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Final Project Work

PLC Control and Automation of a Test Bench for Life Testing of Pneumatic Cylinders.

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Abstract

The propagation in the use of pneumatic cylinders for automatic processes has spread during the last 40 decades [1] . In such processes, high reliable components are the key to determine the performance and durability of the whole system, for this reason is important to take into account the life service of the pneumatic cylinders used to implement such processes and to determine a quantitative amount of time and usage for prevent failures and miss functioning to assure efficiency and productivity. The guide bearing of the pneumatic cylinders shows to be one of the principal causes of failure when it is used by repeated periods of time, showing depletion and allowing leaks to appear, producing an undesired behavior. [2] [3]

Then the purpose of study of this thesis is the proposition and development of a proper manner to determine the life service of pneumatic cylinders by means of **Accelerated testing conditions.** Implementing statistical analysis and through Weibull probability distribution function (pdf) in MATLAB, important metrics for life data analysis were calculated. For this reason, an automatic test bench has been adequate with a programmable logic computer (**PLC)**, and improved to perform the respective test of cylinder usage and to determine the life service of this highly reliable devices.

The Test Bench has been repair to determine two type of tests: a wear test; that was intended to determine the number of cycles a cylinder can endure, and a leak test; that is premeditated to detect if there is a leak inside the cylinders' chambers that can influence its behavior. During its execution the bench can be able to provide information about the pressure drop in the chambers and system, the sealing capacity of the gaskets and the life time of the cylinder. The bench has been enhanced with a human machine interface (Manual Pad) and a TD-200 pad to control, change and monitor the variables, states and procedures of the bench program, allowing its automatic functioning for days and with high autonomy. The control of the bench has been designed with a PLC Siemens S7-200 which is in charge of the whole procedure, its functioning and the signal acquisition system.

For matters of time and simplicity, the probes have been developed with accelerated testing conditions due to the high reliability of this components, and the statistical analysis was made with results obtained in other experimental data, creating a suitable MATLAB program that will ensure to derive the proper statistical analysis and the proper metrics to create a trustful and logical procedure to test and understand the results that will be obtained in the Mechanical Department of Politecnico di Torino (DIEMAS).

The program was designed to develop the statistical analysis under accelerated testing conditions results, this means under higher stress than in normal operating conditions. Even though the stress can be applied in several methods, in this thesis project the probes are planned with radial force in the end effector of the pneumatic cylinder. This overweight causes the wear in the piston rod to appear sooner than in normal conditions and allows us to calculate, by some mathematical techniques, the important metrics that are redundant in the life analysis of the pneumatic cylinder population.

Introduction

Nowadays, electronics and mechanics are being combined together for most of the actual automatic systems. To develop and ensure the right functioning and efficiency for a variety of tasks in different environments. The help provided by unifying this two knowledge fields is robust and most of them are used in daily chores.

Particularly these systems have something in common, most of them need a control unit and most of them are limited by the wear of the structure or components that are used to perform their final job. One of this methodologies to control the automatic systems are Programmable Logic Computer (PLC), which is known by its easy programming and its working principle as a relay, that allows its compressibility and adaptation to different tasks, environments and applications.

This is why in this project work, is based in the adaptation and automation of a Test Bench located in the DIMEAS lab of the Politecnico di Torino controlled with a Siemens PLC S7-200 to ensure proper and cautious probes that helps to understand the behavior of the cylinders that are the subject to the study.
A brief overview of the topics treated in each chapter will be mentioned in this section to help the reader clarify and understand the approach that was acquired; In the first chapter are shown and explained the important background and topics that are intended to deep the reader's knowledge in the important concepts in which this thesis project is based on. In the Second chapter the development and implementation of the relevant updates that were applied to the test bench and how the machine and the acquisition of the data to perform the life data analysis were developed. In the third chapter the elaboration of the statistical analysis and the important metrics that are used when products are subject to life data analysis are shown, together with the results obtained using the data acquired in other experiments because of matter of time, letting the program implemented with MATLAB ready to use when the result in the DIMEAS laboratory are available. Finally, in the last chapter the conclusions and the knowledge acquired in this thesis project is shown, suggesting further improvements to complete and enhance this project.

1. Theoretical Framework

1.1 Actuators.

An actuator is such a part of the system that makes the mechanical actuation or produce a movement transforming an incoming signal into a desired and controlled movement that follows the laws of motion. There might be different actuation, some of them can be manually or pneumatically actuated and electrical methods can be present. The most common in industrial applications are the mechanic, hydraulic, electric and pneumatic actuators [4] .

1.1.1 Mechanic Actuators

This are usually cam devices or articulated mechanisms that using the physical principles and the newton’s laws, produces a movement or a repetitive action due to an incoming signal. This kind of actuators are really precise in the execution and as they are rigid by the newton’s laws, they follow a certain law of motion. In addition to this, they are of high speed reaction and can be repeated at any times as desired, as long as they don’t have any failure. Even though that these mechanic actuators offer a lot of advantages, they have a big drawback: they are very rigid, offering little flexibility and if the purpose of the machine change, they must be completely redesigned and commonly this process is expensive [4].

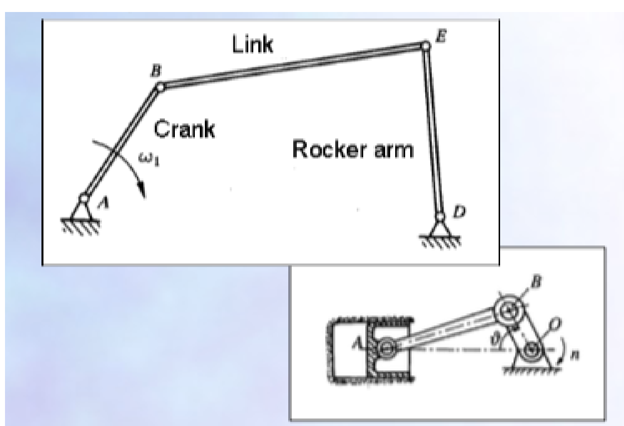


Figure 1: Mechanic Actuator. [5]

1.1.2 Hydraulic Actuators

This type of actuators is usually filled with a fluid different than air, they are really good for operating when high forces need to be exerted and variables laws of motion must be executed following the physical principles of the different fluids, they operate in a range from 80 bar to 500 bar and can express high response forces from 500 to 200,000 daN. But the use of this type of actuation systems is expensive [4].

Figure 2: Hydraulic Actuator. [6]

1.1.3 Electric Actuators

The most common electrical actuation device are the motors, they can actuate the elements of the system moving them directly or indirectly via motion transmission elements such as shafts and gears. The systems that are dotted with an electric actuator are flexible, which can change functioning from one cycle to another. Some of the motors that are present in this categories are: Stepper motors, brushless motors, current motors and some others. The only drawbacks that are present is such systems are that the motors are expensive and that the speed compared with the mechanical actuators is lower [4].

Figure 3: Electric Actuators. [7]

1.1.4 Pneumatic Actuators

They are characterized with applications that needs lower pressure, this type of actuator is filled with pressurized air and the forces exerted are medium range forces, from 2 to 4000 daN. The advantage compared to other types of actuations is that are less expensive and can exert a forces in high quantitates. The more used actuators are the pneumatic cylinders and they are widely implemented in different applications. That's why, the purpose of this thesis project is to determine a method to find the reliability through the life-testing of this type of actuators [4].

Figure 4: Pneumatic Actuator. [8]

1.2 Pneumatic Cylinders

Also known as Pneumatic Actuators, have been developed in a wide variety of types, forms and shapes. They can be divided in three (3) major groups of actuators: linear actuators, rotation actuators and pneumatic motors. They are used to transform the energy from pressurized air into useful work for different purposes and tasks. The Pneumatic actuators are sometimes preferred over the hydraulic ones because of their easy maintenance, long performance standards, in cleaning applications and because they do not need to much space to store the liquid to perform their job. Choosing a Pneumatic actuator for a determined task is really important, they have different operations, performance, environmental issues and costs [1].

The conventional cylinder has a moving part called piston and a stationary part that is called Rod, the piston is usually joined with a rod, that converts the pressurized air in linear motion. Figure 5, shows a general scheme of a double–acting pneumatic cylinder, such as the ones tested in this project [1].

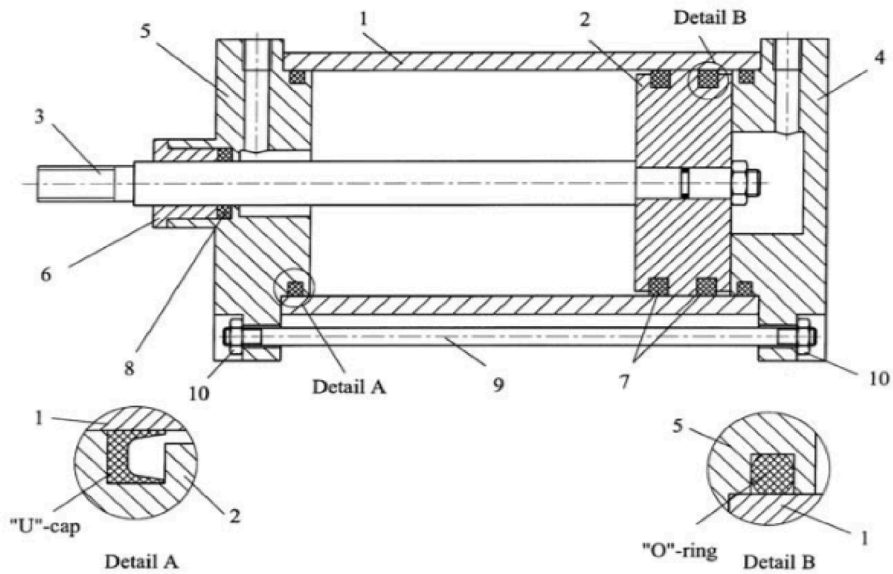


Figure 5 General Scheme of a Double-Acting Pneumatic Cylinder. [1]

The previous image shows the different parts of the cylinder; the sleeve (1), piston (2), piston rod (3), back cover (4), front cover (5), rod bearing (6), piston seals (7), the scraper ring and the rod seal (8), threaded rods (9) and fastening nuts (10) [1].

To have a specific approach to other type of cylinder, the one used in Mazza et al studies will be shown in Figure 6 . [3]

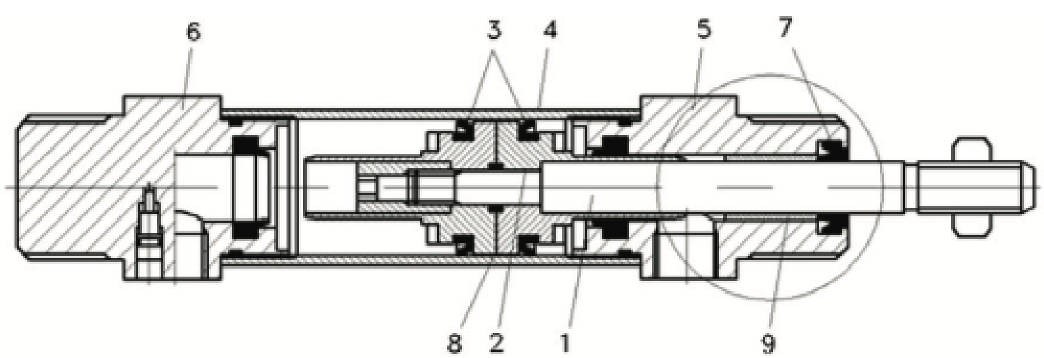


Figure 6: Specific cylinder under Mazza et al studies [3].

Citing the article from which the previous image was taken, referring to an ISO 15552

the parts of the cylinder are the following:

"The rod (1) is connected to the piston (2). The piston seals (3) prevent compressed air leakage between the chambers. The cylinder bore (4) is secured between the cylinder front (5) and rear head (6). The rod seal (7) on the front head (5) is used to prevent compressed air leakage to the outside environment. Linear motion of the piston rod is guided by means of the piston slide ring (8) and the guide bearing (9)". [3]

The cylinders can be made out of different materials, such as aluminum, steel, bronze, nickel or chromed –plated. Depending on the part of the cylinder, shape, environment requirements and the task to be performed, these materials are chosen. The proper functioning of this devices is of great importance and therefore, meticulous developments are required. The **functional reliability** and **service life** of a cylinder depends in great proportion of their own seal, which are cautiously designed because the surface finish of the mating surface is the one that determines the life service of the cylinder. This is why scores, scratches, pores, concentric marks, or spiral machining marks are not permitted. Ideally the dynamic matting surface must not have ground and be spiral free. Normally, Rod seals and guide bearings, located in the front of the piston rod are the principal cause of failure, this component are the ones subject to most wear and are the ones leading to leakages in the cylinders [1]. The scope of this project covers the basis to create an analysis and methodological approach for the life testing of cylinders, and as this is the component subjected to the higher wear, the cylinder life will be determined by the reliability of the rod seals. The initial approach is to start the life testing of the rod bearing seal developed by other students or group of work in the DIMEAS Laboratory and to provide the test bench an autonomous and user friendly environment in which this life testing can be performed automatically. In this thesis project the double acting pneumatic cylinders will be emphasized because they are the subject of study and the ones implemented, this means that the studied cylinder can be filled in both front and rear chamber with pressurized air, occasioning the piston rod to retract or extend depending on the situation.

1.2.1 Piston Rod

The piston rod is a crankshaft joined together with a piston and is the responsible for the linear motion produced in the piston. As stated before, this linear motion is the one caused by the pressurized air in either of the pneumatic cylinder chamber. The pneumatic rod is the part that usually is more subjected to stresses, as is the part of the cylinder that pushes forward or pulls backwards. This component has to be designed to endure in the presence of compressive, tensile forces and bending moments. Depending on the piston rod's length and diameter, the stress to which is subjected can be calculated with the following procedure [1].

$$Fr = P * A$$

Equation 1

This ensuring that the length of the cylinder is at least 10 times higher than the one of its diameter. The Equation 1 shows that the Force exerted by the rod or by an external load in the rod is equal to the distributed load in the surface by the cross sectional area in which the load is acting [1].

For the outstroke of the cylinder rod, having the area of the piston surface, the following relation can be described replacing the area in Equation 1:

$$Fr = P * (\pi * r^2)$$

Equation 2

For the instroke one must take into account that the cross sectional area is reduced and the resulting acting force is determined by the piston surface minus the cross-sectional area of the piston rod.

$$Fr = P * \pi(r_1^2 - r_2^2)$$

Equation 3

This are the basic equations and concepts that are needed to implement an analysis of the air in the pressurized chambers and for further development in the topic [1].

1.2.2 Guide Bearing

The guide bearing in pneumatic cylinders is really important, as stated before, is the part of the pneumatic cylinder that tends to failure easier, determining the life wear in pressurized cylinders. This is due to the fact that is the part in which more wear is present. As a crucial part in pneumatic testing terms, it is important to understand how it works, why deterioration is present in this bearing and why the minimization of friction forces is needed [3].

As cylinders can be subjected to axial and radial loads, the last due to weight mounted in the end effector of the cylinder will be analyzed because is how the subjects in this thesis project were thought to be tested. Some examples of this radial forces can be weld guns, grippers, vacuum devices, video cameras and all sort of devices that can be implemented. This kind of devices exert stress into the piston rod and therefore the guide bearing and seal of the cylinder are compromised, this stress will be transform into wear of the parts and deterioration, making the life and durability of pneumatic cylinders' dependent of this parts [3].

According to the studies developed by Rendon [9], the wear coefficient in the guide bearing can be described as a function of the distance in km travelled. The mathematical analysis of the rod and guide bearing coupling that undergoes the stress in the cylinder can be explained under the assumptions of an isotropic, linear elastic and homogeneous contact surface and simple math using the free body diagram shown in Figure 7. Three different models were used to estimate the wear coefficient due to this interaction (uniform pressure within chambers, trapezoidal pressure within the chamber and a non-linear distribution of the pressure). This approach is not considered in this thesis project and therefore for someone interested in the deduction of the wear coefficient he must refer to the mentioned study. As wear being determined by different factors such the type of load applied, the sliding speed, the temperature and the operating activity time [3], more practical and redundant indicators will be highlighted to fulfill the scope of this project.

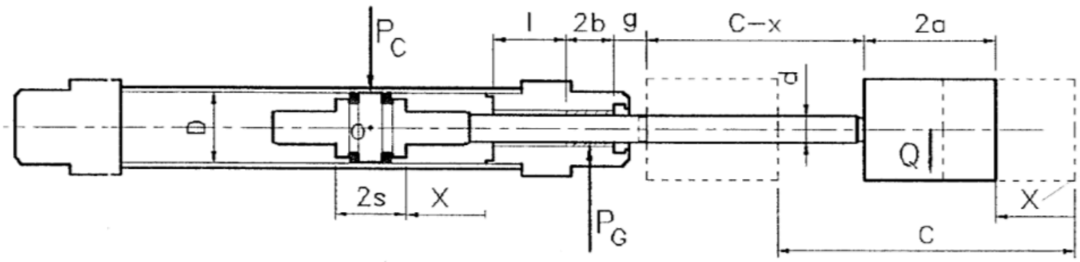


Figure 7: Free Body Diagram Used to determine a Wear Coefficient as Function of Km.

1.3 Valves

There are a variety of valves produced in the pneumatic industry, they are classified depending on their functionality and working principle. In the following section, some of the most common in industrial environments, as well as the ones used in this project will be explained. Taking into account that the general purpose of implementing pneumatic valves is to provide a method to control the flow and direction of the fluid in the network to transform the fluid dynamics into mechanic energy [10].

The pneumatic valves must satisfy some requirements and ISO standards, they must have long operating life under high and low pressure, have a fast response and be easy to maintain. To satisfy this requirements no internal leaks must be present and internal friction forces must be reduced. [11]

Usually the valves are classified by its working principle, for what they are used and the number of ports and the internal cavities they have. The working principle divide the pneumatic valves in five subsections: slide valves, poppet valves, rotatory valves, distributor valves and diaphragm valve. Each of this subsection can have three different used valves [10]:

Directional control valves: This type of valves operation principle is to connect and disconnect internal flow channels inside the valve body, to direct the fluid flow through a desired path [10].

Regulating valves: Usually implemented after a source or supply, it reduces or control the air pressure, they are really useful to protect system components, to set a desired pressure flow or to satisfy security requirements [10]. In the next figure, the general structure of a regulating valve is presented, notice that when the adjusting knob is straighter, the pressure of the system will be lower.

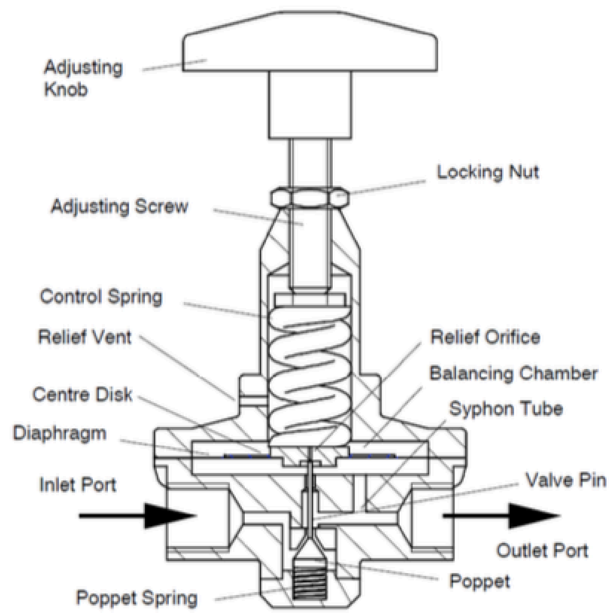


Figure 8: Regulating Valve [9].

Auxiliary Valves: They perform different functions depending on the use that are intended for. They can select a path, set timers, return flow or control a sequence [10].

The valves can be mono-stable or bi-stable. If they are from the first type, a control signal is needed, when the signal is present the mono-stable valve will change of state, if the signal is canceled then the mono-stable valve will return to a predefined position. If it is bi-stable, there will not be a predefined position, and therefore every time a position is set, this valve will keep the position and can be implemented in pneumatic circuits as a memory in some applications [11].

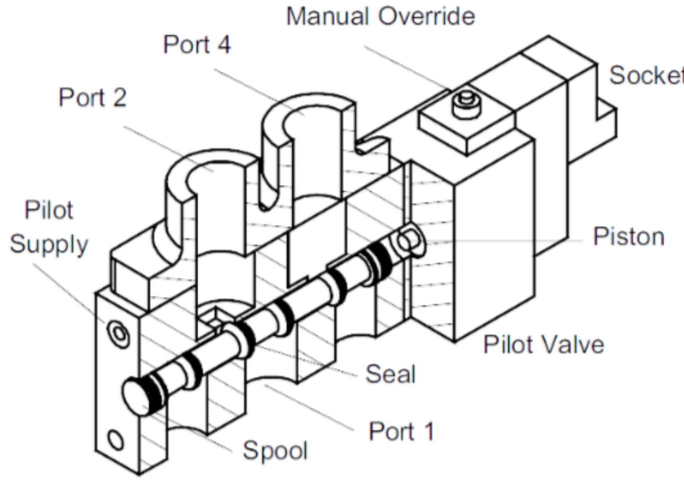


Figure 9: 5/2 Directional control valve cross section [9].

The number of cavities or switching positions and the number of ports present in the valve determine the name. In Figure 9, the cross section of a manual 5/2 directional control valve is show, this valve has 5 ports and 2 switching positions, in Figure 10 can be seen the schematics of different control valves, in the schematics can be shown the actuation method that is needed to actuate the valve, it can be pneumatic, manual, electrical or automatic.

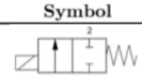
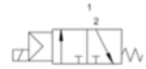
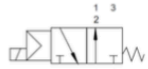
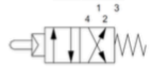
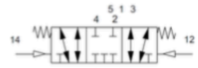
Symbol	Name/Description
	2/2-way valve NC, direct electrically operated
	3/2-way valve NC, electrically operated, with pilot valve
	3/2-way valve NO, electrically operated
	4/2-way valve, mechanically operated
	5/2-way valve, electrically operated, mono-stable
	5/2-way valve, electrically operated, bi-stable
	5/3-way valve, pneumatically operated

Figure 10:Different control valves, actuated with different methods [9].

The following part of this section will be dedicated in showing the valves that were implemented in the Test bench of the DIMEAS Laboratory. In Figure 11 the blocking valve from Metal works is showed, this is implemented in the test bench as a blocking valve to isolate the cylinders' chambers to ensure a proper functioning of the leak test that will be explained in further sections. In the next images, the different valves with their main components that were implemented in the test bench are shown, for further information refer to annexes 1 and 2.

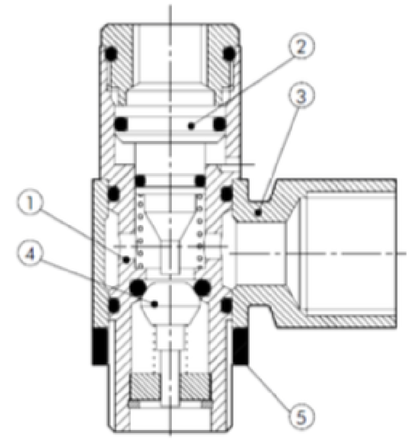


Figure 11: Blocking valve [9].

Components	Material
1. Valve Body	Nickel-plated brass
2. Piston	Steel
3. Turning Ring	Nickel-plated brass
4. Valve	Steel
5. Interface Gaskets	Hostaform

Table 1: Parts of the blocking valve [9].

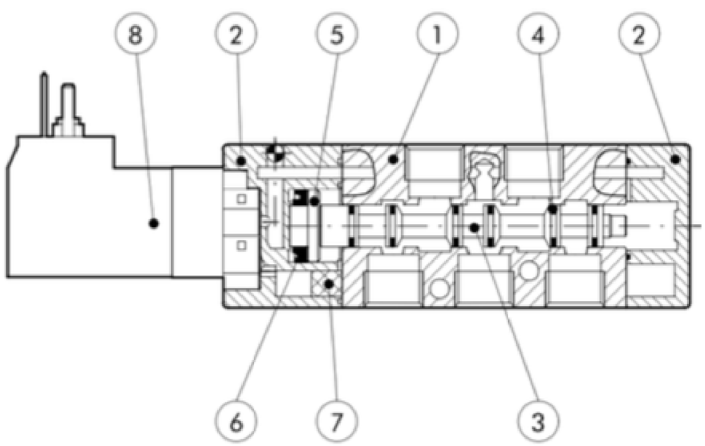


Figure 12: Directional control valve actuated by electric signal [9].

Components		Material
1.	**Valve Body**	Aluminum
2.	**Control/Base**	Hostaform
3.	**Spool**	Aluminum
4.	**Gaskets**	Polyurethane
5.	**Pistons**	Hostaform
6.	**Piston Gasket**	Polyurethane
7.	**Interface Gaskets**	NBR Nitrile Rubber
8.	**Pilot**	With Integrated Coil

Table 2: Parts of the Directional Valve [9].

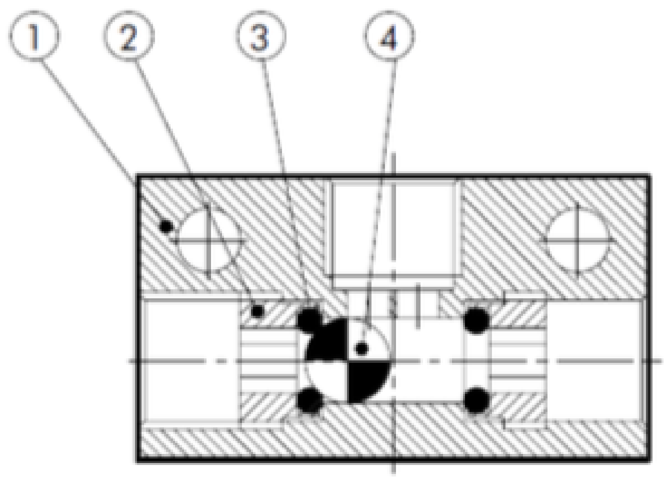


Figure 13: Or valve implemented in the test bench.

Components		Material
1.	**Valve Body**	Aluminum
2.	**Insertions**	Brass
3.	**Gaskets**	NBR
4.	**Sphere**	Stainless Steel

Table 3: Main parts of the OR valve [9].

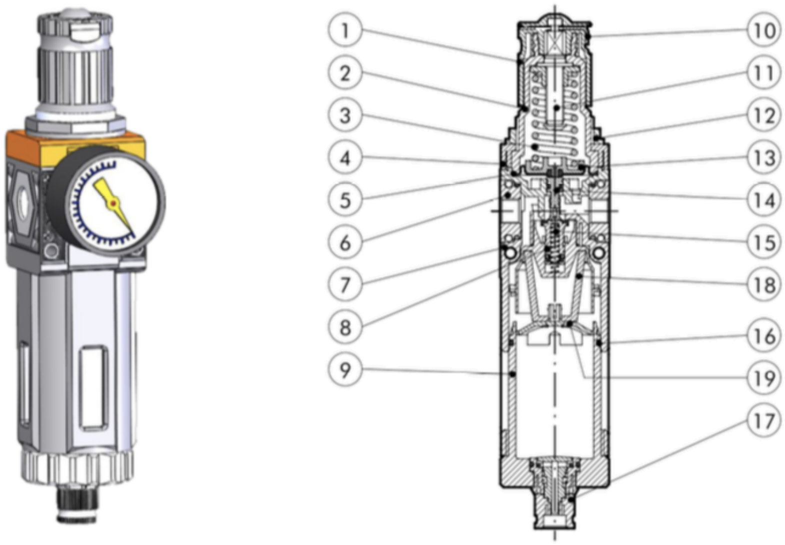


Figure 14: Pressure regulator valve implemented in the test bench.

Item	Component
1	Techno polymer adjusting knob.
2	Techno polymer bell.
3	Steel adjusting spring (with Geomet® treatment for anti-corrosion version).
4	Techno polymer flange.
5	Rolling diaphragm.
6	IN/OUT bushing made of OT58 nickel-plated brass or passivated aluminum for 3/4" - 1".
7	Techno polymer body.
8	OT58 brass valve, with NBR vulcanized valve.
9	Clear techno polymer bow.
10	Galvanized steel plate for knob locking (stainless steel for anti-corrosion version).
11	OT58 brass adjusting screw.
12	Techno polymer ring nut.
13	Techno polymer plate.
14	Techno polymer rod.
15	Stainless steel valve spring.
16	O-ring NBR gaskets.
17	Drain (RMSA.
18	Sintered HDPE filter cartridge.
19	Techno polymer screen.

Table 4: Main parts of the Pressure regulator [9].

1.4 Programmable Automation

Programmable automation technology is an incredible tool used by engineers and technologists who pursues to improve the manufacturing systems of their corresponding industries. It uses computer, mechanical and electrical technologies and used them for very specific automation competences. The expression programmable automation technology, englobes three trends that have a common cord, programming. The programming approach can be divided into three trends: the computer numerical control technology, the robotics technology and the programmable logic control. The last 25 years, programmable automation technology has greatly developed, one cannot enter into a manufacturing facility without seen one of these three trends, modern systems are generalized, less expensive, complicated and more reliable [12].

1.5 Programmable Logic Computer (PLC)

A programmable Logic computer or a PLC is defined by the international electrotechnical commission (IEC 61131-1) as:

"A digitally operating electronic system, designed for use in an industrial environment, which uses a programmable memory for the internal storage of user-oriented instructions for implementing specific functions such as logic, sequencing, timing, counting and arithmetic, to control, through digital or analogue inputs and outputs, various types of machines or processes. Both the PC and its associated peripherals are designed so that they can be easily integrated into an industrial control system and easily used in all their intended functions." [13] Therefore, a PLC is a computer to control a specific industrial task.

Previously in manufacturing processes, an operator was in charge of the material handling of a workpiece, worked on it using tools or machines and was in charge of determine when the task have to be performed. Now a day, the standard device used to control the manufacturing processes, the actuation of the machines or moving parts and the decision making is a Programmable logic computer or PLC. The PLC is in charge of this tasks automatically, through the use of electrical and computer technology. The PLC is basically a small computer ensured to interact with industrial components and equipment, therefore can be used in harsh industrial environment [12].

To make the proper decision, the PLC must collect information from the process that is controlling, this is made by sensors and therefore based on the state of the sensors the decisions are made. Each decision has an actuator that can be a motor, a cylinder or solenoids to interact acting on the process. Before if there was the need to change certain process, the system must be rewired and several configurations must be changed, the implementation of the PLC into the manufacturing processes, make versatility a key concept of the manufacturing systems of the future [12].

The first PLC was developed in the motor manufacturing industry; it was developed by a group of General Motors engineers in 1968, as a substitute for the commonly used relay wired system. The PLC was intended to have simple programming, have changes without changing the wiring of the system, be smaller and cheaper than the conventional relay control system and finally to be simple and have low maintenance expenses [13].

With the PLC there was possible for first time to plot signals into a screen and to file data in electronic memories. Thanks to the microcontrollers the PLC was developed, it was understood that a computer could switch ports to on or off due to different inputs, understanding on as more than 2.5 V and off as less than 2.5 V and therefore easier connections were made to control binary signals controlled by the specifications of the main program [13].

The last 40 decades have had enormous progress in microelectronics developments. Not only with the PLCs but with the programming optimization, hardware size reduction and more important program optimization that leads to least cost expenses because of the reduction of the memory. At first the memory was a mayor inconvenient for programmers and software developers, today there is not an inconvenient because the high capability of the new hardware and the programming optimization that have been achieved [14].

At first the PLC didn't have the range of capabilities that is present today, process visualization, analog processing of signals are features that all the devices are able to perform. This among a wide features made the PLC a great tool to be implemented in a wide variety of applications, functions and environments [14].

Today, the PLCs have an extensive range of applications and they are one type of controller, almost every system or machine requires a main controller. The type of the controlled is determined by its technology, there for they can be divided in different types, such as hydraulic, pneumatic, electronic or electrical controllers. If its hard-wired programmable or programmable logic controller depends on the type of control that needs to be done, if the reprogramming of the system is not required and if the system task needs a special type of controller, for example it can be used in washing machines, cars, coffee machines and cars. The PLC is used when the program must be written and there is the need to implement counters and timers, then the use of a universal controller as the PLC is suitable and the best option to implement, the programs are saved in the internal memory and provides autonomy, and independency of resources; example of this are industrial processes to package wine, sodas and water, in the production of parts for the cars and others [14].

The principal functioning of a PLC is to track and interact with some input signals that are present. This behavior as Boolean algebra, as mentioned before, is the basic principle of their operation, this is why they are very similar to an electromagnetic relay or a pneumatic switching valve controller. However, the memory implemented in the PLC is a significant improvement from those control technologies because it allows to do different mathematical computing operations, timers, counters, memory settings among others [15].

At the first 80s, the function of expansion modules to extend the range of the PLC were being developed, the expansion modules permit to extend the input and outputs number and there is added a new type of useful module; analogical modules. This was a great advantage because know different type of analog inputs can be acquired and expended, as voltage, current. An important tool to foster the new systems and applications allowing to do automatic control setting exact number, comparing to develop action and to achieve different control methodologies [15].

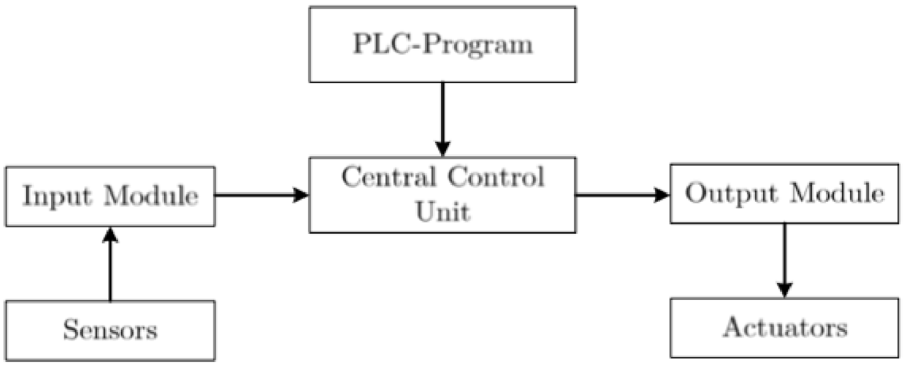


Figure 15: General components and functioning of a PLC system [15].

Figure 15 shows the general functioning and components that are present in an application with a PLC. The sensors are in charge of acquiring the actual state of the system, sending the information to the input module that is in charge of transforming the information for an understandable type information for the PLC control unit, if it is an analog signal the input module must be an analog input module, if it is a digital input signal it must be a digital input module. The input module sends the information to the central control unit that based on the program previously charged into the PLC by the programmer, determines the next action and active in base of this action an internal memory or an output which may activate an actuator, an actuator can be a motor, a cylinder and they will change the state of the system to a new state to continue with the process [15].

The program can be written with different programming techniques:

1. As a text based language, similar to an assembler called **statement list (STL),** it allows the programmer to write the program by entering the instruction mnemonics, it helps the programmer to create programs that cannot be created with the other programming techniques because the STL is the native program of the PLCs, it works more or less as an assembler programming. The PLC follows the instruction as stated in the program from top to bottom and restarts from the top. This programming technique is most appropriated for

experienced programmers, can solve some problems easier than with the other techniques [15].

```
LD      I0.0        //Read one input
A       I0.1        //AND with another input
=       Q1.0        //Write value to output 1
```

Figure 16: STL programming technique [15].

2. The ladder (LAD) another technique used to write programs in PLCs, maybe is the most popular as the PLCs replaced the normal relay control technologies, and the LAD editor displays a graphical representation very similar to the electric wiring connection diagrams, allowing the program to simulate the power flow of current source coming from a source and passing through some logical input conditions that can enable logical outputs. The left rail is energized and the current flows from left to right, the closed contacts allow the energy to flow and the open contacts block the energy. The contacts can represent logic input conditions, such as switches, buttons or internal conditions while the coils represent the logic outputs such as motor starters, cylinders, internal output conditions or interposing relays. Each network is read by the PLC from left to right and then the rest of the program from top to button. Finally, its graphical representation makes it easy for the beginners and as is easy to understand is the most popular. Regarding the popularity of the LAD to develop programs for PLC is the one that is implemented in this thesis work and therefore deeply information will be introduced further on [15].

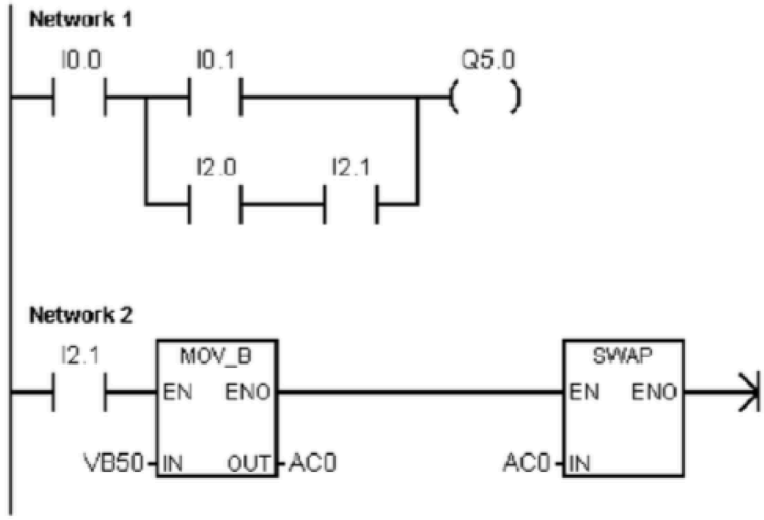


Figure 17: LAD programming technique [15].

3. Another popular programming technique, is the function block diagram (FBD), this approach is a graphical representation similar to the common logic gates, there are neither networks, contacts or coils as in the LAD but there are similar instructions that appear in box representations. This type of approach does not discriminate between right or left, so the power flow is considered as the direction in which the instruction is done. One instruction can be used to active another one, as conditionals for example. As there is no concept of right and left, this type of programing is very useful to solve some logical programs that are difficult to solve with the other type of programming techniques [15].

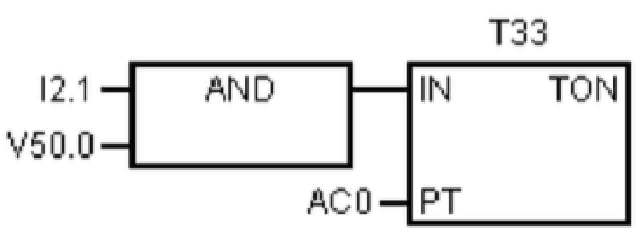


Figure 18: FBD programming technique [15].

The PLC used in this project work and implemented in the test bench is a Siemens S7-200 series which is catalogue as a micro-programmable logic controller, that can look after a wide diversity of automation applications. Its low cost, computer design and a powerful set of instructions do this PLC a suitable option for the control of small and medium applications [15].

The S7-200 can perform different tasks, as all the PLCs can monitor inputs and change the outputs depending on the user determined by the user, it can include Boolean logic, timers, counters, simple and complex math operations, number format transform and communication with other devices. The system must be combined with Windows to download the program into the PLC, the Windows tool that allows the interaction between the programmer and the PLC is called STEP 7-Micro/WIN [15].

The STEP 7 Micro/WIN provides a variety of advantages in the moment of writing a program, depending on the syntaxes used to write the program, there can be find different tools to develop the program, when the program is running is easier to find mistakes and before running it, STEP 7 checks if there has been any bug in the code through the designing phase. Thanks to STEP 7 Micro/Win the designing, implementing and debugging of the program, as well as status verification to improve while running, ensure a proper functioning of control codes implemented in the PLC [15].

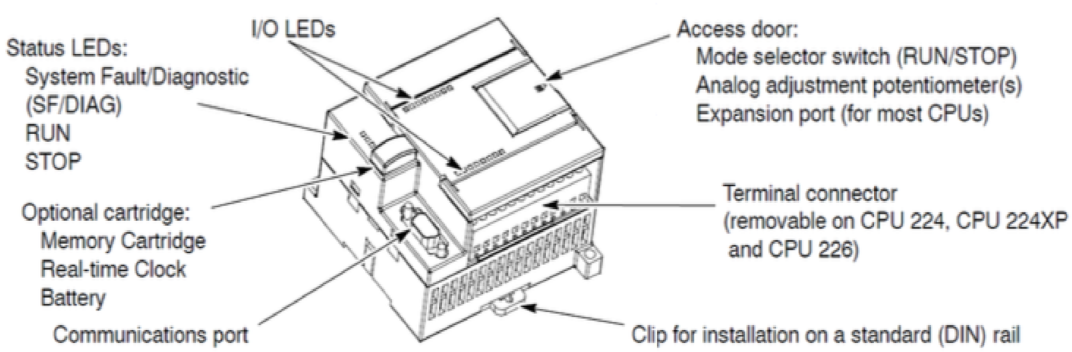


Figure 19: PLC implemented in this project work, this was implemented for the development of the control of the test bench [15].

Figure 19 shows the S7-200 that was implemented in this thesis project. It has some status Led in the left corner that helps to determine if it is running, stop or, a memory to store programs or important data, an analog adjustment potentiometer, an expansion port to adapt other expansion modules and the terminal pins to adapt the output and inputs that are related to the automation process. As others PLC it has a microprocessor, input and output circuits and special specifications that can be observed in the table below. [15].

Feature	CPU 224
Physical size (mm)	120.5 x 80 x 62
Program memory:	
with run mode edit	8192 bytes
without run mode edit	12288 bytes
Data memory	8192 bytes
Memory backup	100 hours typical
Local on-board I/O	
Digital	14 In/10 Out
Analog	N/A
Expansion modules	7 modules
High-speed counters	
Single phase	6 at 30 kHz
Two phase	4 at 20 kHz
Pulse outputs (DC)	2 at 20 kHz
Analog adjustments	2
Real-time clock	Built-in
Communications ports	1 RS – 485
Floating-point math	Yes
Digital I/O image size	256 (128 in, 128 out)
Boolean execution speed	0.22 microseconds/instruction

Table 5: Relevant Specifications of the SIMATIC S7-200 [15].

As stated before, the PLCs have three types of code to write a program, the S7-200 support all this three and the STEP 7 Micro/WIN allows to choose the language that best fit to the application and the programmer that is using it. Figure 16, Figure 17 and Figure 18 shows the text editor for each of the languages that accept the S7-200 in the format that STEP 7 Micro/Win allows. And as explained before the functionalities, advantages and drawbacks are mentioned referred to each of the programming technique (STL, LAD, FBD) [15].

1.6 Basic Elements of a program

A program is composed of blocks of executable code and comments that are read by the control device, in this case the PLC S7-200. The executable code consists usually of a main program, some subroutines and interrupt routines and this one are called organizational elements and are used to structure the control program. The code, after being designed, is compiled and downloaded to the control device, but the comments are not in order to optimize resources. Comments are not read by the PLC and therefore is a waste of space if those are downloaded into the PLC [15].

The main program is the body of the set of instructions that control the application or machine. The S7-200 (in this case our control device) reads the instructions in a sequence, one time in each scan cycle and from left to right. The main program usually is also called OB1 [15].

The subroutines are optional elements; a program can be made by only a OB1. These elements are read only when they are called. When some subroutine is called is because it has been addressed to it in the main program, an interrupt routine or inside another subroutine. It is useful because rather than rewriting the logic for each place in the main program where is wanted the program to happens, the user designer can write the logic once and call it every time that is needed while the main program is still running. The subroutines provide several benefits; gives the programmer flexibility and reduces the overall program size, decreases the scan time because the PLC S7-200 reads all the instructions once in the main program, weather the code is executed or not, and the subroutines code is out of the main program therefore only scan the program of the subroutine if it is called. Finally, the subroutine code is portable and can be isolated as a function and then copy that subroutine in other program or with little or no further work required [15].

At last, the interrupt routines, are also optional items that react to specific interrupt events. The programmer designs an interrupt routine to switch a pre-defined interrupt event. When the specific event occurs, the S7-200 starts the interrupt routine. Usually the interrupt routines are not called by the main program, they are associated to an interrupt event, and the S7-200 only starts the interrupt routine in the presence of this event. Is very important to be aware that the interrupt routine can be activated an unknown number of times, there is why is useful to use the temporary memory inside each interrupt routine for the correct functioning of the program and not cause any trouble with the used variables in the main program [15].

The following program is an example of code taken from the S7-200 system manual, it shows a subroutine and an interrupt routine. It uses a timed interrupt to read the value of an analog input every 100 ms.

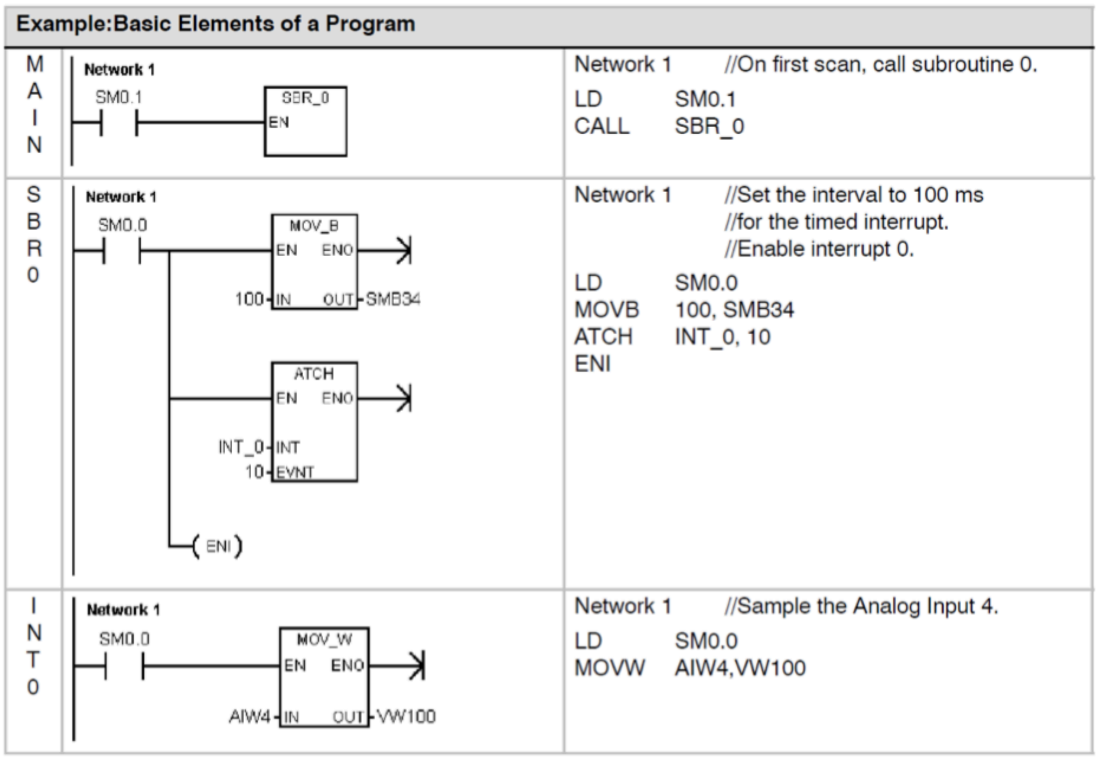


Figure 20: Main program, subroutine and interrupt routine example (Lad and STL representations) [15].

1.7 Communication with the PLC

In this case, Siemens provides two possible options to connect the S7-200 with the computer: A direct connection with PPI Multi-Master cable or a communications processor (CP) card with a MPI cable. As the PPI Multi-Master cable is the most common and economical method, is the one implemented in this project. This cable connects the communications port of the

S7-200 to the serials communication port on the computer and allows other communications to other compatible devices [15].

The Figure 21 shows the cable used to connect the computer to the S7-200 which was implemented in the previous project, this cable was really useful, economic and powerful, since it allows us to interact in a comfortable way with the S7-200. At first this allowed us to transfer data from the PLC to the computer by means of a Scada software, in order to save the pressure in the cylinder's chambers to detect a leak and to do the corresponding statistical analysis and allows us to download the programs written in the STEP 7-Micro/WIN into the PLC without any problem.

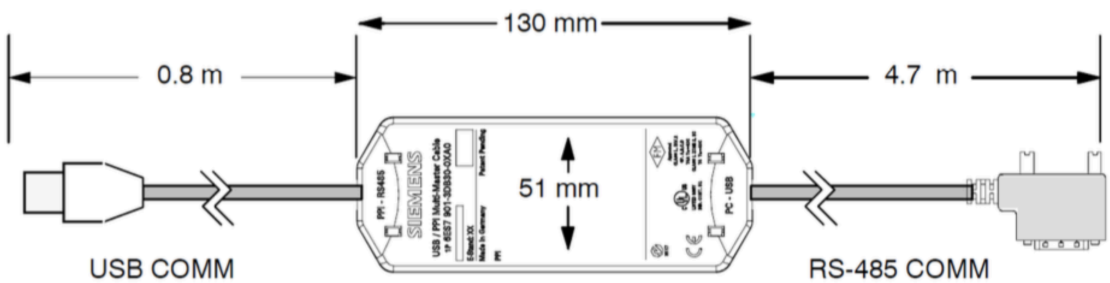


Figure 21:PPI Multi-Master cable [15].

As this PPI Multi-Master cable did have some limitations, as for example there was not possible to achieve the pressure analog signal within the chambers without a Scada interface and the new update of the test bench was with a Manual control pad and a TD 200 pad, there was the necessity to change the communication device implemented to transmit the information from the computer to the PLC, that is why in the new update of the test bench there was included a NETlink Profibus cable, which allows a faster connection and gives the opportunity to work with the memory of the computer instead of the one in the PLC. This cable uses the serial port in the PLC and with an Ethernet high speed connection, provides a suitable connection with the computer. In addition to this the NETlink Profibus cable, acts as a bridge of serial port and the TD-200 pad can be added to the configuration as another component, allowing to control, change and monitor variables from the last one. NETlink Profibus cable can be seen in the figure below.

Figure 22:NetLink Profibus cable.

1.8 Functioning of the S7-200 and Scan cycles:

As any control device, the PLC must be charged with a control program in order to function, these programs are understood by the PLC depending on the logic control which it is made. The S7-200 reads programs from top to button and from left to right, each line at a time in the main program during the scan cycle, having this clear it is easy to understand that the control logic is implemented, there are some status delivered by the sensors and outputs interpreted by the actuators [15].

The PLC starts its control reading the status of the inputs of the system, then using the program previously downloaded in the S7-200 and with the input status, the control logic is executed and the status is updated as the program runs. Finally, the data is written in the outputs and the actuators are actioned by them, changing the status of the inputs and repeating the program until it is done or until is power down [15].

The Figure 23 shows a basic program in the S7-200 in order to clear these concepts and to highlight the operation of the PLC in a basic application. Showing how the inputs and outputs are related to the actual program downloaded in the PLC [15].

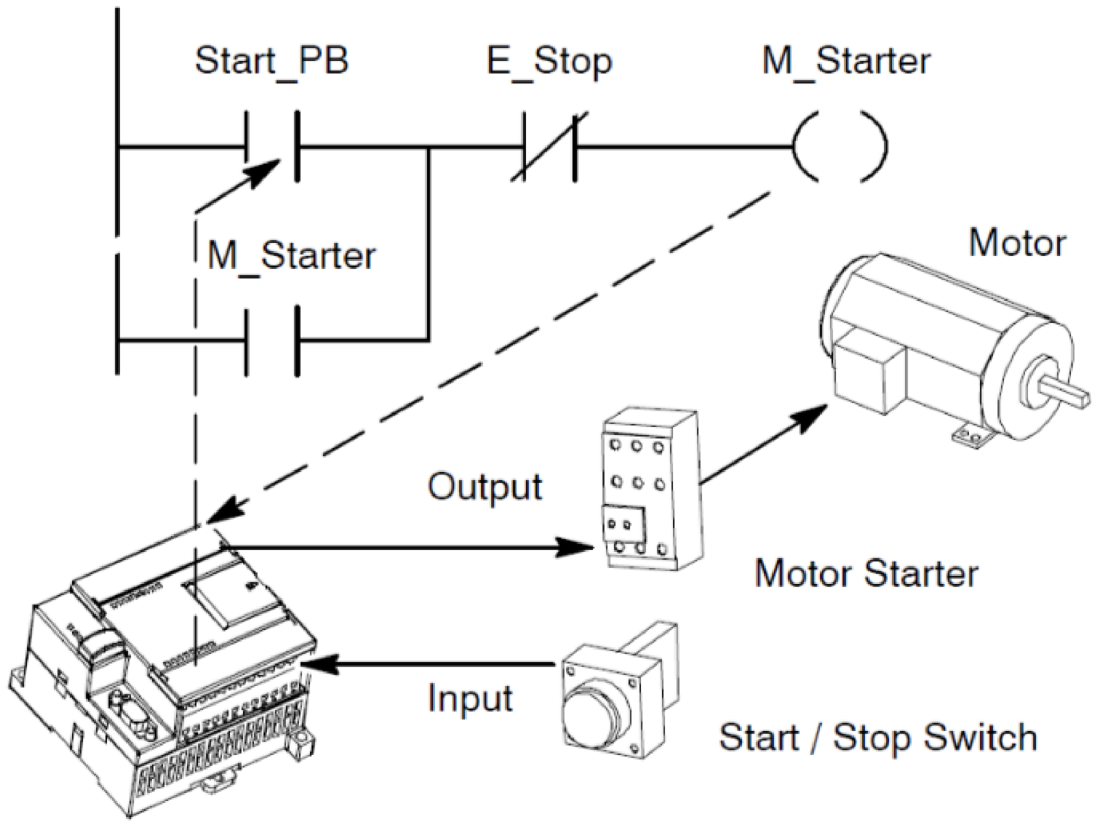


Figure 23:Basic Example for Controlling input and Outputs [15].

In the previous program, other state inputs are combined with the start switch of a motor, then calculations with respect of this states are made to determine the state of the output that goes to the actuator that starts the motor [15].

The S7-200 repeats a series of assignments a determined amount of time, this is called a scan cycle, the S7-200 performs all or most of this operations during a scan cycle:

Reading the inputs: The S7-200 copies the state of the physical inputs into the process image input register. There are two different types of physical inputs:

Analogical Inputs: The S7-200 does not update analog inputs from the expansion modules as part of the normal scan cycle unless filtering of analog inputs is enabled. An analog filter is provided to allow the PLC to achieve a more stable signal, making it easier to recognize and handle. The programmer can enable the analog input filtering for each analog input making that the PLC updates the analog input once in each scan cycle, performing the filtration of the analog inputs allows to 'hold' the filtered value internally. And then this value is used every time that the program needs to use it. If the filtering of the analog input is not activated, then the PLC reads the value of the analog input from expansion modules each time that the program leads to the access of the analog input [15].

Digital Inputs: Each scan cycle begins reading the current value of the digital inputs and then writing these values to the process-image input register.

Execution the control logic in the program: The PLC executes the instructions of the program and stores the values in the various memory areas, during the execution phase, the S7-200 executes the program, with the first instruction from top to bottom or the end instruction. The instant I/O states give immediate inputs and outputs during the execution of either the program or an interrupt routine [15].
If the user or programmer uses interrupts in the program, interrupt routines are associated with the interrupt events that are stored as part of the program. Neither the subroutines or the interrupt routines are executed as part of the program in a normal scan cycle, but are executed when the interrupt event occurs or when the subroutine is called [15].

Processing any communication request: The PLC performs any task that is required for communications. During the message processing phase of the scan cycle, the S7-200 processes any message that is received from the communications port or intelligent I/O output modules [15].

Executing the CPU self-test diagnostics: Each time that the program is downloaded and then started in the PLC, it ensures that the program memory, expansion modules and firmware are working properly [15].

Writing the Outputs: The values stored in the process-image output register are written into the physical outputs that at the time are the control for actuators such as motors, cylinders, etc. At the end of each scan cycle, the values stored in the process-image output register are written into the digital outputs. In contrast of the inputs, the analog outputs are updated immediately independently of the scan cycle [15].

The S7-200 has 3 different states (RUN, STOP and TERM), if the PLC is in STOP mode then the program is not executed, but if it is in RUN then the program is executed. The last state, TERM does not interfere with the operating mode in which the PLC is working. For example, if there is a power loss and the PLC was performing an activity, when the power is recovered the PLC will stop. If it was not performing any activity, them the PLC will also be in stop mode [15].

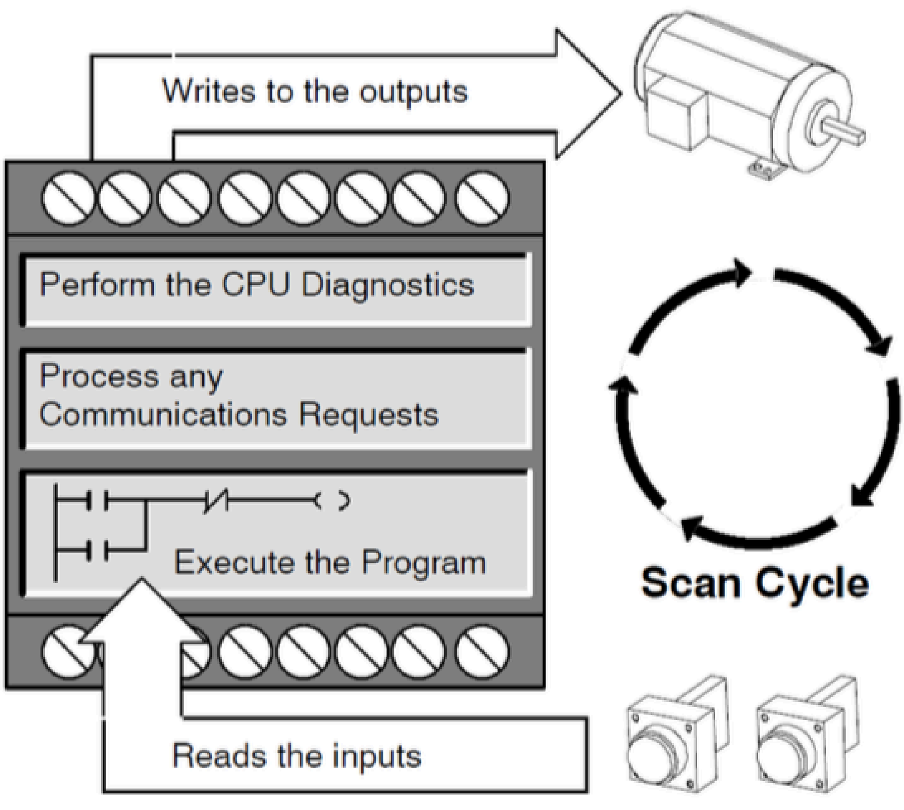


Figure 24:S7-200 scan cycle [15].

1.9 Memories and special memories in the S7-200:

The S7-200 stores information in different memory locations and have a specific addressing system, each address refers to a specific memory location. The programmer can explicitly determine the memory address that is aspired to address. This allows the programmer to have a direct key to access the information and to determine instructions needed for the program to access information that is pertinent for its flow [15].

Representation	Byte (B)	Word (W)	Double Word (D)
Unsigned Integer	0 to 255	0 to 65,535	0 to 4,294,967,295
	0 to FF	0 to FFFF	0 to FFFF FFFF
Signed Integer	–128 to +127	–32,768 to +32,767	–2,147,483,648 to +2,147,483,647
	80 to 7F	8000 to 7FFF	8000 0000 to 7FFF FFFF
Real			+1.175495 E–38 to +3.402823E+38
IEEE 32-bit	*Not applicable*	*Not applicable*	(positive)
Floating Point			–1.175495 E–38 to –3.402823E+38
			(negative)

Table 6: Decimal and Hexadecimal ranges for the different Sizes of Data [9].

To achieve the information in a memory location, the user must specify the address, this address includes the memory area, the type of data that is looked for as well as the byte address, and bit number. In the Figure 25 it can be shown an example taken from the S7-200 manual of the system, in this example the type of data that is an input, the byte address is 3 and the bit address is 4, constructing the complete address I3.4

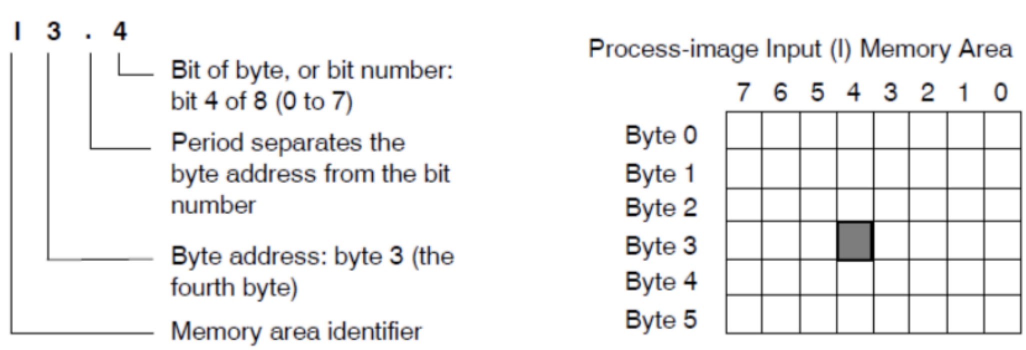


Figure 25:: S7-200 Byte and bit addressing [15].

In addition to this, the programmer can access and save of the PLC data in almost every memory area, such as V, I, Q, M, S, L and SM. There can be words, double words and internal memories and to access to them there is a special reference that is closely related to the nomenclature used before to achieve information in memory locations: the first area is an identifier, followed by a data size designation and finally the starting byte address of the word, byte or double word data that is wanted [15].

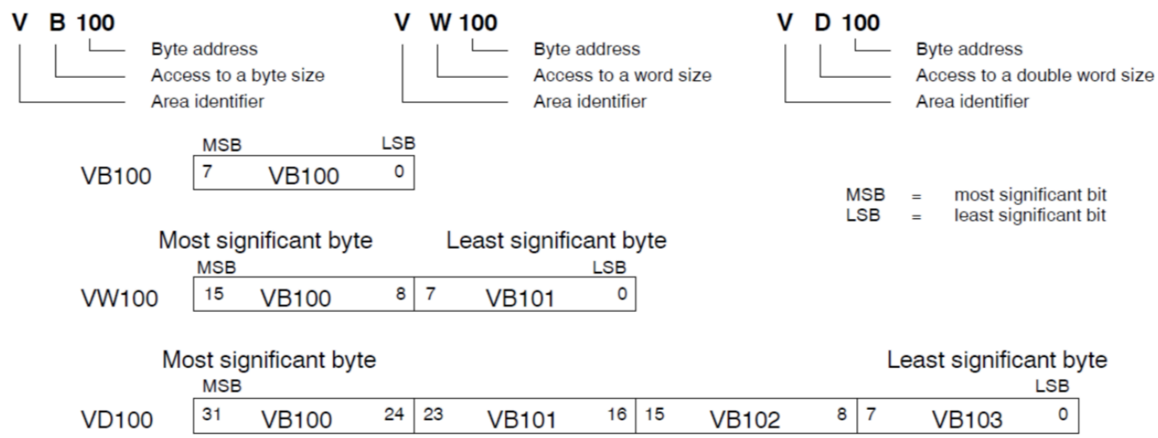


Figure 26: Word, double word and Byte addressing [15].

Data in memory slots in area T, C, HC (timers, counters and accumulators) are special memories and are accessed by the use of an identifier and a device number. Usually this memory slots are designed as a default and they include different timer resolutions and types as shown in the Table 7 , Counters and accumulators.

Timer Type	Resolution	Maximum Value	Timer Number
TONR (retentive)	1 ms	32.767 s (0.546 min.)	T0, T64
	10 ms	327.67 s (5.46 min.)	T1 to T4, T65 to T68
	100 ms	3276.7 s (54.6 min.)	T5 to T31, T69 to T95
TON,TOF (non–retentive)	1 ms	32.767 s (0.546 min.)	T32, T96
	10 ms	327.67 s (5.46 min.)	T33 to T36, T97 to T100
	100 ms	3276.7 s (54.6 min.)	T37 to T63, T101 to T255

Table 7:Timer identification and resolution in the S7-200 [8].

To give a further explanation of how the timers work, the programmer must be interested in achieving for a determined purpose a resolution of a timer of 1ms, 10ms and 100ms:

Looking in the table below is easy to understand that the programmer must identify the timer bit that must be used in every case, to attain 1ms he must use the T0 or the T64, to attain 10ms he must use one of the timers in the range of T1 to T4 or T65 to T68 finally for reach the 100ms timer he must use one in the following ranges T5 to T31 or T69 to T95 and there on.

Using the previous example, the timer bit and the current value of each timer in the first case (1ms) is updated asynchronous time with respect to the scan cycle. For the second case (10ms) the timer bit and the current value of the timer are updated at the beginning of each scan cycle, and will remain constant through all the scan cycle, each time that the scan is started the additional time accumulations will be added to the current value in the start of every cycle. For the last case (100ms) the timer current value and the timer status bit are updated only when the instruction is executed, consequently the instruction for timing a 100ms timer must be done only once per scan cycle for the properly timing on the program.

The counting in the S7-200 allows the programmer to use 3 different type of counters that counts in the presence of a low to high transition (off to on); one to count normal, one to counter count or count backwards and the last one that can count normally and backwards. As for timers, two different variables are associated, the current value of the counter and the counter bit. The current value of the counter is a 16-bit integer signed, that stores the accumulated count. The counter bit is set or reset as a result of comparing the desired value, that is entered as an instruction for the counter, with the current value of the counter. The user can access these two variables associated to each counter by the instruction set that is given to the PLC; the instructions with bit operands access the counter bit, while instructions with word operands access the current value of the counter. As seen in Figure 27, there are two different type of instructions in different networks, the left side represents Move Word instruction, in this case because of the type of instruction the current value of the counter is achieved, the right side at the contrary is a normally open contact which access to the counter status bit [15].

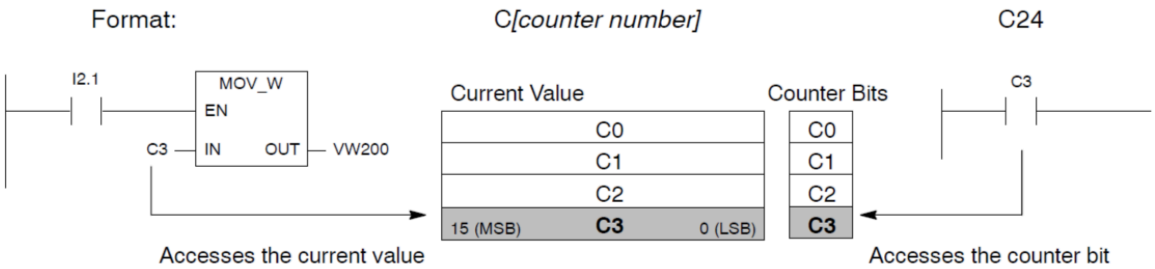


Figure 27: Accessing different variables in a counter in the PLC S7-200 [15].

As the accumulators are not used in this project, there is no need to explain it functionality and neither its variables or nomenclature, to find further information in this matter, the reader can search the manual of the system of the S7-200 in which is easily explained and is covered with examples [15].

1.10 Acquisition of an analog signal in the S7-200:

One of the important matters for this thesis project was the acquisition of the pressure signal that was achieved by the manometers located in each cylinder. This analog signal was of particularly importance to describe the behavior of pressure losses in the chambers of the cylinders in the moment that the leak test was performed. Therefore, the importance to adapt the S7-200 to attain an analog signal. For this purpose, the PLC was dotted with two Simatic EM 231expansion modules. This expansion module, in order to acquire the analog signal, scales it and transfers it into an approach that the PLC can interpret [15].

Standard analog signals (continuous signals in time domain) range from 0 to 10 VDC or from 4 to 20 mA. They are used to represent changing values, such as weight, acceleration, speed and level. A PLC is not capable of processing the signals in analog form, and therefore are expansion modules, that are attached to the principal PLC, which transform the incoming signal into a 12-bit digital representation by means of an Analog to Digital Converter (ADC) and a sample and hold circuit inside the expansion module. Another advantage of this modules is that they can be used with resistance temperature detectors (RTD) sensor and thermocouples, which are sensors used to attain high level of accuracy in the temperature measurement, providing the PLC with a vast range to work with [16].

After processing the analog signal, the PLC S7-200 saves it in the internal memory, the user can access to this 12-bit digital word-length. The operator can access the information via an instruction that must enclose an area identifier (AI), the size of the data (W), and the byte initial address. As the analog information is stores as digital words, they always start on even number bytes by default (i.e. 0, 2, 4), the operator accesses them with even numbers in the byte addresses (i.e. AIW0, AIW2, AIW4). This values are only for the operator to read them from the memory and they cannot be written [15].

The Expansion module SIMATIC EM-231 needs an appropriate setting for the correct acquisition of the analog signals. The appropriate setting of the module affects the instrumentation amplifier stage after the analog multiplexer. This setting will affect all the inputs in such module and this is why is of complete importance to set an appropriate value for the instrumental amplifier stage, usually all the inputs achieved with one module varies in the same range for having a better acquisition. Even if the multiplexer is set in the correct way, factors as variation in components values inside the module's input can lead to slight differences in the readings between the channels connected to the same input signal. To meet the specifications, the operator should enable analog input filters for all inputs of the module [17]

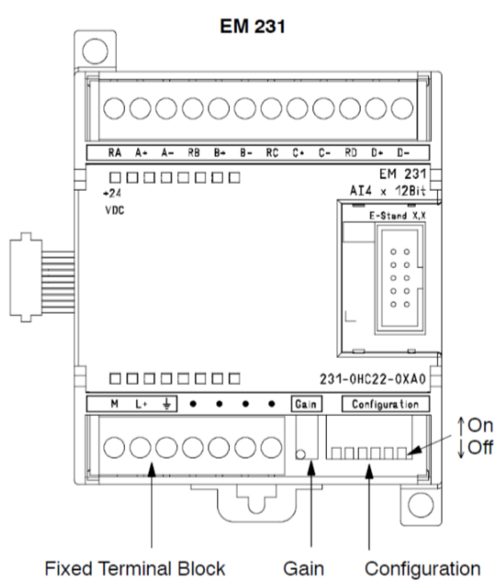


Figure 28: Positions of DIP Switches and calibration potentiometer [17].

The Figure 28 shows the potentiometer position and the DIM Switches in the EM 231 expansion module, they are easy to identify and are labeled in the expansion module, finding the expansion module datasheet is easy and is a good reference to identify the working conditions, the limits in current, voltage and the working range that it can provide.

For this module that is dotted with 8 analog input, switches 1 and 2 select type of signal that is going to be acquired. If switch 1 or 2 status is ON, the channel 6 or 7 (respectively) will be set to acquire current, if it is OFF it will be set to acquire voltage. Switches 3, 4 and 5 select the analog input range as shown in the table below.

Unipolar			Full-Scale Input	Resolution
SW3	SW4	SW5		
ON	OFF	ON	0 to 10 V	2.5 mV
	ON	OFF	0 to 5 V	1.25 mV
			0 to 20 mA	5 µA
Bipolar			Full-Scale Input	Resolution
SW3	SW4	SW5		
OFF	OFF	ON	±5 V	2.5 mV
	ON	OFF	± 2.5 V	1.25 mV

Table 4: Switch configuration in the SIMATIC EM 231 expansion module [17].

The proper calibration for the analog expansion module is usually made following this guideline [9].

1. Select the desired input range with the module not energized.
2. Energize the module and let it stabilize by 10 minutes.
3. Apply a zero value signal to one of the input terminals.
4. Read the value acquired by the PLC.
5. Adjust the offset potentiometer to achieve zero in stored memory.
6. Apply a full-scale signal to one of the input terminals.
7. Read the value acquired by the PLC.
8. Adjust the potentiometer to achieve the desired digital value stored in memory.
9. Repeat the offset and gain calibration until having small tolerance.

In Figure 29 is shown the schematic in the expansion module that helps to acquire the analog signal. When the process is made, the signal passes through a series of resistances, then through an instrumental amplifier (OPAM) that ensures to adjust the signal to the enclosed values, then through a gain adjust and finally through a ADC with the sample and hold (inside it) to retain the value of the signal for the time in which the conversion to a 12-bit word is made.

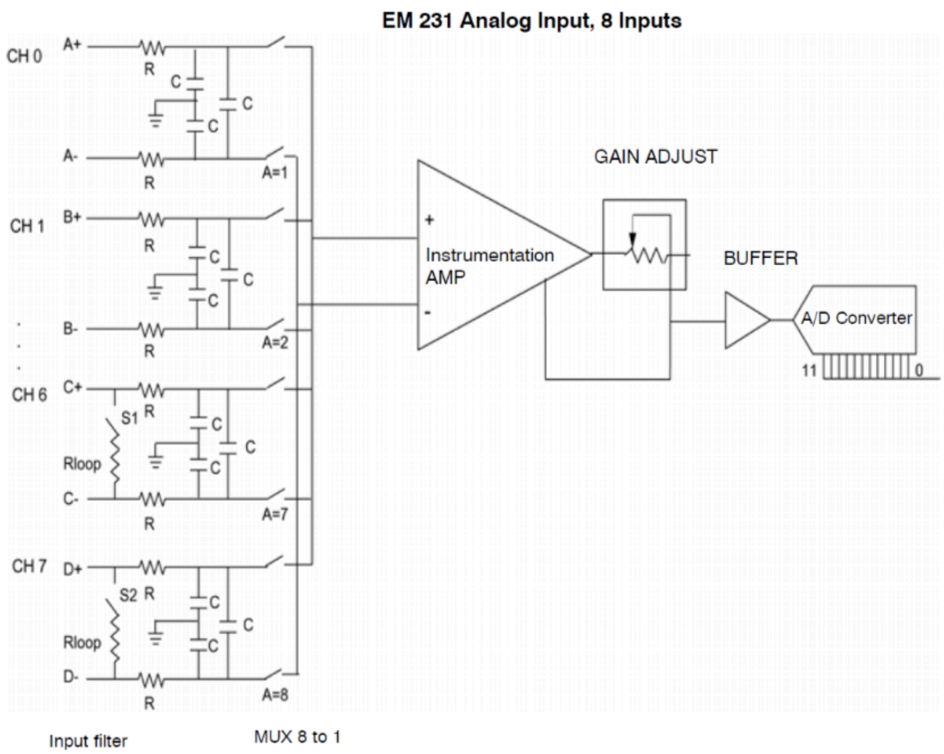


Figure 29: Schematic for the acquisition of a signal of the expansion module SIMATIC EM 231 [9].

Later the acquired data is saved in an excel file that has to be analyzed and processed with statistical model thorough the MATLAB Software, to create and produce a model that can be compared with the real results of the project in the DIMEAS laboratory. This is section is called statistical models; a further section will emphasize in this matter. For further specifications in the Analog Module EM 231, please refer to the annexes.

1.11 Guidelines to develop a Control System:

Now that the control device and the actuators have been described, there will be a short introduction to the recommendations that must be followed to produce an efficient and productive control system. To develop a control system with a PLC there are many methods to address the problem and design a suitable solution. Nevertheless, this process is very important and there are some basic and general guidelines that can be helpful to develop any program and the ones that were used in this thesis project to design the control of the PLC. The following steps can be used to design an efficient code to control any project and a variety of methodologies are based in this few steps.

1. Divide the process: Having the whole process or machine is difficult to determine which necessities are important and is easy to have a misconception of what is really needed. Dividing the process into sections that are independent from each other helps to emphasize what is needed to solve each particular portion and to made a proper decision to ensure an efficient solution exploiting resources as best as possible [15].

2. **Create Functional Specifications:** Describe operations made by each of the sections, recognize the proper input and outputs that are pertinent for the functional description of the operation and states that must be achieve from one action to another one. Identify the actuation methods that are implemented; solenoids, motors, drives, etc. Describe the interaction of the machine and the user, the human machine interface (Manual Pad) and the possible interactions of the operator and other sections of the machine [15].

3. Design the Safety Circuits: First of all, the equipment required during the hard wired and logic safety must be identified. The control devices implemented can collapse in an unusually dangerous manner, occasioning unexpected startup or change in the operation of the machine. Unexpected and improper operation can result in dangerous physical injury to people or significant damage of the property. The following considerations are given to be aware when electro-mechanical devices, in addition to the PLC are used to prevent unsafe operations [15]:

a. Identification of improper and unexpected operation actuators that can be dangerous.

b. Identify the conditions that would assure the operation is not hazardous, and determine how to detect these conditions independently of the PLC

c. Identify the electrical action that is caused by the PLC or the control hardware when the power is applied, removed and when errors are found. This information should be used for the designing of the expected and unexpected operations and to ensure the robust stability of the system. This information must NOT be used for safety purposes or limits.

d. Design the manual or electro-mechanical guide that properly inform the limits of the safety functioning of the device and blocks the operation independent of the control device implemented.

e. Provide appropriate information and states of the independent circuits of the PLC or control devices that are implemented in the process and any operator interfaces that must have the necessary information.

f. Detect any other safety-related requirements for the safe operation process.

4. **Specify the Operator Stations:** Based on the requirements of the functional specifications, create drawings of the operator stations. Include the following items [15]:

a. Overview showing the location of each operator station in relation to the process or machine.

b. Mechanical layout of the devices, such as display, switches, and lights, for the operator station.

c. Electrical drawings with the associated Input Output of the control device.

5. **Create the configuration Drawings:** Based on the functional specification requirements, the configuration and drawings must be implemented including the following elements [15]:

a. Overview showing the location of each I/O of the control device and its relation with the process or machine.

b. Mechanical layout of the control device and expansion modules, including extra equipment.

c. Electrical drawings for each control devise or extra equipment implemented, including the models numbers, general specifications, communication addresses and I/O addresses.

6. **Create a list of Symbolic Names:** The implementation of symbolic names instead of the address of the variables must be documented in a list that represent not only all the possible physical I/O signals but also the internal variables and memories used inside the program (local and global ones) [15].

1.12 GRAFCET

A special type of functional graph is the Functional and command stage transition graph (Graphe Fonctionnel de Commande Etape Transition, GRAFCET by its acronym in French). This type of functional graphs was introduced in 1977 by the French Association for cybernetic, technic and economic development (AFCET) [18].

This type of functional graph is a graphic representation of the internal logic of a program, predefined by the inputs, outputs and control signals. This not only shows the inputs and outputs, but also the actuated signals and components that the process needs to perform to achieve certain task [19].

Initially, this type of graph was developed for the control flow of different discrete control processes. Even though a high number of PLCs can be programmed in this type of graphing tool, it was not categorized as a programming language in the PLCs but as a tool to design a model using the actual behavior and operation principles of the system [18].

Usually the designer can pass from the GRAFCET to the Ladder programming language in easy steps and using the information in a direct approach, in this thesis project, the GRAFCET was an important tool for the development of the program downloaded into the PLC, in upcoming sections this will be shown [18].

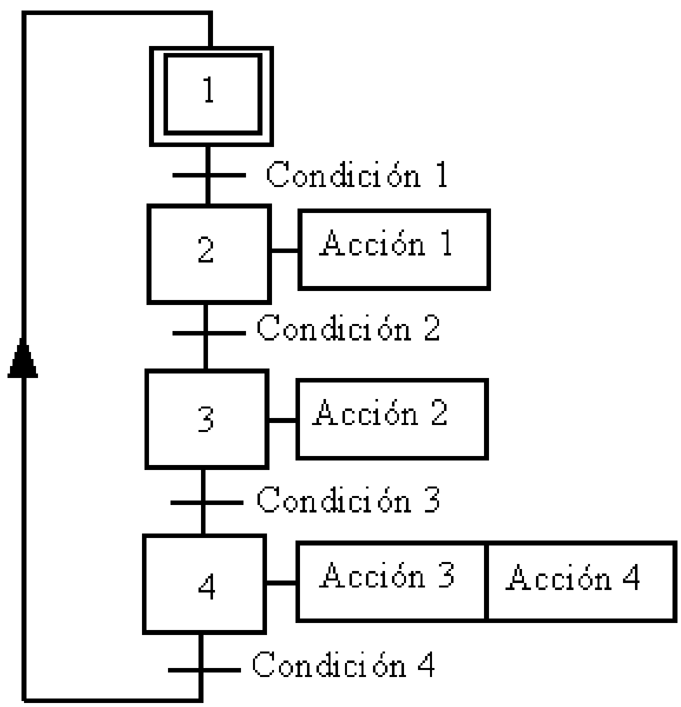


Figure 30: General GRAFCET and control logic [18].

1.13 Manometer

The importance of having the proper analog signal acquisition for this project was to attain the proper value of the pressure that is within the chambers of the cylinders that are going to be the test subjects. For this purpose, a type of manometer called a pressure transducer was implemented. This type of devices transforms the pressure into an analog electrical signal, such as voltage or current.

Even though that there are many kinds of pressure transducers, in this project was implemented a Metal Work 9000600 (see Figure 31) which works with the most popular technology to achieve the signal; the strain gage based method [20].

Figure 31: Pressure transducer implemented in this project

The pressure transducer is dotted of two main fragments, a flexible material which will deform when is exposed to a pressurized environment, and an electrical portion that is in charge of detecting the deformation and translated in an electrical signal. The flexible material can be formed into many different shapes, sizes and colors. It mainly depends on the type of sensing principle and the range in which the pressure that is measured varies. The most popular method is to form this flexible material into a thin and bendable membrane called diaphragm. The electrical part can be based in different electrical components, and its functioning and name depends on the ones that are implemented, this part can be resistive, capacitive or inductive [21].

A resistive pressure transducer: Has strain gages bounded to a surface of the diaphragm and any change in the membrane by the change of pressure in the environment, will produce a change in electrical resistance of each strain gage [21].

A capacitance pressure transducer: The variable capacitance in the pressure transducer has a capacitive plate bounded to the diaphragm and another capacitive plate bounded to an unpressurized surface, the pressure will deform the diaphragm and the distance between the two plates will change, this change in distances will result in a change or difference of electric potential and therefore in the capacitance of the sensor will change [21].

An Inductive pressure transducer: The inductive pressure transducer uses the principle of inductance to change the flexibility in the diaphragm membrane into an electric signal, it consists of two cores, one that is energized and one that is known as the pick-up core. The linear movement in the energized core, will change the electric current induced (by Faraday law) in the pick-up core and this change of current will change the inductive effect of the sensor [21].

As mentioned before, a Metal Work 9000600 is a resistive pressure transducer, so the conversion of the pressure into an electrical signal is due to the deformation of strain gages that are joined together with the diaphragm of the pressure transducer, finally this strain gages are dotted with a Wheatstone bridge configuration (a configuration of resistors that are used to be implemented in sensors to differentiate small changes of the strain gages see Figure 32). Therefore, the pressure applied to the transducer produces a deflection in the diaphragm that is traduced in strain to the gages and changes in the strain gages are directly proportional to the electrical resistance of the whole sensor [21].

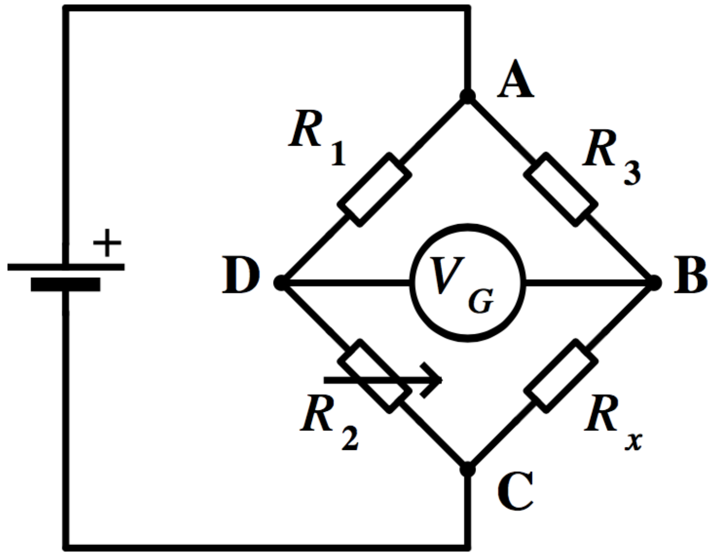


Figure 32: Wheatstone Bridge Resistor Configuration in the Metal Work 9000600.

The strain gage pressure transducers are strong-featured, stable and accurate by their design. Are easy to mount and are able to work in rough or hard environments and can work under tough vibration conditions. They are offered with a variety of electrical and pressure connections and be installed directly to the point of measurement [21].

The pressure to strain produces a resolution of millivolts, this signal is entered to the analog extension module of the PLC and then is used as is inform in this project work. This type of sensors can interact with data loggers, data acquisition systems, computers and readout instruments. This strain gages transducer is available in both low and high level outputs. The low level output is a 3mV/V at a 10 VDC input. The high output level strain gage transducer is from 5 to 10 VDC at an input voltage of 24 -32 VDC and 4-20 mA at a 12 – 36 VDC input. For the digital environment, the analog digital converter is used to translate the analog signals into digital bits (for this project the ADC is inside the expansion module) [21].

These type of sensors are very useful because virtually they do not require a lot of maintenance. Proper application and consciousness of the limitations that are intrinsic to them is important to assure long term life and high integrity performance. The factors that must be considered and are important for their performance are in the Metal Works datasheet but the most important will be listed below [21].

1. **Pressure range:** Transducers are designed to offer a specific electrical output for a given pressure range. For this case, the transducer of Metal Works 9000600 gives a signal that varies between 1 VDC to 5 VCD. This specification is always given by the manufacturer in the datasheet or product specifications. In general transducers are obtainable in discreet pressure ranges from 0-5 to 0-100,000 PSI rated pressure [21]. Usually, the providers can provide the ranges in low or high level electrical outputs. The transducer was chosen by the selected pressure range that was from 0 to 9 bar and the operating pressure was approximately 80% of the full scale [9].

2. Pressure and Electrical Connections: The pressure transducers have two connections, a mechanical pressure connection and an electrical connection. The importance of selecting the right transducer connections for the purposes needed is not determined by any industrial standards and consequently is responsibility of the user to check before achieving the transducer if its connections and configurations are suitable for the application. Pressure fittings are usually made of stainless steel and designed to be leak free in the operating range. The electrical connections are usually dotted by 6 pin conductor cable that goes to the control system. The selection of this pressure transducer was meet not only by performance specifications but also for electrical and mechanical connections [9].

The Metal Works 90006000 pressure transducer was a great choice because it can not only send the pressure to the PLC extension module, but can also show the pressure in the eight segment displays. In addition to this ability, the pressure transducer selected has different parameters that can be adjusted by the buttons in the front section of the transducer, some of this parameters are hysteresis and the resolution (for more information, the datasheet of the Metal Works **9000600** transducer can be find in the annexes).

1.14 Digital Pulse Counters

The digital pulse counters are special counters that have a digital display, this Pulse counters were implemented in the test bench to show the number of cycles that each cylinder have undergo in the wear test in order to identify a failure, to understand normal procedure and to help visualize the state of the probe that is been taken.

In addition to this the ISO standard (ISO 19973) indicates that there is a minimum of 20000 cycles to test a cylinder and therefore is necessary to see the state of the probe. The digital pulse implemented in the test bench is shown in Figure 33, it shows the Kubler Codix 130. A battery powered pulse counter that can be implemented in harsh environments. Depending on the speed that is required to count, the Pulse counter follow and display digits for signals from 7 kHz to 100 kHz. For this project work purpose, the digital pulse counter is used as a reference and is connected in parallel to the electromagnetic reed located in the front compartment of the cylinder's chambers, this is why it will only count the outstroke of the cylinder (for more information, the datasheet of the Kubler Codix 130 digital pulse counter can be find in the annexes) [22].

Figure 33: Digital Pulse Counter Kubler Codix [22].

1.15 Proximity Sensor

There are several methods to sensor the outstroke of a cylinder and it is a really important matter because depending on the effectiveness of this sensor, a test can be carried on or not. For this matter the test bench was dotted by non-contact switching, hence they needed to undergo a stress and had a weight in the cylinder's piston rod, and no need of a mechanical actuating force to ensure that the cylinder has accomplished the stroke. The benefits of this non-contact switching are that provides high reliability (as we need to accomplish a lot of cycles) and a long service life, maintenance free and have a short switching time [23].

There are several types of proximity sensors, the reed switch (used in this project), the inductive proximity switch, the capacitive proximity switch and the optical proximity switch. The capacitive and inductive switches work with similar principles of those of the pressure transducer sensors that were described in previous sections, the optical switch works with the disturb or perpetuation of a light, such as sensors in the elevators. In the other hand, the reed switches work with a magnetic principle (see Figure 34), sometimes they are also called magnetic switches and consist of two reeds in an inert gas filled tube. An external magnetic field causes the two reeds to close together, allowing the current to flow. There can be seen two types of proximity reed sensors, the normally open that are the ones described above and the reed switches are normally closed, this second type are equipped by small magnets that will keep the two reeds closed and when an external magnetic force surpasses the one of the small magnets, the reeds will wide open, restricting the current to flow. It is important to remark that this type of switches cannot be used in strong magnetic fields environments and that the actuators that actives them must be dotted with a magnet (in this case the cylinders have internal magnets and therefore can be equipped with this proximity sensors) [23].

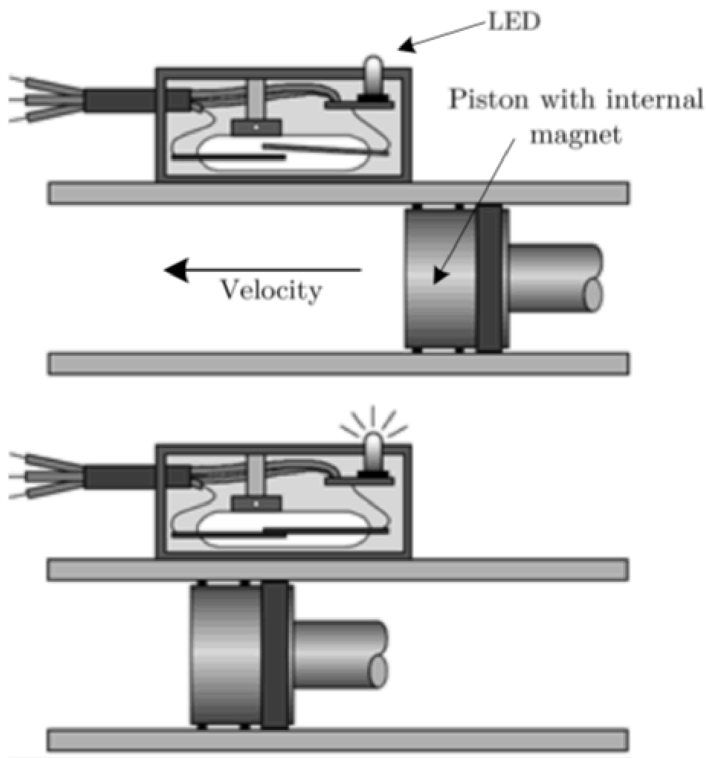


Figure 34: Magnetic Principle for Proximity Sensors [9].

1.16 Wear

Wear is only one of the phenomena that is studied when two bodies are interacting and have physical contact, this subject is very dense and as a matter of fact a science has been developed to understand this interaction. The name of this science is Tribology. Wear, lubrication and friction are the basis for the extremely interdisciplinary science and appeals to several academic areas such as: chemistry, physics, engineering and material science [24, 25].

Anytime that two surfaces interact together and they are subjected to sliding or rotating motion there are several physical phenomena involved in this interaction. The third Newton´s law states that any action has a reaction, following this principle; the movement of a body is caused by the friction and this friction is a force opposed to the movement that can cause wear. Wear is defined as the loss of material, in one or both bodies, caused by the interaction of the contacting surfaces. To understand this tribology science, we must start by describing the interaction of surfaces in microscopic scale

The first important aspect to take into account is that if a surface is glanced with a microscope it is irregular, so this induces that the interaction between two bodies only happens in small areas and not through the hole apparent touching surface that is seen with normal eyes. Then as many small portions of each body are touching together, the tribology remarks that this small protuberance with which the bodies are touched are considered as small spheres or parts of one of this geometric structure. Further on, as tribology studies the microscopic scales and there are many small particles in the environment (it is not a void space), there are chemical reactions that occurs in objects surfaces and contaminants that attaches to them, this surfaces that later on will be exposed to the interactions are covered by these contaminations or are covered by a thin layer of the same material decaying particles. This thin layers prevent objects of having a greater deterioration and therefore reduces wear and friction actin as a kind of lubrication being the first reducing agent. For example, in metal objects, for the type of interatomic particle bound, the metal surfaces still weld even in rubbing contact or when are severely damaged [26].

There exist two different types of wear, the chemical wear and the mechanical wear, the first been very complex and difficult to predict and to explain, it can react in different forms; as an advantage or a drawback for the wear of the object. It is extremely complex that depends on the environment particles and the molecule junctions of the material that is been under study, and affect in a wide range of the areas involved in the wear process. Due to its complexity and the diversification, the models used to predict this type of wear are beyond the studies of this project work and for more detailed topics of this matter one can refer to the Tribology handbook written by M. J. Neale [25].

This Final Project Work emphasizes in mechanical wear, and the models predicted and acquired here are develop in such a way that can calculate as close as possible the behavior of the pneumatic cylinders of the Mechanic and Aerospatiale Engineering Department, for its acronym in Italian (DIMEAS, Dipartimento di Ingenieria Meccanica e Aerospaziale).

As mechanical wear embraces a vast field of topics, and changes in the surface structure throughout the wear interaction; changing local material properties, temperature and chemically aspects of the objects. Its complexity is not trivial, involving many scientific disciplines and the study of it can detach substantial uncertainties. As a matter of fact, there was not been an ISO standard about the actual definition of wear and for this reason it will be addressed (for this thesis project) as the definition of wear from the German Institute of Industrial Norms for its acronym in german (DIN, Deutshes Institut für Normung). This definition states wear as: *"Wear is the progressive loss of substance from the surface of a solid body caused by mechanical action, i.e., contact and relative motion with a solid, liquid or gaseous counter-body"* [27].

Following this definition, we can accept that the wear is not an inherent material property, but is a result of a system that contains two bodies and sometimes contains a lubricant between them. Thys system and the material properties defines the wear and friction by the different interactions of motions, that can be linear motion (sliding) or rotational motion (rolling). Then this system is characterized by the following parameters: structural parameters; characterize the components such as materials, lubricant and environments, operational parameters; characterize the functional conditions (such as movement, load, velocity and disturbances as vibrations) and interaction parameters; which characterizes the action of structural components (temperature, kinematics, duration) and the contact bond and lubricant modes [28]. Figure 35 shows the parameters described above in a normal tribology system.

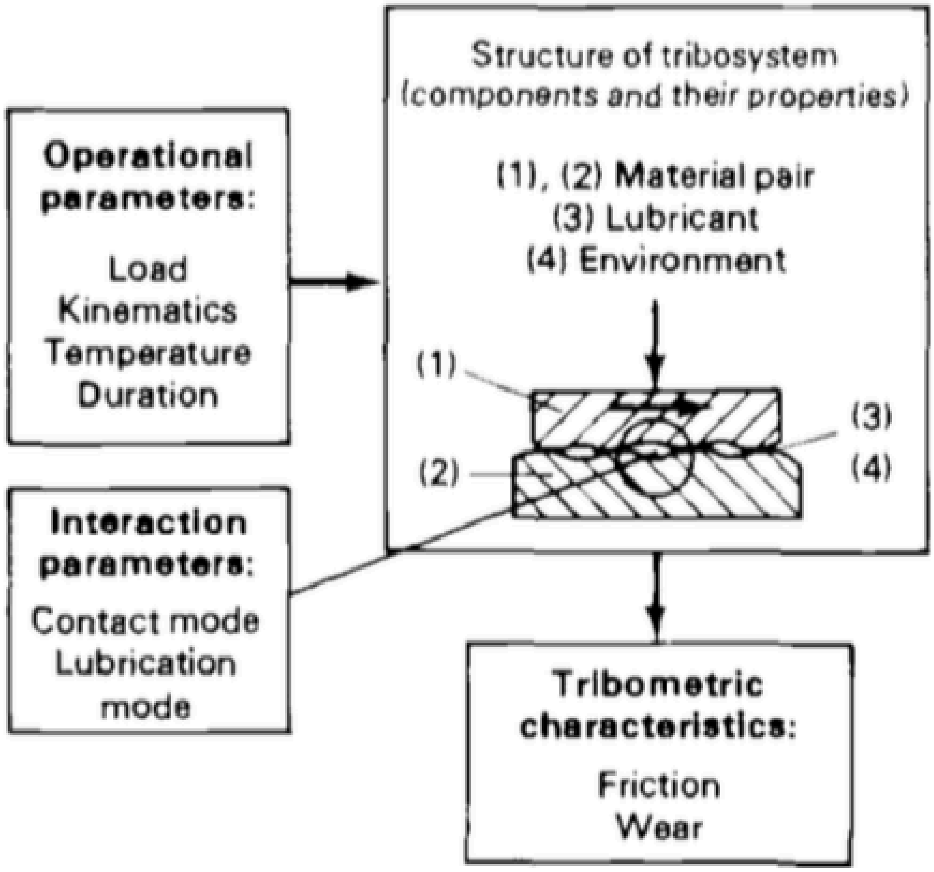


Figure 35: Tribology System Characterization Parameters.

1.17 DIN Wear Classification

Depending on the contact and motion of the bodies subjected to the interaction, there are different wear that can be accentuated, the DIN standard 50320 relates to them as abrasion, adhesion, surface fatigue and corrosive wear. In this section an accurate and detailed description of each of this classes of wear will be mentioned to offer the reader a proper background to continue with the understanding of the following topics. Table 8, shows the different types of wear present in different interactions between bodies, remember that each of this can be considered as different the tribological systems. Even though there can be different wear types in each system, usually there is one that dominates in each case.

System Structure	Tribological Action (symbols)	Types of Wear	Effective Mechanisms (individual or combined)			
			Adhesion	Abrasion	Surface fatigue	Tribochemical reaction
Solid -Interfacial medium (full fluid film separation) -solid	sliding-rolling-impact	-			X	X
Solid -solid (with solid friction, boundary mixed lubrication)	sliding	sliding wear	X	X	X	X
	rolling	rolling wear	X	X	X	X
	impact	impact wear	X	X	X	X
	oscillation	fretting wear	X	X	X	X
Solid -solid and particles	sliding	sliding abrasion		X		
	sliding	sliding abrasion (three body wear)		X		
	rolling	rolling abrasion (three body wear)		X		
Solid -fluid with particles	flow	particle erosion (erosion wear)		X	X	X
Solid -gas with particles	flow	fluid erosion (erosion wear)		X	X	X
	impact	impact particle wear		X	X	X
Solid -fluid	flow oscillation	material cavitation, cavitation erosion			X	X
	impact	drop erosion			X	X

Table 8: Types of Wear present in different tribological systems [28].

1.17.1 Abrasive wear

If one of the system bodies is harder and rough enough or if hard abrasive particles are detached from one of the materials, this type of wear is the one that dominates in the tribological system. The abrasive wear happens when the hard abrasive particles present in one body or cloister into one of the bodies, start cutting or sliding the other body particles due to the negative angles that are present in the hard abrasive particles [25]. This material that is removed from the softer body doesn't fall but displaces and ploughs leaving furrows. This relationship between wear resistance and hardness of the particles can be shown in the following figure:

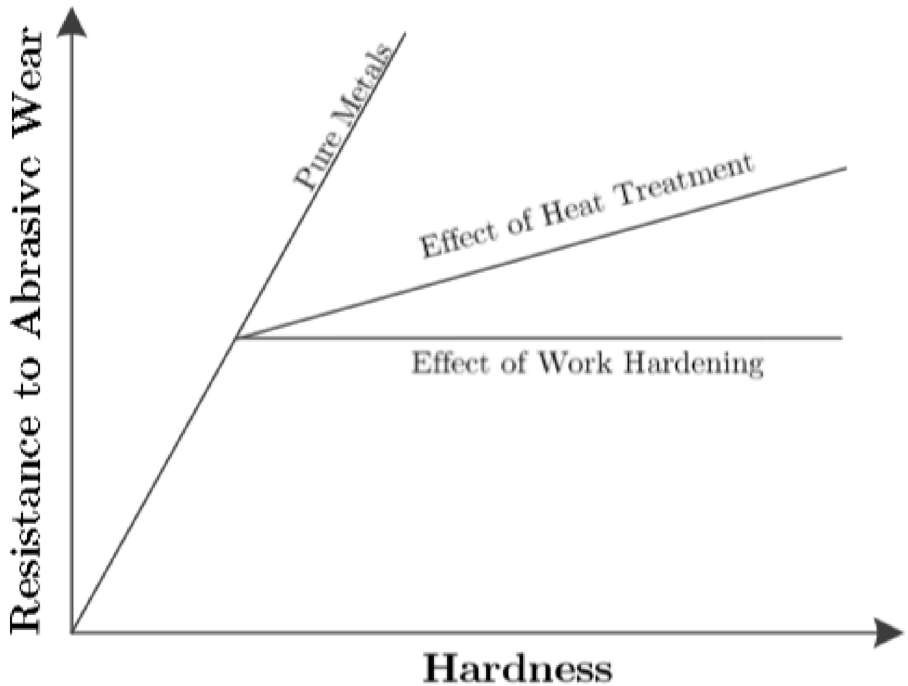


Figure 36: Relationship between abrasive wear and hardness.

As it usually happens in hard materials as metals, the table bellows shows three different trends to understand the abrasive wear. When the metal is pure and does not undergoes plastic deformation, thus no effect of work hardening is present, the result of abrasive wear can be represented by a positive slope and if the material is harder the wear will be greater. If there is a heat threatening the slope of the relationship will decrease after a wear value or when the heat treatment is present, meaning that the hotter the material is less abrasive wear will happen, this could be because rounding of the edges that produces the heat treatment in the cloistered particles. Finally, it is shown that if the material undergoes plastic deformation and therefore is a hard material in which can be present work hardening, the wear will remain constant when the work harden will still increase until the material will eventually enter into the rupture zone and the fracture will take place.

The abrasive wear has a dense theory background and starts by the assumption that the hard negative angle particle is sharp enough to move pieces from the other body from one side to the other. This particle can be modeled as a conic geometric figure and will dig furrows into the other body, such as shown in Figure 37.

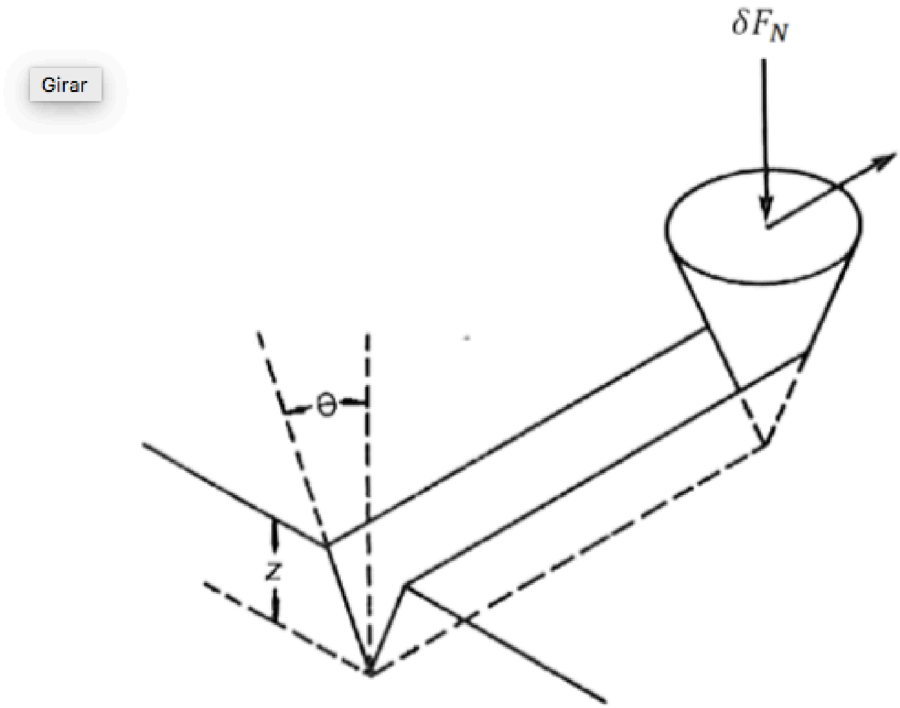


Figure 37: Geometrical assumptions for abrasive wear demonstration [9].

Following the proper analysis for the correct analytical and geometrical assumptions one can demonstrate that the wear coefficient (K) is given by:

$$K = \frac{2 * Cot\,\theta}{\pi} * k2$$

Equation 4: Wear Coefficient in abrasive wear [24].

where k2 can be understood as the proportion of all the abrasive events produced by the appearances of different hardened particles. This wear coefficient is only valid for the conic shape seen in Figure 37, but it can vary depending on the shape that is wanted to analyze [24].

As the conditions in which abrasive wear dominates the tribological system, the preventive measures to prevent it are widely known, as it only happens when the harder and rougher material enters in contact with the softer material. One preventing measure is to reduce the sharpness, this means to decrease the roughness in the harder material to decrease the sharpness of the hard particles that are responsible for the furrows in the softer material [29]

1.17.2 Adhesive Wear

Adhesive wear happens when the materials that are able to adhere together through a solid phase of welding asperities. Posteriorly, the junction breaks resulting in material loss of one or both bodies. As in previous case, the study of metals materials is of interest to this subject and some general conclusions have been find, i.e. [25]:

- When there is the adhesive wear between a harder metal and a softer metal, the softer metal tends to loss more particles than the harder metal after the break down [25].

- Adhesive wear seems to happen more for similar metals than for those of diverse metals [25].

- Adhesive wear seems to happen more for materials that have mutual solubility at the temperature contact [25].

In the void space the metals tend to join into one due to Van der Waal's attraction forces and the bond strength will be higher with the time and the pressure. Therefore, this adhesive wear will not take place, in the open environment are present different things that prevent material bounding to happen i.e. air, surface contaminants and oxides [25].

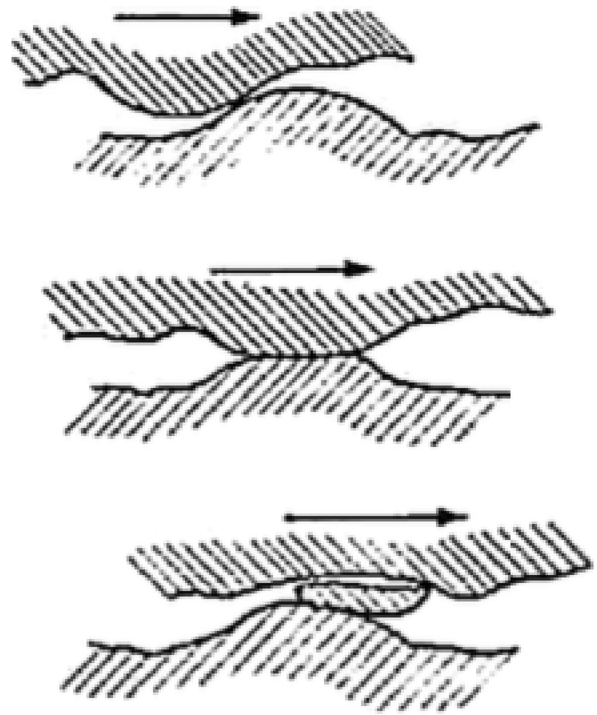


Figure 38: Adhesive wear [25].

By studying the adhesive interaction between two bodies, assuming an isothermal process (thus a constant temperature) and constant mechanical properties, a conclusion can be made: the wear rate is not dependent of the sliding velocity, nor the apparent area of contact and is because the true area of contact depends on the load and wear rate depends on the true area of contact [29].

Many wear processes start as adhesive wear, as seen before if there is a detached particle in an interaction between two bodies, it can act as a lubrication or as a hard particle that cloisters into one of the materials giving the start for abrasive wear or pass for air which contains oxides and will produce hard and abrasive particles into one of the surfaces. This effect can be seen when two surfaces are subjected to high vibration frequencies between each other, there will be particles detachment and it will lead to the transformation between adhesive wear to abrasive wear or to wear due to fatigue [29].

1.17.3 Fatigue Wear

Fatigue Wear can happen in macroscopic and microscopic scale, the difference between them is that at macroscopic scale its referred to a machine or component of a machine, in microscopic scale is referred to an individual asperity contact. A typical failure mode for fatigue wear is when wholes of removed material are present in the junction, sometimes, these wholes grows bigger and bigger and corresponds exactly to the maximum shear stress of the structure or the piece of structure, causing the structure to arise to elastic limit and thus causing elastic deformation and finally rupture in the material. As usually, fatigue is represented and determined with the number of cycles that are needed to achieve failure with the accumulative stress [25].

Depending in the failure condition that the material reach, there can be several conclusions:

-The environment determines how the amount of stress required for crack nucleation and the rate of crack propagation.

-The presence of surface flaws can determine the direct surface crack to become as important as the interior crack.

-If surfaces are subjected to high tangential stresses, the position of maximum shear stress arises to the surface and will lead to fracture.

-The precious conclusion will arise if there is bad lubrication or surface roughness, good lubrication and smooth surfaces will be supported if fatigue wear leads to a stress failure in interior fatigue.

-A lubricant can accelerate crack propagation if it enters into a gap and develops high fluid pressures in the opening and closing cavity.

In the following figures there can be evidenced two different types of fatigue wear, the first on was due to elastic deformation and the second one is due to crack propagation in the surface. As seen before for the adhesive wear, in Figure 39 is shown that some particles are separated from the surface, this phenomenon can induce another type of wear such as abrasive wear and further failure of the structure [24].

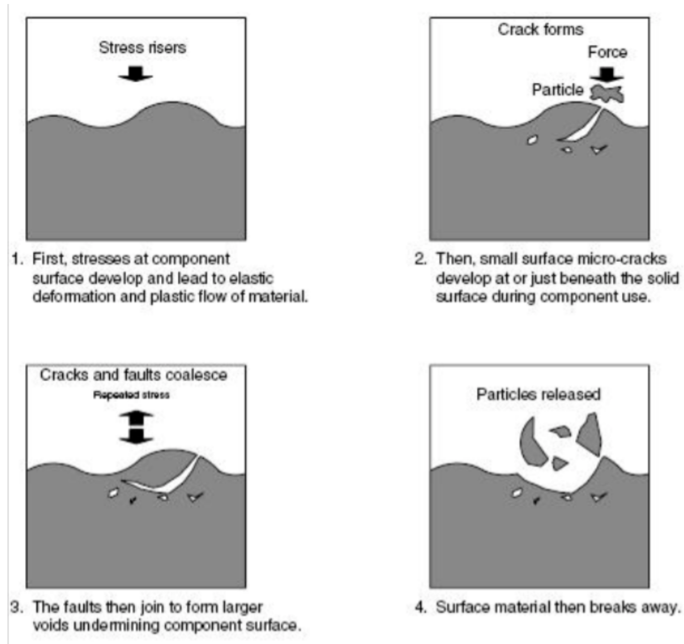


Figure 39: Fatigue wear by elastic deformation [30].

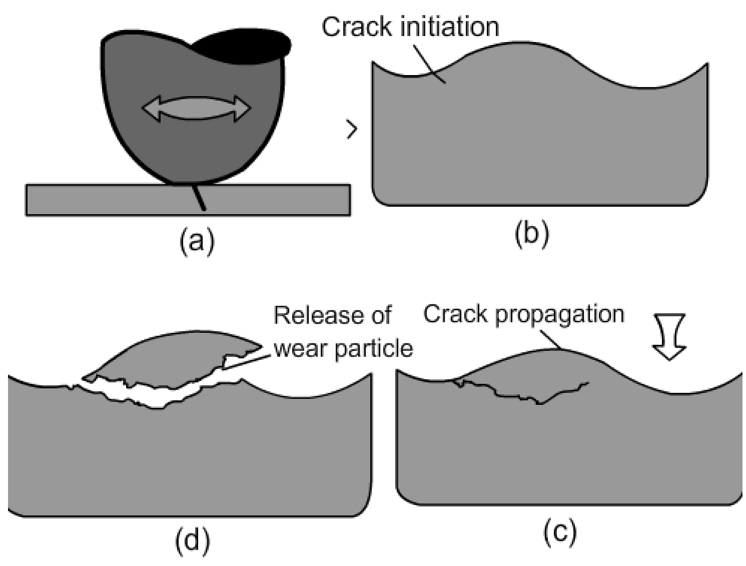


Figure 40: Fatigue wear by crack propagation in the surface [30].

1.17.4 Corrosive Wear

This type of wear happens by the interaction of the surface with the environment, antagonistic with the other fatigue effects that can be explained with the stress interactions and deformation properties of the interaction surfaces, it is due to a chemical reaction with the oxide that is present in the ambient or with the external substances that can be present in a tribological system, as is known, oxide particles are very hard and rough. This reaction produces asperities in the surface and crack formation, relating this type of wear with the others, such as abrasion and fatigue (crack nucleation), this is the most difficult wear case to be explain by mathematical models but with some assumptions an approximation (it is always an approximation, in all types of wear) of the wear coefficient can be made [25].

The following assumptions must be taken into account if there is wanted a mathematical analysis of the corrosive wear:

-Surface rub is due to asperity contacts as in adhesive wear.

-A reaction environment produces a slow and growing protective thin layer upon the surfaces that are interacting.

- This protective layer will remain protective and undamaged until it reaches a thickness determined by λ and then it will be removed by rubbing.

-If there is oxidation in the surfaces, it will be removed by rubbing.

-The growth of the protective film will be directly proportional to the thermal process.

Under the previous assumption, the corrosive wear is protective for the surfaces and is present to protect against severe metallic wear. These assumptions are made having knowledge that the minimum changes in the environment reactivity or in the temperature may cause intolerable changes in the thickness of the corrosive layer [25].

1.18 Accelerated Testing Conditions and Reliability.

Product reliability is the key factor that ensure the quality and competitiveness of a product in the market. If the product is reliable the customers are more likely to buy it and therefore it will generate more incomes. Its normal that manufacturers spend high amounts of money into research and product reliability. Starting from the life testing data, can be found a lot of crucial evidence that held to important decision: changes in design, in manufacture, in materials, and identification of possible failure. However, some products have such an extensive life that life testing is unpractical, therefore accelerated testing conditions is made to acquire information of this type of products, exposing products to high stress conditions to achieve **yield failures** quicker. The proper analysis of the data obtained by the accelerated test conditions leads to an approximation of the behavior under normal design conditions, this means under high stress situations, saving time, money and resources [2] [31] [32].

As more products have a prolonged life, studies in accelerated testing conditions rose. Practical, and modern statistical models and methods for accelerated test data have been created. Starting from basic models and graphical analysis there have been numerous advances that allow to compute the wear and other important features of the products under study, arriving to strong and rigorous processes that can be also applied to find the most approximated results [31].

To understand accelerated testing conditions there must be some background and terminology that must be clarified before starting. The acquisition of data is important and the time in which they are taken is also important. For this purpose, the term **complete data** and **censored data** are taken into account. Complete data is when all the subjects under study or specimens are run to failure, instead censored data is when there are still working specimens when the data analysis time is done [2].

Sometimes engineers are in the need to achieve the reliability results of a product sooner than the time it takes for its failure mechanisms are identified, especially in this high reliable components. As stated before because of money, redesigning concerns, application issues or economical purposes. That is why Accelerated testing conditions (ATC) were developed and they can be from two different natures, qualitative and quantitative ATC [33].

The first one consists in revealing the failure modes or in which approaches a product can fail, this with the purpose of showing where the product is failing and in which approaches its design can be improved. Some of the most common qualitative probes are the highly accelerated life testing (HALT), highly accelerated stress testing HALT, torture test and "shake and bake" [33].

The second type of ATC, the quantitative accelerated test (QALT) are designed to produce significant data that can be related with the reliability and service life of a specific product. Therefore, with the help of the data achieved in the QALT methods, the extrapolation of an estimated probability density function (pdf) that suits to the product of study under normal testing conditions is made [33].

1.18.1 Types of accelerated test and stress loading

There are several types of accelerated test to probe the reliability of different mechanical components, such as pneumatic actuators, some common overstress implemented in the accelerated testing are: high usage rate, overstresses, high censoring rate time, time degradation elements, stress loading conditions, temperature, voltage, vibrations, humidity and any stress that is relevant for the life of the product. Depending on the test purposes or the information that wants to be discovered in the mechanical component, it is recommended to use one or another accelerated test condition. Even a specific stress condition such as stress loading to create an accelerated test environment can be applied in different approaches (Axial or Radial) to achieve different component specifications [32]. An easy example of accelerated test condition can be seen with the stress loading of pneumatic cylinders, the normal stress loading for a cylinder can be for example 5 kg, then the testing may involve testing the product at 10 kg and 12 kg and 15 kg to induce failure quicker than is intended. In the previous example the stress type is the load and the accelerated stress levels are 10 kg, 12 kg and 15 kg [33].

Then using the data obtained at different stress levels carefully selected by the analyst, the standard life data analysis techniques can be implemented to estimate the life distribution that best fits at each stress level. Finally, the results of overstressed conditions can be used to estimate a probability distribution function (pdf) of the normal operation stress level based on the statistical characteristics of the pdf at the different accelerated stress levels [33].

The stress loading method that will be described and considered in this project is the constant stress method due to its compatibility with the type of actuators and the type of test that the mechanical actuators are submitted (leak and wear test). In addition to this, constant stress loading is the most comfortable accelerated test, has a common approach and a systematic method. Each actuator is to be tested and subjected to constant stress levels (10 kg), which helps to simulate the real depletion of the actuator and will create a stress condition to undergo failure in least time. It counts with some advantages, first, it is easy to keep a constant stress level, also it can be developed and verified easily and better than the other loading methods and finally, the analysis of the data and its reliability estimation are easily developed and computerized, avoiding some areas of uncertainty [32].

The engineering considerations have great impact on the validity and accuracy of the results, therefore is important to consider the purpose of the test, the performance of the item to be evaluated, the test conditions type, the accelerating stress method, and the statistical model to be used with the allocation and the planning of the accelerated test. The meaning of the evaluation of a product can be done for different final purposes: identifying design failures, comparison purpose, evaluation of quality standards, identifying manufacturing defects and/or to improve those situations and optimize the reliability of the item, the calculation of an estimated warranty time, failure rates and costs. For the evaluation of the product is also important to consider the statistical test, because it helps to have a more accurate result and estimation, and also is important to specify how accurate these values have to be in order to take further decisions and conclusions [32].

1.18.2 Life-Stress relationship

During years, the life-stress relationship has been studied and therefore based on models previously developed, after an ATC, the extrapolation of a pdf as function of the increased stress levels can be achieve. This models are usually expressed as any defining life parameter as function of the stress level, changing form one stress level to another. One must choose the type of life-stress relationship that better fits the type of data that is being analyzed, some of this methods can be Eyring, inverse power law or Arrhenius models, usually the mentioned models are used to study only one stress condition. There are other type of different models that allows to correlate different stress conditions, but as in this project work is only used one stress condition (load) there is no need to go deeper in this topics [33].

1.18.3 Redundant information achieved from ATC

Once the data achieved from a practical accelerated testing condition is made and the parameters have been calculated to fit a life distribution and a life-stress relationship, there are redundant parameters for normal life data analysis that can be achieved from the ATC achieved data. The metrics that are taken into account in this thesis Project and in the MATLAB program are extracted from the pdf and cumulative density functions (cdf) [33]. This will be explained in further sections with practical examples, with pneumatic cylinder information and applications [34].

1.18.4 Arrhenius Model

The Arrhenius life stress model is the most common relationship in accelerated life testing. The name is due to the Swedish Physic and Chemist Svandte Arrhenius that published his studies in 1887. In his studies, he states a method to pass the achieved results from the accelerated testing conditions to the normal operating life conditions [35].

The Arrhenius rate is given by:

$$R(T) = Ae^{-\frac{E_a}{k*T}}$$

Equation 5:Arrhenius rate

where:

- R is the speed of reaction.

- A is an unknown non-thermal constant.
- E_a is the activation energy.
- K is the Boltzmann's constant
- T is the temperature.

Then this formula states that the energy needed for a molecule to be part of a reaction is the conglomeration of the previous stated parameters. Then assuming that the useful life is inverse from the reaction rate caused from the stress applied in accelerated testing conditions. The Arrhenius life stress relationship is [35].:

$$L(V) = Ce^{\frac{B}{V}}$$

Equation 6:Arrhenius life stress relationship.

where:

- L is the quantitative live measure as such of the metrics achieved in this thesis.
- V represents the stress level.
- C is a parameter of the model determined by the ACT used.
- B is a parameter of the model determined by the ACT used.

Then using the natural logarithmic relationship, the Arrhenius life stress relationship can be plotted in the so called Life vs. Stress plot or Arrhenius Plot.

$$\ln\big(L(V)\big) = \ln(C) + \frac{B}{V}$$

Equation 7:Arrhenius life stress logarithmic relationship.

The calculation of the B parameter is given by the following relationship:

$$\mathrm{B} = \frac{E_a}{k}$$

Equation 8:Arrhenius B parameter calculation.

The calculation of the parameter C is obtained from the Arrhenius life stress relationship having the other parameters.

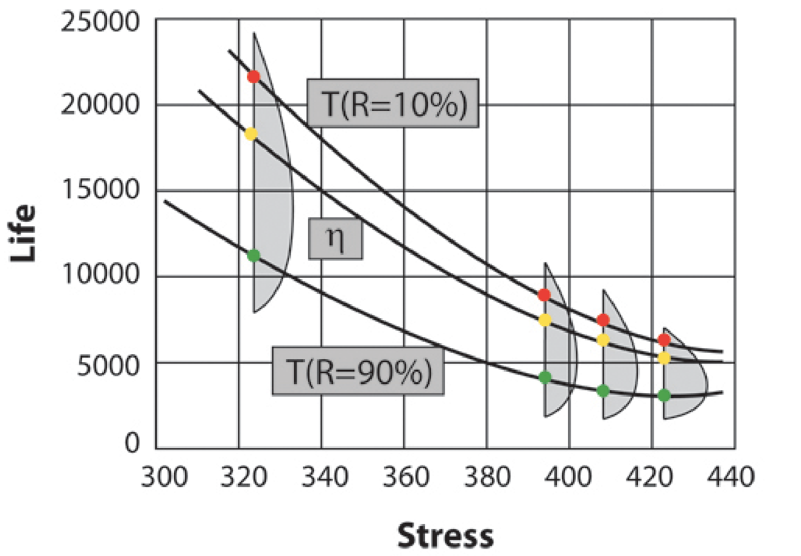


Figure 41:Arrhenius Plot.

Finally, the accelerating factor is determined by the type of prove that is chosen and the ACT conditions that are under study. This factor gives the relationship with the higher stress level used in the accelerated testing and the normal conditions [35]..

$$A_F = \frac{L_{use}}{L_{Accelerated}} = \frac{Ce^{\frac{B}{V_u}}}{Ce^{\frac{B}{V_a}}} = e^{\frac{B}{V_u}-\frac{B}{V_a}}$$

Equation 9:Arrhenius Accelerating Factor Calculation.

Having these parameters calculated then the metrics of interest in normal life conditions using the accelerated test conditions can be found with the following formulas:

$$\bar{T} = C \cdot e^{\frac{B}{V}} \cdot \Gamma\left(\frac{1}{\beta} + 1\right)$$

Equation 10:Arrhenius Mean Time to Failure.

$$\breve{T} = C \cdot e^{\frac{B}{V}} (ln2)^{\frac{1}{\beta}}$$

Equation 11:Arrhenius Median.

$$\tilde{T} = C \cdot e^{\frac{B}{V}} \left(1 - \frac{1}{\beta}\right)^{\frac{1}{\beta}}$$

Equation 12:Arrhenius Mode.

$$\sigma_T = C \cdot e^{\frac{B}{V}} \cdot \sqrt{\Gamma\left(\frac{2}{\beta}+1\right) - \left(\Gamma\left(\frac{2}{\beta}+1\right)\right)^2}$$

Equation 13:Arrhenius Standard Deviation.

$$R(T,V) = e^{-\left(\frac{T}{C\cdot e^{\frac{B}{V}}}\right)^{\beta}}$$

Equation 14:ArrheniusWeibull Reliability Function.

$$R\big((t|T),V\big) = \frac{R(T+t,V)}{R(T,V)} = \frac{e^{-\left(\frac{T+t}{\eta}\right)^{\beta}}}{e^{-\left(\frac{T}{\eta}\right)^{\beta}}}$$

Equation 15:Arrhenius Conditional Reliability Function A.

$$R\big((t|T),V\big) = e^{-\left[\left(\frac{T+t}{C\cdot e^{\frac{B}{V}}}\right)^{\beta} - \left(\frac{T}{C\cdot e^{\frac{B}{V}}}\right)^{\beta}\right]}$$

Equation 16:Arrhenius Conditional Reliability Function B.

1.18.5 The inverse power law (IPL):

The inverse power law is another type of relationship to find the normal operative life results when there are used ACT. This relationship is normally used when non-thermal or isotropic stresses are used, for example vibration, load or voltage. The relationship is given by [36]:

$$L(V) = \frac{1}{K * V^n}$$

Equation 17:Inverse Power Law Life Stress Relationship.

where:

- L is the Quantitative life measured with ACT as in this project.
- V is represented by the stress level.
- K is a parameter of the model determined by the ACT used.
- η is a parameter of the model determined by the ACT used.

The plot of such relationship gives a similar result as that given by the Arrhenius model. This one can be observer in the following figure:

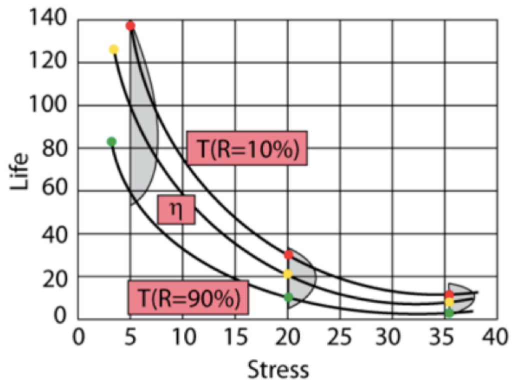


Figure 42:IPL Life Stress Plot [36].

Then the relationship can be also linearized using the natural logarithm and then obtaining

$$ln\big(L(V)\big) = -\ln(k) - n(\ln(V))$$

Equation 18:Inverse Power Law Life Stress Logarithmic Relationship [36].

This relationship when is plotted gives a straight line, and therefore the last two parameters of the model K and η are most of the time found as the slope and the intercept of this equation [36].

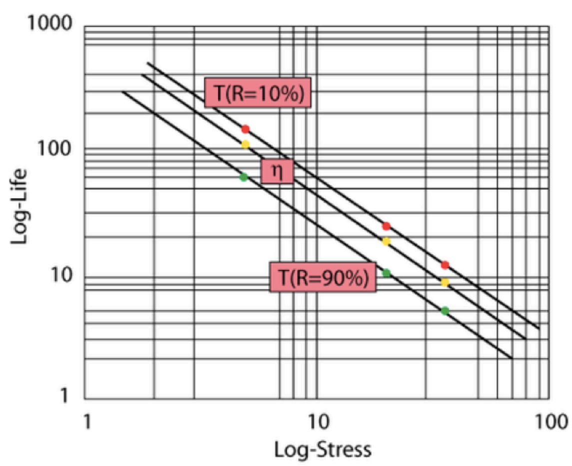


Figure 43:IPL Logarithmic Plot [36].

The parameter η is closely related to the effect of the stress in the life of the product. If η increases then the effect of the stress in the accelerated testing conditions is greater, therefore if eta is close to zero, the effects in of the ATC is meaningless. For this type of proves negative values of eta is rejected because it indicates an elongated life than that of the normal operation conditions.

Finally, the accelerating factor of the Inverse Power Law model is given by the following expression:

$$A_F = \frac{L_{use}}{L_{Accelerated}} = \frac{\frac{1}{K * V_u^n}}{\frac{1}{K * V_a^n}} = \left(\frac{V_a}{V_u}\right)^n$$

Equation 19:Inverse Power Law Accelerating Factor [36].

Where:

- Luse is the life at the used stress level.
- Lacc is the live at the accelerated stress level.
- V_a is the use stress level.
- V_a is the accelerated stress level.

As with the Arrhenius model, all the important metrics can be achieved with the proper analysis and math manipulation of the previously listed equations in conjunction with the Weibull or other pdf relevant for the studies [36].

1.19 Statistical Considerations

The subjects of interest on this section are the statistical models, which consider the population and the sample size, also the data analysis methods, such as the confidence intervals and the hypothesis tests. the model to be used on a data set depends on the type of product, test method, accelerating stress method and product specifications. As in this final project work are discussed the models for life tests with constant stress, the frequently used distributions used with this accelerated testing conditions are: the normal, lognormal and Weibull [32]

1.19.1 Probability Density Function and Cumulative Distribution Function:

The purpose of doing a life testing data analysis is to predict the functioning of the studied product, to predict its performance and the amount of time that is likely to work before a failure mode is present. This prediction is based on the behavior that a smaller group, under test, shows under observation. The common results obtained in the smaller group can be then extended to the representation of the whole population. For life testing, the important trends are the frequency and the probability that a product of the unit at test fails. The obtained results are then analyzed, modeled and predictions about the failure in the specific product are made depending on how the failure manifestations are distributed over time, and this is a probability density function [37]. Instead, the cumulative distribution function is the accumulation of the probability that a continue random variable, in this case the failures, takes a determined value. This two type of plots are really bounded together and the applications that derive from one or another depend on how are they look and the information wanted to be achieved [37].

1.19.2 Variance.

The variance is a way to measure the spread of the numbers of a data set, it allows to understand how far from the mean of the values is the model, for its calculation is necessary to have the difference of each point to the mean, by squaring and summing the difference and then dividing it by the number of sets in the data source (equation 1) [38].

$$Var(T) = \int_{-\infty}^{\infty} t^2 * f(t)dt - [E(T)]^2$$

Equation 20

$$Var(T) = \int_{0}^{\infty} t^2 * \left(\frac{1}{\theta}\right) * e^{\left(-\frac{t}{\theta}\right)} dt - \theta^2 = \theta^2$$

Equation 21

1.19.3 Standard Deviation:

the standard deviation allows to measure the variation or dispersion of a set of data, when there is a low standard deviation this means that the points are closer to the mean and there is low dispersion. The calculation of this value is eased by taking the square root of the variance and therefor having the variance is possible to obtain the standard deviation [38].

$$\sigma = \sqrt{\theta^2} = \theta$$

Equation 22

1.19.4 Mean Value, Median and Percentile:

The mean is the average of all the numbers of a data set and is calculating by summing all the points and diving by the total quantity of points included on a data set, instead the median is the middle number of that data set. The percentile is a number that captures approximately the percentage of the values in each set of data that are equal of less than a specified number, on other worlds the quantity of points that fall into that determinate area [39].

1.19.5 Hazard Functioning

Hazard function is known as the instantaneous failure rate at time t, supposing that the item has survived all the period of analysis from time cero to time t. Wear-out indicates that most failures are due to the increasing failure rate over the life of a product, if this is the case it is better to perform a preventive replacement of the parts [32]. This information in life data analysis can be represented in the bath tub plot, where the wear in, the useful life and the wear out cycle of a determined product are shown.

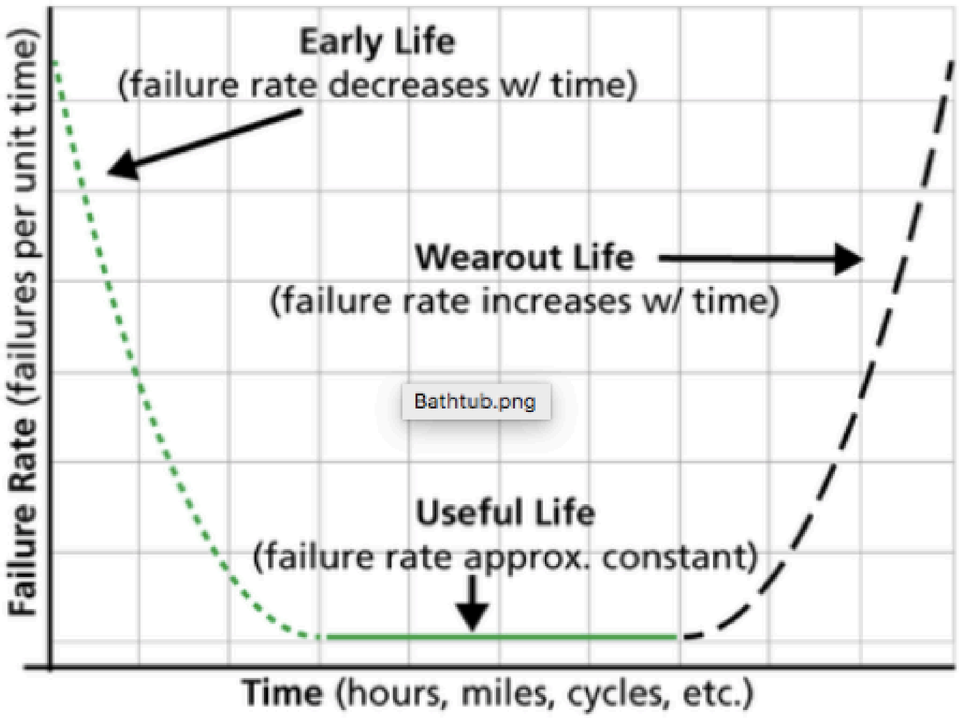


Figure 44: Bath Tub plot representing Wear in, useful life and Wear out.

Considering the previous information, now the focus will be on the Normal, Lognormal and Weibull statistical distributions.

1.19.6 Normal distribution

The normal or Gaussian distribution tends to describe products with a wear-out failure behavior. Is commonly used for the distribution of the properties such as strength, impact resistance in accelerated tests. some characteristics of this distribution are: μ that is the mean and can have any value from – infinity to + infinity, σ is the standard deviation of the data set and must be always positive. The standard cumulative distributed function can be expressed as [32]:

$$F(y) = \Phi\left[\frac{y-\mu}{\sigma}\right], \qquad -\infty < y < \infty$$

Equation 23

As life must be always positive the fraction of the distribution below zero must be low in order to use in a good way this distribution function, the data acquired by the model in which is implemented is usually given by a continue variable that must be sensed (in this case the pressure within the chambers) [32].

The graph of this density function has a bell structure and is symmetrical with respect of the mean value, this curve is also known as the Gauss Bell and is the graph of a widely known Gaussian form as seen in the figure below [40].

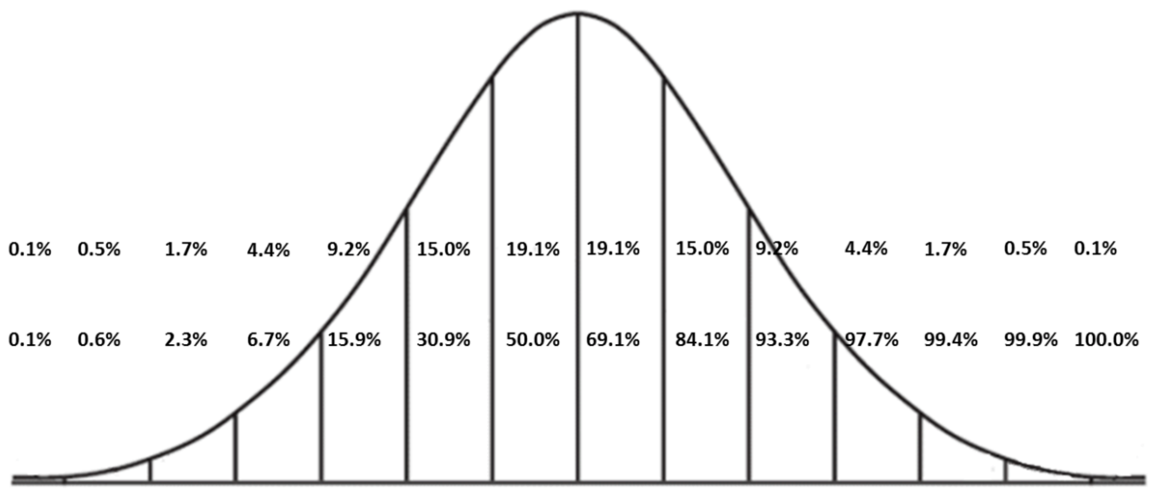


Figure 45: Normal distribution [40].

Even though that for this project it is used to determine a trend in the pressure values when the actuator chambers present a leak, the importance of this statistical model is because allows to model a vast of natural, social and psychologic effects. The use of this normal distribution can be justified by the observation of single event that can be the sum of independent variables present in the subject under study [40].

Implementing this statistical distribution, there can be obtained predictions in the applications by means of the minimum square method, that will latter on help to predict a rational model to predict the life reliability in pneumatic cylinders [32].

1.19.7 Lognormal distribution

The Lognormal distribution is extensively used in life testing data, some of the fields in which is implemented are: metal fatigue, solid state components and electrical insulation. The lognormal and normal distributions are related and one can derive the log-normal from the normal distribution, it is commonly used in statistical studies of data sets, the approach of analyzing the lognormal data set with the commonly known normal data distributions [32].

$$F(t) = \Phi\left\{\frac{[\log(t) - \mu]}{\sigma}\right\}, \qquad t > 0$$

Equation 24

The following figure, shows a lognormal accumulative distribution. In statistics is widely used to sense aleatory variables which logarithm is normally distributed, this is to say that has a normal behavior in a logarithm scale. If the variable of study has a normal distribution, then the lognormal distribution also exists [32].

The base of the logarithm in not relevant for this matter of study because the variable under a normal distribution and can be referenced only if there is one constant value. A variable can be modeled with a lognormal distribution if and only if it can be divided in small independent factors. A normal example of a lognormal distributed variable is the return in an investment because it can easily be seen as the product of many daily returns [41].

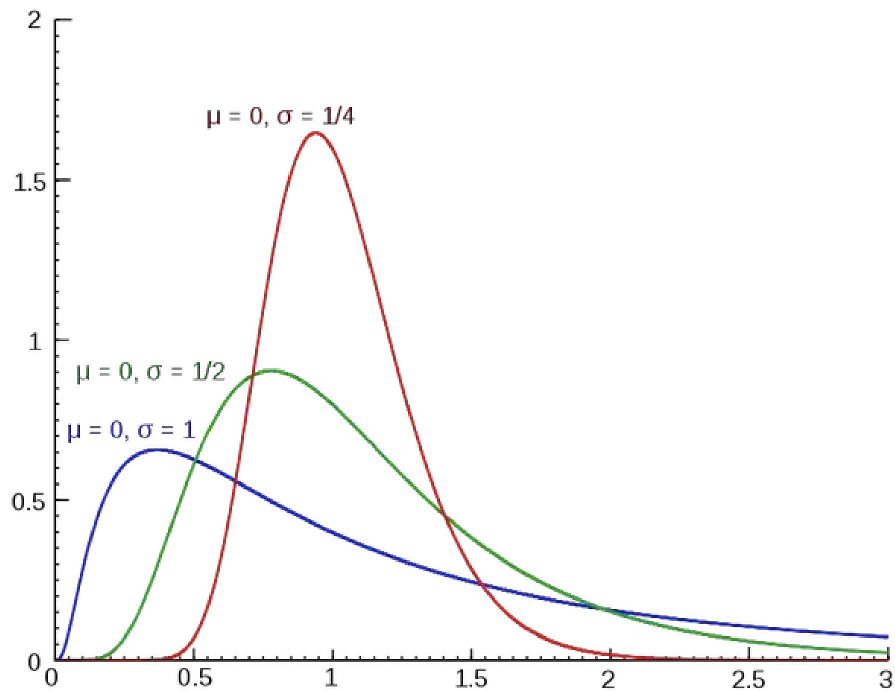


Figure 46: Log-normal distribution [41]

1.18.8 Weibull distribution

This distribution was studied and discover by Waloddi Weibull this is why is call by its name, the Weibull distribution is often used in product life because it helps to create models that can predict the increasing or decreasing of failure rates in an easy and understandable method. It is also widely spread to model the distribution properties of a material or different external effects that undergo products in stress and accelerated conditions, i.e. elongation, strength, resistance, crack nucleation and strain propagation. Usually it is used to describe the life reliability of several devices, such as roller bearings, electronic components, capacitors, ceramics, dielectrics and inductive materials [32].

The basis of the Weibull distribution for the accelerated testing conditions, and in this case for constant strain proves, start in the extreme value theory. In which may be described the weakest link product. Therefore, a product that consist of many small parts can be modeled as the summation of each of the small partitions described by the Weibull distribution and the failure of a component is measure by the failure of each of the partition or small particles. For example, a capacitor life is determined by the shortest-lived portion of its dielectric. In this thesis project then, is useful to understand that the actual failure of the pneumatic cylinder at a macro-level is due to the wear that starts in the smaller particles present in the tribological system [42].

The Weibull distribution is described with the following equation:

$$f(T) = \frac{\beta}{\eta}\left(\frac{T-\gamma}{\eta}\right)^{\beta-1} e^{-\left(\frac{T-\gamma}{\eta}\right)^{\beta}}$$

Equation 25

Where:

- β is the shape or slope parameter.
- η is the scale parameter.
- $K = \frac{\beta}{\eta}$ is the location parameter.
- γ is the location parameter
- T is the time, years and in this case is the number of cycles performed by the cylinders.

"As was mentioned previously, the Weibull distribution is widely used in reliability and life data analysis due to its adaptability. Depending on the values of the parameters, the Weibull distribution can be used to model a variety of life behaviors. An important aspect of the Weibull distribution is how the values of the shape parameter, β, and the scale parameter, η, affect such distribution characteristics as the shape of the curve, the reliability and the failure rate." (Reliability, Weibull.com) [42]

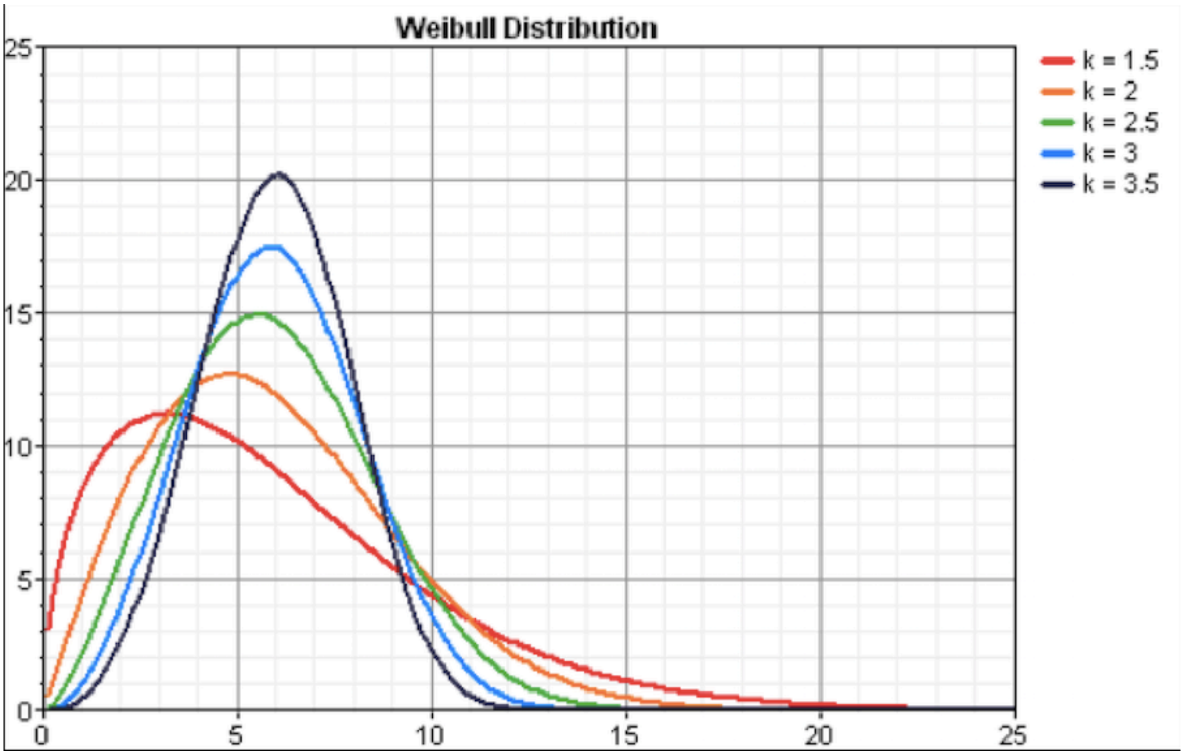


Figure 47: Weibull distribution [42].

Finally, there are many discussions of which of the distributions is better to use depending on the different applications, for some uses, the Lognormal and the Weibull distributions are equally adequate, especially over the middle of the distribution. Also, there are several distributions that will not be taken into a count but could properly fit to our project scope and model prediction fundamentals. Considering the three statistical models mentioned before, when they are fitted to a specific data set, the Weibull distribution has an early lower tail in contrast of the other two, this traduces in earlier component failure and in a lower life prediction than in the other ones, making the Weibull distribution the preferred for the engineers because is the worst case scenario [32].

1.20 Normative Involved

The life testing in high reliable components has widely spread and the benefits denoted by ATC are highly desired. Because of the popular use of the probes in product life, the standardization of proper and trustful tests has been developed. One of the organization that is interested in the standardization of life testing products is the International Organization for Standardization (ISO), they have created a special standardization for pneumatic cylinders to provide reliable characterization of the service life of pneumatic components, the name of this standardization is the ISO 19973 and ensures that the pneumatic components used in industrial machinery must satisfy the security threshold and must surpass the different standardized tests [34].

There are mainly two redundant stages in components reliability: the design analysis; developed with finite element analysis (FEA) to identify the failure mode and effect analysis within a component, and the laboratory testing and reliability modeling; where physics of failure, reliability prediction and pre-production evaluation are made [34].

Some of the test procedures recommended by the ISO standard to test double acting cylinders and the probes that can be used to acknowledge the cylinders' failure behavior are the following: no repairs are allowed during the testing, prior from starting the testing the data acquire must be defined if censored or complete (For this experiment the data acquired corresponds to complete data), the measuring intervals in relation to the total number of cycles must also be specified and defined by the operator, the cushioning technology of the cylinders can be verified during the proves to assure a good and proper functioning during the testing until the cylinders are broken, and the specifications in the following table must be followed [34].

Parameter	Value
Working Pressure	630 kPa ± 30 kPa (6.3 bar±0.3bar)
Ambient Temperature	23°C ± 10°C
Temperature of the Medium	23°C ± 10°C
Air Quality	Filtration: Nominal filtration rating: 5µm
	Dryer: Maximum pressure dew point:+3°C
	Lubrication: None

Table 9: Testing Conditions Parameters Suggested by the ISO 19973 [9].

In addition to the stated suggestions there are some guidelines that must be followed, for example: the accelerated testing conditions must not introduce failure modes different from those that appear during the normal operating mode, this is why choosing the right stress in the testing stage is extremely important for the test not to be invalidated. Also the sample of the cylinders when applying Weibull distribution cannot be less than **7 cylinders** for having a trustful sample that can be representative of all the population [34].

The suggestions from the ISO 6099, another standard that specifies the testing conditions of double acting cylinders under radial forces, shows the location for the stress in the end effector in the cylinder rod must be at a minimum distance L from the theoretical reference point as shown in the following figure. According to this standard, also the stroke should be less than 0.8 seconds and the break of a cylinder is determined when the stroke time is the double than the one at the start of the test. For this purpose, if the cycle last 1.6 s the breaking time will be 3.2 s. For experimental purposes, 4 seconds were determined as the breaking time of the cylinders [34].

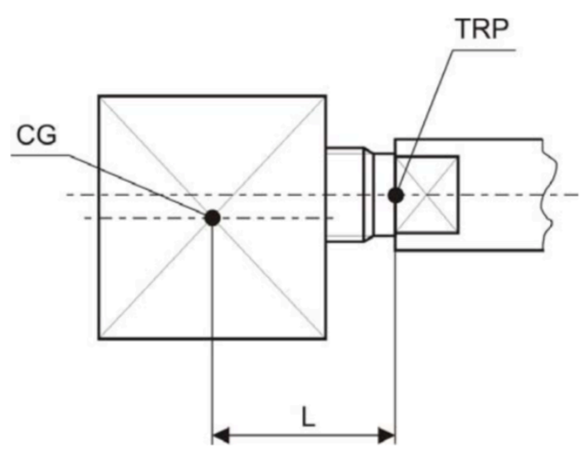


Figure 48:Center of gravity and reference point form the rod and the end effector [34].

1.21 OPC Server

The OPC server is a software that satisfy the OPC Foundation requirements to create a language that can be understood for the industrial devices and different applications. The OPC server makes an interconnection between one or more servers to one or more clients. Usually the OPC server acts like a bridge to communicate the clients; Manual Pads, HMI, SCADA, Excel Files, calculation applications with the source of the data that usually have the native protocols of the PLC, bascules, Data bases, Input Output modules and controllers [43].

Following these ideas, the Server or data source is called slave and the client is called the master. This type of communications is usually bidirectional, meaning that the clients can read and write the values in the device by means of the OPC server [43].

There are four OPC server defined by the OPC Foundation:

DA OPC Server: It was specially designed for the data transmission in real time.

HDA OPC Server: This type of server is used to read the historical data from the device after the application is done.

A&E OPC Server: This OPC Server is special for the alarm and events; this alerts the client when an alarm is activated or in the presence of a determined event.

UA OPC Server: This is the most advanced type of OPC servers and allows the client to work with any type of data.

The first two type of servers are the classic OPC connections that can be observed and the ones that almost all the OPC servers satisfy this first two communications [43].

Figure 49: Server Client communication via OPC Server [43].

The previous figure shows some of the clients in the Top and son Devices that are the ones in the bottom of the image, this communication is able due to the OPC standard technology.

2. Development.

2.1 Test Bench Evolution.

The Test bench that is in the DIMEAS laboratory has had a progressive development over the years. It was the result of a previous project work, this was used to understand and develop some life-tests and to evaluate how the wear of the cylinder takes place. The process to determine the life of a cylinder in this Test Bench consist in two different procedures, one is denoted as a wear test and the other is the leak test. In the first, the cylinder is guided to perform the extension and retraction of the piston rod a determined number of times, each time the cylinder extends and retracts its rod is called a cycle, during each cycle the distance that is travelled by the cylinder can be obtained and the final result will report how many cycles and distance in kilometers can each cylinder perform. The second test, has as purpose to determine if in the cylinder are present leaks that can interfere with the proper functioning of the cylinder. This malfunctioning is determined by supplying for an amount of 2 minutes, the posterior and anterior chambers separately, each at a time, then blocking the inlet port and monitoring each chamber by a pressure manometer or pressure transducer, if the pressure decreases under a defined threshold, the cylinder is damaged and must be replaced, this leak test is the one that determines if the cylinder can undergo another wear test or if is broken and must be replaced.

At first the Test bench performed these tasks manually and an operator must be in the laboratory performing them until the cylinders were damaged. After the first thesis work, this process was enhanced; a PLC, some solenoid valves actuated by electricity signals, manometer sensors and magnetic sensors were implemented to ensure an automatic process without the need of an operator. This was an interesting approach which allows the autonomy of the system and the continuity of the probes, making them faster and more regular.

The first approach of this test bench was conceived with horizontal plates, creating a lack of space in the compressor room, and does not allow the operator to reach all the parts of the system without the need of moving from one place to another. As stated before all the probes that were perform must be manually operated, this can lead to dangerous situations due to the constant manipulation and the manual activation of the different moving parts of the high speed system (compressed air up to 9 bar was present in the circuit, 900 kPa).

After this approach the same plates were reused to design the second model of the test bench, recovering from the old test bench useful parts and redesigning the horizontal approach to a vertical approach that will deliver a comfortable working station and an optimization in the space of the compressor room. The space used to do this was a 4.13 m x 2,88 m x 3.3 m as can be seen in the Figure 50. Figure 51 denotes the layout of the vertical panels that were inserted in the compressors room, in this figure there can be also seen the dimensions from the top. Finally, in Figure 52 there is the final approach and how the vertical plates will look in the compressors room with an orthogonal approach.

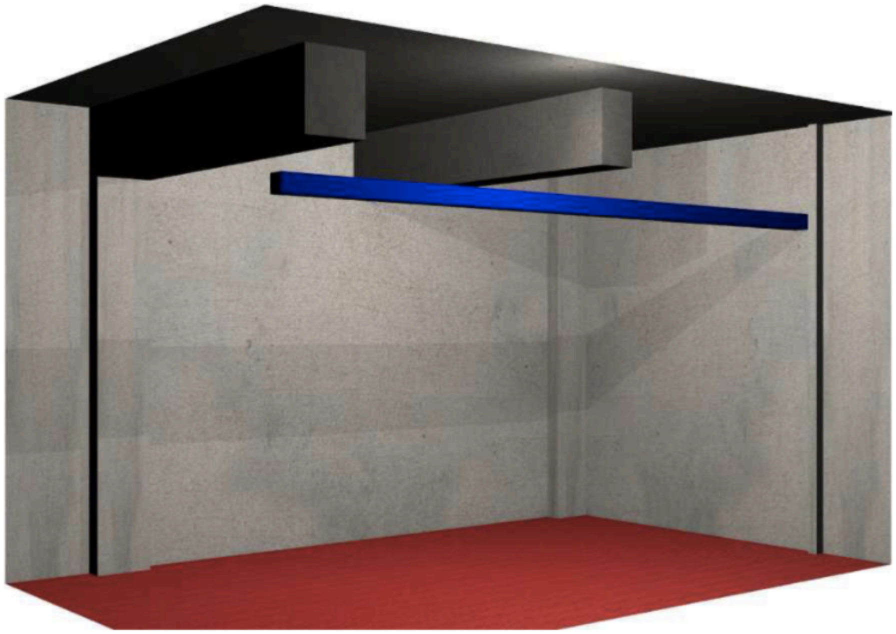


Figure 50: Rendering of the space available in the compressor room [9].

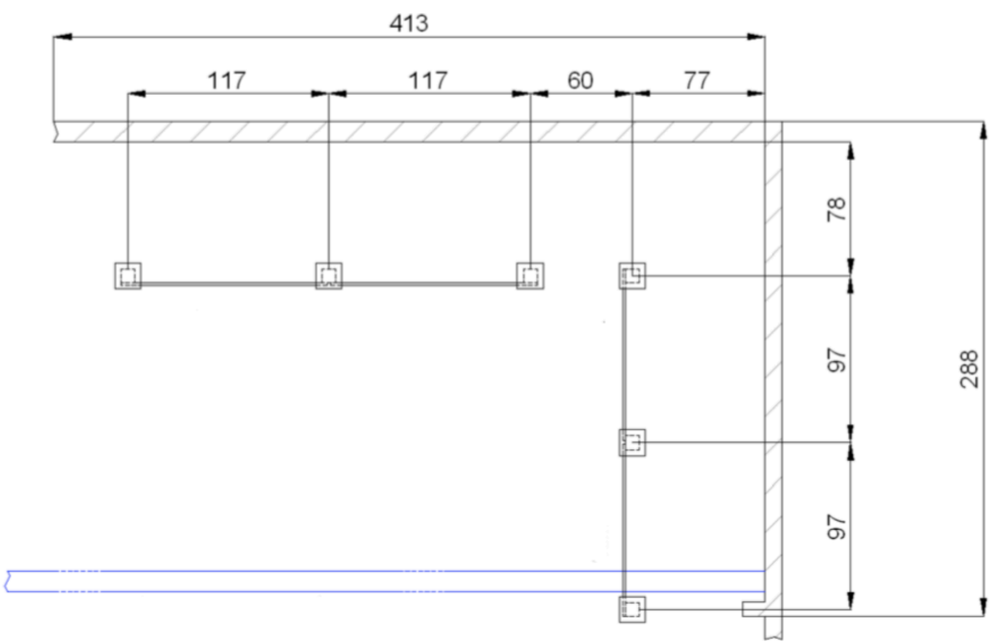


Figure 51: Measures of the vertical Plates [9].

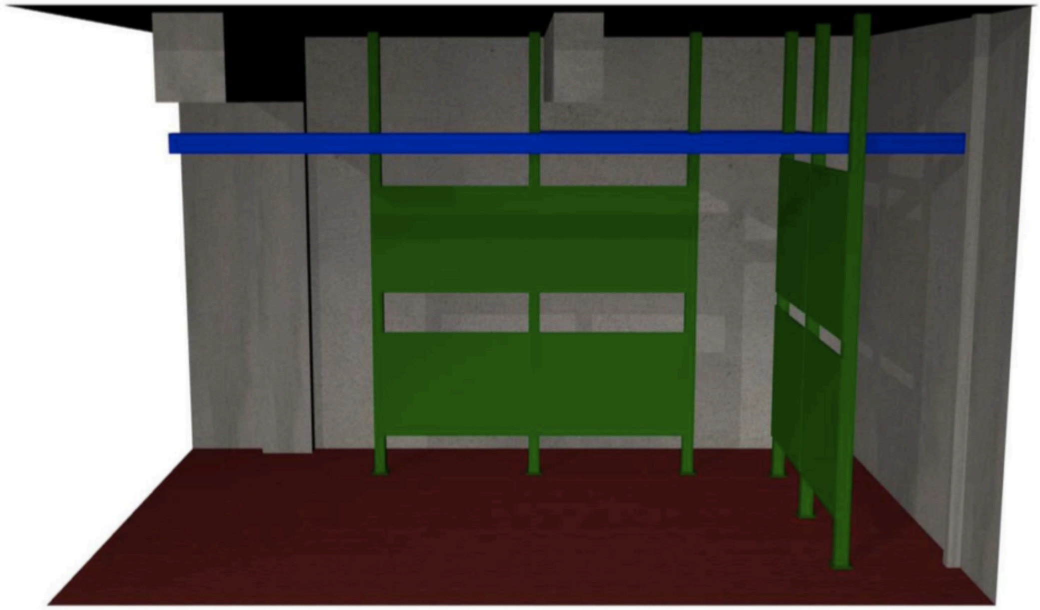


Figure 52: Rendering of the vertical plates mounted [9].

The person in charge of this design was Mauricio Giraldo Rendon and he states that the test bench structure was mounted and consisted in the following components:

*" The columns were formed by an aluminum profile with square section of 80 mm length and 5 mm thick. The structure is clamped to the floor by means of four bolts M8 which grip on square base of 120 mm x 120 mm welded to the bottom of the columns. Between the base and the floor it has been inserted a rubber layer of 2 mm of rubber in order to avoid the transmission of vibrations to the floor. The clamping to the ceiling, however, is via a presser foot. This foot is composed by a tie rod and a base. The two are connected by a spherical joint so as to ensure maximum contact area even if the is not exactly perpendicular to the roof. Besides of that between the presser foot and the ceiling, there is as well a layer of anti-vibration material" (Giraldo Rendon, 2013***)***.**

In the second project work, perform by Mauricio Giraldo Rendon, the system undergoes substantial changes that were really beneficial (see Figure 52 for the test bench with the mounted cylinders). But the test bench was doted by a Scada interface, which limited the autonomy of the test bench for only the ones that were able to achieve the software. In addition to this, the probes were not automated enough, and the time has deterred its components, operational functioning and wiring connections.

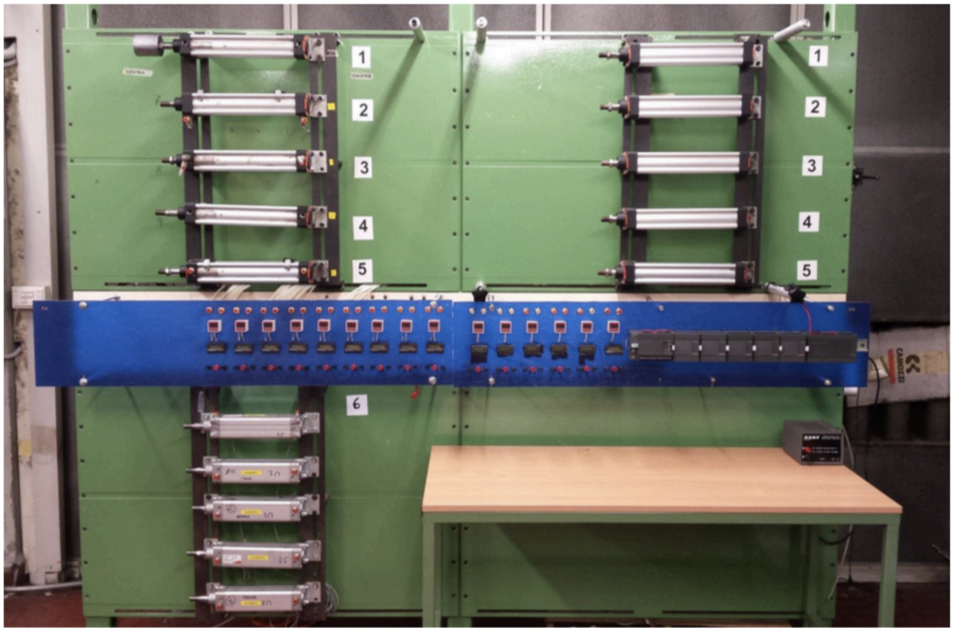


Figure 53: Test bench with cylinders after first update [9].

In this thesis project work the last update of the test bench has been made, the cylinders are replaced, a new and better automated procedure has been implemented (see program in the annexes), prediction models are used to foreseen the life testing performed in the cylinders and for the theoretical understanding on how pneumatic actuators work corroborating the models with upcoming results can be done. In addition to this, the system was dotted with a Manual Pad that provides the autonomy to perform the program even though there is no computer attached to it. And a TD 200 digital panel has been added to the model for the monitoring and control of internal variables, such as timers, counters and statuses. This with the purpose of allowing anyone who want to test pneumatic cylinders to work with the test bench achieving the basic knowledge of the operation principles denoted in the user manual that is given in the annexes of this final thesis project.

Figure 54: Actual Test Bench in the DIMEAS Lab.

2.2 Pneumatic Network:

The test bench is dotted by a pneumatic supply installation with Teseo pipes that are connected to the compressor of the DIMEAS lab, the maximum working conditions of the test bench are 15 bar, but to prevent injuries and component protections, two different pressure regulators are added in the back of each vertical plate, those are set with 9 and 6 bar denoting 9 as high pressure and 6 as low pressure.

The test bench can perform simultaneous probes in maximum 15 different cylinders and its hole configuration allows it a vast range of configurations i.e. cylinders with different strokes can be tested at the same time even though that this is not the desired for a population testing.

In the following figure can be observed the two different supplies (high and low pressure), the valves involved in the schematic of the test bench and the cylinder 1, the same approach comes to the other 15 cylinders, sharing the blocking valves and the actuation methods. Allowing to control the isolation of the 15 cylinders at the same time.

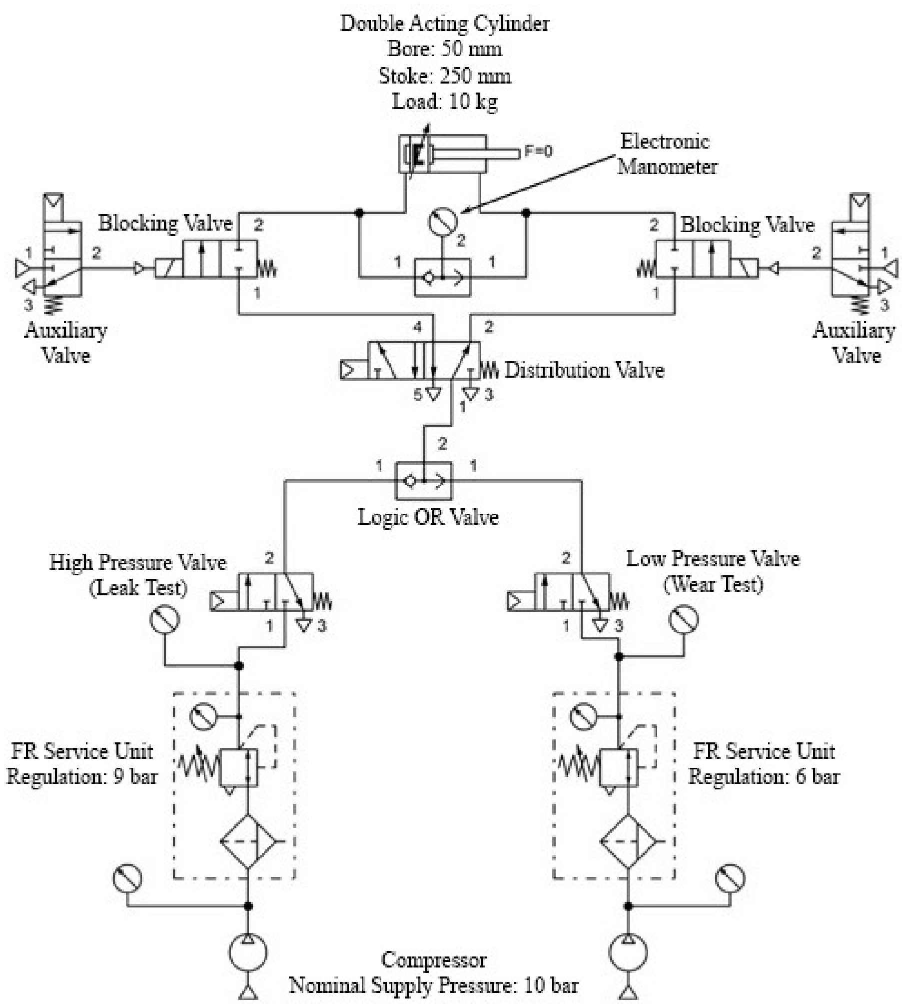


Figure 55: Schematic of the Pneumatic Cylinder in the test bench [9].

2.3 Test Performed by the Test Bench

The test bench is programed to perform two different test for the cylinders that are installed in the test bench. The first test is the wear mode, this wear test is done by a low pressure source that consist in 6 bars, which will make the cylinder's rear and front chamber to fill up with air, one after the other, and therefore the rod to extend and retract, this movement is called a cycle. Depending on the user's interest, the test bench can be programed to do from 30000 to 900,000,000 cycles. Be aware that the life testing of this high reliability products can take long and several cycles must be undertaken, if the operator needs to perform more than 900,000,000 cycles, he can restart and launch the test several times but must be aware of the number of cycles that are done in each test, some external digital counters were implemented to help user in this task. The cylinders perform one cycle in approximately 1,80s so if the user press the button 10 times, the 300,000 cycles will be performed in 150 hours or approximately 6,25 days. If the cylinder is in the outstroke stage, in the instroke stage or in between for 4 seconds (the double than the time that is needed to perform a cycle), the system will determine that the cylinder is broke and that internal leakages are present. This is denoted by putting an internal memory active and showing that the cylinder is broken with a led in the Manual pad. If the operator needs to relaunch the test, he can simply turn off the broken cylinder or restart the test and the cylinder will last more than 4 seconds in one of those 3 states activating the internal memory and displaying the led. Each cylinder is actuated by its own mono-stable valve that is commanded by solenoid valve that is activated by magnetic sensors and the PLC when the cylinders are in instroke position. The retraction of the cylinder is due to the deactivation of the solenoid valve, when it achieves the outstroke position, the solenoid valve is deactivated and therefore it will not actuate the mono-stable valve, causing the low pressure source to fill the front chamber occasioning the cylinder to retract again, this until a counter that counts each outstroke has ended activating an internal memory that will take the cylinder out of a subroutine that was specified in the program. The following figure shows the schematic of the wear mode that was previously described, the mono-stables valves where replaced by bi-stable valves to help visualize and simulate better the functioning of the wear test in the required software. As can be observed in the schematic, the blocking valves for this purpose will always be activated and therefore the free flow from the low pressure supply is allowed in this test.

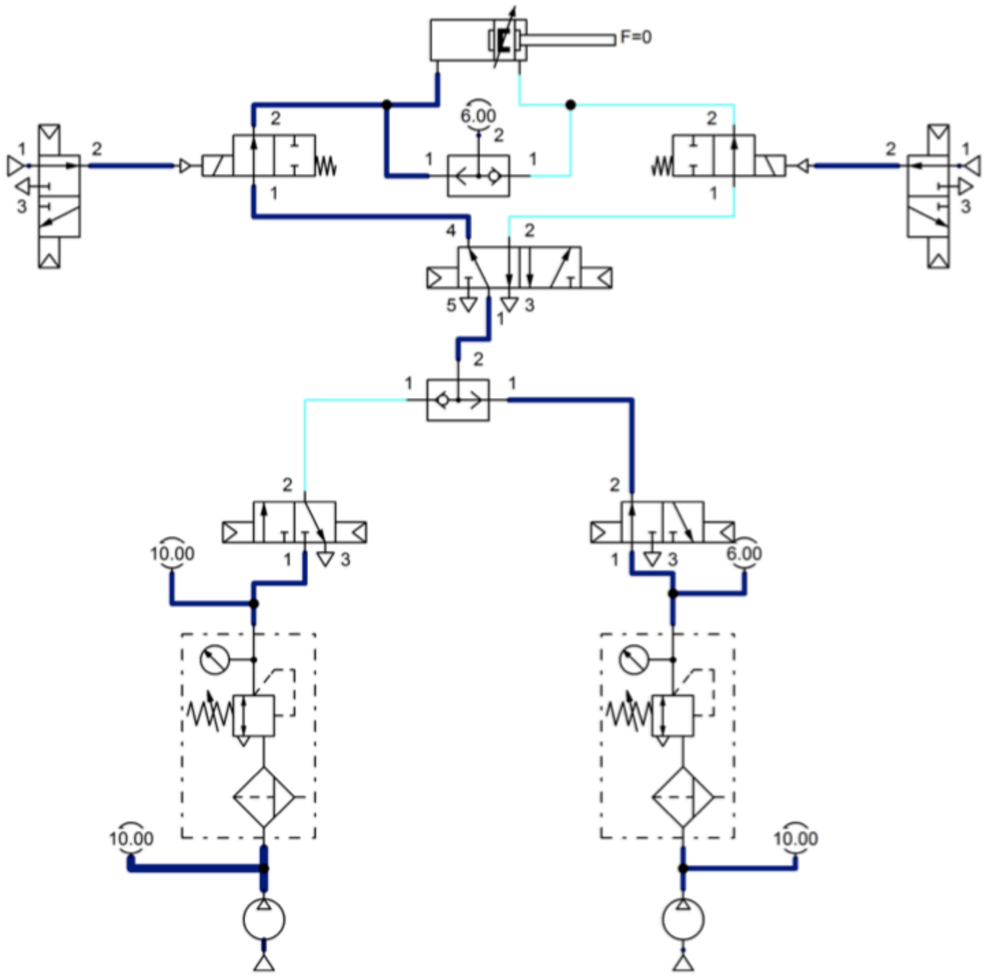


Figure 56:Wear mode schematic in the test bench [8].

The second test is the leak test; this test is designed to determine if the leaks present in the cylinder's chambers are relevant to determine if the cylinder has failed. The test consists in supplying the cylinders with a high pressure, normally of 9 bars, filling the front and rear chamber, separately and starting with the rear chamber, this is in outstroke position or when the piston rod is extended (See Figure 57). The cylinders which are activated, will be actuated by its own mono-stable valve in the same way as in the wear test. The rear chamber will start filling with air for 1 minute, then the blocking valve that isolates the rear chamber with the rest of the pneumatic network will be deactivated and isolate the cylinder from the rest of the network, afterwards the high pressure supply will be powered off, the sensing will be initiated as soon as the leak subroutine is started and the chamber is filling with pressurized air, after the blocking valve is powered off, the rear chamber will be still sensed during 30 minutes, 1800 seconds. Taking measures of the chambers pressure every 0.2 s and monitoring if the pressure is lower than 1 bar, if the pressure inside of the chamber is lower than 1 bar the cylinder is considered as a fail cylinder and therefore, as in the wear test, an internal memory will be activated and the Manual pad will light a red led referring to the broken cylinder. The data acquire in this test will be achieved and saved into an excel file which will then be submitted to posterior analysis with MATLAB software to achieve redundant cylinders' indicators and reliability indicators. The solenoids to activate the mono-stable valves will be deactivated and the source of high pressure will be activated to bring the cylinders to the retracted position. At the same time the blocking valve will be actuated again letting the cylinders' rear chamber to connect with the rest of the network emptying the rear chamber finishing the first half of the leak test. Consequently the cylinder now will be in the instroke position, and following the same steps of the first half of the test the network will perform the following routine in the front chamber: The front chamber will be filled by air for 1 minutes, then the blocking valve of the front chamber will be deactivated isolating the front chamber of the cylinders with the rest of the network preventing the pressurized air to be expelled, then the high pressure source will be turn of and then the pressure in the front chamber and will be measured for 30 minutes, taking data samples and saving them into an excel file every 0.2 s. Finally, after finishing the test in the front chamber and recording the data samples in an excel file, the leak test is done and the blocking valve that isolates the front chamber of the cylinders will be energized connecting the cylinders to the rest of the network, letting the pressurized air to be expelled (see Figure 58). In addition to all the previous features explained before it is useful to inform the operator that the program can be edited if the user wants to change the amount of time that is required to fill the chambers or to measure the pressure within the chambers.

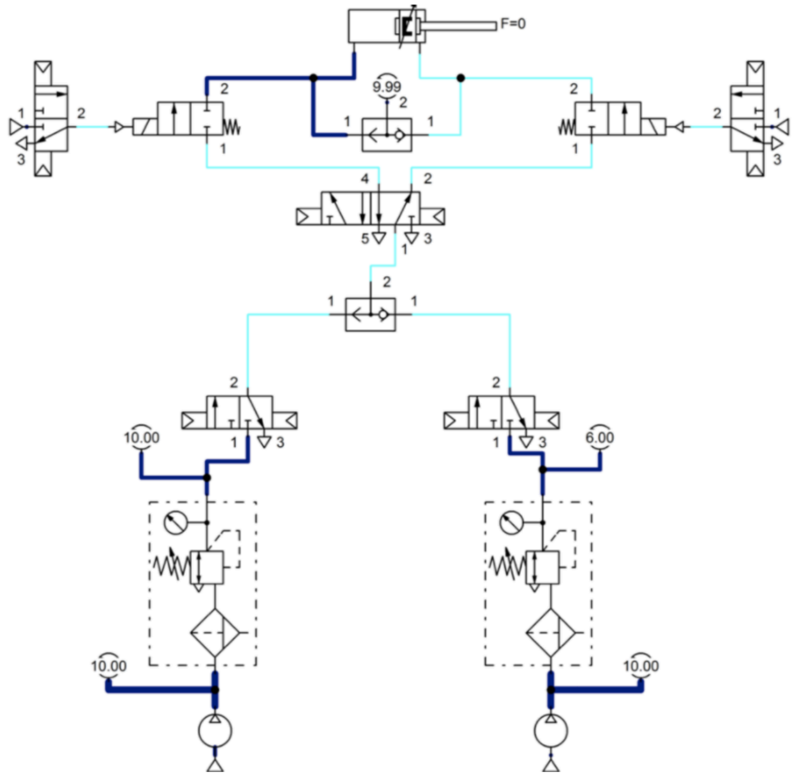


Figure 57: Leak Test Schematic performed in the test bench in the rear chamber [9].

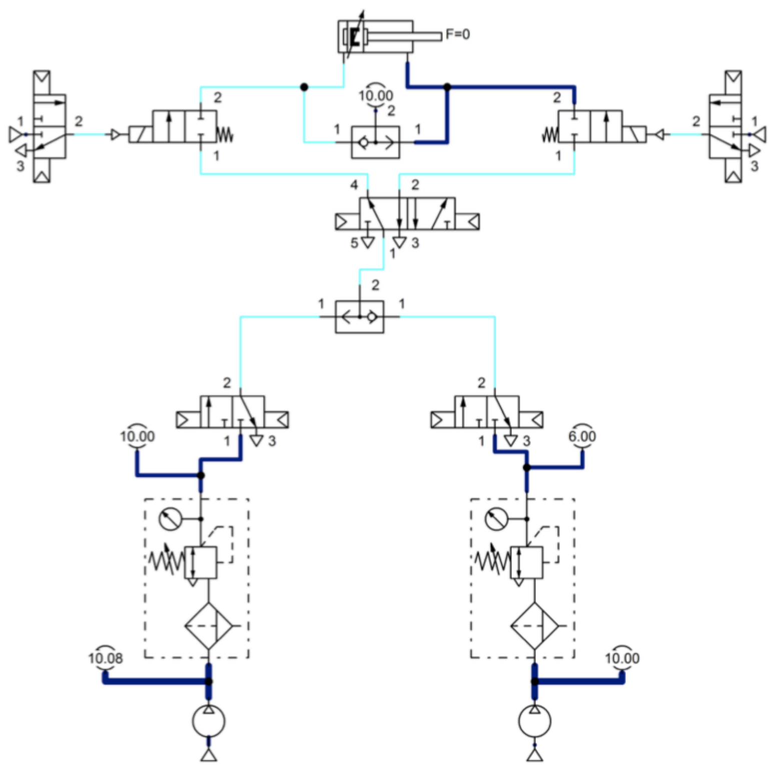


Figure 58: Leak Test Schematic performed in the test bench in the front chamber [9].

The following figure shows how the pressure curve is drawed after the data collection, this and some statistical analysis, that allows us to determine some redundant cylinders' indicators and reliability indicators will be performed with MATLAB because of its high computing ability and high adaptability.

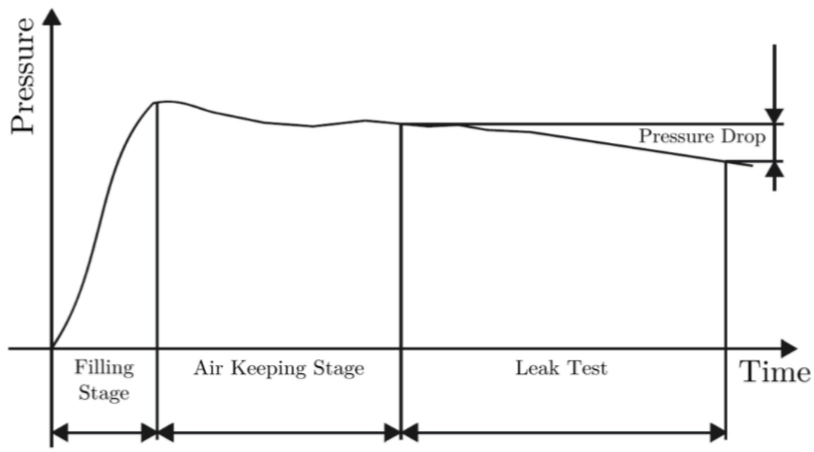


Figure 59: Pressure curve inside one of the cylinder chambers during the leak test [9].

2.4 Operator Test Bench Interaction:

For the Manual pad, there were used two different components: an own manufactured pad to control the test bench and a TD 200 pad to control the number of cycles that will be preset in the test and to monitor different variables of high redundancy for the operator.

Figure 60: Manual Pad for controlling the Test Bench.

The implementation of the Leds included in the Manual Pad was difficult, the addition of internal resistors to avoid heating and Led burning, it was needed to control the Leds via software to prevent overheating in the small Manual Pad box. Therefore, the cylinders’ blink instead of having a continuous lighting, they are turned ON for 3 seconds and turned OFF for 7 seconds if they are active. When the normal operating mode is performed, the white and green Leds will blink, when the wear operating mode is performed, only the white Leds will blink and if the Leak operating mode is preformed, only the green Leds will blink. To distinguish from the Normal operating mode and the wear mode, the Red Lamp that indicates that the test bench program is running is turned ON (following the same ON and OFF principle of the Leds), to determine that the test bench has ended the task required, the red Lamp is turned ON. The following Figure will show the internal connections of the Manual Pad and the development of the Manual Pad box in the DIMEAS Laboratory.

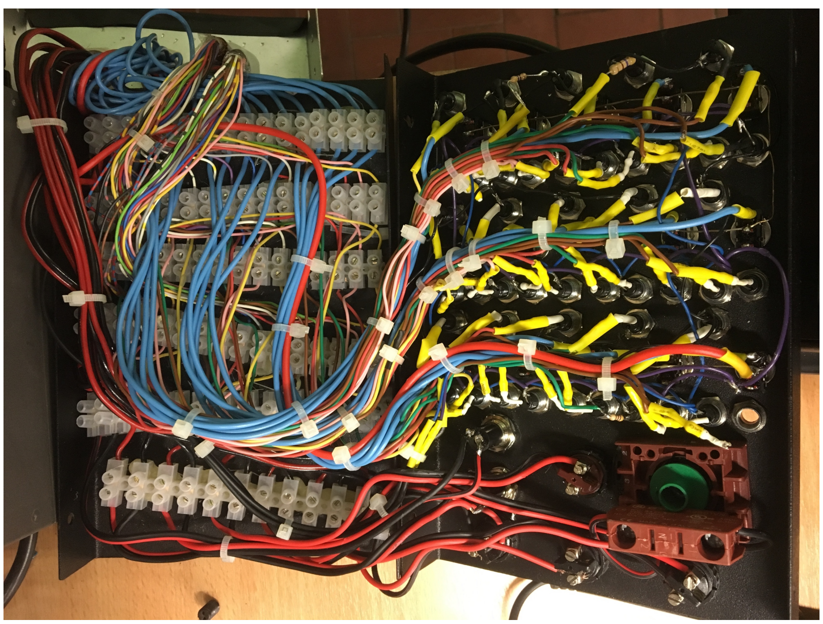


Figure 61: Internal connections of the Manual Pad.

Figure 62:TD 200 Pad

The Manual pad which is designated to control the basis of the test bench doted by 3 normally open push buttons, 1 normally closed, one emergency button and 15 switches to control the cylinders. The different type of probes that are going to be taken (wear and the Leak) are controlled by the normally opened buttons, such as can be seen in the Figure 60. The black buttons (the normally opened buttons) are the ones that ensure the functioning of the test bench. The program designed in this thesis project ensures that when the push buttons are activated, an input signal is send to the PLC and then some internal memories are activated to continue with the control of the program. By pressing the buttons, the operator can indicate the working phase and the test that want for the cylinders to be performed. The test bench can be started in 3 different modes:

If the operator presses the first button, the test bench will operate in normal operation mode, this mode is composed by the wear and when is done, the leak test will be started as sudden as the wear is done, from now on this operation mode will be called the normal operation mode.

Figure 63: Manual Pad when the Normal Operation Button is Pressed.

If the operator presses the second button only the wear test will be performed a determined number of cycles and from now on this operation mode will be called the wear mode.

Figure 64: Manual Pad when the Wear Button is Pressed.

Finally, if the operator presses the third button, only the leak test will be performed and the cylinders will fill the chambers of the activated cylinders to detect possible leaks during 30 minutes in the front and 30 minutes in the rear chamber, from now on this operation mode will be called the leak mode.

Figure 65: Manual Pad when the Leak Button is Pressed.

Only the cylinders that are activated previously than the push buttons are pressed to start the test are going to be taken into account in the specified operating mode.

In the other hand, the TD 200 pad will allow to monitor different variables of the test bench. Furthermore, the TD 200 can be used to select the number of cycles to be performed in the wear mode, 30000 or 900,000,000 cycles in intervals of 30000 cycles. If none of the buttons of the pad are pressed, the test bench will perform 30000 cycles as default settings.

2.5 PLC Program Development:

From previous programming PLC experiences, and following the guidelines mentioned in the section 1.11 of the chapter 1, the GRAFCET for the functioning of the PLC program was created. This graphic representation helps to be smoother in the program development, to divide the program in different subtask and to understand better the functioning principles of the machine in which will be applied. To develop the GRAFCET, the internal memories, the inputs, the outputs and the actuation modes must be deeply understood and that is why the program difficulty and efficiency can be reduced and enhanced, respectively.

The following GRAFCET was design to produce the program developed in the test bench PLC (see in the annexes the actual Ladder program and complete GRAFCET images), the Siemens S7 200 PLC is a powerful tool for automation and control of machines and is easy and user friendly but is obsolete and finding different parts and programs is not an easy task. In addition to the previous drawback, some of the functions of the modern PLCs are not available and memory is reduced.

The program is made of a main program in which are specified the different methods in which the PLC can be activated, the normal operation mode, the wear mode and the leak mode introduced as sub routines. In total the program has 19 subroutines, one for the control of the wear mode, two for the leak control and other for the actual leak test, one for the restart of the internal memories and counters and 15 for the different cylinders' logic control that must be implemented in the wear test.

In the Figure 66, the GRAFCET of the main program is shown. When the system is started, the test bench enters in a waiting state, once the operator indicates which of the operating modes described earlier by pressing the buttons in the Manual pad, the system will receive an input signal that will activate one of the 3 branches of the GRAFCET, it can only perform one operating mode at a time. After the PLC receives one of the 3 finishing signal flags (internal memories that act as states will be activated, indicating that the process is done), the last state will be activated and then the operator must see the results or relaunch the testing stage by pressing the reset button.

GRAFCET MAIN

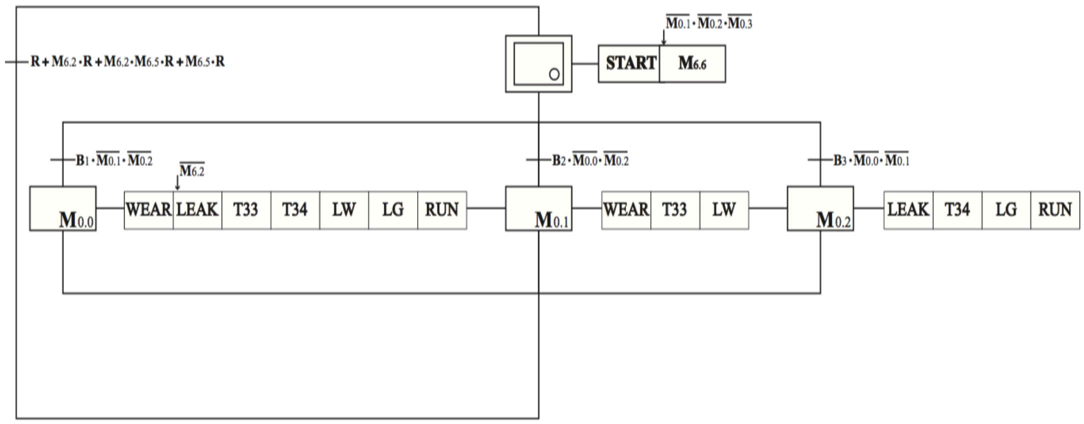


Figure 66: Main Program GRAFCET.

Symbol	Description	Actual Signal in the Program
B1	Button 1	I4.0
B2	Button 2	I4.1
B3	Button 3	I4.2
R	Reset	I4.3
W	Wear Done	M6.2
LG	Green Led	M3.6
LW	White Led	M3.7
WEAR	Wear control	Subroutine
LEAK	Leak control	Subroutine
START	Reset valves and Memories	Subroutine
L	Leak Done	M7.3
Run	Led Run Green	M6.0

Table 10: Translation of the different entering signals in the main program.

The Table 10 shows what does each of the input signals means when enters into the GRAFCET. The different signals were expressed in symbols rather than the actual input signals that triggers the change of the stage inside the GRAFCET to help understand better the user and the flow of the program. Another important aspect to be highlighted is that the internal memories denoted as M#.# are used as states in this program, timers and all the other input signals can be observed in the annexes, in the PLC S7-200 technical specifications.

As can be evidenced in the main program GRAFCET, the normal operation mode will perform the wear and the leak mode, the wear mode will only perform the wear test and the leak mode will only perform the leak test. The multiplication in the incoming signal after the stage 1 (M0.0) means that both, the wear AND the leak must be done to move from one stage to the next stage.

GRAFCET WEAR

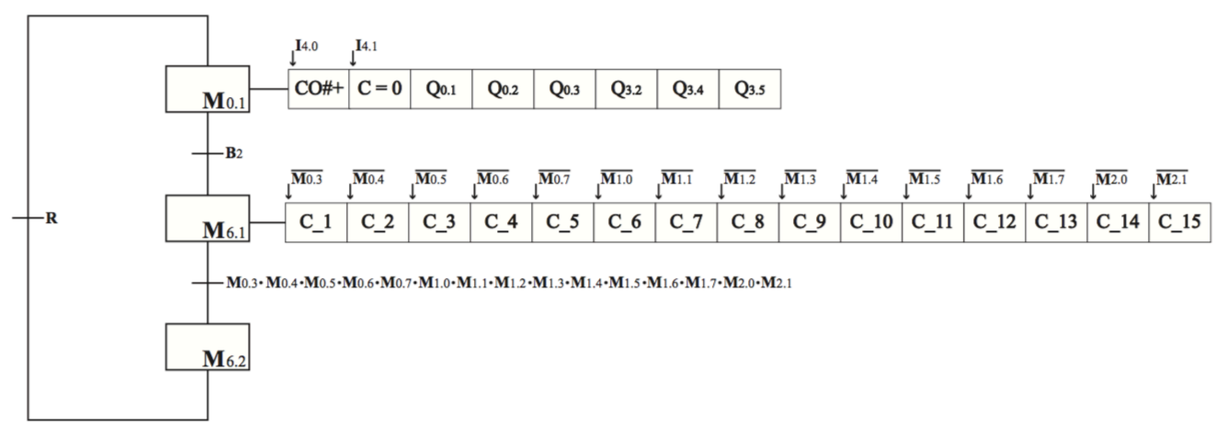


Figure 67: Wear Test GRAFCET.

The Figure 67 shows the GRAFCET of the wear operating mode, this explains the control logic of the PLC during the wear mode. Each subroutine will be only activated if the auxiliary memory denoting that the subroutine is done is not present. In the Manual pad the white leds will light denoting that the wear operation mode is selected, if the normal operation mode is selected, both green and white Leds will light. At the start of the wear operating mode, the respective actuating valves are actioned for the right and left side of the test bench (they work separately): Q0.1; the low pressure source is activated for left side, Q0.2 and Q0.3 rear and front chamber blocking valves for left side, Q3.2; the low pressure source is activated for right side, Q3.4 and Q3.5; rear and front chamber blocking valves for right side. If one of the switch is activated. Finally, when the active cylinders are done doing the wear test, a stage with the state M6.2 will be the last state in the wear operating mode, returning to the main program GRAFCET. In this case, the operator has the opportunity also to restart the program but as the button Reset is the same for this and the main program, the reset stage will reset all the different branches and processes. In this case, the addition symbol denotes the logical OR, meaning that one or the other condition must be satisfying to advance from one stage to another. The subroutines that control the outstroke and instroke of each cylinder can be seen in the annexes for all 15 cylinders, here only the subroutine of the cylinder 1 will be shown to help the user to understand.

GRAFCET C_1

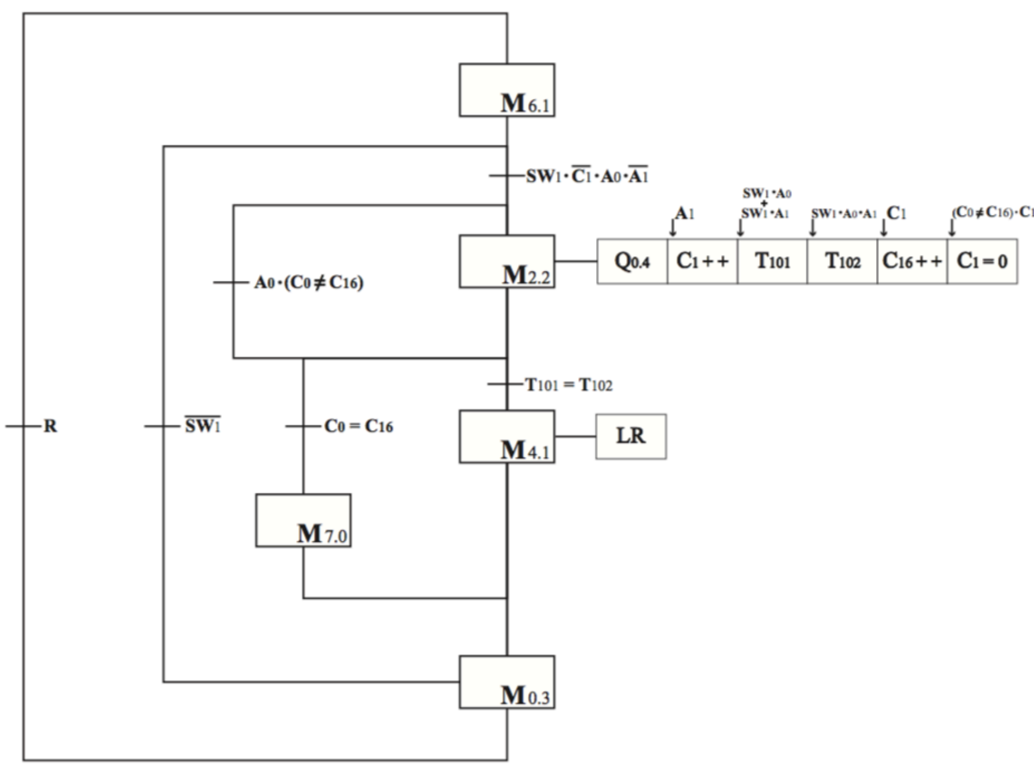


Figure 68: Cylinder 1 GRAFCET

The control logic of the cylinder 1 can be seen in the Figure 68. If the internal memories of each cylinder subroutine is not present, as denoted in the wear GRAFCET. As soon as the cylinder GRAFCET is activated, the main input signals to start the test in the cylinder 1 are the switch 1 (I4.5) and the instroke (I0.0), after this input signals are received the stage of the wear test will change from the waiting state to the activated stated (M2.2) and then depending on the internal memory activated by the TD200 pad, the cylinder will perform cycles until the conditions are meet. Also, the timers T101 and T102 will be activated to be aware if the cylinder is broken. The cylinder is considered as broken if the waiting time to achieve one of the sensors indicating the end of the stroke is the double than the 1,8, time in which the cylinder does one cycle, if the cylinder is broken then a red led indicating that the cylinder didn't passed the test will light in the Manual pad. If the cylinder works correctly, the counter indicating the number of times that the cycles must be done is confronted with the actual number of cycles that the cylinder has performed, if the number is the same, then this control logic will be finished. Therefore, there are three methods to end this GRAFCET, the broken cylinder, cylinder with proper function but with enough cycles performed and when the cylinder is not activated or the switch is turned OFF, once OFF, the switch will not be read if the user wants to start again, the use of the reset button will be needed. The same logic is implemented in the control logic of each cylinder changing the corresponding inputs, timers and counters. To see the other GRAFCETs of the cylinders please refer to the annexes of this thesis project.

Finally, if the operator chooses only to perform the leak test, the GRAFCET that explain the control logic of this operating mode is explained in the Figure 69 (it is not complete for matters of space, the user can refer to annexes to see the complete Leak GRAFCET). For the control logic of this last operating mode, the starting signal to perform the test is the pressure measure in the supply port of the system, this must be higher than 7 bars or 700 kPa. If the pressure is less than 7 bars during the leak test, the test will not be performed or will be exited and then the use of the reset button will be needed. As it can be observed, there is a boucle and a counter that ensures the activation of some valves to extend the cylinders, this is because depending on the counter cycle, the program will perform the leak test in the rear or in the front chamber, changing in their execution only the status of the solenoid that controls the extension of the cylinder. As mentioned before, the leak test will fill the rear or front chamber with the pressurized air coming from the high pressure port. After filling the chambers with pressurized air, the cylinders blocking valve will isolate the chamber form the rest of the cylinder and the pressure inside the chamber will be measured for 30 minutes, saving the pressure in an excel file and monitoring if it decreases in each chamber. If the pressure inside the cylinder chamber is lower than 1 bar, then the cylinder is denoted as broken and the red led in Manual pad will light indicating that the cylinder is broke. This process will be performed first in the rear chamber and then in the anterior chamber. If both of the chambers passed the leak test, the state (M6.5) will be activated and the program will return to the main program.

GRAFCET

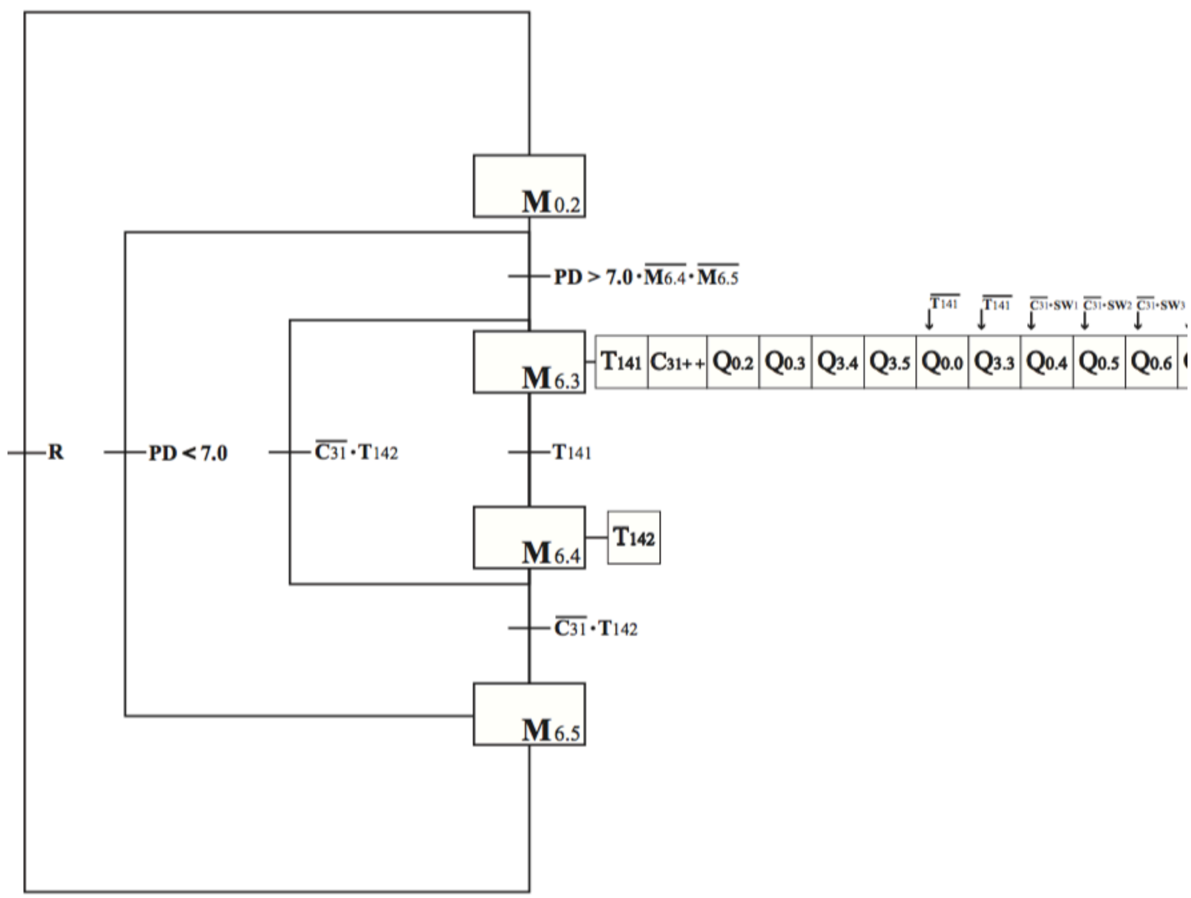


Figure 69: Leak Operating Mode GRAFCET.

Finally, the Emergency button is not denoted in this GRAFCET to keep simplicity, but it can be imagined as flags, such as the ones in the leak operating mode, in each of the actuating boxes, activating the action. If the emergency signal is not present (because is a normally closed button) then the emergency button is pressed and the machine will stop its functioning in the current state, as soon as the program is resume (by setting emergency in its normal position) the state in which was stopped will restart. This will provide a momentary pause in whatever stage of the process, the same action has been implemented with the switch that indicates that the tempered glass cover of the test bench is opened. After the emergency is activated, the button must be returned to the original state and the process will continue from the stage that is was prior that the emergency was activated, if the operator wants to restart the program he must press first the reset button and then return the emergency to the original state.

2.6 Virtual Machine

As mentioned before, one of the drawbacks of the PLC S7-200 is that is a little obsolete, therefore the software to program it follows the same trend. The STEP 7-Micro/WIN only runs in Microsoft Windows XP operative system.

As now a day, the last Microsoft software is the Windows 10 and the new operative system is not suitable to run the STEP 7-Micro/WIN and finding a computer to work with Microsoft XP was not an option, this is why the development of a Virtual Machine was considered. The selected Virtual Machine was the Oracle Virtual Box, that with the help of an authorized version of the operating system (referred from now on as OS) Microsoft XP allows the user to create a partition on the host hard disk to run the needed OS. This help to install STEP 7 software, to connect and program the PLC without any problem.

The host system in which the Virtual Machine (referred from now on as VM) was installed to develop this thesis project was a Macbook Air with mac Os high Sierra as operative system. The VM worked very well and the development of the program was successful. Even though there were some setbacks in the connection with the PLC and the data achieving, at the end everything was accomplished.

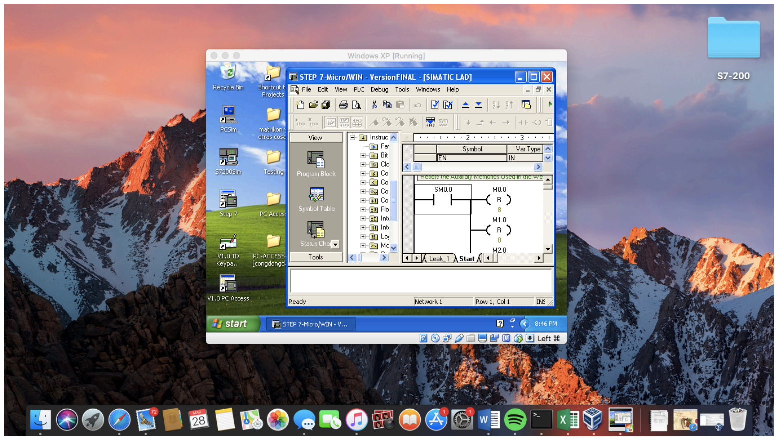


Figure 70: Virtual Machine Running Windows XP OS, in MacOS host.

Figure 70 shows the VM successfully working in the apple host and running STEP 7, the software to communicate with the PLC. Although that no SCADA was implemented to give more freedom to the operator, as in previous updates, the use of a VM was necessary because the OS in which the STEP 7 run was needed. The advantage of having the virtual machine is that it can be installed in any host computer and as soon as it is configured as in this project, the PLC can be controlled and the data from the life testing of the cylinders can be achieved. (To understand better the technical data of the VM please refer to the annexes).

Finally, the VM was installed in a computer form the Lab DIMEAS and in the personal computer of the Professor Luigi Mazza this for further studies and control of the test bench and future life testing in pneumatic cylinders with the test bench.

2.7 Connection PLC with Virtual Machine

As stated in chapter 1, section 1.7, there are several methods to communicate the PLC with the controller computer, one of the most challenging stages of the project was to connect the PLC with the NETlink profibus cable. This connection method was preferred because of its versatilely and both advantages of providing high speed data transfer and a bridge adapter that will allow to connect the TD 200 pad and a computer at the same time. The connection of the computer was of vital importance for the data acquisition system because the data was transferred in real time with the help of a OPC server.

The first option for connecting the program with the PPI Multi-Master cable, in fact an extensive fragment of the program was created with this communication, but the option was discarded as soon as there was not possibility to communicate in real time due to the speed of the communication. For this reason, the NETlink profibus with Ethernet cable was preferred. The only problem was to configure the VM with the proper settings to accept the NETlink cable and to create an internal LAN to achieve the communication between the VM, the host computer and finally the PLC through the Ethernet cable.

Figure 71:Connection with computer and TD 200 pad due to the NETlink Profibus cable.

2.8 OPC server development (PC Access)

Once we have all the important features that were developed, the proper functioning and the correct acquisition of signals inside of our program, we can use an OPC server to access the data inside the PLC as the PLC is in run status. The OPC server required for this application and to gather the data as the probe is executed is the DA OPC server. For this purpose, the

PC Access, created by Siemens, gives an extra add to the excel file (until Excel 2010) to program the excel tabs. Windows 2000 and Windows XP support Visual Basic for Applications (VBA) and with the help of PC Access, the MS Access data base provided by Microsoft, creates a micro OPC server that allows the communication with the S7-200, helping the users to achieve the values stored in variables as symbols, saving them in an excel file such as shown in the following figure.

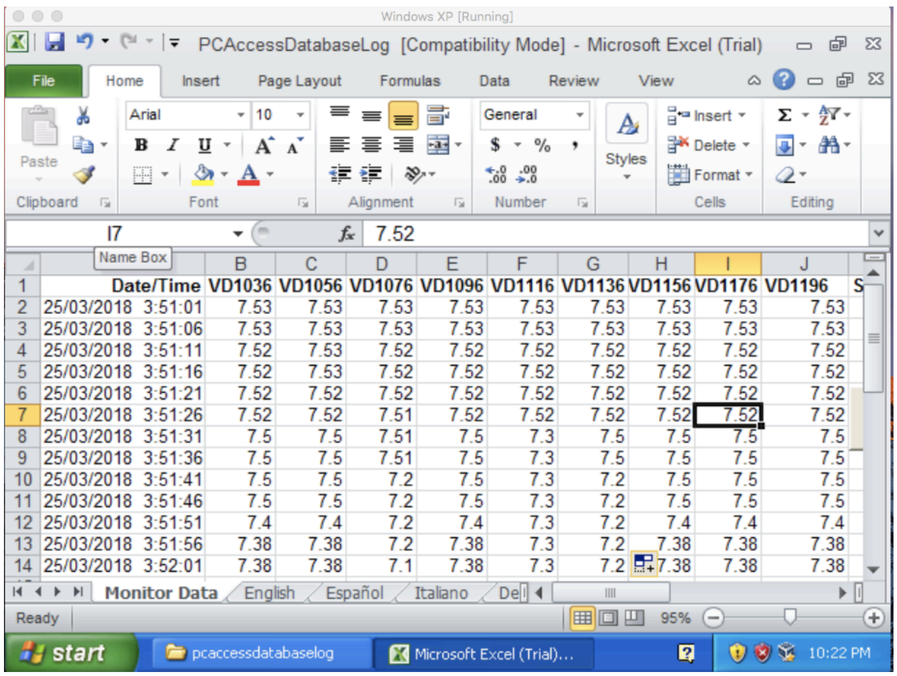


Figure 72: Format of the data acquired and stores in MS Excel.

As seen before, every 5 seconds the data is saved in the datalog in excel, but the interval of time can be adjusted to a desired sensing time. In the previous figure it can be observed that the variables from VD1036, pressure in the cylinder 1 chambers, until VD1196, pressure in the cylinder 9. This goes on until the variable VD1316 is sensed which is the pressure in the cylinder 15. Also the number of cycles endured by each of the cylinders.

3. Computational Implementation and Statistical Analysis:

After having the Excel file filled with the data values achieved during the leak and wear test, the pressure in the front and in the rear chamber and the number of cycles performed by each of the cylinders, the statistical analysis can be performed. The Weibull distribution probability is the one that better suits to the data achieved and in further sections the statistical analysis and the redundant indicators for data of the subjected samples will be analyzed. This time because of time issues, not even with the Accelerated testing conditions data of the life testing of these high reliable components was achieved. Therefore, the data used for the implementation in this project work was a projection of the normal conditions of the cylinders which the ones we are working on, also the approximation of the cycles endured was estimated with the help of the articles of Juan Chen et all [31]. and Seong Chang et all [2]. As is normally seen, the actual data achieved from testing in similar conditions is available and that is why the scope of the thesis project was to design a trust worth method and program to convert the achieved data (when it is done in the DIMEAS Laboratory) by the Accelerated testing conditions in indicators of reliability estimation and life testing in pneumatic cylinders.

Even though Excel is a very useful tool, further analysis was performed in MATLAB software because of the numerous advantages that this software provides, for example: A large database built-in algorithms for statistical use, helps you to interact actively with the data stored, keeping track of files and variables simplifying programming and debugging states. In addition to this, the data can be very easily plotted and change of colors, sizes, scales and legends can be made using graphical interactive tools. Finally, as it is used outside of the VM, the computation and the computer agility is faster and better.

3.1 Redundant metrics achieved with MATLAB.

As stated before, the program developed in MATLAB must be able to take the data collected during both wear (number of cycles performed until failure) and leak test (information about the pressure within the chambers) and extract form this data important parameters and redundant information about the reliability and life service of the pneumatic cylinders subjected into the test. Knowing the format in which the data values were stored in MS Excel, the program was developed. For the proper running of the MATLAB program the excel file must be moved or added into the folder in which MATLAB saves the projects, by defect the excel file will have the name “PneumaticCylinderDataLog”, the user has to be really careful at the time that he is performing **multiple probes**; he must extract the excel file from the location before launching the next Leak test because the file will be overwritten and the information of the first test will be lost. Following these easy steps then the MATLAB program can run without any inconvenient and the following metrics are calculated (To see the complete program please refer to the annexes of this project work).

Having the excel file data in the MATLAB folder, then the Weibull probability function for the data acquired is achieved using the **maximum likelihood estimation (MLE)** method in MATLAB, pulling out scale and shape parameters (η, β), then the distribution can be plotted. For the broken cylinders' cycle data extracted from the articles written by Juan Chen et all [31]. and Seong Chang et all [2]. (Figure 73)

C1	C2	C3	C4	C5	C6	C7	C8
3.190.900	3.132.600	3.653.500	3.971.100	4.188.700	3.110.900	3.662.900	2.879.700

Figure 73:Data From other experimetns of the cylinders failure observation in cycles.

After having the exact number of cycles at which the cylinder is considered to be broken, the previously obtained data is graphed in a probability plot to see the statistical data such as the variance, median and other important metrics for reliability analysis. This time the amount of data was limited only to 8 cylinders and was extracted, as mentioned before, from other experiments. This doesn't mean that the program is limited to do the data analysis with just 8 cylinders but it is able to do the data analysis with the number of cylinders that are active in the test bench, from 0 to 15, remember that the minimum number to have a significant sample of cylinders is 7 cylinders. The figure below shows the probability plot mentioned before.

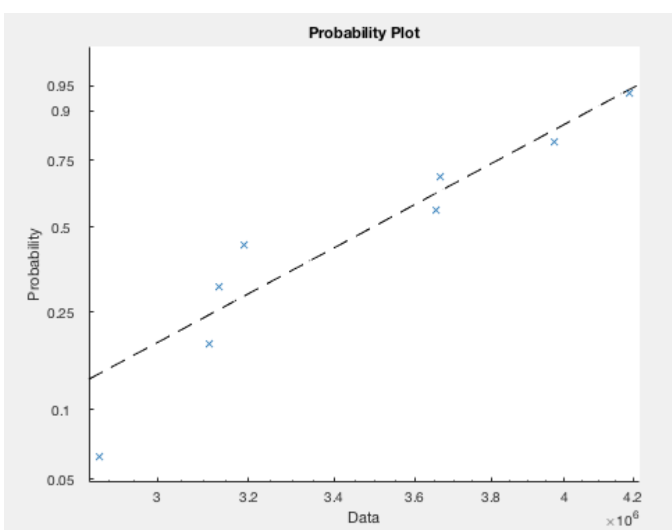


Figure 74:Probability Plot of the Data extracted from MS Excel.

After this, a cumulative distribution plot was implemented and then with the help of 95% confidence intervals (Red doted lines) was estimated a Weibull model. As stated before, the method used was the MLE method to estimate the eta and beta parameters.

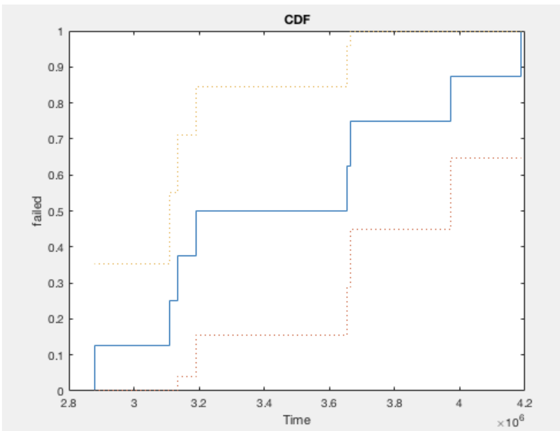


Figure 75:CDF and MLE 95% estimation

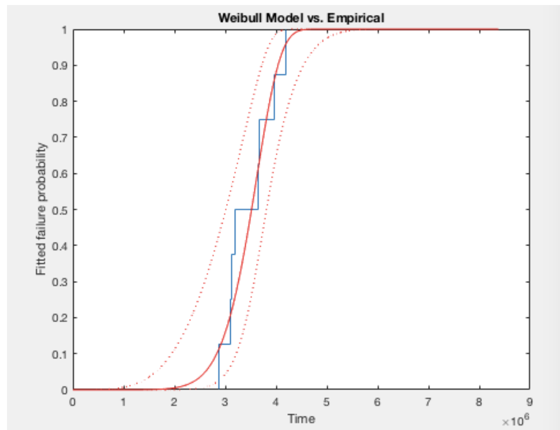


Figure 76:Weibull model achieved, red continuos line.

After the proper adjustments and the proper data threatening and analysis developed by the MATLAB software, the Weibull probability density function was founded Figure 77, having this curve, the important metrics that are relevant for our life data analysis of the pneumatic cylinders can be derive, see the Weibull pdf in the following figure.

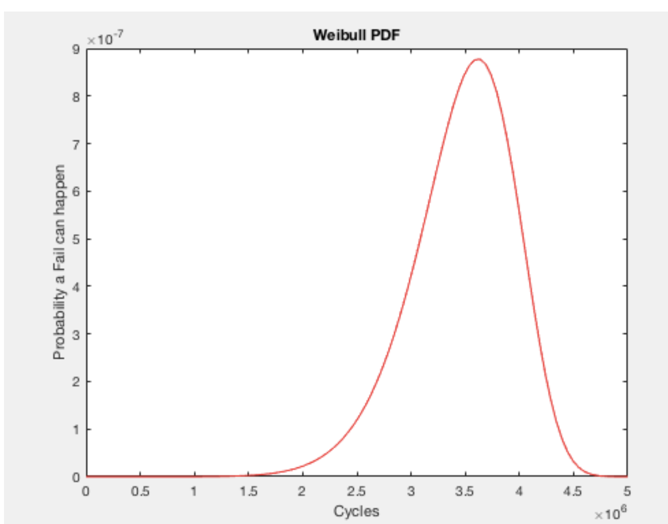


Figure 77:Data From other experimetns of the cylinders failure observation in cycles.

The first redundant parameter that is extracted from the designed program is the **reliability given time** of a pneumatic cylinder of those specifications, for example that one of these cylinders will have the 75% of probability to continue its life service after a 3,182,000 cycles of normal operation given a specific stress level. (As default, the stress level will be 10 kg, but it can be modified in the program if the user needs other specifications).

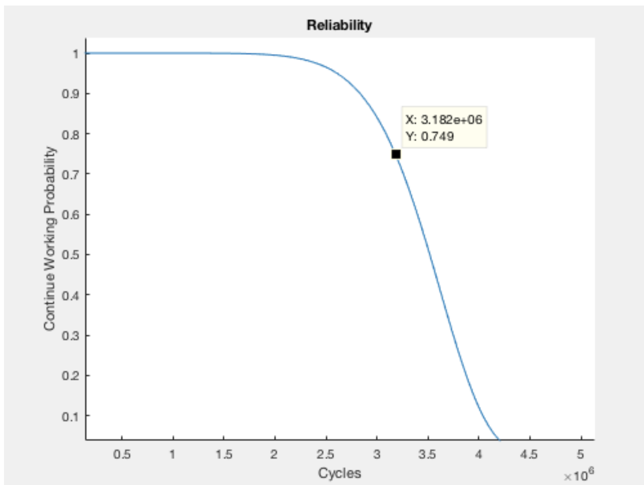


Figure 78:Relieability Curve, extracted from the Weibull pdf.

$$R(T) = e^{-\left(\frac{T-\gamma}{\eta}\right)^{\beta}}$$

The second important parameter was the **probability of failure given time**, this means that under normal conditions, a cylinder can fail. This is also known as unreliability, and is reciprocal to the reliability given time, so for example if the mentioned pneumatic cylinder has 75 % of working after 3,182,000 cycles period, then the same cylinder has 25% of probability that after a 3,182,000 cycles period it will not work.

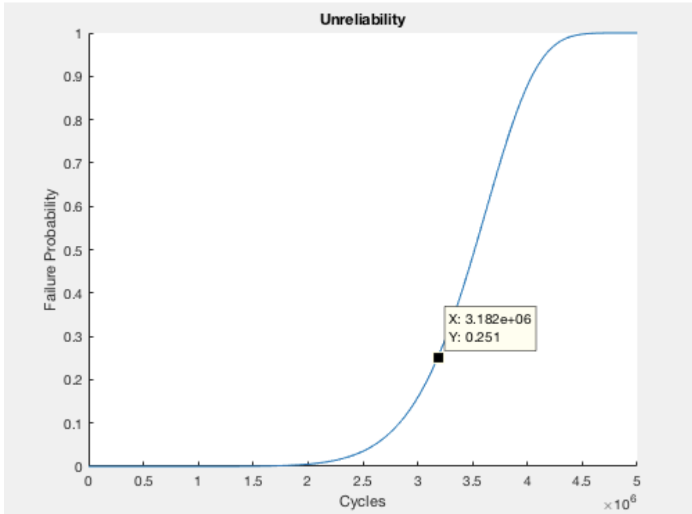


Figure 79: Unrelieability Curve, extracted from the Weibull pdf..

$$UR(T) = 1 - e^{-\left(\frac{T-\gamma}{\eta}\right)^{\beta}}$$

MTTF or MTBF is also given by the program, the first one meaning the **mean time to failure** and the **second mean time before failure.** This metric shows the average time in which a unit in the population is likely to work under a given stress level before failure. For this example, the mean time to failure is 3.4698e+06.

$$\bar{T} = \gamma + \eta \cdot \Gamma\left(\frac{1}{\beta} + 1\right)$$

The **Failure rate**, or the number of times that the pneumatic cylinder is estimated to fail at a given stress during its life service. With these results, it can be seen that the failures will increase when the cylinders are used. As in the following figures.

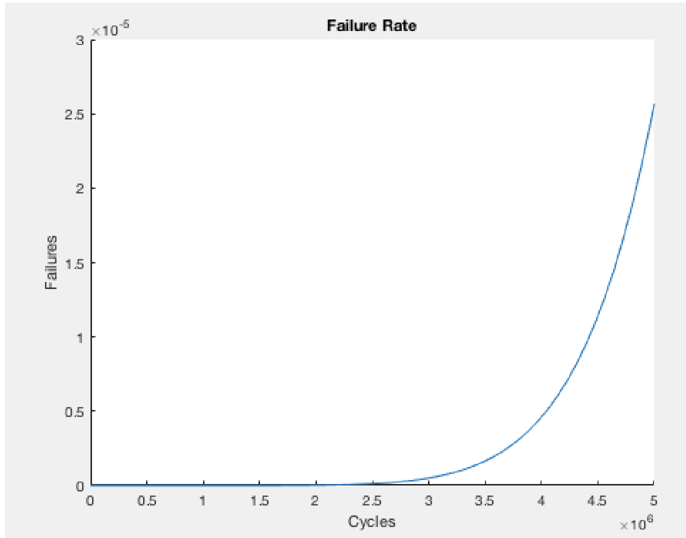


Figure 80: Failure Rate data obtained.

The **Reliable life** or time to warranty is the time at which the reliability is equal to a determined goal, in this thesis project the time is given in cycles. For example, 0% of the population will be able to endure infinity cycles, 10 % of the population will be able to endure 4.0390e6 cycles before failing and so on, this metric was calculated every 10% of the population, as can be seen in the figure bellow.

```
R_X =

   1.0e+06 *

      Inf    4.0390    3.8761    3.7489    3.6331    3.5184    3.3971    3.2597    3.0887    2.8334
```

Finally, the **beta life ($\boldsymbol{\beta_{x\%}}$)** was one of the most highlighted metrics and this shows the amount of time that X % of the population is likely to fail. In this thesis project the time is given in cycles. For example, it can be seen that 10 % of the population is predicted to fail before 2.8334e06 cycles. One can notice that 20% of the population is likely to fail before 3.0887e6 cycles and that in this is equivalent to the number of cycles that 80% of the population can endure before failing (notice that this is the previous metric). As the reliable life, this one is also calculated in intervals of 10% of the population.

```
B_X =

   1.0e+06 *

    2.8334    3.0887    3.2597    3.3971    3.5184    3.6331    3.7489    3.8761    4.0390       Inf
```

4. Conclusions and further improvements:

This chapter is intended to describe the knowledge acquired with this thesis project, the topics that were analyzed and the concepts that were learned during its development and implementation. Furthermore, there are added important point of view that can be improved to make this project better, new approaches of the technology that can be used and another update that will bring the test bench up-to-date for letting it to prevail and be competitive with the new and modern testing technologies that are coming into the world day by day.

4.1 Conclusions:

When engineers are performing a life data analysis, the attempt is to make predictions about the life off the devices following specifically trends that are shown by a smaller sample of the populations behavior, fitting a probability density function and finding a model to make forecasts of the possible behavior a member of the population can follow is exceedingly important. The analysis implemented in the MATLAB program and the metrics shown before, if are properly achieved, are part of the data that is redundant for engineers in a life data analysis and can determine the reliability of a machines component. Taking this into account if a machine is used with different components, they will determine the reliability of the machine. If these components are tested and the reliability of a machine improves, by the proper and careful selection of the items, then the producer will have a better profit as more satisfied clients will continue to buy its products and the warranty cost will be reduced.

In addition to this, by the development of this project the enrichment of many topics was achieved, for example the statistical analysis to identify certain behavior in a population, to use the life data analysis in a proper manner and to develop proper hypothesis to check the work developed. Even though that the statistical analysis is of great importance in a lot of different fields, it’s important to apply and select the proper sample, to search for the standardization of the process, if it exist, and to validate the results with other experiments to see its confidence and variations.

Was also learned that the use of Weibull pdf as probability function is chosen extensively to do the life data analysis of a project and in many other fields, because of its versatility and using the appropriate method to estimate its parameters and model a wide variety of behaviors.

Moreover, the accelerated testing and the diversity of the methods in which stress can be applied are a very useful tool to help in the life data analysis of very reliable products that in normal operating conditions can have a very long useful life and long iterations.

The uncertainty that is associated with the statistical models is always an important factor that can change the results or the functioning of a machine, a study or a behavior and therefore accidents are still likely to appear. The future cannot be fully predicted but the statistics are a very useful tool to help diminish property damages and life preventing issues.

Finally, the PLCs are a very versatile and useful control method that can be implemented in a variety of processes and that is why they are widely used in the industry and are still coming updates and technology, making them faster, better and more productive. Even that there are other technologies such as microcontrollers, the PLC and the languages in which they can be programmed, the easy implementation and the applications that require harsh environments will still favor the PLC implementation and propagation.

4. 2 Further improvements:

The test bench update let it in perfect conditions to work and perform the previously related test, the operator can be able to achieve and collect the important data of the pneumatic cylinders under test and with the use of the statistical analysis implemented in the MATLAB program, be able to understand the behavior of the whole population of pneumatic cylinders with the same specifications. Even though that the test bench is able to perform all the probes in a satisfactory manner, the update of the device implemented to control the automatization and to gather the data from the test is strongly recommended. Not because is unable to perform the probes but because its technology is obsolete and the use of a virtual machine is needed to connect between the computer and the PLC S7-200, this implies a lot of limitations and doesn’t allow many important features that a proper connection can set. The speed of connection is reduced and therefore the live pressure curves and live data analysis cannot be performed. The future updates in the world of the technology, sooner or later, will not allow the software to run in the new and better software computers and the use of MS windows XP will eventually expire, that is why adding a PLC Siemens 1200 that is able to work with MS windows 10 can be an option to consider.

The update in the PLC not will only allow the user to get rid of the virtual machine step and to enhance the connection between the PLC and the computer but enlarging the memory inside the PLC the statistical analysis can be performed inside the last one, allowing the redundant information to be achieved without the use of the MATLAB program. In addition to this, if a newer PLC is implemented, it might have the possibility to interconnect with newer and useful information displays, allowing to inform, change and display different variables important for life testing analysis data inside the PLC without further inconvenient. At this time the test bench can be used without a computer, but the data of the leak test will not be save because of the lack of memory, at this point the independency of the test bench is reduced because only can perform the wear test giving important information (the number of cycles endured until the cylinders are broke). The use of the leak test without computer is reduced to the recognition of leaks inside the cylinders and if the cylinder surpasses the threshold of 1 bar it is considered broken letting the operator know that the cylinder is out of use. Even though this information is useful and can be achieved without the computer for some of the operator interests, it is not enough to perform the life data estimation analysis for the rest of the population (this part must be performed adding the computer, performing the data acquisition and then passing the excel file into the MATLAB program developed manually).

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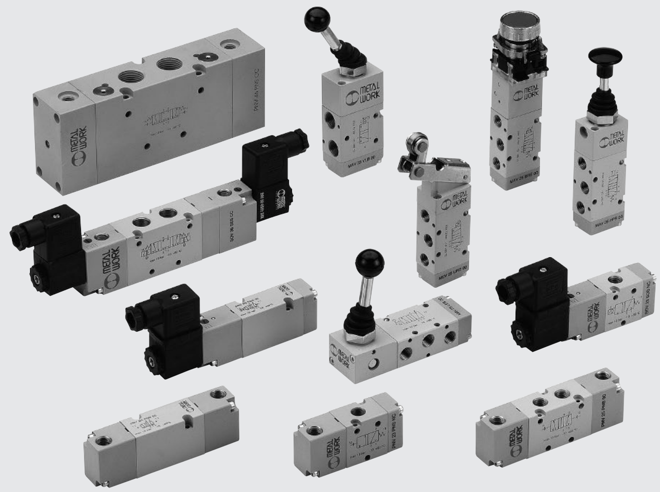
Annex 1:
PNEUMATIC VALVES DATA SHEET

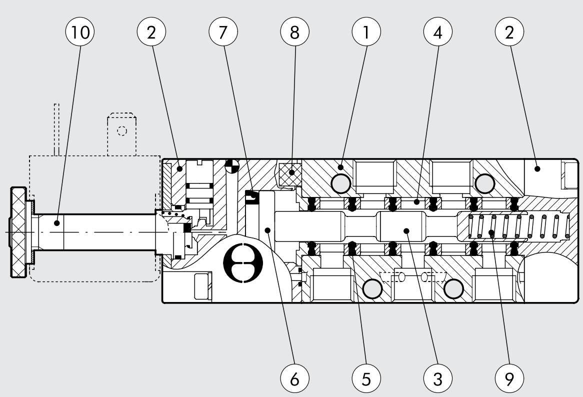
This is Metal Work's full range. Available in three sizes: 1/8", 1/4", 3/8", 1/2". Three versions: 3/2; 5/2; 5/3, four different types of actuation (mechanical, manual, pneumatic and electric).
Series 70 valves can be used for a wide range of applications as they can be mounted in line, on the wall, on the cylinder using a special bracket, or in series on a multiple or manifold base.



TECHNICAL DATA		1/8"	1/4"	3/8"	1/2"
Thread on the valve ports		1/8"	1/4"	3/8"	1/2"
Operating pressure:					
• monostable	bar	2.5 to 10			
• bistable	bar	1 to 10			
• asserved	bar	vacuum to 10			
Minimum pilot pressure	bar	2.5			
Operating temperature range	°C	−10 to +60			
Nominal diameter	mm	5	7.5	13.3	15
Conductance C	Nl/min · bar	121.43	264.26	505.52	971.43
Critical ratio b	bar/bar	0.32	0.27	0.32	0.43
Flow rate at 6 bar ΔP 0.5 bar	Nl/min	400	750	1560	3200
Flow rate at 6 bar ΔP 1 bar	Nl/min	550	1100	2150	4600
Installation		In any position (vertical assembly is not recommended for bistable valves subjected to vibration)			
Fluid		Filtered air without lubrication; lubrication, if used, must be continuous			
Recommended lubricant		ISO and UNI FD 22			
Maximum coil nut torque	Nm	1			
Compatibility with oils		Please refer to page 6-7 of the tecnical documentation			

COMPONENTS

① VALVE BODY: Aluminium
② CONTROL/END CAP: plastic
③ SPOOL: chemically nickel-plated aluminium
④ DISTANCE PLATES: plastic
⑤ GASKETS: NBR
⑥ PISTONS: Hostaform®
⑦ PISTON GASKET: NBR
⑧ FILTER: sintered bronze
⑨ SPRINGS: special steel
⑩ OPERATOR: Brass pipe - Stainless steel core

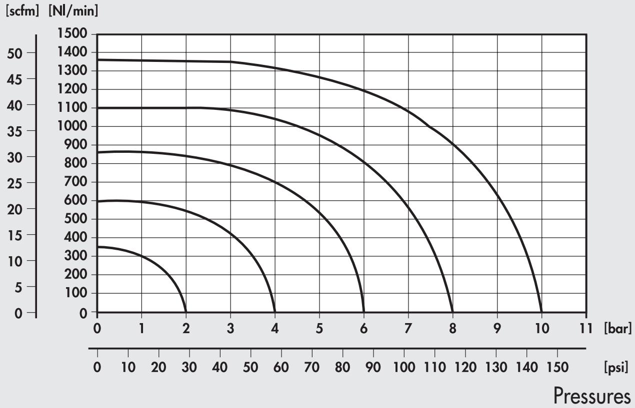


METAL WORK PNEUMATIC

FLOW CHARTS

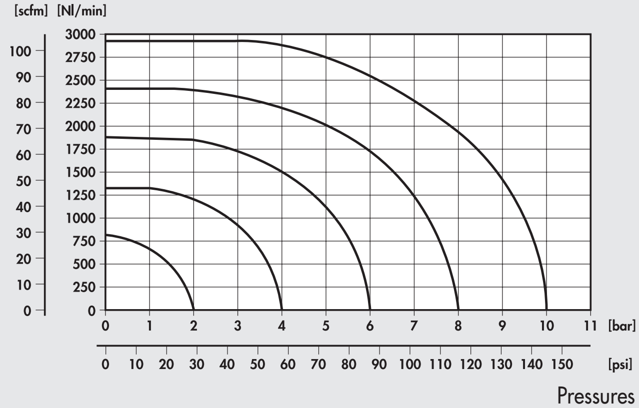
VALVES SERIES 70, 1/8"

Flow rates



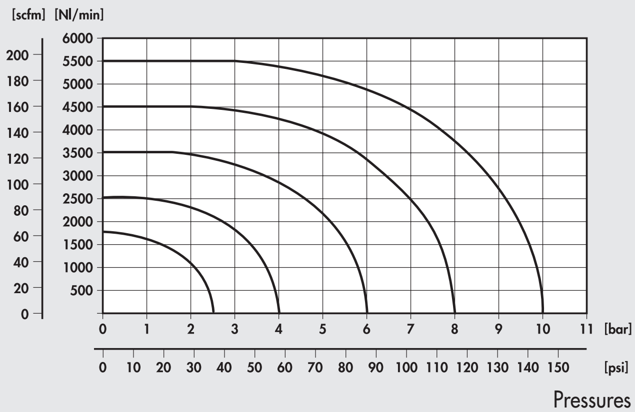
VALVES SERIES 70, 1/4"

Flow rates



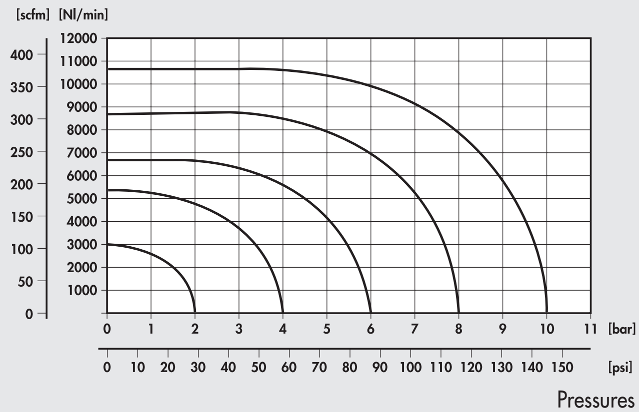
VALVES SERIES 70, 3/8"

Flow rates



VALVES SERIES 70, 1/2"

Flow rates



NOTES

VALVES SERIES 70, PNEUMATIC

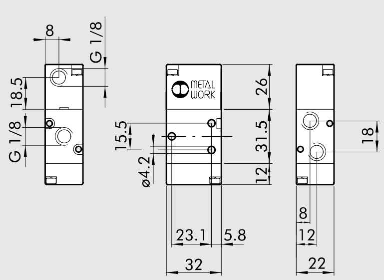
TECHNICAL DATA		1/8"	1/4"	3/8"	1/2"
Operating pressure	bar	Vacuum to 10			
Minimum pilot pressure					
• monostable	bar	2.5			
• bistable	bar	1			
Operating temperature range	°C	-10 to +60			
Nominal diameter	mm	5	7.5	13.3	15
Conductance C	Nl/min · bar	121.43	264.26	505.52	971.43
Critical ratio b	bar/bar	0.32	0.27	0.32	0.43
Flow rate at 6 bar ΔP 0.5 bar	Nl/min	400	750	1560	3200
Flow rate at 6 bar ΔP 1 bar	Nl/min	550	1100	2150	4600
TRA / TRR monostable at 6 bar	ms	6/15	7/15	5/28	16/46
TRA / TRR bistable at 6 bar	ms	7/7	7/7	13/13	16/16

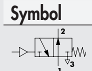
KEY TO CODES

P N V	2	3	P N	S	N C
FAMILY	DIMENSIONS	FUNCTION	OPERATORS 14	RESETTING (12)	FURTHER DETAILS
PNV pneumatic valves	**2** 1/8" **3** 1/4" **C** 3/8" **4** 1/2"	**3** 3/2 **5** 5/2 **6** 5/3	**PN** pneumatic	**S** mechanical springs **B** bistable **D** differential **O** stable for 5/3 **A** pneumatic/mechanical spring* *on demand	**OO** 5/2 **NC** normally closed **NO** normally open **CC** closed centres **OC** open centres **PC** pressure centres

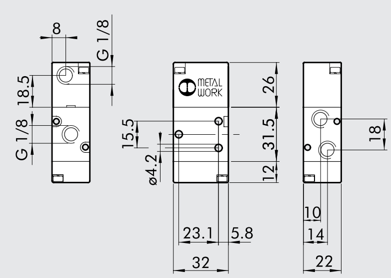
VALVES SERIES 70, PNEUMATIC, 1/8"

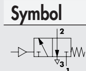
MONOSTABLE 3/2 NO, 1/8"



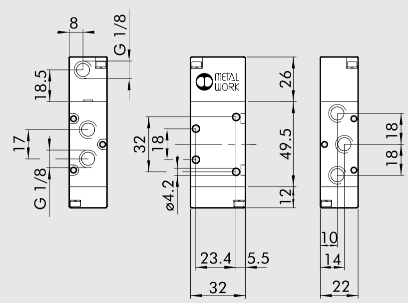
Symbol	Code	Abbrev.	Weight [g]
	**7010010400**	PNV 23 PNS NO	82

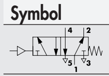
MONOSTABLE 3/2 NC, 1/8"



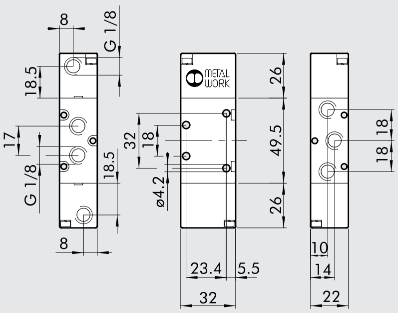
Symbol	Code	Abbrev.	Weight [g]
	**7010010200**	PNV 23 PNS NC	82

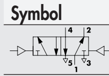
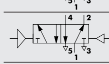
MONOSTABLE 5/2, 1/8"



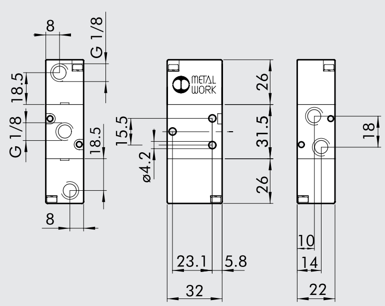
Symbol	Code	Abbrev.	Weight [g]
	**7010011100**	PNV 25 PNS OO	108

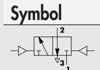
BISTABLE 5/2, 1/8"



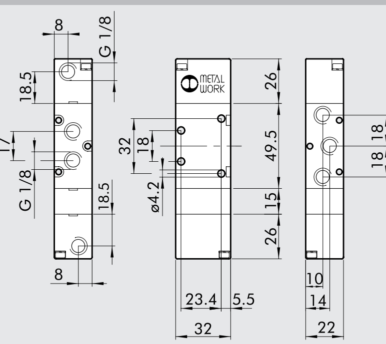
Symbol	Code	Abbrev.	Weight [g]
	**7010011200**	PNV 25 PNB OO	122
	**7010011300**	PNV 25 PND OO	128

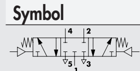
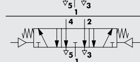
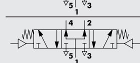
BISTABLE 3/2, 1/8"



Symbol	Code	Abbrev.	Weight [g]
	**7010010100**	PNV 23 PNB OO	96

MONOSTABLE 5/3, 1/8"

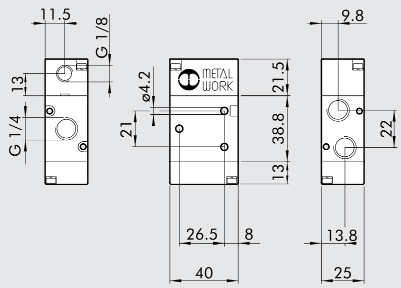


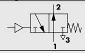
Symbol	Code	Abbrev.	Weight [g]
	**7010012100**	PNV 26 PNS CC	150
	**7010012200**	PNV 26 PNS OC	150
	**7010012300**	PNV 26 PNS PC	150

NOTES

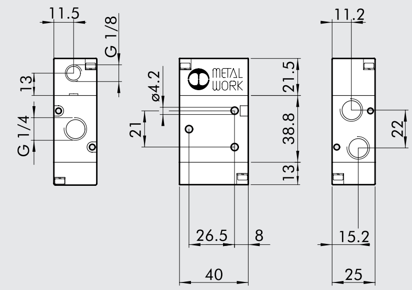
METAL WORK PNEUMATIC

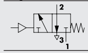
MONOSTABLE 3/2 NO, 1/4"



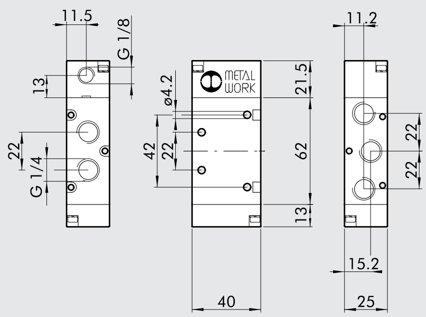
Symbol	Code	Abbrev.	Weight [g]
	7020010400	PNV 33 PNS NO	124

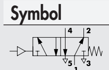
MONOSTABLE 3/2 NC, 1/4"



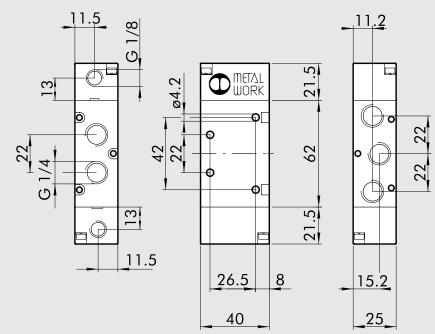
Symbol	Code	Abbrev.	Weight [g]
	7020010200	PNV 33 PNS NC	122

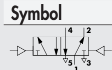
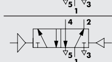
MONOSTABLE 5/2, 1/4"



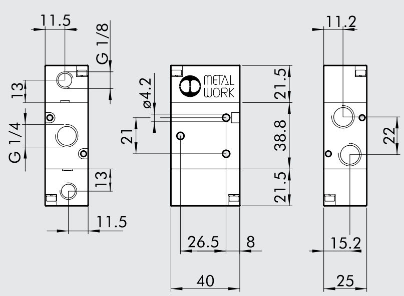
Symbol	Code	Abbrev.	Weight [g]
	7020011100	PNV 35 PNS OO	174

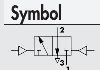
BISTABLE 5/2, 1/4"



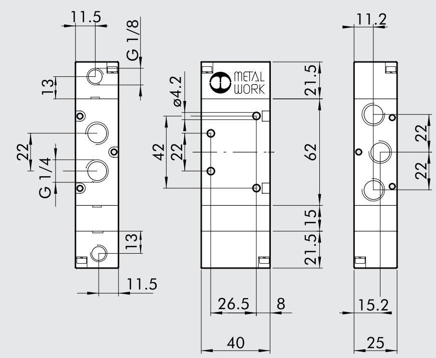
Symbol	Code	Abbrev.	Weight [g]
	7020011200	PNV 35 PNB OO	174
	7020011300	PNV 35 PND OO	198

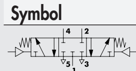
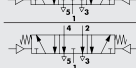
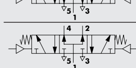
BISTABLE 3/2, 1/4"



Symbol	Code	Abbrev.	Weight [g]
	7020010100	PNV 33 PNB OO	134

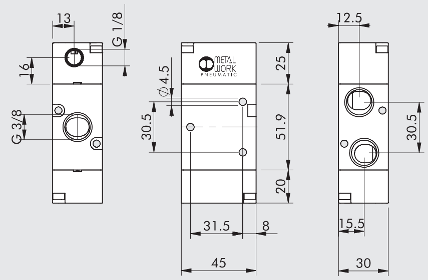
MONOSTABLE 5/3, 1/4"

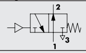


Symbol	Code	Abbrev.	Weight [g]
	7020012100	PNV 36 PNS CC	124
	7020012200	PNV 36 PNS OC	124
	7020012300	PNV 36 PNS PC	124

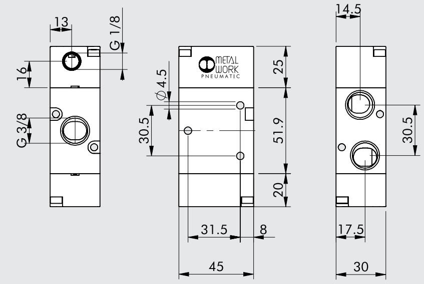
VALVES SERIES 70, PNEUMATIC, 3/8”

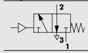
MONOSTABLE 3/2 NO, 3/8”



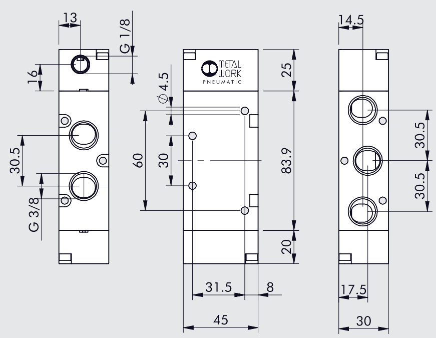
Symbol	Code	Abbrev.	Weight [g]
	7040010400	PNV C3 PNS NO	223

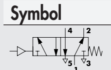
MONOSTABLE 3/2 NC, 3/8”



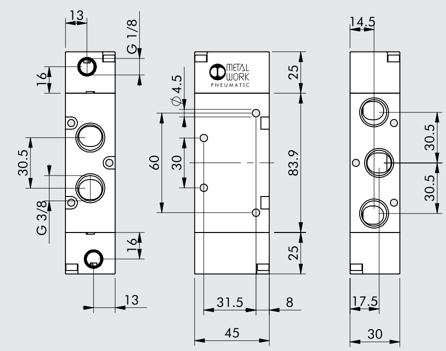
Symbol	Code	Abbrev.	Weight [g]
	7040010200	PNV C3 PNS NC	223

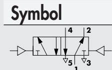
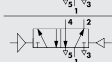
MONOSTABLE 5/2, 3/8”



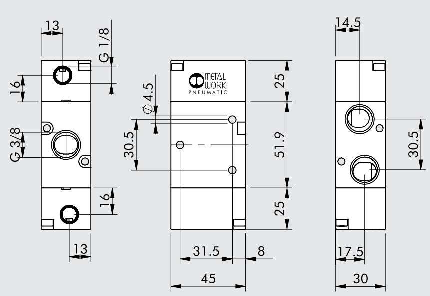
Symbol	Code	Abbrev.	Weight [g]
	7040011100	PNV C5 PNS OO	329

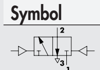
BISTABLE 5/2, 3/8”



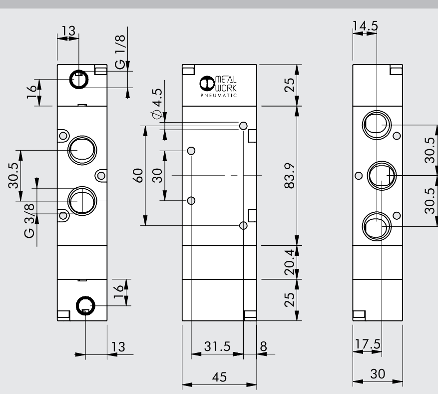
Symbol	Code	Abbrev.	Weight [g]
	7040011200	PNV C5 PNB OO	324
	7040011300	PNV C5 PND OO	360

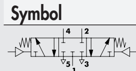
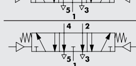
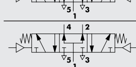
BISTABLE 3/2, 3/8”



Symbol	Code	Abbrev.	Weight [g]
	7040010100	PNV C3 PNB OO	230

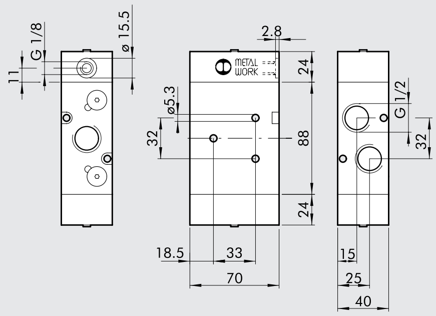
MONOSTABLE 5/3, 3/8”

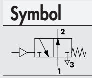


Symbol	Code	Abbrev.	Weight [g]
	7040012100	PNV C6 PNS CC	411
	7040012200	PNV C6 PNS OC	409
	7040012300	PNV C6 PNS PC	409

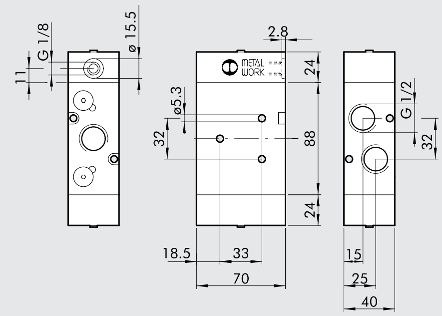
VALVES SERIES 70, PNEUMATIC, 1/2"

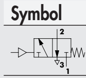
MONOSTABLE 3/2 NO, 1/2"



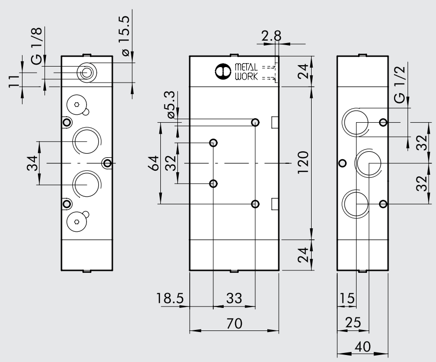
Symbol	Code	Abbrev.	Weight [g]
	**7030010400**	PNV 43 PNS NO	905

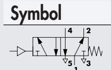
MONOSTABLE 3/2 NC, 1/2"



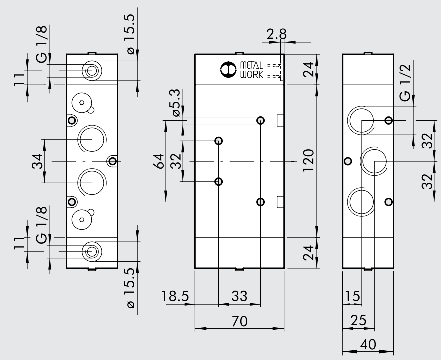
Symbol	Code	Abbrev.	Weight [g]
	**7030010200**	PNV 43 PNS NC	905

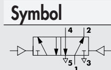
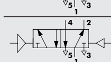
MONOSTABLE 5/2, 1/2"



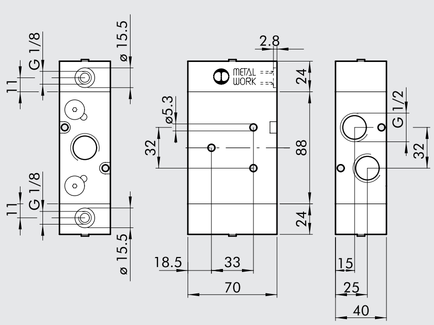
Symbol	Code	Abbrev.	Weight [g]
	**7030011100**	PNV 45 PNS OO	1090

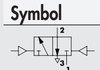
BISTABLE 5/2, 1/2"



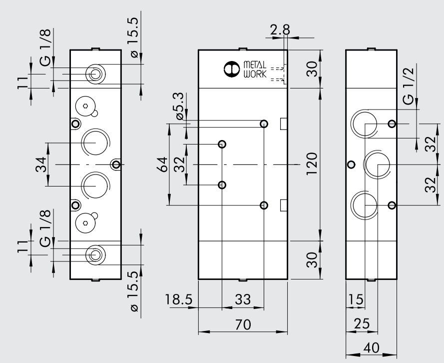
Symbol	Code	Abbrev.	Weight [g]
	**7030011200**	PNV 45 PNB OO	1077
	**7030011300**	PNV 45 PND OO	1090

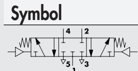
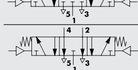
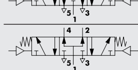
BISTABLE 3/2, 1/2"



Symbol	Code	Abbrev.	Weight [g]
	**7030010100**	PNV 43 PNB OO	921

MONOSTABLE 5/3, 1/2"



Symbol	Code	Abbrev.	Weight [g]
	**7030012100**	PNV 46 PNS CC	1200
	**7030012200**	PNV 46 PNS OC	1194
	**7030012300**	PNV 46 PNS PC	1196

VALVES SERIES 70, SOLENOID/PNEUMATIC

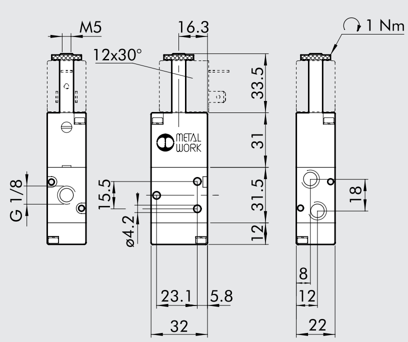
TECHNICAL DATA		1/8″	1/4″	3/8″	1/2″
Operating pressure:					
• monostable	bar	2.5 to10			
• bistable	bar	1 to 10			
• asserved	bar	Vacuum to 10			
Minimum pilot pressure	bar	2.5			
Operating temperature range	°C	-10 to +60			
Nominal diameter	mm	5	7.5	13.3	15
Conductance C	Nl/min · bar	121.43	264.26	505.52	971.43
Critical ratio b	bar/bar	0.32	0.27	0.32	0.43
Flow rate at 6 bar ΔP 0.5 bar	Nl/min	400	750	1560	3200
Flow rate at 6 bar ΔP 1 bar	Nl/min	550	1100	2150	4600
TRA / TRR monostable at 6 bar	ms	15/35	19/45	21/72	36/60
TRA / TRR bistable at 6 bar	ms	20/20	21/21	18/18	30/30
Hand operation		bistable			
Coil voltage values		12; 24 VDC - 24; 110; 220V AC 50/60Hz			
Power		2 W (DC) 3.5VA (AC)			
Voltage tolerance	%	-10 to +15			
Insulation class		F 155			
Maximum coil nut torque	Nm	1			

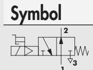
KEY TO CODES

S O V	2	3	S O	S	N C
FAMILY	DIMENSIONS	FUNCTION	OPERATORS 14	RESETTING (12)	FURTHER DETAILS
SOV solenoid/ pneumatic	**2** 1/8″	**3** 3/2	**SO** solenoid	**S** mechanical springs	**NC** normally closed
	3 1/4″	**5** 5/2	**SE** solenoid assisted	**B** bistable	**NO** normally open
	C 3/8″	**6** 5/3		**D** differential	**CC** closed centres
	4 1/2″			**P** pneumatic	**OC** open centres
				A pneumatic/mechanical spring*	**PC** pressure centres
					OO 5/2
				*on demand	

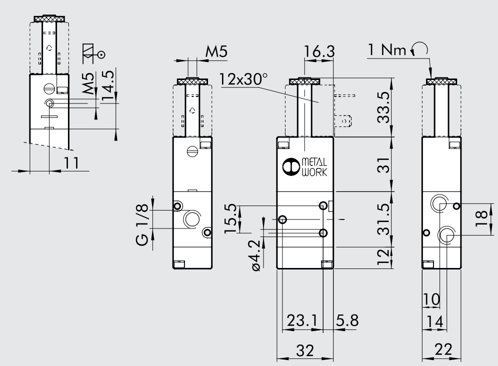
VALVES SERIES 70, SOLENOID/PNEUMATIC-PILOT-ASSISTED SOLENOID/PNEUMATIC, 1/8″

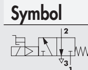
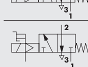
MONOSTABLE 3/2 NO, 1/8″



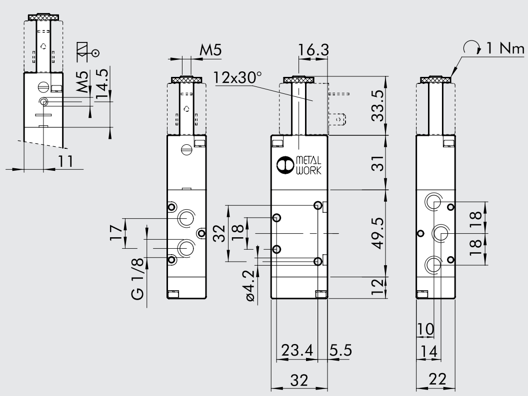
Symbol	Code	Abbrev.	Weight [g]
	**7010020400**	SOV 23 SOS NO	100

MONOSTABLE 3/2 NC, 1/8″



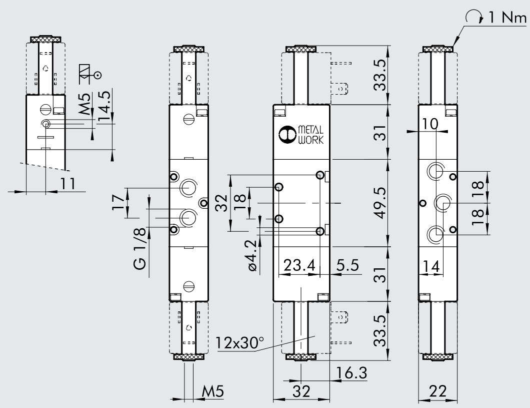
Symbol	Code	Abbrev.	Weight [g]
	**7010020200**	SOV 23 SOS NC	100
	**7010020500**	SOV 23 SES NC	100

MONOSTABLE 5/2, 1/8"



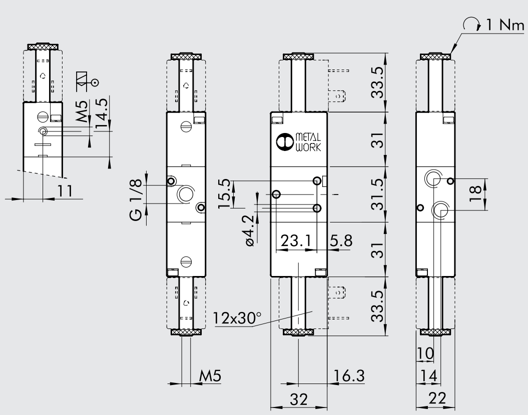
Symbol	Code	Abbrev.	Weight [g]
	7010021100	SOV 25 SOS OO	128
	7010021500	SOV 25 SES OO	129

BISTABLE 5/2, 1/8"



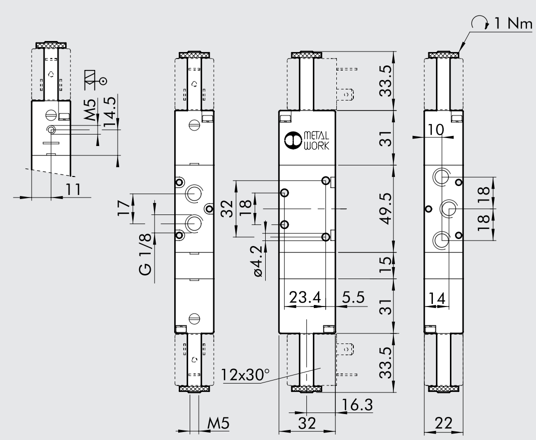
Symbol	Code	Abbrev.	Weight [g]
	7010021200	SOV 25 SOB OO	160
	7010021300	SOV 25 SOD OO	166
	7010021600	SOV 25 SEB OO	160

BISTABLE 3/2, 1/8"



Symbol	Code	Abbrev.	Weight [g]
	7010020100	SOV 23 SOB OO	135
	7010020300	SOV 23 SEB OO	136

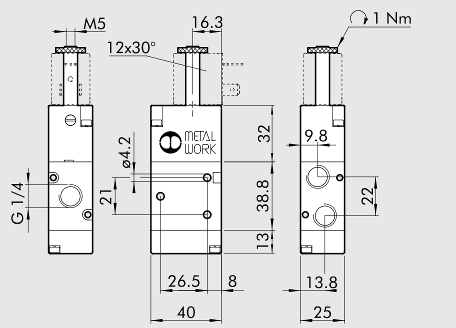
MONOSTABLE 5/3, 1/8"



Symbol	Code	Abbrev.	Weight [g]
	7010022100	SOV 26 SOS CC	190
	7010022200	SOV 26 SOS OC	190
	7010022300	SOV 26 SOS PC	190
	7010022400	SOV 26 SES CC	188
	7010022500	SOV 26 SES OC	188
	7010022600	SOV 26 SES PC	188

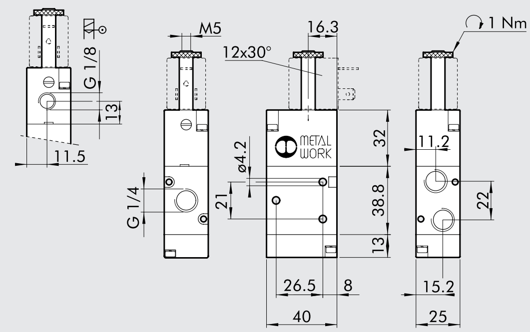
VALVES SERIES 70, SOLENOID/PNEUMATIC-PILOT-ASSISTED SOLENOID/ PNEUMATIC, 1/4"

MONOSTABLE 3/2 NO, 1/4"



Symbol	Code	Abbrev.	Weight [g]
	7020020400	SOV 33 SOS NO	152

MONOSTABLE 3/2 NC, 1/4"



Symbol	Code	Abbrev.	Weight [g]
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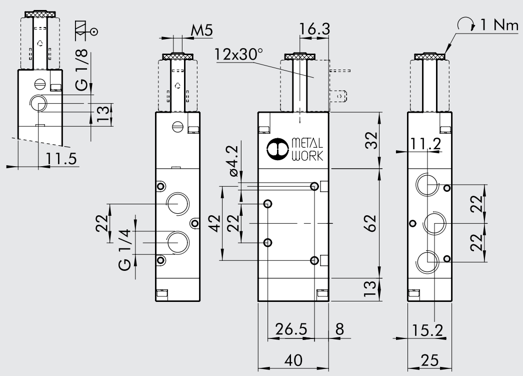
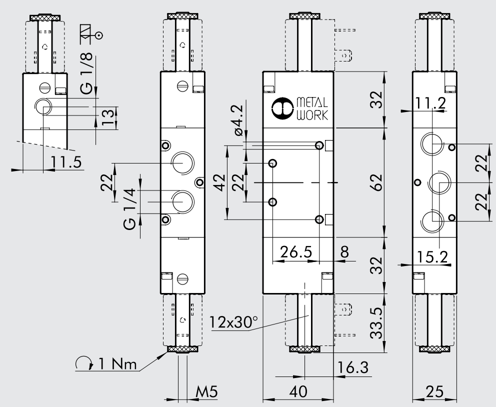
	7020020500	SOV 33 SES NC	152

MONOSTABLE 5/2, 1/4"



Symbol	Code	Abbrev.	Weight [g]
	7020021100	SOV 35 SOS OO	200
	7020021500	SOV 35 SES OO	200

BISTABLE 5/2, 1/4"



Symbol	Code	Abbrev.	Weight [g]
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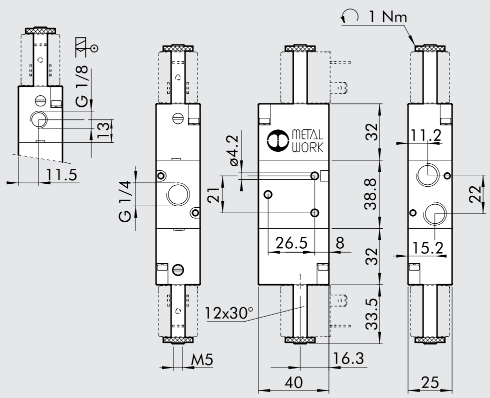
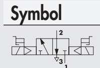
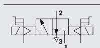
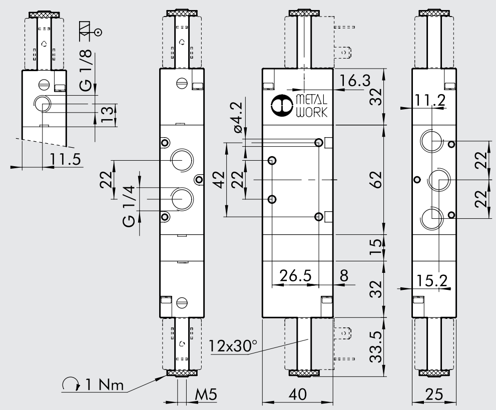
	7020021300	SOV 35 SOD OO	252
	7020021600	SOV 35 SEB OO	242

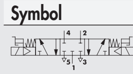
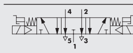
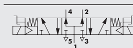
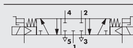
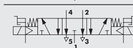
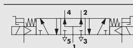
BISTABLE 3/2, 1/4"



Symbol	Code	Abbrev.	Weight [g]
	7020020100	SOV 33 SOB OO	190
	7020020300	SOV 33 SEB OO	190

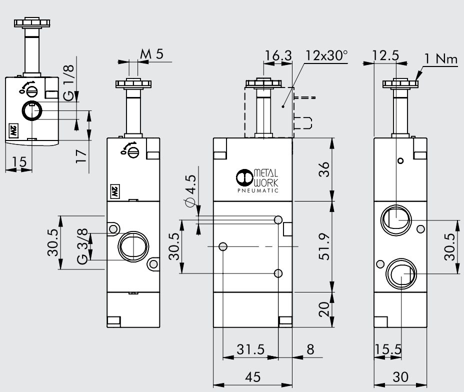
MONOSTABLE 5/3, 1/4"

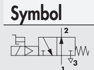
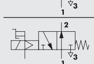


Symbol	Code	Abbrev.	Weight [g]
	7020022100	SOV 36 SOS CC	274
	7020022200	SOV 36 SOS OC	274
	7020022300	SOV 36 SOS PC	274
	7020022400	SOV 36 SES CC	277
	7020022500	SOV 36 SES OC	277
	7020022600	SOV 36 SES PC	277

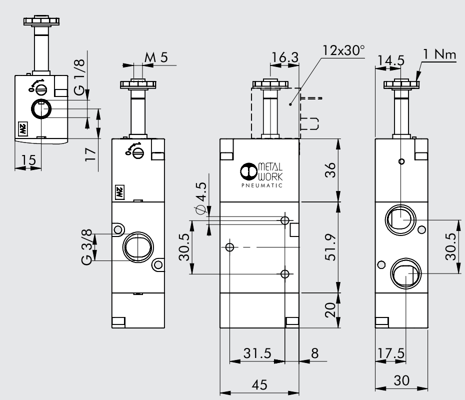
VALVES SERIES 70, SOLENOID/PNEUMATIC-PILOT-ASSISTED SOLENOID/ PNEUMATIC, 3/8"

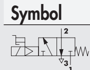
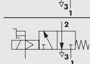
MONOSTABLE 3/2 NO,3/8"



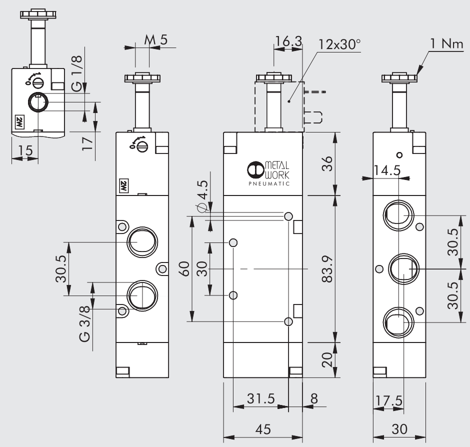
Symbol	Code	Abbrev.	Weight [g]
	7040020400	SOV C3 SOS NO	256
	7040020600	SOV C3 SES NO	255

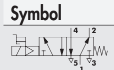
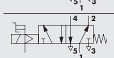
MONOSTABLE 3/2 NC, 3/8"



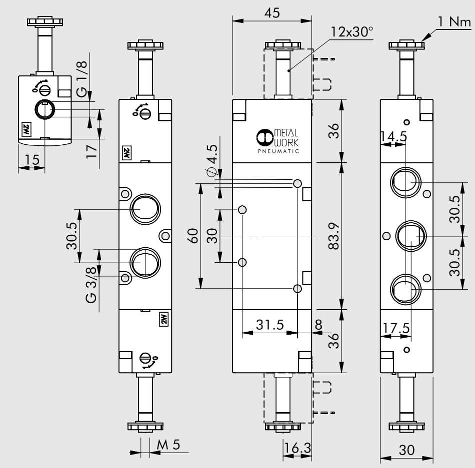
Symbol	Code	Abbrev.	Weight [g]
	7040020200	SOV C3 SOS NC	256
	7040020500	SOV C3 SES NC	255

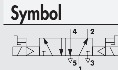
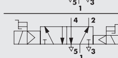
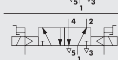
MONOSTABLE 5/2, 3/8"



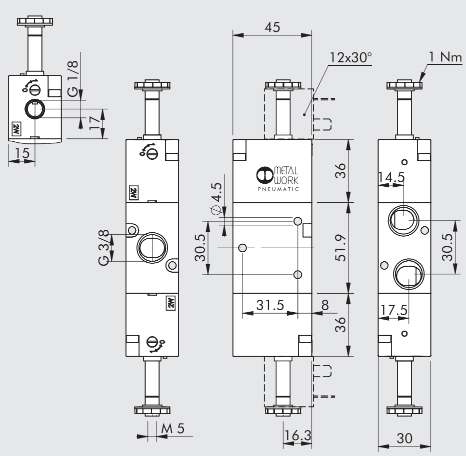
Symbol	Code	Abbrev.	Weight [g]
	7040021100	SOV C5 SOS OO	361
	7040021500	SOV C5 SES OO	361

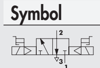
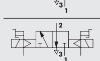
BISTABLE 5/2, 3/8"



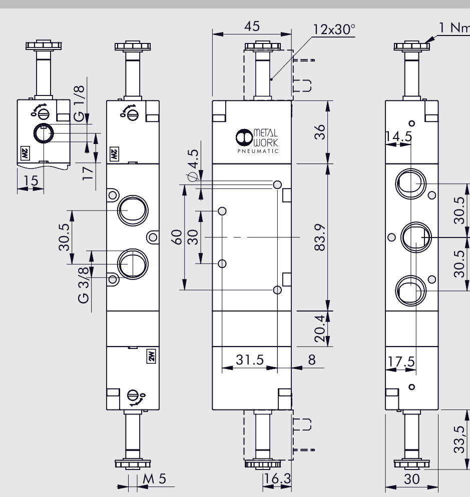
Symbol	Code	Abbrev.	Weight [g]
	7040021200	SOV C5 SOB OO	400
	7040021300	SOV C5 SOD OO	425
	7040021600	SOV C5 SEB OO	400

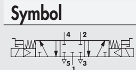
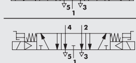
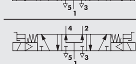
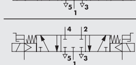
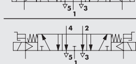
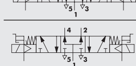
BISTABLE 3/2, 3/8"



Symbol	Code	Abbrev.	Weight [g]
	7040020100	SOV C3 SOB OO	307
	7040020300	SOV C3 SEB OO	307

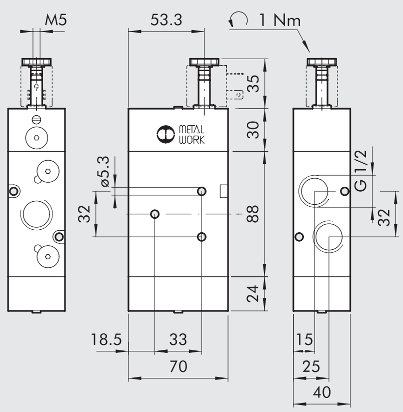
MONOSTABLE 5/3, 3/8"

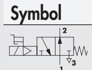


Symbol	Code	Abbrev.	Weight [g]
	7040022100	SOV C6 SOS CC	476
	7040022200	SOV C6 SOS OC	474
	7040022300	SOV C6 SOS PC	474
	7040022400	SOV C6 SES CC	476
	7040022500	SOV C6 SES OC	474
	7040022600	SOV C6 SES PC	474

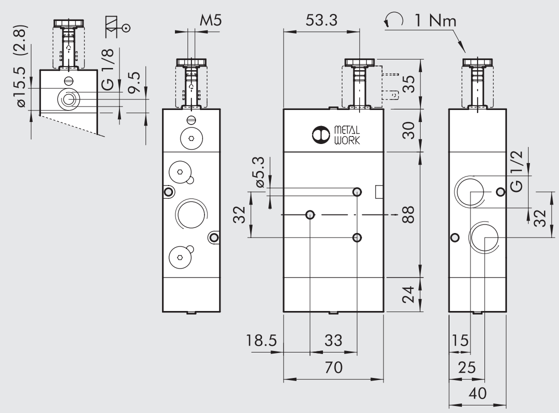
VALVES SERIES 70, SOLENOID/PNEUMATIC-PILOT-ASSISTED SOLENOID/PNEUMATIC, 1/2"

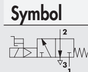
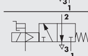
MONOSTABLE 3/2 NO, 1/2"



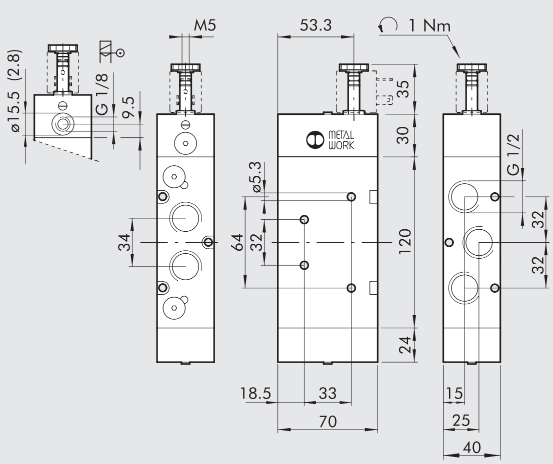
Symbol	Code	Abbrev.	Weight [g]
	**7030020400**	SOV 43 SOS NO	930

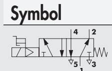
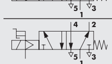
MONOSTABLE 3/2 NC, 1/2"



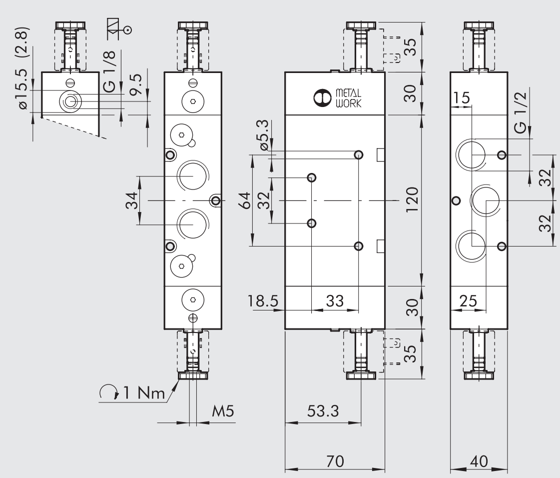
Symbol	Code	Abbrev.	Weight [g]
	**7030020200**	SOV 43 SOS NC	930
	**7030020500**	SOV 43 SES NC	923

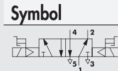
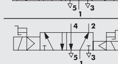
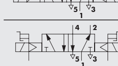
MONOSTABLE 5/2, 1/2"



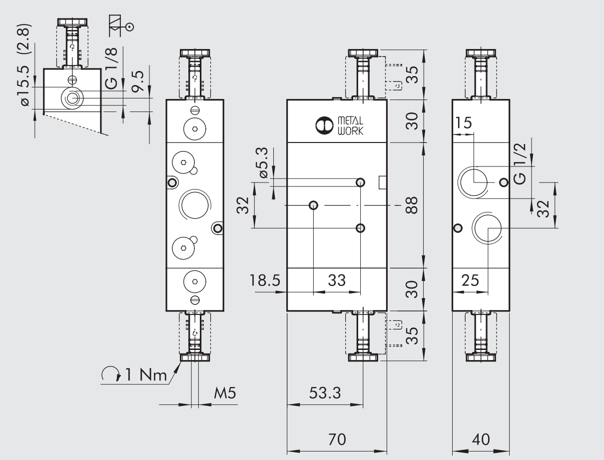
Symbol	Code	Abbrev.	Weight [g]
	**7030021100**	SOV 45 SOS OO	1120
	**7030021500**	SOV 45 SES OO	1113

BISTABLE 5/2, 1/2"



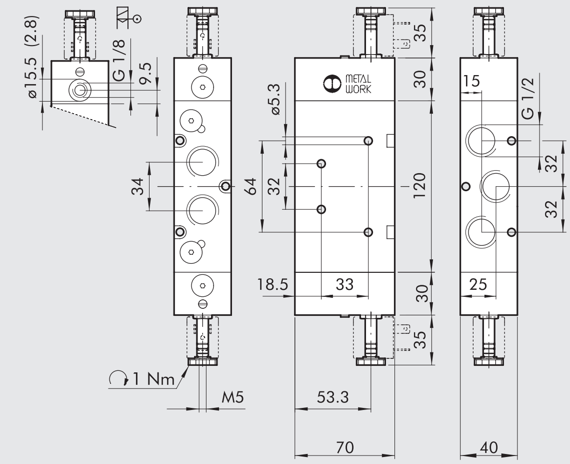
Symbol	Code	Abbrev.	Weight [g]
	**7030021200**	SOV 45 SOB OO	1140
	**7030021300**	SOV 45 SOD OO	1152
	**7030021600**	SOV 45 SEB OO	1127

BISTABLE 3/2, 1/2"



Symbol	Code	Abbrev.	Weight [g]
	7030020100	SOV 43 SOB OO	955
	7030020300	SOV 43 SEB OO	942

MONOSTABLE 5/3, 1/2"



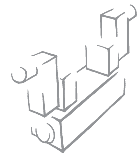
Symbol	Code	Abbrev.	Weight [g]
	7030022100	SOV 46 SOS CC	1265
	7030022200	SOV 46 SOS OC	1265
	7030022300	SOV 46 SOS PC	1265
	7030022400	SOV 46 SES CC	1252
	7030022500	SOV 46 SES OC	1252
	7030022600	SOV 46 SES PC	1252

ACCESSORIES FOR SERIES 70 SOLENOID/PNEUMATIC VALVES

Refer to page 2-48 for coils and connectors

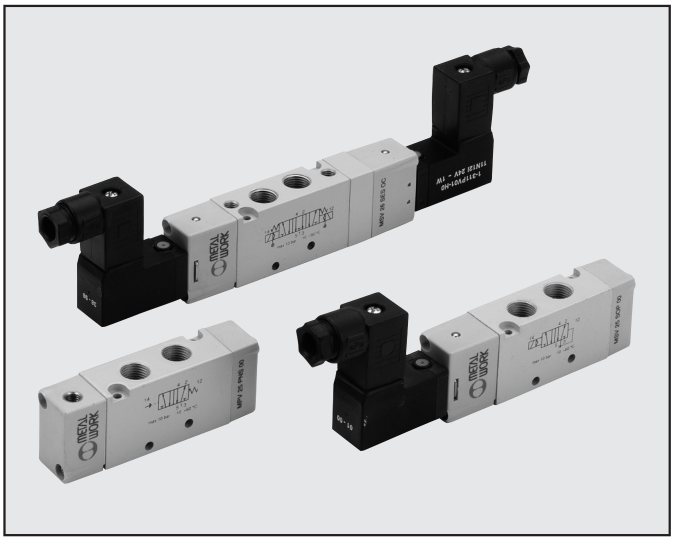
NOTES

Annex 2:
MATCH 16 PNEUMATIC VALVE DATA SHEET



MACH 16 VALVES

Available in size 1/8" only, versions 5/2 and 5/3 and with pneumatic and solenoid actuation. The Mach 16 valve is a typical small size valve, only 16 mm wide, with excellent performance 750 NL/min flow rate at 6 bar ΔP 1 Bar.
The valve can be used in line, on a panel or on a base (multiple or manifold)
The Mach design is the result of the miniaturisation concept with the same durability, sturdiness and reliability.

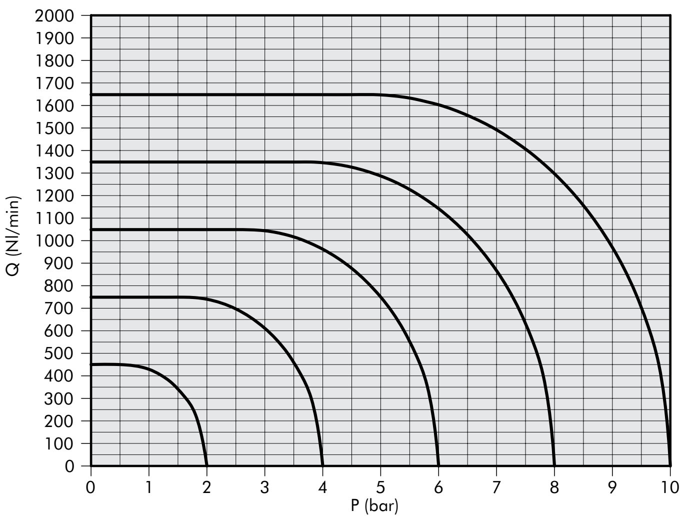


2

TECHNICAL DATA

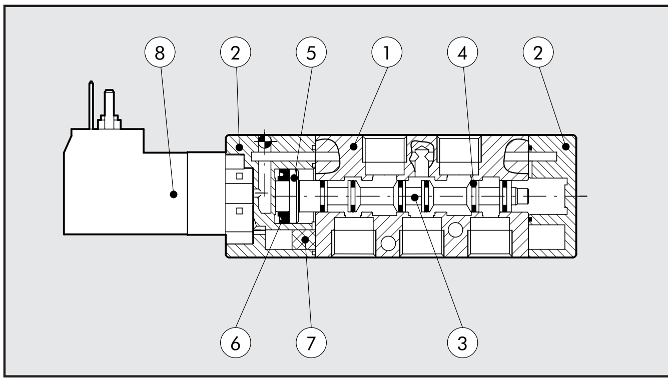
Valve port thread	1/8"
Type of control	M5 pneumatic actuation
	solenoid/pneumatic operation with integrated coil
Maximum outer diameter of gaskets	15 mm
for ports 1 – 3- 5	
Maximum outer diameter for ports 2 – 4	15 mm
Operating temperature range	–10°C to 60°C
Minimum actuation pressure pilot –	monostable with pneumatic spring: see picture on page 2.2/88
pneumatic controls	1.6 bar for monostable valves – mechanical spring
	1 bar for bistable valves – 1.9 bar for valves 5/3
Maximum operating pressure	10 bar
Fluid	Filtered lubricated or unlubricated air
	lubrication, if used, must be continuous
Recommended lubricant	ISO and UNI FD22
Solenoid pilot	Integrated coil DIN 43650 C shape
Manual	monostable on solenoid pilot (with bistable manual valve on request)
Number of ways in base	1-3-5 and pilot exhaust
Screws for wall-mounting single valve	2 screws M3
Screws for base-mounting valve	2 screws M2.5x30
Installation	in any position (vertical assembly is not recom-
	mended for bistable valves subjected to vibration)
Flow rate at 6 Bar ΔP 0.5 Bar	540 Nl/min
Flow rate at 6 Bar ΔP 1 Bar	750 Nl/min
Conductance C	149.8 Nl/min · bar
Critical ratio b	0.525 bar/bar
Compatibility with oils	please refer to page 6.1/08

FLOW CHART



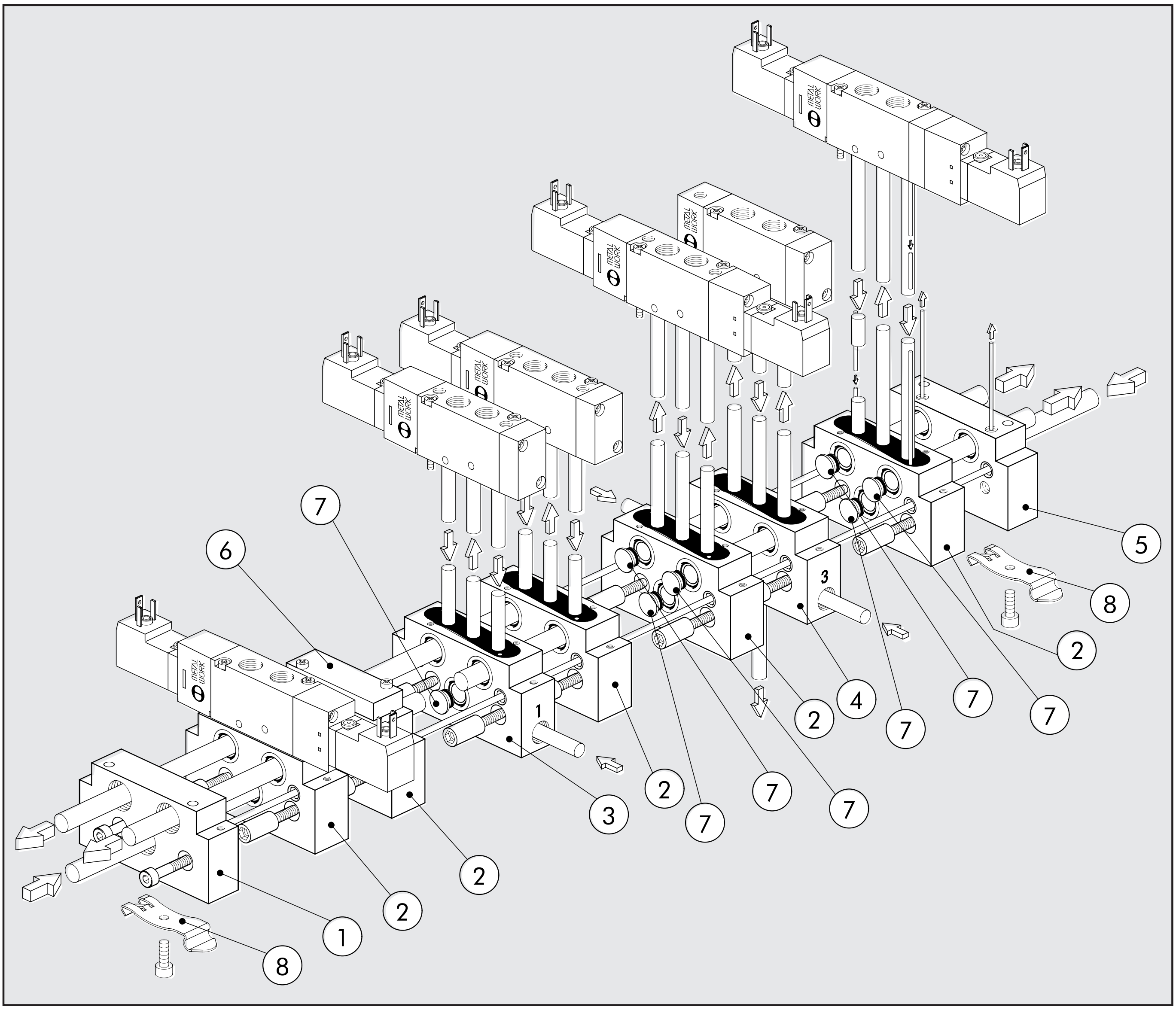
COMPONENTS

① VALVE BODY: Aluminium
② CONTROL/END CAP: HOSTAFORM®
③ SPOOL: Aluminium
④ GASKETS: Polyurethane
⑤ PISTONS: HOSTAFORM®
⑥ PISTON GASKET: Polyurethane
⑦ FILTER: sintered bronze
⑧ PILOT: with integrated coil



METAL WORK PNEUMATIC

MANIFOLD BASES FOR MACH 16



Ref.	Description	Code
①	M16/VDMA Input end-plate kit	0227100201
②	M16 manifold base kit	0227100150
③	M16 separate feed manifold base kit	0227100301
④	M16 exhaust feed manifold base kit	0227100302
⑤	M16/VDMA output end-plate kit	0227100200
⑥	M16 blanking plate	0225004500
⑦	Intermediate diaphragm	0227100000
⑧	Connection bracket on DIN-bar	0227300600

KEY TO CODES

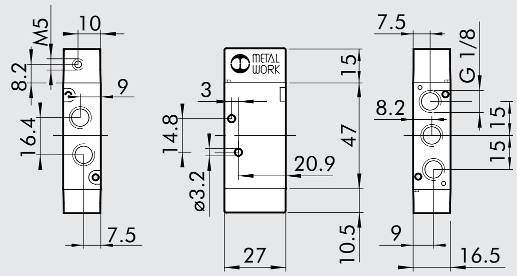
M S V	2	5	S O	P	O O	24VDC
FAMILY	PORT	FUNCTION	OPERATORS 14	RESETTING 12	FURTHER DETAILS	VOLTAGE
MSV solenoid/pneumatic MPV pneumatic	2 1/8″	5 5/2 6 5/3	SO solenoid/pneumatic SE solenoid pilot PN pneumatic	P pneumatic spring S mechanical spring B bistable	OO 5/2 CC closed centres OC open centres PC pressure centres	24VDC 24VAC 110VAC 220VAC

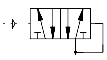
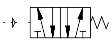
MACH 16 VALVES MPV, PNEUMATIC

TECHNICAL DATA

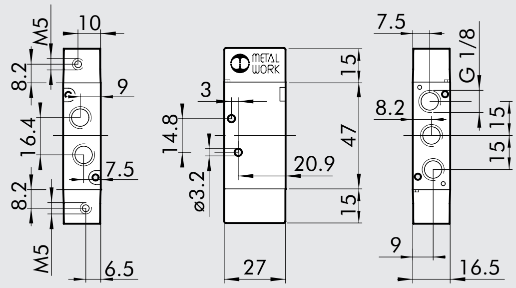
Operating pressure	vacuum – 10 bar
Minimum operating pressure:	
• monostable with pneumatic spring	see graph page 2.2/88
• monostable with mechanical spring	1.6 bar
• monostable 5/3	1.9 bar
• bistable	1 bar
Conductance C	149.8 Nl/min · bar
Critical ratio b	0.525 bar/bar
Flow rate at 6 Bar ΔP 0.5 Bar	540 Nl/min
Flow rate at 6 Bar ΔP 1 Bar	750 Nl/min
Repositioning response times at 6 Bar:	
• monostable	4 ms
• bistable	4 ms
Repositioning response times at 6 Bar:	
• monostable	8.4 ms
• bistable	4 ms

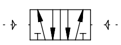
MONOSTABLE 5/2



Symbol	Abbrev.	Code	Weight [g]
	MPV 25 PNP OO	7062010100	60
	MPV 25 PNS OO	7062010130	61

BISTABLE 5/2

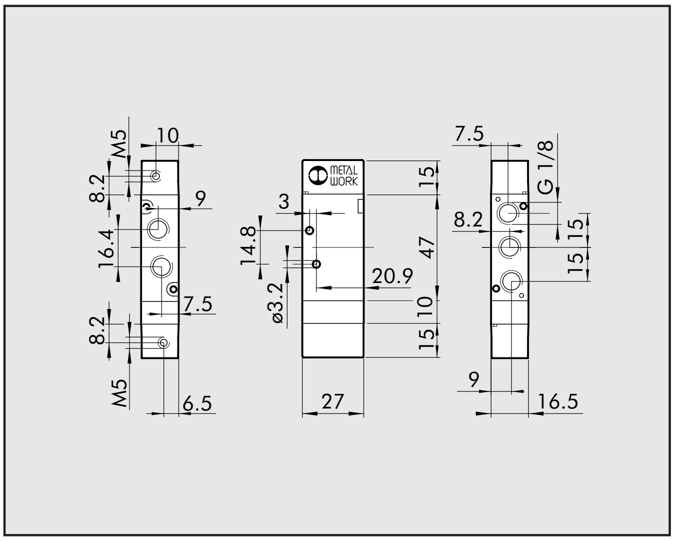


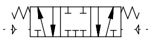
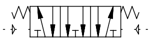
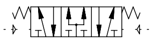
Symbol	Abbrev.	Code	Weight [g]
	MPV 25 PNB OO	7062010110	62

2

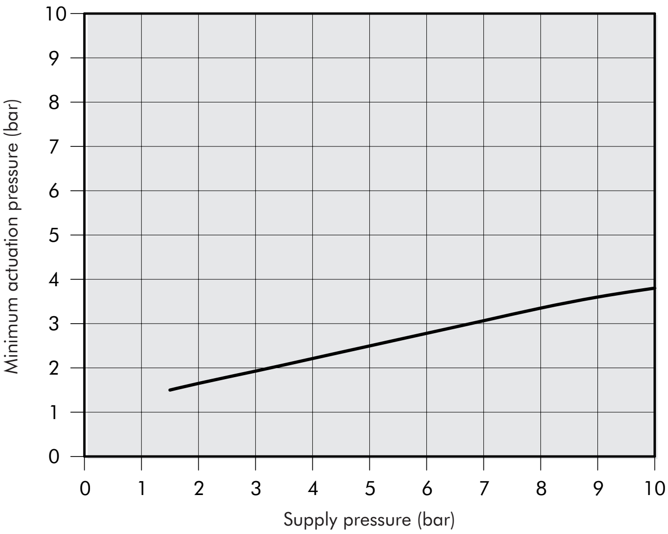
METAL WORK PNEUMATIC

MONOSTABLE 5/3

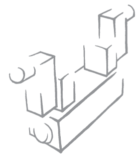


Symbol	Abbrev.	Code	Weight [g]
	MPV 26 PNS CC	7062010210	73
	MPV 26 PNS OC	7062010310	73
	MPV 26 PNS PC	7062010410	73

OPERATING PRESSURE



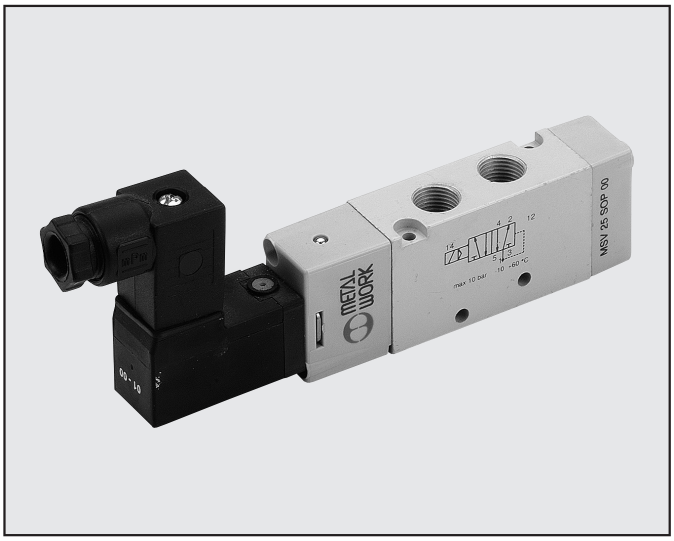
NOTES



MACH 16 VALVES MPV, SOLENOID/PNEUMATIC

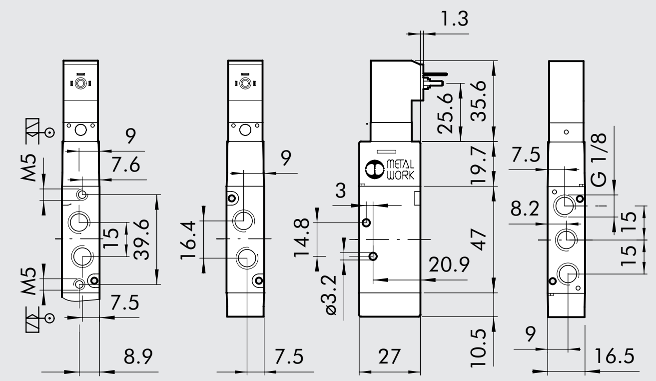
TECHNICAL DATA

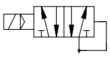
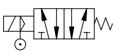
Operating pressure:	
• monostable	1.9-10 bar
• bistable	1-10 bar
• pilot-assisted	vacuum – 10 bar
Minimum pilot pressure	2 bar
Operating temperature range	-10° to 60°C
Conductance C	149.8 Nl/min · bar
Critical ratio b	0.525 bar/bar
Flow rate at 6 Bar ΔP 0.5 Bar	540 Nl/min
Flow rate at 6 Bar ΔP 1 Bar	750 Nl/min
TRA/TRR monostable at 6 bar	12 ms / 26 ms
TRA/TRR bistable at 6bar	21 ms / 21 ms
Type of operation: Manual	monostable on the solenoid pilot
	(also with bistable manual valve on request)
Pilot with integrated coil	24 VDC - 24 VAC - 110 VAC - 220 VAC
Powers	1 W
Voltage tolerance	-10% ÷ +15%
Insulation class	F 155
Degree of protection	IP 65 EN60529 with connector
Solenoid rating	100% ED
Electrical contacts	DIN 43650 C shape



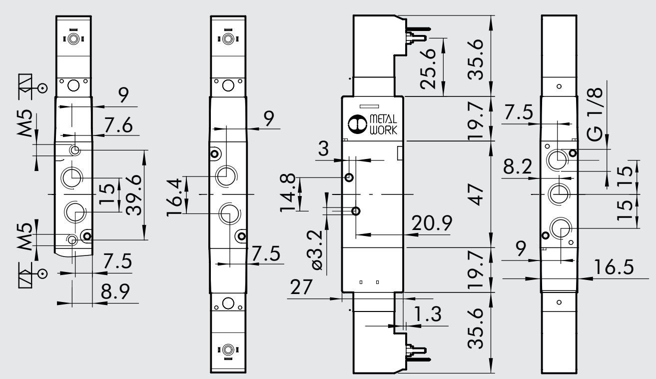
2

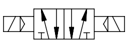
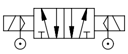
MONOSTABLE 5/2



Symbol	Abbrev.	Code	Weight [g]
	MSV 25 SOP 00 24VDC	7062020102	92
	MSV 25 SOP 00 24VAC	7062020103	92
	MSV 25 SOP 00 110VAC	7062020104	92
	MSV 25 SOP 00 220VAC	7062020105	92
	MSV 25 SOS 00 24VDC	7062020132	93
	MSV 25 SOS 00 24VAC	7062020133	93
	MSV 25 SOS 00 110VAC	7062020134	93
	MSV 25 SOS 00 220VAC	7062020135	93
	MSV 25 SES 00 24VDC	7062030132	93
	MSV 25 SES 00 24VAC	7062030133	93
	MSV 25 SES 00 110VAC	7062030134	93
	MSV 25 SES 00 220VAC	7062030135	93

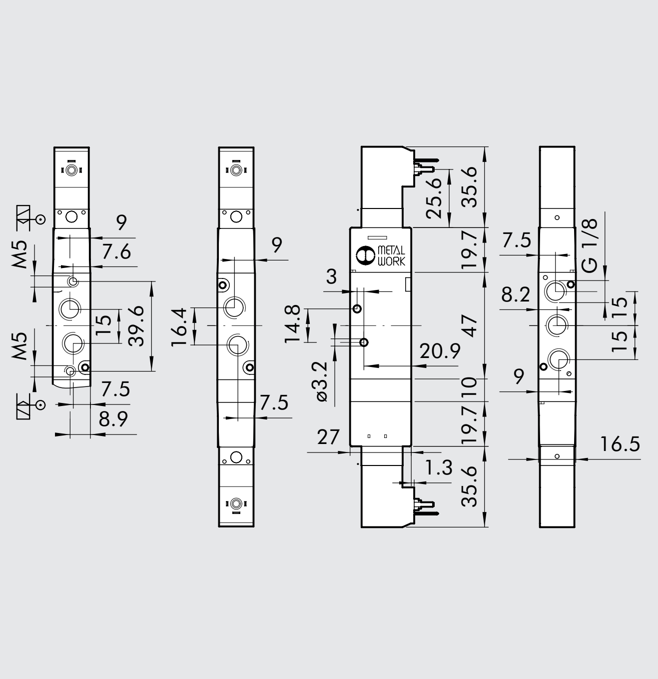
BISTABLE 5/2

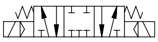
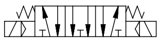
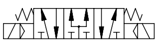
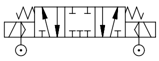
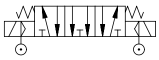
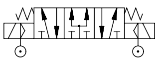


Symbol	Abbrev.	Code	Weight [g]
	MSV 25 SOB 00 24VDC	7062020112	124
	MSV 25 SOB 00 24VAC	7062020113	124
	MSV 25 SOB 00 110VAC	7062020114	124
	MSV 25 SOB 00 220VAC	7062020115	124
	MSV 25 SEB 00 24VDC	7062030112	125
	MSV 25 SEB 00 24VAC	7062030113	125
	MSV 25 SEB 00 110VAC	7062030114	125
	MSV 25 SEB 00 220VAC	7062030115	125

METAL WORK PNEUMATIC

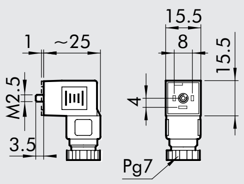
MONOSTABLE 5/3



Symbol	Abbrev.	Code	Weight [g]
	MSV 26 SOS CC 24VDC	7062020212	142
	MSV 26 SOS CC 24VAC	7062020213	142
	MSV 26 SOS CC 110VAC	7062020214	142
	MSV 26 SOS CC 220VAC	7062020215	142
	MSV 26 SOS OC 24VDC	7062020312	142
	MSV 26 SOS OC 24VAC	7062020313	142
	MSV 26 SOS OC 110VAC	7062020314	142
	MSV 26 SOS OC 220VAC	7062020315	142
	MSV 26 SOS PC 24VDC	7062020412	142
	MSV 26 SOS PC 24VAC	7062020413	142
	MSV 26 SOS PC 110VAC	7062020414	142
	MSV 26 SOS PC 220VAC	7062020415	142
	MSV 26 SES CC 24VDC	7062030212	143
	MSV 26 SES CC 24VAC	7062030213	143
	MSV 26 SES CC 110VAC	7062030214	143
	MSV 26 SES CC 220VAC	7062030215	143
	MSV 26 SES OC 24VDC	7062030312	143
	MSV 26 SES OC 24VAC	7062030313	143
	MSV 26 SES OC 110VAC	7062030314	143
	MSV 26 SES OC 220VAC	7062030315	143
	MSV 26 SES PC 24VDC	7062030412	143
	MSV 26 SES PC 24VAC	7062030413	143
	MSV 26 SES PC 110VAC	7062030414	143
	MSV 26 SES PC 220VAC	7062030415	143

ACCESSORIES: MACH 16 VALVES MSV, SOLENOID/PNEUMATIC

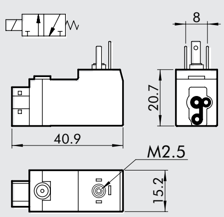
CONNECTOR 15 mm SHAPE C TO DIN 43650



Code	Description
W0970501021	CONNECTOR 15 mm SHAPE C DIN 43650
W0970501022	CONNECTOR 15 mm SHAPE C DIN 43650 LED 24V
W0970501025	CONNECTOR 15 mm SHAPE C DIN 43650 LED+VDR 24V

SPARE PARTS: COIL MACH 16

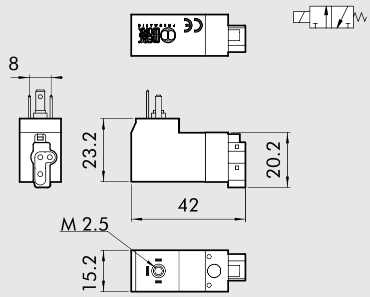
OLD



Code	Description
W4015101000	IN-LINE PILOT 24 VDC
W4015101010	IN-LINE PILOT 24 VAC 50/60 Hz
W4015101020	IN-LINE PILOT 110 VAC 50/60 Hz
W4015101030	IN-LINE PILOT 220 VAC 50/60 Hz

SPARE PARTS: COIL MACH 16

NEW



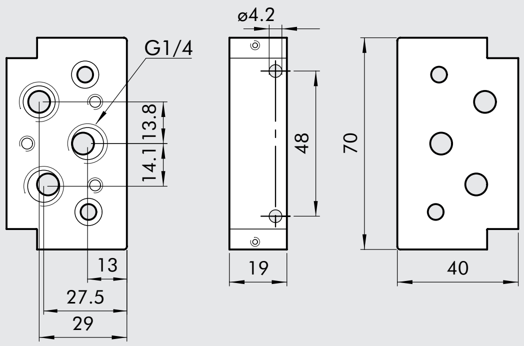
Code	Description
W4015301000	IN-LINE PILOT 24 VDC
W4015301010	IN-LINE PILOT 24 VAC 50/60 Hz
W4015301020	IN-LINE PILOT 110 VAC 50/60 Hz
W4015301030	IN-LINE PILOT 220 VAC 50/60 Hz

NB: if the pilot to be replaced bears the writing CE, you have to order among the NEW pilots, otherwise order among the OLD pilots

MANIFOLD BASES FOR MACH 16 VALVES

MACH 16 INPUT END-PLATE

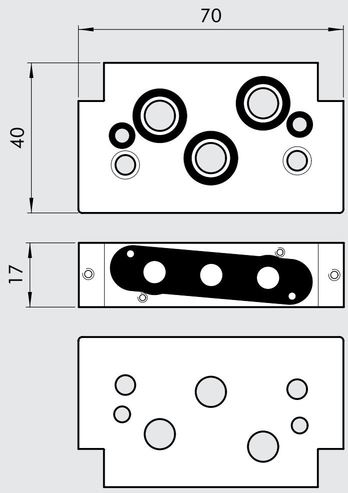
1



Code	Description	Weight [g]
0227100201	INPUT END-PLATE KIT M16/VDMA	125

MACH 16 MANIFOLD BASE

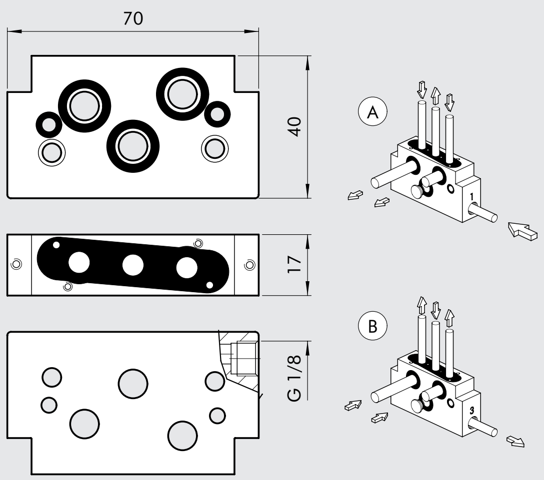
2



Code	Description	Weight [g]
0227100150	MANIFOLD BASE KIT M16	121

MACH 16 SEPARATE FEED MANIFOLD BASE

3

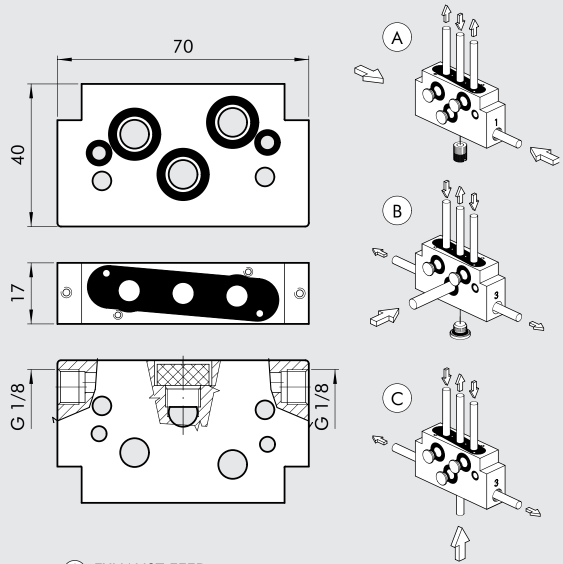


Ⓐ SEPARATE FEED
Ⓑ SEPARATE EXHAUST

Code	Description	Weight [g]
0227100301	MANIFOLD BASE KIT– SEPARATE FEED M16	119

MACH 16 EXHAUST FEED MANIFOLD BASE

4

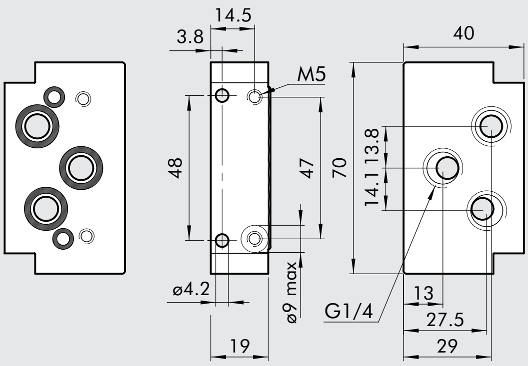


Ⓐ EXHAUST FEED
Ⓑ SEPARATE EXHAUSTS
Ⓒ SEPARATE FEED/EXHAUSTS

Code	Description	Weight [g]
0227100302	MANIFOLD BASE KIT– EXHAUST FEED	113

MACH 16 OUTPUT END-PLATE

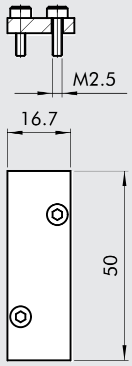
5



Code	Description	Weight [g]
0227100200	OUTPUT END-PLATE KIT M16/VDMA	122

BLANKING PLATE – UNUSED POSITION

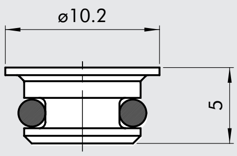
6



Code	Description	Weight [g]
0225004500	ACCESSORIES – BLANKING PLATE FOR MACH 16	18

INTERMEDIATE DIAPHRAGM

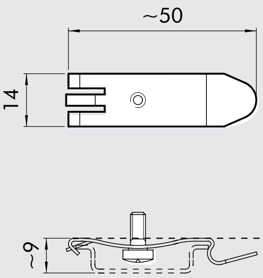
7



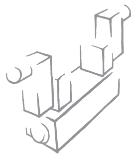
Code	Description	Weight [g]
0227100000	INTERMEDIATE DIAPHRAGM	1

CONNECTION BRACKET ON DIN BAR

8

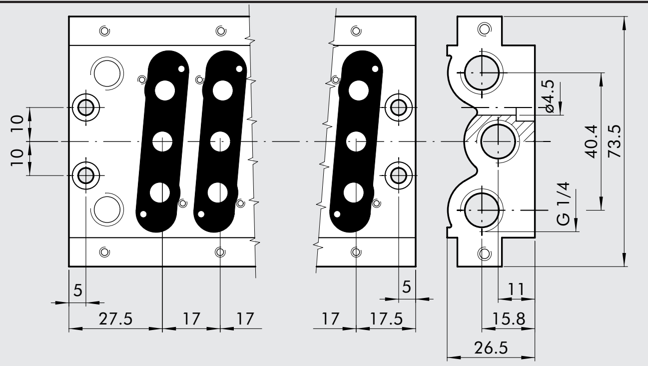


Code	Description	Weight [g]
0227300600	CONNECTION BRACKET ON DIN BAR	7



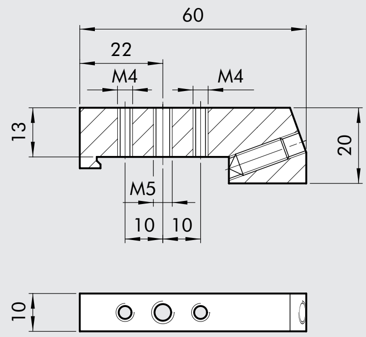
MULTIPLE BASES FOR MACH 16 VALVES

MULTIPLE BASE FOR MACH 16



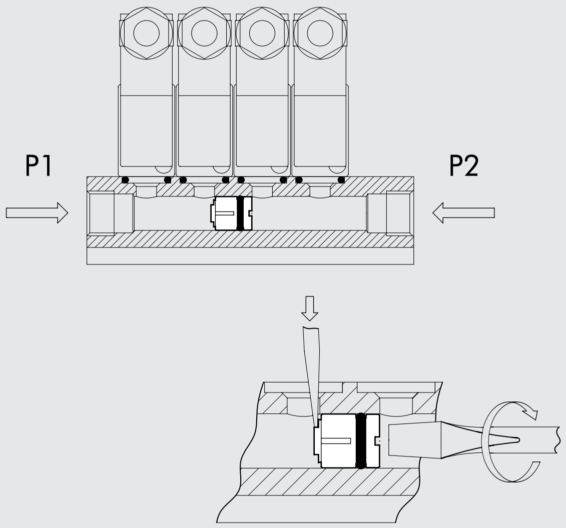
Code	Description	Posn.	Weight [g]
0225000201	ACC. BASE CVM.PN-08-02-0-000	2	180
0225000401	ACC. BASE CVM.PN-08-04-0-000	4	286
0225000601	ACC. BASE CVM.PN-08-06-0-000	6	390
0225000801	ACC. BASE CVM.PN-08-08-0-000	8	500
0225001001	ACC. BASE CVM.PN-08-10-0-000	10	613
0225001201	ACC. BASE CVM.PN-08-12-0-000	12	706

Ω BAR ADAPTER MULTIPLE BASES FOR MACH 16



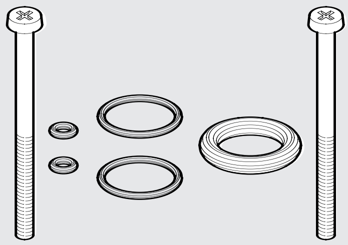
Code	Description	Weight [g]
0225004600	ACCESSORIES: OMEGA-ADAPTER MACH 16	46

INTERMEDIATE DIAPHRAGM



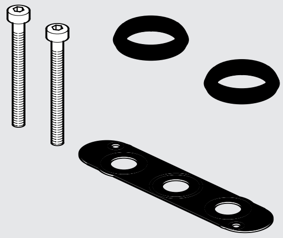
Code	Description	Weight [g]
0227100001	ACC. MULTIPLE BASE DIAPHRAGM	6

GASKET KIT



Code	Description	Weight [g]
0226007001	M16 MULTIPLE BASE GASKET KIT	5

KIT OF SPARE INTEGRATED GASKET



Code	Description	Weight [g]
0226007003	M16 MULTIPLE BASE GASKET KIT	5

2

Annex 3:
PLC S7-200 DATA SHEET

SIEMENS

SIMATIC S7-200 Data Sheet for EM231, EM232, and EM235

Description Order Number	EM231 Analog Input AI 4 x 12 Bits 6ES7 231–0HC20–0XA0	EM232 Analog Output AQ 2 x 12 Bits 6ES7 232–0HB20–0XA0	EM235 Analog Combo AI 4/AQ 1 x 12 Bits 6ES7 235–0KD20–0XA0	
	Input Specifications	Output Specifications	Input Specifications	Output Specifications
General Specifications				
Dimensions (W x H x D) Weight Power loss (dissipation)	71.2 mm x 80 mm x 62 mm 183 g 2 W	46 mm x 80 mm x 62 mm 148 g 2 W	71.2 mm x 80 mm x 62 mm 186 g 2 W	
Number of points reserved for this module	4 analog input points	2 analog output points	4 analog input points, 2 analog output points (actual physical points: 4 input, 1 output)	
Power Consumption From +5 VDC (from I/O bus) From L+ L+ voltage range, Class 2 or DC sensor supply	 10 mA 60 mA 20.4 to 28.8	 10 mA 70 mA (with both outputs at 20 mA) 20.4 to 28.8	 10 mA 60 mA (with output at 20 mA) 20.4 to 28.8	
LED indicator	24 VDC Power Supply Good, ON = no fault, OFF = no 24 VDC power	24 VDC Power Supply Good, ON = no fault, OFF = no 24 VDC power	24 VDC Power Supply Good, ON = no fault, OFF = no 24 VDC power	
Analog Input Specifications				
No. of Analog Input Points	4		4	
Isolation (Field side to logic circuit)	None		None	
Input type	Differential		Differential	
Input ranges Voltage (unipolar) Voltage (bipolar) Current	 0 to 10 V, 0 to 5 V ±5 V, ± 2.5 V 0 to 20 mA		 0 to 10 V, 0 to 5 V, 0 to 1 V, 0 to 500 mV, 0 to 100 mV, 0 to 50 mV ± 10 V, ± 5 V, ± 2.5 V, ± 1 V, ± 500 mV, ± 250 mV, ± 100 mV, ± 50 mV, ± 25 mV 0 to 20 mA	
Input Resolution Voltage (unipolar) Voltage (bipolar) Current	see Table 1		see Table 1	
Analog to digital conversion time	< 250 μs		< 250 μs	
Analog input step response	1.5 ms to 95%		1.5 ms to 95%	
Common mode rejection	40 dB, DC to 60 Hz		40 dB, DC to 60 Hz	
Common mode voltage	Signal voltage plus common mode voltage (must be ≤ 12 V)		Signal voltage plus common mode voltage (must be ≤ 12 V)	
Data word format Bipolar, full-scale range Unipolar, full-scale range	(see Table 2) –32000 to +32000 0 to 32000		(see Table 4) –32000 to +32000 0 to 32000	
Input impedance	≥10 mΩ		≥ 10 mΩ	
Input filter attenuation	–3 db @ 3.1 Khz		–3 db @ 3.1 Khz	
Maximum input voltage	30 VDC		30 VDC	
Maximum input current	32 mA		32 mA	
Resolution	12 bit A/D converter		12 bit A/D converter	

Description Order Number	EM231 Analog Input AI4x12 Bits 6ES7 231–0HC20–0XA0	EM232 Analog Output AQ2x12 Bits 6ES7 232–OHB20–0XA0	EM235 Analog Combo AI4/AQ 1 x 12 Bits 6ES7 235–0KD20–0XA0	
	Input Specifications	Output Specifications	Input Specifications	Output Specifications
Analog Output Specifications				
No. of Analog Output Points		2		1
Isolation (Field side to logic circuit		None		None
Signal range Voltage output Current output		 ± 10 V 0 to 20 mA		 ± 10 V 0 to 20 mA
Resolution, full-scale Voltage Current		 12 bits 11 bits		 12 bits 11 bits
Data word format Voltage Current		 –32000 to +32000 0 to +32000		 –32000 to +32000 0 to +32000
Accuracy Worst case, 0° to 55° C Voltage output Current output Typical, 25° C Voltage output Current output		 ± 2% of full-scale ± 2% of full-scale ± 0.5% of full-scale ± 0.5% of full-scale		 ± 2% of full-scale ± 2% of full-scale ± 0.5% of full-scale ± 0.5% of full-scale
Settling time Voltage output Current output		 100 μS 2 mS		 100 μS 2 mS
Maximum drive @ 24 V user supply Voltage output Current output		 5000 Ω maximum 500 Ω maximum		 5000 Ω maximum 500 Ω maximum

Table 1 EM231 and EM235 Specifications

Full Scale Input Range	Repeatability[1]		Mean (average) Accuracy [1,2,3,4]	
	% of Full Scale	Counts	% of Full Scale	Counts
EM231 Specifications				
0 to 5 V	± 0.075%	± 24	± 0.01%	± 32
0 to 20 mA				
0 to 10 V				
± 2.5 V		± 48	± 0.05%	
± 5 V				
EM235 Specifications				
0 to 50 mV	± 0.075%	± 24	± 0.25%	± 80
0 to 100 mV			± 0.2%	± 64
0 to 500 mV			± 0.05%	± 16
0 to 1 V				
0 to 5 V				
0 to 20 mA				
0 to 10 V				
± 25 mV	± 0.075%	± 48	± 0.25%	± 160
± 50 mV			± 0.2%	± 128
± 100 mV			± 0.1%	± 64
± 250 mV			± 0.05%	± 32
± 500 mV				
± 1 V				
± 2.5 V				
± 5 V				
± 10 V				

1 Measurements made after the selected input range has been calibrated.
2 The offset error in the signal near zero analog input is not corrected, and is not included in the accuracy specifications.
3 There is a channel-to-channel carryover conversion error, due to the finite settling time of the analog multiplexer. The maximum carryover error is 0.1% of the difference between channels.
4 Mean accuracy includes effects of non-linearity and drift from 0 to 55 degrees C.

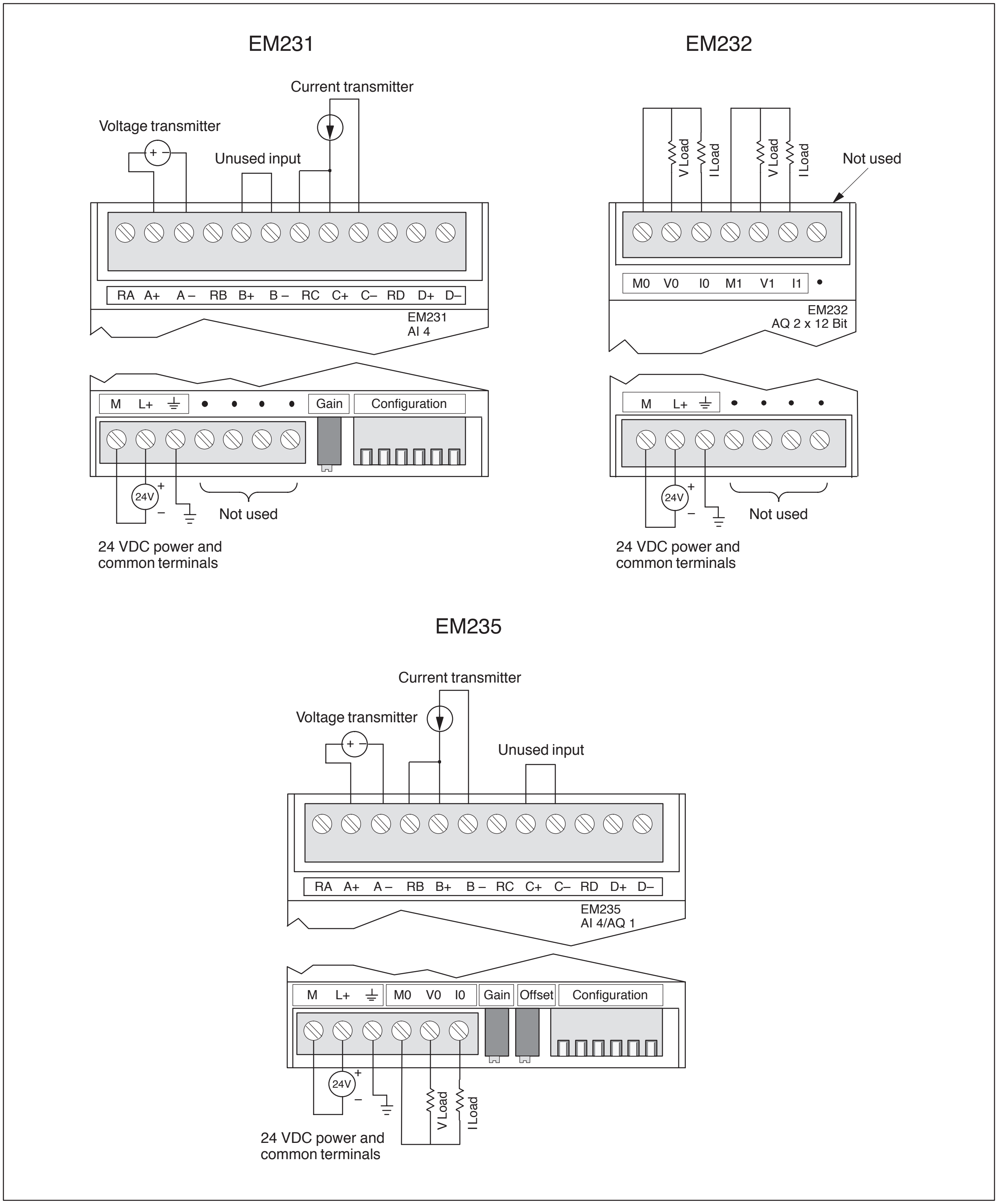


Figure 1 Connector Terminal Identification for Expansion Modules EM231, EM232, and EM235

Input Calibration

The calibration affects all four input channels, and there may be a difference in the readings between the channels after calibration.

To meet the specifications contained in this data sheet, you should enable analog input filters for all inputs of the module. Select 64 or more samples in calculating the average value. For more information about analog input filters, see the *S7-200 Programmable Controller System Manual*.

To calibrate the input, use the following steps.

1. Turn off the power to the module. Select the desired input range.
2. Turn on the power to the CPU and module. Allow the module to stabilize for 15 minutes.
3. Using a transmitter, a voltage source, or a current source, apply a zero value signal to one of the input terminals.
4. Read the value reported to the CPU by the appropriate input channel.
5. Adjust the OFFSET potentiometer until the reading is zero, or the desired digital data value.
6. Connect a full-scale value signal to one of the input terminals. Read the value reported to the CPU.
7. Adjust the GAIN potentiometer until the reading is 32000, or the desired digital data value.
8. Repeat OFFSET and GAIN calibration as required.

Calibration and Configuration Location for EM231 and EM235

The calibration potentiometer and configuration DIP switches are located on the right of the bottom terminal block of the module, as shown in Figure 2.

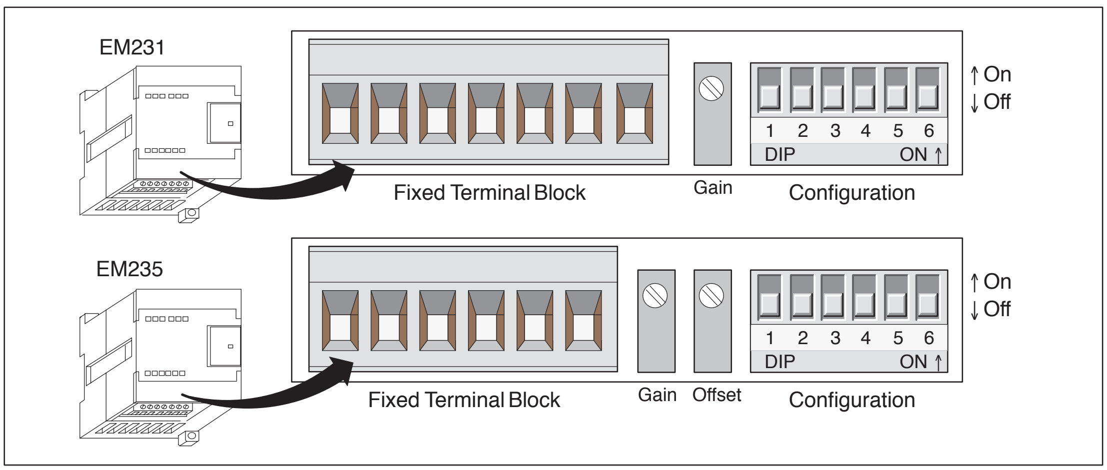


Figure 2 Calibration Potentiometer and Configuration DIP Switches for EM231 and EM235

Configuration for EM231

Table 2 shows how to configure the EM231 module using the configuration DIP switches. Switches 1, 2, and 3 select the analog input range. All inputs are set to the same analog input range. In this table, ON is closed, and OFF is open.

Table 2 EM231 Configuration Switch Table to Select Analog Input Range

Unipolar			Full-Scale Input	Resolution
SW1	**SW2**	**SW3**		
ON	OFF	ON	0 to 10 V	2.5 mV
	ON	OFF	0 to 5 V	1.25 mV
			0 to 20 mA	5 µA
Bipolar			**Full-Scale Input**	**Resolution**
SW1	**SW2**	**SW3**		
OFF	OFF	ON	± 5 V	2.5 mV
	ON	OFF	± 2.5 V	1.25 mV

Configuration for EM235

Table 3 shows how to configure the EM235 module using the configuration DIP switches. Switches 1 through 6 select the analog input range and resolution. All inputs are set to the same analog input range and format. Table 4 shows how to select for unipolar/bipolar (switch 6), gain (switches 4 and 5), and attenuation (switches 1, 2, and 3). In these tables, ON is closed, and OFF is open.

Table 3 EM235 Configuration Switch Table to Select Analog Input Range and Resolution

Unipolar						Full-Scale Input	Resolution
SW1	**SW2**	**SW3**	**SW4**	**SW5**	**SW6**		
ON	OFF	OFF	ON	OFF	ON	0 to 50 mV	12.5 μV
OFF	ON	OFF	ON	OFF	ON	0 to 100 mV	25 μV
ON	OFF	OFF	OFF	ON	ON	0 to 500 mV	125 μV
OFF	ON	OFF	OFF	ON	ON	0 to 1 V	250 μV
ON	OFF	OFF	OFF	OFF	ON	0 to 5 V	1.25 mV
ON	OFF	OFF	OFF	OFF	ON	0 to 20 mA	5 μA
OFF	ON	OFF	OFF	OFF	ON	0 to 10 V	2.5 mV
Bipolar						**Full-Scale Input**	**Resolution**
SW1	**SW2**	**SW3**	**SW4**	**SW5**	**SW6**		
ON	OFF	OFF	ON	OFF	OFF	±25 mV	12.5 μV
OFF	ON	OFF	ON	OFF	OFF	±50 mV	25 μV
OFF	OFF	ON	ON	OFF	OFF	±100 mV	50 μV
ON	OFF	OFF	OFF	ON	OFF	±250 mV	125 μV
OFF	ON	OFF	OFF	ON	OFF	±500 mV	250 μV
OFF	OFF	ON	OFF	ON	OFF	±1 V	500 μV
ON	OFF	OFF	OFF	OFF	OFF	±2.5 V	1.25 mV
OFF	ON	OFF	OFF	OFF	OFF	±5 V	2.5 mV
OFF	OFF	ON	OFF	OFF	OFF	±10 V	5 mV

Table 4 EM235 Configuration Switch Table to Select Unipolar/Bipolar, Gain, and Attenuation

EM235 Configuration Switches						Unipolar/Bipolar Select	Gain Select	Attenuation Select
SW1	**SW2**	**SW3**	**SW4**	**SW5**	**SW6**			
					ON	Unipolar		
					OFF	Bipolar		
			OFF	OFF			x1	
			OFF	ON			x10	
			ON	OFF			x100	
			ON	ON			invalid	
ON	OFF	OFF						0.8
OFF	ON	OFF						0.4
OFF	OFF	ON						0.2

Input Data Word Format for EM231 and EM235

Figure 3 shows where the 12-bit data value is placed within the analog input word of the CPU.

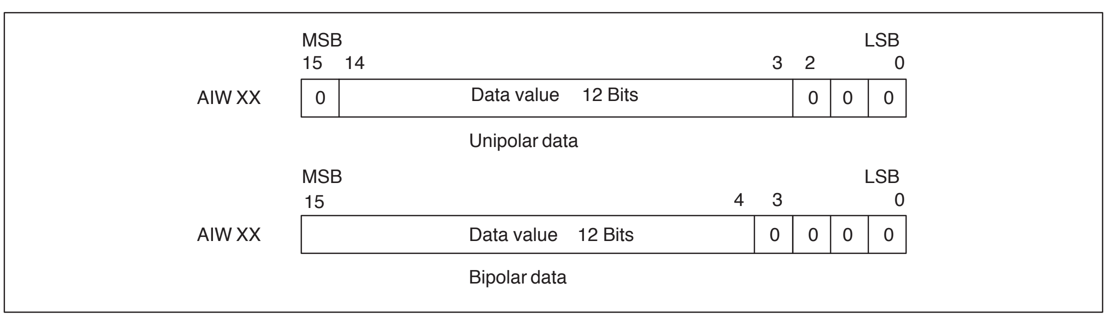


Figure 3 Input Data Word Format for EM231 and EM235

Note
The 12 bits of the analog-to-digital converter (ADC) readings are left-justified in the data word format. The MSB is the sign bit: zero indicates a positive data word value. In the unipolar format, the three trailing zeros cause the data word to change by a count of eight for each one-count change in the ADC value. In the bipolar format, the four trailing zeros cause the data word to change by a count of sixteen for each one count change in the ADC value.

Output Data Word Format for EM232 and EM235

Figure 4 shows where the 12-bit data value is placed within the analog output word of the CPU.

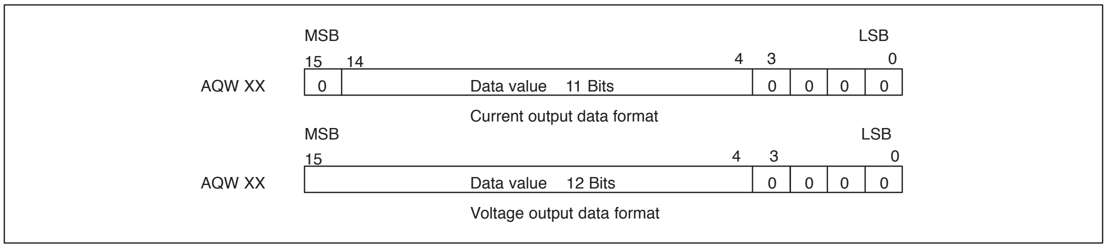


Figure 4 Output Data Word Format for EM232 and EM 235

Note

The 12 bits of the digital-to-analog converter (DAC) readings are left-justified in the output data word format. The MSB is the sign bit: zero indicates a positive data word value. The four trailing zeros are truncated before being loaded into the DAC registers. These bits have no effect on the output signal value.

Installation Guidelines

Use the following guidelines to ensure good accuracy and repeatability:

- Ensure that the 24-VDC Sensor Supply is free of noise and is stable.
- Use the shortest possible sensor wires.
- Use shielded twisted pair wiring for sensor wires.
- Terminate the shield at the Sensor location only.
- Short the inputs for any unused channels, as shown in Figure 1.
- Avoid bending the wires into sharp angles.
- Use wireways for wire routing.
- Avoid placing signal wires parallel to high-energy wires. If the two wires must meet, cross them at right angles.
- Ensure that the input signals are floating, or referenced to the external 24V common of the analog module.

Note

The EM231 and EM235 expansion modules are not recommended for use with thermocouples.

Definitions of the Analog Specifications

- Accuracy: deviation from the expected value on a given point.
- Resolution: the effect of an LSB change reflected on the output.

Agency Standards

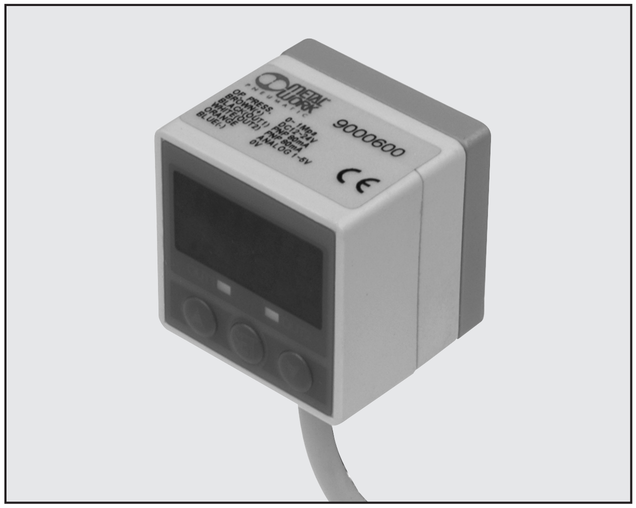
These modules adhere to the following agency standards: UL 508 Listed (Industrial Control Equipment); CSA C22.2 Number 142 Certified (Process Control Equipment); FM Class I, Division 2, Groups A, B, C, & D Hazardous Locations, T4A; VDE 0160: Electronic equipment for use in electrical power installations; European Community (CE) Low Voltage Directive 73/23/EEC, EN 61131–2: Programmable controllers – Equipment requirements; European Community (CE) EMC Directive 89/336/EEC

For more information about these standards, refer to the *S7-200 Programmable Controller System Manual.*

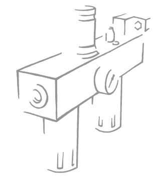
Annex 4:
DIGITAL PRESSURE MANOMETER DATA SHEET

DIGITAL PRESSURE SWITCH

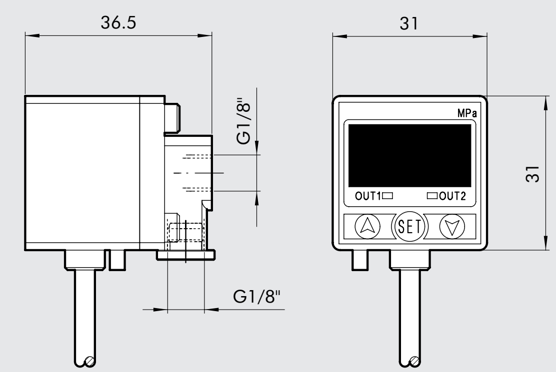
The digital pressure switch can be used to transmit electric pressure signals and also display the pressure instantly. The signal is transmitted for two settable pressure values and with an analogue voltage signal. The values are clearly displayed on a LED video and different parameters can be entered from the keypad. Hysteresis can be adjusted and the unit of measurement for pressure can be modified. Two compressed air ports are provided, one at the back and one on the bottom. The pressure switch comes with a threaded plug in the bottom port. If you wish to connect to this port, merely unscrew the plug and screw it into the back port.
A kit of accessories is provided for fixing to the top or wall, or to a panel.



TECHNICAL DATA		
Working pressure range	bar	0 ÷ 10
	Mpa	0 ÷ 1
Maximum admissible pressure	bar	15
	Mpa	1.5
Readable resolution:	bar	0.01
	Mpa	0.001
	kg/cm^2	0.01
	Psi	0.1
Power supply	VDC	12 ÷ 24 ±10%, max ripple10%
Current consumption	mA	≤ 55
Digital outputs		2 type PNP, with max current 80 mA, max voltage 30 VDC;
		residual voltage ≤ 1V (at 80 mA)
Digital output repeatability		≤ ±0,2 % full scale ±2 digits
Hysteresis		Adjustable or fixed at 3 digits for operation within a pressure range
Actuation response time	ms	≤ 2.5
Interference suppression selectable at		24 ms, 192 ms, 768 ms
Short-circuit protection at the outputs		Yes
LED 7 segment display		3 1/2 digit display (image update 5 times/ s)
Display accuracy		±2% full scale ±1 digit, ambient temperature 25° ±3°C
Indicators		green LED (output 1), red LED (output 2)
Analogue output		1-5 V ±2.5 %
		Linearity ≤ 1% full scale
Thermal characteristic		≤ ±2% full scale of the calibration pressure (at 25°C), in the temperature range 0 - 50°C
Compressed air ports		Two 1/8''
Power cable		2 m, with five 0.15 mm^2 wires, oil-resistant
Weight	g	135, including 2 m cable
AMBIENT CONDITIONS:		
Fluid		Filtered and unlubricated air, inert non-corrosive and non-explosive gas
Degree of protection		IP 40
Temperature range	°C	0 ÷ 50
Storage temperature	°C	-20 to +60, but without condensate or ice
Ambient humidity		35 ÷ 85% relative humidity; no condensate
Insulation voltage		1000 VAC for one minute between casing and cable
Resistance of Insulation		Min. 50 M Ohm minimo (at 500 VDC between casing and cable)
Vibration admitted		1.5 mm amplitude with scanning every minute from 10 to 55 Hz at 10 Hz, for 2 hours in each direction x, y and z
Impact		980 m/s^2 (100 g), 3 times in each direction x, y and z

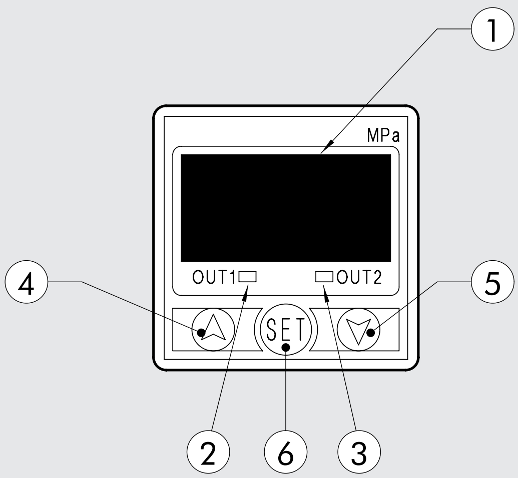


DIMENSIONS



Code	Description
9000600	DIGITAL PRESSURE SWITCH

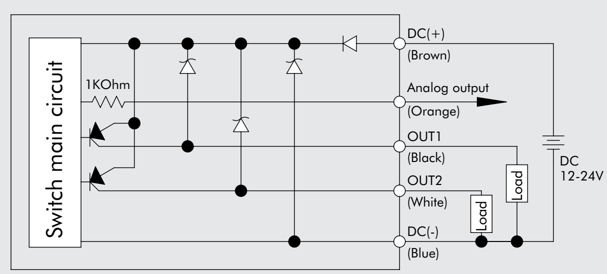
USER INTERFACE



① 3 1/2 digit display: showing the pressure reading, all setting information, and the error code
② Digital output 1: green LED
③ Digital output 2: red LED
④ Button: modifies the value of the selected parameter
⑤ Button: modifies the value of the selected parameter
⑥ Setting button: selects the parameter to modify

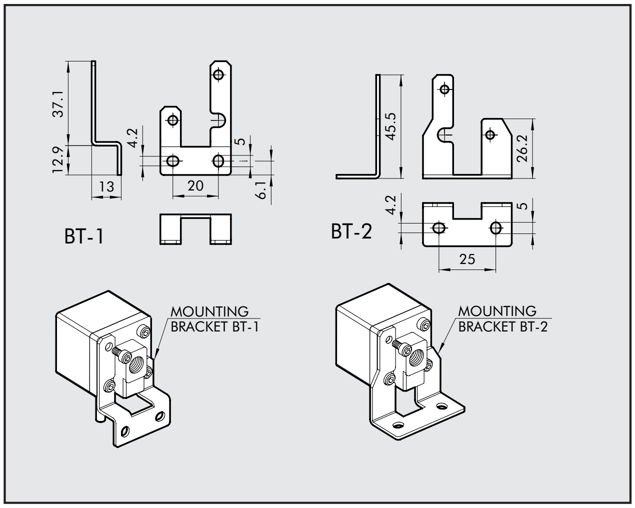
WIRING DIAGRAM

PNP output



ACCESSORIES

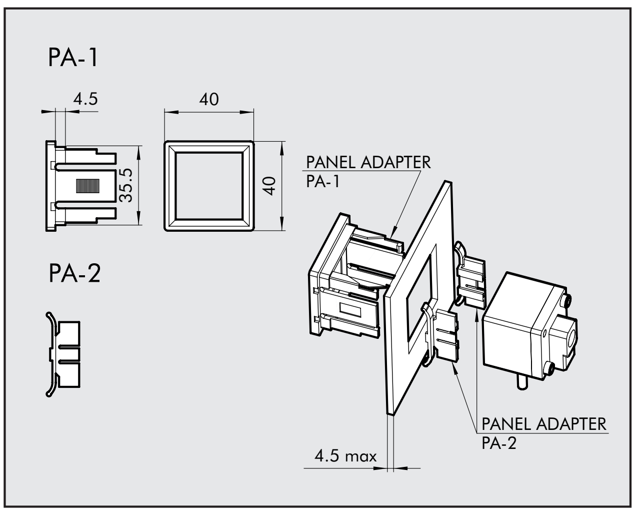
FIXING BRACKET KIT



Code	Description
9000601	KIT OF FIXING BRACKETS FOR DIGITAL PRESSURE SWITCHES

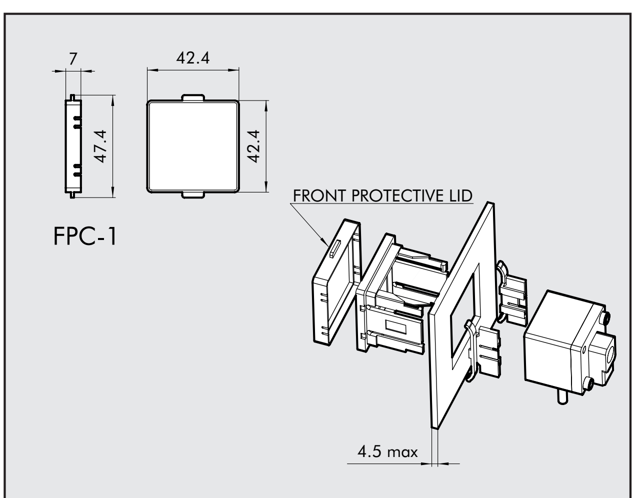
NB: Each kit contains a bracket for fixing on the back and one for fixing at the bottom.

PANEL FIXING KIT



Code	Description
9000602	KIT FOR PANEL FIXING FOR THE DIGITAL PRESSURE SWITCH

PANEL FIXING KIT WITH VIDEO SCREEN

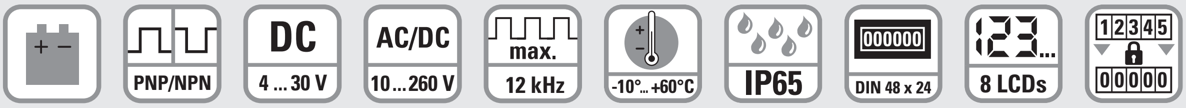


Code	Description
9000603	KIT FOR PANEL FIXING WITH SCREEN FOR THE DIGITAL PRESSURE SWITCH

Pulse counters, electronic

LCD pulse counters	Adding or subtracting (battery)	Codix 130

The Codix 130 is a simple battery powered pulse counter for fast and slow count pulses with 8-digit LCD display, optional backlighting, for NPN, PNP and high voltage applications.



Battery powered | Input type | Pulse voltage | Max. count frequency | Temperature range | High protection level | DIN front bezel | LCD display | Lockable reset

Powerful

- High quality LCD display with 8 mm high figures.
- Count direction adding and subtracting via control input.
- Battery life approx. 8 years.
- Optional display backlighting.
- Filter function for bounce-free counting with mechanical contacts.
- Count frequency max. 12 kHz.
- High protection level IP65.

Simple

- Screw terminals, RM 5 mm.
- Reset key can be enabled via “Reset Enable“ input.
- For positive and negative counting edges, depending on version.
- High voltage version for 10 … 260 V AC/DC voltage pulses.
- Large 8-digit LCD display with 8 mm high figures.

Order code

6.130 . 012 . 8 X X (a) (b)

(a) *Backlighting*
5 = without 1)
6 = with 1)

(b) *Input type: add/sub 2) – single-channel, adding or subtracting counting*

Input type	*INP A*				*INP B*			
0 1) = *add/sub* 2)	0 ... 0.7 V DC	count	NPN	7 kHz	0 ... 0.7 V DC	count	NPN	30 Hz
2 1) = *add/sub* 2)	4 ... 30 V DC	count	PNP	12 kHz	0 ... 0.7 V DC	count	NPN	30 Hz
3 1) = *add/sub* 2)	10 ... 260 V AC/DC	count	AC/DC	30 Hz	10 ... 260 V AC/DC	reset	AC/DC	–

Delivery specification
- Pulse counter
- Mounting clip
- Front bezel for screw mounting (T008181) 56 x 40 mm [2.20 x 1.57“], panel cut-out 50 x 25 mm [1.97 x 0.98“]
- Front bezel for clip mounting (T008180) 53 x 28 mm [2.09 x 1.10“], panel cut-out 50 x 25 mm [1.97 x 0.98“]
- Gasket
- Instruction manual, multilingual

1) Stock types.
2) Single-channel, adding or subtracting counting.

LCD pulse counters	Adding or subtracting (battery)	Codix 130

Accessories	Dimensions in mm [inch]		Order no.
Adapter front bezel, 72 x 36 [2.83 x 1.42]	for cut-out 68 x 33 [2.68 x 1.30] to cut-out 45 x 22.2 [1.77 x 0.87], for counters 48 x 24 [1.89 x 0.94], as set	black and silver anodised	**162704 Set**
Adapter front bezel, 48 x 48 [1.89 x 1.89]	for cut-out 45 x 45 [1.77 x 1.77] to cut-out 45 x 22.2 [1.77 x 0.87], with clip mounting for counters 48 x 24 [1.89 x 0.94]	black	**T008883**
Adapter front bezel, 60 x 50 [2.36 x 1.97]	for cut-out 54 x 29 [2.13 x 1.14] to cut-out 45 x 22.2 [1.77 x 0.87], with screw mounting and gasket for counters 48 x 24 [1.89 x 0.94]	black	**N003001**
Transparent cover, lockable, IP65	for cut-out 54 x 29 [2.13 x 1.14], for screw mounting to front bezel F1B or adapter front bezel N003001, for counters with cut-out 50 x 25 [1.97 x 0.98] or 45 x 22.2 [1.77 x 0.87]		**N003002**
Sealing cover type K1, IP65	suitable for front bezel 60 x 50 [2.36 x 1.97], for screw mounting of electromech. counters and via adapter front bezel N003001 for counters 48 x 24 [1.89 x 0.94]		**G008301**
Mounting frame with cut-out 50 x 25 [2.36 x 1.97] via separate adapter also for 45 x 22.2 [1.77 x 0.87]	for snap-on mounting on 35 [1.38] top-hat DIN rail, for counters 53 x 28 [2.09 x 1.10] and via separate adapter (T008180) for counters 48 x 24 [1.89 x 0.94]	chromated	**G300004**

Suitable gaskets, other accessories and installation examples for optional accessories can be found in chapter accessories or in the accessories section under: www.kuebler.com/accessories.

Technical data

General technical data		
Display		LCD, 8 digits, 8 mm [0.32"] high
Backlighting		external electrical source 24 V DC ±20 %, 50 mA
Modes		adding or subtracting (selectable)
Display range		-9999999 ... 99999999, with overflow display
Reset		manual and electrical
Working temperature		-10°C ... +55°C [+14°F ... +131°F] (non-condensing)
Operating temperature		-10°C ... +60°C [+14°F ... +140°F] (non-condensing)
Storage temperature		-20°C ... +70°C [-4°F ... +158°F]
Altitude		up to 2000 m [6562']

Electrical characteristics		
Power supply		internal lithium battery approx. 8 years at 20°C [68°F]
EMC standards		EN 55011 class B, EN 61000-6-2, EN 61000-6-3
Device safety	designed to protection class application area	EN 61010 part 1 2 pollution level 2
UL approval		file E128604

Mechanical characteristics	
Housing	dark grey RAL 7021
Protection	IP65 (front side)
Weight	approx. 50 g [1.76 oz]

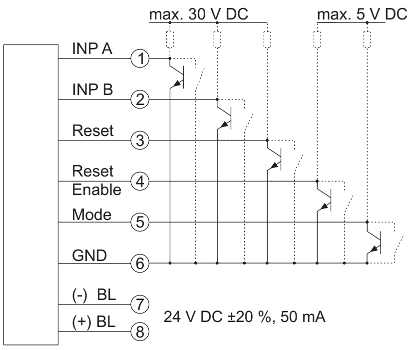
Counting inputs		
Counting input of the DC-versions (max. 30 V DC)		
slow counting input		max. 30 Hz NPN
fast counting input		max. 12 kHz (PNP), 7 kHz (NPN)
switching level NPN	LOW	0 ... 0.7 V DC
	HIGH	3 ... 30 V DC
switching level PNP	LOW	0 ... 0.7 V DC
	HIGH	4 ... 30 V DC
Counting input of the high voltage versions (10 ... 260 V DC/V AC)		
optocoupler input,		max. 30 Hz
min. pulse time		16 ms
switching level	LOW	0 ... 2 V AC/DC
	HIGH	10 ... 260 V AC/DC
Counting direction switching (only DC-version)		
mode		adding / subtracting
contact input		open collector NPN (switching at 0 V)
switching level NPN	LOW	0 ... 0.7 V DC
	HIGH	3 ... 5 V DC
Reset input (only DC and high voltage)		
minimum pulse time	DC	50 ms
	high voltage	16 ms
contact input DC – NPN	LOW	0 ... 0.7 V DC
	HIGH	3 ... 30 V DC
high voltage input		10 ... 260 V AC/DC
Electrical reset key locking (for DC and high voltage)		
contact input		open collector NPN (switching at 0 V)
switching level NPN	LOW	0 ... 0.7 V DC
	HIGH	3 ... 5 V DC

Pulse counters

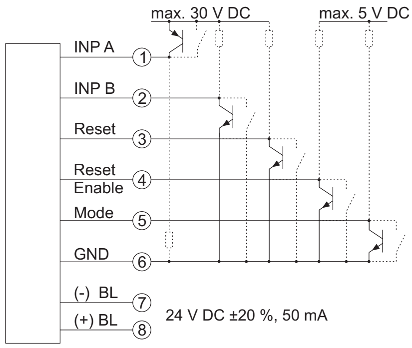
LCD pulse counters	Adding or subtracting (battery)	Codix 130

Terminal assignment

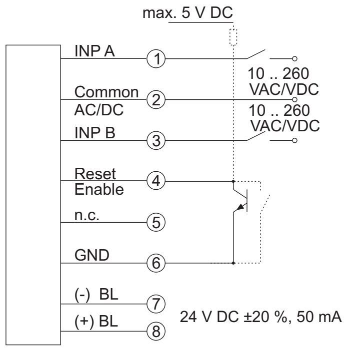
DC type: 6.130.012.8x0



DC type: 6.130.012.8x2



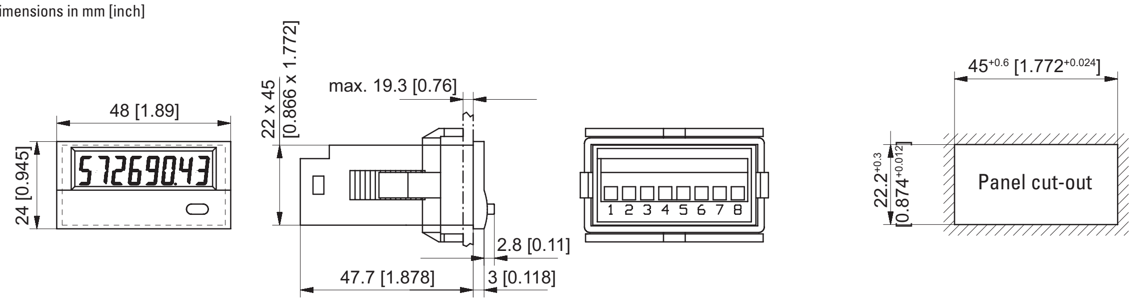
AC type: 6.130.012.8x3



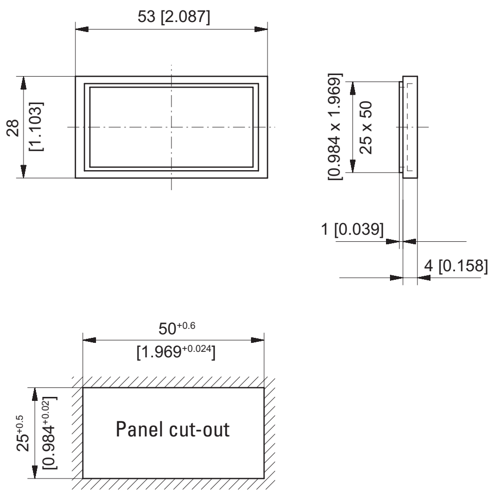
BL = backlighting

Dimensions

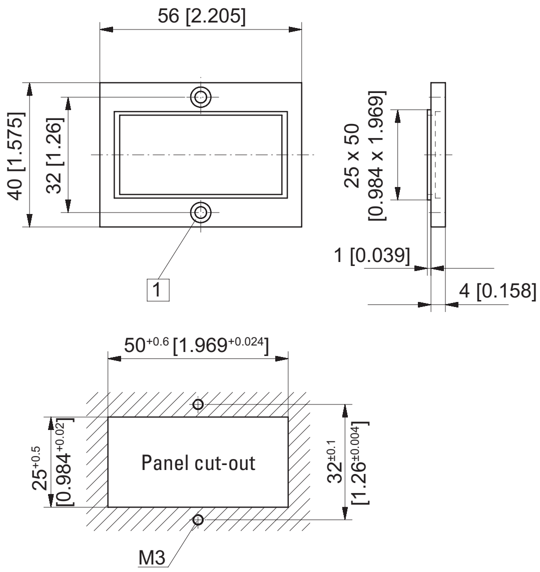
Dimensions in mm [inch]



Front bezel for clip mounting (included in delivery)



Front bezel for screw mounting (included in delivery)



1 Countersinking Af3, DIN 74

Annex 6:
95% AND 5% CONFIDENCE TABLES.

j*	Sample size n 1	2	3	4	5	6	7	8	9	10
1	.0500	.0253	.0170	.0127	.0102	.0085	.0074	.0065	.0057	.0051
2		.2236	.1354	.0976	.0764	.0629	.0534	.0468	.0410	.0368
3			.3684	.2486	.1893	.1532	.1287	.1111	.0978	.0873
4				.4729	.3426	.2713	.2253	.1929	.1688	.1500
5					.5493	.4182	.3413	.2892	.2514	.2224
6						.6070	.4793	.4003	.3449	.3035
7							.6518	.5293	.4504	.3934
8								.6877	.5709	.4931
9									.7169	.6058
10										.7411

5% ranks

j*	Sample size n 11	12	13	14	15	16	17	18	19	20
1	.0047	.0043	.0040	.0037	.0034	.0032	.0030	.0029	.0028	.0026
2	.0333	.0307	.0281	.0263	.0245	.0227	.0216	.0205	.0194	.0183
3	.0800	.0719	.0665	.0611	.0574	.0536	.0499	.0476	.0452	.0429
4	.1363	.1245	.1127	.1047	.0967	.0910	.0854	.0797	.0761	.0725
5	.2007	.1824	.1671	.1527	.1424	.1321	.1247	.1173	.1099	.1051
6	.2713	.2465	.2255	.2082	.1909	.1786	.1664	.1575	.1485	.1396
7	.3498	.3152	.2883	.2652	.2459	.2267	.2128	.1990	.1887	.1785
8	.4356	.3909	.3548	.3263	.3016	.2805	.2601	.2449	.2298	.2183
9	.5299	.4727	.4274	.3904	.3608	.3350	.3131	.2912	.2749	.2587
10	.6356	.5619	.5054	.4600	.4226	.3922	.3542	.3429	.3201	.3029
11	.7616	.6613	.5899	.5343	.4893	.4517	.4208	.3937	.3703	.3469
12		.7791	.6837	.6146	.5602	.5156	.4781	.4460	.4196	.3957
13			.7942	.7033	.6366	.5834	.5395	.5022	.4711	.4434
14				.8074	.7206	.6562	.6044	.5611	.5242	.4932
15					.8190	.7360	.6738	.6233	.5809	.5444
16						.8274	.7475	.6871	.6379	.5964
17							.8358	.7589	.7005	.6525
18								.8441	.7704	.7138
19									.8525	.7818
20										.8609

Ranges at 5% for values of the numerousness of the sample.

j^*	Sample size n 1	2	3	4	5	6	7	8	9	10
1	.9500	.7764	.6316	.5271	.4507	.3930	.3482	.3123	.2831	.2589
2		.9747	.8646	.7514	.6574	.5818	.5207	.4707	.4291	.3942
3			.9830	.9024	.8107	.7287	.6587	.5997	.5496	.5069
4				.9873	.9236	.8468	.7747	.7108	.6551	.6076
5					.9898	.9371	.8713	.8071	.7436	.6965
6						.9915	.9466	.8889	.8312	.7776
7							.9926	.9532	.9032	.8500
8								.9935	.9590	.9127
9									.9943	.9632
10										.9949

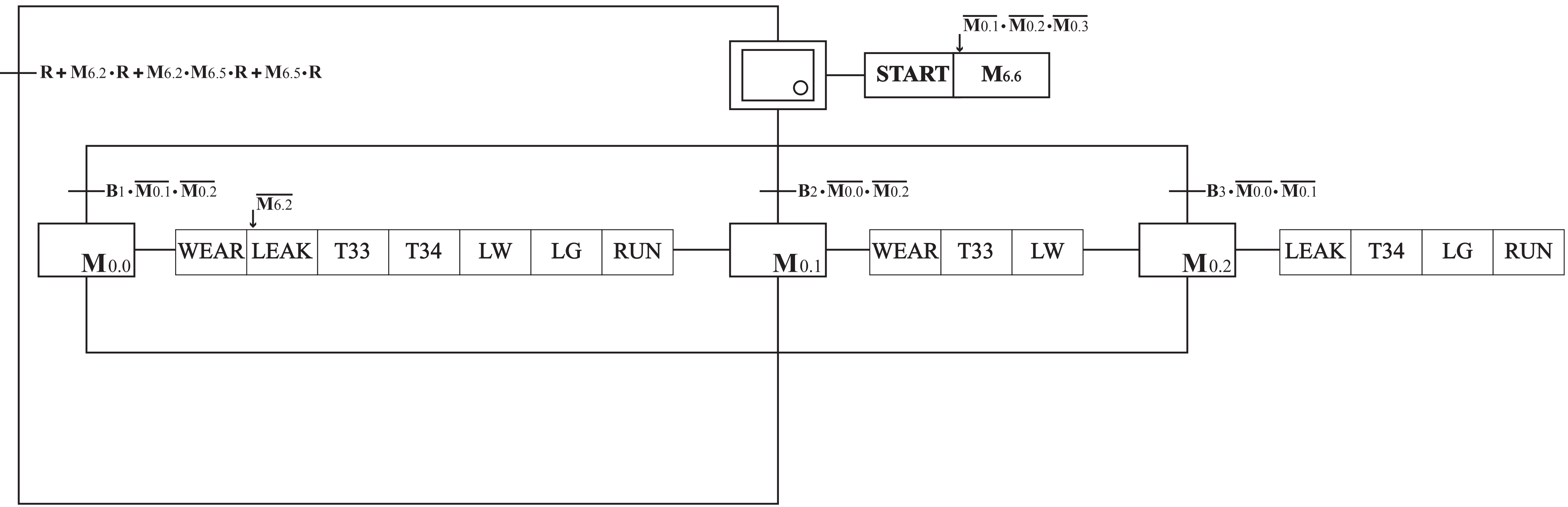
95% ranks

j^*	Sample size n 11	12	13	14	15	16	17	18	19	20
1	.2384	.2209	.2058	.1926	.1810	.1726	.1642	.1559	.1475	.1391
2	.3644	.3387	.3163	.2967	.2794	.2640	.2525	.2411	.2296	.2182
3	.4701	.4381	.4101	.3854	.3634	.3438	.3262	.3129	.2995	.2862
4	.5644	.5273	.4946	.4657	.4398	.4166	.3956	.3767	.3621	.3475
5	.6502	.6091	.5726	.5400	.5107	.4844	.4605	.4389	.4191	.4036
6	.7287	.6848	.6452	.6096	.5774	.5483	.5219	.4978	.4758	.4556
7	.7993	.7535	.7117	.6737	.6392	.6078	.5792	.5540	.5289	.5068
8	.8637	.8176	.7745	.7348	.6984	.6650	.6458	.6063	.5804	.5666
9	.9200	.8755	.8329	.7918	.7541	.7195	.6869	.6571	.6297	.6043
10	.9667	.9281	.8873	.8473	.8091	.7733	.7399	.7088	.6799	.6531
11	.9953	.9693	.9335	.8953	.8576	.8214	.7872	.7551	.7251	.6971
12		.9957	.9719	.9389	.9033	.8679	.8336	.8010	.7702	.7413
13			.9960	.9737	.9426	.9090	.8753	.8425	.8113	.7817
14				.9963	.9755	.9464	.9146	.8827	.8525	.8215
15					.9966	.9773	.9501	.9203	.8901	.8604
16						.9968	.9784	.9534	.9239	.8949
17							.9970	.9795	.9548	.9275
18								.9971	.9806	.9571
19									.9972	.9817
20										.9974

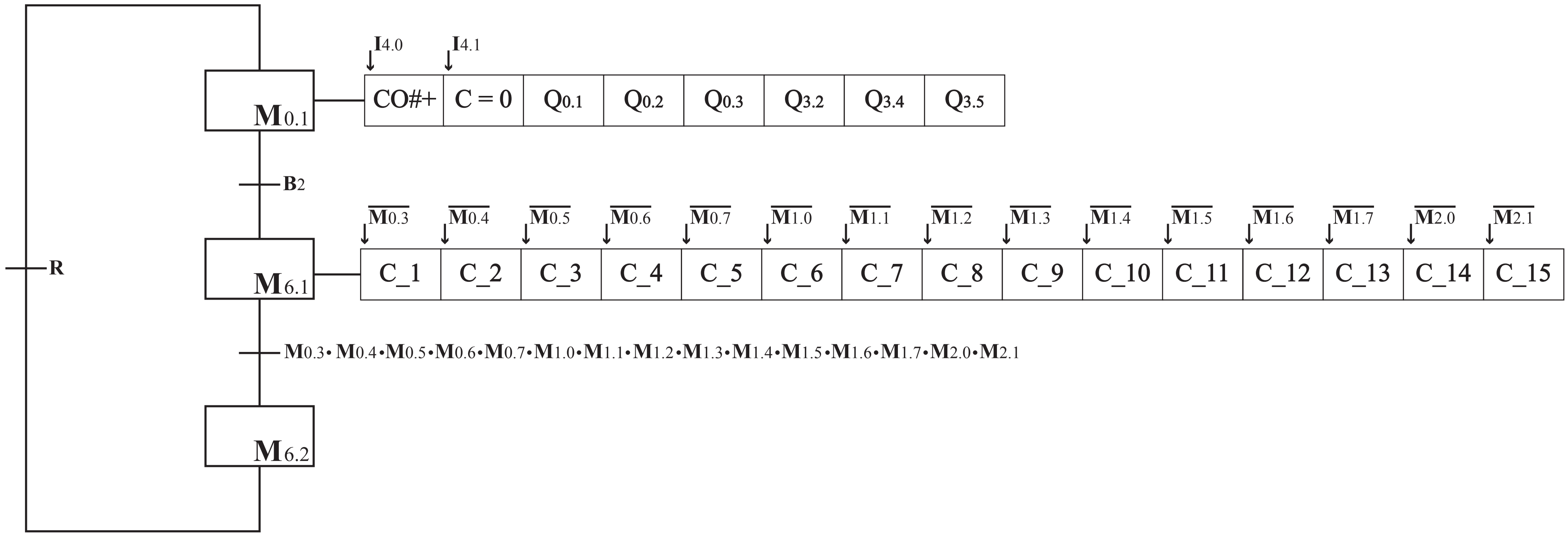
Ranges at 95% for values of the numerousness of the sample.

Annex 7:
COMPLETE GRAFCET IMPLEMENTATION

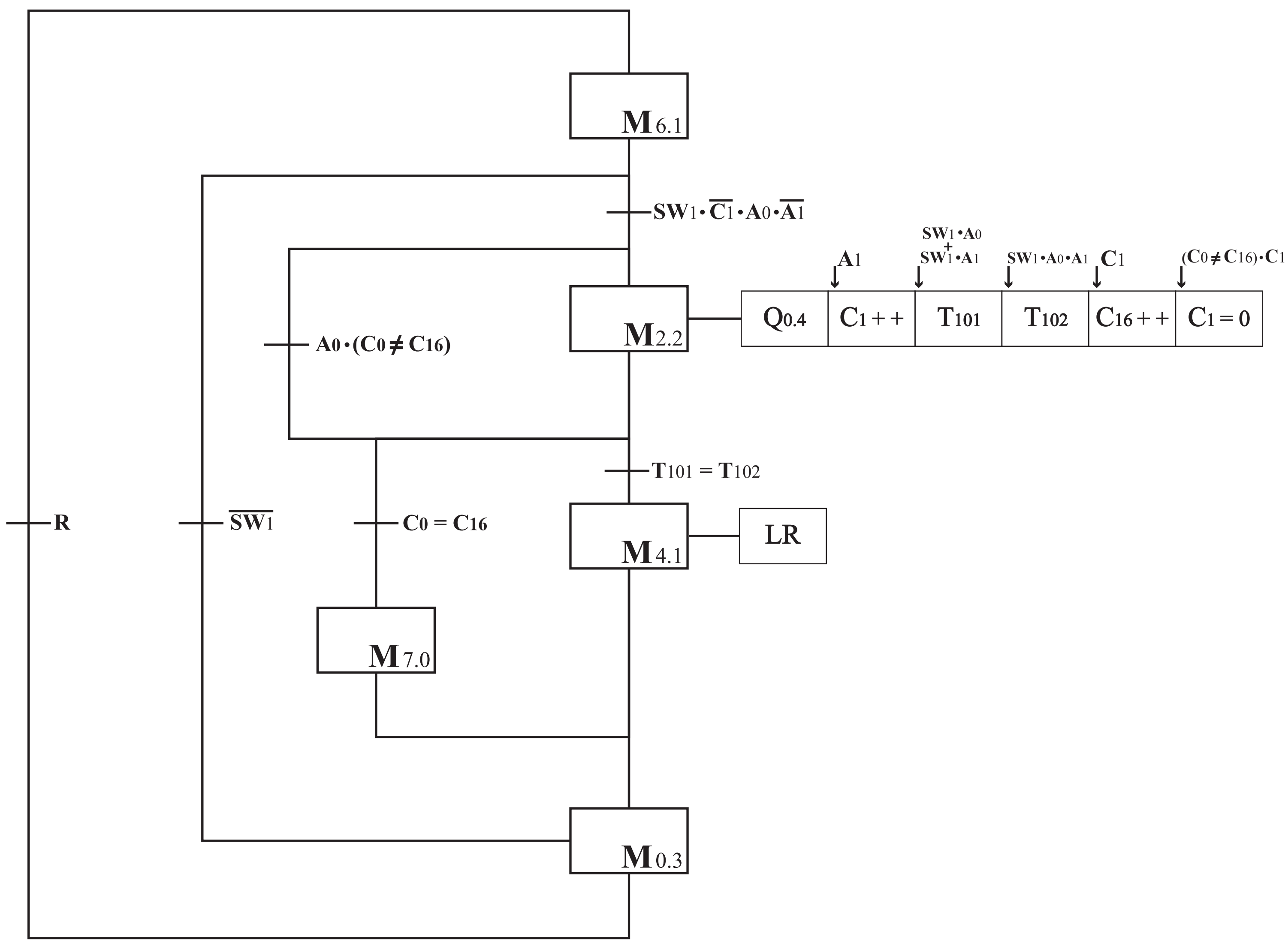
GRAFCET MAIN



GRAFCET WEAR

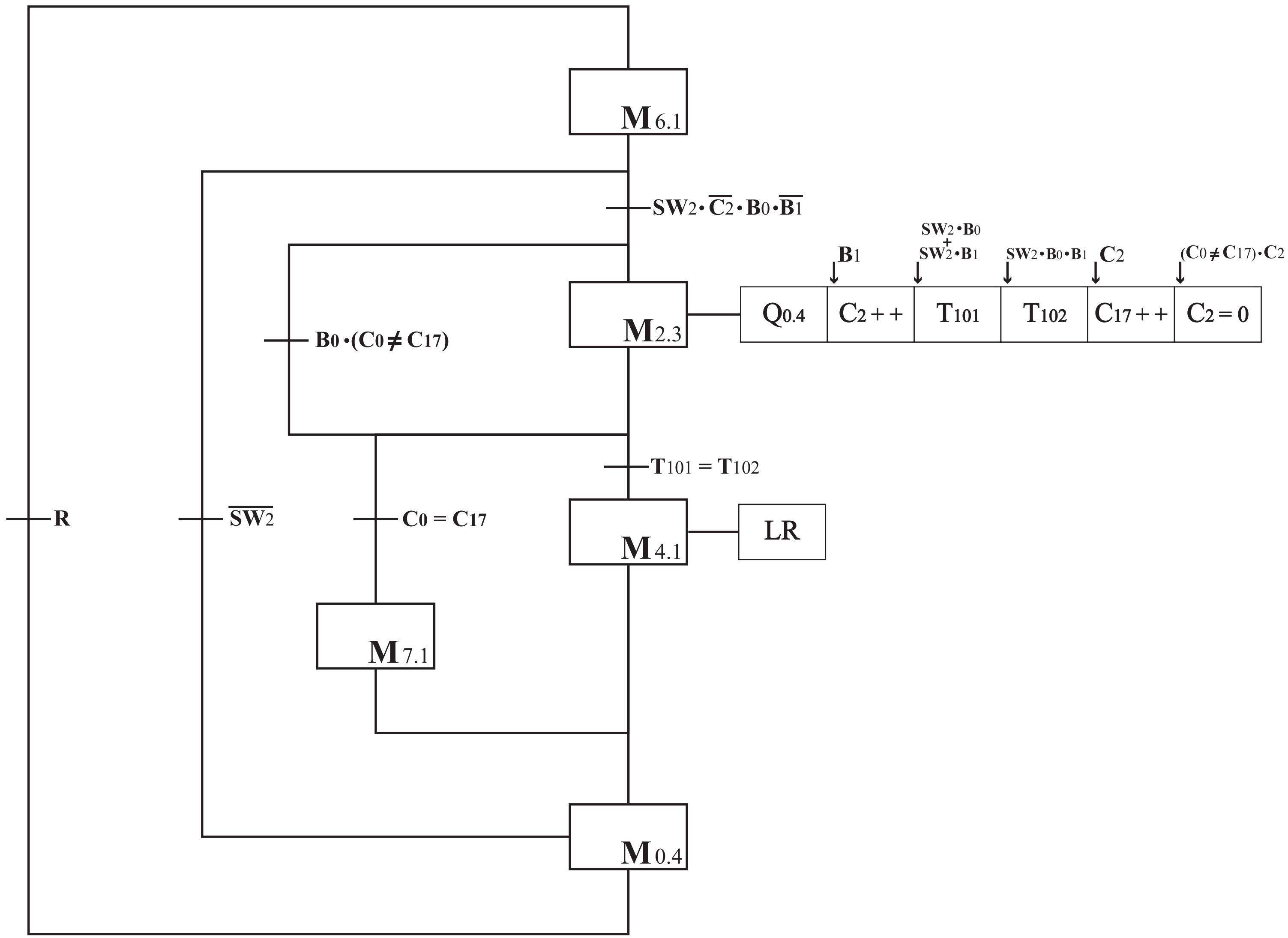


GRAFCET C_1



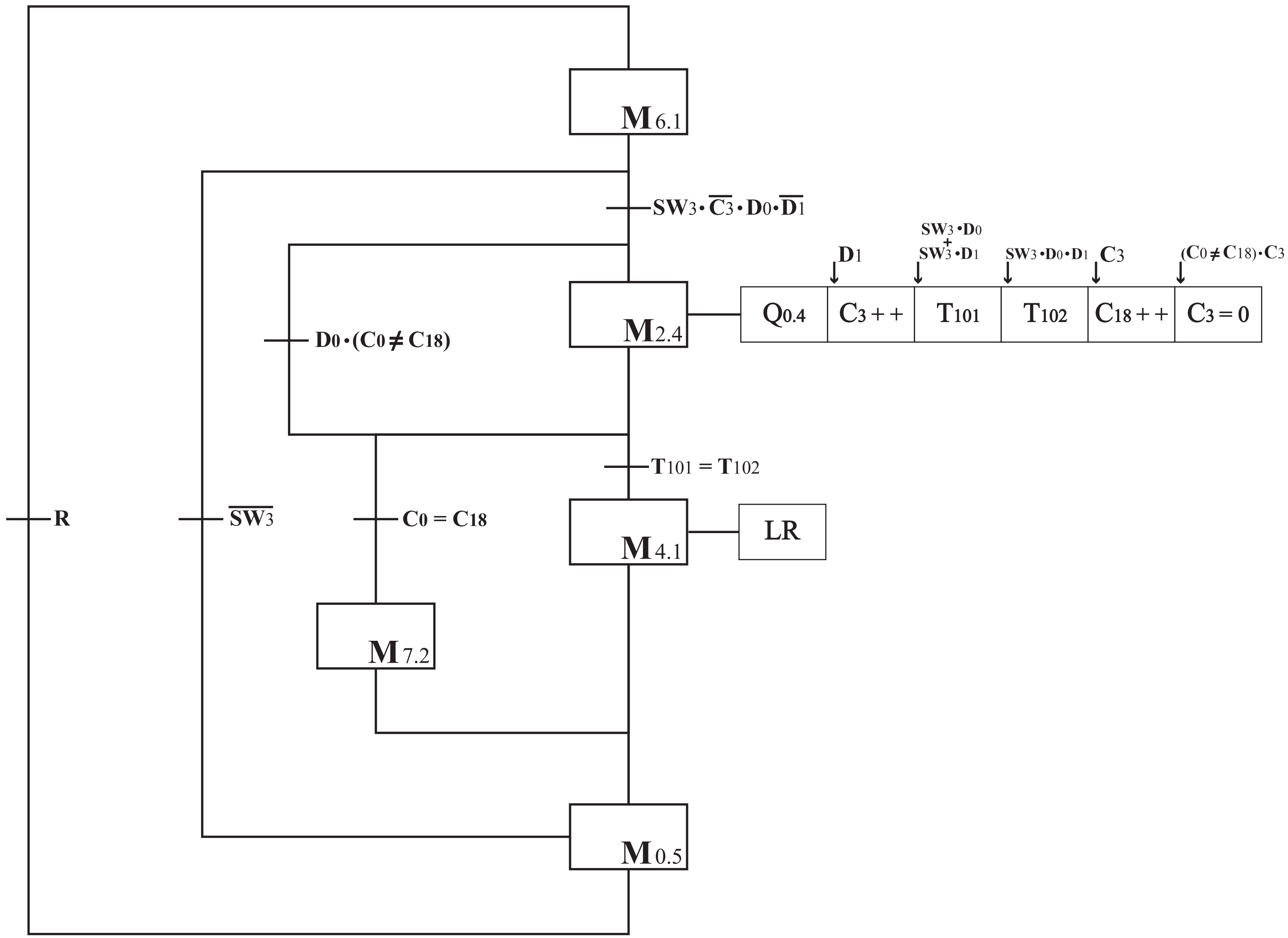
M6.1
SW1 • C̄1 • A0 • Ā1
M2.2
Q0.4
A1
C1 + +
SW1 • A0 + SW1 • A1
T101
SW1 • A0 • A1
T102
C1
C16 + +
(C0 ≠ C16) • C1
C1 = 0
A0 • (C0 ≠ C16)
T101 = T102
M4.1
LR
C0 = C16
M7.0
S̄W̄1
R
M0.3

GRAFCET C_2

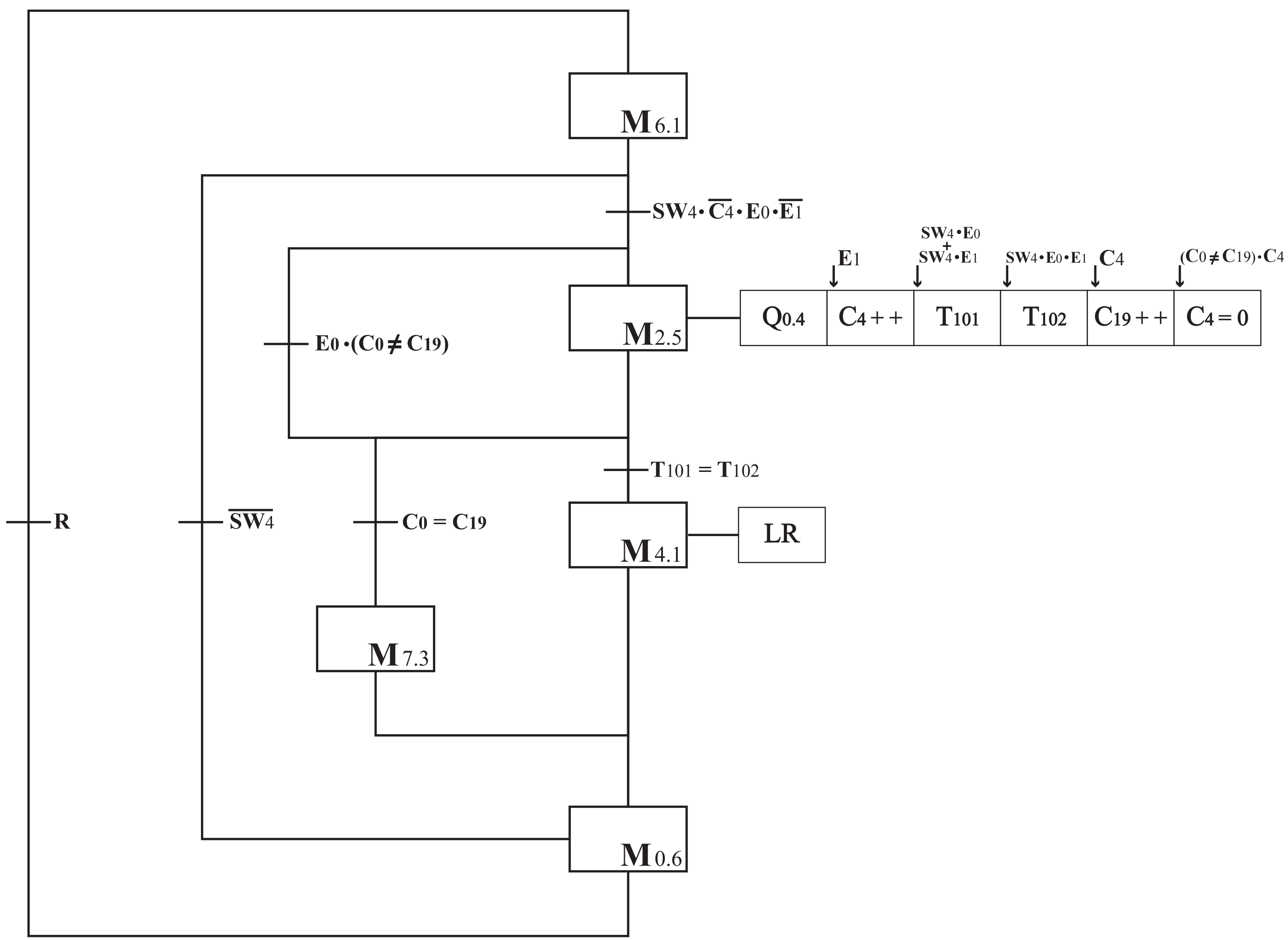


M6.1
SW2 • C2 • B0 • B1
M2.3
Q0.4
B1
C2 + +
SW2 • B0 + SW2 • B1
T101
SW2 • B0 • B1
T102
C2
C17 + +
(C0 ≠ C17) • C2
C2 = 0
B0 • (C0 ≠ C17)
T101 = T102
M4.1
LR
C0 = C17
M7.1
SW2
R
M0.4

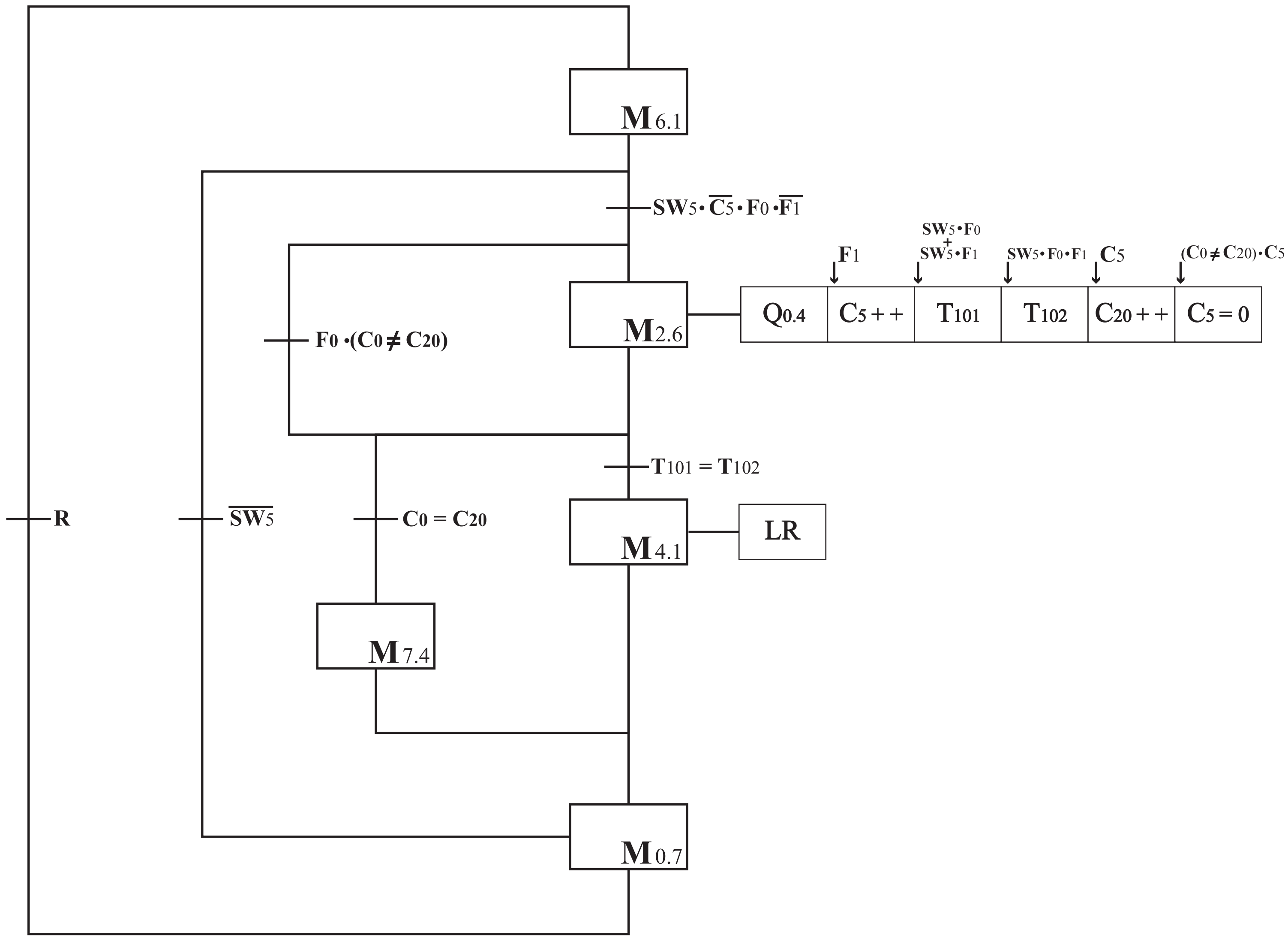
GRAFCET C_3


M6.1
SW3 · C̄3 · D0 · D̄1
M2.4
Q0.4
D1
C3 + +
SW3 •D0
+
SW3 •D1
T101
SW3 •D0 •D1
T102
C3
C18 + +
(C0 ≠ C18) • C3
C3 = 0
D0 • (C0 ≠ C18)
T101 = T102
M4.1
LR
R
SW̄3
C0 = C18
M7.2
M0.5

GRAFCET C_4

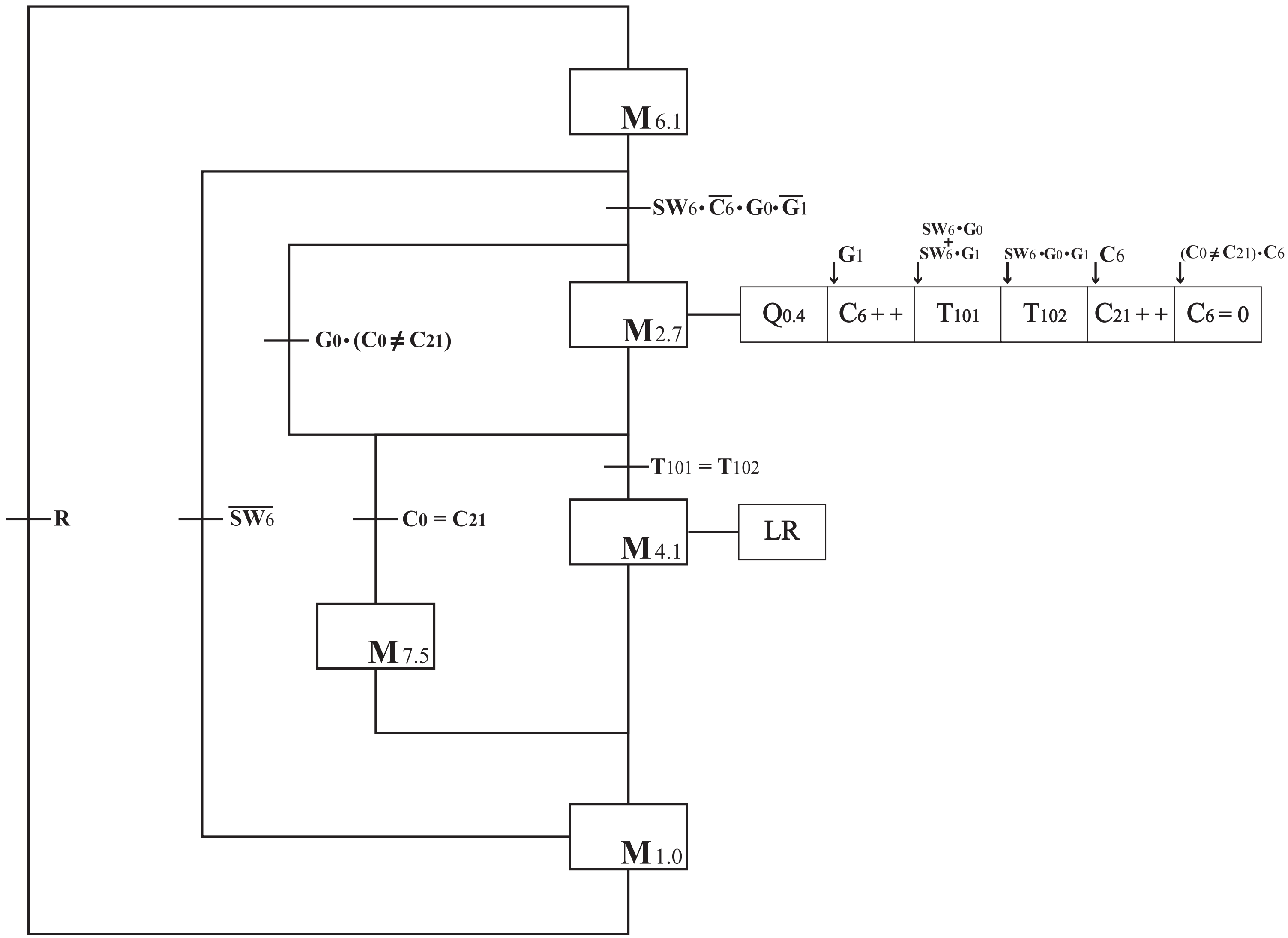

M6.1
SW4 • C̄4 • E0 • Ē1
M2.5
Q0.4
E1
C4 + +
SW4 • E0 + SW̄4 • E1
T101
SW4 • E0 • E1
T102
C4
C19 + +
(C0 ≠ C19) • C4
C4 = 0
E0 • (C0 ≠ C19)
T101 = T102
M4.1
LR
C0 = C19
M7.3
SW̄4
R
M0.6

GRAFCET C_5

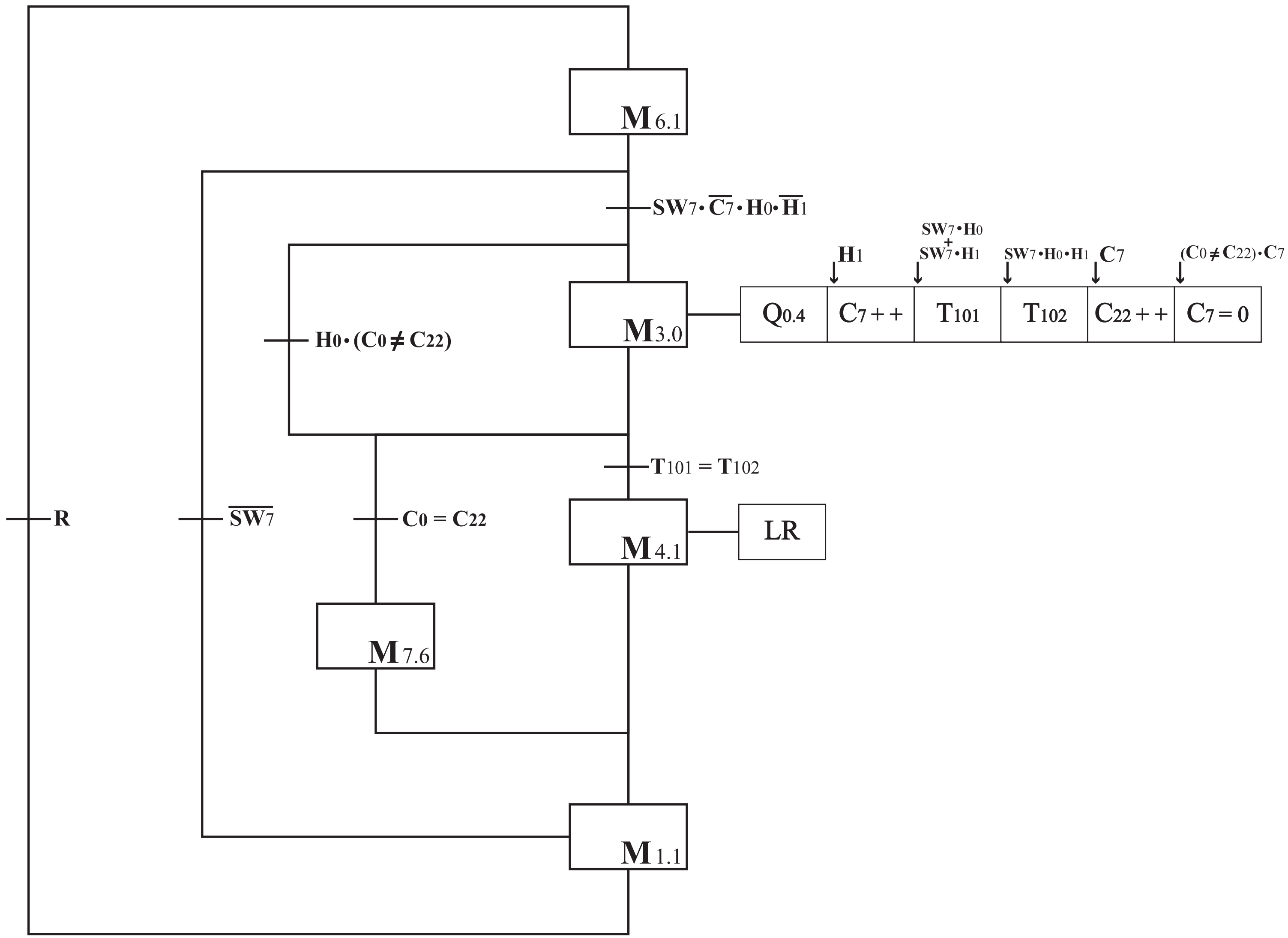


M6.1
SW5 • C5 • F0 • F1
M2.6
Q0.4
F1
C5 + +
SW5 • F0 + SW5 • F1
T101
SW5 • F0 • F1
T102
C5
C20 + +
(C0 ≠ C20) • C5
C5 = 0
F0 • (C0 ≠ C20)
T101 = T102
M4.1
LR
C0 = C20
M7.4
SW5
R
M0.7

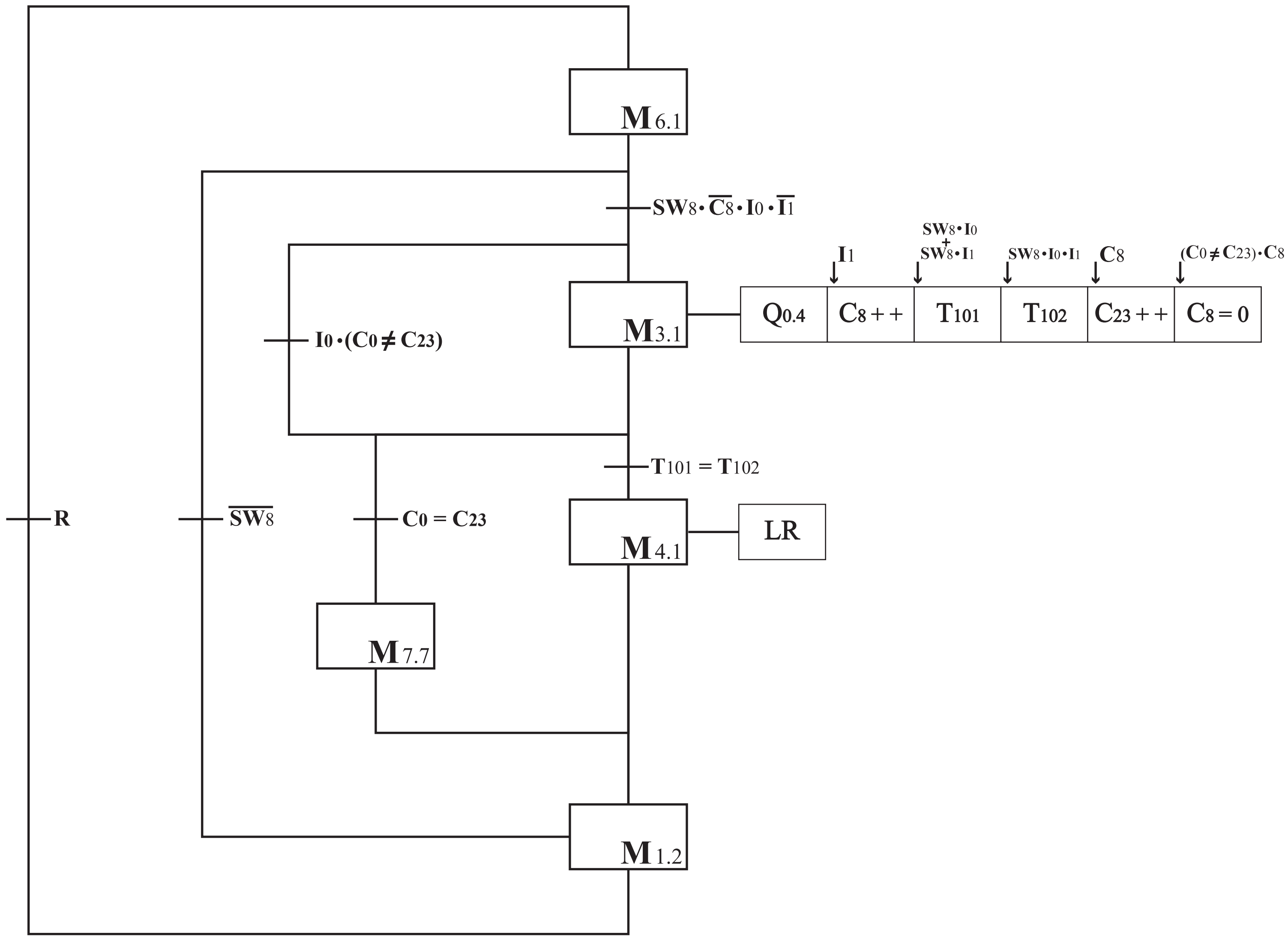
GRAFCET C_6


M6.1
SW6·C6·G0·G1
G1
SW6·G0
+
SW6·G1
SW6·G0·G1
C6
(C0≠C21)·C6
M2.7
Q0.4
C6++
T101
T102
C21++
C6=0
G0·(C0≠C21)
T101 = T102
R
SW6
C0 = C21
M4.1
LR
M7.5
M1.0

GRAFCET C_7

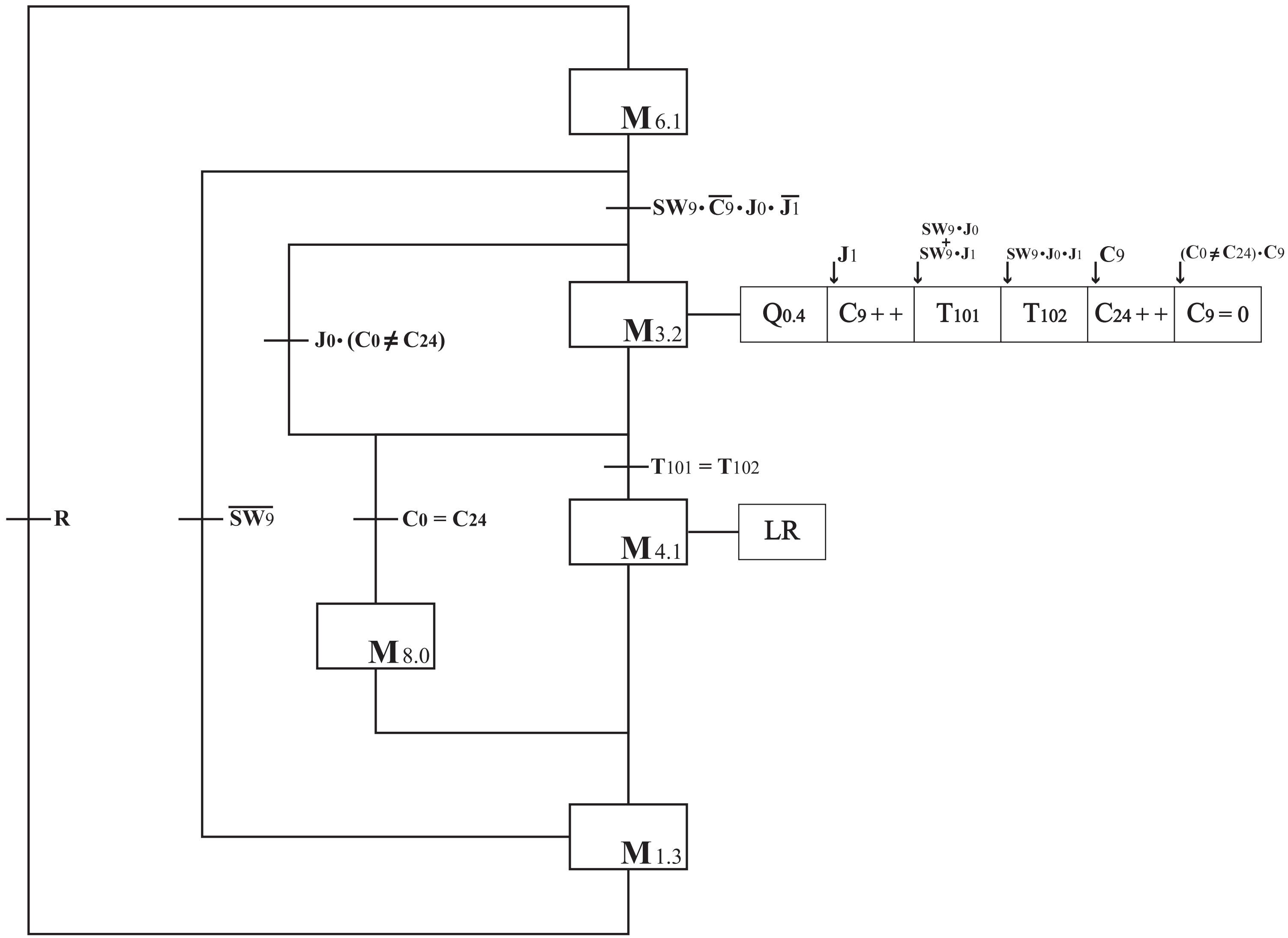

M6.1
SW7 · C̄7 · H0 · H̄1
M3.0
Q0.4
H1
C7 + +
SW7 · H0 + SW7 · H1
T101
SW7 · H0 · H1
T102
C7
C22 + +
(C0 ≠ C22) · C7
C7 = 0
H0 · (C0 ≠ C22)
T101 = T102
M4.1
LR
R
S̄W̄7
C0 = C22
M7.6
M1.1

GRAFCET C_8

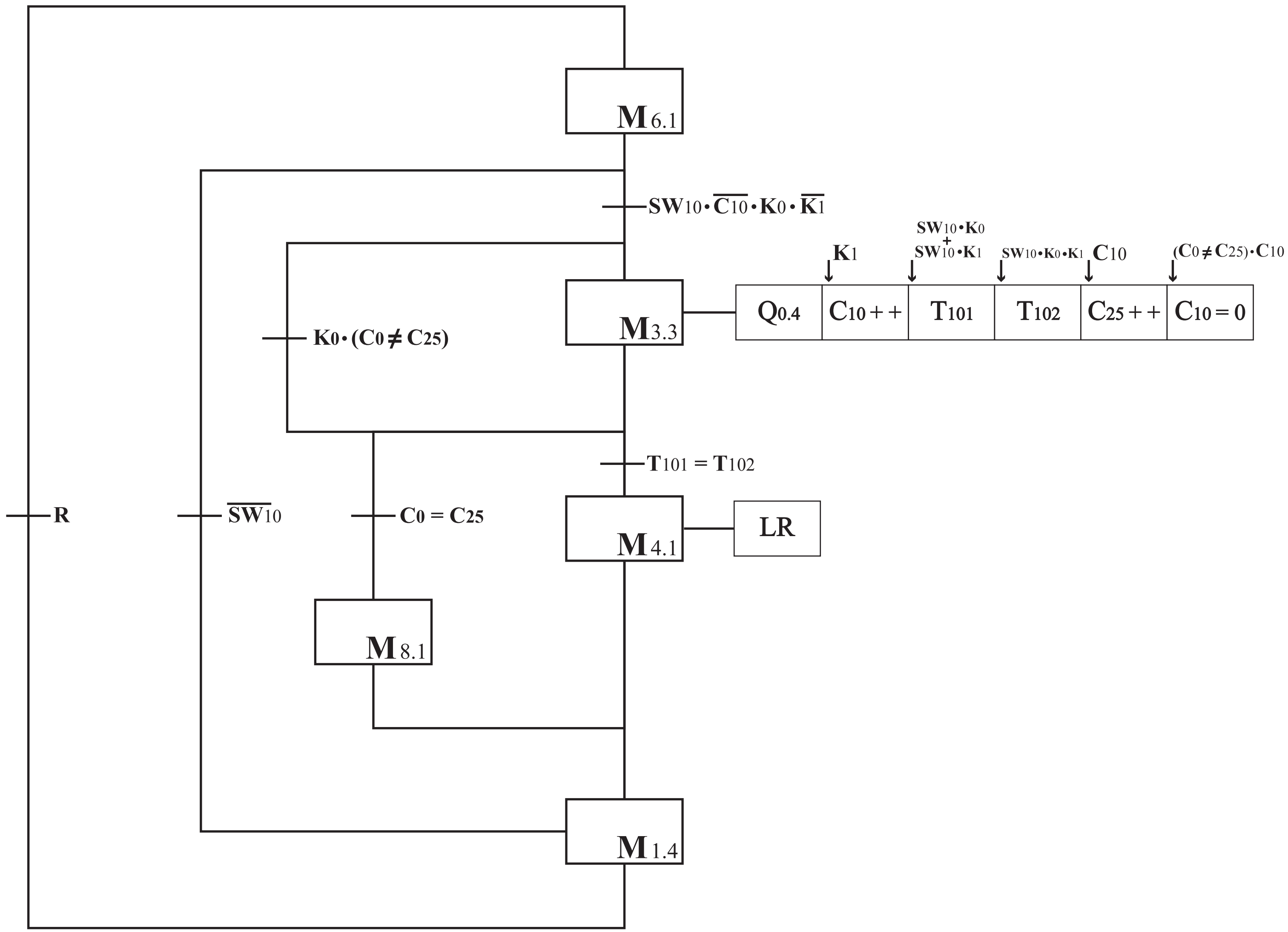


M6.1
SW8 • C̄8 • I0 • Ī1
M3.1
Q0.4
I1
C8 + +
SW8 • I0
+
SW8 • I1
T101
SW8 • I0 • I1
T102
C8
C23 + +
(C0 ≠ C23) • C8
C8 = 0
I0 • (C0 ≠ C23)
T101 = T102
M4.1
LR
C0 = C23
M7.7
R
S̄W̄8
M1.2

GRAFCET C_9

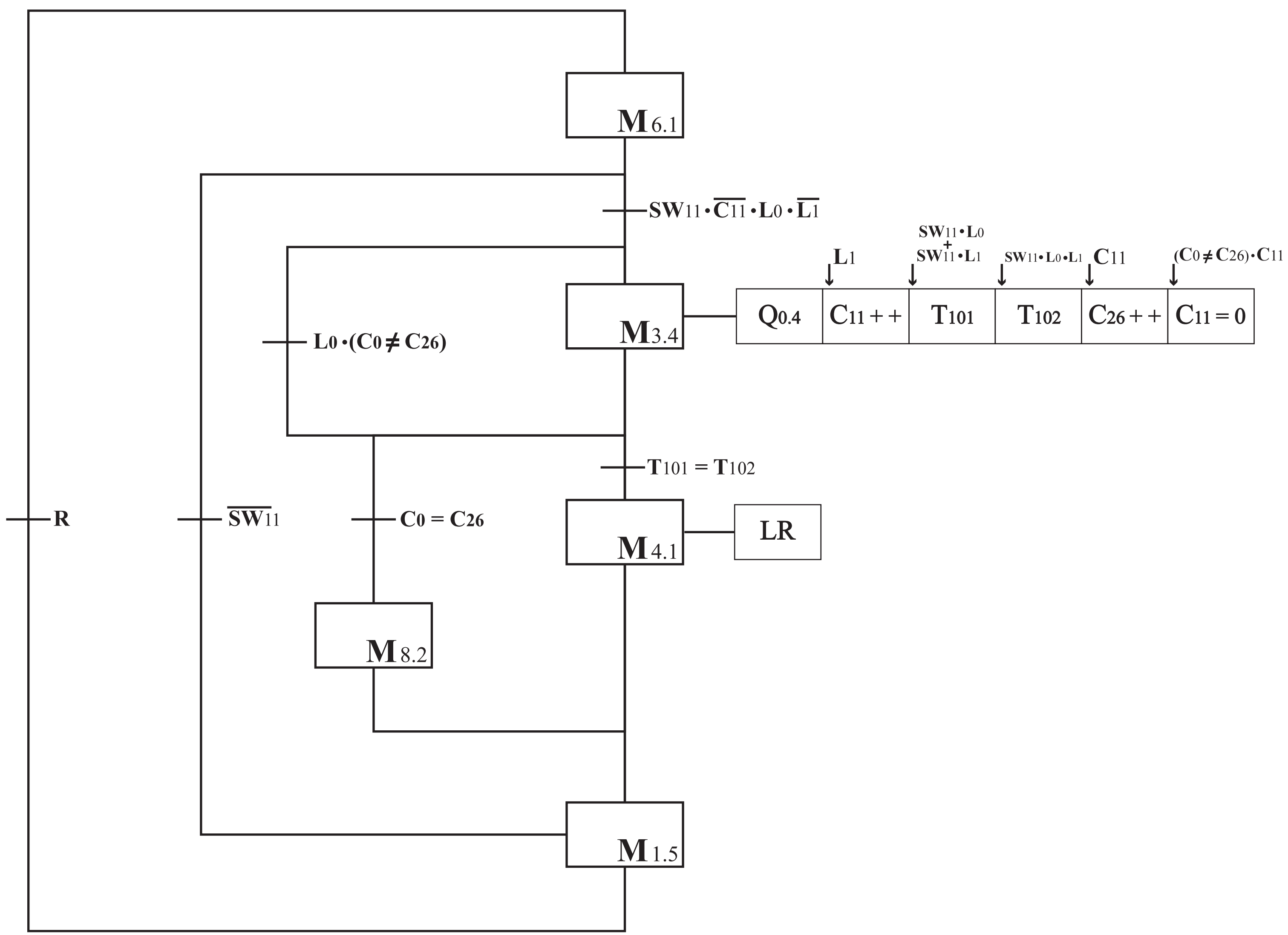

M6.1
SW9 • C9 • J0 • J1
M3.2
Q0.4
J1
C9 + +
SW9 • J0 + SW9 • J1
T101
SW9 • J0 • J1
T102
C9
C24 + +
(C0 ≠ C24) • C9
C9 = 0
J0 • (C0 ≠ C24)
T101 = T102
M4.1
LR
C0 = C24
M8.0
SW9
R
M1.3

GRAFCET C_10



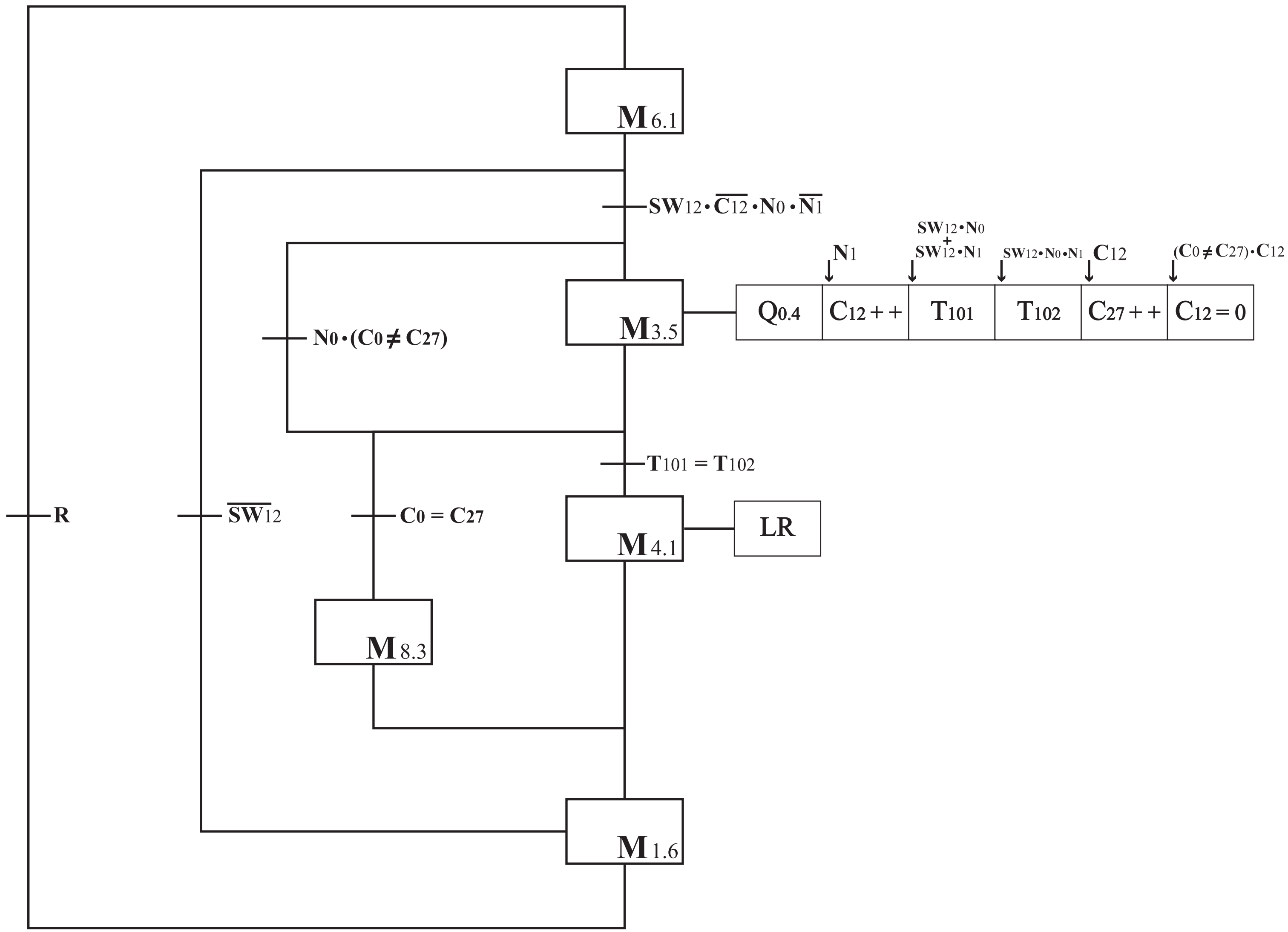
M6.1
SW10 • C10 • K0 • K1
M3.3
Q0.4
K1
C10 + +
SW10 • K0 + SW10 • K1
T101
SW10 • K0 • K1
T102
C10
C25 + +
(C0 ≠ C25) • C10
C10 = 0
K0 • (C0 ≠ C25)
T101 = T102
M4.1
LR
R
SW10
C0 = C25
M8.1
M1.4

GRAFCET C_11

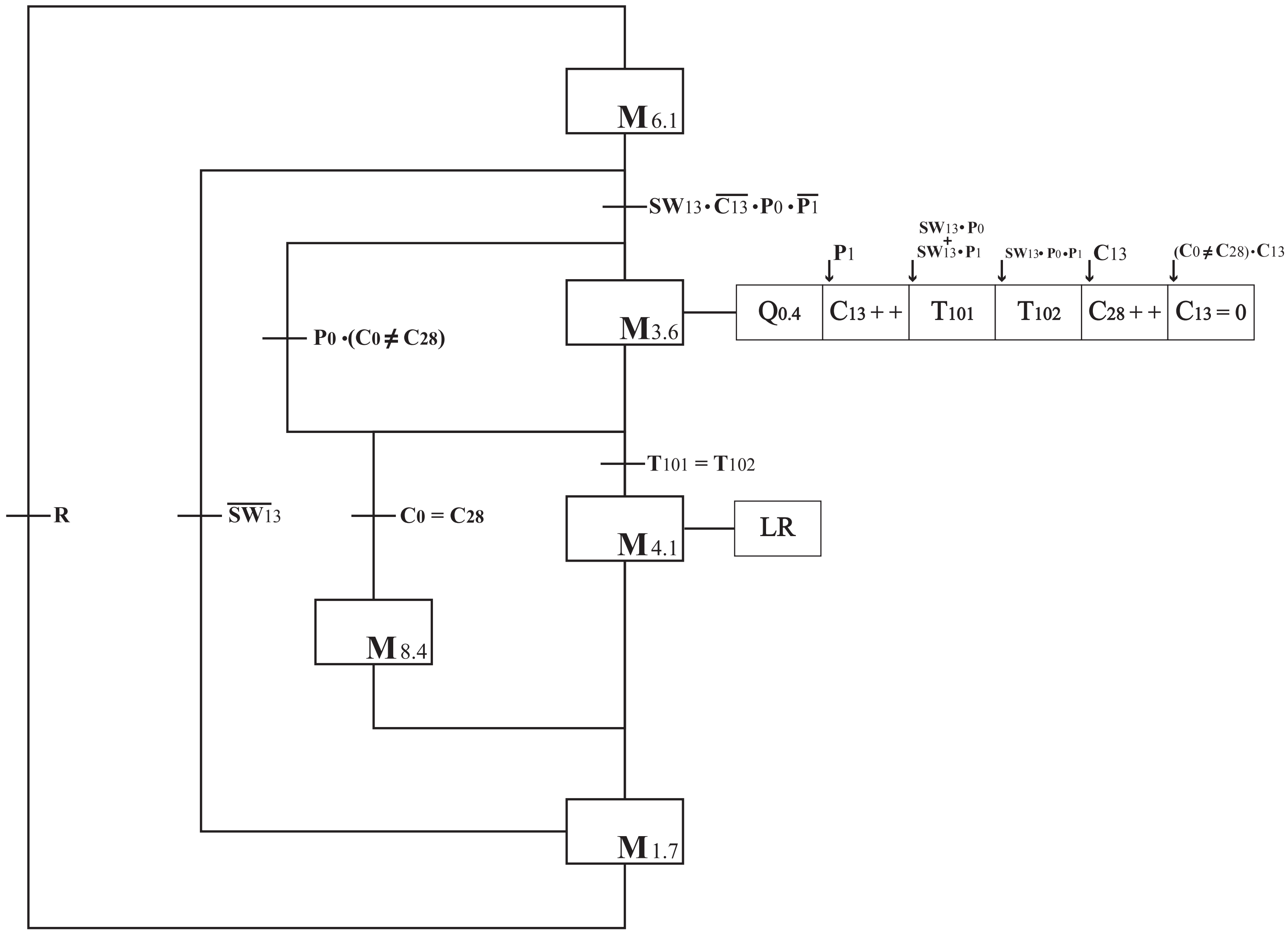


M6.1
SW11 • C11 • L0 • L1
M3.4
Q0.4
L1
C11 + +
SW11 • L0 + SW11 • L1
T101
SW11 • L0 • L1
T102
C11
C26 + +
(C0 ≠ C26) • C11
C11 = 0
L0 • (C0 ≠ C26)
T101 = T102
M4.1
LR
C0 = C26
M8.2
SW11
M1.5
R

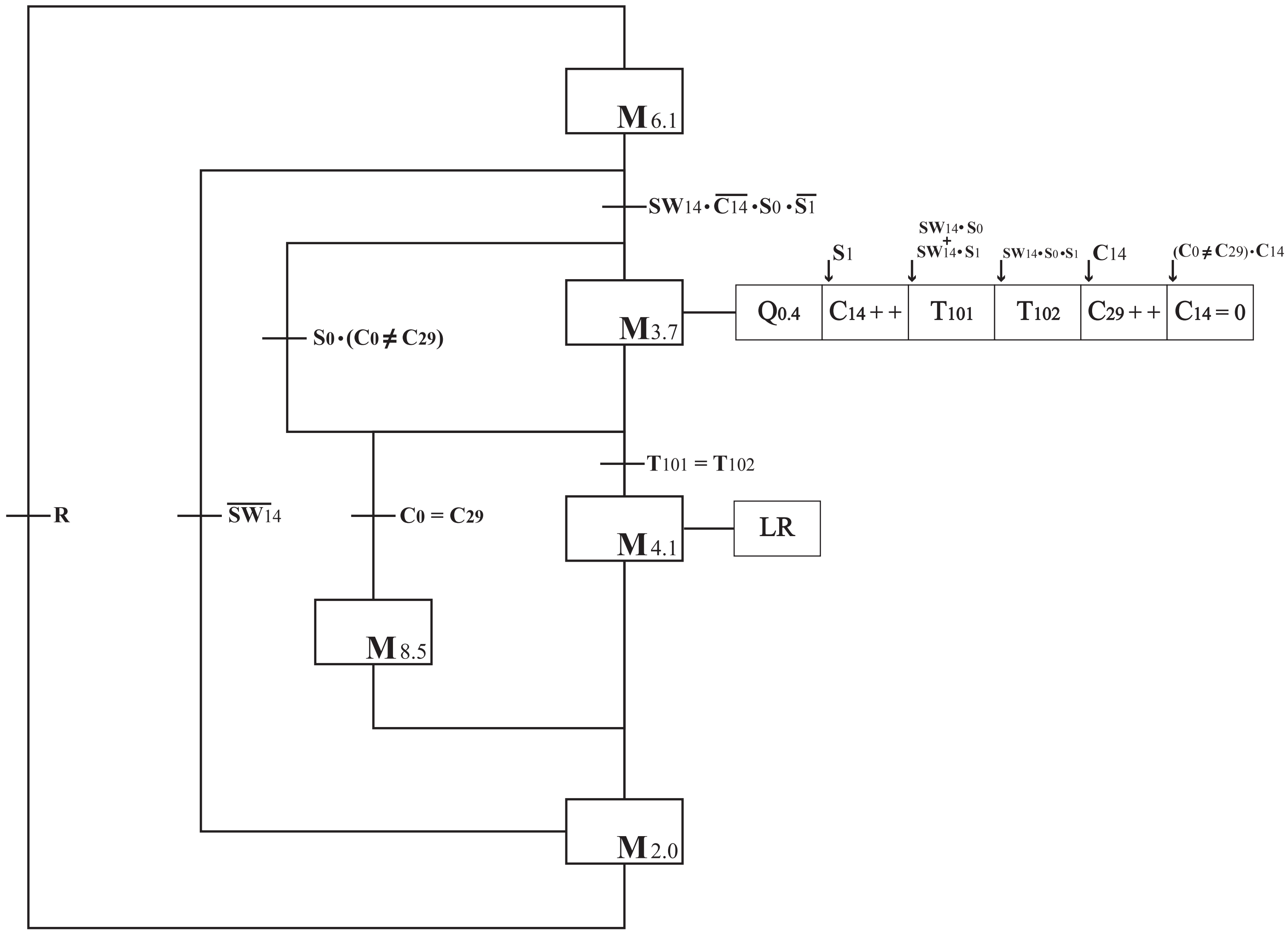
GRAFCET C_12


M6.1
SW12 • C12 • N0 • N1
M3.5
Q0.4
N1
C12 + +
SW12•N0 + SW12•N1
T101
SW12•N0•N1
T102
C12
C27 + +
(C0 ≠ C27)•C12
C12 = 0
N0 • (C0 ≠ C27)
T101 = T102
M4.1
LR
R
SW12
C0 = C27
M8.3
M1.6

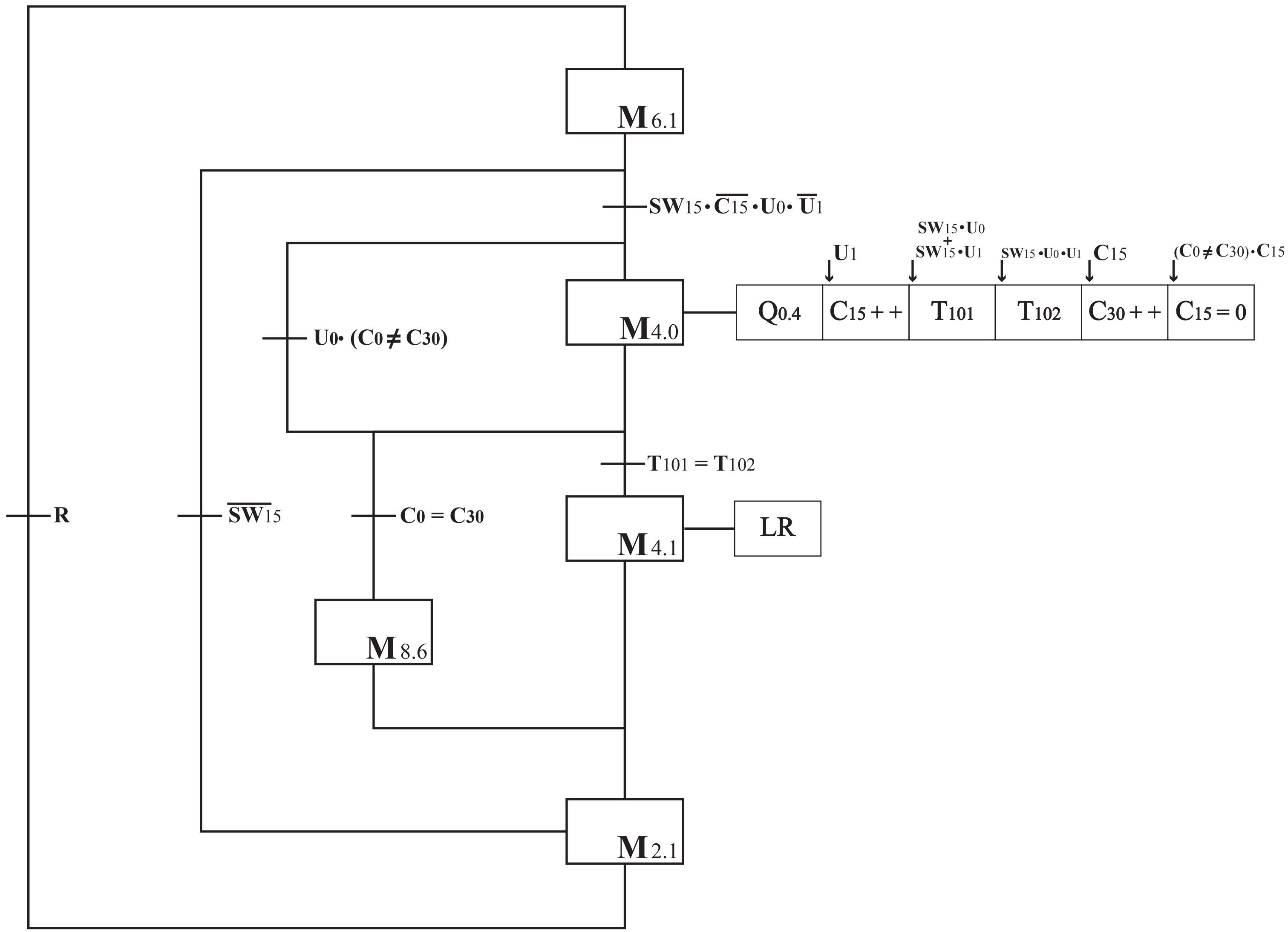
GRAFCET C_13


M6.1
SW13 • C13 • P0 • P1
M3.6
Q0.4
P1
C13 + +
SW13 • P0
+
SW13 • P1
T101
SW13 • P0 • P1
T102
C13
C28 + +
(C0 ≠ C28) • C13
C13 = 0
P0 •(C0 ≠ C28)
T101 = T102
M4.1
LR
R
SW13
C0 = C28
M8.4
M1.7

GRAFCET C_14

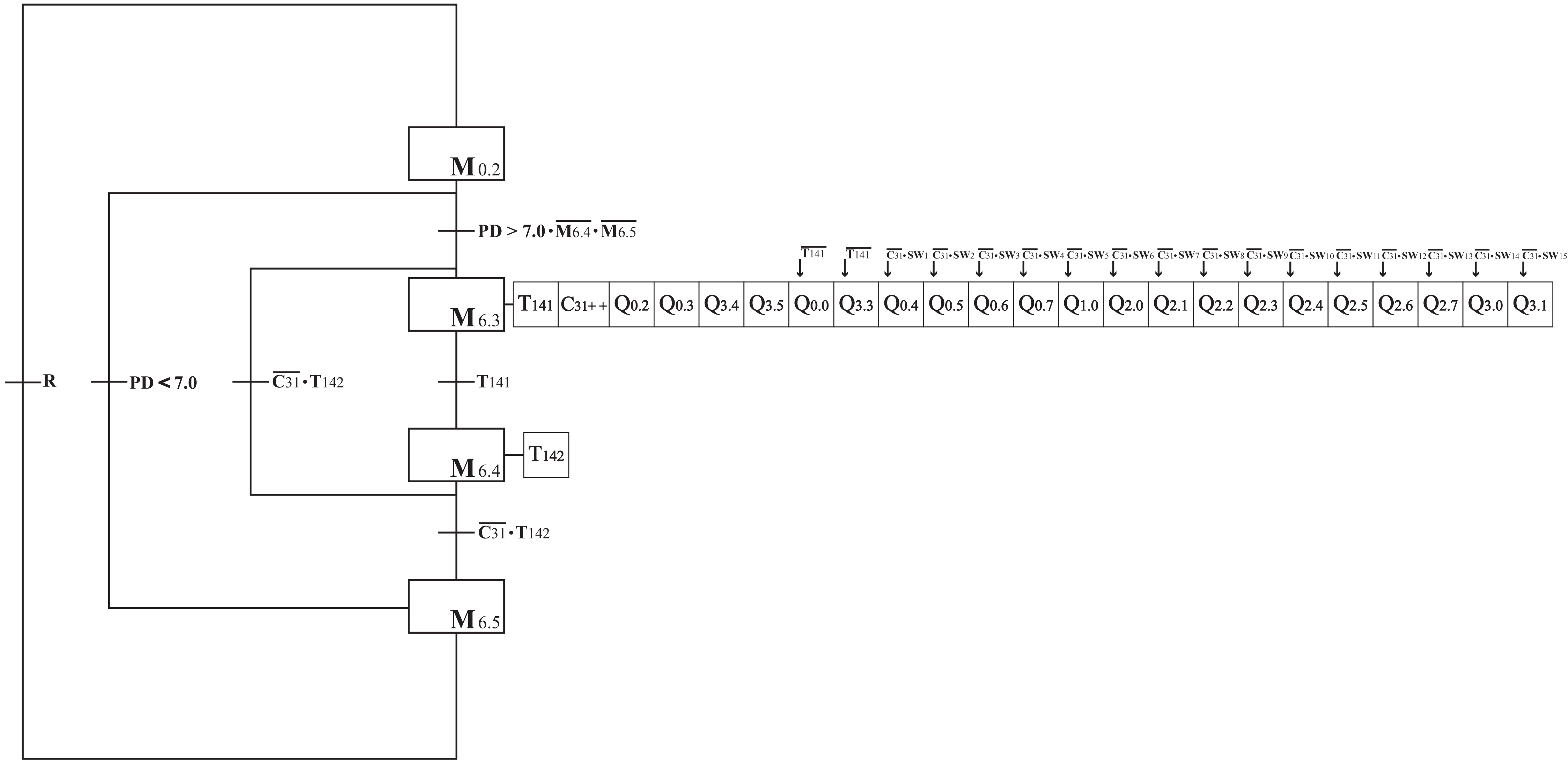

M6.1
SW14 • C14 • S0 • S1
M3.7
Q0.4
S1
C14 + +
SW14 • S0 + SW14 • S1
T101
SW14 • S0 • S1
T102
C14
C29 + +
(C0 ≠ C29) • C14
C14 = 0
S0 • (C0 ≠ C29)
T101 = T102
M4.1
LR
C0 = C29
M8.5
SW14
R
M2.0

GRAFCET C_15



M6.1
SW15 • C15 • U0 • U1
M4.0
Q0.4
C15 + +
T101
T102
C30 + +
C15 = 0
U1
SW15 • U0 + SW15 • U1
SW15 • U0 • U1
C15
(C0 ≠ C30) • C15
U0 • (C0 ≠ C30)
T101 = T102
M4.1
LR
R
SW15
C0 = C30
M8.6
M2.1

GRAFCET


M0.2
PD > 7.0 • M̄6.4 • M̄6.5
M6.3
T141
C31++
Q0.2
Q0.3
Q3.4
Q3.5
T̄141 Q0.0
T̄141 Q3.3
C̄31•SW1 Q0.4
C̄31•SW2 Q0.5
C̄31•SW3 Q0.6
C̄31•SW4 Q0.7
C̄31•SW5 Q1.0
C̄31•SW6 Q2.0
C̄31•SW7 Q2.1
C̄31•SW8 Q2.2
C̄31•SW9 Q2.3
C̄31•SW10 Q2.4
C̄31•SW11 Q2.5
C̄31•SW12 Q2.6
C̄31•SW13 Q2.7
C̄31•SW14 Q3.0
C̄31•SW15 Q3.1
T141
M6.4
T142
C̄31 • T142
M6.5
R
PD < 7.0
C̄31 • T142

S7-200 Quick Reference Information

G

To help you find information more easily, this section summarizes the following information:

- ❑ Special Memory Bits
- ❑ Descriptions of Interrupt Events
- ❑ Summary of S7-200 CPU Memory Ranges and Features
- ❑ High-Speed Counters HSC0, HSC1, HSC2, HSC3, HSC4, HSC5
- ❑ S7-200 Instructions

Table G-1 Special Memory Bits

Special Memory Bits			
SM0.0	Always On	SM1.0	Result of operation = 0
SM0.1	First Scan	SM1.1	Overflow or illegal value
SM0.2	Retentive data lost	SM1.2	Negative result
SM0.3	Power up	SM1.3	Division by 0
SM0.4	30 s off / 30 s on	SM1.4	Table full
SM0.5	0.5 s off / 0.5 s on	SM1.5	Table empty
SM0.6	Off 1 scan / on 1 scan	SM1.6	BCD to binary conversion error
SM0.7	Switch in RUN position	SM1.7	ASCII to hex conversion error

Table G-2 Interrupt Events in Priority Order

Event Number	Interrupt Description	Priority Group	Priority in Group
8	Port 0: Receive character	Communications (highest)	0
9	Port 0: Transmit complete		0
23	Port 0: Receive message complete		0
24	Port 1: Receive message complete		1
25	Port 1: Receive character		1
26	Port 1: Transmit complete		1
19	PTO 0 complete interrupt	Discrete (middle)	0
20	PTO 1 complete interrupt		1
0	I0.0, Rising edge		2
2	I0.1, Rising edge		3
4	I0.2, Rising edge		4
6	I0.3, Rising edge		5
1	I0.0, Falling edge		6
3	I0.1, Falling edge		7
5	I0.2, Falling edge		8
7	I0.3, Falling edge		9
12	HSC0 CV=PV (current value = preset value)		10
27	HSC0 direction changed		11
28	HSC0 external reset		12
13	HSC1 CV=PV (current value = preset value)		13
14	HSC1 direction input changed		14
15	HSC1 external reset		15
16	HSC2 CV=PV		16
17	HSC2 direction changed		17
18	HSC2 external reset		18
32	HSC3 CV=PV (current value = preset value)		19
29	HSC4 CV=PV (current value = preset value)		20
30	HSC4 direction changed		21
31	HSC4 external reset		22
33	HSC5 CV=PV (current value = preset value)		23
10	Timed interrupt 0	Timed (lowest)	0
11	Timed interrupt 1		1
21	Timer T32 CT=PT interrupt		2
22	Timer T96 CT=PT interrupt		3

Table G-3 Summary of S7-200 CPU Memory Ranges and Features

Description		CPU 221	CPU 222	CPU 224	CPU 226	CPU 226XM
User program size		2 Kwords	2 Kwords	4 Kwords	4 Kwords	8 Kwords
User data size		1 Kwords	1 Kwords	2.5 Kwords	2.5 Kwords	5 Kwords
Process-image input register		I0.0 to I15.7	I0.0 to I15.7	I0.0 to I15.7	I0.0 to I15.7	I0.0 to I15.7
Process-image output register		Q0.0 to Q15.7	Q0.0 to Q15.7	Q0.0 to Q15.7	Q0.0 to Q15.7	Q0.0 to Q15.7
Analog inputs (read only)		--	AIW0 to AIW30	AIW0 to AIW62	AIW0 to AIW62	AIW0 to AIW62
Analog outputs (write only)		--	AQW0 to AQW30	AQW0 to AQW62	AQW0 to AQW62	AQW0 to AQW62
Variable memory (V)		VB0 to VB2047	VB0 to VB2047	VB0 to VB5119	VB0 to VB5119	VB0 to VB10239
Local memory (L)[1]		LB0 to LB63	LB0 to LB63	LB0 to LB63	LB0 to LB63	LB0 to LB63
Bit memory (M)		M0.0 to M31.7	M0.0 to M31.7	M0.0 to M31.7	M0.0 to M31.7	M0.0 to M31.7
Special Memory (SM)		SM0.0 to SM179.7	SM0.0 to SM299.7	SM0.0 to SM549.7	SM0.0 to SM549.7	SM0.0 to SM549.7
Read only		SM0.0 to SM29.7	SM0.0 to SM29.7	SM0.0 to SM29.7	SM0.0 to SM29.7	SM0.0 to SM29.7
Timers		256 (T0 to T255)	256 (T0 to T255)	256 (T0 to T255)	256 (T0 to T255)	256 (T0 to T255)
Retentive on-delay	1 ms	T0, T64	T0, T64	T0, T64	T0, T64	T0, T64
	10 ms	T1 to T4, and T65 to T68	T1 to T4, and T65 to T68	T1 to T4, and T65 to T68	T1 to T4, and T65 to T68	T1 to T4, and T65 to T68
	100 ms	T5 to T31, and T69 to T95	T5 to T31, and T69 to T95	T5 to T31, and T69 to T95	T5 to T31, and T69 to T95	T5 to T31, and T69 to T95
On/Off delay	1 ms	T32, T96	T32, T96	T32, T96	T32, T96	T32, T96
	10 ms	T33 to T36, and T97 to T100	T33 to T36, and T97 to T100	T33 to T36, and T97 to T100	T33 to T36, and T97 to T100	T33 to T36, and T97 to T100
	100 ms	T37 to T63, and T101 to T255	T37 to T63, and T101 to T255	T37 to T63, and T101 to T255	T37 to T63, and T101 to T255	T37 to T63, and T101 to T255
Counters		C0 to C255	C0 to C255	C0 to C255	C0 to C255	C0 to C255
High-speed counter		HC0, HC3, HC4, and HC5	HC0, HC3, HC4, and HC5	HC0 to HC5	HC0 to HC5	HC0 to HC5
Sequential control relays (S)		S0.0 to S31.7	S0.0 to S31.7	S0.0 to S31.7	S0.0 to S31.7	S0.0 to S31.7
Accumulator registers		AC0 to AC3	AC0 to AC3	AC0 to AC3	AC0 to AC3	AC0 to AC3
Jumps/Labels		0 to 255	0 to 255	0 to 255	0 to 255	0 to 255
Call/Subroutine		0 to 63	0 to 63	0 to 63	0 to 63	0 to 127
Interrupt routines		0 to 127	0 to 127	0 to 127	0 to 127	0 to 127
Positive/negative transitions		256	256	256	256	256
PID loops		0 to 7	0 to 7	0 to 7	0 to 7	0 to 7
Ports		Port 0	Port 0	Port 0	Port 0, Port 1	Port 0, Port 1

1 LB60 to LB63 are reserved by STEP 7-Micro/WIN, version 3.0 or later.

G

Table G-4 High-Speed Counters HSC0, HSC3, HSC4, and HSC5

Mode	HSC0			HSC3	HSC4			HSC5
	I0.0	**I0.1**	**I0.2**	**I0.1**	**I0.3**	**I0.4**	**I0.5**	**I0.4**
0	Clk			Clk	Clk			Clk
1	Clk		Reset		Clk		Reset	
2								
3	Clk	Direction			Clk	Direction		
4	Clk	Direction	Reset		Clk	Direction	Reset	
5								
6	Clk Up	Clk Down			Clk Up	Clk Down		
7	Clk Up	Clk Down	Reset		Clk Up	Clk Down	Reset	
8								
9	Phase A	Phase B			Phase A	Phase B		
10	Phase A	Phase B	Reset		Phase A	Phase B	Reset	
11								

Table G-5 High-Speed Counters HSC1 and HSC2

Mode	HSC1				HSC2			
	I0.6	**I0.7**	**I1.0**	**I1.1**	**I1.2**	**I1.3**	**I1.4**	**I1.5**
0	Clk				Clk			
1	Clk		Reset		Clk		Reset	
2	Clk		Reset	Start	Clk		Reset	Start
3	Clk	Direction			Clk	Direction		
4	Clk	Direction	Reset		Clk	Direction	Reset	
5	Clk	Direction	Reset	Start	Clk	Direction	Reset	Start
6	Clk Up	Clk Down			Clk Up	Clk Down		
7	Clk Up	Clk Down	Reset		Clk Up	Clk Down	Reset	
8	Clk Up	Clk Down	Reset	Start	Clk Up	Clk Down	Reset	Start
9	Phase A	Phase B			Phase A	Phase B		
10	Phase A	Phase B	Reset		Phase A	Phase B	Reset	
11	Phase A	Phase B	Reset	Start	Phase A	Phase B	Reset	Start

Boolean Instructions

LD	Bit	Load
LDI	Bit	Load Immediate
LDN	Bit	Load Not
LDNI	Bit	Load Not Immediate
A	Bit	AND
AI	Bit	AND Immediate
AN	Bit	AND Not
ANI	Bit	AND Not Immediate
O	Bit	OR
OI	Bit	OR Immediate
ON	Bit	OR Not
ONI	Bit	OR Not Immediate
LDBx	IN1, IN2	Load result of Byte Compare IN1 (x:<, <=,=, >=, >, <>I) IN2
ABx	IN1, IN2	AND result of Byte Compare IN1 (x:<, <=,=, >=, >, <>) IN2
OBx	IN1, IN2	OR result of Byte Compare IN1 (x:<, <=,=, >=, >, <>) IN2
LDWx	IN1, IN2	Load result of Word Compare IN1 (x:<, <=,=, >=, >, <>) IN2
AWx	IN1, IN2	AND result of Word Compare IN1 (x:<, <=,=, >=, >, <>)I N2
OWx	IN1, IN2	OR result of Word Compare IN1 (x:<, <=,=, >=, >, <>) IN2
LDDx	IN1, IN2	Load result of DWord Compare IN1 (x:<, <=,=, >=, >, <>) IN2
ADx	IN1, IN2	AND result of DWord Compare IN1 (x:<, <=,=, >=, >, <>)IN2
ODx	IN1, IN2	OR result of DWord Compare IN1 (x:<, <=,=, >=, >, <>) IN2
LDRx	IN1, IN2	Load result of Real Compare IN1 (x:<, <=,=, >=, >, <>) IN2
ARx	IN1, IN2	AND result of Real Compare IN1 (x:<, <=,=, >=, >, <>) IN2
ORx	IN1, IN2	OR result of Real Compare IN1 (x:<, <=,=, >=, >, <>) IN2
NOT		Stack Negation
EU		Detection of Rising Edge
ED		Detection of Falling Edge
=	Bit	Assign Value
=I	Bit	Assign Value Immediate
S	Bit, N	Set bit Range
R	Bit, N	Reset bit Range
SI	Bit, N	Set bit Range Immediate
RI	Bit, N	Reset bit Range Immediate
LDSx	IN1, IN2	Load result of String Compare IN1 (x: =, <>) IN2
ASx	IN1, IN2	AND result of String Compare IN1 (x: =, <>) IN2
OSx	IN1, IN2	OR result of String Compare IN1 (x: =, <>) IN2
ALD		And Load
OLD		Or Load
LPS		Logic Push (stack control)
LRD		Logic Read (stack control)
LPP		Logic Pop (stack control)
LDS	N	Load Stack (stack control)
AENO		And ENO

Math, Increment, and Decrement instructions

+I +D +R	IN1, OUT IN1, OUT IN1, OUT	Add Integer, Double Integer or Real IN1+OUT=OUT
-I -D -R	IN1, OUT IN1, OUT IN1, OUT	Subtract Integer, Double Integer, or Real OUT-IN1=OUT
MUL	IN1, OUT	Multiply Integer (16*16->32)
*I *D *R	IN1, OUT IN1, OUT IN1, IN2	Multiply Integer, Double Integer, or Real IN1 * OUT = OUT
DIV	IN1, OUT	Divide Integer (16/16->32)
/I /D, /R	IN1, OUT IN1, OUT IN1, OUT	Divide Integer, Double Integer, or Real OUT / IN1 = OUT
SQRT	IN, OUT	Square Root
LN	IN, OUT	Natural Logarithm
EXP	IN, OUT	Natural Exponential
SIN	IN, OUT	Sine
COS	IN, OUT	Cosine
TAN	IN, OUT	Tangent
INCB INCW INCD	OUT OUT OUT	Increment Byte, Word or DWord
DECB DECW DECD	OUT OUT OUT	Decrement Byte, Word, or DWord
PID	TBL, LOOP	PID Loop

Timer and Counter Instructions

TON	Txxx, PT	On-Delay Timer
TOF	Txxx, PT	Off-Delay Timer
TONR	Txxx, PT	Retentive On-Delay Timer
CTU	Cxxx, PV	Count Up
CTD	Cxxx, PV	Count Down
CTUD	Cxxx, PV	Count Up/Down

Real Time Clock Instructions

TODR	T	Read Time of Day clock
TODW	T	Write Time of Day clock

Program Control Instructions

END		Conditional End of Program
STOP		Transition to STOP Mode
WDR		WatchDog Reset (300 ms)
JMP	N	Jump to defined Label
LBL	N	Define a Label to Jump to
CALL	N [N1,...]	Call a Subroutine [N1, ... up to 16 optional parameters]
CRET		Conditional Return from SBR
FOR NEXT	INDX,INIT,FINAL	For/Next Loop
LSCR SCRT CSCRE SCRE	N N	Load, Transition, Conditional End, and End Sequence Control Relay

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Move, Shift, and Rotate Instructions		
MOVB	IN, OUT	Move Byte, Word, DWord, Real
MOVW	IN, OUT	
MOVD	IN, OUT	
MOVR	IN, OUT	
BIR	IN, OUT	Move Byte Immediate Read
BIW	IN, OUT	Move Byte Immediate Write
BMB	IN, OUT, N	Block Move Byte, Word, DWord
BMW	IN, OUT, N	
BMD	IN, OUT, N	
SWAP	IN	Swap Bytes
SHRB	DATA, S_BIT, N	Shift Register Bit
SRB	OUT, N	Shift Right Byte, Word, DWord
SRW	OUT, N	
SRD	OUT, N	
SLB	OUT, N	Shift Left Byte, Word, DWord
SLW	OUT, N	
SLD	OUT, N	
RRB	OUT, N	Rotate Right Byte, Word, DWord
RRW	OUT, N	
RRD	OUT, N	
RLB	OUT, N	Rotate Left Byte, Word, DWord
RLW	OUT, N	
RLD	OUT, N	
Logical Instructions		
ANDB	IN1, OUT	Logical AND of Byte, Word, and DWord
ANDW	IN1, OUT	
ANDD	IN1, OUT	
ORB	IN1, OUT	Logical OR of Byte, Word, and DWord
ORW	IN1, OUT	
ORD	IN1, OUT	
XORB	IN1, OUT	Logical XOR of Byte, Word, and DWord
XORW	IN1, OUT	
XORD	IN1, OUT	
INVB	OUT	Invert Byte, Word and DWord
INVW	OUT	(1's complement)
INVD	OUT	
String Instructions		
SLEN	IN, OUT	String Length
SCAT	IN, OUT	Concatenate String
SCPY	IN, OUT	Copy String
SSCPY	IN, INDX, N, OUT	Copy Substring from String
CFND	IN1, IN2, OUT	Find First Character within String
SFND	IN1, IN2, OUT	Find String within String

Table, Find, and Conversion Instructions		
ATT	DATA, TBL	Add data to table
LIFO	TBL, DATA	Get data from table
FIFO	TBL, DATA	
FND=	TBL, PTN, INDX	Find data value in table that matches comparison
FND<>	TBL, PTN, INDX	
FND<	TBL, PTN, INDX	
FND>	TBL, PTN, INDX	
FILL	IN, OUT, N	Fill memory space with pattern
BCDI	OUT	Convert BCD to Integer
IBCD	OUT	Convert Integer to BCD
BTI	IN, OUT	Convert Byte to Integer
ITB	IN, OUT	Convert Integer to Byte
ITD	IN, OUT	Convert Integer to Double Integer
DTI	IN, OUT	Convert Double Integer to Integer
DTR	IN, OUT	Convert DWord to Real
TRUNC	IN, OUT	Convert Real to Double Integer
ROUND	IN, OUT	Convert Real to Double Integer
ATH	IN, OUT, LEN	Convert ASCII to Hex
HTA	IN, OUT, LEN	Convert Hex to ASCII
ITA	IN, OUT, FMT	Convert Integer to ASCII
DTA	IN, OUT, FM	Convert Double Integer to ASCII
RTA	IN, OUT, FM	Convert Real to ASCII
DECO	IN, OUT	Decode
ENCO	IN, OUT	Encode
SEG	IN, OUT	Generate 7-segment pattern
ITS	IN, FMT, OUT	Convert Integer to String
DTS	IN, FMT, OUT	Convert Double Integer to String
RTS	IN, FMT, OUT	Convert Real to String
STI	STR, INDX, OUT	Convert Substring to Integer
STD	STR, INDX, OUT	Convert Substring to Double Integer
STR	STR, INDX, OUT	Convert Substring to Real
Interrupt Instructions		
CRETI		Conditional Return from Interrupt
ENI		Enable Interrupts
DISI		Disable Interrupts
ATCH	INT, EVNT	Attach Interrupt routine to event
DTCH	EVNT	Detach event
Communications Instructions		
XMT	TBL, PORT	Freeport transmission
RCV	TBL, PORT	Freeport receive message
NETR	TBL, PORT	Network Read
NETW	TBL, PORT	Network Write
GPA	ADDR, PORT	Get Port Address
SPA	ADDR, PORT	Set Port Address
High-Speed Instructions		
HDEF	HSC, MODE	Define High-Speed Counter mode
HSC	N	Activate High-Speed Counter
PLS	Q	Pulse Output

Annex 9:
VIRTUAL MACHINE ESPECIFICATIONS

ORACLE VM SERVER VIRTUALIZATION & MANAGEMENT

OVERVIEW

ORACLE'S CERTIFIED VIRTUALIZATION SOLUTION

- Complete server virtualization and management with no license costs;
- Speeds application deployment with VM Templates;
- Modern, low overhead architecture for leading price/performance;
- Included Secure Live Migration, VM High-Availability, P2V and V2V conversion, Web Services API, and other advanced features.

Oracle VM is a free, next-generation server virtualization and management solution that makes enterprise applications easier to deploy, manage, and support. Backed worldwide by affordable enterprise-quality support for both Oracle and non-Oracle environments, Oracle VM facilitates the deployment and operation of your enterprise applications on a fully certified platform to reduce operations and support costs while simultaneously increasing IT efficiency and agility.

The Virtualization Platform for Your Enterprise Server Workloads

You are facing the challenges of a rapidly expanding data center—increased operating costs, inefficient resource utilization and an appetite for real estate. But any solution also has to increase your flexibility, meet your price/performance needs, and make applications easier to deploy, manage, and support.

Oracle VM delivers:

- **Oracle VM Manager Web Services API** – Enable integration of third party products with Oracle VM Manager;
- **Faster Software Deployment with Oracle VM Templates –** Download and import pre-configured virtual machines containing pre-installed Oracle enterprise applications or other software to get up and running in hours not weeks;
- **Leading Price/Performance –** Low-overhead architecture provides scalable performance under increasing I/O workloads with no license costs, to meet the most aggressive price/performance requirements;
- **Secure Live VM Migration** – Completely eliminate service outages associated with planned maintenance or scale up your resources quickly by migrating running VMs to other servers over secure SSL links without interruption;
- **High Availability** – Reliably and automatically restart failed VMs on other servers in the server pool after unexpected server- or individual VM outage.
- **Automatic or Manual Server Pool Load Balancing** – Guest VMs are automatically placed on the server with the most resources available in the pool at start-up, or can be started within a user-designated subset of servers;
- **Physical-to-Virtual / Virtual-to-Virtual Machine Conversion** – Quickly convert existing Linux or Windows physical servers or VMware® virtual machines to Oracle VM virtual machines to reduce license expenses;

- **Virtualization and Management: Zero License Costs, Zero License Keys** – Includes Oracle VM Manager for centralized, browser-based management of your resource pools;
- **Virtual Machine I/O Resource Management** – Set bandwidth cap for each virtual network interface and prioritize the virtual disks;
- **Linux and Windows Support** – Linux and Windows guest operating systems;
- **Official Certification Based On Real-World Testing** – Supported for use with the most sophisticated enterprise workloads under real-world conditions;
- **Affordable, Full-Stack Enterprise-Class Support** – Worldwide support from Oracle for the entire virtualization environment and workloads together.

Integrated Server Virtualization and Management

Consisting of Oracle VM Server, open source server software, and an integrated web browser-based management console, Oracle VM Manager, Oracle VM provides an easy-to-use, feature-rich graphical interface for creating and managing virtual server pools, running on x86 and x86_64 based systems across the enterprise.

Users can create and manage virtual machines (VMs) that exist on the same physical server but that can behave independently, with each VM having its own virtual CPUs, network interfaces, storage, and operating system

Oracle VM supports the following guest operating systems (both 32-bit and 64-bit):

- **Both paravitualized- (PV, “virtualization aware”) and hardware-virtualized kernels**:
  - Enterprise Linux 4 and 5 (from Oracle or Red Hat®).
- **Hardware-virtualized kernels only (Virtualization support in hardware – Intel VT or AMD-V required):**
  - Red Hat Enterprise Linux 3 (32-bit PV drivers also available);
  - Windows 2008 SP1, Windows Vista, Windows 2003, Windows XP Pro (32-bit and 64-bit PV drivers available) learn more;
  - Windows 2000

Please refer to the product documentation for complete information on supported guest operating system configurations.

Oracle VM Server installs on physical, “bare-metal” servers from a single CD or from a network in about a minute to provide the environment for hosting guest virtual machines. Virtual Machines can be created, configured, and managed from either the Oracle VM Server command-line, or hundreds of servers can be managed centrally from a browser using the included Oracle VM Manager software.

Advanced VM Management

Creating and configuring guest VMs is only the beginning. With Oracle VM’s included management solution, Oracle VM Manager, administrators can enable advanced functionality to load balance across resource pools and automatically reduce or eliminate outages associated with server downtime.

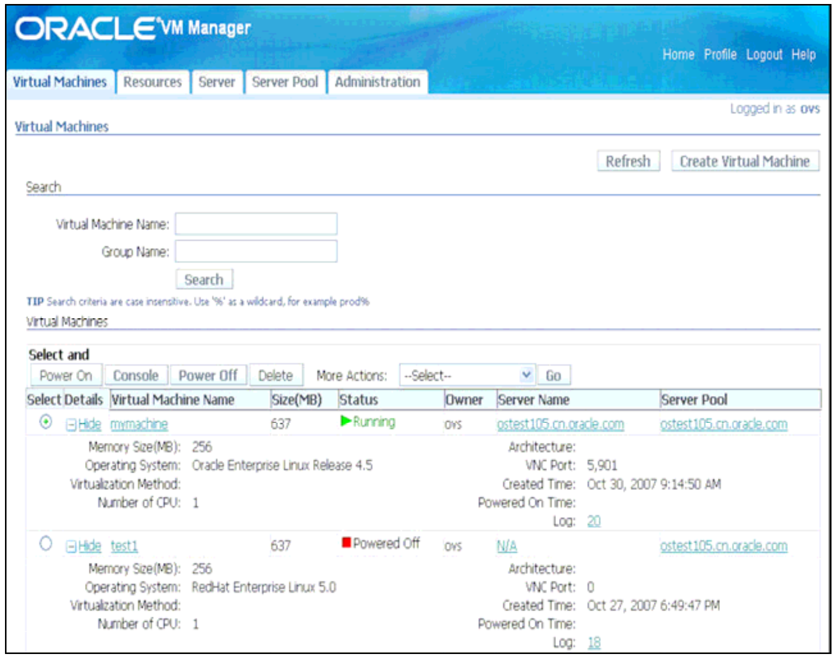


Figure 1. Oracle VM Manager Interface

Oracle Enterprise Manager 10*g* Release 5 introduces the Oracle VM Management Pack, which provides a comprehensive management solution for managing both the virtual machines and the operating systems and software running inside the virtual machines from a single product. The Oracle VM Management Pack provides integrated in-depth health and performance monitoring, configuration management, and lifecycle automation for both virtual- and physical infrastructure for maximum operational efficiency.

System Requirements

Two systems with static IP addresses are needed to install Oracle VM: one to install Oracle VM Server and the other to install Oracle VM Manager.

- Oracle VM Server installs directly on server hardware and does not require a host operating system;
- Oracle VM Manager is a Java-based management server running on Linux;
- Oracle VM Manager uses an Oracle database as its management repository, which can be installed either on the management server or a separate server. Oracle Database Express Edition (XE), Standard Edition (SE), Enterprise Edition (EE), and Real Application Clusters (RAC) are supported as the management repository.

Oracle VM Server hardware requirements:

- Oracle VM Server is available as a single CD image for systems with x86 or x86_64 processors that support PAE (Physical Address Extension);
- Guest operating systems that are not virtualization aware (“hardware virtualized” VMs or “unmodified” guest kernels) including Microsoft Windows

require a CPU with hardware virtualization support (Intel VT or AMD-V);

- A minimum of one dual core CPU or multiple single-core CPUs is recommended when hosting multiple guest VMs;
- 1GB of RAM (minimum) or 2GB (recommended) per Server. Memory requirements can vary significantly depending on the workload and operating systems hosted. Server memory should be sized based on the maximum aggregate requirements when the Server is hosting the maximum planned number of guest VMs to provide optimum performance.

Oracle VM Manager server requirements (minimum):

- x86 (32bit) server hardware, 1 or more 1.83GHz (or faster) CPUs, 2GB RAM;
- 2GB configured swap space, 4GB hard disk space;
- Enterprise Linux Release 4 Update 5 from Oracle or Enterprise Linux Release 4 or later from Red Hat.

The Certified and Supported Virtualization Environment for Oracle

Oracle performs real-world testing on its broad portfolio of products with Oracle VM to ensure bulletproof reliability and streamlined support. Consult Support Note 464754.1 on the My Oracle Support website for the latest information on exact product versions certified.

Oracle VM Support: The Complete Stack – One Call Worldwide

Oracle's world-class support organization offers Oracle VM Premier Support including:

- Access to patches, fixes, and updates delivered via a subscriber network, the Unbreakable Linux Network;
- 24x7 global support.

Oracle VM software is available for free download. Support for Oracle VM can be purchased via the Oracle VM Store.

Pricing for Oracle VM support is calculated on a per system basis: Consult Oracle's pricing guide for further details.

More Information

For more information, visit oracle.com/virtualization

Oracle is committed to developing practices and products that help protect the environment

Annex 10:
LADDER PROGRAM

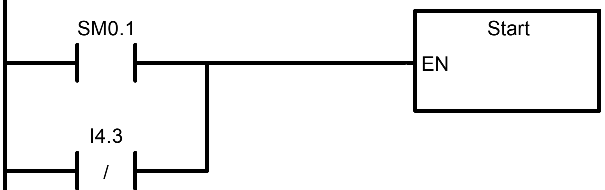
Block: MAIN
Author: Heiller Andres Torres Barona
Created: 03/06/2018 05:52:47 pm
Last Modified: 04/03/2018 01:42:42 am

Symbol	Var Type	Data Type	Comment
	TEMP		
	TEMP		
	TEMP		
	TEMP		

PROGRAM COMMENTS

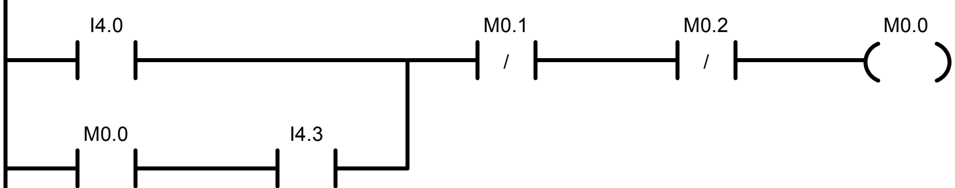
Network 1 Network Title

This Network restart all the possible counters, auxiliary memories and timers in the turn ON.
This network is activated to reset all the possible counters, auxiliary memories and timers at any time during the program execution.



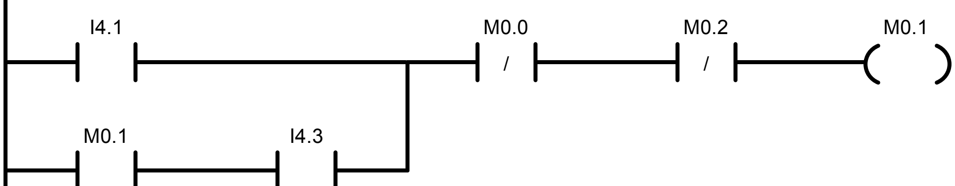
Network 2

The user must press one of the 3 buttons to chose an operating mode.
This network choses the normal operating mode, performs the Wear and the Leak test.



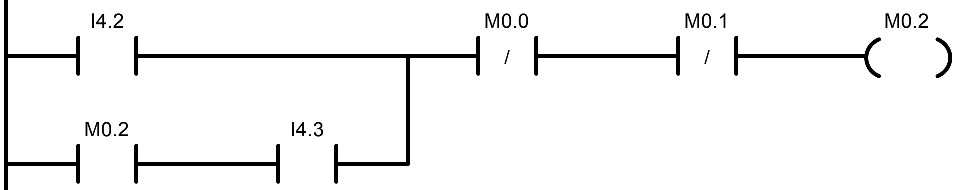
Network 3

This network choses the Wear operating mode.
Just Preform the Wear test.



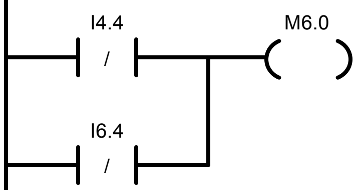
Network 4

This network choses the Leak operating mode.
Just Preform the Leak test.



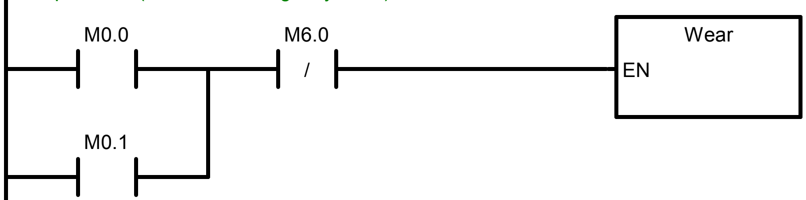
Network 5

This network is encharged of activating the emergency state that will only be active if the emergency button is pressed or if the signal of the tempered glass is open.



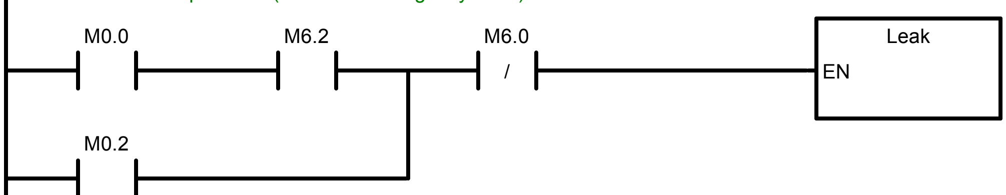
Network 6

This network will activate the wear test if the normal operating condition button or if the wear operating condition button are pressed. (and if not emergency state)



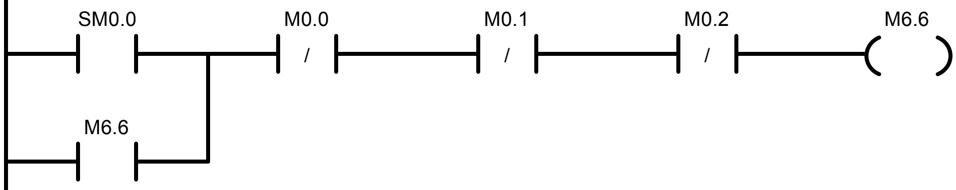
Network 7

This network will activate the wear test if the normal operating condition button and the wear test is done or if the leak operating condition button is pressed. (and if not emergency state)



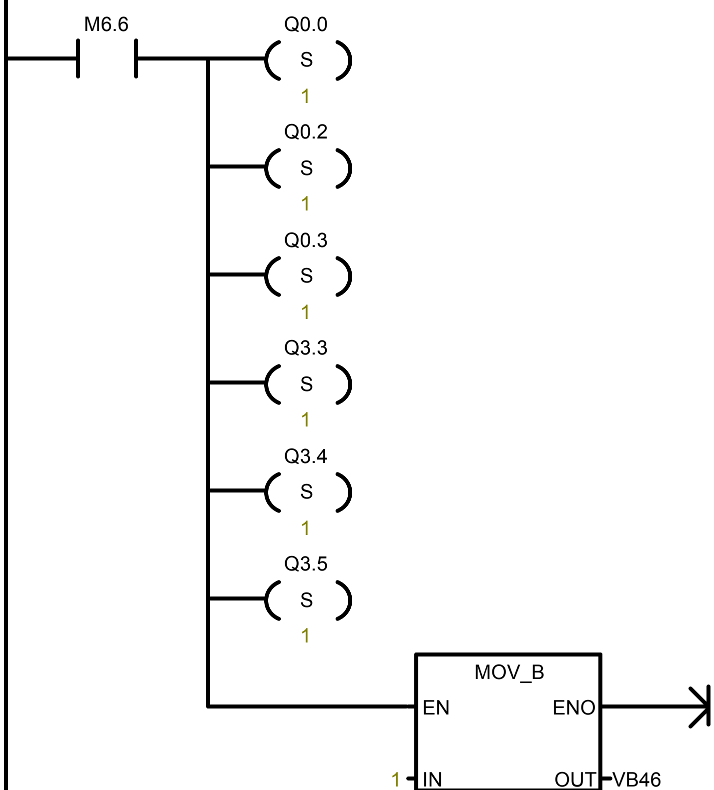
Network 8

The starting state of the machine will put the machine in the initial state, all cylinders retracted.



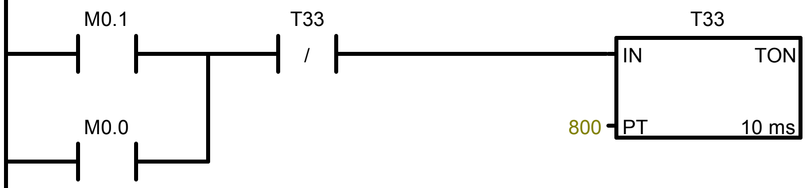
Network 9 Network Title

Activation of valves to satisfy initial state requirements. *All cylinders in instroke position.



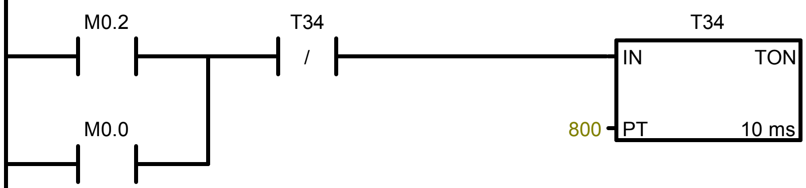
Network 10

Will start the timer to light White leds



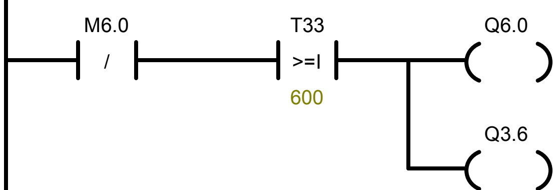
Network 11

Will start the timer to light Green leds



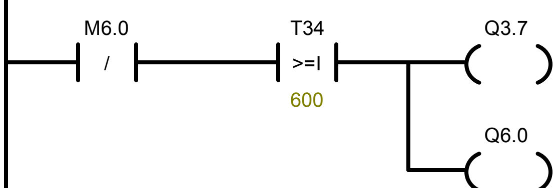
Network 12

Will start to light White leds and red lamps



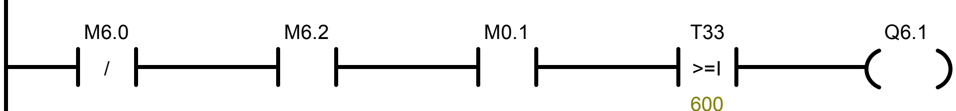
Network 13

Will start the timer to light green leds and green lamp



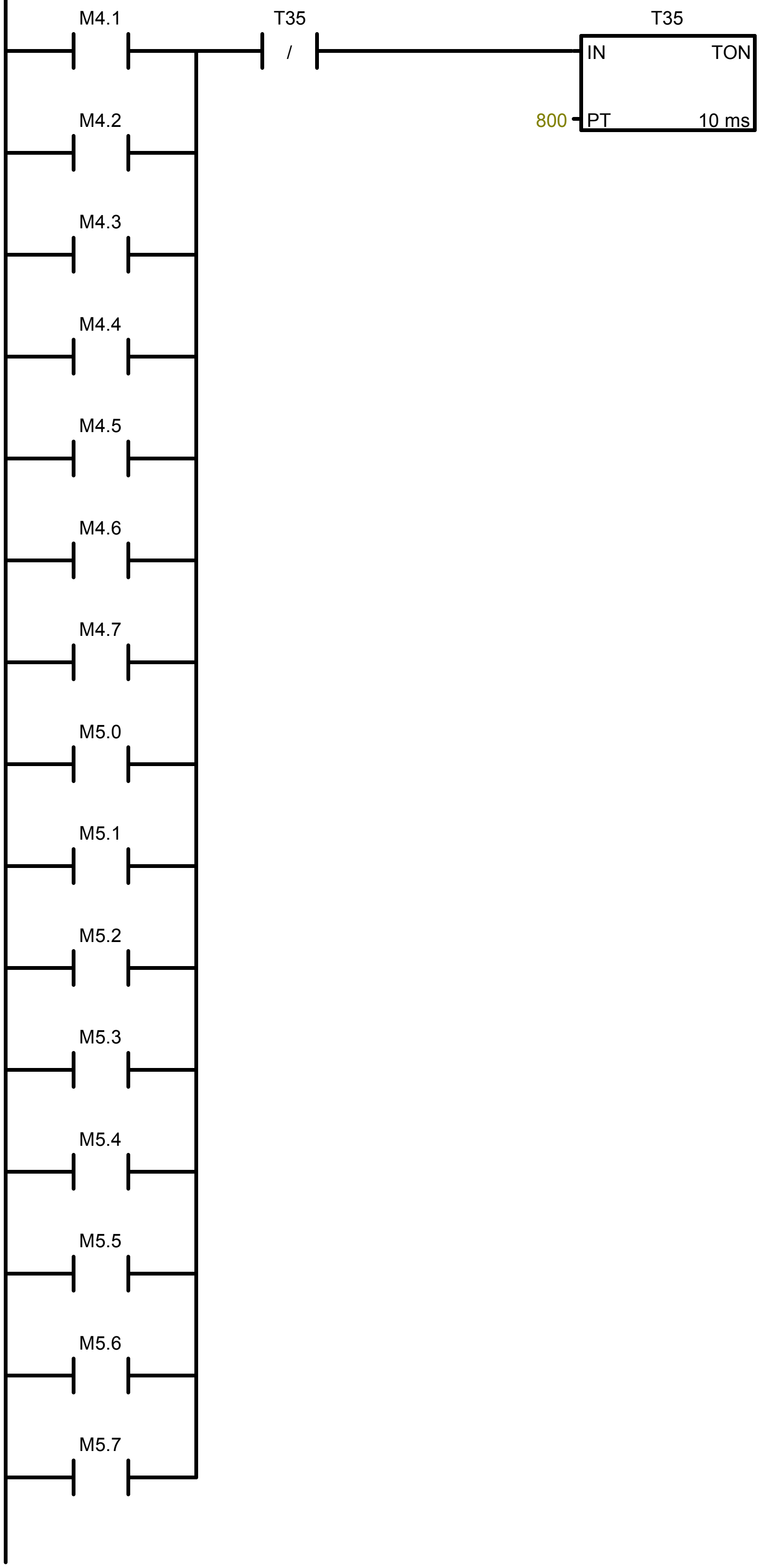
Network 14

Will start the timer to light red lamp when the probes are done



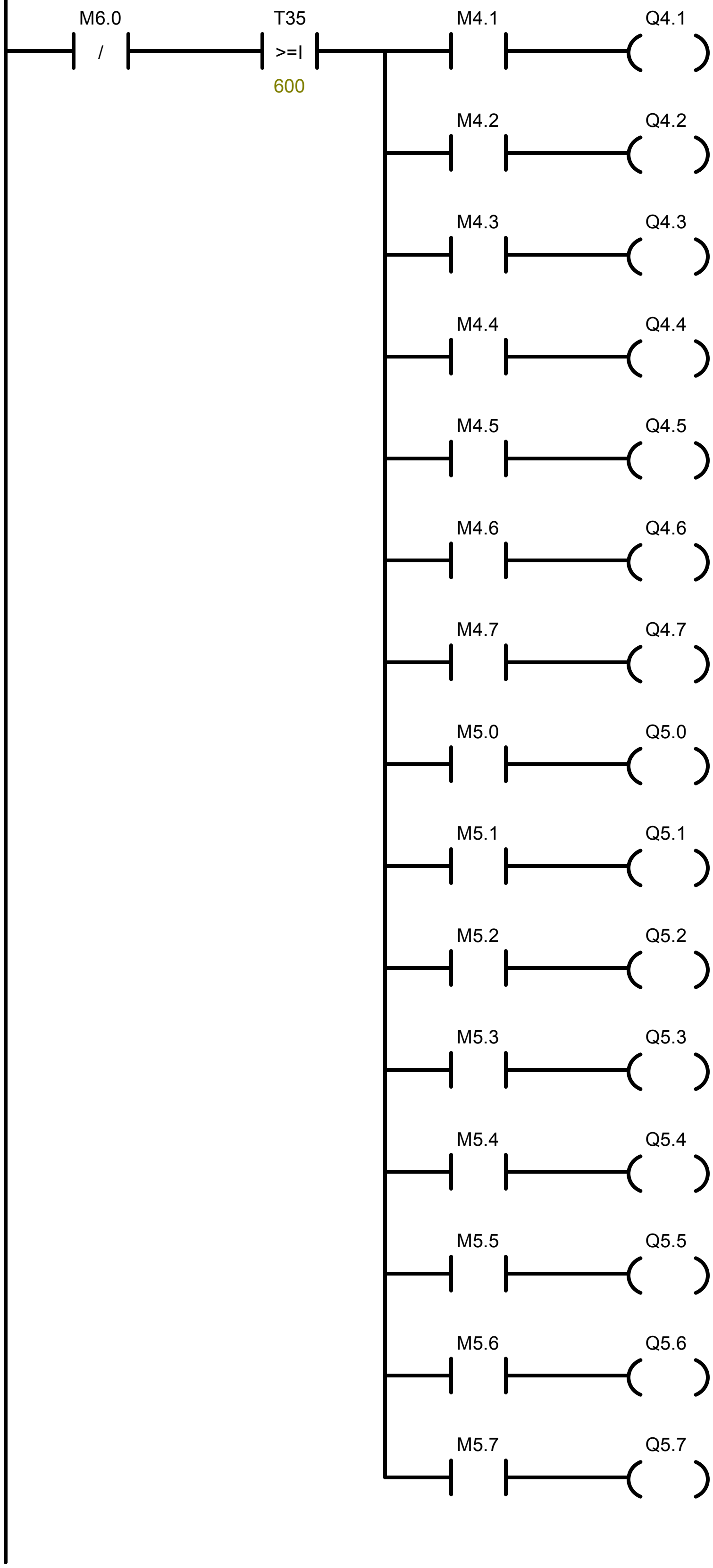
Network 15

Will start the timer to light Red leds



Network 16

Will start to light Red leds if failure is present

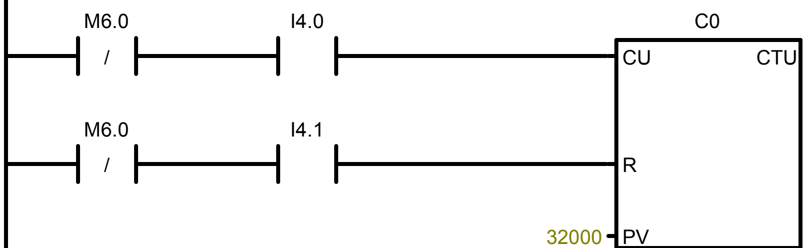


Block: Wear
Author: Heiller Andres Torres Barona
Created: 03/06/2018 05:52:47 pm
Last Modified: 04/02/2018 07:22:13 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

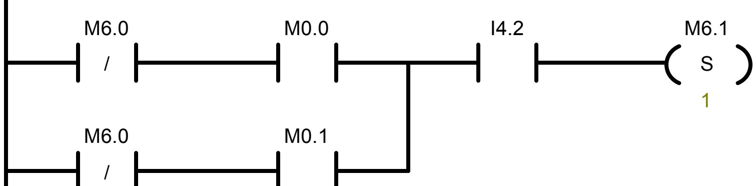
Network 1

The user must especify the number of times that the test bench must repeat the cycles, each time that the user presses the button 1 the test bench will perform 30000 cycles in each activated cylinder. If the user commits an error durring the setting, the process can be reset by pressing the button 2 or wear operating mode button



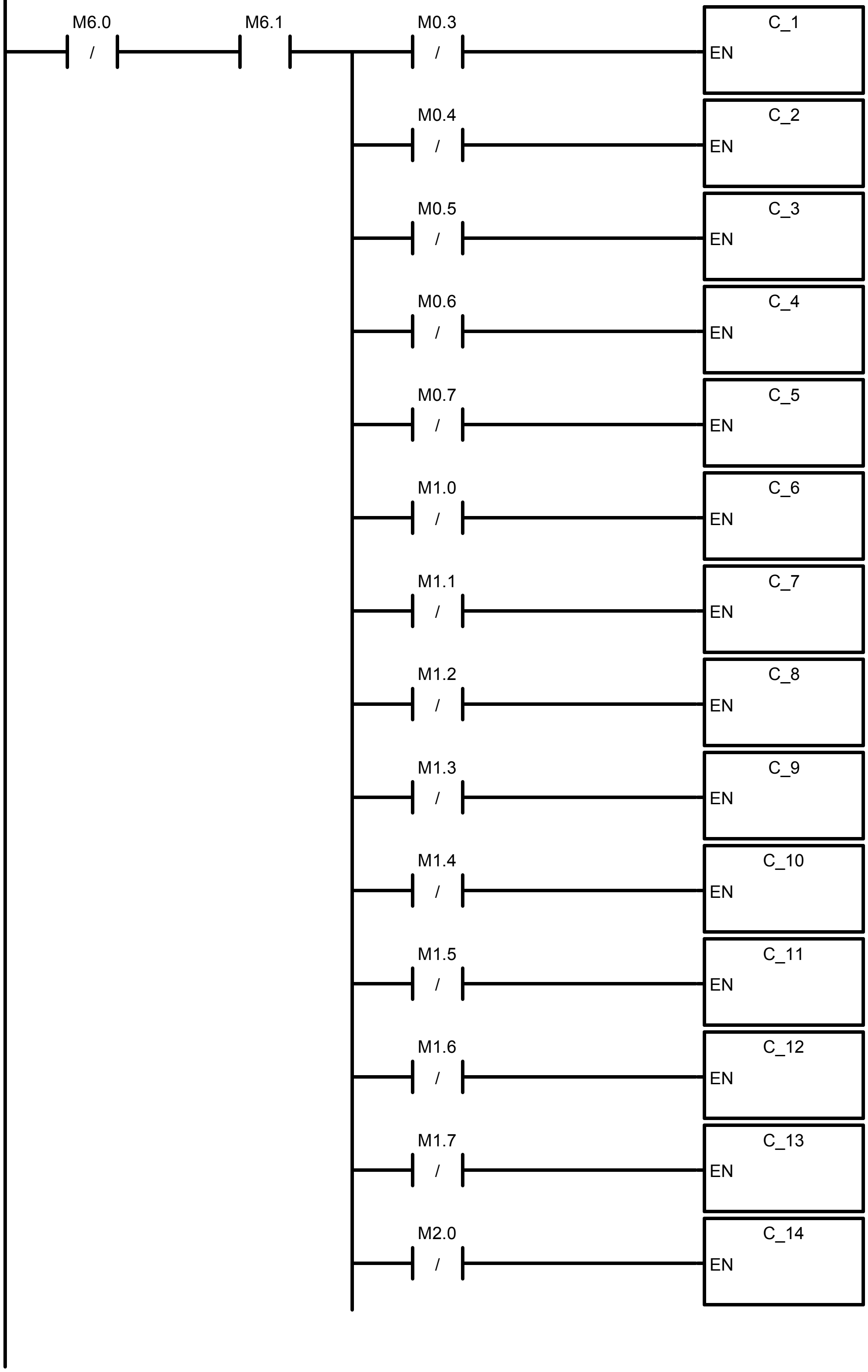
Network 2

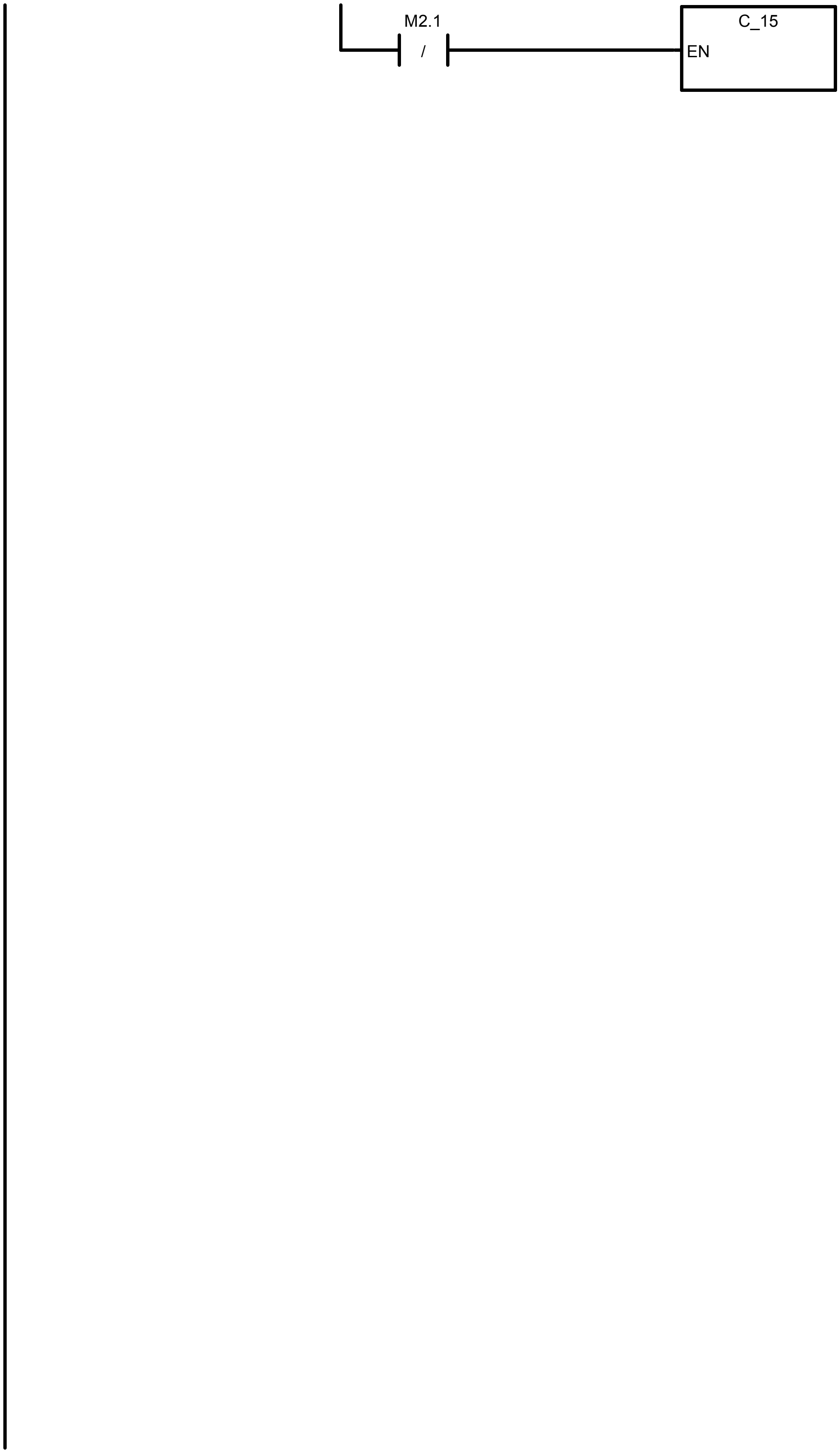
After setting the counter with the number of times the cycle to repeat, the push button of the leak operating mode must be pressed (button 3). This will launch the wear probes.



Network 3 Network Title

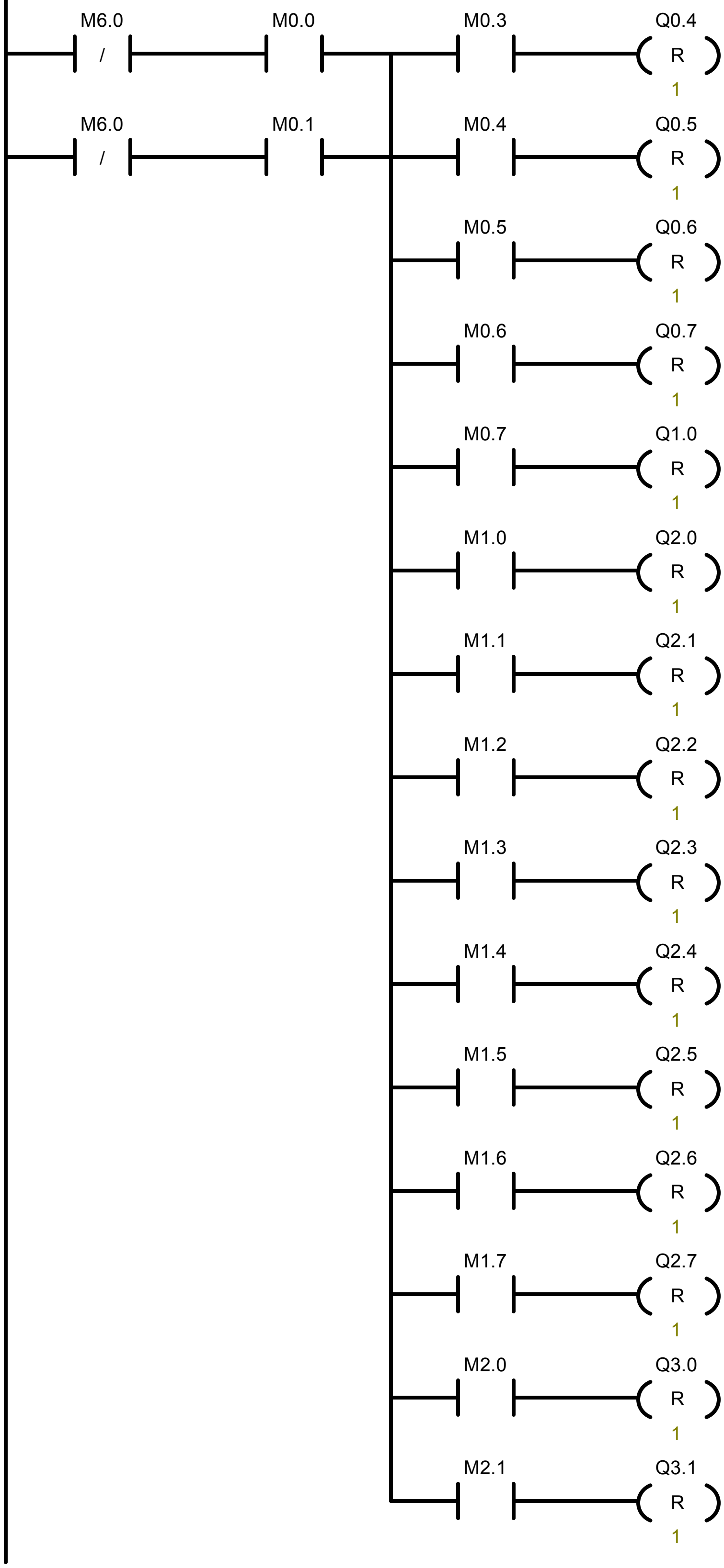
When on of the two operating modes are pressed (normal operating mode or wear operating mode),
the system will wait until the user set the number of times that wants the cycles to repeat.
After setting the number of times and the cylinders that must perform the test,
the user must press the button 3.




M2.1
/
C_15
EN

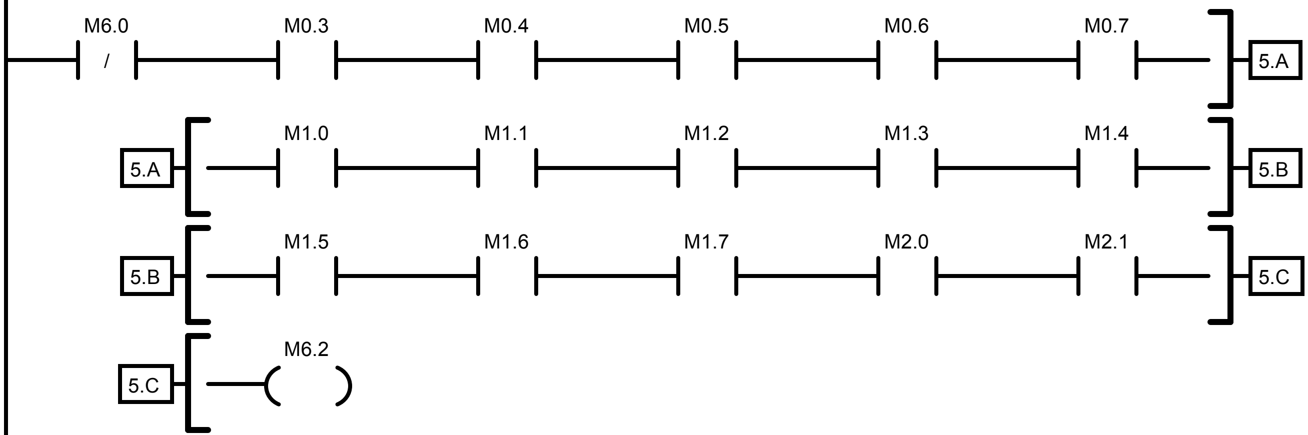
Network 4

This Network will reset the valves of each cylinder if the Test is done and the cylinder is broken.



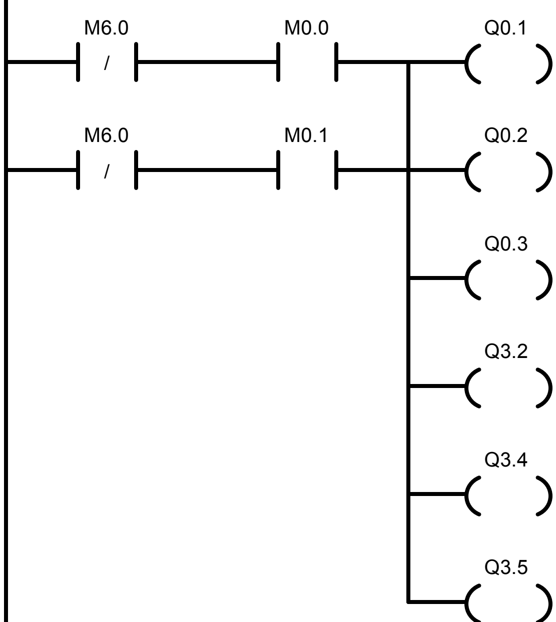
Network 5

This is intended to wait that all the cylinders finish the wear test in order to get out of the subroutine.
activating state M6.2



Network 6

Activate all the low pressure supplies and activate the blocking valves,
letting the free flow of pressurized air.



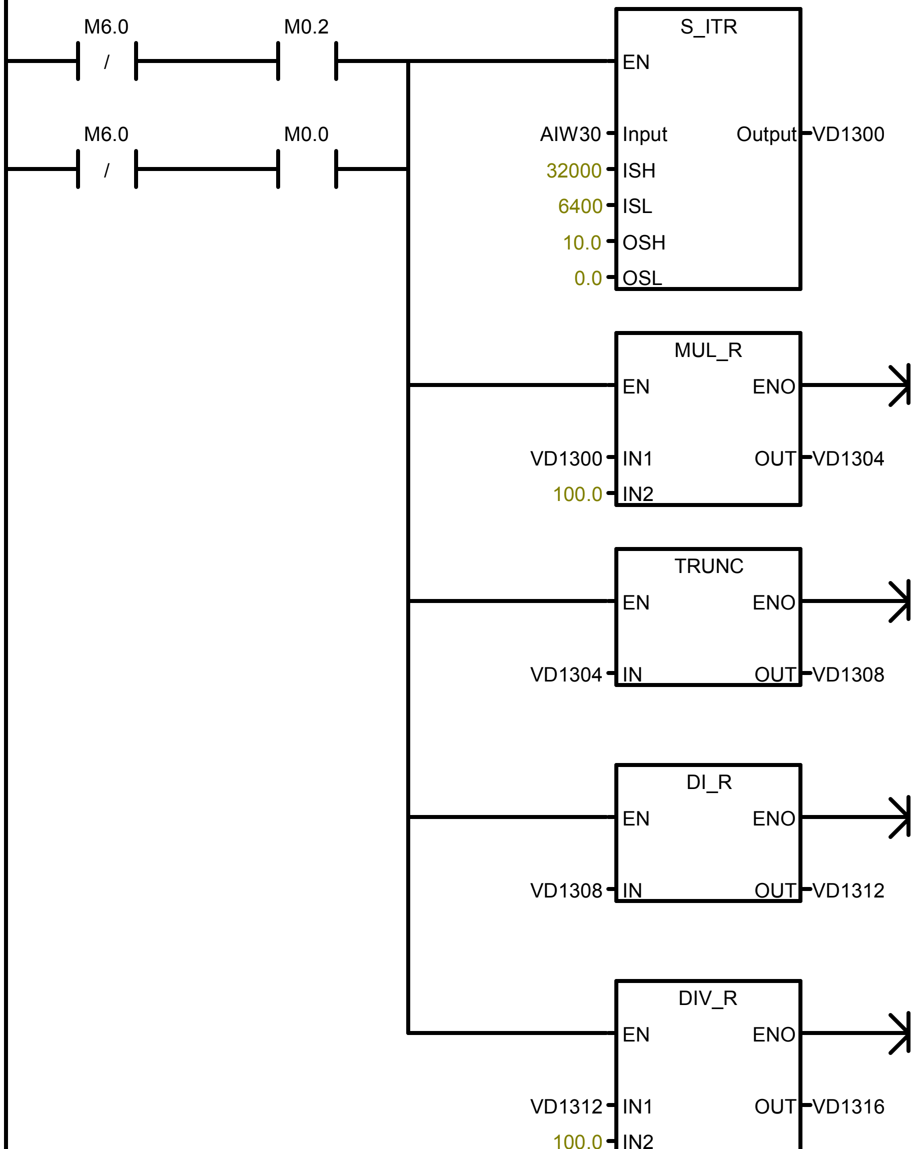
Block: Leak
Author: Heiller Andres Torres Barona
Created: 03/06/2018 06:09:45 pm
Last Modified: 04/02/2018 07:37:43 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

SUBROUTINE COMMENTS

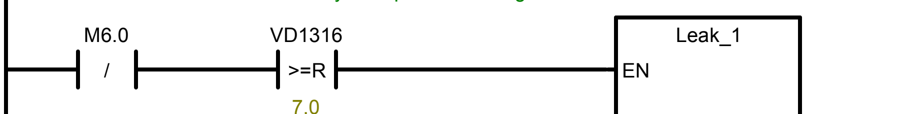
Network 1 Network Title

This network will messure the pressure of the whole system.



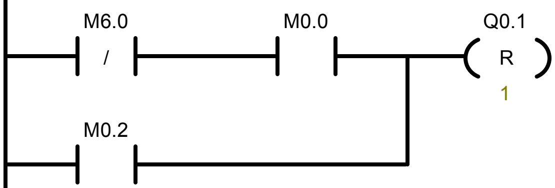
Network 2 Network Title

This network will active leak if the system pressure is higher than 7 bars.



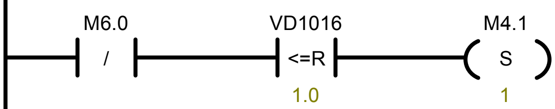
Network 3

This network will reset low pressure valve when the wear is done prior than to the leak test.



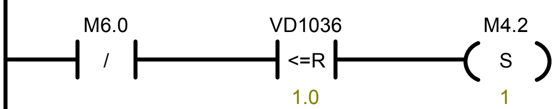
Network 4

This network will determine if C1 is broken and pressure gets lower than 1 bar.



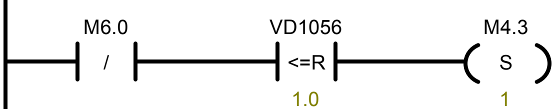
Network 5

This network will determine if C2 is broken and pressure gets lower than 1 bar.



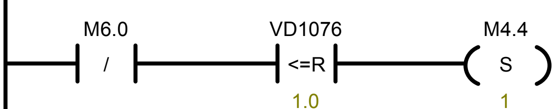
Network 6

This network will determine if C3 is broken and pressure gets lower than 1 bar.



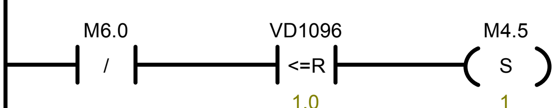
Network 7

This network will determine if C4 is broken and pressure gets lower than 1 bar.



Network 8

This network will determine if C5 is broken and pressure gets lower than 1 bar.



Network 9

This network will determine if C6 is broken and pressure gets lower than 1 bar.

M6.0 ─┤ / ├─ VD1116 ┤ <=R ├ 1.0 ─(S) M4.6, 1

Network 10

This network will determine if C7 is broken and pressure gets lower than 1 bar.

M6.0 ─┤ / ├─ VD1136 ┤ <=R ├ 1.0 ─(S) M4.7, 1

Network 11

This network will determine if C8 is broken and pressure gets lower than 1 bar.

M6.0 ─┤ / ├─ VD1156 ┤ <=R ├ 1.0 ─(S) M5.0, 1

Network 12

This network will determine if C9 is broken and pressure gets lower than 1 bar.

M6.0 ─┤ / ├─ VD1176 ┤ <=R ├ 1.0 ─(S) M5.1, 1

Network 13

This network will determine if C10 is broken and pressure gets lower than 1 bar.

M6.0 ─┤ / ├─ VD1196 ┤ <=R ├ 1.0 ─(S) M5.2, 1

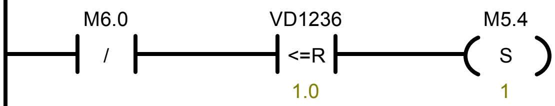
Network 14

This network will determine if C11 is broken and pressure gets lower than 1 bar.

M6.0 ─┤ / ├─ VD1216 ┤ <=R ├ 1.0 ─(S) M5.3, 1

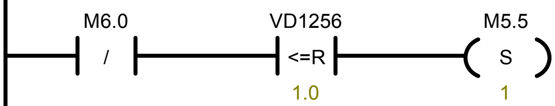
Network 15

This network will determine if C12 is broken and pressure gets lower than 1 bar.



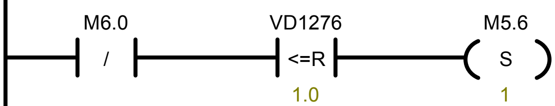
Network 16

This network will determine if C13 is broken and pressure gets lower than 1 bar.



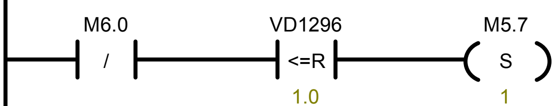
Network 17

This network will determine if C14 is broken and pressure gets lower than 1 bar.



Network 18

This network will determine if C15 is broken and pressure gets lower than 1 bar.



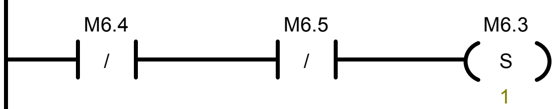
Block: Leak_1
Author: Heiller Andres Torres Barona
Created: 03/06/2018 06:09:53 pm
Last Modified: 03/26/2018 04:35:27 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

SUBROUTINE COMMENTS

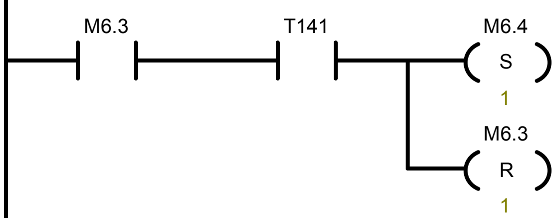
Network 1

If the start of the leak this network will execute.



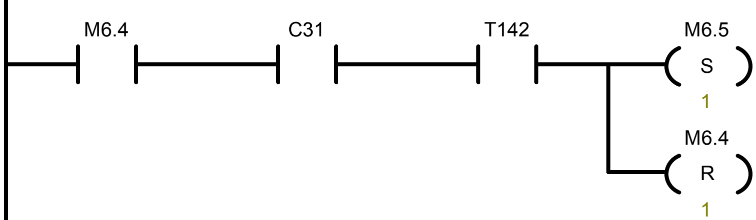
Network 2

This is for the control logic and will set state M6.4 only if state M6.3 and timer T141 are present.



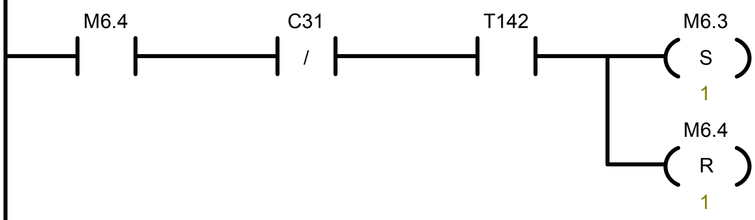
Network 3

This is for the control logic and will set state M6.5 only if state M6.4, timer T142 and Counter C31 are present.



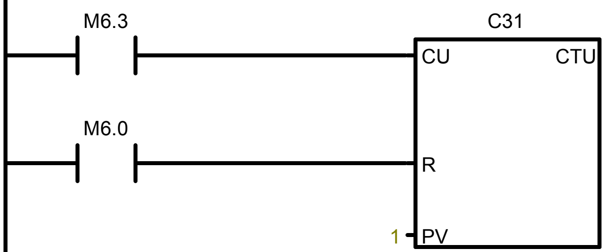
Network 4

This is for the control logic and will set state M6.3 only if state M6.4 and timer T142 and NO C31 are present.



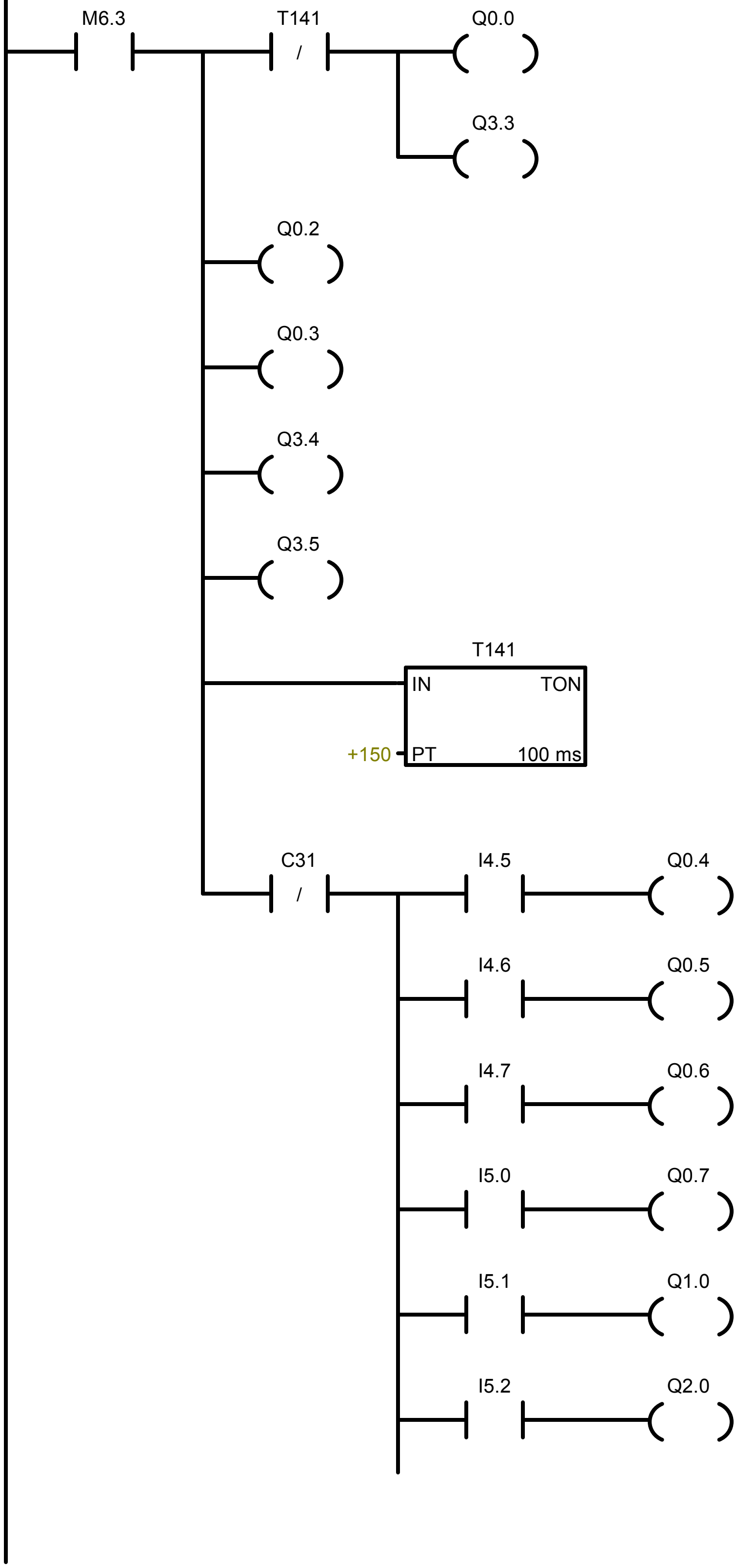
Network 5

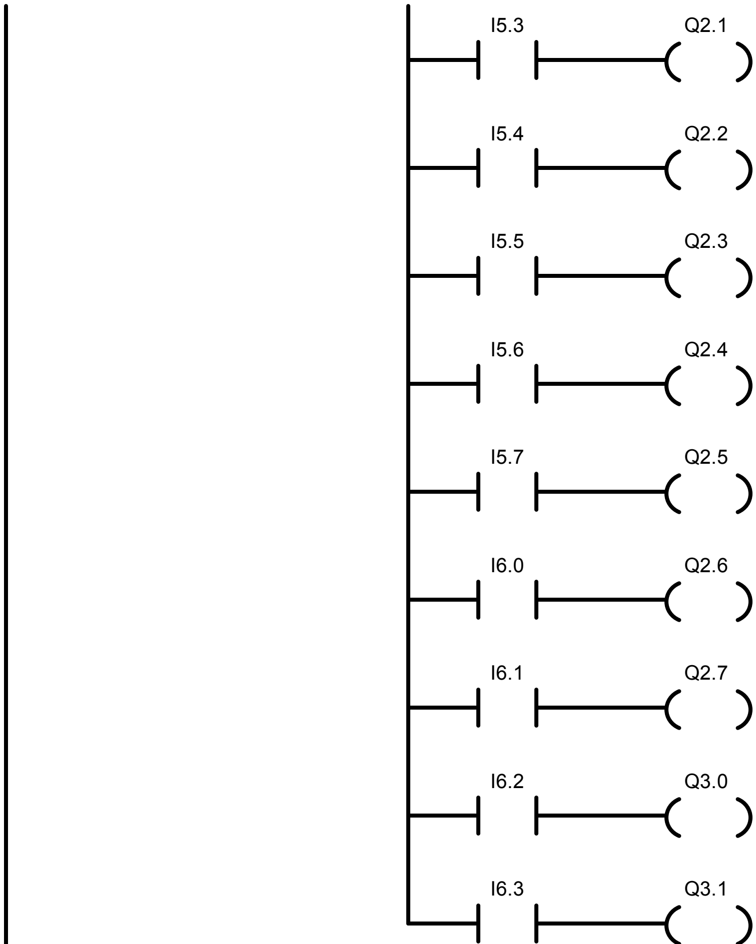
The inside counter to identify in which of the chambers the leak test is performed.



Network 6

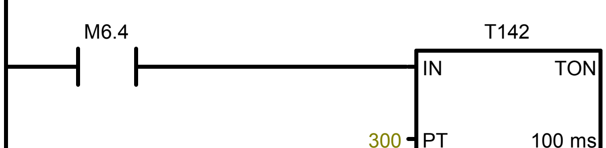
When M6.3 is present, the valve are activated is the test is been performed in the rear chamber and the cylinders are active. If the test is been perform in the anterior chamber, the valves to active the solenoids will not activate.





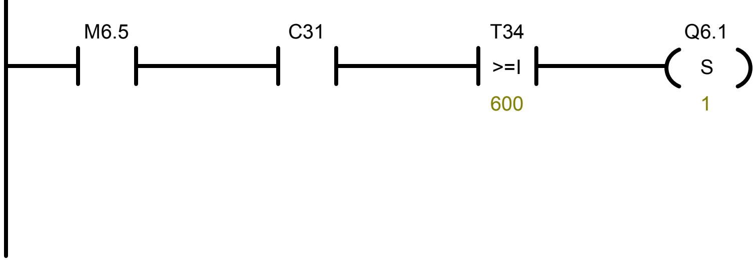
Network 7

If state M6.4 is active, it will activate the timer.



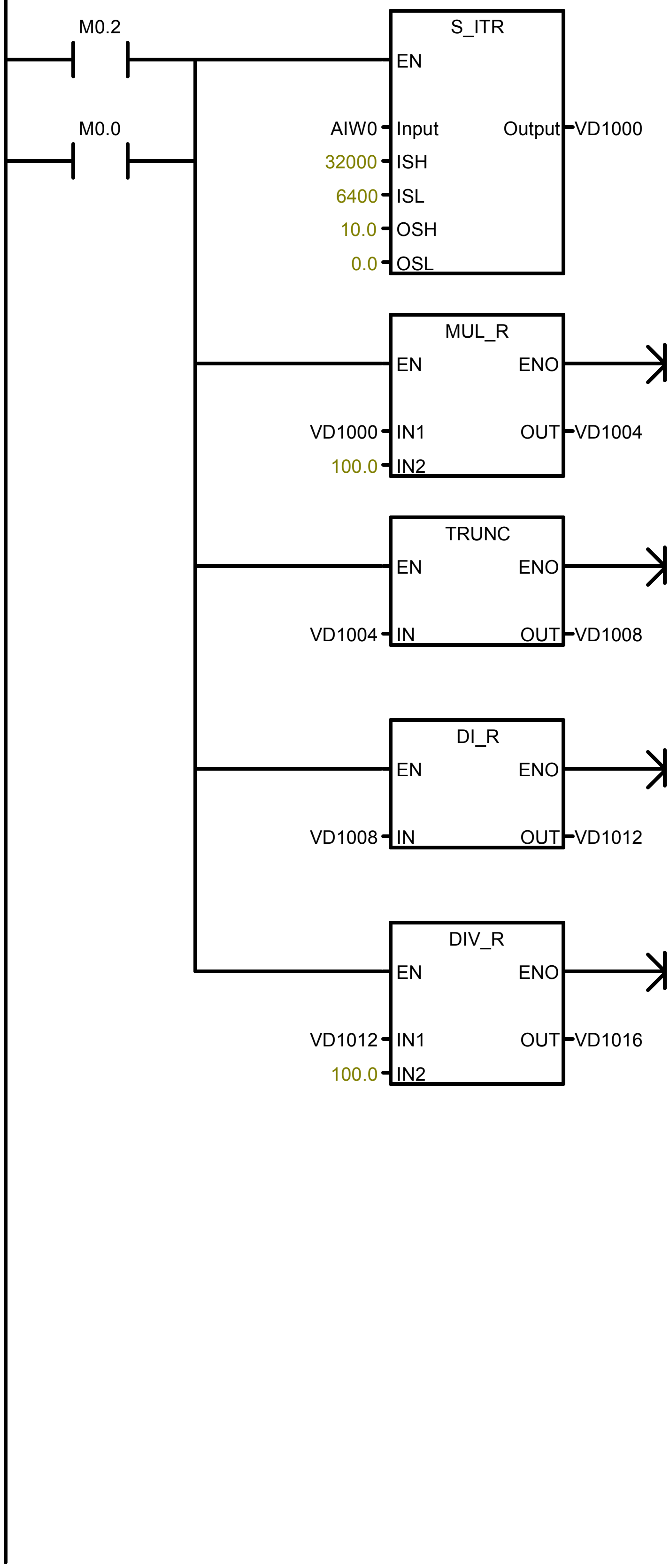
Network 8

If the state M6.5 is done, then the red lamp will light.



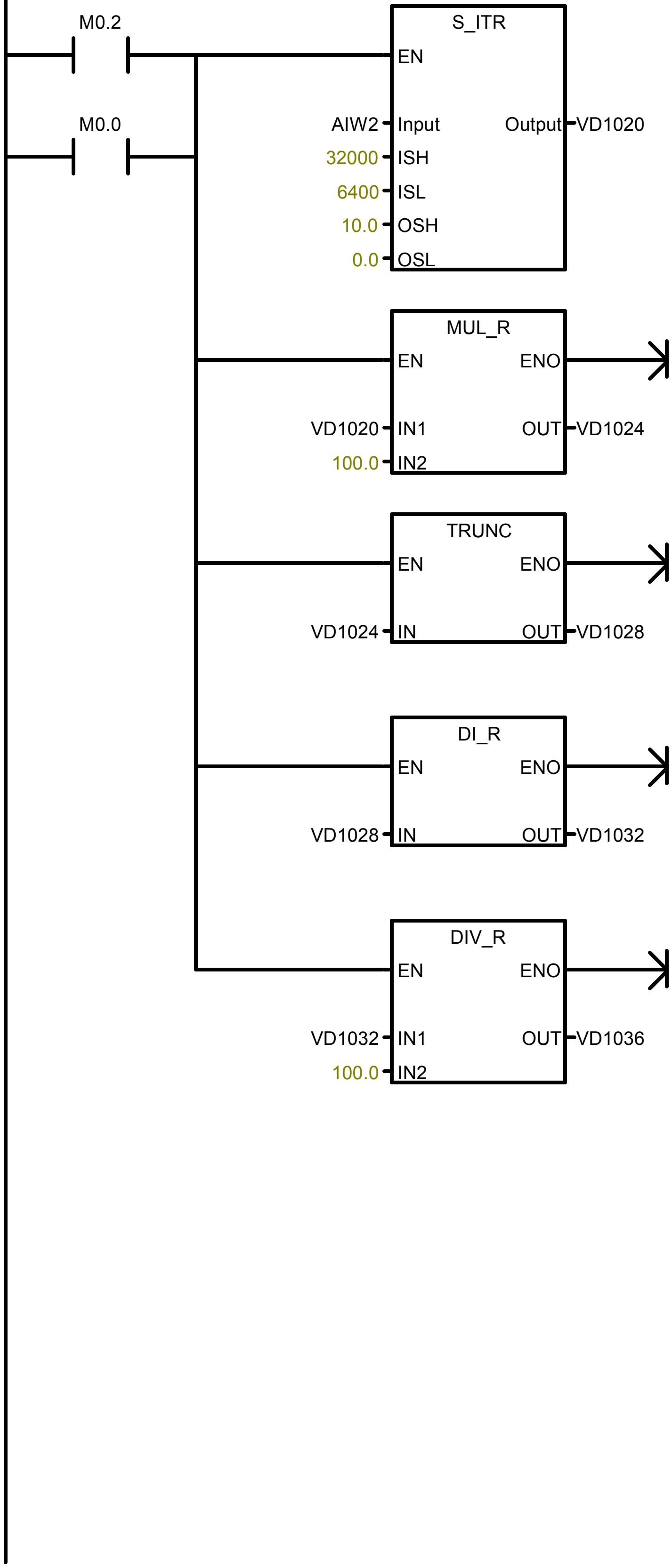
Network 9 Network Title

This network will messure pressure in C1 Chambers.



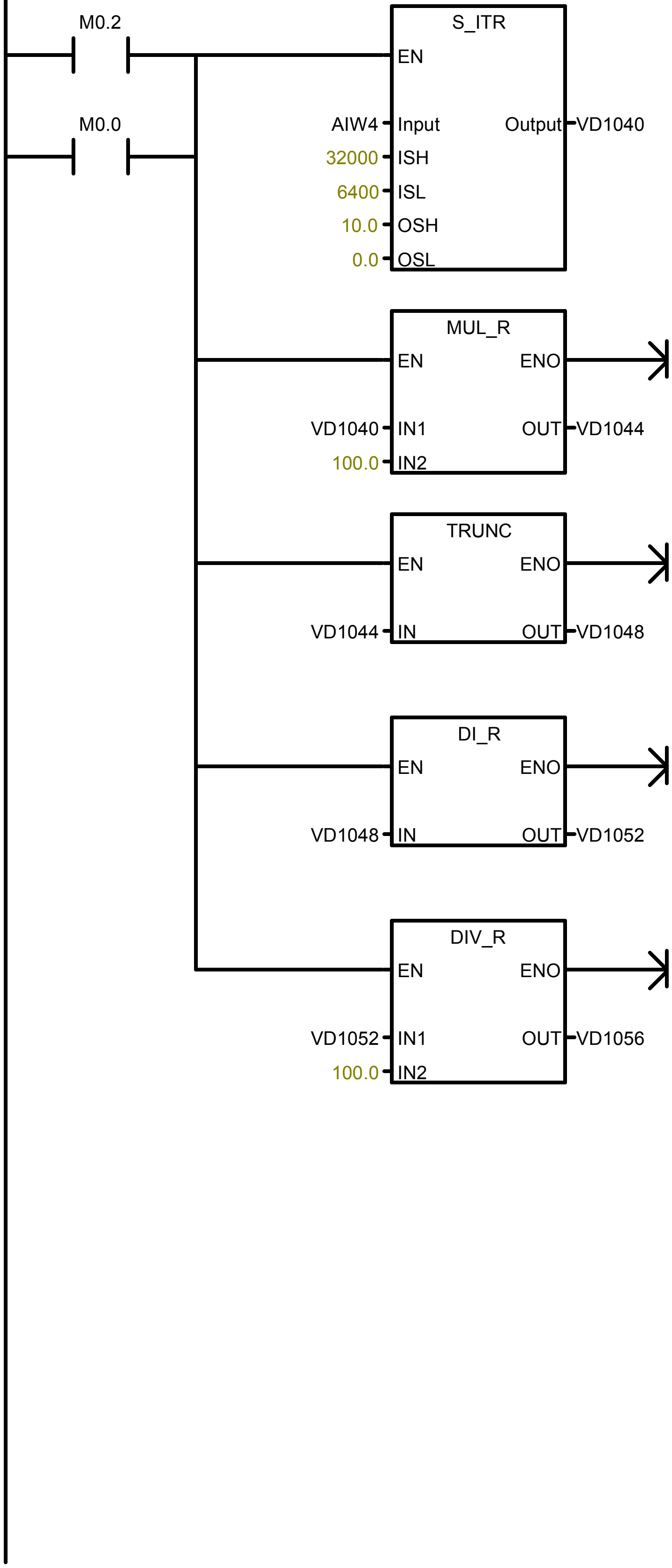
Network 10 Network Title

This network will messure pressure in C2 Chambers.



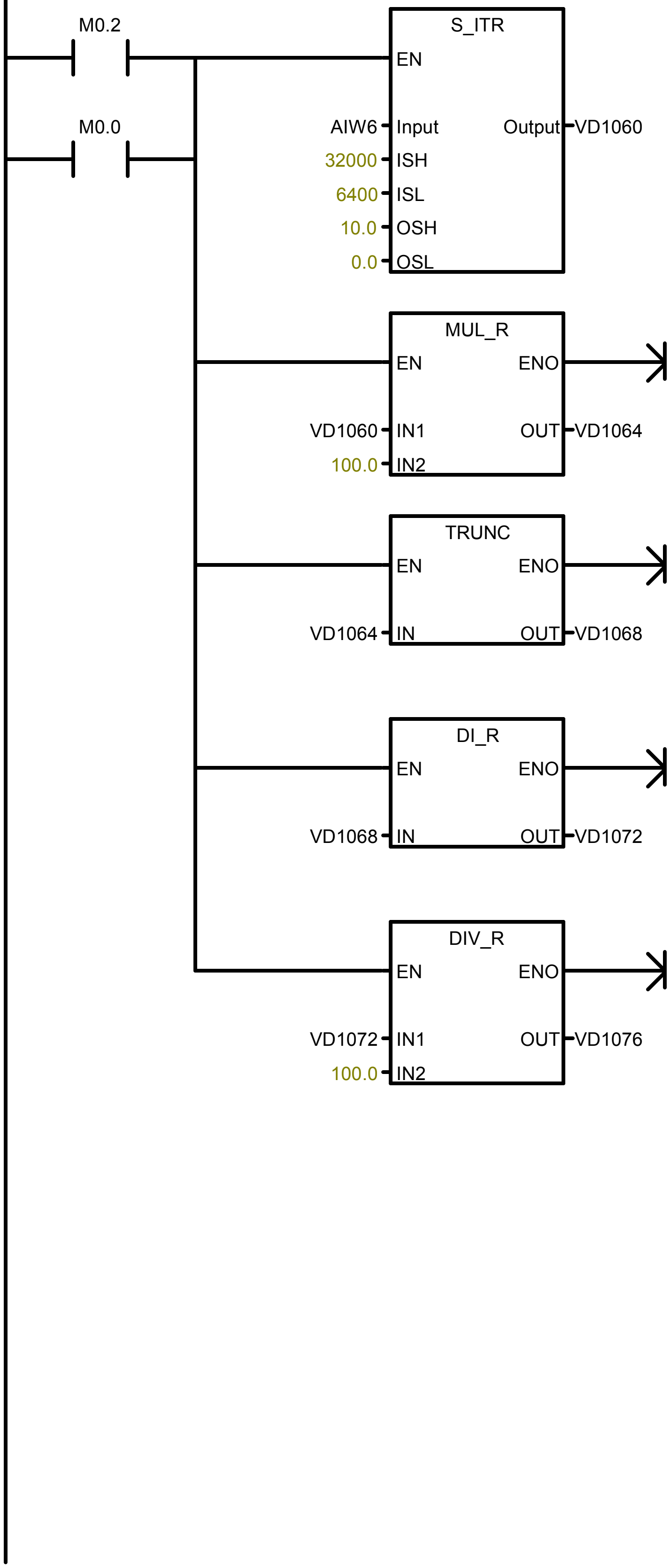
Network 11 Network Title

This network will messure pressure in C3 Chambers.



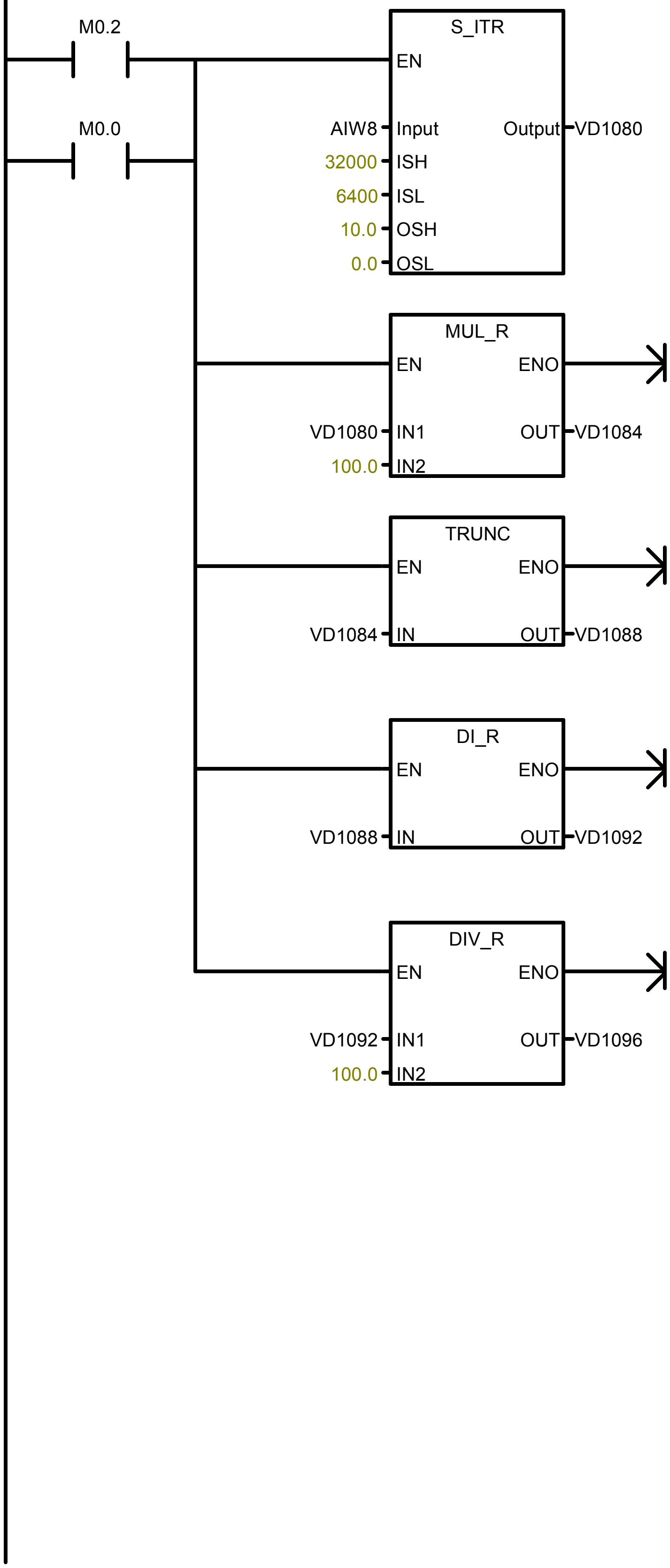
Network 12 Network Title

This network will messure pressure in C4 Chambers.



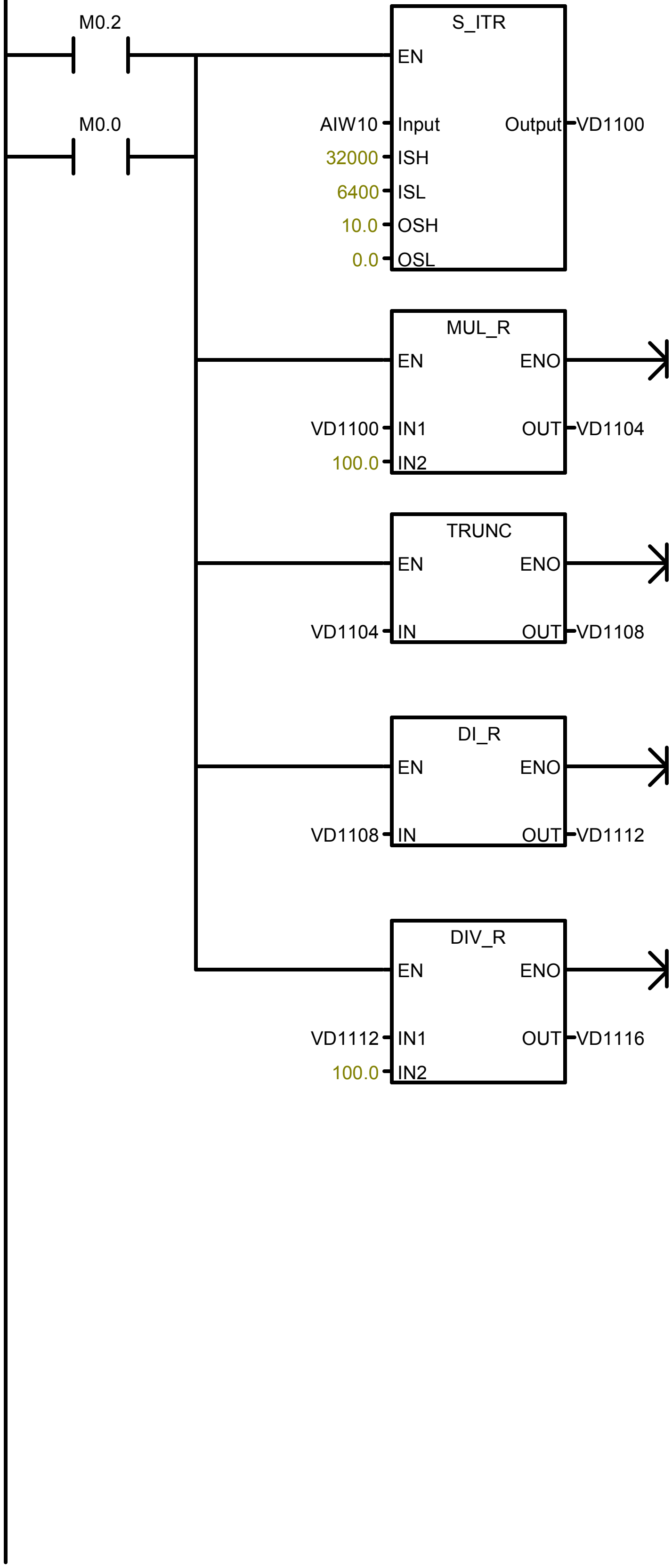
Network 13 Network Title

This network will messure pressure in C5 Chambers.



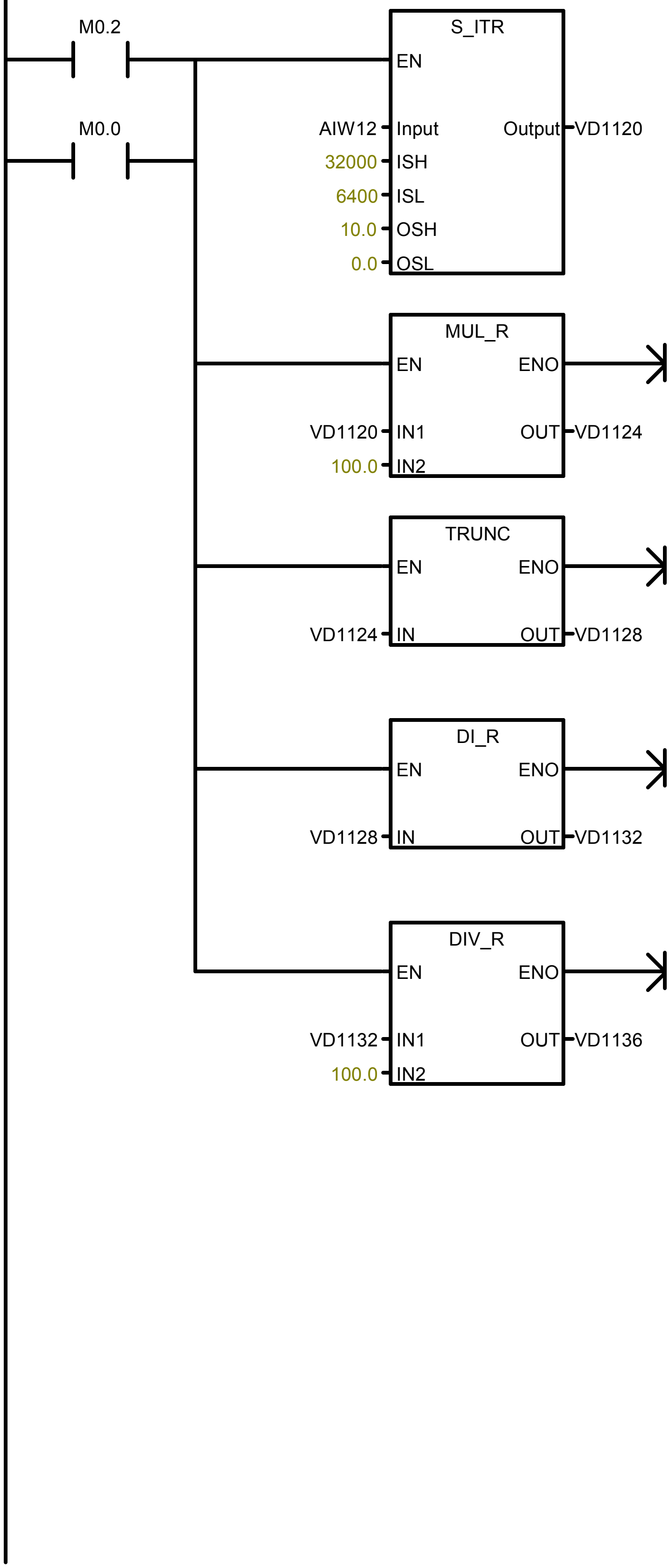
Network 14 Network Title

This network will messure pressure in C6 Chambers.



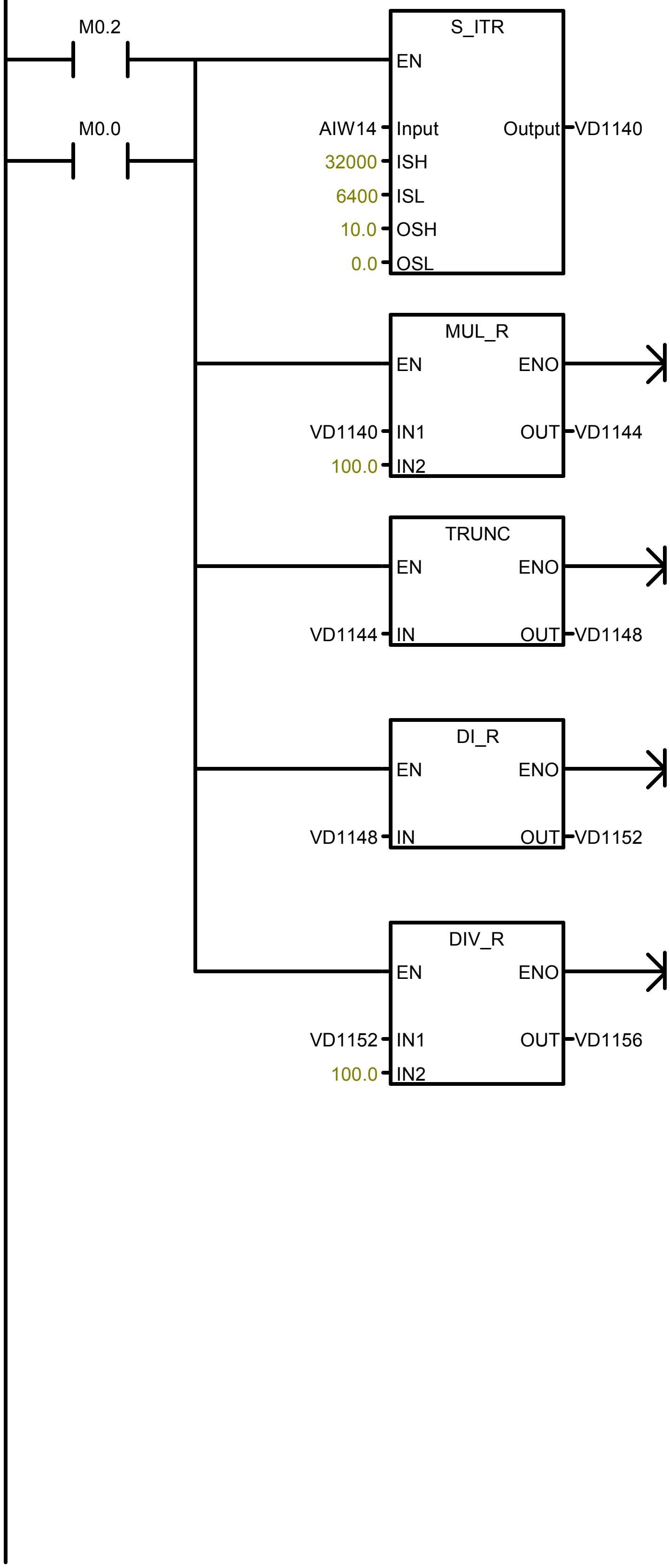
Network 15 Network Title

This network will messure pressure in C7 Chambers.



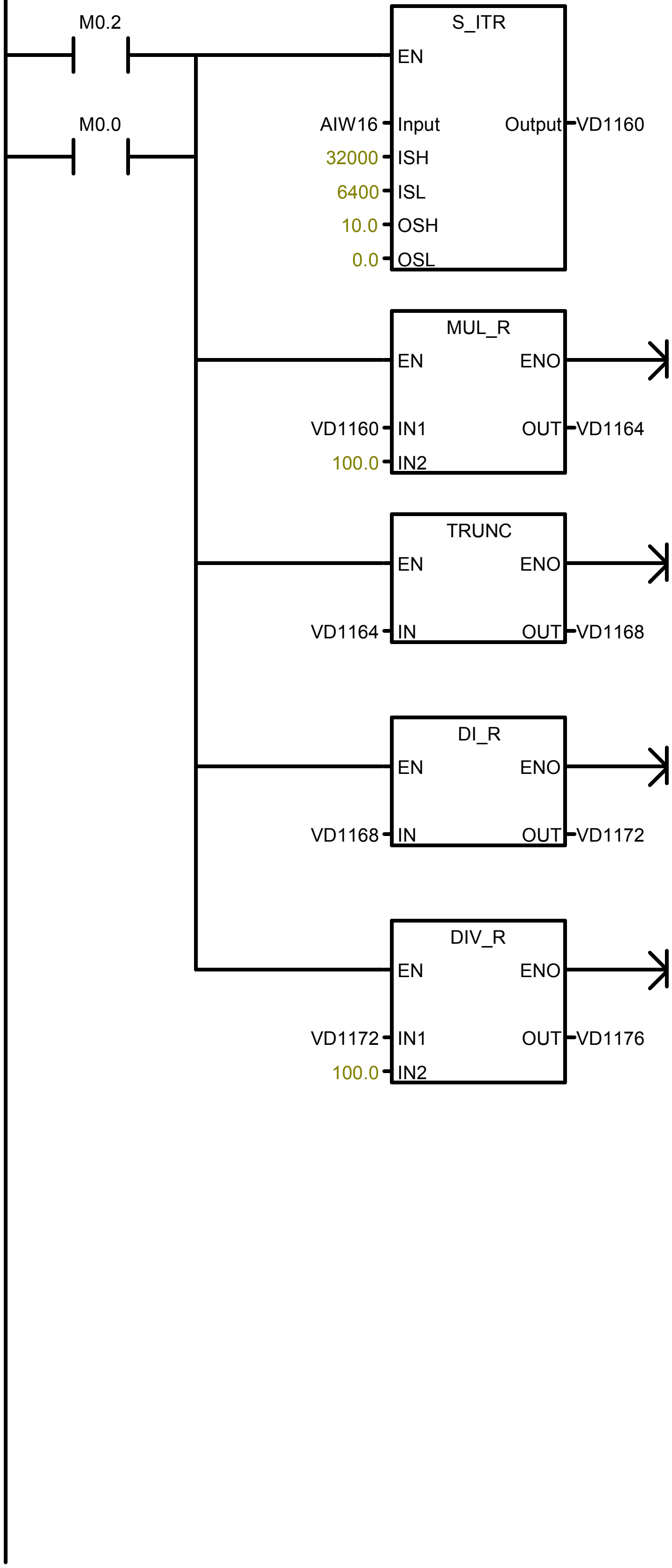
Network 16 Network Title

This network will messure pressure in C8 Chambers.



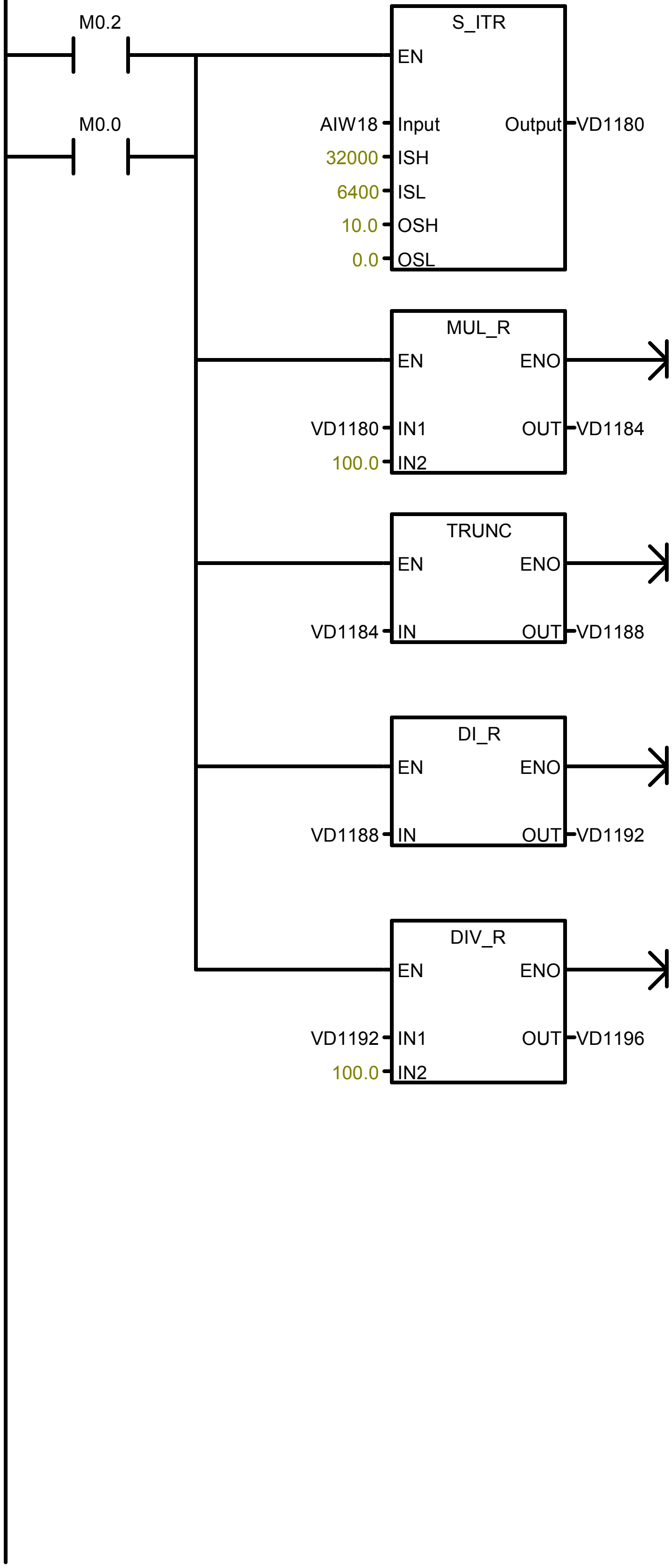
Network 17 Network Title

This network will messure pressure in C9 Chambers.



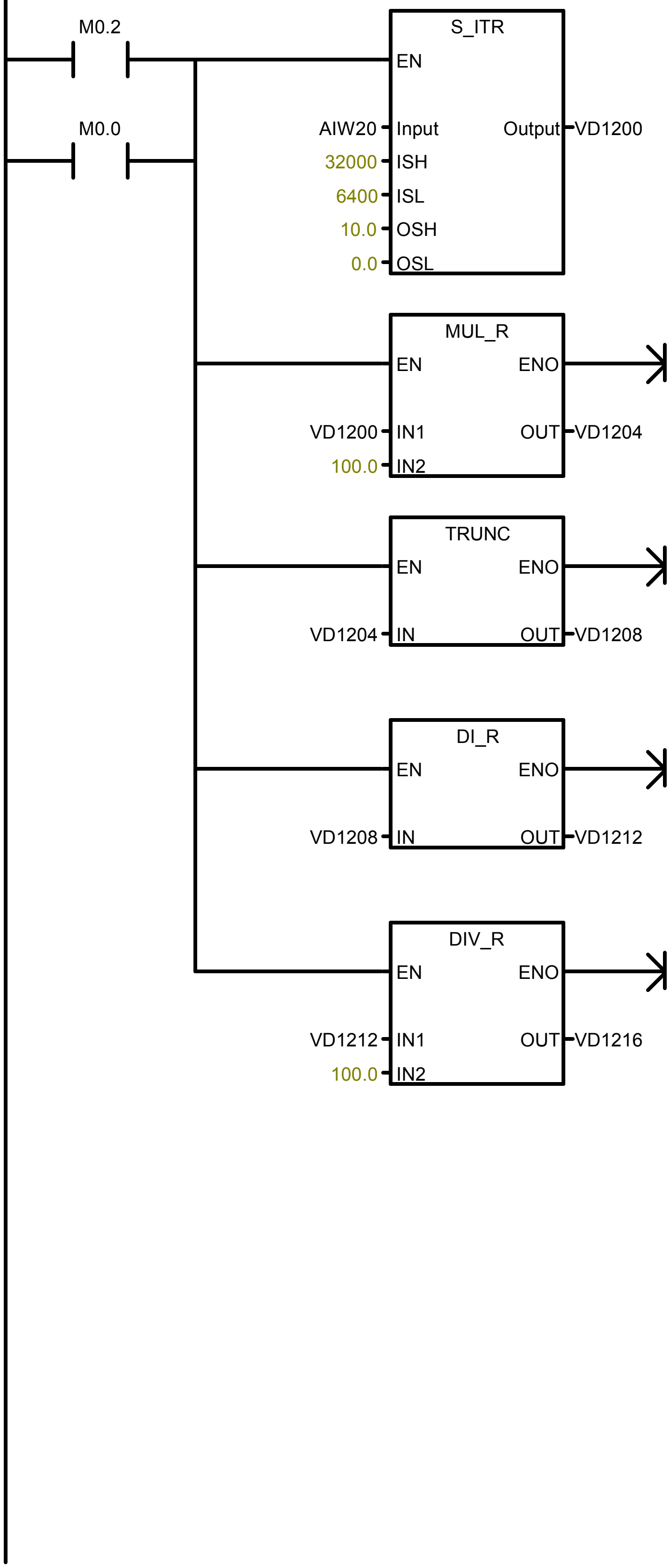
Network 18 Network Title

This network will messure pressure in C10 Chambers.



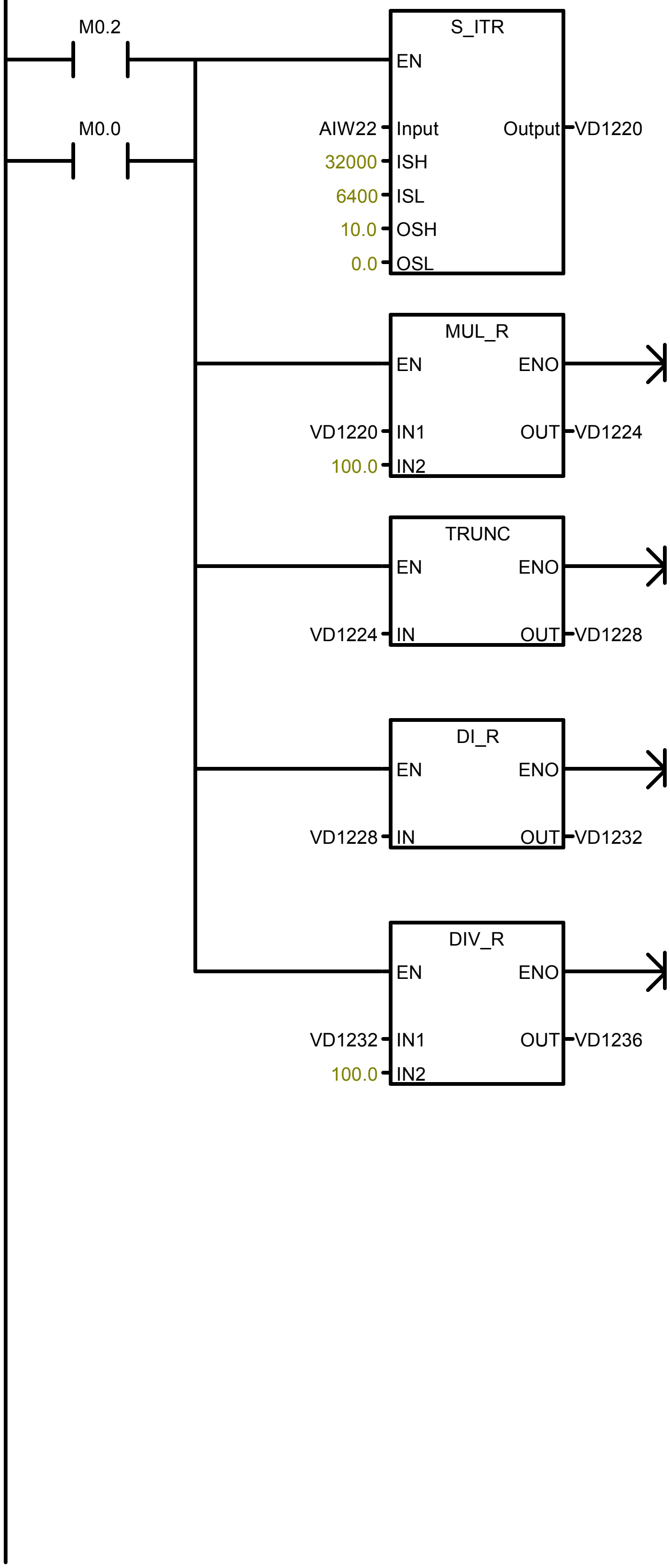
Network 19 Network Title

This network will messure pressure in C11 Chambers.



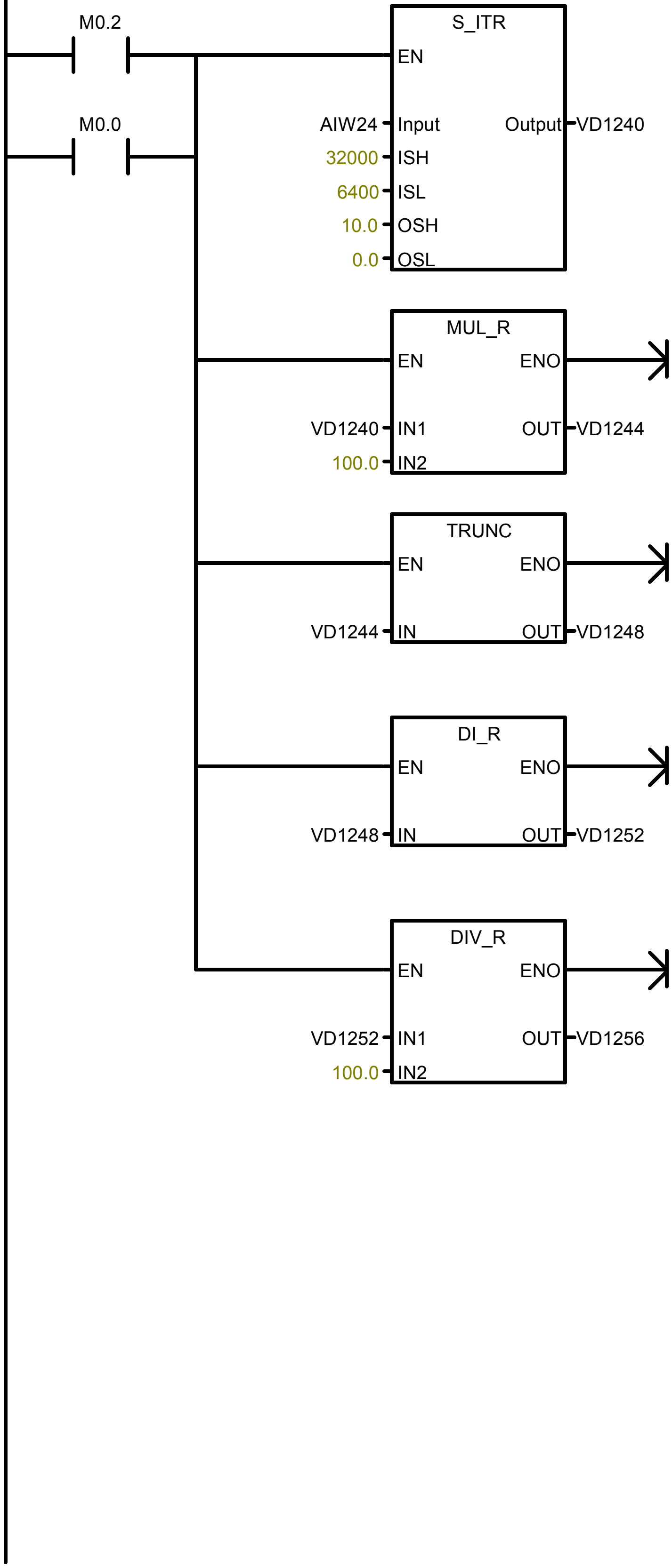
Network 20 Network Title

This network will messure pressure in C12 Chambers.



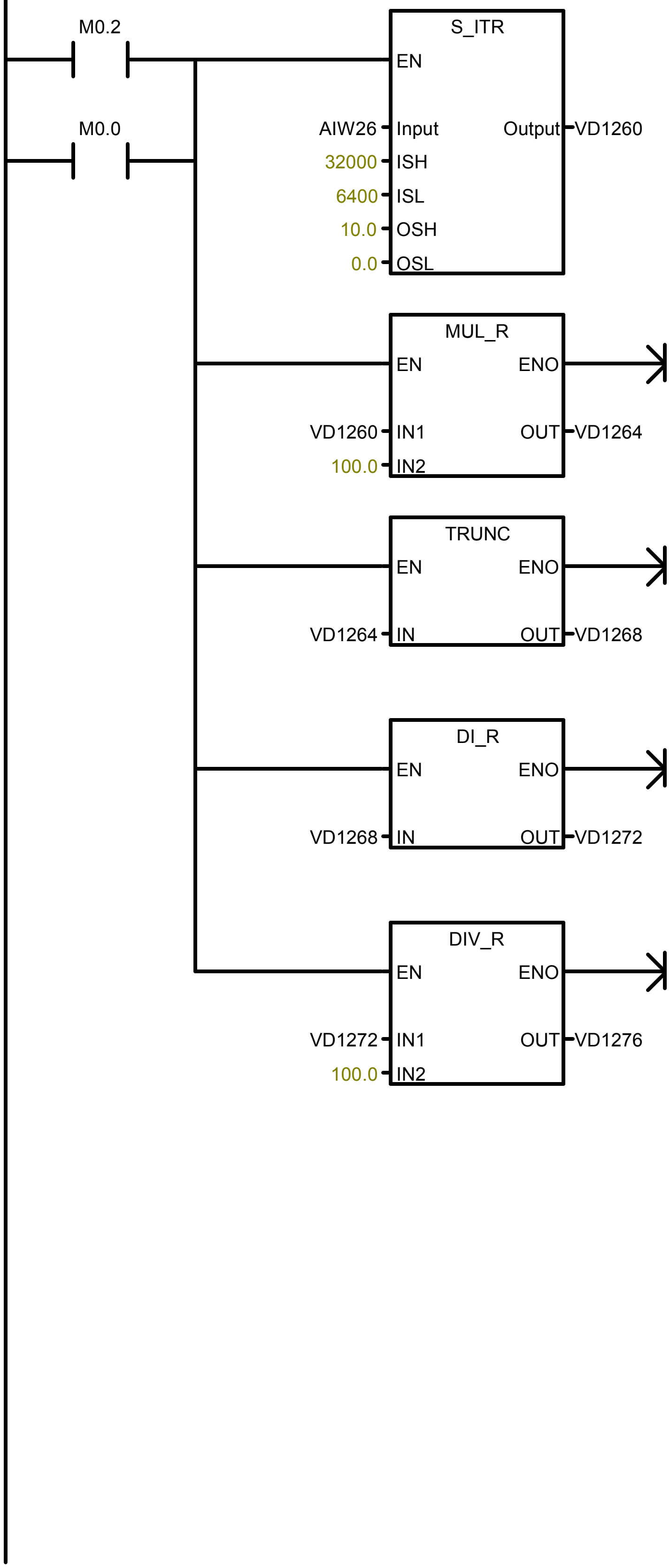
Network 21 Network Title

This network will messure pressure in C13 Chambers.



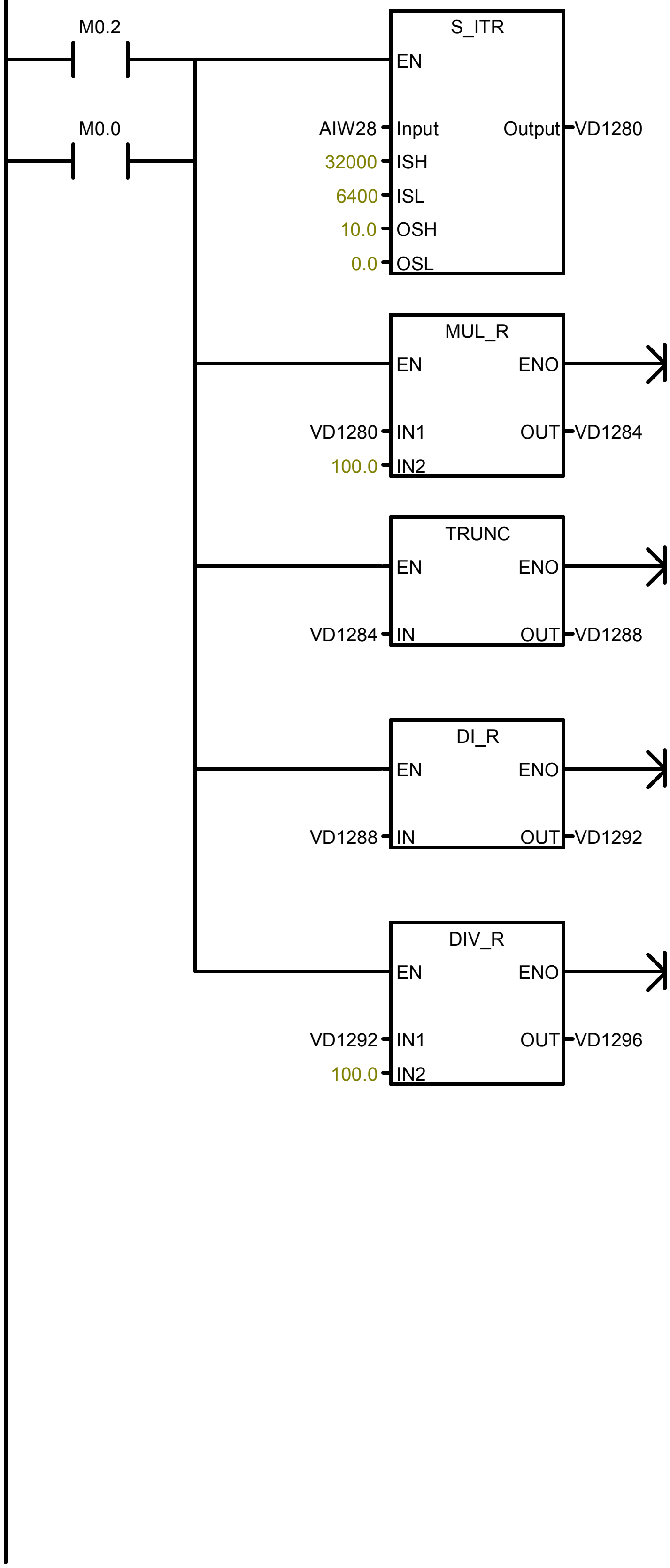
Network 22 Network Title

This network will messure pressure in C14 Chambers.



Network 23 Network Title

This network will messure pressure in C15 Chambers.



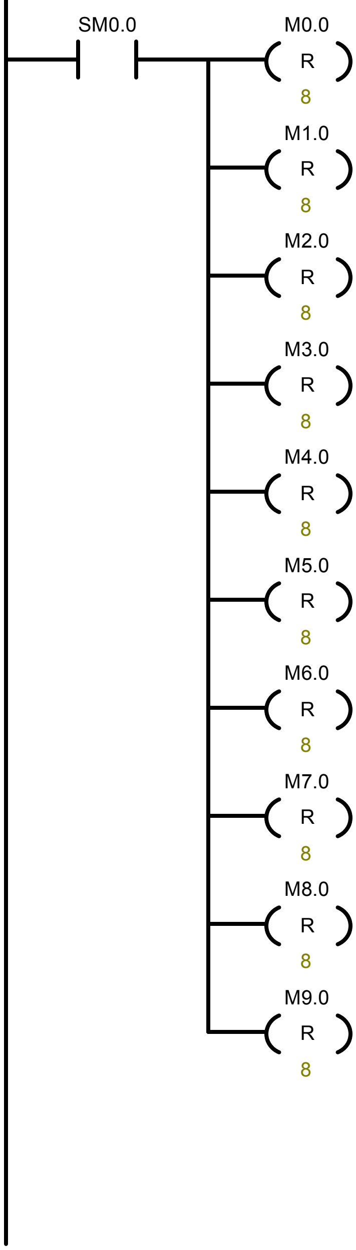
Block: Start
Author: Heiller Andres Torres Barona
Created: 03/06/2018 07:02:37 pm
Last Modified: 04/02/2018 07:47:24 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

SUBROUTINE COMMENTS

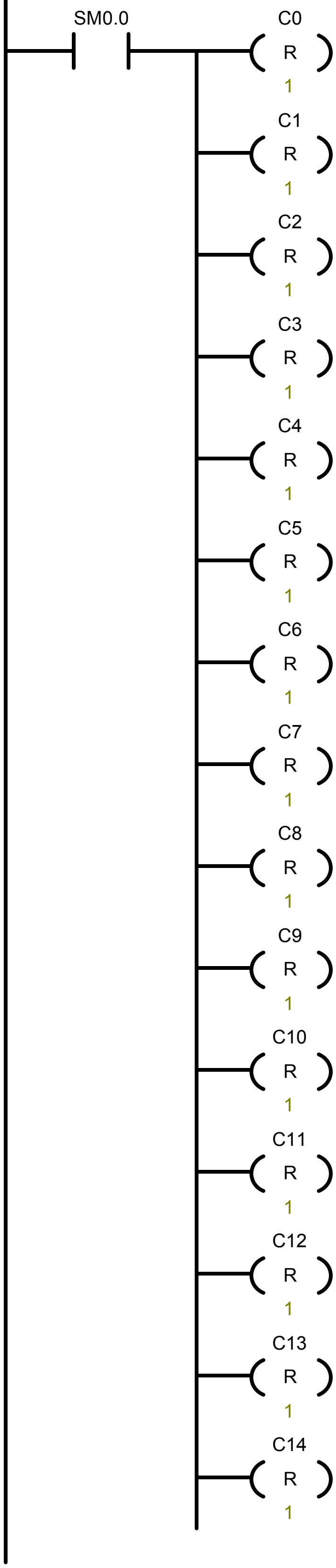
Network 1 Network Title

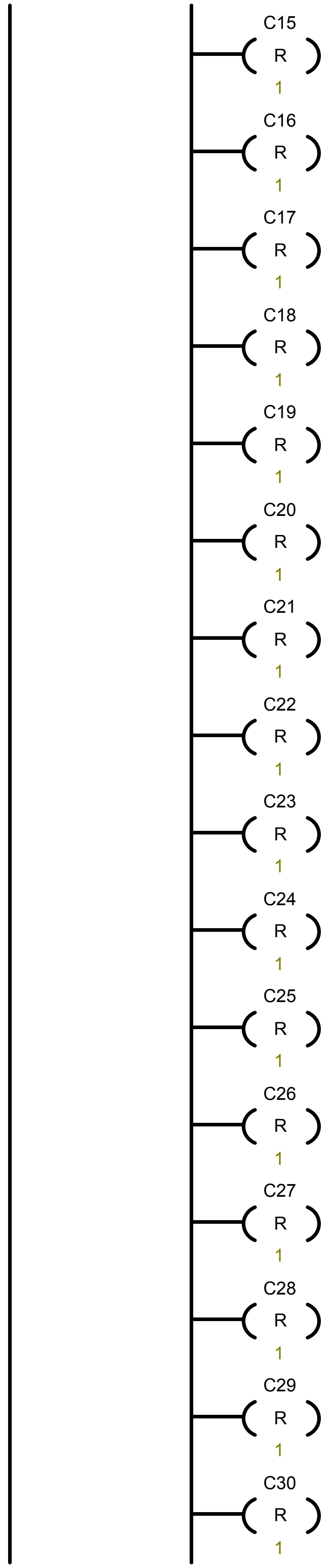
Resets the Auxiliary Memories Used in the Wear Subroutine



Network 2 Network Title

Resets the counter in each of the subroutines of the cylinders.

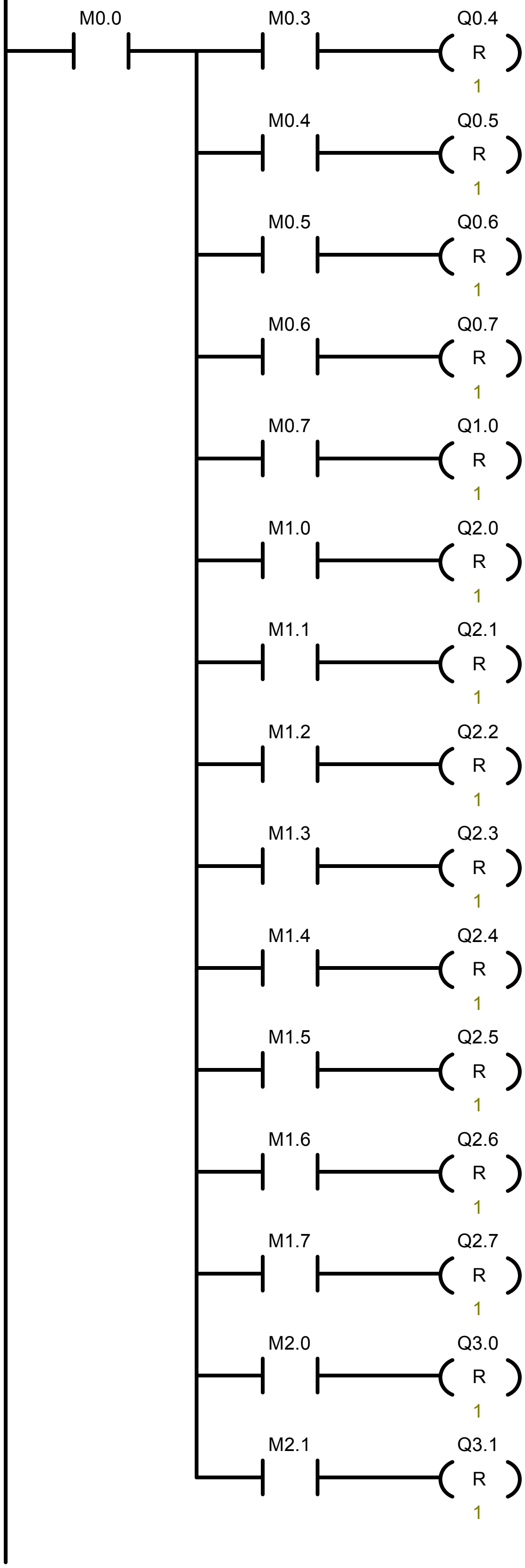



C15
R
1
C16
R
1
C17
R
1
C18
R
1
C19
R
1
C20
R
1
C21
R
1
C22
R
1
C23
R
1
C24
R
1
C25
R
1
C26
R
1
C27
R
1
C28
R
1
C29
R
1
C30
R
1


C31
R
1

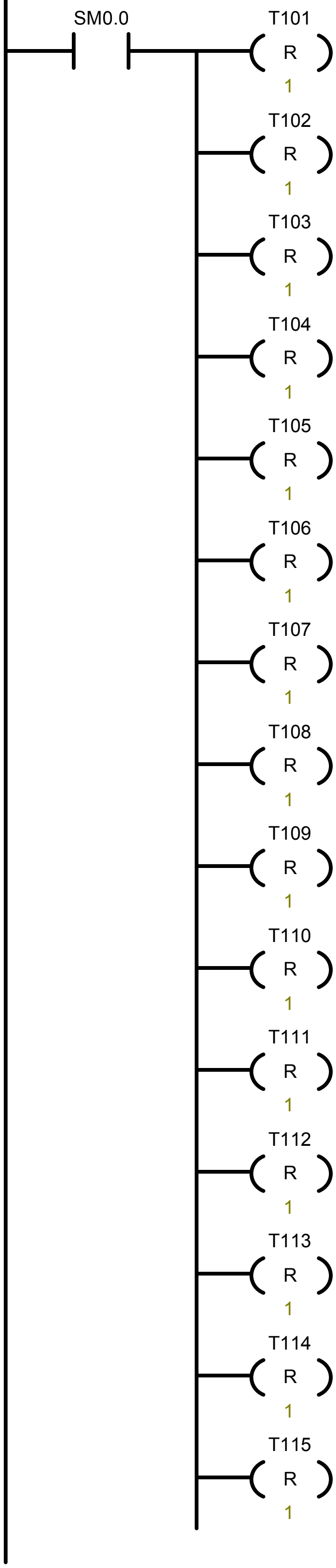
Network 3

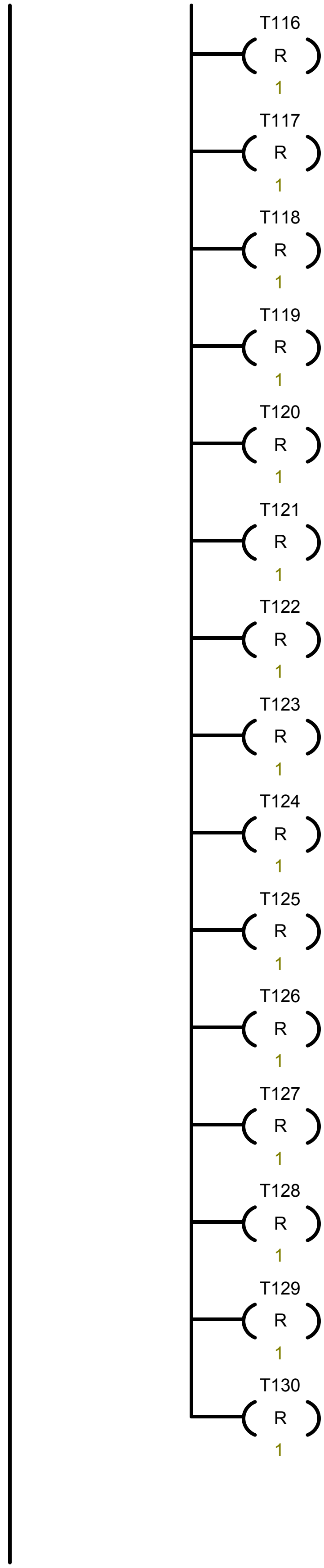
This will reset all the posible activated outputs when reset is pressed



Network 4 Network Title

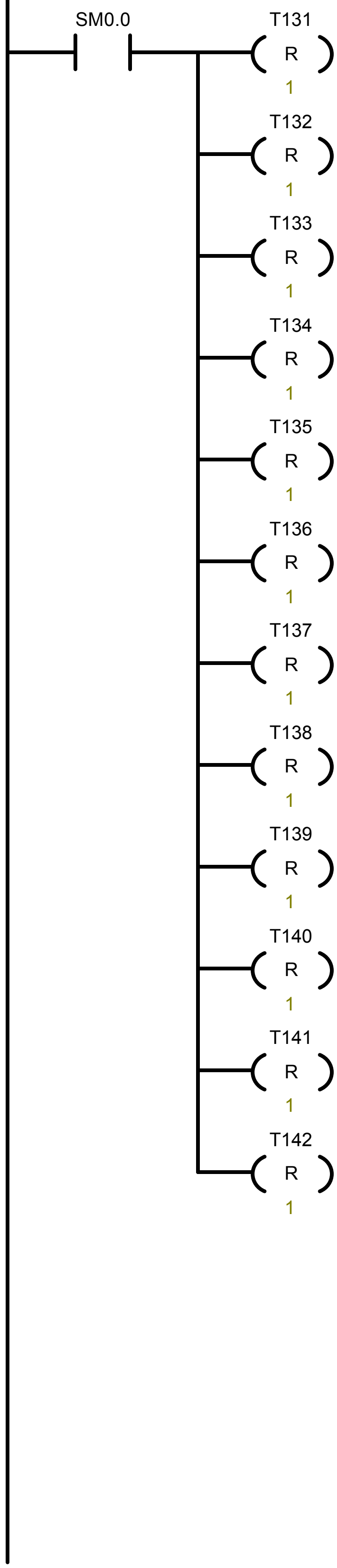
This network will reset all the Timers.




T116
R
1
T117
R
1
T118
R
1
T119
R
1
T120
R
1
T121
R
1
T122
R
1
T123
R
1
T124
R
1
T125
R
1
T126
R
1
T127
R
1
T128
R
1
T129
R
1
T130
R
1

Network 5 Network Title

This Network will continue reseting timers.

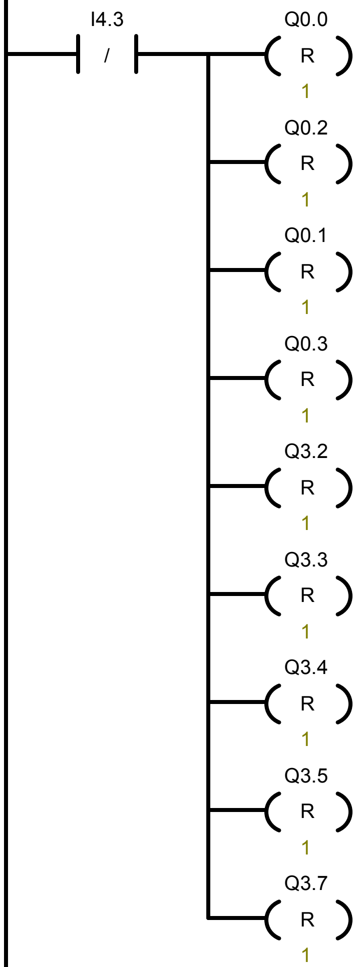


Network 6

When the reset button is pressed then this outputs will be reseted.

Network 7

When the reset button is pressed then this outputs will be reseted.



Network 8

Network 9

Network 10

Network 11

Network 12

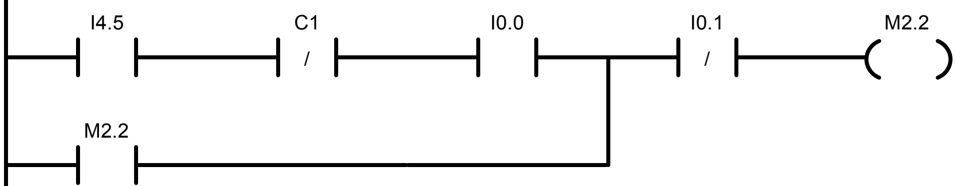
Block: C_1
Author: Heiller Andres Torres Barona
Created: 03/06/2018 07:31:34 pm
Last Modified: 03/26/2018 04:35:27 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

SUBROUTINE COMMENTS

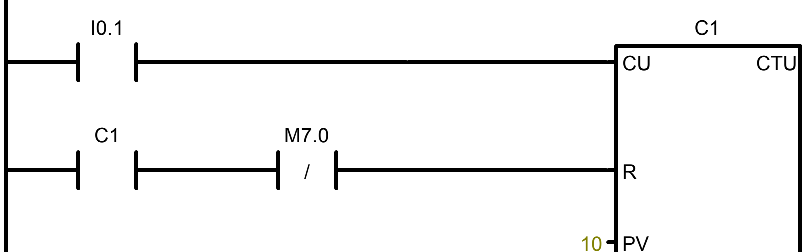
Network 1 Network Title

In this network the state that actuates the cylinder valve is activated.



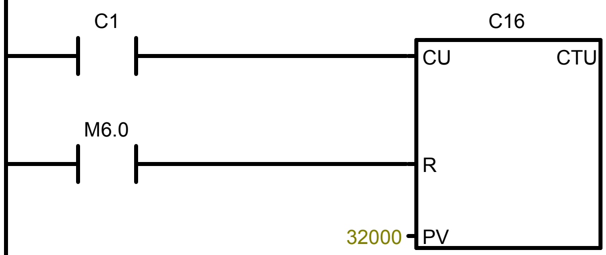
Network 2

The counter is actuated each time the cylinder achieve the outstroke position. It will be reseted when the cylinder achieve the first cycle 30000 times



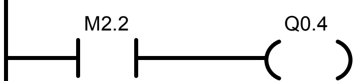
Network 3

This counter will count each time that cylinder 1
has accomplish the 30000 times



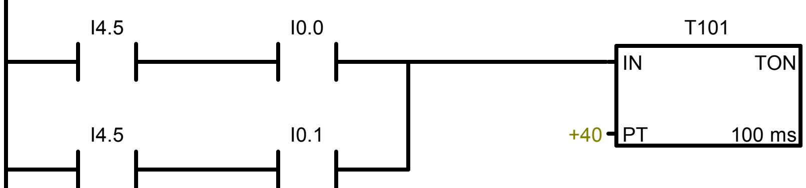
Network 4

This network will actuate the solenoid to actuate
the cylinder.



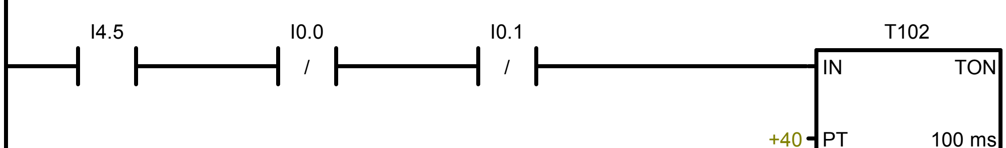
Network 5

This timer will determine if cylinder is broken if the end stroke are
active for more than 4 seconds.



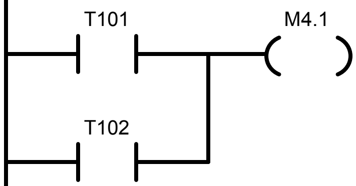
Network 6

This timer will determine if cylinder is broken if no end stroke is
achieved before 4 seconds.



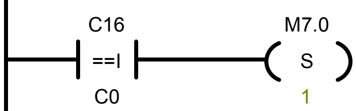
Network 7

If failure is met then the auxiliary memory is activated.



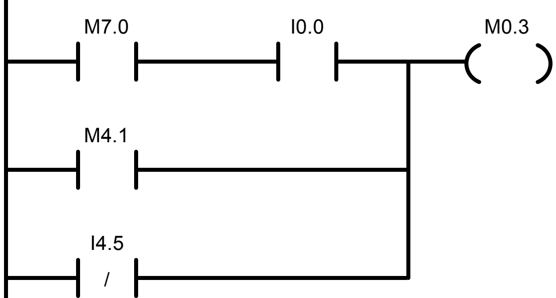
Network 8

This compares if the times that the second counter
is the same of that of the counter in the wear subroutine
if it is the same it will active the auxiliary memory.



Network 9

If one of the three conditions is meet, then the Wear
test in this cylinder is done.

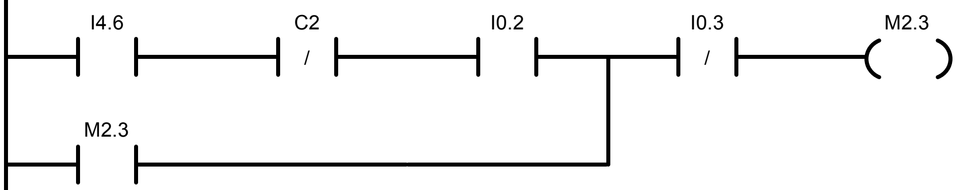


Block: C_2
Author: Heiller Andres Torres Barona
Created: 03/06/2018 07:31:34 pm
Last Modified: 04/02/2018 08:12:21 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

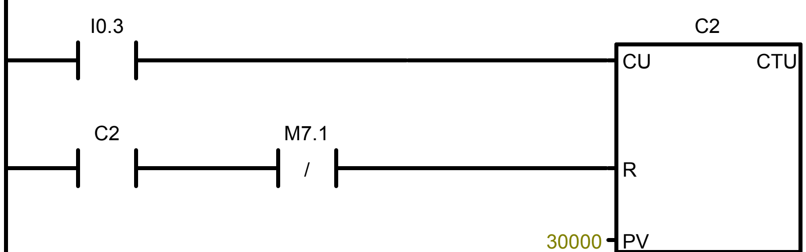
Network 1 Network Title

In this network the state that actuates the cylinder valve is activated.



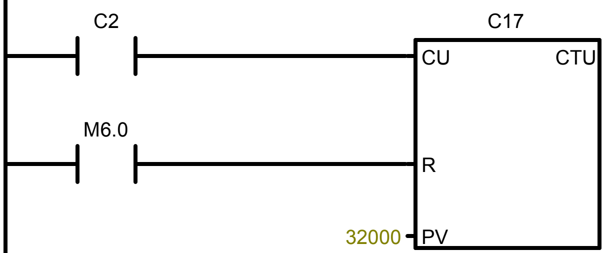
Network 2

The counter is actuated each time the cylinder achieve the outstroke position. It will be reseted when the cylinder achieve the first cycle 30000



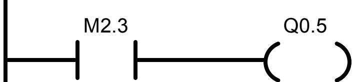
Network 3

This counter will count each time that cylinder
has accomplish the 30000 times



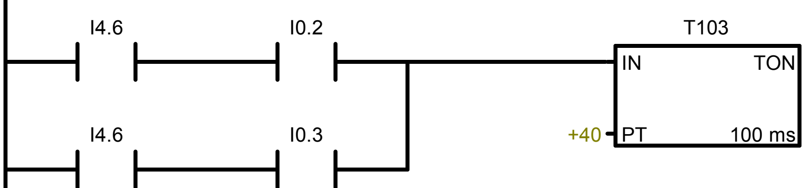
Network 4

This network will active the solenoid to actuate
the cylinder.



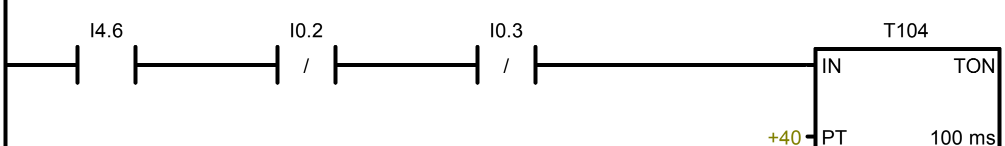
Network 5

This timer will determine if cylinder is broken if the end stroke are
active for more than 4 seconds.



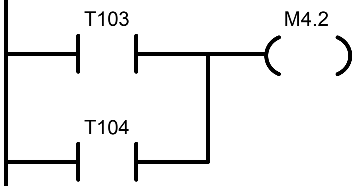
Network 6

This timer will determine if cylinder is broken if no end stroke is
achieved before 4 seconds.



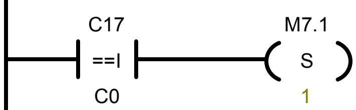
Network 7

If failure is met then the auxiliary memory is activated.



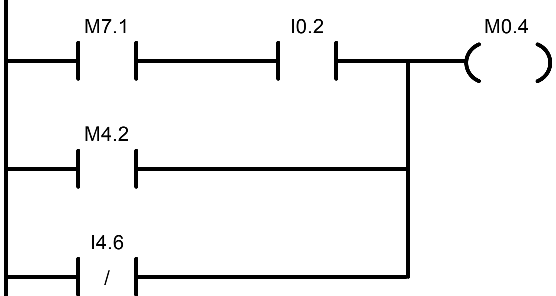
Network 8

This compares if the times that the second counter
is the same of that of the counter in the wear subroutine
if it is the same it will active the auxiliary memory.



Network 9

If one of the three conditions is meet, then the Wear
test in this cylinder is done.

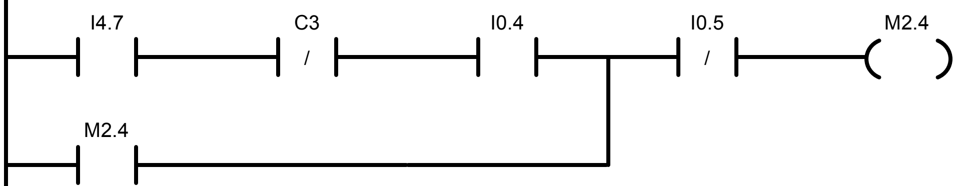


Block: C_3
Author: Heiller Andres Torres Barona
Created: 03/06/2018 07:31:34 pm
Last Modified: 04/02/2018 08:12:32 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

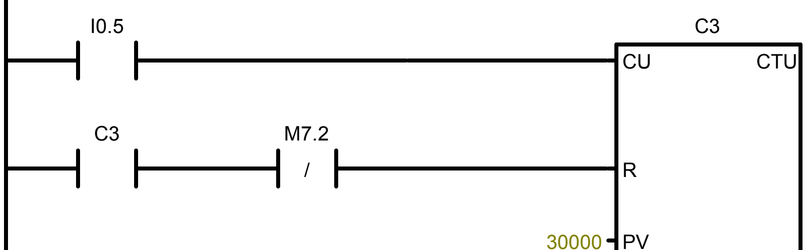
Network 1 Network Title

In this network the state that actuates the cylinder valve is activated.



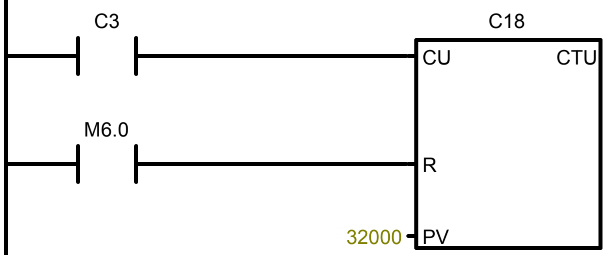
Network 2

The counter is actuated each time the cylinder achieve the outstroke position. It will be reseted when the cylinder achieve the first cycle 30000



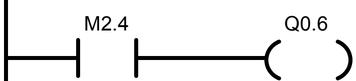
Network 3

This counter will count each time that cylinder
has accomplish the 30000 times



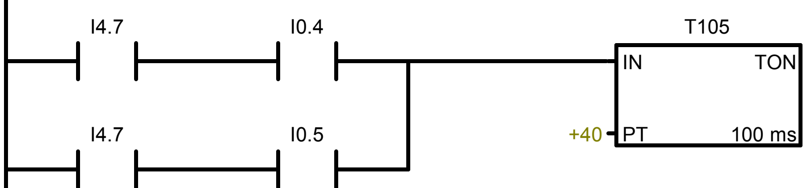
Network 4

This network will active the solenoid to actuate
the cylinder.



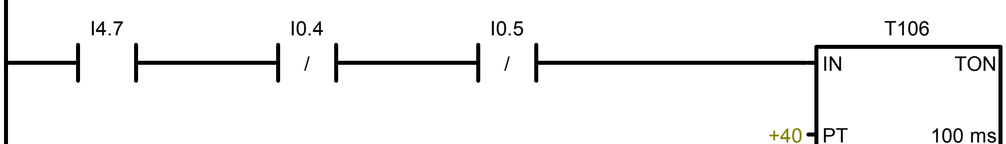
Network 5

This timer will determine if cylinder is broken if the end stroke are
active for more than 4 seconds.



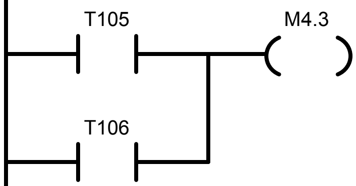
Network 6

This timer will determine if cylinder is broken if no end stroke is
achieved before 4 seconds.



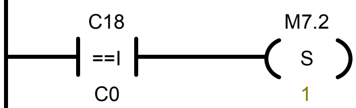
Network 7

If failure is met then the auxiliary memory is activated.



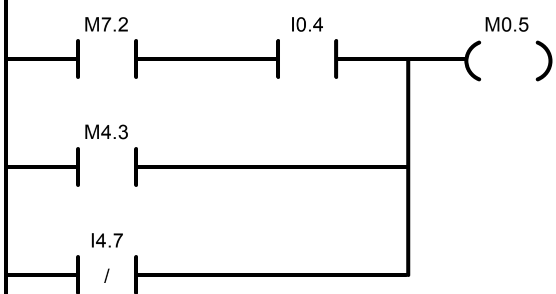
Network 8

This compares if the times that the second counter
is the same of that of the counter in the wear subroutine
if it is the same it will active the auxiliary memory.



Network 9

If one of the three conditions is meet, then the Wear
test in this cylinder is done.

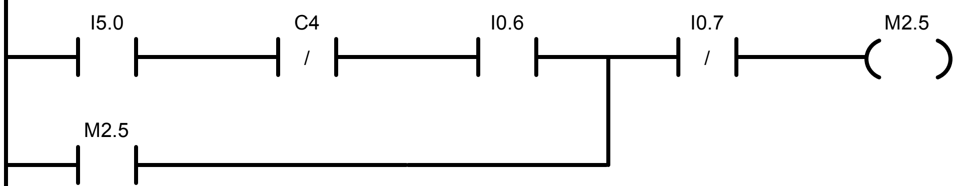


Block: C_4
Author: Heiller Andres Torres Barona
Created: 03/06/2018 07:31:34 pm
Last Modified: 04/02/2018 08:12:42 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

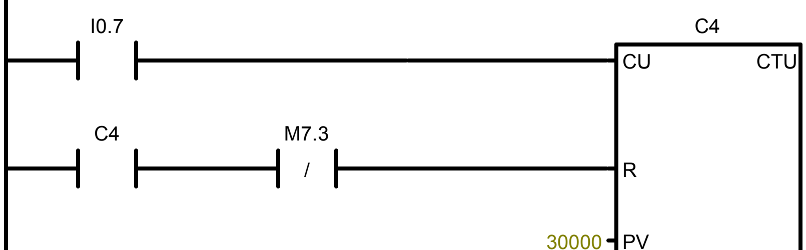
Network 1 Network Title

In this network the state that actuates the cylinder valve is activated.



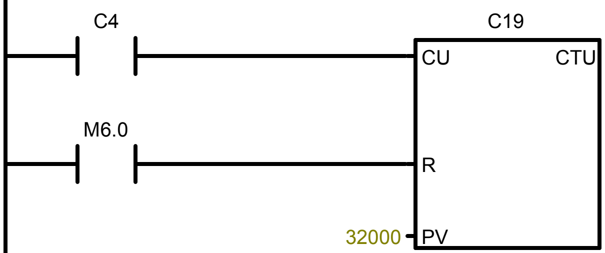
Network 2

The counter is actuated each time the cylinder achieve the outstroke position. It will be reseted when the cylinder achieve the first cycle 30000



Network 3

This counter will count each time that cylinder
has accomplish the 30000 times

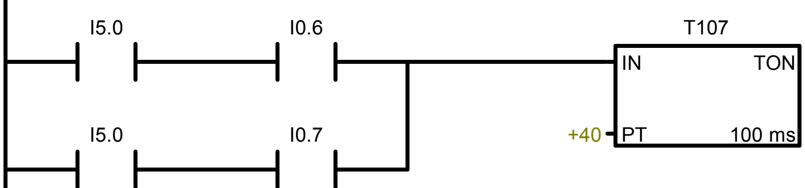


Network 4

This network will active the solenoid to actuate
the cylinder.

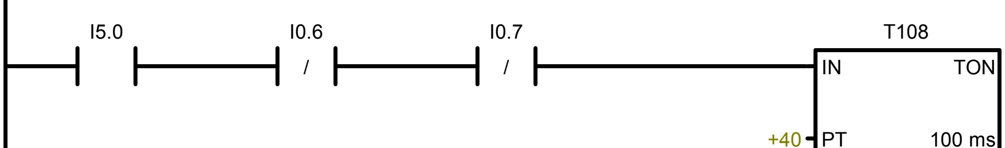
Network 5

This timer will determine if cylinder is broken if the end stroke are
active for more than 4 seconds.



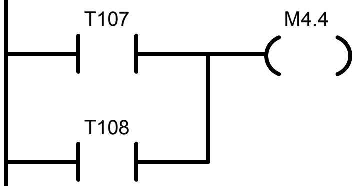
Network 6

This timer will determine if cylinder is broken if no end stroke is
achieved before 4 seconds.



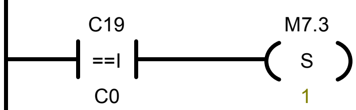
Network 7

If failure is met then the auxiliary memory is activated.



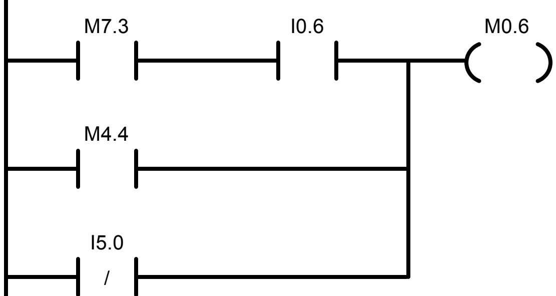
Network 8

This compares if the times that the second counter
is the same of that of the counter in the wear subroutine
if it is the same it will active the auxiliary memory.



Network 9

If one of the three conditions is meet, then the Wear
test in this cylinder is done.

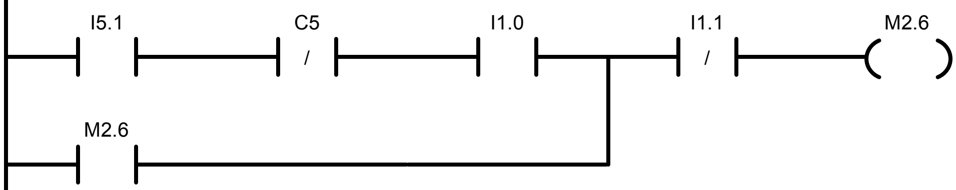


Block: C_5
Author: Heiller Andres Torres Barona
Created: 03/06/2018 07:31:34 pm
Last Modified: 04/02/2018 08:13:00 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

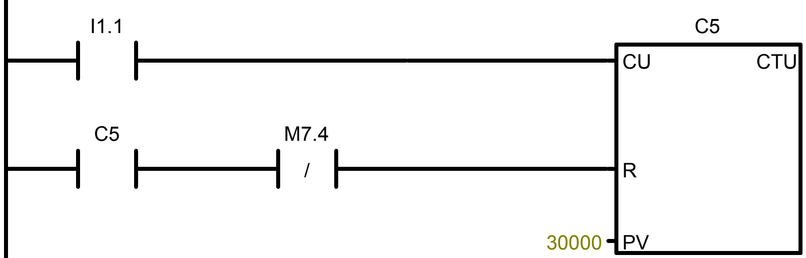
Network 1 Network Title

In this network the state that actuates the cylinder valve is activated.



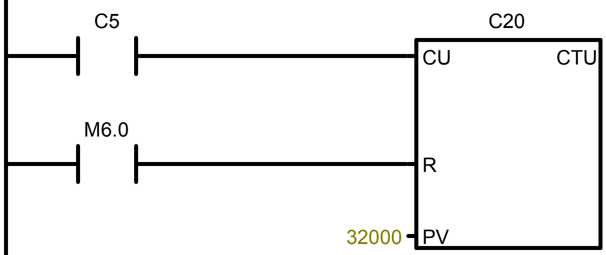
Network 2

The counter is actuated each time the cylinder
achieve the outstroke position. It will be reseted
when the cylinder achieve the first cycle 30000



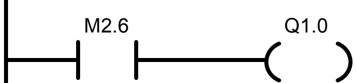
Network 3

This counter will count each time that cylinder has accomplish the 30000 times



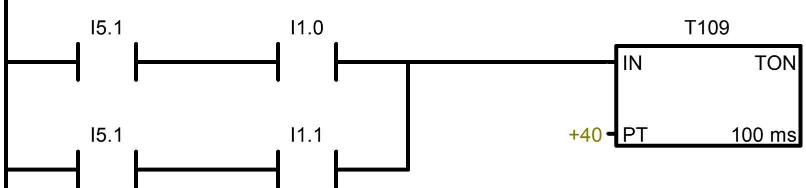
Network 4

This network will active the solenoid to actuate the cylinder.



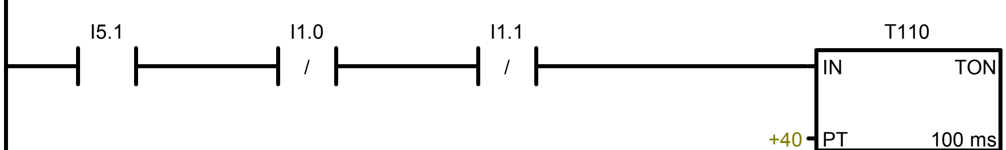
Network 5

This timer will determine if cylinder is broken if the end stroke are active for more than 4 seconds.



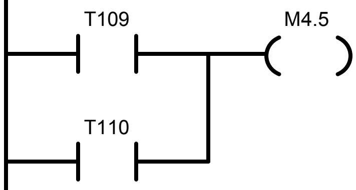
Network 6

This timer will determine if cylinder is broken if no end stroke is achieved before 4 seconds.



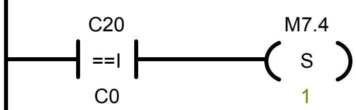
Network 7

If failure is met then the auxiliary memory is activated.



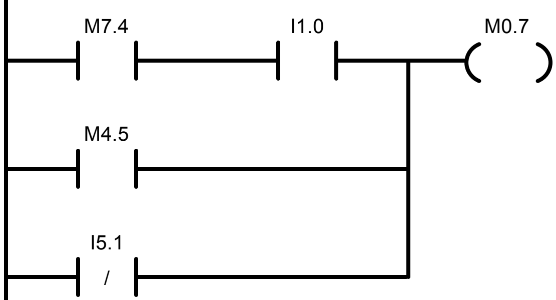
Network 8

This compares if the times that the second counter
is the same of that of the counter in the wear subroutine
if it is the same it will active the auxiliary memory.



Network 9

If one of the three conditions is meet, then the Wear
test in this cylinder is done.

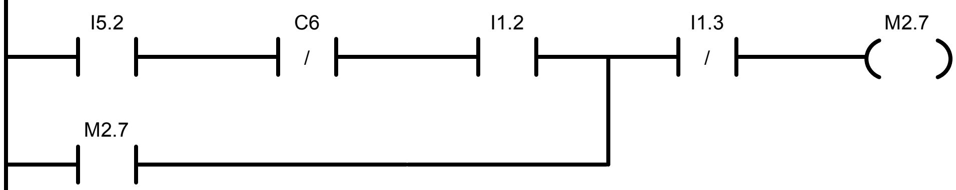


Block: C_6
Author: Heiller Andres Torres Barona
Created: 03/06/2018 07:31:34 pm
Last Modified: 04/02/2018 08:13:09 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

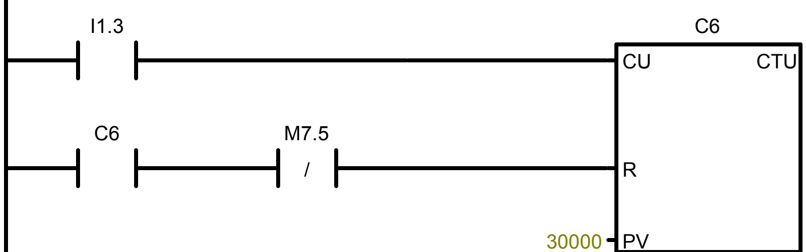
Network 1 Network Title

In this network the state that actuates the cylinder valve is activated.



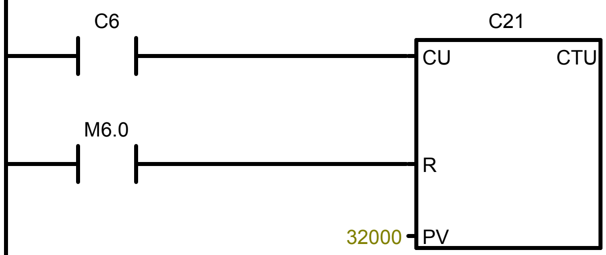
Network 2

The counter is actuated each time the cylinder achieve the outstroke position. It will be reseted when the cylinder achieve the first cycle 30000



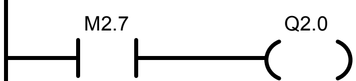
Network 3

This counter will count each time that cylinder has accomplish the 30000 times



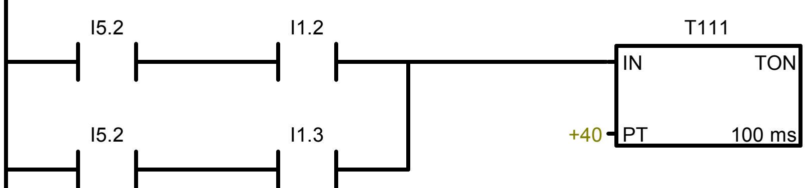
Network 4

This network will active the solenoid to actuate the cylinder.



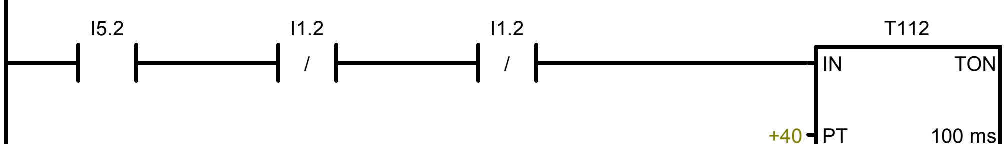
Network 5

This timer will determine if cylinder is broken if the end stroke are active for more than 4 seconds.



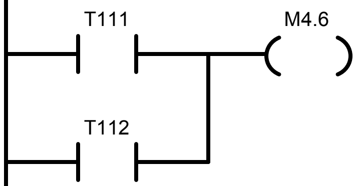
Network 6

This timer will determine if cylinder is broken if no end stroke is achieved before 4 seconds.



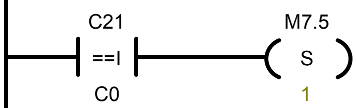
Network 7

If failure is met then the auxiliary memory is activated.



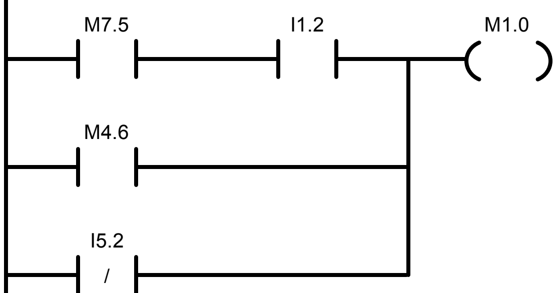
Network 8

This compares if the times that the second counter
is the same of that of the counter in the wear subroutine
if it is the same it will active the auxiliary memory.



Network 9

If one of the three conditions is meet, then the Wear
test in this cylinder is done.

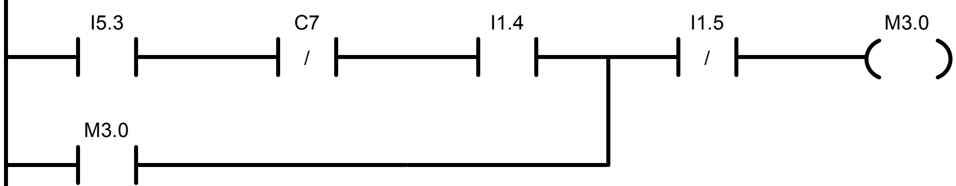


Block: C_7
Author: Heiller Andres Torres Barona
Created: 03/06/2018 07:31:34 pm
Last Modified: 04/02/2018 08:13:20 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

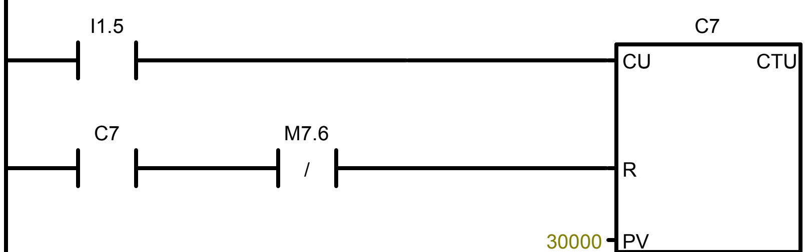
Network 1 Network Title

In this network the state that actuates the cylinder valve is activated.



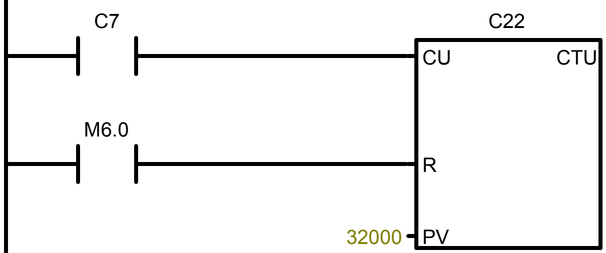
Network 2

The counter is actuated each time the cylinder achieve the outstroke position. It will be reseted when the cylinder achieve the first cycle 30000



Network 3

This counter will count each time that cylinder has accomplish the 30000 times

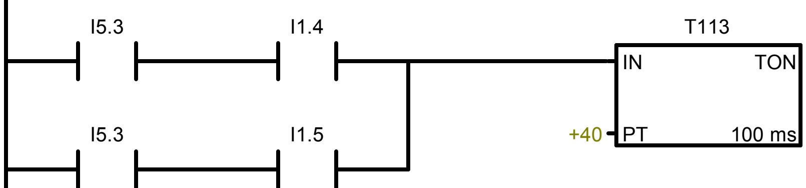


Network 4

This network will active the solenoid to actuate the cylinder.

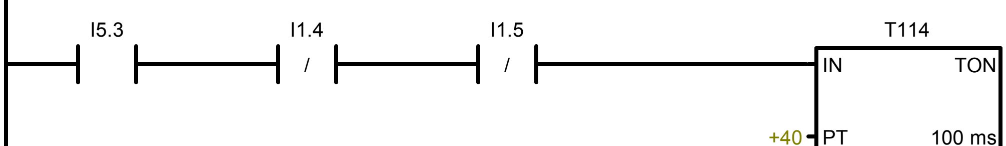
Network 5

This timer will determine if cylinder is broken if the end stroke are active for more than 4 seconds.



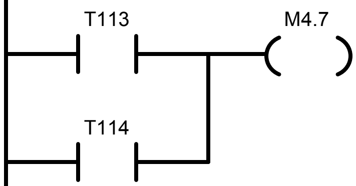
Network 6

This timer will determine if cylinder is broken if no end stroke is achieved before 4 seconds.



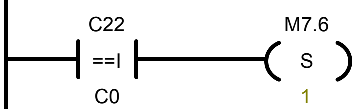
Network 7

If failure is met then the auxiliary memory is activated.



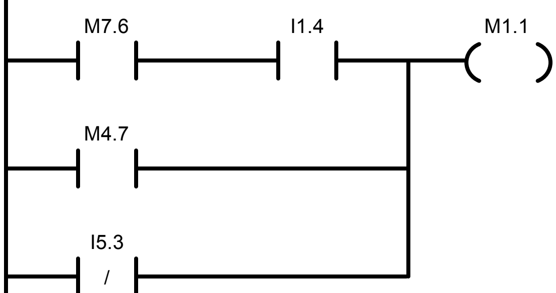
Network 8

This compares if the times that the second counter
is the same of that of the counter in the wear subroutine
if it is the same it will active the auxiliary memory.



Network 9

If one of the three conditions is meet, then the Wear
test in this cylinder is done.

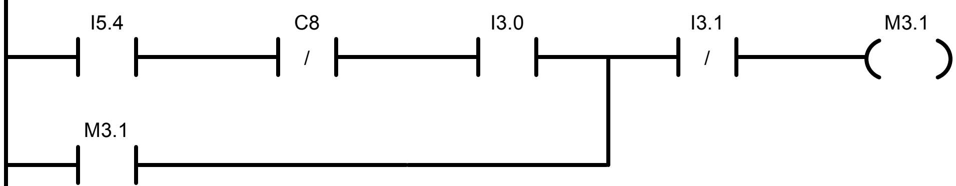


Block: C_8
Author: Heiller Andres Torres Barona
Created: 03/06/2018 07:31:34 pm
Last Modified: 04/02/2018 08:13:27 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

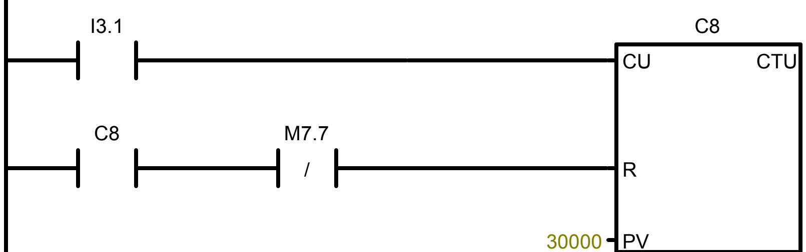
Network 1 Network Title

In this network the state that actuates the cylinder valve is activated.



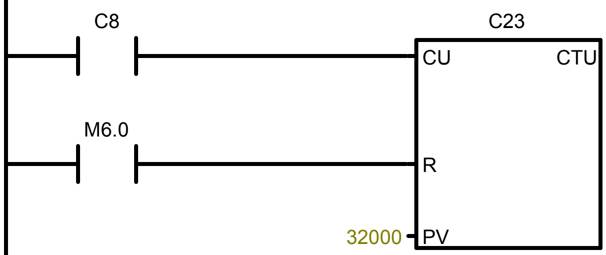
Network 2

The counter is actuated each time the cylinder achieve the outstroke position. It will be reseted when the cylinder achieve the first cycle 30000



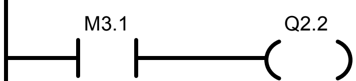
Network 3

This counter will count each time that cylinder has accomplish the 30000 times



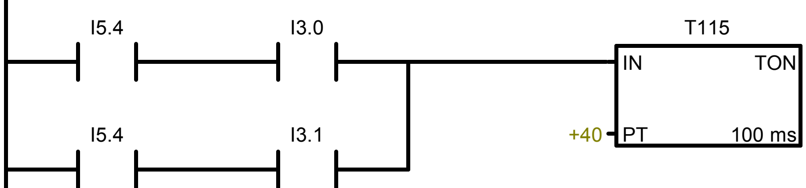
Network 4

This network will active the solenoid to actuate the cylinder.



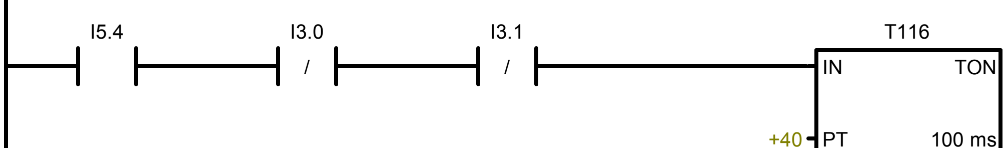
Network 5

This timer will determine if cylinder is broken if the end stroke are active for more than 4 seconds.



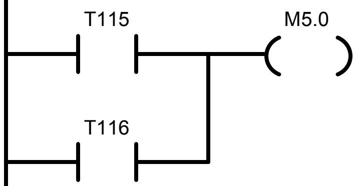
Network 6

This timer will determine if cylinder is broken if no end stroke is achieved before 4 seconds.



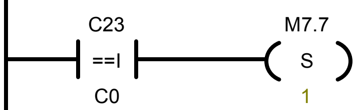
Network 7

If failure is met then the auxiliary memory is activated.



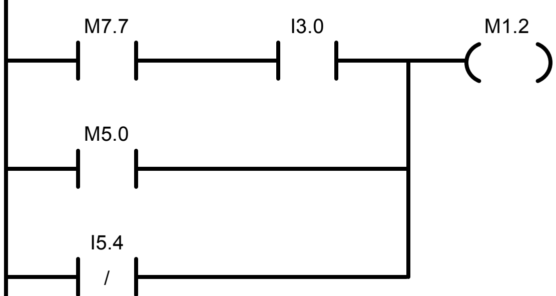
Network 8

This compares if the times that the second counter
is the same of that of the counter in the wear subroutine
if it is the same it will active the auxiliary memory.



Network 9

If one of the three conditions is meet, then the Wear
test in this cylinder is done.

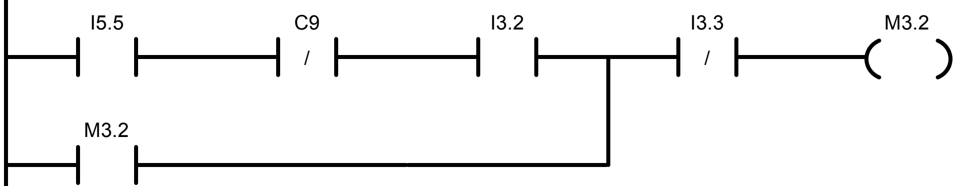


Block: C_9
Author: Heiller Andres Torres Barona
Created: 03/06/2018 07:31:34 pm
Last Modified: 04/02/2018 08:13:36 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

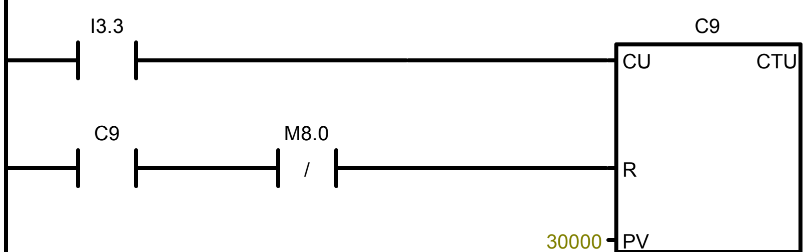
Network 1 Network Title

In this network the state that actuates the cylinder valve is activated.



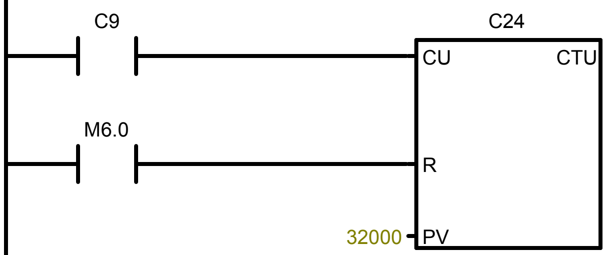
Network 2

The counter is actuated each time the cylinder
achieve the outstroke position. It will be reseted
when the cylinder achieve the first cycle 30000



Network 3

This counter will count each time that cylinder
has accomplish the 30000 times

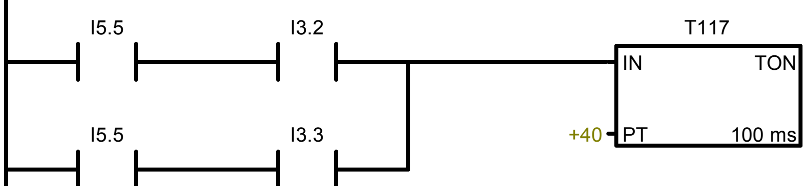


Network 4

This network will active the solenoid to actuate
the cylinder.

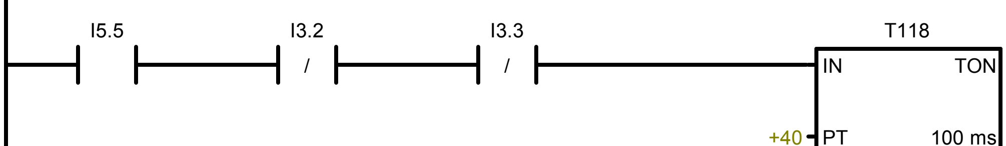
Network 5

This timer will determine if cylinder is broken if the end stroke are
active for more than 4 seconds.



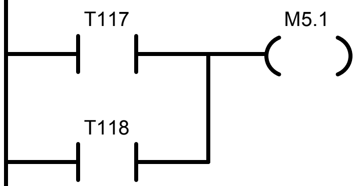
Network 6

This timer will determine if cylinder is broken if no end stroke is
achieved before 4 seconds.



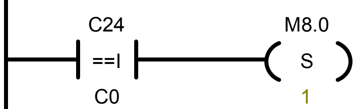
Network 7

If failure is met then the auxiliary memory is activated.



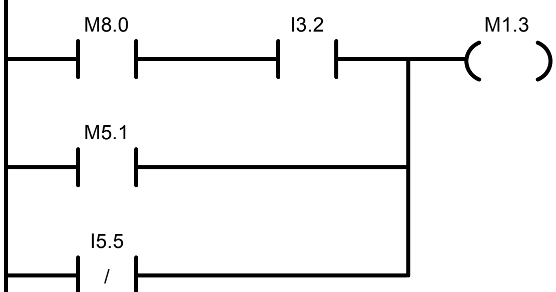
Network 8

This compares if the times that the second counter
is the same of that of the counter in the wear subroutine
if it is the same it will active the auxiliary memory.



Network 9

If one of the three conditions is meet, then the Wear
test in this cylinder is done.

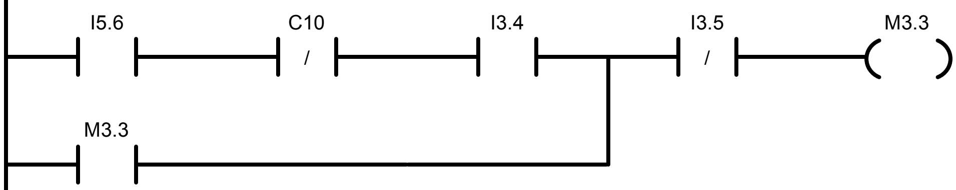


Block: C_10
Author: Heiller Andres Torres Barona
Created: 03/06/2018 07:31:34 pm
Last Modified: 04/02/2018 08:13:43 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

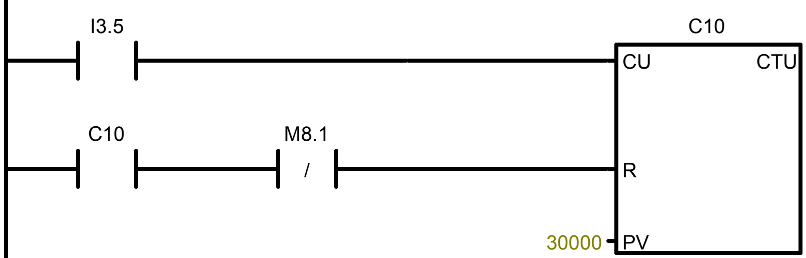
Network 1 Network Title

In this network the state that actuates the cylinder valve is activated.



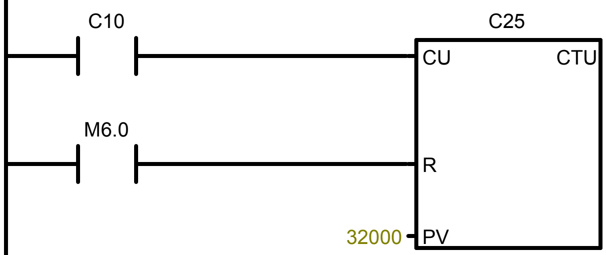
Network 2

The counter is actuated each time the cylinder achieve the outstroke position. It will be reseted when the cylinder achieve the first cycle 30000



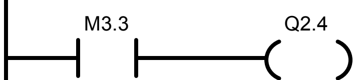
Network 3

This counter will count each time that cylinder
has accomplish the 30000 times



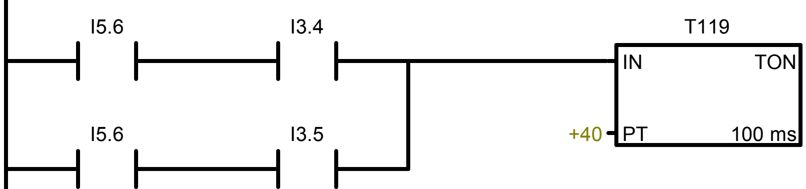
Network 4

This network will active the solenoid to actuate
the cylinder.



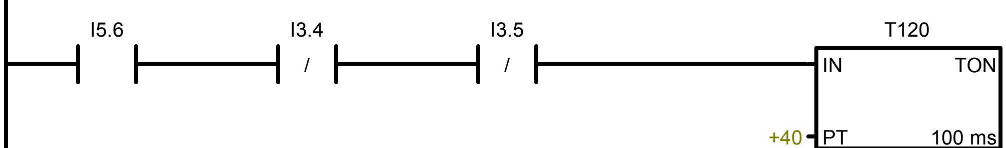
Network 5

This timer will determine if cylinder is broken if the end stroke are
active for more than 4 seconds.



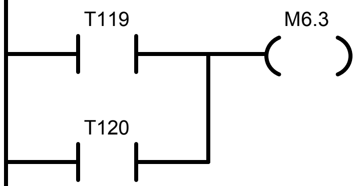
Network 6

This timer will determine if cylinder is broken if no end stroke is
achieved before 4 seconds.



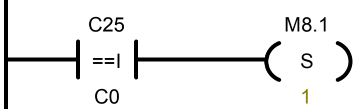
Network 7

If failure is met then the auxiliary memory is activated.



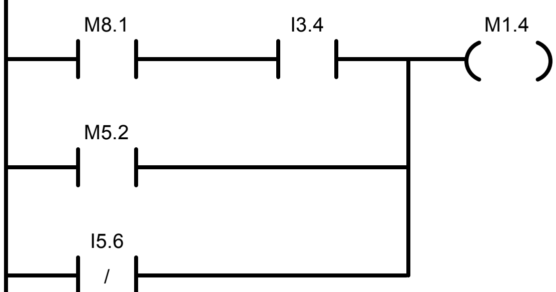
Network 8

This compares if the times that the second counter
is the same of that of the counter in the wear subroutine
if it is the same it will active the auxiliary memory.



Network 9

If one of the three conditions is meet, then the Wear
test in this cylinder is done.

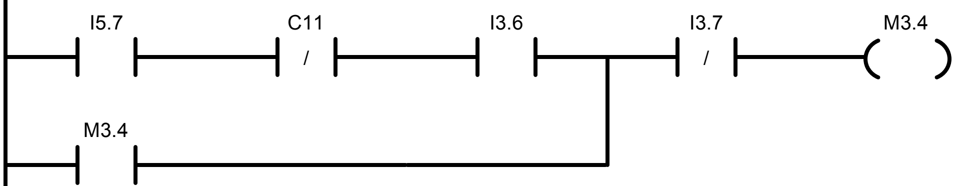


Block: C_11
Author: Heiller Andres Torres Barona
Created: 03/06/2018 07:31:34 pm
Last Modified: 04/02/2018 08:13:52 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

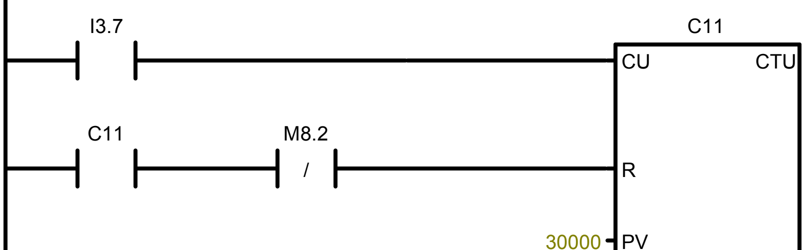
Network 1 Network Title

In this network the state that actuates the cylinder valve is activated.



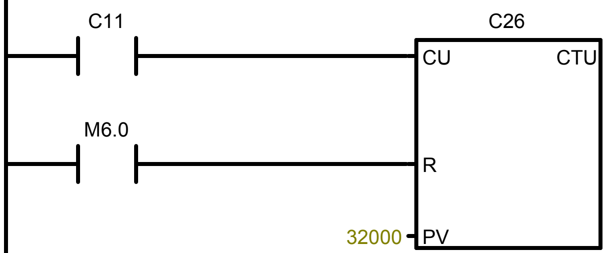
Network 2

The counter is actuated each time the cylinder
achieve the outstroke position. It will be reseted
when the cylinder achieve the first cycle 30000



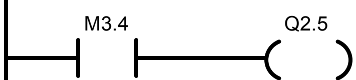
Network 3

This counter will count each time that cylinder
has accomplish the 30000 times



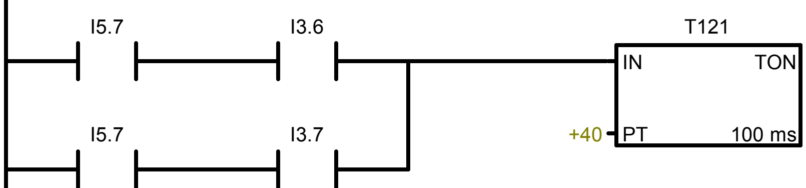
Network 4

This network will active the solenoid to actuate
the cylinder.



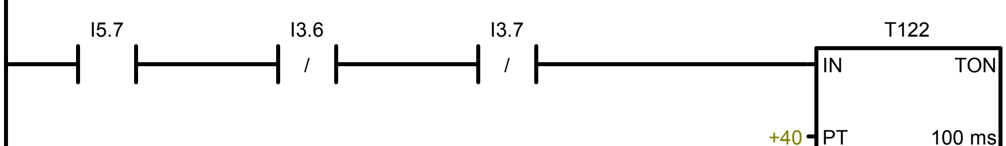
Network 5

This timer will determine if cylinder is broken if the end stroke are
active for more than 4 seconds.



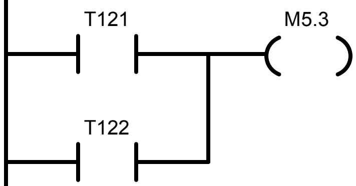
Network 6

This timer will determine if cylinder is broken if no end stroke is
achieved before 4 seconds.



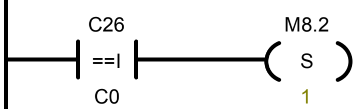
Network 7

If failure is met then the auxiliary memory is activated.



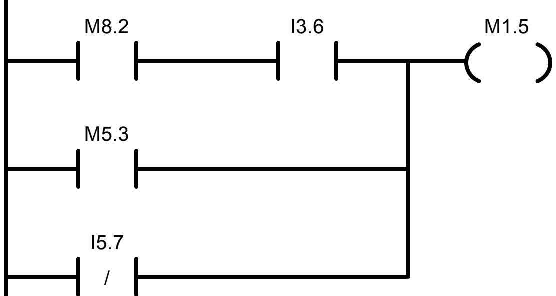
Network 8

This compares if the times that the second counter
is the same of that of the counter in the wear subroutine
if it is the same it will active the auxiliary memory.



Network 9

If one of the three conditions is meet, then the Wear
test in this cylinder is done.

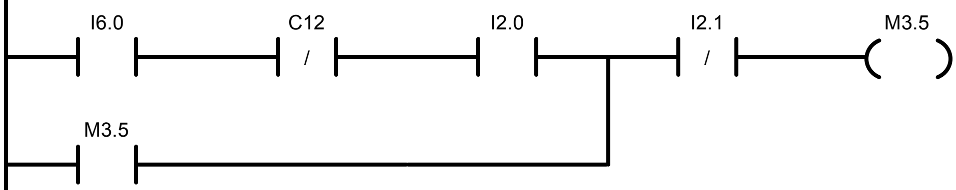


Block: C_12
Author: Heiller Andres Torres Barona
Created: 03/06/2018 07:31:34 pm
Last Modified: 04/02/2018 08:14:00 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

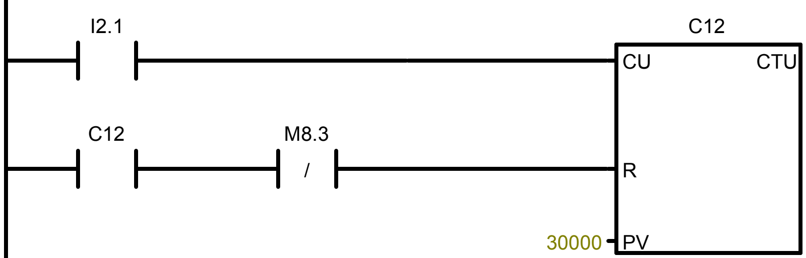
Network 1 Network Title

In this network the state that actuates the cylinder valve is activated.



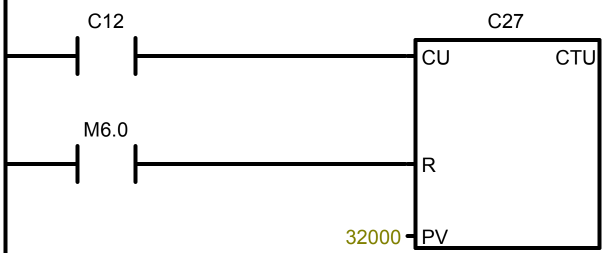
Network 2

The counter is actuated each time the cylinder
achieve the outstroke position. It will be reseted
when the cylinder achieve the first cycle 30000



Network 3

This counter will count each time that cylinder has accomplish the 30000 times

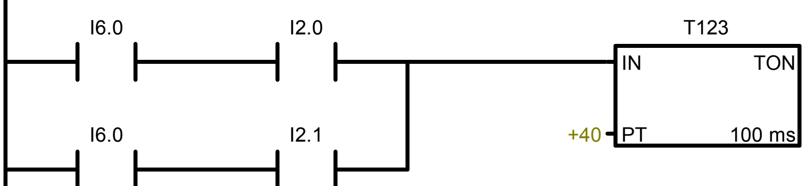


Network 4

This network will active the solenoid to actuate the cylinder.

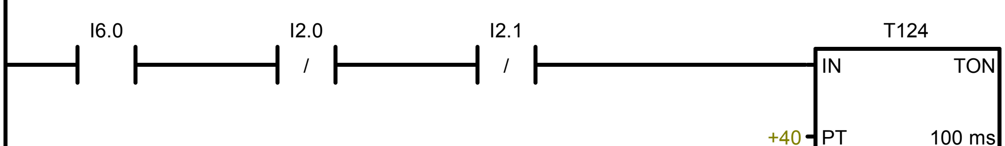
Network 5

This timer will determine if cylinder is broken if the end stroke are active for more than 4 seconds.



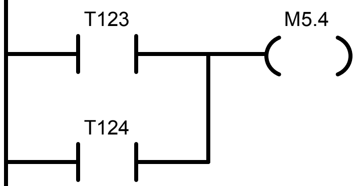
Network 6

This timer will determine if cylinder is broken if no end stroke is achieved before 4 seconds.



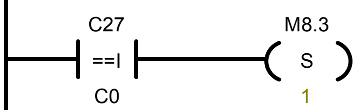
Network 7

If failure is met then the auxiliary memory is activated.



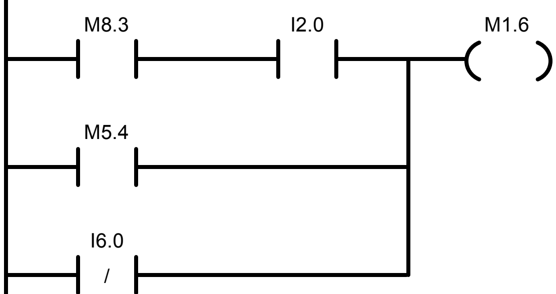
Network 8

This compares if the times that the second counter
is the same of that of the counter in the wear subroutine
if it is the same it will active the auxiliary memory.



Network 9

If one of the three conditions is meet, then the Wear
test in this cylinder is done.

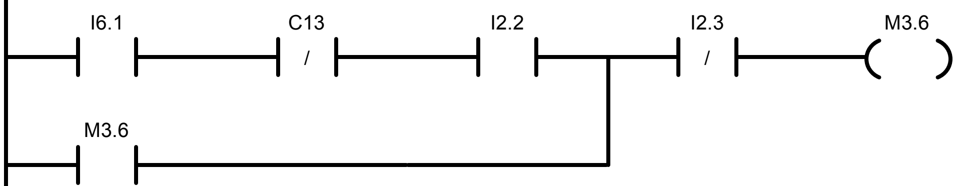


Block: C_13
Author: Heiller Andres Torres Barona
Created: 03/06/2018 07:31:34 pm
Last Modified: 04/02/2018 08:14:08 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

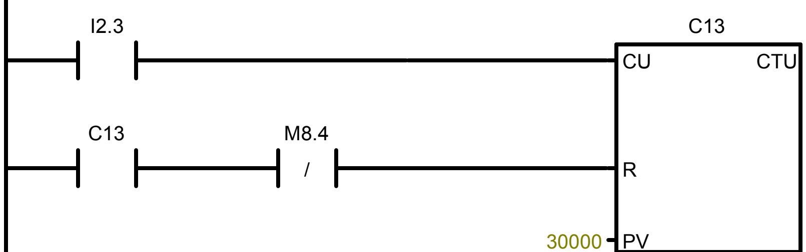
Network 1 Network Title

In this network the state that actuates the cylinder valve is activated.



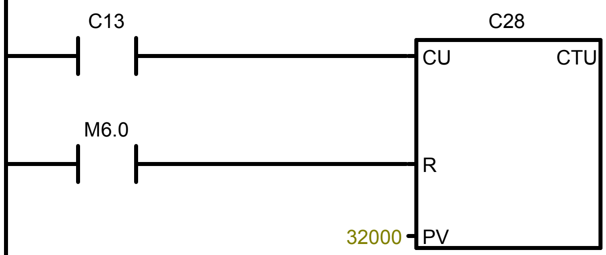
Network 2

The counter is actuated each time the cylinder
achieve the outstroke position. It will be reseted
when the cylinder achieve the first cycle 30000



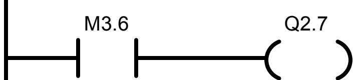
Network 3

This counter will count each time that cylinder
has accomplish the 30000 times



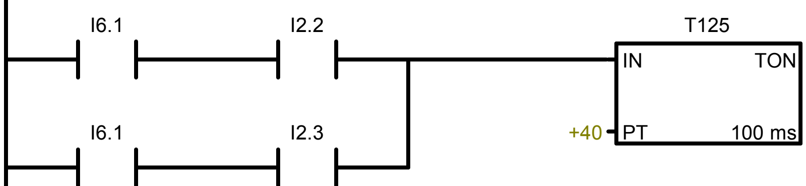
Network 4

This network will active the solenoid to actuate
the cylinder.



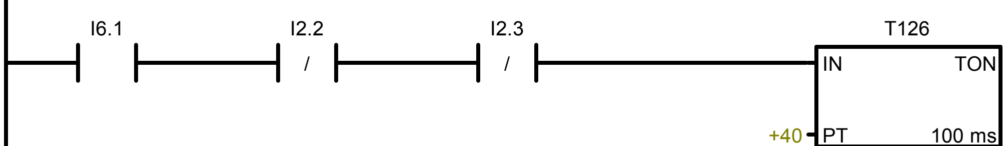
Network 5

This timer will determine if cylinder is broken if the end stroke are
active for more than 4 seconds.



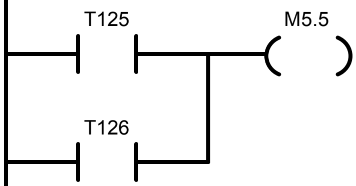
Network 6

This timer will determine if cylinder is broken if no end stroke is
achieved before 4 seconds.



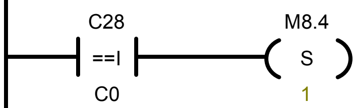
Network 7

If failure is met then the auxiliary memory is activated.



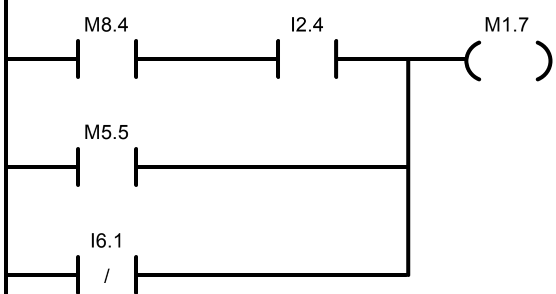
Network 8

This compares if the times that the second counter
is the same of that of the counter in the wear subroutine
if it is the same it will active the auxiliary memory.



Network 9

If one of the three conditions is meet, then the Wear
test in this cylinder is done.

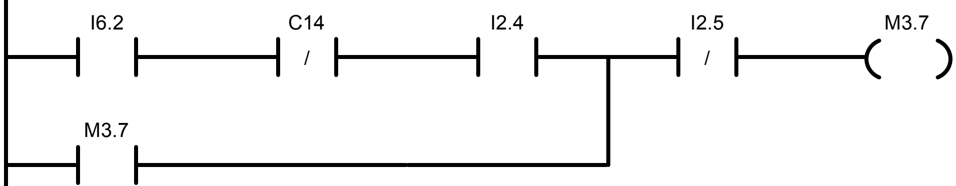


Block: C_14
Author: Heiller Andres Torres Barona
Created: 03/06/2018 07:31:34 pm
Last Modified: 04/02/2018 08:12:05 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

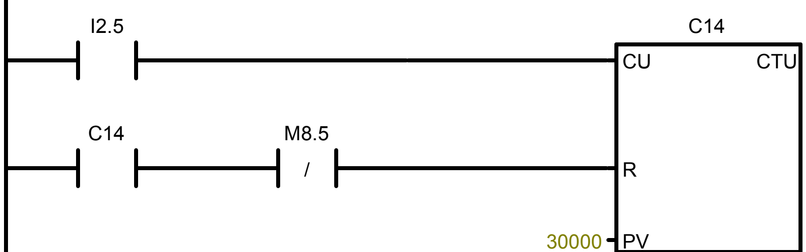
Network 1 Network Title

In this network the state that actuates the cylinder valve is activated.



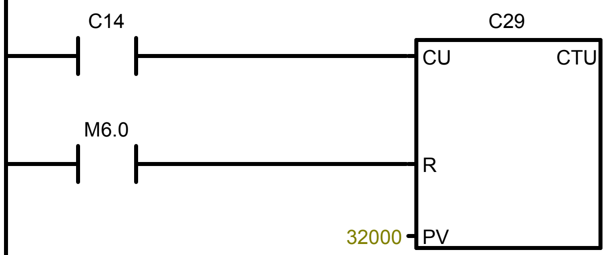
Network 2

The counter is actuated each time the cylinder achieve the outstroke position. It will be reseted when the cylinder achieve the first cycle 30000



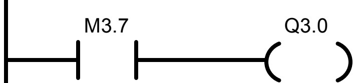
Network 3

This counter will count each time that cylinder
has accomplish the 30000 times



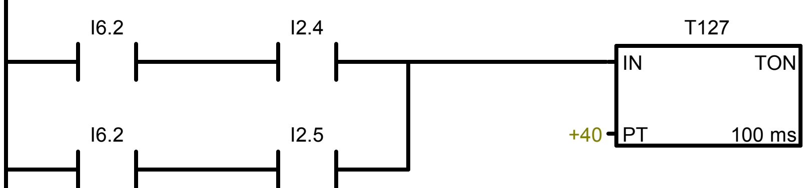
Network 4

This network will active the solenoid to actuate
the cylinder.



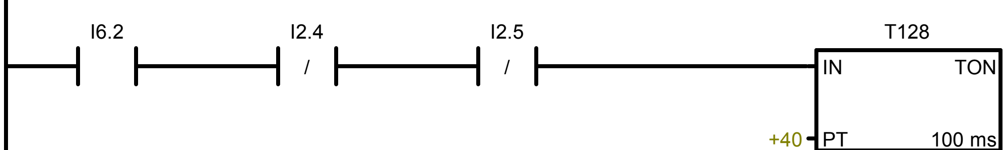
Network 5

This timer will determine if cylinder is broken if the end stroke are
active for more than 4 seconds.



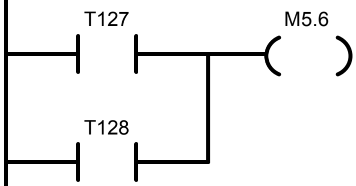
Network 6

This timer will determine if cylinder is broken if no end stroke is
achieved before 4 seconds.



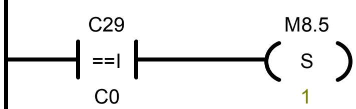
Network 7

If failure is met then the auxiliary memory is activated.



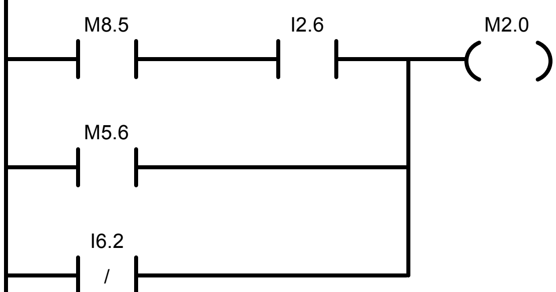
Network 8

This compares if the times that the second counter
is the same of that of the counter in the wear subroutine
if it is the same it will active the auxiliary memory.



Network 9

If one of the three conditions is meet, then the Wear
test in this cylinder is done.

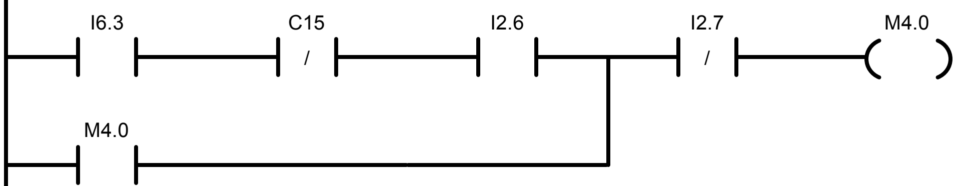


Block: C_15
Author: Heiller Andres Torres Barona
Created: 03/06/2018 07:31:34 pm
Last Modified: 04/02/2018 08:11:20 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

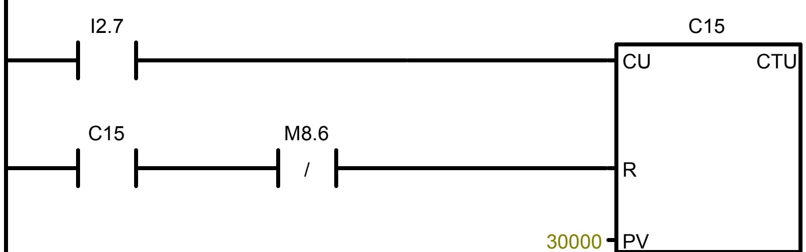
Network 1 Network Title

In this network the state that actuates the cylinder valve is activated.



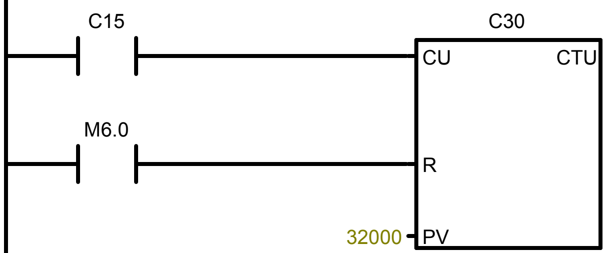
Network 2

The counter is actuated each time the cylinder achieve the outstroke position. It will be reseted when the cylinder achieve the first cycle 30000



Network 3

This counter will count each time that cylinder
has accomplish the 30000 times

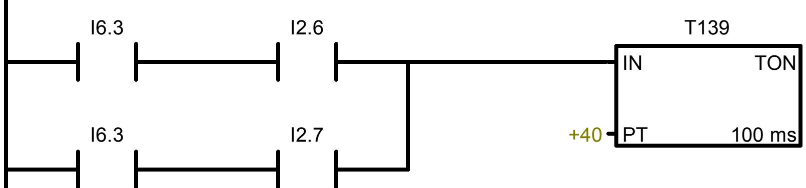


Network 4

This network will active the solenoid to actuate
the cylinder.

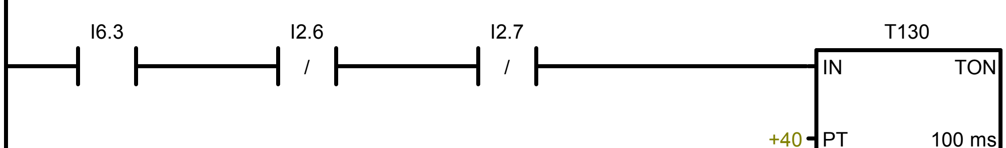
Network 5

This timer will determine if cylinder is broken if the end stroke are
active for more than 4 seconds.



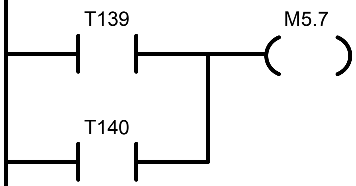
Network 6

This timer will determine if cylinder is broken if no end stroke is
achieved before 4 seconds.



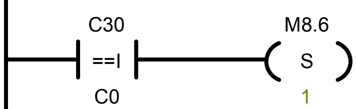
Network 7

If failure is met then the auxiliary memory is activated.



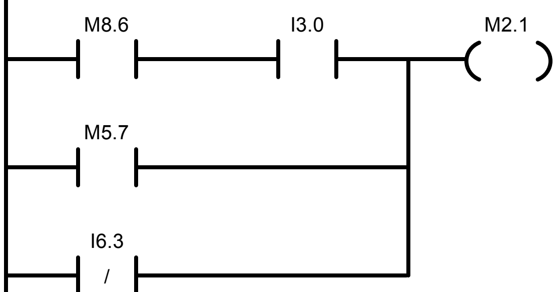
Network 8

This compares if the times that the second counter
is the same of that of the counter in the wear subroutine
if it is the same it will active the auxiliary memory.



Network 9

If one of the three conditions is meet, then the Wear
test in this cylinder is done.



Block:	TD_CTRL_0
Author:	TD 200 Wizard
Created:	03/22/2018 03:11:03 pm
Last Modified:	03/26/2018 04:35:27 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

This POU was generated by the TD 200 Wizard as part of the configuration: TD 200 Configuration 0. The TD_CTRL_X (TD Control) instruction is used to clear all alarm enables. Individual alarms should then be enabled as appropriate.

Block: TD_ALM_0
Author: TD 200 Wizard
Created: 03/22/2018 03:11:03 pm
Last Modified: 03/26/2018 04:35:27 pm

	Symbol	Var Type	Data Type	Comment
	EN	IN	BOOL	
		IN		
L0.0	ALM_EN	IN_OUT	BOOL	The enable bit for the desired alarm.
		IN_OUT		
		OUT		
		TEMP		

This POU was generated by the TD 200 Wizard as part of the configuration: TD 200 Configuration 0. The TD_ALM_X (Enable Alarm) instruction is used to enable the display of an alarm.

Block: S_ITR
Author:
Created: 12/17/2007 03:15:23 pm
Last Modified: 03/26/2018 04:35:27 pm

	Symbol	Var Type	Data Type	Comment
	EN	IN	BOOL	
LW0	Input	IN	INT	
LW2	ISH	IN	INT	
LW4	ISL	IN	INT	
LD6	OSH	IN	REAL	
LD10	OSL	IN	REAL	
		IN		
		IN_OUT		
LD14	Output	OUT	REAL	
		OUT		
LD18	Input_DI	TEMP	DINT	
LD22	ISL_DI	TEMP	DINT	
LD26	ISH_DI	TEMP	DINT	
LD30	delta_R	TEMP	REAL	
LD34	delta_max	TEMP	REAL	
		TEMP		

LIBARY: Scale V1.2 (bipolar scaling)
=============================

LIABILITY
Siemens AG does not accept liability of any kind for damages arising from the use of this application, except where it is obliged to by law, in cases such as damage to items used for personal purposes, personal injury, willful damage or gross negligence.

WARRANTY
The program examples given are specific solutions to complex tasks which were worked on by Customer Support. We must also point out that it is not possible in the current state of the technology to exclude all errors in software programs under all conditions of use. The program examples were prepared according to the best of our knowledge. However, we cannot accept any liability beyond the standard guarantee for Class C software in accordance with our General Terms of Sale for Software Products for Automation and Drive Technology". The program examples can be purchased on the Internet as single licenses. They may not be transferred to a third party.

PASSWORD
The password of the library is "1234"

S_ITR
Scale Integer to Real

The formula is as follows:
Ov = [(OSH - OSL) * (Iv - ISL) / (ISH - ISL)] + OSL
with ISL <= Iv <= ISH
and OSL <= Ov <= OSH

Ov	=	output value (REAL)
Iv	=	input value (INT)
OSH	=	high limit of the scale for the output value (REAL)
OSL	=	low limit of the scale for the output value (REAL)
ISH	=	high limit of the scale for the input value (INT)
ISL	=	low limit of the scale for the input value (INT)

BIBLIOTHEK: Scale V1.2 (bipolare Skalierung)
======================================

HAFTUNGSAUSSCHLUSS
Bei diesem Programmbaustein handelt es sich um FREEWARE.
Jedem Benutzer steht es frei, dieses Programm UNENTGELTLICH zu nutzen, zu kopieren und weiterzugeben.
Die Autoren und Rechtsinhaber dieses Programms schließen jegliche Haftung für die Funktionstüchtigkeit oder Kompatibilität dieser Software aus.
Die Benutzung erfolgt auf eigene Gefahr.
Da diese Software kostenlos ist, entfällt jegliche Gewährleistung, Anspruch auf Fehlerkorrektur und Hotlinesupport.

PASSWORT
Das Passwort der Bibliothek ist "1234"

S_ITR
Ganze Zahl in Realzahl skalieren

Die Formel lautet wie folgt:
Ov = [(OSH - OSL) * (Iv - ISL) / (ISH - ISL)] + OSL
mit ISL <= Iv <= ISH
und OSL <= Ov <= OSH

Ov	=	Ausgangswert (REAL)
Iv	=	Eingangswert (INT)
OSH	=	oberer Grenzwert der Skala für den Ausgangswert (REAL)
OSL	=	unterer Grenzwert der Skala für den Ausgangswert (REAL)
ISH	=	oberer Grenzwert der Skala für den Eingangswert (INT)
ISL	=	unterer Grenzwert der Skala für den Eingangswert (INT)

Annex 11:
MATLAB PROGRAM

```
%Program developed for the Thesis Project:
%PLC Control and Automation of a Test Bench for Life Testing of Pneumatic
Cylinders.
%Written by Heiller Andres Torres Barona
%Tutored by: Prof Ing. Luigi Mazza.
%Programmed by Heiller Andres Torres.
%SUMMARY:
%The following program is the responsible of taking the Excel data
achieved
%by the probes in the DIMEAS lab (Wear and Leak test) for a certain group
%of the population of pneumatic cylinders to model the behavior of the
%whole population by the use of the Weibull probability density function.
% Its important to notice that depending on the cylinder sample, the type
% of cylinder and the stressed to which the cylinders are subjected, some
% parameters must be change manually by the user to achieve a the proper
% data that is needed for the life analysis of the pneumatic cylinders.
% Remember to move the Excel file to the pointing directory of MATLAB and
% to save it with the following name: PneumaticCylinderDataLog for the
% program to run correctly.


%Close, clear and erase all the possible previous written lines or open
%figures.

clear all;
close all;
clc;

%Extract the Excel data is extracted from excel but the user must
especify
%the following parameters:
% As default they are 5 samples per second.
% 1 minute of chamber filling.
% 30 minutes of chamber leak test measurement.


Smp=1;    % The user must specify how many samples per second are taken.
T1=1;     % The amount of time of chamber filling in minutes.
T2=30;    % The amount of time the leak test is done in minutes.
cyl_stroke=0.250; %stroke of cylinder
dis_cycle= 0.500; %Distance traveled by the cylinder in m.
km=1000;
%This will tell MATLAB the amount of data that is needs to extract form
%MS Excel.

File=xlsread('PneumaticCylinderDataLog1.xlsx'); %Charge the related File.
del = [1];      %Determine the rows that are not of importance.
L=size(File) ;      %identify the size of the array columns and rows.
File(del,:)=[];  %Delete the selected rows.
File(:,del) =[];
L=size(File)    ;    %identify the size of the array columns and rows.
col=L(1)        ;    %number of columns in the array, first 15 are
cylinders.
```

```
row=L(2)       ;   %number of rows or samples taken

%Divides the Excel File in the data of the anterior and Posterior Chamber
%and number of cycles endured after breaking.
sel=[1:1:col/2];       %
A1=File(sel,:);        % Matrix of data of pressure in the rear chamber.
A2=File(col/2+sel,:); % Matrix of data of pressure in the anterior
chamber.
tmp=File(1,21:1:35);  % Matrix of data of cycles endured by the
cylinders.

for (ii=1:1:15)
    if (tmp(ii)~= 0);
        A3(ii)=(tmp(ii));% Matrix of data of cycles endured by the
cylinders.
    end                 % Without the unused cylinders.
end


%The following lines will create the time vector in wich the samples were
%taken.

% Then the plot for every 15 cylinders chambers during the Leak test are
made.
for (i=1:1:15);
    figure ;
    plot(A1(:,i));
    str=strcat({'\fontsize{16} Rear Chamber Cylinder '}, num2str(i));
    title(str)
    xlabel('Time in Seconds')
    ylabel('Pressure in Bars')
    figure ;
    plot(A2(:,i));
    str=strcat({'\fontsize{16} Anterior Chamber Cylinder '},num2str(i));
    title(str)
    xlabel('Samples')
    ylabel('Pressure in Bars')

end

%Then the program finds using the Maximum Likelihood Estimation method,
the
%eta and beta parameters of the Weibull distribution function.
PARMHAT= wblfit(A3) ;
eta=PARMHAT(1);
beta=PARMHAT(2);
gama=0 ; %Gama is set to 0 as default, but can be changed by the user.

T = max(A3); %Chooses the higher Failure out of the complete data.
obstime = sort(min(T, A3)); %Sort values from lower to higher.
x = linspace(1,5000000); %Creates a linear space taken as time to draft
pdf.

%The probability of the data will be plotted.
probplot('weibull',A3)
title('Probability Plot')
```

```
%This will show the CDF of the Data acquired
figure
[empF,x1,empFlo,empFup] = ecdf(A3);
stairs(x1,empF);
hold on;
stairs(x1,empFlo,':'); stairs(x1,empFup,':');
hold off
xlabel('Time'); ylabel('failed'); title('CDF');

%The estimation of the parameters with 95% of confidence bonds
paramEsts = wblfit(A3);
[nlogl,paramCov] = wbllike(paramEsts,A3);
xx = linspace(1,2*T,500);
[wblF,wblFlo,wblFup] = wblcdf(xx,paramEsts(1),paramEsts(2),paramCov);

%Comparison between the mentioned plots
figure
stairs(x1,empF);
hold on
handles = plot(xx,wblF,'r-',xx,wblFlo,'r:',xx,wblFup,'r:');
hold off
xlabel('Time'); ylabel('Fitted failure probability'); title('Weibull
Model vs. Empirical');


figure %Opens the figure
Wbl=wblpdf(x,eta,beta);
plot(x,Wbl,'r') %Draws the Final Weibull probability density function
xlabel('Cycles'); ylabel('Probability a Fail can happen'); title('Weibull
PDF') %with the parameters founded before.


%Once having the Weibull probability distributive function the mean and
%varaiance can be calculated:
[M,V] = wblstat(eta,beta);
Mean=M
Variance=V
Characteristic_Life=eta

%The Reliability is given by:
R = (1-wblcdf(x,eta,beta));
figure
hold on
plot(x,R)
xlabel('Cycles'); ylabel('Continue Working Probability');
title('Reliability');

%The Unreliability is given by:
UR = 1-(1-wblcdf(x,eta,beta));
figure
hold on
plot(x,UR)
xlabel('Cycles'); ylabel('Failure Probability'); title('Unreliability');

%The Failure rate is given by:
```

```
F_R=(beta/eta)*((x-gama)/eta).^(beta-1);
figure
hold on
plot(x,F_R)
xlabel('Cycles'); ylabel('Failures'); title('Failure Rate');

%The beta life of the data acquiered is:
B10=eta*(-log(1-0.1))^(1/beta);
B20=eta*(-log(1-0.2))^(1/beta);
B30=eta*(-log(1-0.3))^(1/beta);
B40=eta*(-log(1-0.4))^(1/beta);
B50=eta*(-log(1-0.5))^(1/beta);
B60=eta*(-log(1-0.6))^(1/beta);
B70=eta*(-log(1-0.7))^(1/beta);
B80=eta*(-log(1-0.8))^(1/beta);
B90=eta*(-log(1-0.9))^(1/beta);
B100=eta*(-log(1-1))^(1/beta) ;

B_X=[B10 B20 B30 B40 B50 B60 B70 B80 B90 B100]
%Reliable life is reciprocal to beta life
R_X=[B100 B90 B80 B70 B60 B50 B40 B30 B20 B10]
```

Annex 12:

USER INSTALLATION MANUAL:

In order to learn the operation modes and the methods in which the test bench is used, a user manual has been developed. Here the approach to install all the programs that are related to the use of the test bench will be describe. At first, the virtual machine (VM) to run Windows XP is required, the VM given in this thesis project is the free software by Oracle. This File will be able to be installed in any host. The name of the file is: VirtualBox-5.2.8-121009-Win, this is a compressed file, once that is uncompressed the user must install it and then the implementation of Windows XP will take place. To create the virtual machine, the user must hit the button "New" and follow the instructions, using as virtual disk the file named MicWinXP32.exe, this file must be the 32 bit version in order to follow the other programs. The previous file is protected by password and the password to extract it before using it as the virtual disk is: youtube.com/saltypeanutboi. (Also steps to install it can be seen in this YouTube link).

Once the Windows XP is installed, the following files must be installed in the Virtual Machine that, at this time it will be in blank:

- wrar32.exe (To extract the up-coming archives).
- MICROWIN_STEPS7.rar (Inside this file there is a video to help install it).
- Microsoft Office Home and Student 2010.exe (This File Contains Excel and the Key of the product).

After this step, the complements to Excel and to MICROWIN step to read the data from the PLC.

- PC-ACCESS-S7200.exe (This will install the OPC server into the VM).
- Scale.mwl (A library that must be saved in the library folder of the MICROWIN-STEP 7 software, this file is found in the following address: C:/Program Files/Siemens/STEP7-MicroWIN V4.0/Lib).

After having instaled all the programs mentioned before, the instalation process is done.

Then the user can achieve the program that is installed in the PLC by opening MICROWIN-STEP 7 and pressing the button upload when the computer and the PLC are connected or can extracted from the file in which has find all the previous files with the name of PLC1.mwp.

Then after making sure that this program is installed in the PLC, (if not the user must download the program in the PLC), the comunication with the PLC is stablished, it can be through PPI or NETLink profibus cable. The PLC must be in RUN stage and then the process mentioned in the section 2.3 and 2.4 of the thesis Project will be executed.
After having the important data in the computer, the steps mentioned in the chapter 3 of the thesis Project (moving the program to MATLAB folder) and runing the MATLAB code will give the important metrics that are needed in life data analysis of pnumatic cylinders as shown in chapter 3.