A9K17216, and their information is available in Appendices 4.8 and 4.9.

Signaling column:

The 8WD4 series from Siemens has been chosen for the application:

Figure 90- 8WD4 red light 50 mm (Source: hmall.industry.siemens.com)

The green, yellow, red led lights have been selected, as well as the buzzer element for acoustic alarms.

5.3 Electrical cabinet design

In this section, the electrical cabinet is designed so that it can contain all the electric elements and can be located in an accessible position in order to provide easy access to the maintenance and control crew. It is important to remind that in this project, it has been deemed appropriate to separate the pneumatic cabinet from the electric one. Gaining in safety and easier local access to the PLC in case of need.

For the cabinet selection, IDE brand cabinets (ide.es) were selected to be suitable for the project for the reasons discussed in the previous cabinet design, in the same way, no material requirements need to be accomplished as the cabinet is meant to be located in a control room outside the cleanroom. The cabinet's size is determined later in the design when the size requirements for fitting the components are known.

Previous to the cabinet design, some additional material choices need to be done referring to components that will be essential in the cabinet manufacturing but are not as technically relevant as the ones described in the previous sections of this thesis.

As mentioned in section 5.1.1 of this document, terminal blocks are an essential component in electric cabinets as they provide a secure and organized way to connect electrical wires and cables. In this case, for the 2.5 mm wires used for the PLC inputs, outputs, and supply connections, the Phoenix Contact (www.phoenixcontact.com) push-in terminal blocks have been considered optimal for the application, as their innovative connection method makes the job much easier for the person installing and connecting the cables as it consists in a push-in button rather than a screwed connector or a lever system.

Figure 91- Phoenix contact push-in terminal block (Source: www.phoenixcontact.com)

Once the terminal blocks are selected, the terminal block dividers need to be selected accordingly. The terminal block dividers are partitions that are inserted between adjacent terminal locks to create separate sections. Dividers help to organize and segregate different circuits or functions within the same terminal block assembly.

By separating circuits, it can be easier to identify specific wires and prevent errors during installation or maintenance. The suggested terminal blocks dividers by Phoenix Contact as accessory to the chosen terminal blocks are selected for the cabinet design:

Figure 92- Terminal block divider (Source: www.phoenixcontact.com)

Additionally, end covers are also installed in the ends of terminal blocks to cover the exposed metal parts. End covers help prevent accidental contact with live parts and reduce the risk of electrical shock while preventing dust, debris, and moisture from entering the terminal block assembly, which can improve reliability and prevent corrosion:

Figure 93- Terminal block end cover (Source: www.phoenixcontact.com)

In the same way as in the terminal block dividers, the suggested option by Phoenix Contact has been chosen for the application.

When multiple terminal blocks are used, it can be challenging to connect all the necessary wires, and in the event that the same electrical signal needs to be in different terminals at the same time, as a 24 volt supply, a 0 volt reference, or an output signal used in more than one device, the wire connections can imply problems and additional complexities to the design of the cabinet. The terminal block bridges, jumpers, or links, are important accessories that provide a solution in these cases:

Figure 94- Terminal block link (Source: www.phoenixcontact.com)

These elements can help to save space in electrical enclosures by reducing the number of wires required to connect multiple terminal blocks together, reducing wiring errors and providing a faster structure in case of maintenance or modifications as they are easily removed or added to the terminal blocks.

Before proceeding to the cabinet design, it is important to cover a specific element that is crucial to comply with the safety features in electrical systems, the ground terminal blocks. Grounding is essential in electrical systems as it helps to protect against electrical shocks and other hazards. Ground terminal blocks provide a secure and reliable way to connect the grounding wires, ensuring that the electrical system is grounded and safe for operation.

Figure 95- Ground terminal block (Source: automaq.pe)

Ground terminal blocks can help to prevent damage by providing a low-impedance path for electrical currents, which can help to dissipate the energy and prevent damage to sensitive electronic components. Therefore, all the elements that provide a ground terminal should be connected to the cabinet's ground terminal blocks and conducted to the ground wire entering the installation.

To finalize, a last element to achieve organized and safe cabinet distribution is the Wire Duct:

Figure 96- Wire duct (Source: www.digikey.fi)

Wire ducts help to organize and manage the cables within the electrical cabinet, reducing the likelihood of tangles and crossed wires. Making it easier to locate specific cables during maintenance or repair operations.

Most of these elements' 3D models are retrieved from Traceparts (www.traceparts.com) library in the case they were not available in the manufacturers' official sites. Once they are achieved and imported to the DWG format for AutoCad manipulation, the design stage is started.

In the first stage, the electrical protections and the socket are assembled and located over a DIN rail:

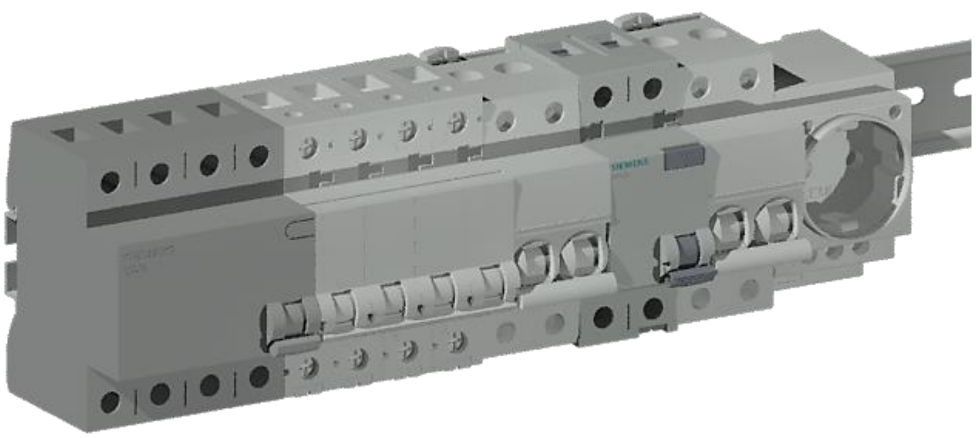


Figure 97- Electric protections and electric socket over DIN rail (Author's own)

Additionally, the 24-volt power supply module is also added in the same DIN rail for space saving and distribution reasons:

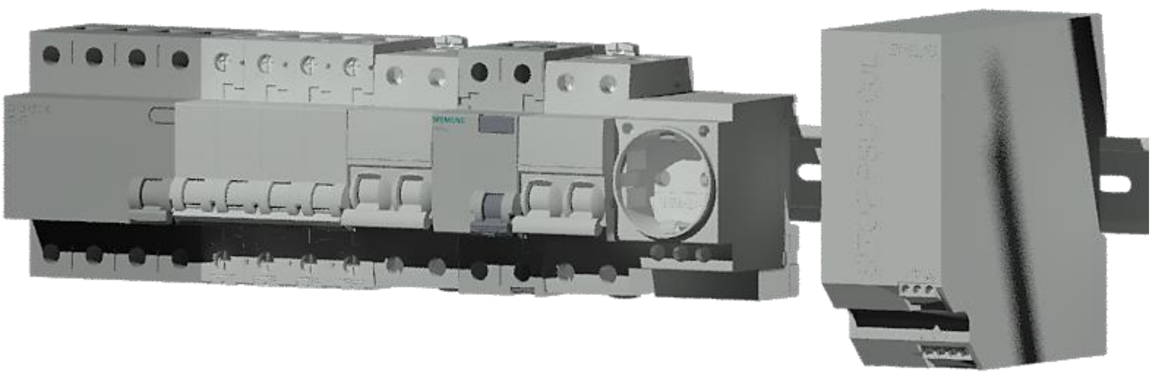


Figure 98- Electric protections and 24-volt supply over DIN rail (Author's own)

In the following row, the PLC and the Output module are also assembled over a DIN rail and some space is left in case additional expansion modules are needed in the future in the system.

Figure 99- PLC and Output module over DIN rail (Author's own)

More Input/Output modules could be added subsequently, as well as safety relays, communication switches, and other elements.

The Variable Frequency Drive is located independently due to its significant size, additionally, providing separation from other devices is advisable to avoid overheating problems:

Figure 100- 3D Model of the VFD (Source: mall.industry.siemens.com)

The VFD is not located over a DIN rail because of its big dimensions, it is located directly over the metal sheet of the cabinet where all DIN rails are mounted.

Once all the electric elements are located, the DIN rail, the terminal blocks need to be located over DIN rails as well. In the following Figure, the ones designed for the signal wires are visible.

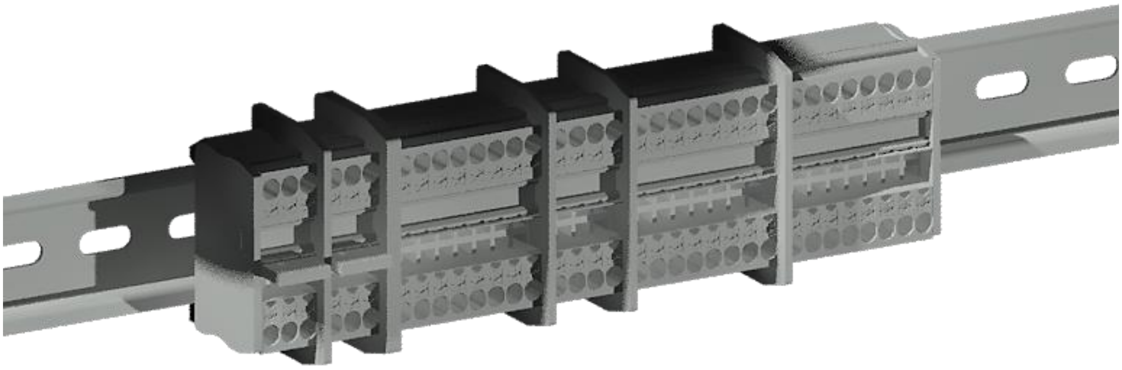


Figure 101- 2.5mm wire terminal blocks (Author's own)

The first two divisions starting from the left are reserved for the 24-volt supply and the 0-volt reference, having three terminal blocks reserved per each just in case they are necessary for additions in the cabinet. The following block is reserved for 8 digital inputs, and the next 4 for analog inputs. The two last divisions are reserved for 16 digital outputs.

Meanwhile, the lines and ground terminal blocks are added at the left of the previous terminal blocks. These terminals are meant to be located near the entrance of the cables to the cabinet in the lower left corner of the cabinet.

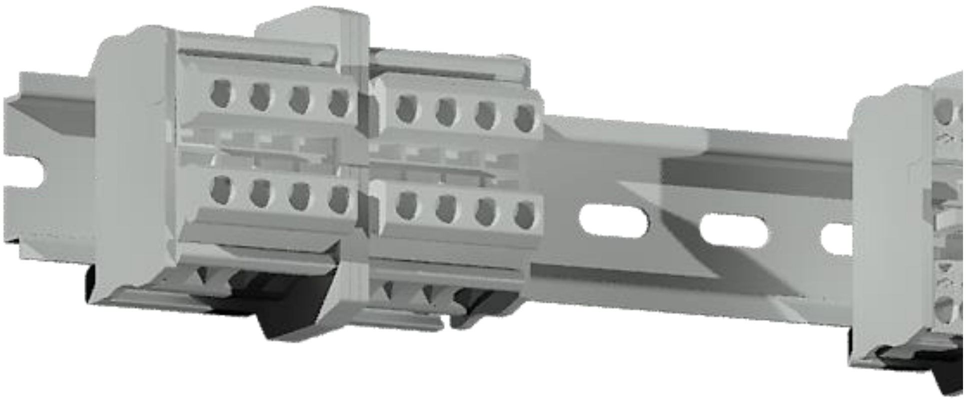


Figure 102- 5mm Terminal Blocks (Author's own)

The terminals for the VFD and Motor connections are added in between the two previously mentioned block groups.

Once all the elements are located over their DIN rail and an approximate distribution plan is created, it is possible to calculate that an appropriate size for the cabinet is, in millimeters: 1000x1200x400. According to the IDE documentation, the corresponding reference of their catalog is GN10012040PD:

Figure 103- IDE GN10012040PD (Source: ide.es)

The 3D model is imported to the AutoCad 3D format so that it is possible to work with it and modify some features according to the design desires. The isolator switch, the emergency and restart buttons, and the cable glands for the cables entering and leaving the cabinet are installed as seen in the following figures:

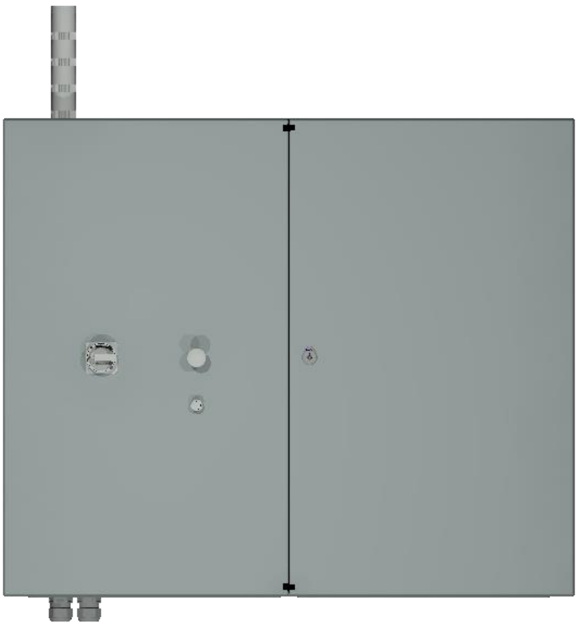


Figure 104- Cabinet door with mounted elements (Author's own)

Another external element is to be located in the superior part of the cabinet, the signaling column. This column is composed by a green buzzer in the bottom, and above it, in this order, a green, yellow, and red-light element.

More elements could be added in the cabinet's doors, as an HMI to enable operation with a SCADA system, additional alarms, or operation sequences. This design is limited to the necessary items for operation and is expandable according to the desires of the customer in each application.

About the inside distribution, the elements have been distributed by locating the safety and power distribution elements in the higher part of the cabinet, the control elements in the middle, and the terminal blocks at the bottom.

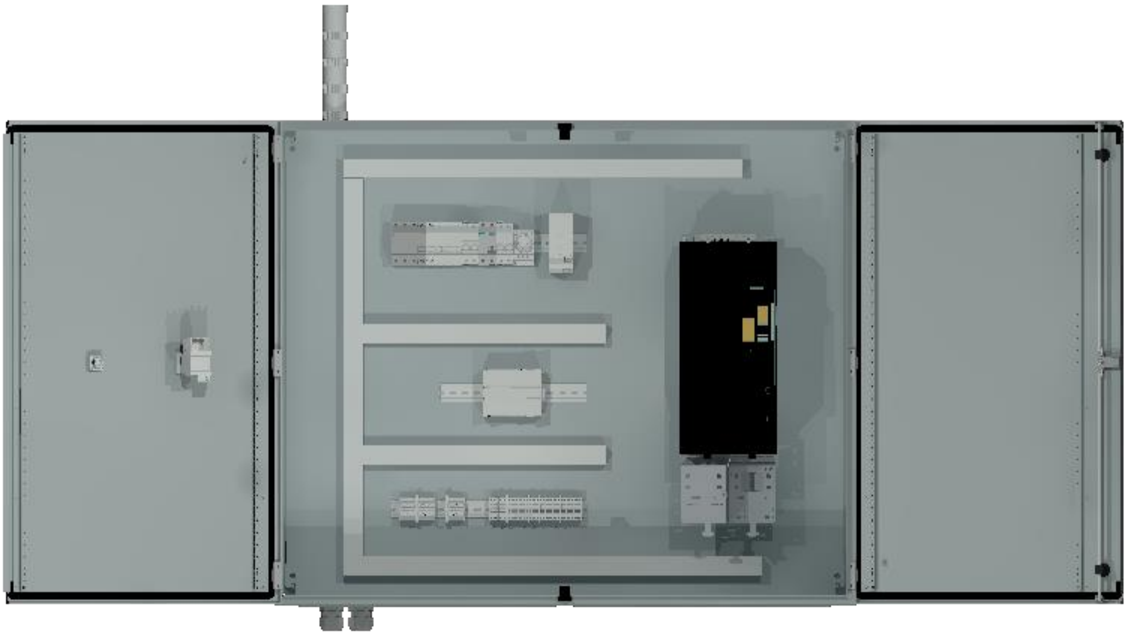


Figure 105- Interior distribution of the cabinet (Author's own)

Once the distribution is defined, the wires need to be connected to each terminal according to the electric schemes stated in the previous section. It is advisable to carefully tag and identify each wire for future maintenance work or modifications.

With the obtained result, the 3D design objective is reached successfully for the electrical part as a presentable and realistic model has been achieved.

6 PLC Programming

In this section, all the aspects referred to the automation of the system are covered. The program designed is explained step-by-step and additional information is provided for possible modifications or future improvements.

6.1 TIA Portal

Totally Integrated Automation Portal, commonly known as TIA Portal (www.siemens.com), is the software platform used for the development of the automation of the system designed in this thesis. TIA Portal is a software platform developed by Siemens for programming and configuring their automation and control systems such as the PLC used along this project.

The main feature of the platform is that it provides a way to write and debug programs for Siemens PLCs using different programming languages such as Ladder Logic (LAD), function blocks diagrams (FBD), and structured text (ST/SCL).

Another crucial feature is the simulation and testing environments where engineers can test and validate their automation programs without the need for physical hardware. This particular feature has been essential as, even the S-7 1200 PLC was available during the development of the thesis, the SM 1222 output module and the variable frequency drive were not available as they are more specific components that are purchased depending on the needs of this project.

As it is not an objective to actually test the PLC sequence in real life and there is the possibility of simulating within the TIA Portal environment, it was decided to carry on with the material provided by Novia UAS and simulate the missing elements in the PLC programming environment.

In the TIA Portal platform, it is also possible to stablish the Profinet communication between the PLC and the peripheral devices as the I/O module and the VFD as seen in the following figure:

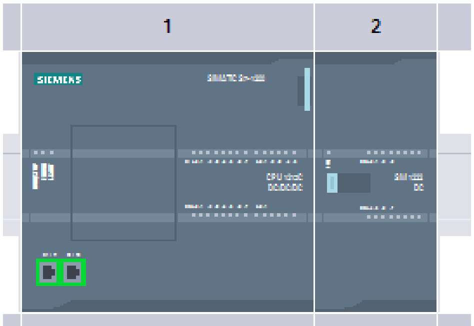


Figure 106- PLC to Output module connection (Author's own)

However, as visible in the previous figure, only the I/O module has been possible to virtually connect because of version compatibilities and the impossibility to obtain the drives extension because of the license limitations, it has not been possible to virtually connect the VFD.

While this could represent a setback in the automation section of this thesis, it has been deemed appropriate to continue to design the sequence as if the connection was possible as it will be in any industrial application where this kind is project will be replicated.

The programming block for controlling speed axis in SINAMICS G drives is the "sina_speed" block, which is perfectly explained in the document provided in Appendix 6.1, where all the settings, configurations, and programming instructions are defined.

The fact that the connection has not been possible does not change many things in the programming of the sequence, as the speed values are defined in the code in internal variables that would posteriorly be inputted to the "sina_speed" block (not available) that would enable the communication with the drive.

All the changes in speed velocity in the VFD are meant to be done with the ramp-function generation enabled, making smooth velocity changes.

6.2 Sequence

The sequence programmed is composed by a main program that will execute repeatedly, various subroutines, and the timers that will control the sequences. All the Tags defined along the program are available in Appendix 6.2.

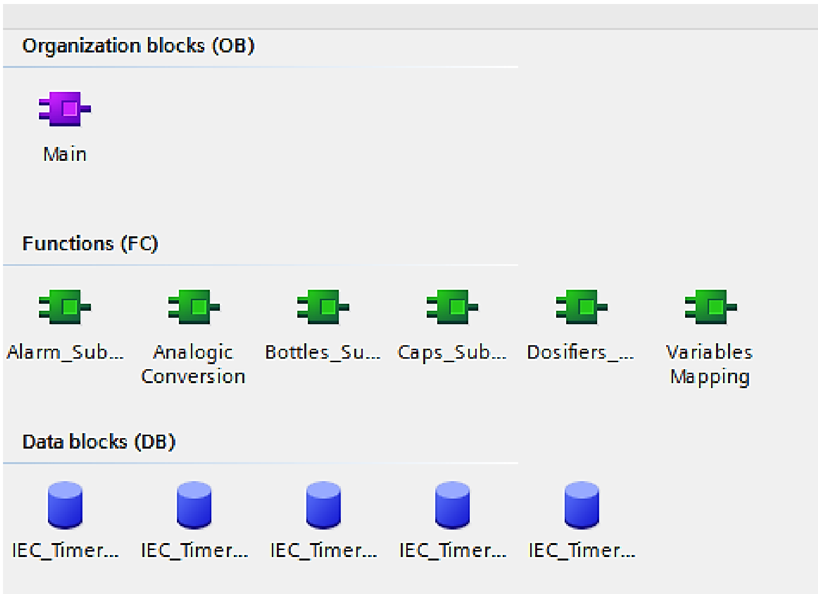


Figure 107- Elements composing the PLC program (Author's own)

It is considered best practice in the PLC programming world, and according to Romanov (2023), to properly map Inputs and Outputs before starting to program. This means basically to create a subroutine that contains the I/O tags and links them to memory variables. By doing this, it is possible to one, have access to all the inputs and outputs within the same subroutine, and two, troubleshoot and detect problems in the future as it will be possible to monitor the state of the devices connected and the operation of the output elements.

To do so, a variable mapping subroutine is created, there, all the inputs and outputs are mapped in SCL text, as it is visually understandable and more compact than ladder for this kind of assignations.

```
//Digital Inputs
"Emergency_Stop" := "Emergency_Stop_Input";
"24v_OK" := "24V_OK_Input";
"Restart" := "Restart_Input";

//Analog Inputs are normalized and scaled: The variables below are not of the same datatype.
//"Pressure" := "Pressure_Input";
//"Vacuum" := "Vacuum_Input";

//Digital Outputs
"Air_Supply_Output" := "Air_Supply";
"FV-30_Output" := "FV-30";
"FV-01_Output" := "FV-01";
"FV-02_Output" := "FV-02";
"FV-03_Output" := "FV-03";
"FV-11_Output" := "FV-11";
"FV-12_Output" := "FV-12";
"FV-13_Output" := "FV-13";
"FV-21_Output" := "FV-21";
"FV-22_Output" := "FV-22";
"FV-23_Output" := "FV-23";
"FV-00_Output" := "FV-00";
"Buzzer_Output" := "Buzzer";
"Green_Output" := "Green";
"Yellow_Output" := "Yellow";
"Red_Output" := "Red";
```

Figure 108- Variable mapping (Author's own)

The TAGs that are actually linked to the Input and Output TAGs, are the ones defined with the "_Input/_Output" ending in the name, that way, no modifications can ever be made directly over those tags, only to the memory ones. Once the variables are mapped, it is possible to define the Main function.

Main:

In the main function, the first rung is dedicated to enabling the air supply and the restart button.

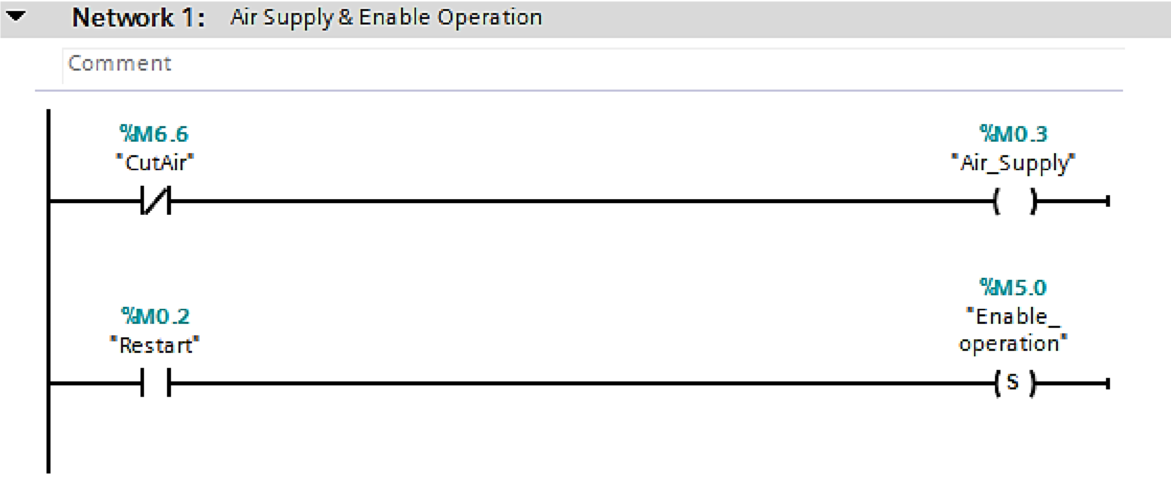


Figure 109- Networks 1 of the Main code (Author's own)

It is easily visible that, in case the “CutAir” bit is toggled, the air supply will be removed, and in case the restart button is pressed, the enable operation tag is set to a logic 1.

In the second network, the 24V supply and the pressure regulation of the line are checked:

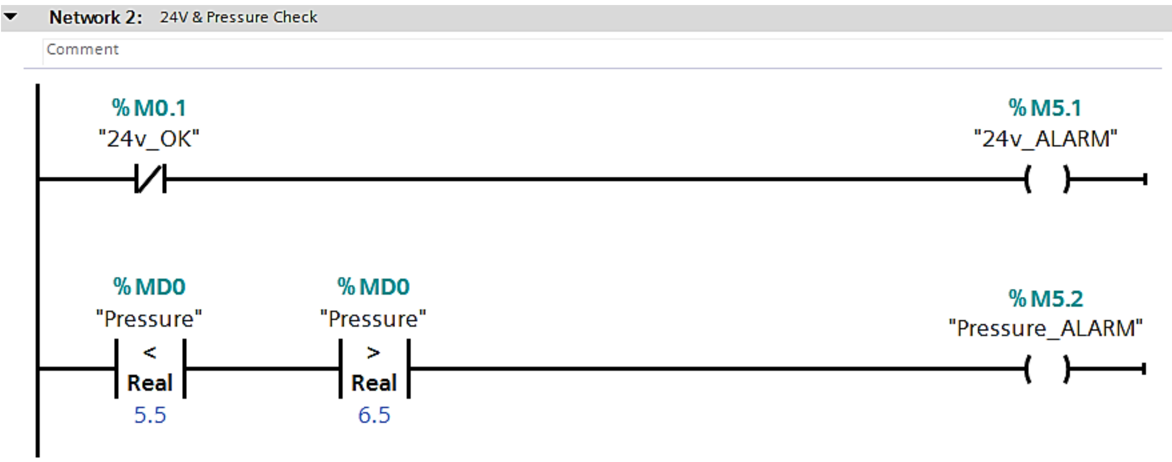


Figure 110- Network 2 of the Main code (Author's own)

An alarm bit will be set in case there is any problem with the 24V power supply. Similarly, another alarm bit will be set in case that the pressure value in the pneumatic service unit is not around the 6 bar.

After that, the pump is started in the 3rd network.

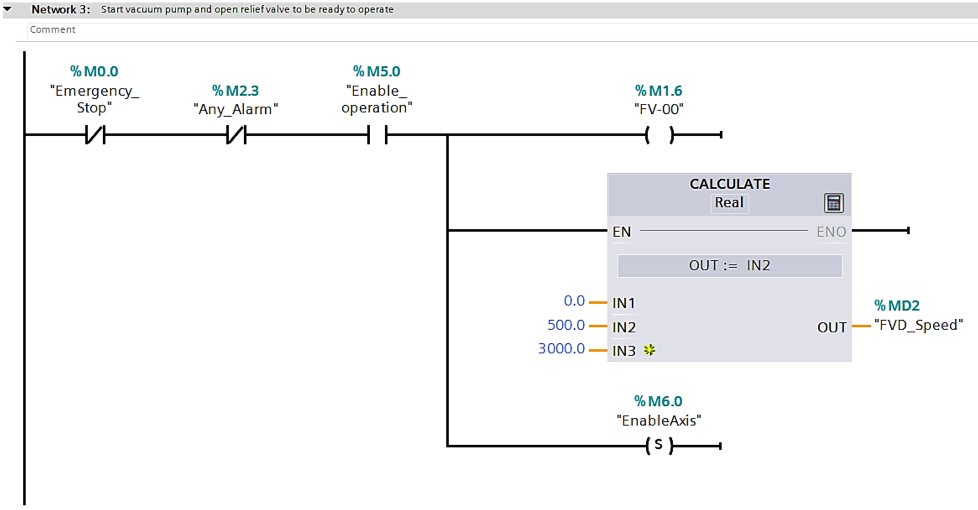


Figure 111- Network 3 of the Main code (Author's own)

In case the emergency stop button is not pressed, there are no active alarms, and the operation is enabled, the VFD axis will be enabled, and the pump will be set to 500 rpm while the relief valve will open. This way, the system will be ready to operate once there is a material request in any of the lines. Subsequently, the three subroutines that will operate the material transport functions are declared.

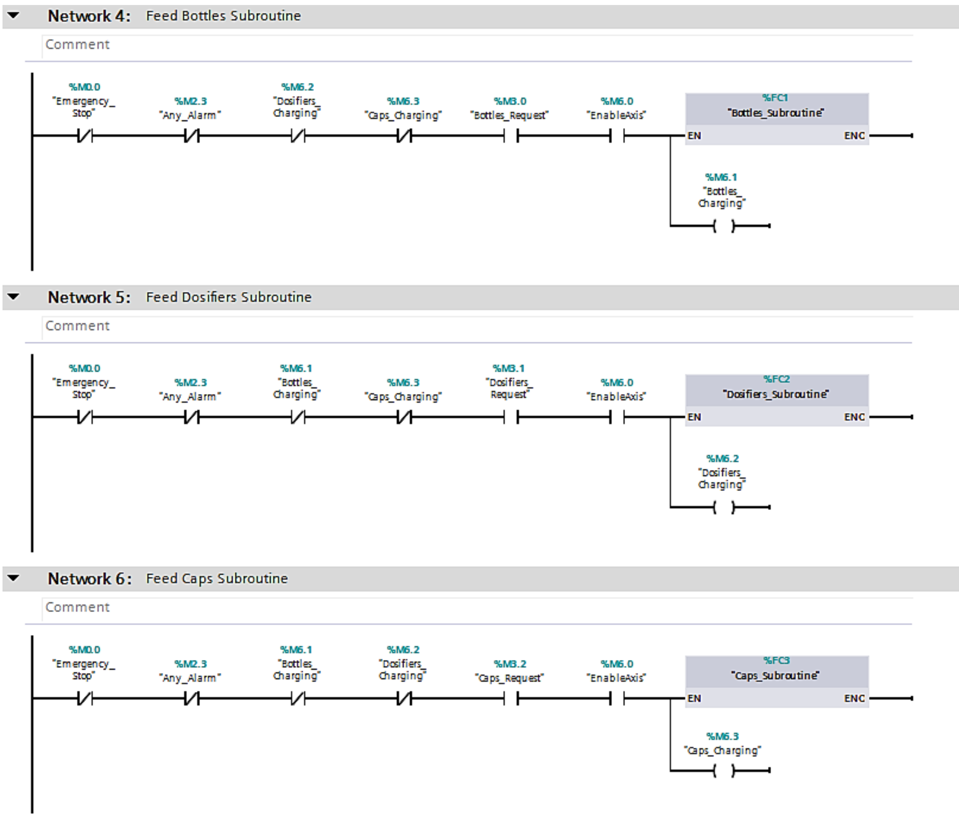


Figure 112- Networks 4, 5 & 6 of the Main Code (Author's own)

These subroutines will be called when there is a material request, always that the system is operating properly with no alarms, the emergency button is not pressed, the VFD axis is enabled and there is not another charging subroutine being executed at the same time.

Three more subroutines are called, in this case, these are continuously being called:

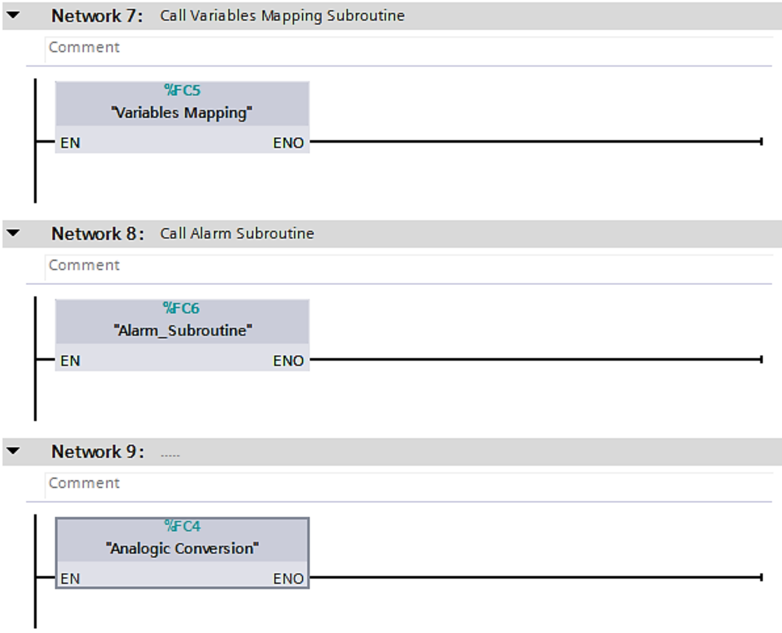


Figure 113- Network 7,8 & 9 of the Main code (Author's own)

The first one has already been mentioned, as it is the one containing the variables mapping. The second one calls the alarm subroutine, and the third one is the one in charge to convert the two analogic values to comparable ones by Normalizing and Scaling them to the units to compare.

Finally, the emergency stop functionality is stated:

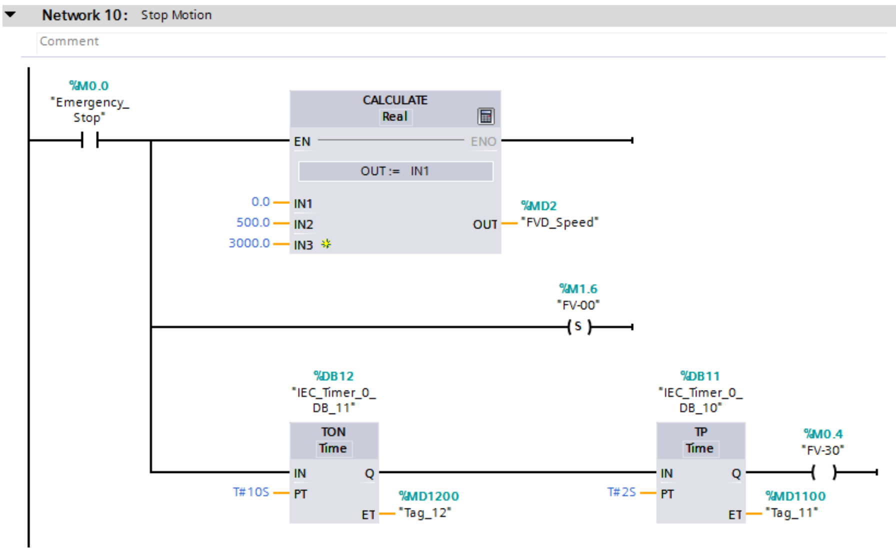


Figure 114- Emergency stop motion (Author's own)

In the sequence, to keep it short and simple, the only stopping motion defined apart from the one generated by the alarms and discussed posteriorly, is the emergency stop. In case the emergency stop button is pressed, the previous subroutines will stop their execution. However, it is important to establish a sequence to securely stop the system. In this case, when the button is pressed, the FVD speed is set to 0 rpm, and the air supply is not cut.

In many safety applications the air supply of the pneumatic elements is cut so that the elements stop working. However, in this application, cutting the air supply would imply not being able to bring the valves to the secure positions in case of emergency. If the air was to be cut at any time, it should be after securing that the valves are in a position that cannot harm individuals or the system.

In this case, as it was stated in the process design, once the pump stops the aspiration will be cleaned by a powerful air blow. To do so, when the pump is stopped, the relief valve is opened to provide an outlet for the air and particles, and after 10 seconds, the rapid exhaust pneumatic valve is actioned so that the air from the air reservoir is liberated against the filter for 2 seconds.

Alarm:

In the alarm subroutine, the following evaluations are made:

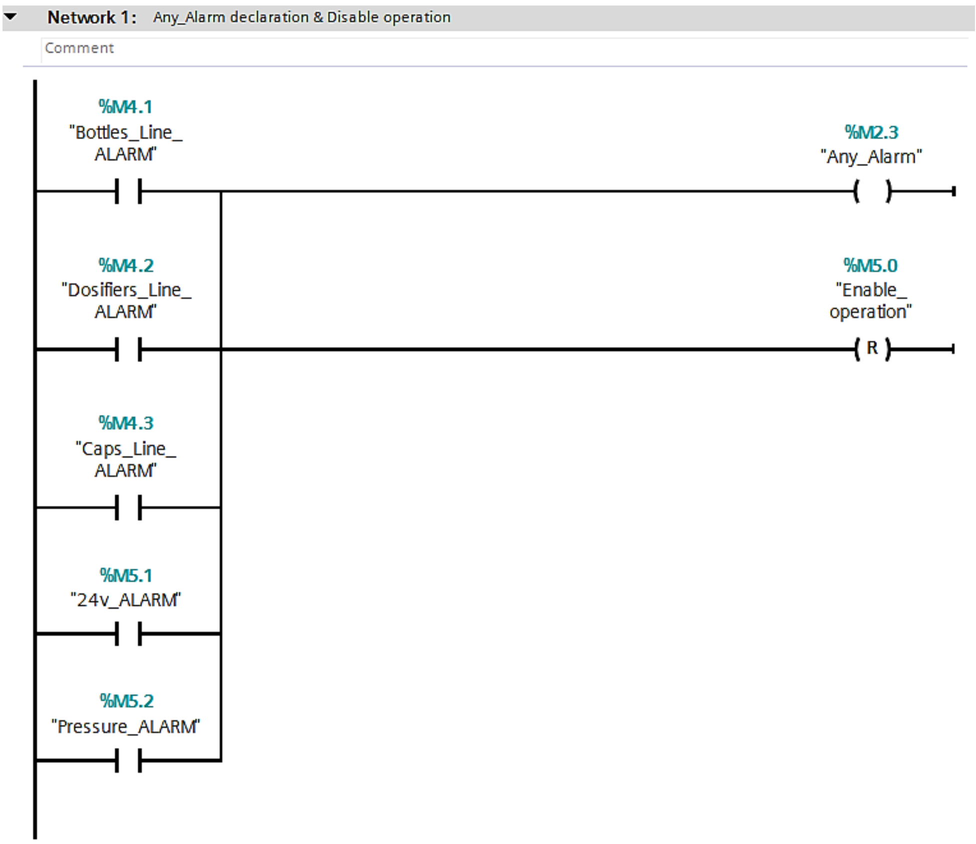


Figure 115- Network 1 in Alarm subroutine (Author's own)

The first network evaluates all the possible alarms, and in case one of them is active, it sets the bit "Any_Alarm" and disables the operation simultaneously.

The following rung states what happens after the "Any_Alarm" bit is set:

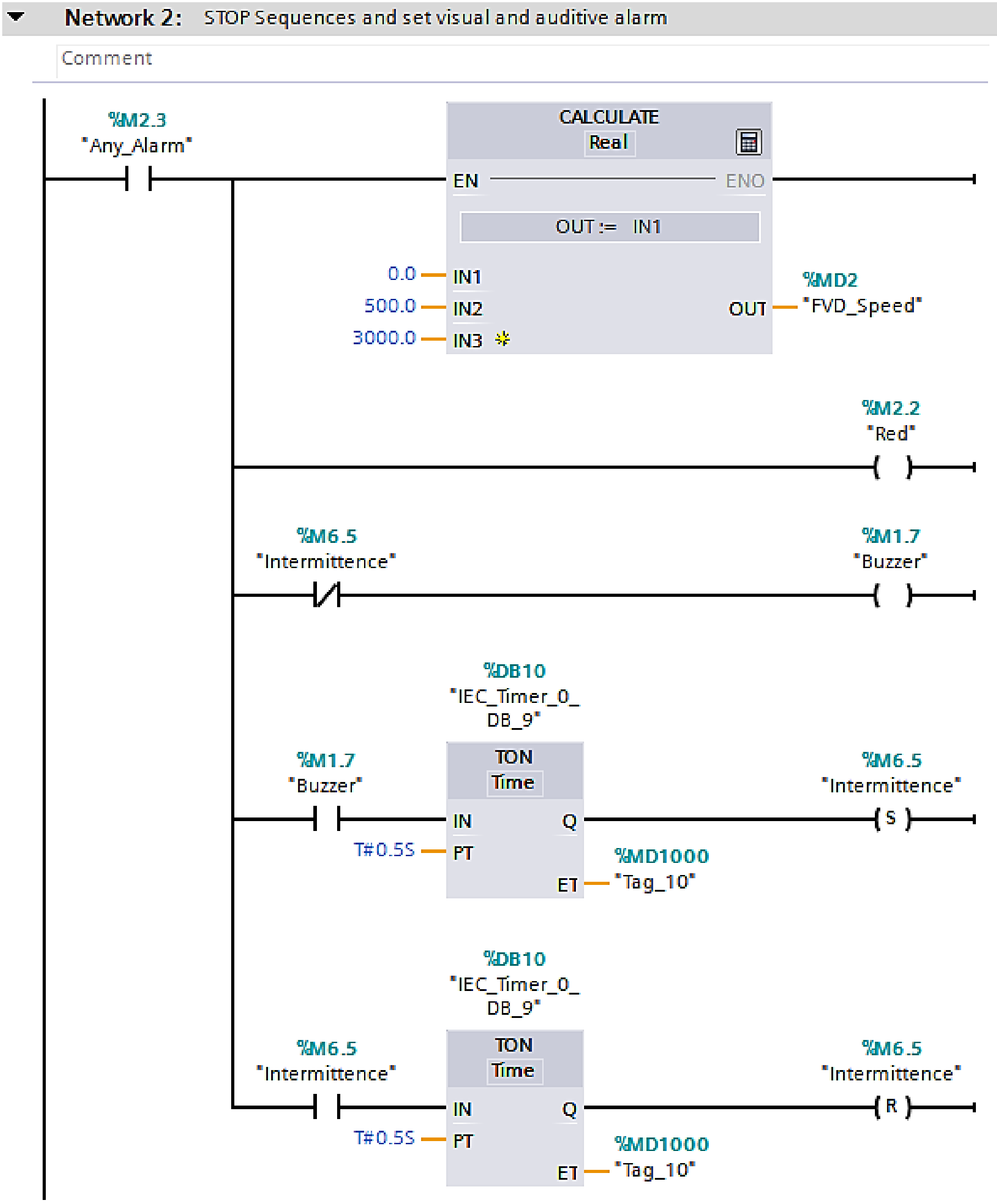


Figure 116- Network 2 in Alarm subroutine (Author's own)

When the bit is set, it sets the motor velocity to 0 rpm, it turns the red light on as well as an intermittent buzzer (originated with two timers) so that the operator can see and hear the alarm and identify the problem.

Once the operator is aware that there is an emergency, he can press the emergency button to recognize the alarm and stop the buzzer.

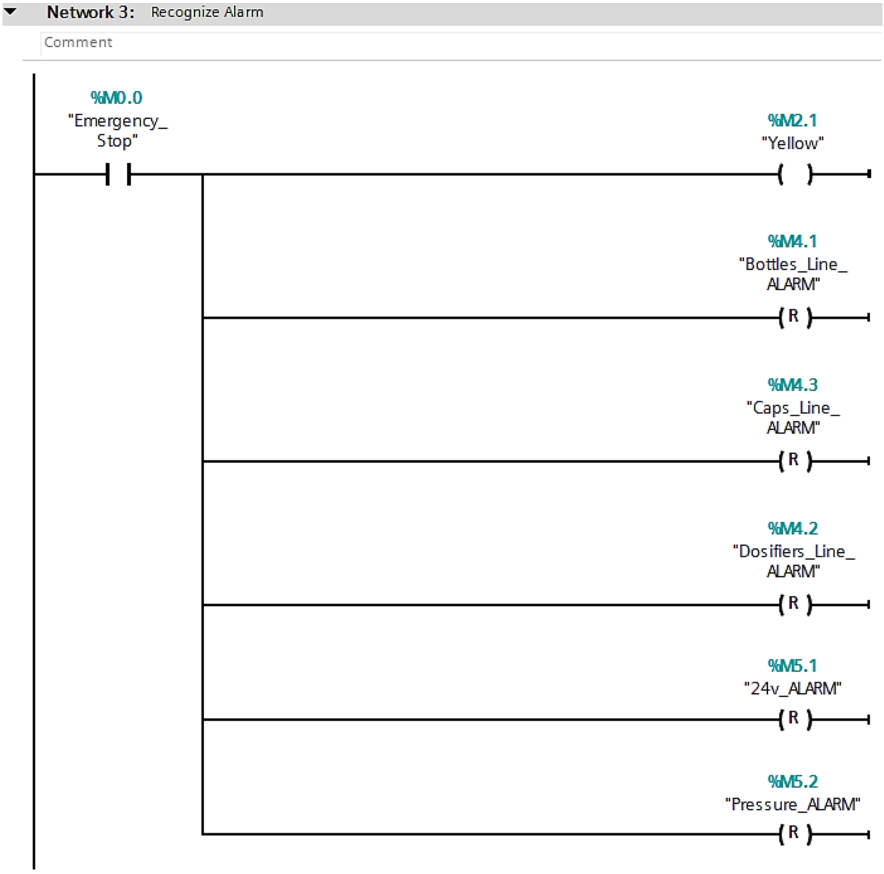


Figure 117- Network 3 in Alarm subroutine (Author's own)

Once the operator presses the emergency stop, all the alarm bits are reset, and the yellow light switches on. The operator must fix the problem, otherwise, the alarm will start again as the error bit will activate again. Once the error is fixed, the emergency button can be unlatched to return to normal operation:

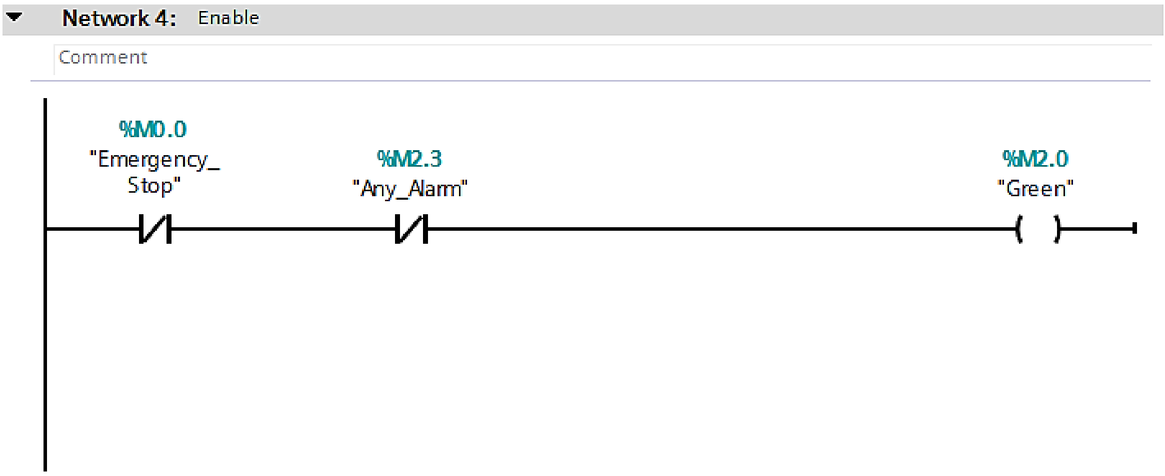


Figure 118- Network 4 in Alarm Subroutine (Author's own)

The system is ready to work again, however, it will not start until the restart button is pressed as stated in the 1st and 3rd rung of the Main routine as stated in Figures 109 and 111.

When there is a material request through to the system (normally by a server, or input) and the system is running, the request tag in question is activated and the subroutine is executed.

Bottles subroutine:

The design of the following sequence is made with timers with approximate values. The time values should be adjusted according to the system characteristics. In the same way, the alarms are also set with timers, the use of valve positioners would be more reliable, but they were not considered in the design.

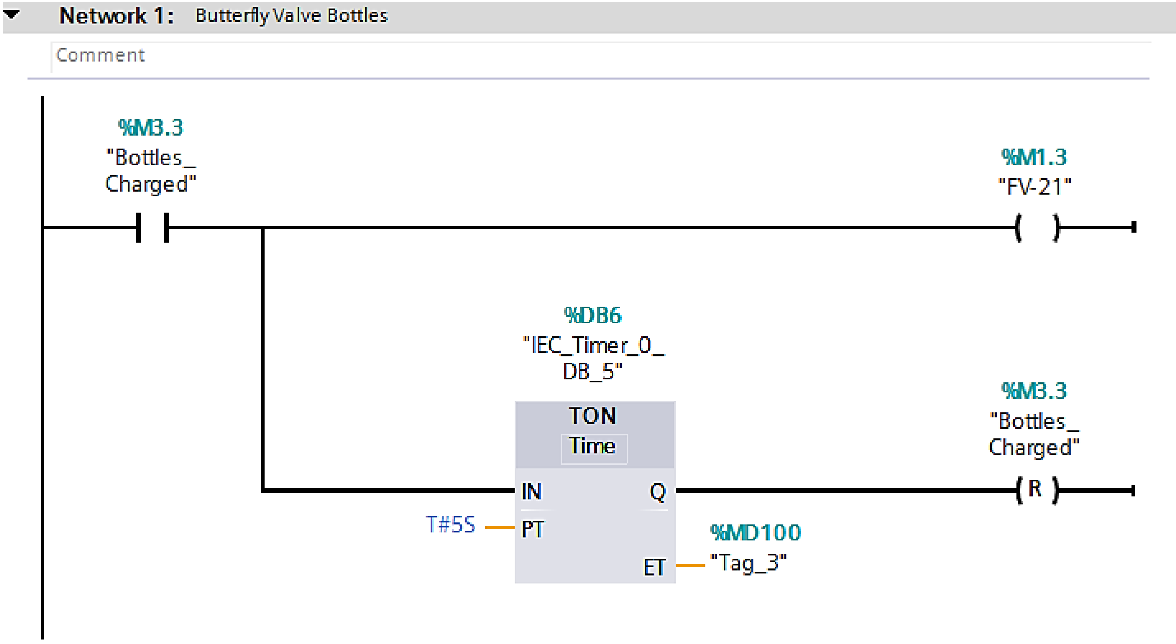


Figure 119- Network 1 in the Bottles subroutine (Author's own)

In case that when the subroutine is called, there are already bottles in the storage tank, the sequence starts by emptying it by opening the butterfly valve and waiting for 5 seconds. After five seconds pass, the "Bottles_Charged" bit is toggled and cleared to 0.

In case that there were no bottles in the storage tank, meaning that it is the first operation, this sequence will not be executed, however, the intention of this subroutine is to empty the tanks and fill them again for the next cycle, meaning that if the tanks where empty in the beginning, two request will be needed for a first material deploy.

After the bottles being discharged, the Motor is set to the high-speed value to generate vacuum:

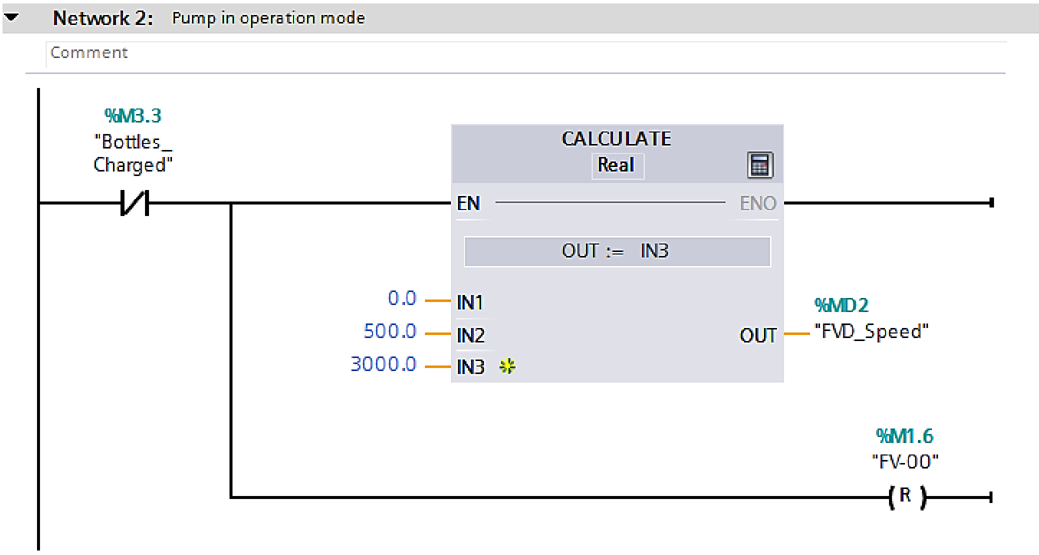


Figure 120- Network 2 in Bottles subroutine (Author's own)

The relief valve is closed so that vacuum can be generated. Once the vacuum pump is generating vacuum, the Bottles ball valve must be open so that vacuum can be generated in the bottles line:

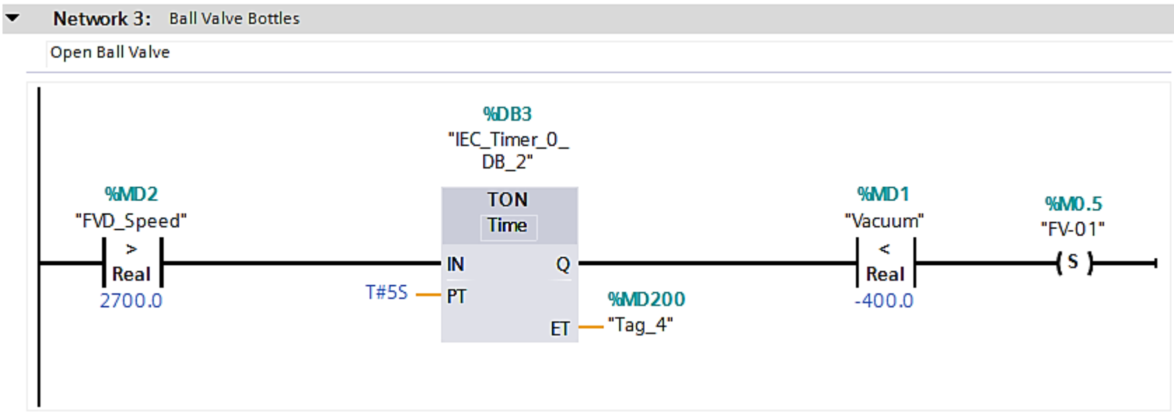


Figure 121- Network 3 in Bottles subroutine (Author's own)

After five seconds (test time for simulation) of the pump high speed regime, the vacuum value is evaluated and compared. For simulation purposed, it has been assumed that the proper value for vacuum transport in the application is around -450 mbar, then, when the analogic input for vacuum provides a value of vacuum lower than -400 mbar, the ball valve is opened, and the vacuum is generated in the bottles line.

To evaluate the correct operation of the system or the need of an alarm, the following rung is designed. Again, this is a solution proposed and the time values are meant to be indicative and must vary according to the application.

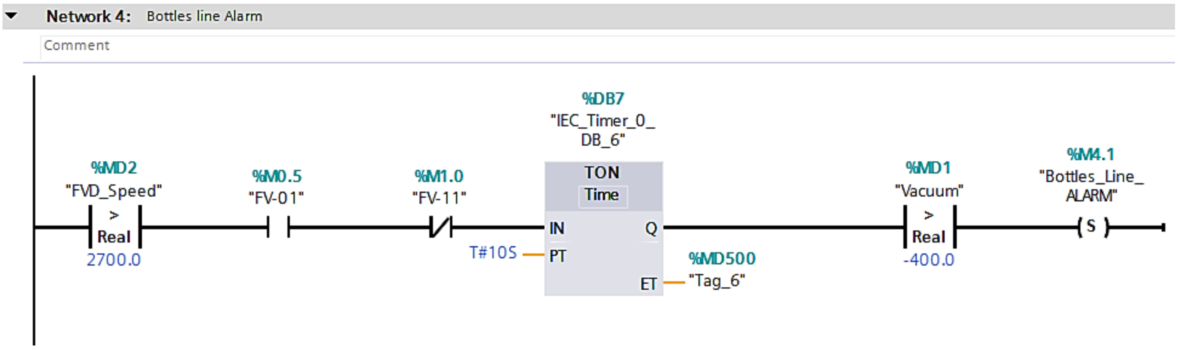


Figure 122- Network 4 in Bottles subroutine (Author's own)

This rung evaluates that, in case that the pump is running at high-speed regime, the ball valve is open, and the pinch valve is closed, if after 10 seconds, the vacuum level is not below the -400 mbar, being a sealed environment, must mean that there is an open gap, which could be the butterfly valve, that could have not closed for some reason.

An open point in the system can result into danger for the application and for the sterility of the product transported, therefore, in case this alarm is set, the process must stop for further supervision. Which is what happens in the alarm subroutine after the alarm is set. If there is no problem in the line, the 4th network will be ignored, and the one in the following figure will be executed:

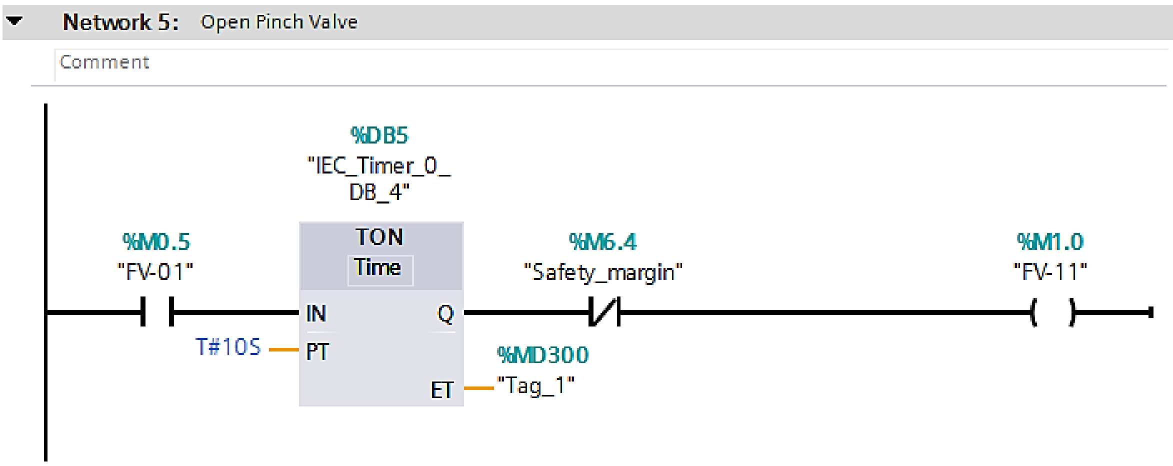


Figure 123- Network 5 in Bottles subroutine (Author's own)

After 10 seconds of opening the ball valve, the vacuum is generated in the line and the pinch valve can be opened. Then the material transport starts. The safety margin bit is discussed later.

After 10 seconds of transporting (example time), it is considered that a sufficient amount of material is moved, and the pinch valve is closed.

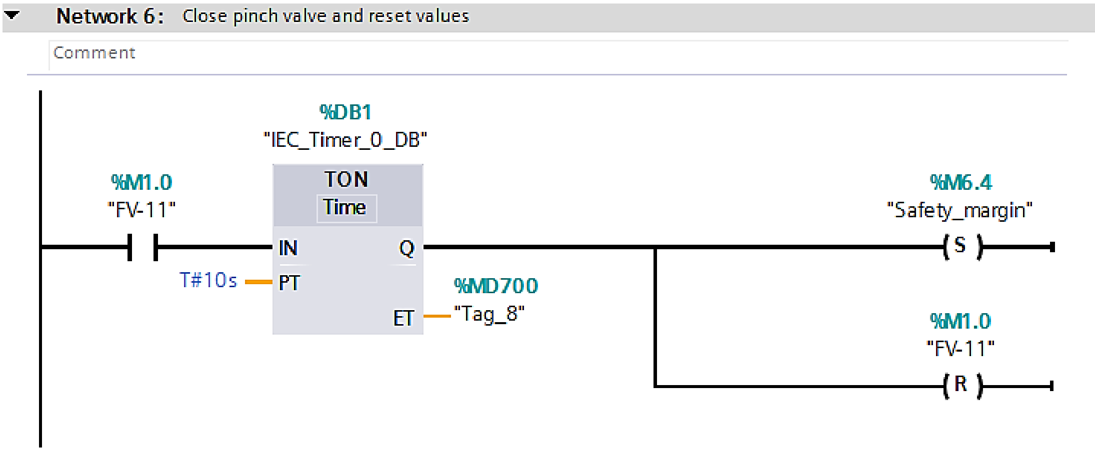


Figure 124- Network 6 in Bottles subroutine (Author's own)

Then a safety margin is needed so that the material in the pipes between the pinch valve and the ball valve is transported to the storage tanks and does not stay in the pipes. In the following rung, after 10 seconds, the process is finished.

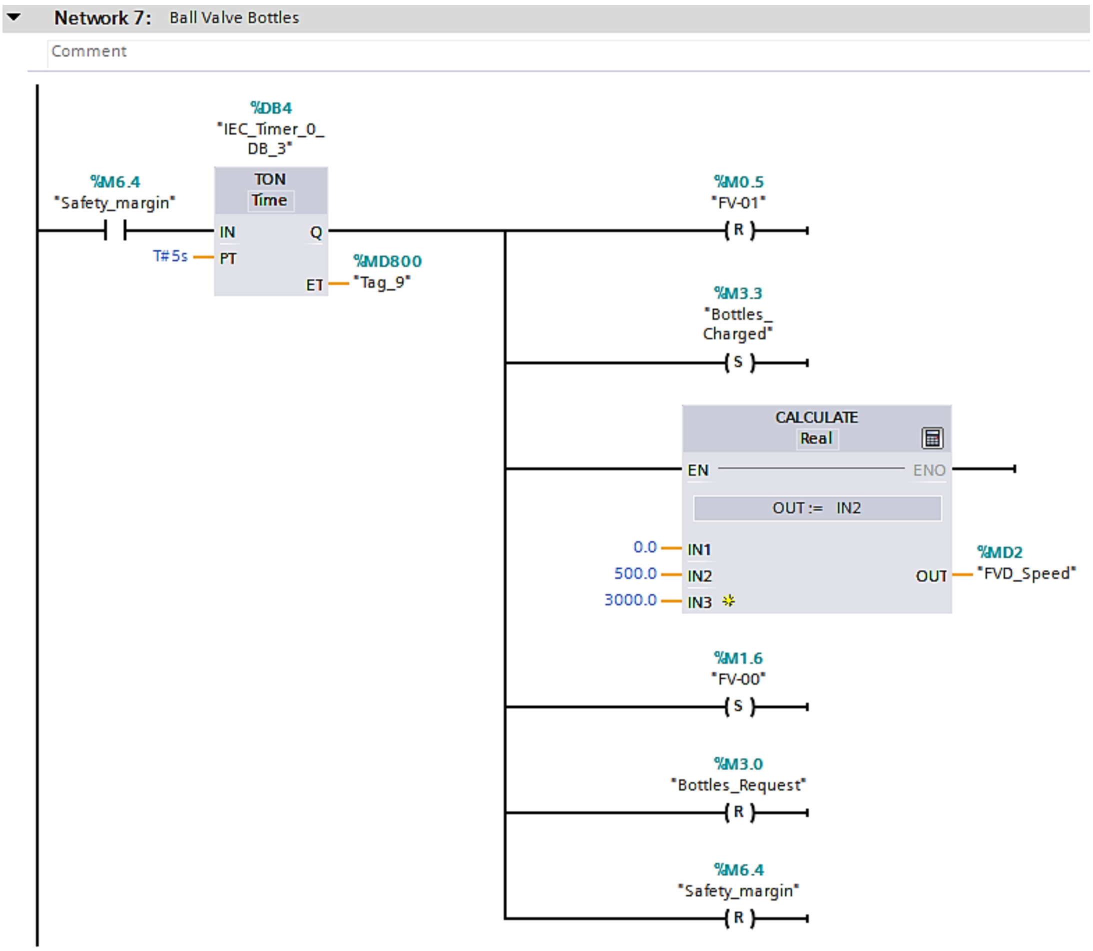


Figure 125- Network 7 in Bottles subroutine (Author's own)

After 10 seconds, the ball valve is closed, the bit that states that the bottles are charged is set to one, the VFD speed is set to 500 rpm, and the relief valve is opened. Also, the bottles request bit is cleared and the safety margin as well to finish the execution of the subroutine.

The dosifiers and caps subroutines follow the same structure and only modify the TAGs that are activated according to each line. The TAGs list can be found in Appendix 6.2.

Once all these elements are discussed, the automation part of the thesis is concluded. A standard sequence for operation has been achieved, and the documentation provided can be used as a starting point and foundation for similar projects that might have similar characteristics to this one.

7 Results

This section is an inside look and evaluation of the thesis' results. The project was built around the aim of designing and automating a vacuum transport system as an effective alternative to conventional transport in pharmaceutical industrial production.

The aim was carried on by developing designs that conform to industrial standards for the electrical, pneumatical and process systems, which was supported by the theoretical background studied in Sections 2.2, 2.3 and 2.4, and furtherly developed for the specific needs of the project in Sections 3, 4 and 5 of this document.

Concerning the process design part, the following Process and Instrumentation Diagram (P&ID) was designed according to the ISA 5 norm, while considering the pneumatic needs of the system in terms of air quality and location of the pneumatically activated elements, together with a tagging system to properly identify the elements:

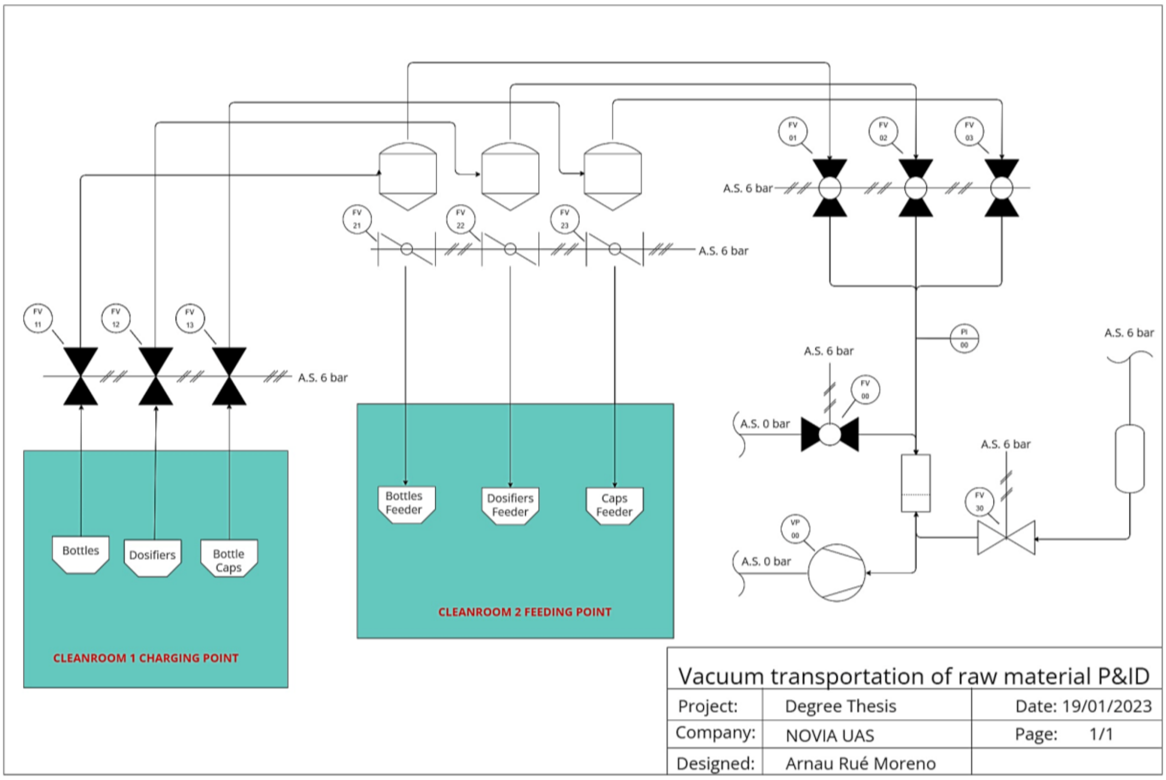


Figure 126- Definitive P&ID (Author's own)

Moreover, process elements were chosen as suggestions for each important element of the process, always taking into account that those needed to be exchangeable according to the dimensions and the requirements of the system.

Once the P&ID and the elements were defined, the pneumatic system was designed to control the pneumatic valves that are meant to be managed by the PLC. To do so, the design stage was divided in the pneumatic scheme confection, and the elements choice to provide an optimal solution.

In the case of the pneumatic scheme, the following design was decided to be definitive:

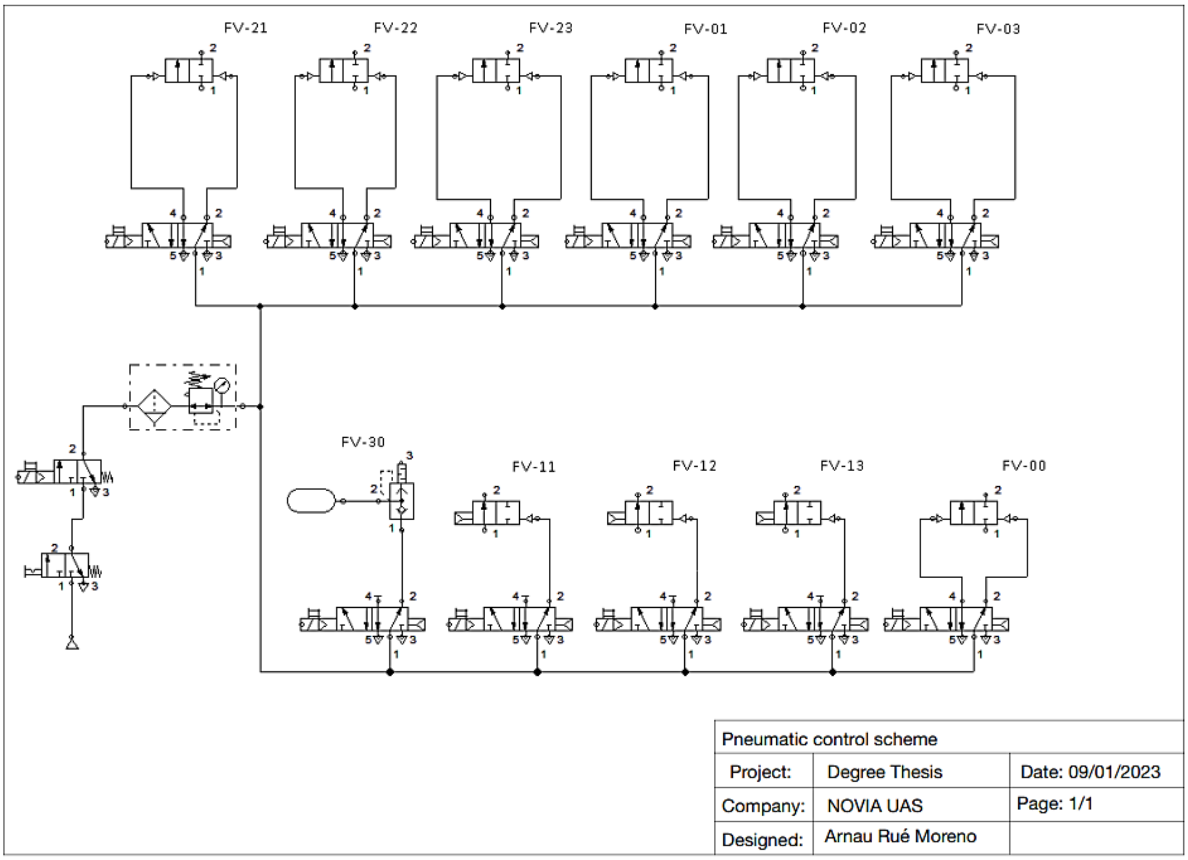


Figure 127- Definitive pneumatic scheme (Author's own)

Subsequently, with further development and study of the FESTO (www.festo.com) product range, the MSB6 series for the service unit and the VTUG valve terminal were configured according to the requirements of the system.

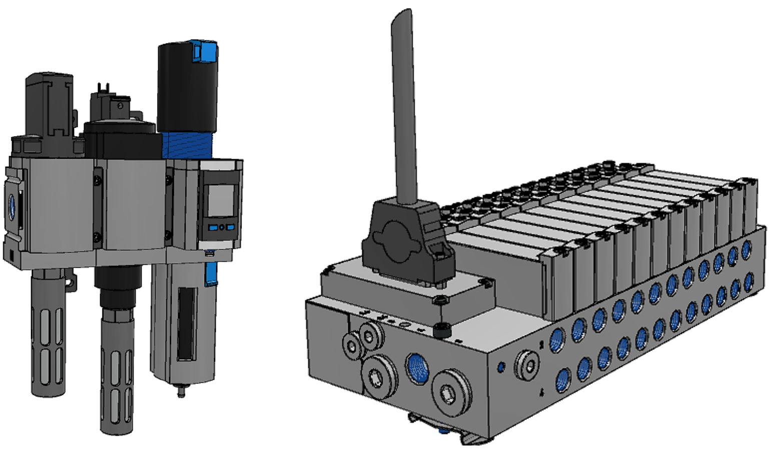


Figure 128- MSB6 Service unit and VTUG valve terminal (Festo Quick Search)

Finally, the electric system is designed to supply the elements in the electric cabinet while considering the safety devices required to protect the installation and the personnel that can interact with it, obtaining the following general electric supply scheme:

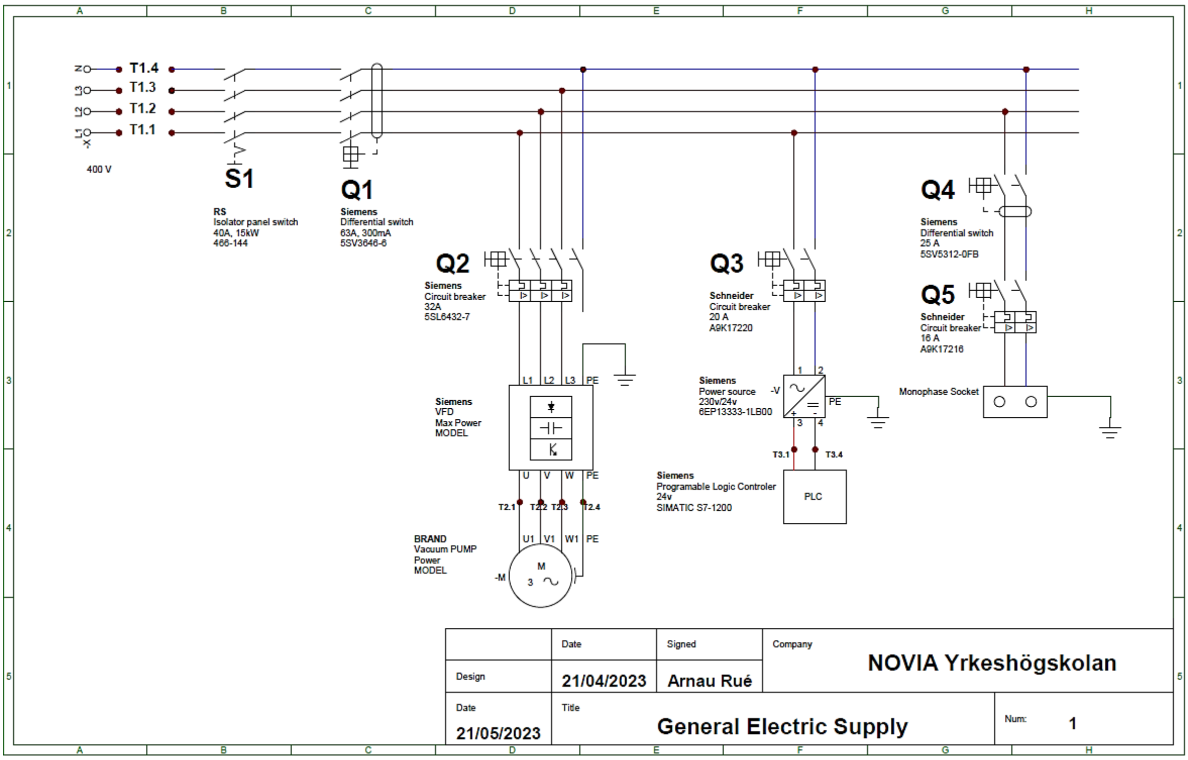


Figure 129- General electric supply scheme (Author's own)

Moreover, the digital and analogic inputs, and the digital outputs of the system are defined in the 5.1.3 section of this document with the respective I/O schemes and the specific elements are selected as the needs of this kind of system are easier to predict.

Once the first objective was achieved, the second objective was pursued by designing the 3D models of the important elements or systems to give the client a visual input of the prototype. Basically, two crucial elements were 3D designed. The pneumatic cabinet, and the electric cabinet.

In each of the designs, all the elements used, and the elements distribution are explained and justified with the usual practices in cabinet manufacturing in the industry.

The pneumatic cabinet 3D design obtained is the following:

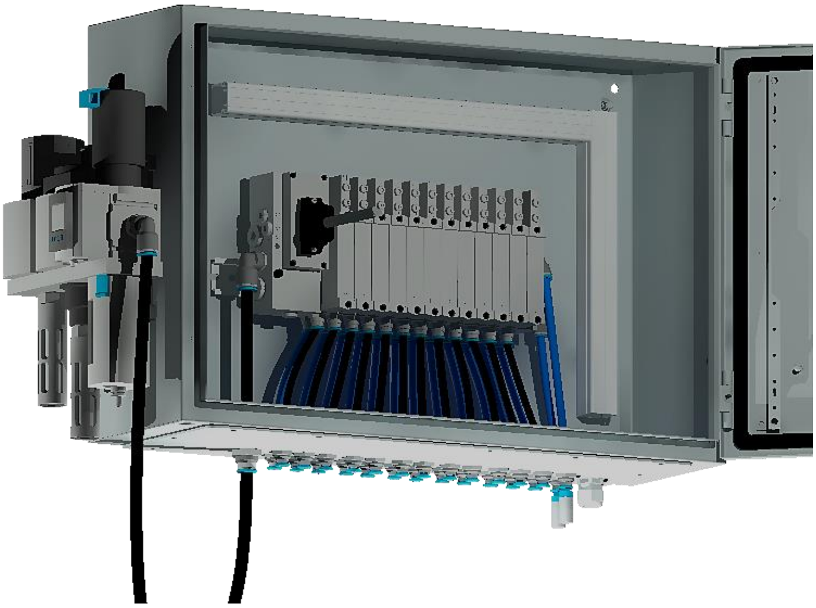


Figure 130- Pneumatic cabinet 3D design (Author's own)

Where the service unit and terminal valves are located and connected for the future control of the process elements.

In a similar way, and along with a step-by-step explanation, the 3D design of the electric cabinet is provided in section 5.3:

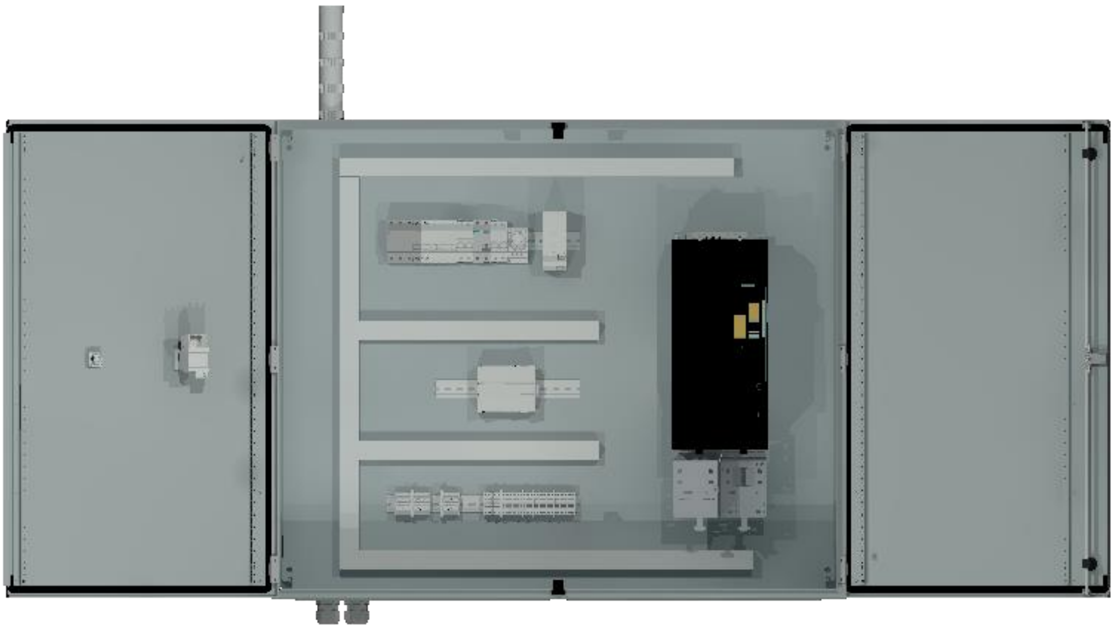


Figure 131- Electric cabinet 3D design (Author's own)

Finalizing with this, the 3D documentation deliverable stated in the second objective of the thesis.

At last, a PLC sequence was provided in section 6, with the TIA Portal software platform in which a S7-1200 PLC was programmed to execute the process while virtually communicating with the SM 1222 extra digital output module. It was not possible to stablish virtual communication with a VFD, however, the sequence could be provided anyways as the values that would have been assigned to the VFD programming block were assigned to memory variables that would allow future usage once the virtual or physical VFD was available.

A final component list is provided in Appendix 1.1 as an overview of all the elements selected within the project. The list comes along with indicative retail prices of the products, adding up to: 44.344,93€ Note that this price only includes the elements discussed. A project overall would add the engineering and mounting costs and would imply other factors that the companies that develop these systems consider.

8 Discussion

With respect to the initial aims and objectives

To meet the aim of the project, three objectives were defined. The first proposed objective was to develop designs conform to industrial standards for the electrical, pneumatical and process systems. This objective was greatly accomplished as the designs successfully adhered to established industry norms and guidelines. Rigorous research and analysis were engineered to ensure proper functionality, safety and efficiency.

The process system design complied with the standards required for P&IDs according to ISA 5. The pneumatic system encompasses the necessary components and takes into account the multiple factors that are crucial in such a critical industry as the pharmaceutical one, while the electrical system is equipped with the necessary protections to prevent any kind of material and personal accidents.

Additionally, for further approval, the technical documentation was sent to professionals in the field that responded with positive feedback on the designs. Overall, the achievement of this objective showcases the project’s commitment to delivering designs that align with industrial requirements and sets a solid foundation for subsequent objectives.

Concerning the second objective, the main focus was to provide the 3D designs of both the pneumatic and electrical cabinets, as these are elements that are often taken for granted in projects and end up being poorly executed. The result obtained has been surprisingly satisfactory for the author. Additionally, there was a desire to propose creating a 3D model of the entire process. However, due to scheduling constraints, it was not possible to achieve this. Although it could have been done, it would have required sacrificing the outcome of the third objective of the project.

With respect to the third and last objective, which focused on creating a PLC sequence that could be adapted to the requirements of similar processes through slight modifications. Was additionally an opportunity to become familiar with the TIA Portal environment, which was previously unknown to the author.

The obtained result is quite satisfactory, although the difference in quality of work can be noticed when compared to the previous sections in which the author has more confidence. A favorable outcome was achieved, although it was a setback not being able to virtually connect the frequency drive to create a fully functional system in case the components were available.

With respect to other published work

One of the most interesting aspects of this thesis is the scarcity of technical information available on the internet regarding this type of system. This is because the companies that build such system work for large pharmaceutical companies and understandably do not publish their designs as it is their main source of income.

While it is possible to find devices or components used in these systems, such as the AR Vacuum storage tanks that were selected in the process, information regarding designs, materials, processes, and regulations is highly limited. This was essentially the reason why the decision was made to work on this topic. The author had the opportunity to encounter similar systems and was curious to explore how one could be designed, resulting in this thesis.

With respect to the limitations of the work

The limitations of the work done are evident. While it is true that the set objectives have been accomplished, this thesis does not provide all the necessary information to create such a system. Essentially, two elements are missing, namely the aerodynamic calculation of the system considering all the influencing factors, and the posterior sizing of all the components. This carries a subsequent limitation, which is that the material selection for the designs is a suggested approximation of what could be as again, the system is not dimensioned.

To achieve this, further project requirements would need to be specified, which goes beyond the available resources and time constraints of the development of this thesis.

With respect to the consistencies and inconsistencies

Focusing on the consistencies and inconsistencies of the project, it is possible to affirm that the documentation provided, and the standards are a suitable starting point upon which to build a project of these characteristics once its dimensions are known. The information presented in the thesis, such as the designs conforming to industrial standards and the selection of components, can serve as a solid foundation for project development.

However, it is important to note that each project is unique and may require specific adjustments based on its particular needs. The project presented in this thesis has not been physically tested, and it has not been possible to prove how energetically efficient and/or convenient it would be compared to the conventional systems that it is supposed to replace.

9 Conclusions

The pharmaceutical industry has strict requirements and regulations for maintaining clean and sterile environments in production processes, which are defined by the International Organization for Standardization (ISO). Compliance with ISO standards is necessary for all materials and personnel entering the cleanroom environment, including raw materials used for production. However, transporting these materials from the reception area to the production area can be challenging due to the need for sterility and special handling.

The author, with experience in cleanroom automation, observed that raw material transportation was often the least automated process and required special handling by personnel or limited conveyor systems. To address this issue, the author proposed to independently design and automate a Vacuum Transport System for raw material transportation, using the eye-drop medicine bottling process as an example.

After a brief study of the pharmaceutical industry requirements in the related aspects, and an extensive overview of the industrial standards for proper design. This thesis has successfully achieved its objectives of developing electrical, pneumatic and process system documentation conforming to industrial standards, designing 3D models as a presentable product for potential clients, and creating a PLC sequence as a standard of operation. The prototype designed is calculated to have an approximate material cost around 44.344,93€.

The results obtained in this study demonstrate a significant accomplishment in meeting the aim of the project, the designs adhere to established industry norms and guidelines, providing a solid foundation the development of similar systems. Therefore, this thesis fills the gap in the available technical information regarding vacuum transport systems in the pharmaceutical industry.

However, it is important to acknowledge the limitations of this study. Some elements such as the aerodynamic calculations and detailed sizing of components are necessary to complete the system design, even if they were defined to be out of scope from the beginning of the project.

Moving forward, there are several exciting opportunities for further research and development. Firstly, conducting a comprehensive aerodynamic analysis considering all influencing factors would provide a more in-depth understanding of the system's behaviour and allow to define proper sizing of the components. Additionally, in the automation aspect, it would be very interesting to create a server simulating the production process and connect it to the PLC and its TAGS, this server could generate material requests and simulate the whole operation. Even further development could be made by developing a SCADA and integrating it to the previously mentioned server.

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Appendix 1: Components list

1.1 Components list and retail prices

Component	Reference	Field	Quantity	Brand	Price/unit	Total	Source
Air blower	Samos SB 0710 D0	Process	1	Busch	5.226,60 €	5.226,60 €	Appendix 1.2
Storage tank	TMF06TC4BRRC5M10	Process	3	AR-Vacuum	8.667,96 €	26.003,88 €	Email communication
Pinch Valve	VARVMANG	Process	3	AR-Vacuum	1.208,06 €	3.624,18 €	Appendix 1.2
Ball Valve	VZBC	Process	3	Festo	1.343,20 €	4.029,60 €	website
Rapid exhaust valve	SEU-1/4	Process/ pneumatic	1	Festo	40,90 €	40,90 €	website
Air Reservoir	CRVZS-2	Process/ pneumatic	1	Festo	103,10 €	103,10 €	website
Valve Terminal	VTUG-18-MSD-B1T-25V20-G38L-DTR-G14S-11PL+HM1	Pneumatic	1	Festo	548,48 €	548,48 €	website
Service unit	MSB6-1/2:C4:D4:J126-WP	Pneumatic	1	Festo	278,73 €	278,73 €	website
12 mm Ø Bulkhead connectors	QSS-12	Pneumatic	1	Festo	12,07 €	12,07 €	website

8mm Ø Bulkhead connectors	QSS-8	Pneumatic	24	Festo	6,36 €	152,64 €	website
8mm Ø to G1/4 push-in connector	QS-1/4-8	Pneumatic	24	Festo	2,57 €	61,68 €	website
12mm Ø to G1/2 L push-in connector	QSL-1/2-12	Pneumatic	1	Festo	9,06 €	9,06 €	website
12mm Ø to G3/8 L push-in connector	QSL-3/8-12	Pneumatic	1	Festo	6,36 €	6,36 €	website
8mm Ø to G1/4 L push-in connector	QSL-1/4-8	Pneumatic	2	Festo	3,85 €	7,70 €	website
Exhaust fitting	UC-QS-8	Pneumatic	2	Festo	4,54 €	9,08 €	website
Cable gland	669-4673	Electric	3	RS PRO	4,09 €	12,27 €	website
Simatic S7-1200 PLC	Simatic S7-1200	Electric	1	Siemens	588,80 €	588,80 €	website
Output module	SM-1222	Electric	1	Siemens	112,80 €	112,80 €	website
Variable Frequency Drive	6SL3210-1PC25-4UL0	Electric	1	Siemens	1.761,96 €	1.761,96 €	website
24-Volt Supply	6EP1333-1LB00	Electric	1	Siemens	98,01 €	98,01 €	website
Differential Switch 300mA	5SV3646-6	Electric	1	Siemens	290,40 €	290,40 €	website

Differential Switch 30mA	5SV5312-0FB	Electric	1	Siemens	47,95 €	47,95 €	website
Circuit breaker 4-poles	5SL6432-7	Electric	1	Siemens	40,83 €	40,83 €	website
Circuit breaker 2-poles 20A	A9D17220	Electric	1	Schneider	14,42 €	14,42 €	website
Circuit breaker 2-poles 16A	A9D17216	Electric	1	Schneider	16,02 €	16,02 €	website
Isolator switch	466-144	Electric	1	RS PRO	28,03 €	28,03 €	website
Signaling column	8WD4420-5AC	Electric	4	Siemens	96,74 €	386,96 €	website
Terminal connections & ends	3209510	Electric	50	Phoenix	1,75 €	87,50 €	website
Pneumatic cabinet	GN406020	Pneumatic	1	IDE	124,09 €	124,09 €	Email communication
Electrical cabinet	GN10012040PD	Electric	1	IDE	620,83 €	620,83 €	Email communication

TOTAL	44.344,93 €

1.2 Formal offers obtained from companies

TARJOUS

Numero	Päiväys	Sivu
12435	15.5.2023	1 (2)

BUSCH VACUUM SOLUTIONS

Laskutusosoite
Ab Yrkeshögskolan vid Åbo Akademi
Yrkeshögskolan Novia
PL 853
00026 BASWARE

Viitteemme: 2169 SHA 3040
Myyjä: Sami Haulivuori | +358505275749
Yhteyshenkilönne: Arnau Rue Morano
Viitteenne:

Toimitusosoite
Ab Yrkeshögskolan vid Åbo Akademi
Yrkeshögskolan Novia
PL 853
00026 BASWARE

Tarjouksen laajuus

Pos	Koodi	Nimike	Määrä	Yks	a-hinta (EUR)	Yhteensä
1	1321137532	Samos SB 1400 D 0H0 UMXX 18,5kW; D/Y; 200-240V/346-415V; 50Hz 21,5kW; D/Y; 220-275V/380-480; 60Hz 3000/3600rpm; ins.cl.F; IP54 UL-certified Connection G4 50Hz: p max. -310/ +320hPa 60Hz: p max. -300/ +280hPa	1,00	kpl	4100,00	4100,00
2	SCH.SYS	DB Schenker Express lavarahti	1,00	kpl	115,00	115,00

Veroton summa		**4215,00**
Alv-erittely		
+ Alv 24%	4 215,00	1011,60
Alv yhteensä		1011,60
Yhteensä	**EUR**	**5226,60**

(Formal quote requested to Busch Vakuumteknik Oy)

AR VACUUM TECHNOLOGY

Miembro de aiftop Oleohidráulica y Neumática

OFERTA

AR VACUUM TECHNOLOGY
Samontà 6-C, P.I. Fontsanta
08970 SANT JOAN DESPI
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www.ar-vacuum.com
Tel (+34) 93 480 88 70
Fax (+34) 93 373 02 84

AR VACUUM TECHNOLOGY S.L. NIF: B67690818 / VIES-VAT Number: ESB67690818

Nº Oferta	Fecha	Página	[redacted]
1247	[redacted]	1 / 1	
NIF Cliente	Código Proveedor	Código cliente	[redacted]
[redacted]		[redacted]	

Artículo	Descripción	Uds.	Precio	%Desc.	Importe EUR
VARVMANG65NRL	Válv. mang de caucho calidad alimentaria para prod semisolidos o pulverulentos Ø 65 (R 2 1/2")	1,00	1.208,06	[redacted]	[redacted]

(Formal quote requested to AR-Vacuum)

Appendix 2: Process components' technical information

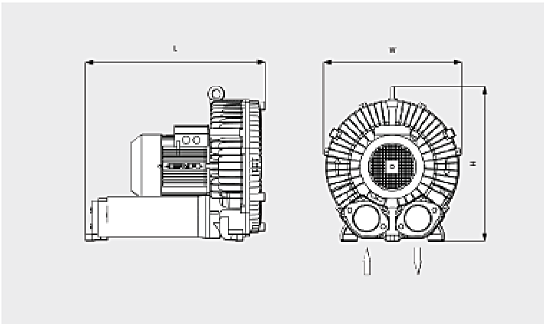
2.1 Vacuum Pump datasheet

SAMOS SB 0710–1400 D0

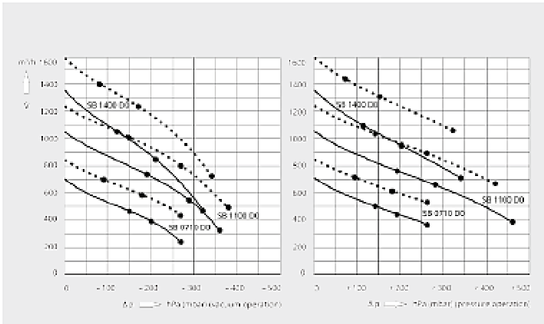
Side channel blowers

BUSCH
VACUUM SOLUTIONS

Dimensional drawing



Pumping speed/Volume flow
Air at 20ºC. Tolerance: ± 10%   __ 50 Hz ..... 60 Hz



	SAMOS SB 0710 D0	SAMOS SB 0710 D0	SAMOS SB 0710 D0
Nominal pumping speed/volume flow	700 / 840 m³/h (50 / 60 Hz)	700 / 840 m³/h (50 / 60 Hz)	700 / 840 m³/h (50 / 60 Hz)
Max. differential pressure (vacuum version)	-150 / -90 hPa (mbar) (50 / 60 Hz)	-200 / -180 hPa (mbar) (50 / 60 Hz)	-270 hPa (mbar) (50 / 60 Hz)
Max. differential pressure (overpressure version)	+140 / +90 hPa (mbar) (50 / 60 Hz)	+190 / +180 hPa (mbar) (50 / 60 Hz)	+260 hPa (mbar) (50 / 60 Hz)
Nominal motor rating	4.0 / 4.6 kW (50 / 60 Hz)	5.5 / 6.3 kW (50 / 60 Hz)	7.5 / 8.6 kW (50 / 60 Hz)
Nominal motor speed	2850 / 3450 min⁻¹ (50 / 60 Hz)	2850 / 3450 min⁻¹ (50 / 60 Hz)	2850 / 3450 min⁻¹ (50 / 60 Hz)
Noise level (ISO 3744)	70 / 74 dB(A) (50 / 60 Hz)	70 / 74 dB(A) (50 / 60 Hz)	70 / 74 dB(A) (50 / 60 Hz)
Weight approx.	112 kg	126 kg	128 kg
Dimensions (L x W x H)	495 x 498 x 514 mm	495 x 498 x 514 mm	495 x 498 x 514 mm
Gas inlet / outlet	G 2½" / G 2½"	G 2½" / G 2½"	G 2½" / G 2½"

(Source: www.buschvacuum.com)

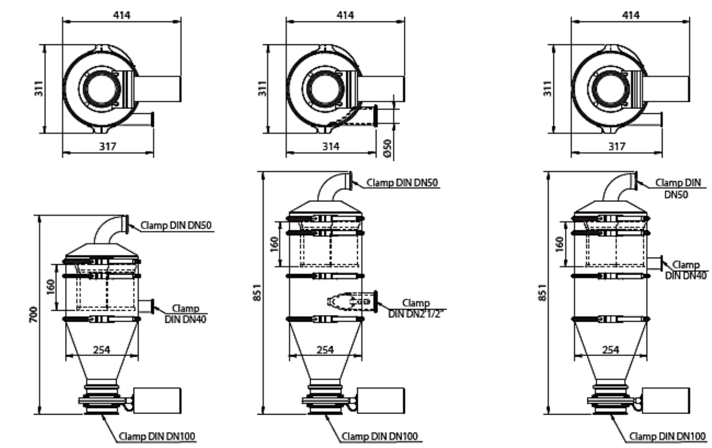
2.2 Storage Tanks datasheet

TRANSPORTE POR VACÍO
VACUUM CONVEYING

TOLVAS
VACUUM CONVEYORS

TMF

INFO	
Tolvas diseñadas especialmente para farmacia *Vacuum conveyors designed for pharmacy industry*	Modelos específicos para comprimidos *With specific pills models*
Pulido espejo interno y externo R_a=0,8 µ *Internal and external mirror polished R_a=0,8 µ*	Construcción robusta *Robust construction*



CARACTERÍSTICAS · *CHARACTERISTICS*

		6 L	6L PLS	13 L
Volumen interno *Internal volume*	[L]	6	6	13
Conexión de aspiración *Convey pipeline connection*	[mm]	Clamp DIN DN40	Clamp DIN DN65	Clamp DIN DN40
Conexión de descarga *Unload pipeline connection*	[mm]	Clamp DIN DN100	Clamp DIN DN150	Clamp DIN DN100
Temperatura de trabajo *Working Temperature*	[ºC]	-20 ... 70	-20 ... 70	-20 ... 70
Peso *Weight*	[Kg]	16,5	18,8	19
Materiales *Materials*: Módulos *Modules*		AISI 316L	AISI 316L	AISI 316L
Juntas *Rubber seals*		Silicona FDA *Silicone*	Silicona FDA *Silicone*	Silicona FDA *Silicone*
Filtros *Filters*		Poliester, Inox *Polyester, SS*	Poliester, Inox *Polyester, SS*	Poliester, Inox *Polyester, SS*
Jaulas de filtros *Filters cages*		AISI 304	AISI 304	AISI 304
Soportes jaulas *Cage support*		Delrin	Delrin	Delrin

CÓMO PEDIR · *HOW TO ORDER*

	6 L	6L PLS	13 L
Tolva de aspiración modular con entrada tangencial *Modular suction conveyor with tangent entrance*	TMF06TCSBC0	TMF06TCSBR0	TMF13TCSBC0

	Conjuntos con generador neumático
Presión de aire necesaria	> 5,5 bar para alimentación del generador y maniobra de descarga y soplado MÁXIMO 2 bar para válvula neumática de manguito anti-retorno (opcional)
Consumo de aire (Nl/min)	Ver manual específico del generador
Temperatura de ambiente permitida	-20 a 70º C
Material del cuerpo tolva y abrazaderas	INOX 316 L

(Source: ar-vacuum.com)

2.3 Pinch valves datasheet

E EN

Valvula de Manguito
Pinch Valve

Hoja Técnica
Technical Data Sheet

Descripción *Description*

Válvula neumática de manguito de NRL para productos semisolidos o pulverulentos. Funcionamiento: Válvula ON/OFF. La válvula cierra al aplicar aire comprimido en el cuerpo.

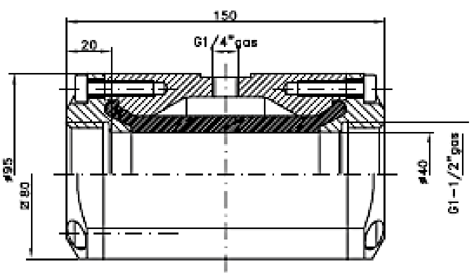
Pneumatic pinch valve of NRL for dusty or semi-solid products. Funcion: valve ON/OFF. The valve closes when compressed air is applied to the entrance port.

Especificaciones *Specifications*

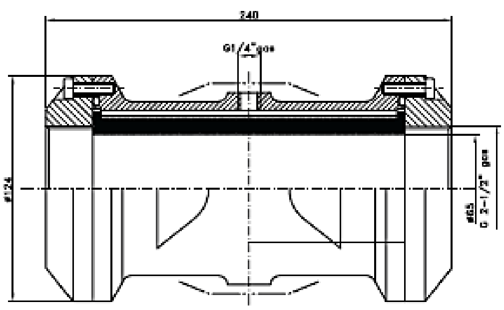
Válvula ***Valve***	**Ø40**	**Ø65**
Presión de pilotaje *Pilot pressure*	**2** a *to* **2.5 bar**	
Presión de fluido *Fluid Pressure*	**0** a *to* **4 bar**	
Fluido de control *Control Fluid*	aire comprimido *compressed air*	
Rango de temperatura ambiente *Enviromental range temperature*	**-20ºC** a *to* **+50ºC**	
Montaje *Mounting*	cualquier posición *any position*	
Función *Function*	**2/2** normalmente abierta en reposo ***2/2*** *normally opened at rest*	
Materiales *Materials*	POM blanco, NRL, aluminio, acero *White POM, NRL, aluminium, steel*	
Volumen *Volumen*	**0,13 L**	**0,49 L**
Peso *Weight*	**0,9 Kg**	**2,8 Kg**

Dimensiones *Dimensions*

VARVMANG40NRL



VARVMANG65NRL



Referencias *References*

Válvula *Valve*	**VARVMANG40NRL**	**VARVMANG65NRL**
Recambio *Spare Parts*	**VARVMANG40KITNRL**	**VARVMANG65KITNRL**

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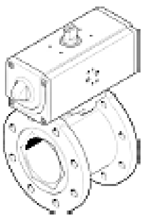
ar@ar-vacuum.com www.ar-vacuum.com
02 Marzo *March* 2023

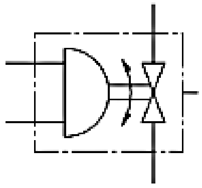
(Source: ar-vacuum.com)

2.4 Ball valves datasheet

Ball valve actuator unit
VZBC-100-FF-16-22-F0710-V4V4T-PP240-R-90-C
Part number: 1913374

FESTO





Data sheet

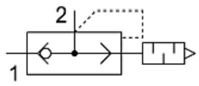
Feature	Value
Structural design	2-way ball valve Quarter turn actuator
Actuation type	Pneumatic
Mounting position	Any
Type of mounting	Line installation
Fitting connection	Ring housing with threaded flange
Switching position indication	Slot direction = flow direction
Nominal width DN	100
Operating pressure	6 bar ... 8.4 bar
Nominal pressure of fitting PN	16
Symbol	00991921
Medium	Compressed air as per ISO 8573-1:2010 [-:-:-] Inert gas Water – no water vapor Neutral liquids
Operating medium	Compressed air as per ISO 8573-1:2010 [7:4:4]
Information on operating and pilot media	Operation with oil lubrication possible (required for further use)
Temperature of medium	-10 °C ... 200 °C
Ambient temperature	-10 °C ... 80 °C
Flow rate Kv	1414 m^3/h
Max. surface temperature of assembly	TX
Explosion group of assembly	IIC, IIIC
Note on materials	RoHS-compliant
LABS (PWIS) conformity	VDMA24364 zone III
Housing material	High-alloy stainless steel
Material number of housing	1.4408
Seals material	PTFE PTFE-reinforced
Ball material	High-alloy stainless steel
Material number for ball	1.4408
Shaft material	High-alloy stainless steel
Material number for shaft	1.4401
Product weight	26000 g
Explosion prevention and protection	Zone 1 (ATEX) Zone 2 (ATEX) Zone 21 (ATEX) Zone 22 (ATEX)

(Source: Festo Quick Search)

2.5 Rapid exhaust valve datasheet

Quick exhaust valve
SEU-1/4
Part number: 6753

FESTO



Data sheet

Feature	Value
Valve function	Quick exhaust
Selection of additional function	with muffler
Pneumatic connection 1	G1/4
Pneumatic connection 2	G¼
Type of mounting	Screw-in
Standard nominal flow rate exhaust air 6->5 bar	1100 l/min
Standard flow rate exhaust 6-> 0 bar	2300 l/min
Standard nominal flow rate pressurization 6->5 bar	960 l/min
Operating pressure	0.5 bar ... 10 bar
Ambient temperature	-20 °C ... 75 °C
Housing material	Die-cast zinc
Operating medium	Compressed air as per ISO 8573-1:2010 [7:-:-]
Nominal width	7 mm
Mounting position	Any
Symbol	00991460
Information on operating and pilot media	Operation with oil lubrication possible (required for further use)
LABS (PWIS) conformity	VDMA24364-B1/B2-L
Temperature of medium	-20 °C ... 75 °C
Noise level	95 dB(A)
Product weight	120 g
Seals material	NBR

(Source: Festo Quick Search)

2.6 Air reservoir datasheet

Air reservoir
CRVZS-2
Part number: 160236

FESTO

Data sheet

Feature	Value
Volume	2 l
Mounting position	Any
Conforms to standard	AD 2000
Symbol	00991528
Operating pressure	-0.095 MPa ... 1.6 MPa
Operating pressure	-0.95 bar ... 16 bar
Operating pressure	-13.78 psi ... 232 psi
Certification	CRN German Technical Control Board (TÜV)
Certificate issuing authority	TSSACRN0H17477.5C
Operating medium	Compressed air as per ISO 8573-1:2010 [-:-:-] Nitrogen
Corrosion resistance class (CRC)	3 - High corrosion stress
LABS (PWIS) conformity	VDMA24364-B1/B2-L
For use in the food industry	See supplementary material information
Temperature of medium	-10 °C ... 100 °C
Ambient temperature	-10 °C ... 100 °C
Max. tightening torque for connecting thread	55 Nm
Product weight	1681 g
Type of mounting	With through-hole
Pneumatic connection	G1/2
Note on materials	RoHS-compliant
Air reservoir material	High-alloy stainless steel

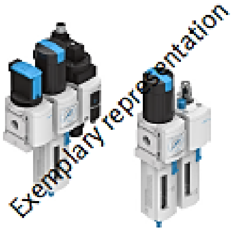
(Source: Festo Quick Search)

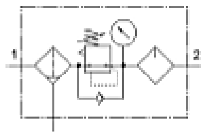
Appendix 3: Pneumatic components' technical information

3.1 MS4 vs MS6 series

Air preparation combination unit
MSB4
Part number: 531029

FESTO





Data sheet

Overall data sheet – Individual values depend upon your configuration.

Feature	Value
Size	4
Series	MS
Actuation type	Electrical Manual Pneumatic
Actuator lock	Rotary knob with integrated lock
Mounting position	Any Vertical +/- 5°
Grade of filtration	0.01 µm ... 40 µm
Condensate drain	Fully automatic Manually rotating Semi-automatic
Structural design	Branching module Active carbon filter Pressure regulator with pressure gauge Soft start valve Shut off valve Fiber filter Filter regulator with pressure gauge Filter regulator without pressure gauge Membrane dryer Proportional standard oil mist lubricator Sinter filter with centrifugal separator with non-return function
Controller function	Outlet pressure constant With primary pressure compensation With secondary exhausting With return flow function
Bowl guard	Plastic bowl guard
Symbol	00991761
Differential pressure display	Visual display With pressure sensor
Pressure gauge	with pressure sensor with pressure gauge
Operating pressure	1.5 bar ... 14 bar
Pressure regulation range	1 bar ... 12 bar
Standard nominal flow rate	800 l/min ... 1400 l/min
Coil characteristics	110 V AC: 50/60 Hz, initial power 3.0 VA, holding power 2.4 VA 230 V AC: 50/60 Hz, initial power 3.0 VA, holding power 2.4 VA 24 V DC: 1.5 W 24 V DC: 1.8 W

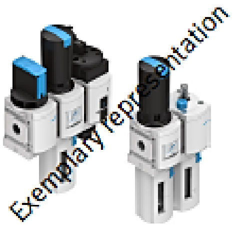
Feature	Value
Certification	c UL us - Recognized (OL)
CE marking (see declaration of conformity)	As per EU EMC directive as per EU explosion protection directive (ATEX) As per EU low voltage directive
UKCA marking (see declaration of conformity)	acc. to UK EX instructions
Explosion protection certification outside the EU	EPL Db (GB) EPL Gb (GB)
Explosion prevention and protection	Zone 1 (ATEX) Zone 1 (UKEX) Zone 2 (ATEX) Zone 21 (ATEX) Zone 21 (UKEX) Zone 22 (ATEX)
ATEX category gas	II 2G II 3G
ATEX category for dust	II 2D II 3D
Type of ignition protection for gas	Ex h IIC T6 Gb X Ex nA IIC T4 X Gc
Type of (ignition) protection for dust	Ex h IIIC T60°C Db X Ex tc IIIC T105°C X Dc IP65
Information on operating and pilot media	Operation with oil lubrication possible (required for further use)
Corrosion resistance class (CRC)	2 - Moderate corrosion stress
LABS (PWIS) conformity	VDMA24364-B1/B2-L
Storage temperature	-10 °C ... 60 °C
For use in the food industry	See supplementary material information
Temperature of medium	-10 °C ... 60 °C
Ambient temperature	-10 °C ... 60 °C
Type of mounting	With accessories
Pneumatic connection 1	G1/8 G1/4
Pneumatic connection 2	G1/8 G¼
Pneumatic connection 3	G1/4
Housing material	Die-cast aluminum
Material of bowl	PC

(Source: Festo Quick Search)

Air preparation combination unit MSB6

Part number: 531030

FESTO



Data sheet

Overall data sheet – Individual values depend upon your configuration.

Feature	Value
Size	6
Series	MS
Actuation type	Electrical Manual Pneumatic
Actuator lock	Rotary knob with integrated lock
Mounting position	Vertical +/- 5°
Grade of filtration	0.01 µm ... 40 µm
Structural design	Branching module Active carbon filter Pressure regulator with pressure gauge Soft start/quick exhaust valve Soft start valve Air flow sensor Shut off valve Fiber filter Filter regulator with pressure gauge Filter regulator without pressure gauge Membrane dryer Proportional standard oil mist lubricator Sinter filter with centrifugal separator Water trap Electrically adjustable pressure regulator Pilot-controlled precision diaphragm regulator
Controller function	Outlet pressure constant With primary pressure compensation With secondary exhausting With return flow function
Bowl guard	Plastic bowl guard Integrated as metal bowl guard
Differential pressure display	Visual display With pressure sensor
Pressure gauge	with pressure sensor with pressure gauge
Operating pressure	1.5 bar ... 20 bar
Pressure regulation range	1 bar ... 12 bar
Standard nominal flow rate	1700 l/min ... 4800 l/min
Coil characteristics	110 V AC: 50/60 Hz, initial power 3.0 VA, holding power 2.4 VA 230 V AC: 50/60 Hz, initial power 3.0 VA, holding power 2.4 VA 24 V DC: 1.5 W 24 V DC: 1.8 W
Certification	c UL us - Recognized (OL)

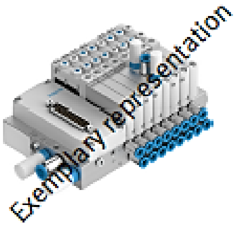
Feature	Value
CE marking (see declaration of conformity)	As per EU EMC directive as per EU explosion protection directive (ATEX) As per EU low voltage directive
UKCA marking (see declaration of conformity)	acc. to UK EX instructions
Explosion protection certification outside the EU	EPL Db (GB) EPL Gb (GB)
Explosion prevention and protection	Zone 1 (ATEX) Zone 1 (UKEX) Zone 2 (ATEX) Zone 21 (ATEX) Zone 21 (UKEX) Zone 22 (ATEX)
ATEX category gas	II 2G II 3G
ATEX category for dust	II 2D II 3D
Type of ignition protection for gas	Ex h IIC T6 Gb X Ex nA IIC T4 X Gc
Type of (ignition) protection for dust	Ex h IIIC T60°C Db X Ex tc IIIC T105°C X Dc IP65
Corrosion resistance class (CRC)	2 - Moderate corrosion stress
LABS (PWIS) conformity	VDMA24364-B1/B2-L
Storage temperature	-10 °C ... 60 °C
For use in the food industry	See supplementary material information
Type of mounting	With accessories
Housing material	Die-cast aluminum
Material of bowl	PC

(Source: Festo Quick Search)

3.2 VTUG characteristics according to size

Valve manifold
VTUG
Part number: 573606

FESTO



Data sheet

Overall data sheet – Individual values depend upon your configuration.

Feature	Value
Electrical actuation	AP interface Individual connection Fieldbus I-Port IO-Link® Multi-pin
Electrical I/O system	no
Operating medium	Compressed air as per ISO 8573-1:2010 [7:4:4]
Pilot medium	Compressed air as per ISO 8573-1:2010 [7:4:4]
Information on operating and pilot media	Operation with oil lubrication possible (required for further use)
Temperature of medium	-5 °C ... 60 °C
Ambient temperature	-5 °C ... 60 °C
Storage temperature	-10 °C ... 60 °C
Degree of protection	IP40 IP65 IP67 IP69K NEMA 4X
Corrosion resistance class (CRC)	2 - Moderate corrosion stress
Vibration resistance	Transport application test with severity level 2 as per FN 942017-4 and EN 60068-2-6
Shock resistance	Shock test with severity level 2 as per FN 942017-5 and EN 60068-2-27
Operating pressure	-0.09 MPa ... 1 MPa
Operating pressure	-0.9 bar ... 10 bar
Pilot pressure MPa	0.15 MPa ... 0.8 MPa
Pilot pressure	1.5 bar ... 8 bar
Operating pressure for valve manifold with internal pilot air supply	1.5 bar ... 8 bar
LABS (PWIS) conformity	VDMA24364-B1/B2-L
CE marking (see declaration of conformity)	As per EU EMC directive As per EU RoHS directive
UKCA marking (see declaration of conformity)	To UK instructions for EMC To UK RoHS instructions
KC characters	KC EMC
Certification	RCM compliance mark c UL us - Recognized (OL)
Certificate issuing authority	UL MH19482
Note on materials	RoHS-compliant
Seals material	HNBR NBR

Feature	Value
Valve manifold design	Fixed grid
Max. no. of valve positions	24
Max. no. of pressure zones	13
Actuation type	Electrical
Valve function	2x3/2, closed, monostable 2x3/2, open, monostable 2x3/2, open/closed, monostable 3/2, closed, monostable 3/2, open, monostable 5/2, bistable 5/2, monostable 5/3, pressurized 5/3, exhausted 5/3, closed
Structural design	Piston gate valve
Sealing principle	Soft
Type of control	Pilot-controlled
Valve size	18 mm
Pilot air supply port	External Internal
Max. standard nominal flow rate	330 l/min at 10 mm 630 l/min at 14 mm 1200 l/min at 18 mm
Standard nominal flow rate	130 l/min ... 1150 l/min
Suitability for vacuum	yes
Exhaust air function	With flow control option
Pneumatic working port	M5 M7 G1/8 G1/4 QS-3 QS-4 QS-6 QS-8 QS-10 QS-5/32 QS-1/8 QS-3/16 QS-1/4 QS-5/16 QS-3/8
Pneumatic connection 1	G1/8 G1/4 G3/8 QS-3 QS-4 QS-6 QS-8 QS-10 QS-12 QS-16 QS-1/4 QS-5/16 QS-3/8 QS-1/2
Pilot air port 12/14	G1/8
Signal status display	LED
Nominal operating voltage DC	24 V
Permissible voltage fluctuations	+/- 10 % +/- 25 %
Nominal pick-up current per solenoid coil	47 mA to 20 ms
Nominal current with current reduction	15.5 mA after 20 ms

(Source: Festo Quick Search)

3.3 Connecting cable datasheet

www.festo.com

4 Pages, 172KB

Connecting cable, Sub-D

Technical data

FESTO

Connecting cable KMP6

- Connecting cable for multi-pin plug connection
- Pre-assembled
- Cable lengths 2.5 m, 5 m or 10 m
- 9-pin, 15-pin, 25-pin or 26-pin
- Sub-D

General technical data

Type		KMP6-09P-8-...	KMP6-15P-12-...	KMP6-25P-12-...	KMP6-25P-20-...	KMP6-26P-16-...
Electrical connection		Straight socket Sub-D 9-pin	Straight socket Sub-D 15-pin	Straight socket Sub-D 25-pin	Straight socket Sub-D 25-pin	Straight socket Sub-D 26-pin
		Open cable end 9-wire	Open cable end 15-wire	Open cable end 15-wire	Open cable end 25-wire	Open cable end 20-wire
Type of mounting		Via through-hole				
Mounting position		Any				
Operating voltage range	[V DC]	0 ... 24				
Acceptable current load	[A]	2.8	2.8	2.8	2.8	2.5
Cable composition	[mm^2]	8x0.34	15x0.34	15x0.34	20x0.25	20x0.25
	[mm^2]	1x0.5	–	–	5x0.34	–
Cable diameter	[mm]	7.6	8.5	8.5	10.3	8.6
Degree of protection to EN 60529		IP40 (assembled)				

Materials

Housing	PBT reinforced
Pin contacts	Gold-plated copper alloy
Cable sheath	PVC

Operating and environmental conditions

Ambient temperature	[°C]	–30 ... +80
Ambient temperature with flexible cable installation	[°C]	–5 ... +80

Appendix 4: Electric components' technical information

4.1 Programmable Logic Controller

media.automation24.com

7 pages, 140 KB

SIEMENS

Data sheet **6ES7215-1AG40-0XB0**

SIMATIC S7-1200, CPU 1215C, compact CPU, DC/DC/DC, 2 PROFINET ports, onboard I/O: 14 DI 24 V DC; 10 DO 24 V DC; 0.5A; 2 AI 0-10 V DC, 2 AO 0-20 mA DC, Power supply: DC 20.4-28.8V DC, Program/data memory 125 KB

General information	
Product type designation	CPU 1215C DC/DC/DC
Firmware version	V4.4
Engineering with	
• Programming package	STEP 7 V16 or higher
Supply voltage	
Rated value (DC)	
• 24 V DC	Yes
permissible range, lower limit (DC)	20.4 V
permissible range, upper limit (DC)	28.8 V
Reverse polarity protection	Yes
Load voltage L+	
• Rated value (DC)	24 V
• permissible range, lower limit (DC)	20.4 V
• permissible range, upper limit (DC)	28.8 V
Input current	
Current consumption (rated value)	500 mA
Current consumption, max.	1 500 mA; CPU with all expansion modules
Inrush current, max.	12 A; at 28.8 V DC
I^2t	0.5 $A^2 \cdot s$
Output current	
for backplane bus (5 V DC), max.	1 600 mA; Max. 5 V DC for SM and CM
Encoder supply	
24 V encoder supply	
• 24 V	L+ minus 4 V DC min.
Power loss	
Power loss, typ.	12 W
Memory	
Work memory	
• integrated	125 kbyte
• expandable	No
Load memory	
• integrated	4 Mbyte
• Plug-in (SIMATIC Memory Card), max.	with SIMATIC memory card
Backup	
• present	Yes
• maintenance-free	Yes

4.2 Digital outputs Module

SIEMENS

Data sheet **6ES7222-1BF32-0XB0**

SIMATIC S7-1200, Digital output SM 1222, 8 DO, 24 V DC, transistor 0.5 A

General information	
Product type designation	SM 1222, DQ 8x24 V DC/0.5 A
Supply voltage	
permissible range, lower limit (DC)	20.4 V
permissible range, upper limit (DC)	28.8 V
Input current	
from backplane bus 5 V DC, max.	120 mA
Power loss	
Power loss, typ.	1.5 W
Digital outputs	
Number of digital outputs	8
• in groups of	1
Short-circuit protection	No; to be provided externally
Limitation of inductive shutdown voltage to	typ. (L+) -48 V
Switching capacity of the outputs	
• with resistive load, max.	0.5 A
• on lamp load, max.	5 W
Output voltage	
• Rated value (DC)	24 V
• for signal "0", max.	0.1 V; with 10 kOhm load
• for signal "1", min.	20 V DC
Output current	
• for signal "1" rated value	0.5 A
• for signal "0" residual current, max.	10 µA
Output delay with resistive load	
• "0" to "1", max.	50 µs
• "1" to "0", max.	200 µs
Total current of the outputs (per group)	
horizontal installation	
— up to 50 °C, max.	4 A; Current per mass
Cable length	
• shielded, max.	500 m
• unshielded, max.	150 m
Interrupts/diagnostics/status information	
Alarms	
• Diagnostic alarm	Yes
Diagnostics indication LED	
• for status of the outputs	Yes
Potential separation	
Potential separation digital outputs	

• between the channels, in groups of	1
• between the channels and backplane bus	500 V AC
Degree and class of protection	
IP degree of protection	IP20
Standards, approvals, certificates	
CE mark	Yes
CSA approval	Yes
UL approval	Yes
cULus	Yes
FM approval	Yes
RCM (formerly C-TICK)	Yes
KC approval	Yes
Marine approval	Yes
Ambient conditions	
Free fall	
• Fall height, max.	0.3 m; five times, in product package
Ambient temperature during operation	
• min.	-20 °C
• max.	60 °C
• horizontal installation, min.	-20 °C
• horizontal installation, max.	60 °C
• vertical installation, min.	-20 °C
• vertical installation, max.	50 °C
• permissible temperature change	5°C to 55°C, 3°C / minute
Ambient temperature during storage/transportation	
• min.	-40 °C
• max.	70 °C
Air pressure acc. to IEC 60068-2-13	
• Storage/transport, min.	660 hPa
• Storage/transport, max.	1 080 hPa
Relative humidity	
• Operation at 25 °C without condensation, max.	95 %
connection method / header	
required front connector	Yes
Mechanics/material	
Enclosure material (front)	
• Plastic	Yes
Dimensions	
Width	45 mm
Height	100 mm
Depth	75 mm
Weights	
Weight, approx.	180 g

(Source: www.automation.siemens.com)

4.3 Variable Frequency Drive

SIEMENS

Data sheet for SINAMICS G120C

Article No. : 6SL3210-1KE23-2UF1

Figure similar

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

Item no. :
Consignment no. :
Project :

Rated data		
Input		
Number of phases	3 AC	
Line voltage	380 ... 480 V +10 % -20 %	
Line frequency	47 ... 63 Hz	
Rated current (LO)	40.60 A	
Rated current (HO)	36.40 A	
Output		
Number of phases	3 AC	
Rated voltage	**400V IEC**	**480V NEC[1)]**
Rated power (LO)	15.00 kW	20.00 hp
Rated power (HO)	11.00 kW	15.00 hp
Rated current (LO)	31.00 A	
Rated current (HO)	25.00 A	
Rated current (IN)	32.00 A	
Max. output current	50.00 A	
Pulse frequency	4 kHz	
Output frequency for vector control	0 ... 240 Hz	
Output frequency for V/f control	0 ... 550 Hz	
Overload capability		
Low Overload (LO)		
150 % base load current IL for 3 s, followed by 110 % base load current IL for 57 s in a 300 s cycle time		
High Overload (HO)		
200 % base load current IH for 3 s, followed by 150 % base load current IH for 57 s in a 300 s cycle time		

General tech. specifications	
Power factor λ	0.70 ... 0.85
Offset factor cos φ	0.95
Efficiency η	0.97
Sound pressure level (1m)	66 dB
Power loss	361.0 W
Filter class (integrated)	Unfiltered

Communication	
Communication	PROFINET, EtherNet/IP

Inputs / outputs	
Standard digital inputs	
Number	6
Switching level: 0→1	11 V
Switching level: 1→0	5 V
Max. inrush current	15 mA
Fail-safe digital inputs	
Number	1
Digital outputs	
Number as relay changeover contact	1
Output (resistive load)	DC 30 V, 0.5 A
Number as transistor	1
Output (resistive load)	DC 30 V, 0.5 A
Analog / digital inputs	
Number	1 (Differential input)
Resolution	10 bit
Switching threshold as digital input	
0→1	4 V
1→0	1.6 V
Analog outputs	
Number	1 (Non-isolated output)
PTC/ KTY interface	
1 motor temperature sensor input, sensors that can be connected PTC, KTY and Thermo-Click, accuracy ±5 °C	

Closed-loop control techniques	
V/f linear / square-law / parameterizable	Yes
V/f with flux current control (FCC)	Yes
V/f ECO linear / square-law	Yes
Sensorless vector control	Yes
Vector control, with sensor	No
Encoderless torque control	No
Torque control, with encoder	No

SIEMENS

Data sheet for SINAMICS G120C

Article No. : 6SL3210-1KE23-2UF1

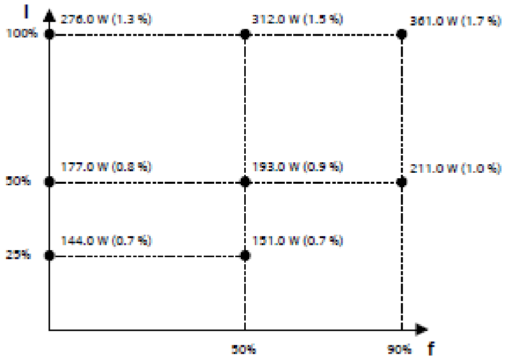
Ambient conditions	
Cooling	Air cooling using an integrated fan
Cooling air requirement	0.018 m³/s (0.636 ft³/s)
Installation altitude	1,000 m (3,280.84 ft)
Ambient temperature	
Operation	-10 ... 40 °C (14 ... 104 °F)
Transport	-40 ... 70 °C (-40 ... 158 °F)
Storage	-40 ... 70 °C (-40 ... 158 °F)
Relative humidity	
Max. operation	95 % At 40 °C (104 °F), condensation and icing not permissible

Connections	
Signal cable	
Conductor cross-section	0.15 ... 1.50 mm² (AWG 24 ... AWG 16)
Line side	
Version	Plug-in screw terminals
Conductor cross-section	6.00 ... 16.00 mm² (AWG 10 ... AWG 6)
Motor end	
Version	Plug-in screw terminals
Conductor cross-section	6.00 ... 16.00 mm² (AWG 10 ... AWG 6)
DC link (for braking resistor)	
Version	Plug-in screw terminals
Conductor cross-section	6.00 ... 16.00 mm² (AWG 10 ... AWG 6)
Line length, max.	15 m (49.21 ft)
PE connection	On housing with M4 screw
Max. motor cable length	
Shielded	150 m (492.13 ft)
Unshielded	150 m (492.13 ft)

Mechanical data	
Degree of protection	IP20 / UL open type
Frame size	FSC
Net weight	4.40 kg (9.70 lb)
Dimensions	
Width	140 mm (5.51 in)
Height	295 mm (11.61 in)
Depth	208 mm (8.19 in)

Standards	
Compliance with standards	UL, cUL, CE, C-Tick (RCM)
CE marking	EMC Directive 2004/108/EC, Low-Voltage Directive 2006/95/EC

Converter losses to IEC61800-9-2*	
Efficiency class	IE2
Comparison with the reference converter (90% / 100%)	33.3 %



The percentage values show the losses in relation to the rated apparent power of the converter.

The diagram shows the losses for the points (as per standard IEC61800-9-2) of the relative torque generating current (I) over the relative motor stator frequency (f). The values are valid for the basic version of the converter without options/components.

*converted values

[1)] The output current and HP ratings are valid for the voltage range 440V-480V

(Source: mall.industry.siemens.com)

4.4 Power supply

www.automation.siemens.com

3 Pages, 189 KB

SIEMENS

Data sheet **6EP1333-1LB00**

SITOP PSU100L/1AC/24VDC/5A

SITOP PSU100L 24 V/5 A Stabilized power supply input: 120/230 V AC, output: 24 V DC/5 A

Input	
type of the power supply network	1-phase AC
supply voltage at AC	
• initial value	Set by means of selector switch on the device
supply voltage	
• 1 at AC rated value	120 V
• 2 at AC rated value	230 V
input voltage	
• 1 at AC	93 ... 132 V
• 2 at AC	187 ... 264 V
design of input wide range input	No
overvoltage overload capability	2.3 × Vin rated, 1.3 ms
operating condition of the mains buffering	at Vin = 93/187 V
buffering time for rated value of the output current in the event of power failure minimum	20 ms
operating condition of the mains buffering	at Vin = 93/187 V
line frequency	
• 1 rated value	50 Hz
• 2 rated value	60 Hz
line frequency	47 ... 63 Hz
input current	
• at rated input voltage 120 V	2.1 A
• at rated input voltage 230 V	1.15 A
current limitation of inrush current at 25 °C maximum	32 A
duration of inrush current limiting at 25 °C	
• typical	3 ms
I2t value maximum	0.8 A²·s
fuse protection type	T 3,15 A/250 V (not accessible)
• in the feeder	Recommended miniature circuit breaker: from 6 A characteristic C
Output	
voltage curve at output	Controlled, isolated DC voltage
output voltage at DC rated value	24 V
output voltage	
• at output 1 at DC rated value	24 V
relative overall tolerance of the voltage	3 %
relative control precision of the output voltage	
• on slow fluctuation of input voltage	0.1 %
• on slow fluctuation of ohm loading	0.5 %
residual ripple	
• maximum	150 mV
• typical	50 mV
voltage peak	

4.5 Differential switch (300mA)

www.automation.siemens.com

7 pages, 1792 KB

SIEMENS

Data sheet 5SV3646-6

Residual current operated circuit breaker, 4-pole, type A, In: 63 A, 300 mA, Un AC: 400 V

Model	
Product brand name	SENTRON
Product designation	RCCB
Design of the product	Instantaneous
General technical data	
Number of poles	4
Size of installation devices / acc. to DIN 43880	1
Protection against electrical shock	Finger and back-of-hand safe
Short-circuit current rating	10 kA
circuit-breaker / Design	5SV3
Mechanical service life (switching cycles) / typical	10 000
Switching function / short-term delayed	No
Overvoltage category	III
Supply voltage	
Supply voltage	
• at AC / rated value	230/400 V
• for testing equipment / minimum	100 V
Supply voltage frequency	

4.6 Differential switch (30mA)

www.automation.siemens.com

2 pages, 490 KB

SIEMENS

Data sheet **5SV5312-0FB**

Residual current operated circuit breaker, 2-pole, Type AC, In: 25 A, 30 mA, Un AC: 230 V

Model	
product brand name	SENTRON
product designation	RCCB
design of the product	Instantaneous
General technical data	
number of poles	2
size of installation devices according to DIN 43880	1
mechanical service life (operating cycles) typical	2 000
short-circuit current of series fuse maximum permissible	63 A
short-circuit current rating	6 kA
switching function short-term delayed	No
overvoltage category	III
Supply voltage	
supply voltage for testing equipment minimum	195 V
value range of the supply voltage frequency	50 Hz
value range of the operating frequency	50 Hz
value range of the supply voltage at AC	230 V
Protection class	
protection class IP	IP20, if the distribution board is installed, with connected conductors
Switching capacity	
switching capacity current	
• according to IEC 61008-1 rated value	0.5 kA
Dissipation	
power loss [W]	
• for rated value of the current at AC in hot operating state per pole	1 W
• maximum	2 W
Product details	
product feature silicon-free	Yes
product extension installable supplementary devices	No
Connections	
connectable conductor cross-section solid	
• minimum	0.75 mm²
• maximum	35 mm²
connectable conductor cross-section stranded	
• minimum	0.75 mm²
• maximum	35 mm²
tightening torque with screw-type terminals	
• minimum	2.5 N·m
• maximum	3 N·m

4.7 4 Poles Circuit breaker (32 A)

www.automation.siemens.com

5 pages, 593 KB

SIEMENS

Data sheet **5SL6432-7**

Miniature circuit breaker 400 V 6kA, 4-pole, C, 32 A

Model	
product brand name	SENTRON
product designation	Miniature circuit breaker
General technical data	
number of poles	4
design of pole	4P
tripping characteristic class	C
mechanical service life (operating cycles) typical	10 000
overvoltage category	III
degree of pollution	2
Voltage	
type of voltage of the operating voltage	AC
insulation voltage (Ui)	
• with multi-phase operation at AC rated value	440 V
Supply voltage	
supply voltage at AC rated value	400 V
value range of the supply voltage frequency	50/60 Hz
operating voltage	
• with multi-phase operation at AC maximum	440 V
• at DC rated value maximum	72 V
Protection class	
protection class IP	IP20, with connected conductors
Switching capacity	
switching capacity current	
• according to EN 60898 rated value	6 kA
• according to IEC 60947-2 rated value	6 kA
energy limitation class	3
Dissipation	
power loss [W] for rated value of the current at AC in hot operating state per pole	3.1 W
suitability for operation	Residential buildings/infrastructure
Product details	
product feature	
• halogen-free	Yes
• sealable	Yes
• silicon-free	Yes
product extension installable supplementary devices	Yes
Connections	
connectable conductor cross-section solid	
• minimum	0.75 mm²

4.8 Monophasic circuit breaker (20 A)

www.se.com

3 pages, 87 KB

Product datasheet
Characteristics

A9K17220
miniature circuit breaker - iK60N - 2P - 20 A - C curve

Green Premium

Main

Device application	Distribution
Range	Acti 9
Product name	Acti 9 iK60
Product or component type	Miniature circuit-breaker
Device short name	IK60N
Poles description	2P
Number of protected poles	2
[In] rated current	20 A at 30 °C
Network type	AC
Trip unit technology	Thermal-magnetic
Curve code	C
Breaking capacity	6000 A Icn at 230 V AC 50/60 Hz conforming to EN/IEC 60898-1
Suitability for isolation	Yes conforming to EN/IEC 60898-1
Standards	EN/IEC 60898-1
Product certifications	AENOR

Complementary

Network frequency	50/60 Hz
Magnetic tripping limit	5...10 x In
[Ics] rated service breaking capacity	6000 A 100 % conforming to EN/IEC 60898-1 - 230 V AC 50/60 Hz
Limitation class	3 conforming to EN/IEC 60898-1
[Ui] rated insulation voltage	440 V AC 50/60 Hz conforming to EN/IEC 60898-1
[Uimp] rated impulse withstand voltage	4 kV conforming to EN/IEC 60898-1
Control type	Toggle
Local signalling	ON/OFF indication
Mounting mode	Clip-on

4.9 Monophasic circuit breaker (16 A)

www.se.com

3 pages, 87 KB

Product datasheet
Characteristics

A9K17216

miniature circuit breaker - iK60N - 2P - 16 A - C curve

Green Premium™

Main

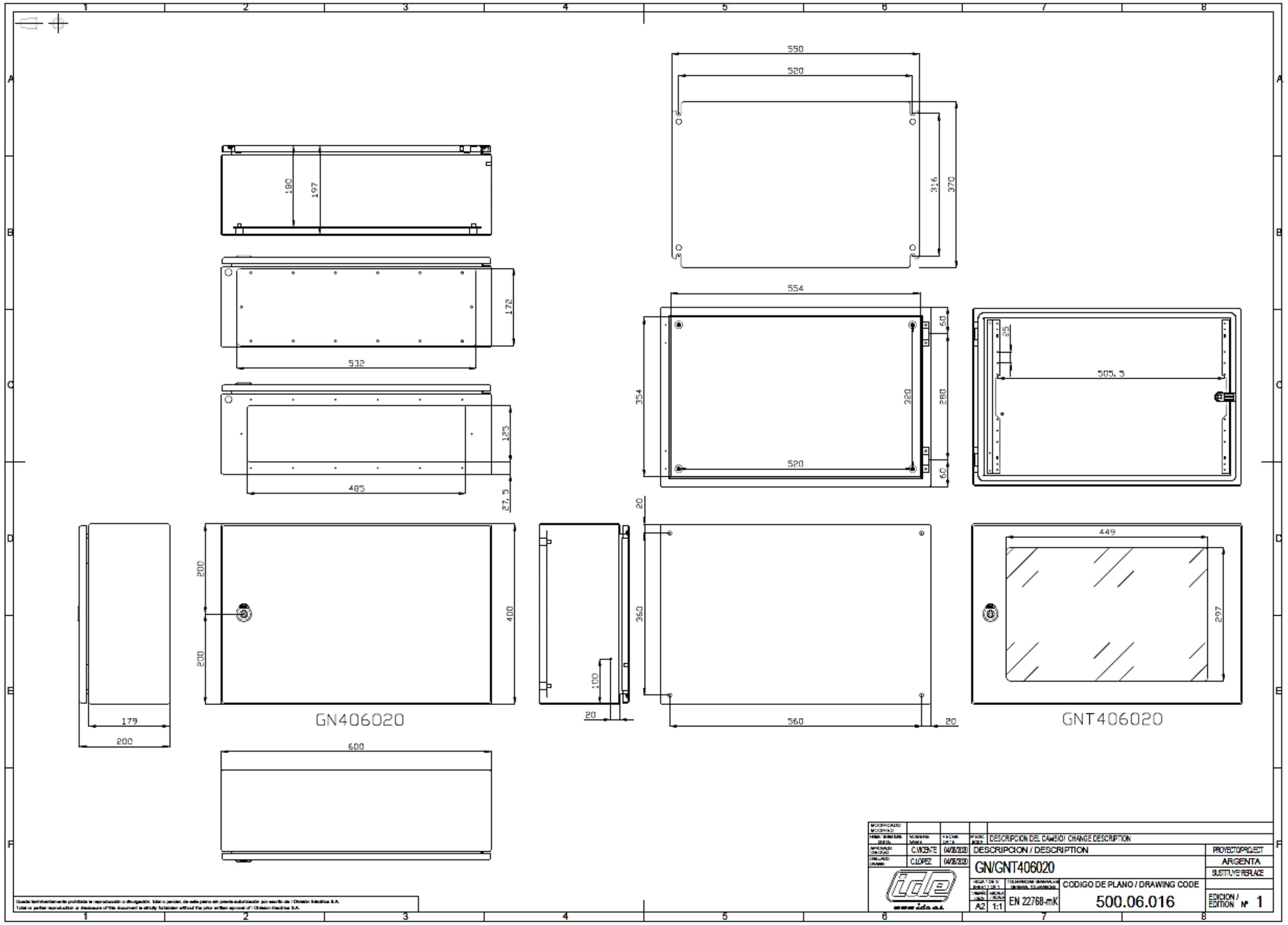
Device application	Distribution
Range	Acti 9
Product name	Acti 9 iK60
Product or component type	Miniature circuit-breaker
Device short name	IK60N
Poles description	2P
Number of protected poles	2
[In] rated current	16 A at 30 °C
Network type	AC
Trip unit technology	Thermal-magnetic
Curve code	C
Breaking capacity	6000 A Icn at 230 V AC 50/60 Hz conforming to EN/IEC 60898-1
Suitability for isolation	Yes conforming to EN/IEC 60898-1
Standards	EN/IEC 60898-1
Product certifications	AENOR

Complementary

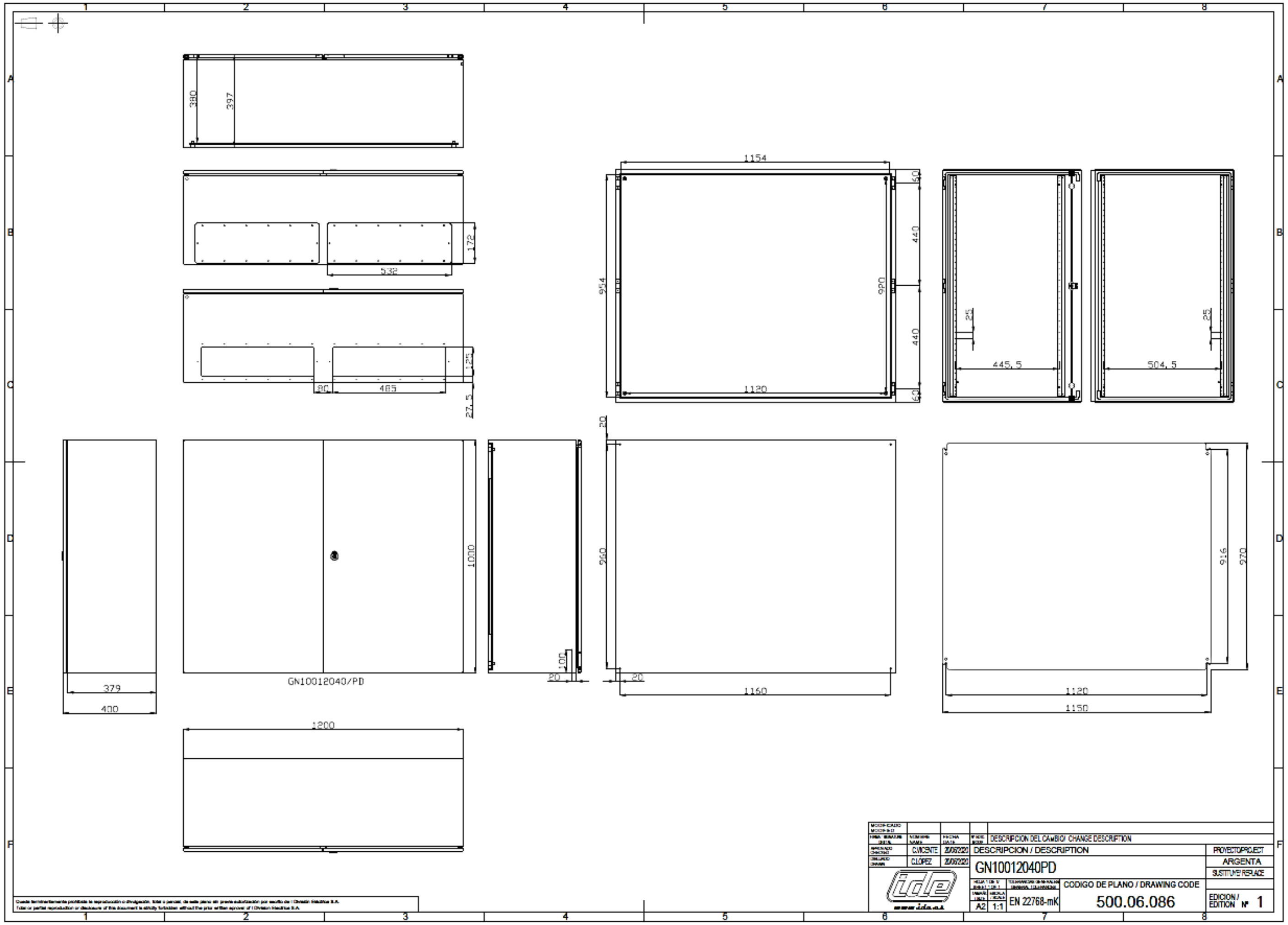
Network frequency	50/60 Hz
Magnetic tripping limit	5...10 x In
[Ics] rated service breaking capacity	6000 A 100 % conforming to EN/IEC 60898-1 - 230 V AC 50/60 Hz
Limitation class	3 conforming to EN/IEC 60898-1
[Ui] rated insulation voltage	440 V AC 50/60 Hz conforming to EN/IEC 60898-1
[Uimp] rated impulse withstand voltage	4 kV conforming to EN/IEC 60898-1
Control type	Toggle
Local signalling	ON/OFF indication
Mounting mode	Clip-on

Appendix 5: Cabinets' technical information

5.1 Pneumatic cabinet dimensions



5.2 Electric cabinet dimensions



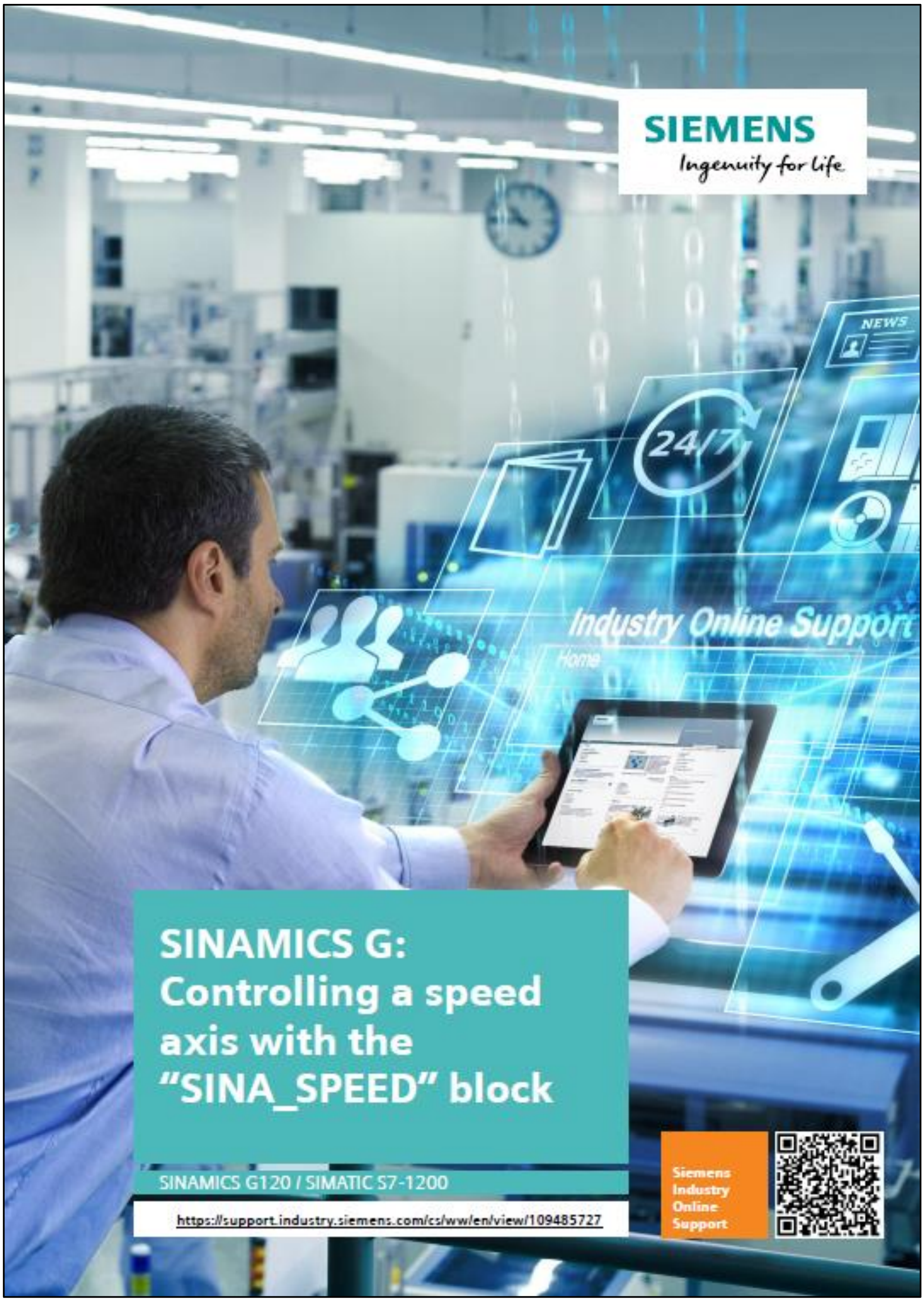
(Source: [ide.es](ide.es))

Appendix 6: Automation aspects

5.1 Sina_Speed documentation

support.industry.siemens.com

31 pages, 2160 KB



5.2 PLC TAGs

PLC tags

	Name	Tag table	Data type	Address	Retain	Acces...	Writa...	Visibl...	Comment
1	Emergency_Stop_Input	Default tag table	Bool	%I0.0	☐	☑	☑	☑	
2	24V_OK_Input	Default tag table	Bool	%I0.1	☐	☑	☑	☑	
3	Restart_Input	Default tag table	Bool	%I0.2	☐	☑	☑	☑	
4	Emergency_Stop	Default tag table	Bool	%M0.0	☐	☑	☑	☑	
5	24v_OK	Default tag table	Bool	%M0.1	☐	☑	☑	☑	
6	Restart	Default tag table	Bool	%M0.2	☐	☑	☑	☑	
7	Air_Supply_Output	Default tag table	Bool	%Q0.0	☐	☑	☑	☑	
8	FV-30_Output	Default tag table	Bool	%Q0.1	☐	☑	☑	☑	
9	FV-01_Output	Default tag table	Bool	%Q0.2	☐	☑	☑	☑	
10	FV-02_Output	Default tag table	Bool	%Q0.3	☐	☑	☑	☑	
11	FV-03_Output	Default tag table	Bool	%Q0.4	☐	☑	☑	☑	
12	FV-11_Output	Default tag table	Bool	%Q0.5	☐	☑	☑	☑	
13	FV-12_Output	Default tag table	Bool	%Q0.6	☐	☑	☑	☑	
14	FV-13_Output	Default tag table	Bool	%Q0.7	☐	☑	☑	☑	
15	FV-21_Output	Default tag table	Bool	%Q1.0	☐	☑	☑	☑	
16	FV-22_Output	Default tag table	Bool	%Q1.1	☐	☑	☑	☑	
17	FV-23_Output	Default tag table	Bool	%Q1.2	☐	☑	☑	☑	
18	FV-00_Output	Default tag table	Bool	%Q1.3	☐	☑	☑	☑	
19	Buzzer_Output	Default tag table	Bool	%Q1.4	☐	☑	☑	☑	
20	Green_Output	Default tag table	Bool	%Q1.5	☐	☑	☑	☑	
21	Yellow_Output	Default tag table	Bool	%Q1.6	☐	☑	☑	☑	
22	Red_Output	Default tag table	Bool	%Q1.7	☐	☑	☑	☑	
23	Pressure_Input	Default tag table	Word	%IW64	☐	☑	☑	☑	
24	Vacuum_Input	Default tag table	Word	%IW66	☐	☑	☑	☑	
25	Pressure	Default tag table	Real	%MD0	☐	☑	☑	☑	
26	Vacuum	Default tag table	Real	%MD1	☐	☑	☑	☑	
27	Air_Supply	Default tag table	Bool	%M0.3	☐	☑	☑	☑	
28	FV-30	Default tag table	Bool	%M0.4	☐	☑	☑	☑	
29	FV-01	Default tag table	Bool	%M0.5	☐	☑	☑	☑	Ball Valve Bottles
30	FV-02	Default tag table	Bool	%M0.6	☐	☑	☑	☑	Ball Valve Dosifiers
31	FV-03	Default tag table	Bool	%M0.7	☐	☑	☑	☑	Ball Valve Caps
32	FV-11	Default tag table	Bool	%M1.0	☐	☑	☑	☑	Pinch Valve Bottles
33	FV-12	Default tag table	Bool	%M1.1	☐	☑	☑	☑	Pinch Valve Dosifiers
34	FV-13	Default tag table	Bool	%M1.2	☐	☑	☑	☑	Pinch Valve Caps
35	FV-21	Default tag table	Bool	%M1.3	☐	☑	☑	☑	Butterfly Valve Bottles
36	FV-22	Default tag table	Bool	%M1.4	☐	☑	☑	☑	Butterfly Valve Dosifiers
37	FV-23	Default tag table	Bool	%M1.5	☐	☑	☑	☑	Butterfly Valve Caps
38	FV-00	Default tag table	Bool	%M1.6	☐	☑	☑	☑	Relief Valve
39	Buzzer	Default tag table	Bool	%M1.7	☐	☑	☑	☑	
40	Green	Default tag table	Bool	%M2.0	☐	☑	☑	☑	
41	Yellow	Default tag table	Bool	%M2.1	☐	☑	☑	☑	
42	Red	Default tag table	Bool	%M2.2	☐	☑	☑	☑	
43	Any_Alarm	Default tag table	Bool	%M2.3	☐	☑	☑	☑	
44	Bottles_Request	Default tag table	Bool	%M3.0	☐	☑	☑	☑	
45	Dosifiers_Request	Default tag table	Bool	%M3.1	☐	☑	☑	☑	
46	Caps_Request	Default tag table	Bool	%M3.2	☐	☑	☑	☑	
47	Bottles_Charged	Default tag table	Bool	%M3.3	☐	☑	☑	☑	
48	Dosifiers_Charged	Default tag table	Bool	%M3.4	☐	☑	☑	☑	
49	Caps_Charged	Default tag table	Bool	%M3.5	☐	☑	☑	☑	
50	EnableAxis	Default tag table	Bool	%M6.0	☐	☑	☑	☑	
51	FVD_Speed	Default tag table	Real	%MD2	☐	☑	☑	☑	
52	Bottles_Line_ALARM	Default tag table	Bool	%M4.1	☐	☑	☑	☑	
53	Dosifiers_Line_ALARM	Default tag table	Bool	%M4.2	☐	☑	☑	☑	
54	Caps_Line_ALARM	Default tag table	Bool	%M4.3	☐	☑	☑	☑	
55	Tag_3	Default tag table	Time	%MD100	☐	☑	☑	☑	
56	Tag_4	Default tag table	Time	%MD200	☐	☑	☑	☑	
57	Tag_1	Default tag table	Time	%MD300	☐	☑	☑	☑	
58	Tag_5	Default tag table	Time	%MD400	☐	☑	☑	☑	
59	Tag_6	Default tag table	Time	%MD500	☐	☑	☑	☑	
60	Tag_7	Default tag table	Time	%MD600	☐	☑	☑	☑	
61	Tag_8	Default tag table	Time	%MD700	☐	☑	☑	☑	
62	Tag_9	Default tag table	Time	%MD800	☐	☑	☑	☑	
63	Enable_operation	Default tag table	Bool	%M5.0	☐	☑	☑	☑	
64	Pressure_ALARM	Default tag table	Bool	%M5.2	☐	☑	☑	☑	
65	24v_ALARM	Default tag table	Bool	%M5.1	☐	☑	☑	☑	
66	Bottles_Charging	Default tag table	Bool	%M6.1	☐	☑	☑	☑	
67	Dosifiers_Charging	Default tag table	Bool	%M6.2	☐	☑	☑	☑	
68	Caps_Charging	Default tag table	Bool	%M6.3	☐	☑	☑	☑	
69	Safety_margin	Default tag table	Bool	%M6.4	☐	☑	☑	☑	
70	Intermittence	Default tag table	Bool	%M6.5	☐	☑	☑	☑	
71	Tag_2	Default tag table	Time	%MD900	☐	☑	☑	☑	
72	Tag_10	Default tag table	Time	%MD1000	☐	☑	☑	☑	
73	<Add new>				☐	☑	☑	☑	

(Author's own, retrieved from TIA Portal)