PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA

Ministry of Higher education and Scientific Research

Ecole Nationale Polytechnique

المدرسة الوطنية المتعددة التقنيات

Ecole Nationale Polytechnique

BMS ELECTRIC

Control Engineering Department

BMS Company

In Partial fulfillment of the requirement for Engineer's Degree

Entitled:

THE DESIGN AND IMPLEMENTATION OF AN AUTOMATED ASSEMBLY MACHINE

Zineddine RIFINE

Supervised by:

Mr: Iloul (ENP)

Mr: M.Y.Gaddouche (BMS)

Presented and supported publically on October 12th, 2017

Jury members:

- Chairman: Mr.O Stihi (Professor at National Polytechnic School of Algiers)
- Examiner: Mr D.Saidi (Professor at National Polytechnic School of Algiers)
- Guest : Mr M.Y. Gaddouche (Head engineer at BMS)

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Dedications

I dedicate this work:

To my dear parents who stood by my side from the beginning of my studies, also to my grandmother and to my grandfather (May God Rests His Soul). A special feeling of gratitude to my loving aunts, whose words of encouragement and push for tenacity still ring in my ears.

To my colleagues, friends and to all people who know me from near or far.

To Mr. Boucherit Mohamed Salim who gave me the opportunity to intern in BMS.

To Mr. Yazid, my mentor and my role model, who was a big help during my internship in BMS.

To all BMS staff who helped me in my project especially Mr. Miloud, Mr.Mehdi. Mr. Hocine and Mr. Mohamed.

And to all my teachers and professors throughout the years.

Acknowledgements

At first, I thank ALMIGHTY ALLAH for giving me power, patience, and guidance to reach this point, and I pray TO ALLAH to give me strength to complete this work until the end.

I take this advantage to thank Mr.Yazid and Mr.Iloul for their help.

Special thanks go to all members of the jury who have honored me with their presence.

ملخص:

الهدف من هذا المشروع هو انجاز آلة تجميع أوتوماتيكية و تم انجازها وفق 3 مراحل, المرحلة الأولى هي مرحلة التصميم الميكانيكي و تتضمن تصميم الآلة باستعمال الحاسوب و ذلك لتجريب الآلة قبل الشروع في انجازها و التأكد من صلابة التصميم و قدرته على تحمل القوى بالاضافة الى دراسة تأثير الاحتكاك و الحرارة .و فالأخير تم تصنيع القطع بمراعات المعايير المعتمدة في الصناعة و تم تجميع هيكل الآلة.
المرحة الثانية تتضمن تنصيب أنظمة التحكم الهوائية و ذلك بتوصيل الأسطوانات الهوائية بموزعات الهواء المضغوط و أيضا تنصيب الدارات الكهربائية التي تكوِن لوحة التحكم التي بدورها تحتوي على المتحكم الآلي الذي يتضمن البرنامج و الذي يمثل عقل الآلة و تحتوي لوحة التحكم أيضا على وحدة التغذية و القاطع التفاضلي الذي يحمي الدارة الكهربائية و في الأخير تم تطوير البرنامج و تحميله على المتحكم الآلي باستعمال الحاسوب.
المرحلة الأخيرة تتضمن تجربة الآلة و التأكد من سلامة البرنامج و تصحيح الأخطاء التقنية و البرجية إن وجدت.

الكلمات الدالة :آلت تجميع أوتوماتيكية, لوحة التحكم, أنظمة التحكم الهوائية .

Résumé :

Le but de ce projet est de concevoir et mettre en place une machine d'assemblage automatique qui a été réalisée en 3 étapes. La première étape est la phase de conception mécanique, qui comprend la conception de la machine à l'aide du SolidWorks. Il s'agit de tester la machine avant qu'elle ne soit effectuée et d'assurer sa capacité à résister les forces, les frottements et la chaleur. Ce dernier a été fabriqué conformément aux normes adoptées dans l'industrie et la structure de la machine a été assemblée.
La deuxième étape consiste à installer des systèmes de commande pneumatique en connectant les vérins avec des vannes de commande et en installant également les circuits électriques qui sont le panneau de commande qui, à son tour, contient l'automate programmable industriel qui comprend le programme qui représente le cerveau de la machine. Le panneau de commande contient également une unité d'alimentation et le disjoncteur, après le programme a été développé et transféré vers l'automate
La phase finale comprend les essais, la vérification de sécurité du programme et la correction des erreurs techniques et de programme.

Mots Clés : Machine d'assemblage automatique, Conception Mécanique, Systèmes de commande, automate programmable industriel, armoire de commande.

Abstract:

The aim of this project is to design and implement an automatic assembly machine, which has been completed according to 3 stages. The first stage is the mechanical design stage, which includes the design of the machine using the computer. This is to test the machine before it is carried out and to ensure the rigidity of the design and its ability to withstand the forces, friction and heat. The latter was manufactured in accordance with the standards adopted in the industry and the structure of the machine was assembled.
The second stage involves the installation of pneumatic control systems by connecting air cylinders with control valves and also installing the electric circuits which are the control panel which in turn contains the programmable logic controller which includes the program which represents the machine's mind. The control panel also contains a power supply unit and the circuit breaker, after that, the program was developed and downloaded to the programmable logic controller.
The final stage includes try outs, the program's safety check, and the correction of technical and program errors, if any.

Key Words: automated assembly machine, mechanical design, control systems , programmable logic controller , control cabinet.

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GENERAL INTRODUCTION

Control systems are an integral part of modern society, numerous applications are all around us; the rockets fire and a space shuttle lifts off to earth's orbit, a metallic part is automatically machined with CNC apparatus (Computer Numerical Control), production lines and assembly lines. These are just a few examples of the automatically controlled systems that we can create.

Control engineering or control systems engineering is the engineering discipline that applies control theory to design systems with desired behaviors. The practice uses sensors to measure the output performance of the device being controlled and those measurements can be used to give feedback to the input actuators that can make corrections toward desired performance. When a device is designed to perform without the need of human inputs for correction it is called automatic control (such as cruise control for regulating the speed of a car). Multidisciplinary in nature, control systems engineering activities focus on implementation of control systems mainly derived by mathematical modeling of systems of a diverse range.

A Control Engineer designs ways to control the behavior of dynamic systems. Any system that constantly changes is considered dynamic. Some common examples of dynamic systems are a car that is travelling on a road, the temperature outside and manufacturing equipment. Control Engineering aims to create stability in these systems through various strategies. The first step to control a system's behavior is to measure and identify the system. Depending on the application of the control system, a Control Engineer has access to a wide range of sensors which can be used by other Engineers to measure any variable(s) to be controlled (e.g. pressure, voltage, acceleration and force).For complex systems, which is usually the case in real world applications, computer simulations based on first principles (mathematical equations) are used to investigate how to best control these variables. A Control Engineer will perform calculations and design software to best control the system as required. They also design the physical units that execute the software.

Modern day control engineering is a relatively new field of study that gained significant attention during the 20th century with the advancement of technology. It can be broadly defined or classified as practical application of control theory. Control engineering has an essential role in a wide range of control systems, from simple household washing machines to high-performance robotics arms and assembly machines. It seeks to understand physical systems, using mathematical modeling, in terms of inputs, outputs and various components with different behaviors, use control systems design tools to develop controllers for those systems and implement controllers in physical systems employing available technology. A system can be mechanical, electrical, fluid, chemical, financial and even biological, and the mathematical modeling, analysis and controller design uses control theory in one or many of the time, frequency and complex-s domains, depending on the nature of the design problem.
The main application where Control Engineering is mostly needed is: Factory Automation.

GENERAL INTRODUCTION

Since the dawn of the industrial era ,factory owners and product designers have looked to increase productivity by automating manufacturing which is the process of integrating industrial machinery to automatically perform tasks such as welding, assembly, pick and place, material handling, packing, palletizing, cutting, etc…

Factory automation has evolved significantly in the last few decades, and is today, a complex interdisciplinary scientific area, improving cost competitiveness and remaining abreast in high technology are some of the challenges that are faced by enterprises in the modern times. In this context, the roles of engineering, manufacturing and plant automation are becoming important factors to enhance product quality.

A product is any item that is designed, manufactured and delivered with the intention of making a profit for the producer by enhancing the quality of life of the customer. Most products are made up of various parts, where a part can be described as a single unit of a product that are brought together with others to form the finished product. Assembly, therefore, can be explained as the operation of bringing parts together, either manually by operators or automatically by robots, to form a finished product.

There are two primary methods of assembly in the industry, which are bench assembly, and line assembly. In bench assembly, the work-piece stays stationary on a bench; all required parts and equipment for assembly are brought to the bench and assemblers move around the bench to perform the assembly. Line assembly is an assembly method where work-pieces move through a sequence of stations for assembly one piece at a time. An assembly line is the production system in which assembly stations are organized in a serial layout and line assembly method is applied.

BMS ELECTRIC, as an Algerian enterprise thriving in the industrial sector, is faced by the challenges stated earlier, to beat the competition in the market and to protect its leadership in the e field, BMS is seeking a full automation of its factory but the ground idea is “We don’t buy automated machines, we build our own”.

I was a part of this exciting project, and I had the honor to work with BMS ELECTRIC on building its first semi-automatic assembly machine, a simple pick, place and fix machine.

In the course of my internship, I learnt what it takes to be a real engineer in general and an automation engineer in particular; it requires you to master many branches from other engineering domains like electrical and electronic engineering, mechanical engineering, computer science and essential tools: applied mathematics, applied physics and chemistry. Automation engineering is all about imagination and intuition, to bring ideas and concepts to reality, to machines that will help the industry and robots which will replace humans in factories and help them in their daily lives.

Our main objective in BMS Electric is to design and build an efficient assembly machine that will do the task needed in a short time and with a low cost; these key specifications were achieved at the end.
The methodology used to achieve the objective of the project, as a first task a similar assembly machine was chosen to identify the losses and to evaluate the ergonomics risks. The procedure was to collect the time studies.

The times studies of the manual assembly process were undertaken in terms of video analysis with the help of a company supervisor and operators. Information regarding assembly instructions, error types and adjustment times and procedures was gathered. The information was vital and used to evade and improve these things in a new assembly line.

Our machine’s main objective is to assemble and fix four spacers (one of the components of a power strip) on top of the internal surface of a power strip, it’s a simple pick, place and fix machine.

Introductory to machine design

Faster, better, and cheaper is the name of the game for machine and device designers. Demands for higher performance and increasingly efficient machines designed in a shorter amount of time with smaller design teams are challenging machine designers to improve their design processes. The Aberdeen Group (American technology and Services Company) identified these top machine design challenges after interviewing engineering managers and designers from 160 machine design companies (see table 1). The study also discovered that to meet these challenges, successful companies follow the mechatronics design approach – they increase integration between mechanical, electrical, control, and embedded programming design processes.

Pressures	Response
Shorter product development schedules	69%
Increased customer demand for better performing products	44%
Reduced development budgets	25%
Accelerated product customization	20%
Increased requirements to incorporate electronics and software into product	16%

Source: Aberdeen Group, January 2008

The Aberdeen Group's research of 160 machine design companies identified the top challenges machine designers face.

Intense competition is putting pressure on machine and device builders to deliver systems with higher throughput, reduced operating cost, and increased safety. Machine builders have switched from rigid, single-purpose machines relying purely on mechanical gears and cams to flexible multipurpose machines by adopting modern control systems and servomotors. Although these improvements have made machines flexible, they have also introduced a significant amount of complexity to the machines and subsequently to the machine design process.

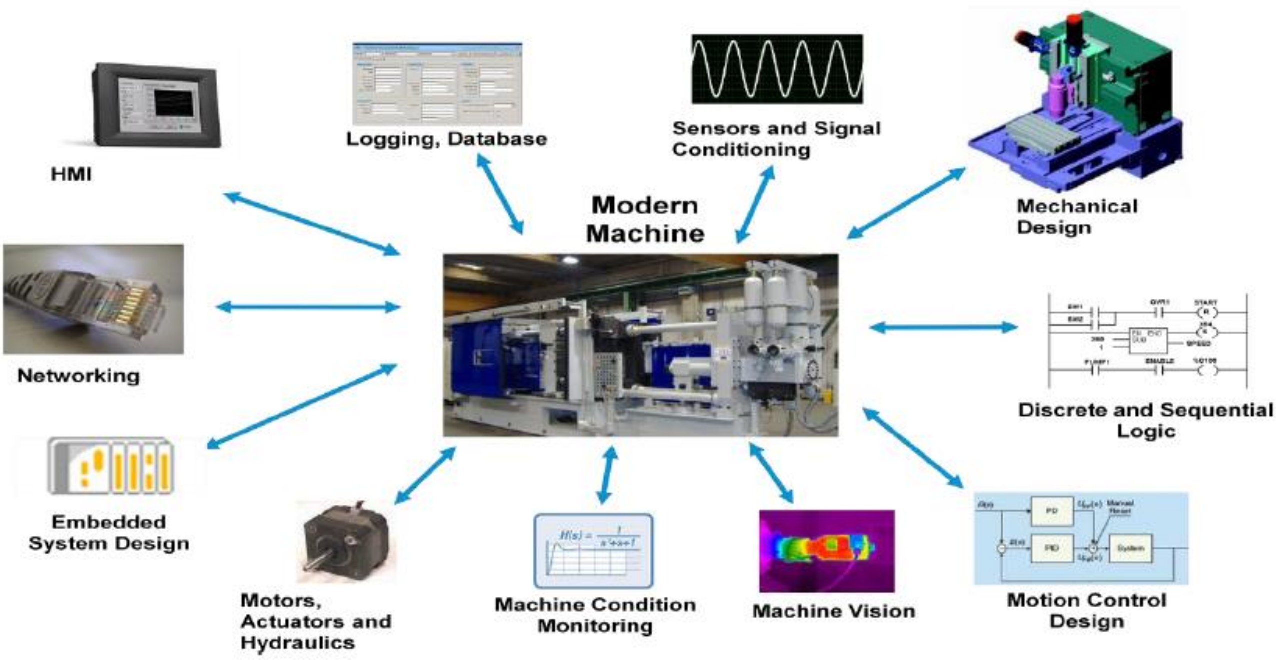


Figure: To maintain a leadership position, machine builders are designing increasingly complex machines.

There is no fixed machine design procedure for when the new machine element of the machine is being designed a number of options have to be considered. When designing machine one cannot apply rigid rules to get the best design for the machine at the lowest possible cost. The designer who develops the habit of following a fixed line of steps for designing the machine or machine elements cannot come out with the best product. When the new product is to be developed the problems keep on arising at design stage, and these can be solved only by having flexible approach and considering various ways.

Next section I will present the most important steps of designing a machine

I. Important steps of designing a Machine

Though the machine design procedure is not standard, there are some common steps to be followed; these can be followed as per the requirements wherever and whenever necessary. Here are some guidelines as to how the machine design engineer can proceed with the design:

1) Making the written statement: or defining the requirements which is making the written statement of what exactly is the problem for which the machine design has to be done. This statement should be very clear and as detailed as possible. If you want to develop the new produce write down the details about the project. This statement is sort of the list of the aims that are to be achieved from machine design.

2) Consider the possible mechanisms: When you designing the machine consider all the possible mechanisms which help desired motion or the group of motions in your proposed machine. From the various options the best can be selected whenever required.

3) Transmitted forces: Machine is made up of various machine elements on which various forces are applied. Calculate the forces acting on each of the element and energy transmitted by them.

4) Material selection: Select the appropriate materials for each element of the machine so that they can sustain all the forces and at the same time they have least possible cost.

5) Find allowable stress: All the machine elements are subjected to stress whether small or large. Considering the various forces acting on the machine elements, their material and other factors that affect the strength of the machine calculate the allowable or design stress for the machine elements.

6) Dimensions of the machine elements: Find out the appropriate dimensions for the machine elements considering the forces acting on it, its material, and design stress. The size of the machine elements should be such that they should not distort or break when loads are applied.

7) Consider the past experience: If you have the past experience of designing the machine element or the previous records of the company, consider them and make the necessary changes in the design. Further, designer can also consider the personal judgment so as to facilitate the production of the machine and machine elements.

8) Make drawings: After designing the machine and machine elements make the assembly drawings of the whole machines and detailed drawings of all the elements of the machine. In the drawings clearly specify the dimensions of the assembly and the machine elements, their total number required, their material and method of their production.

The designer should also specify the accuracy, surface finish and other related parameters for the machine elements.

9) Leverage CAD Software for Visualization
Use available computing resources to make a professional, detailed physical design. A design defined in CAD software with dimensions, notes, and materials specified is much more powerful than a back-of-the-napkin sketch. It implies a detailed, well-thought-out design and a serious intent. This helps you gain consensus and get buy-in because others can more effectively visualize your design. This is strictly for visualization purposes. Resist the temptation to move forward with the detailed design of your functional prototype at this stage. A more detailed design comes later. [1]

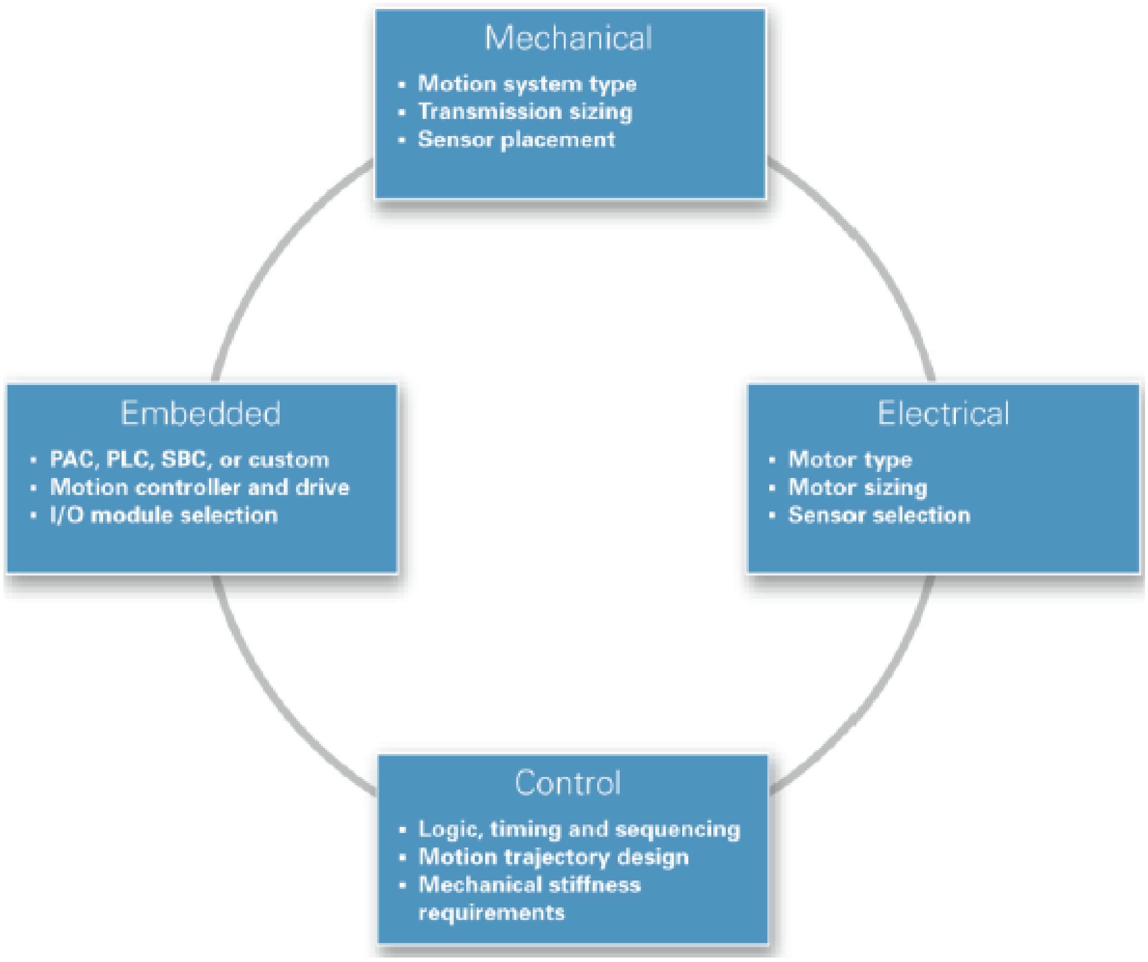


Figure: Machine design requires effective communication between engineering disciplines.

II: Different approaches for machine design

Machine designers today are dealing with new challenges. A few decades ago, time to market was not an impending issue and different design areas had different teams with specific expertise. Teamwork was not enforced because every design team took the design inputs and generated a design output. But with the fierce competitive environment in which companies have to operate today, a modern design approach must incorporate efficiencies and symbiosis as well as a high-level view of the machine requiring design team interaction. To make the design process even more challenging, machines are expected to be more complex with higher precision and tolerances. As machines require higher throughput, faster loop rates with more complex algorithms are no longer limited to high-performance, high-cost machines – they have become a commodity.

Earlier machine designers adopted a traditional approach for machine conception where each stage of the development process (design stages, manufacturing, testing, production is carried out separately or sequentially , and the next stage cannot start until the previous stage is finished.

Nowadays engineers use the mechatronics parallel design approach which regroups all of the design stages (mechanical, electrical, embedded hardware and control) in one bloc or parallel sub-stages where they are carried out simultaneously (in parallel) by multiple teams and adds a virtual prototyping stage which is missing in the traditional sequential approach.

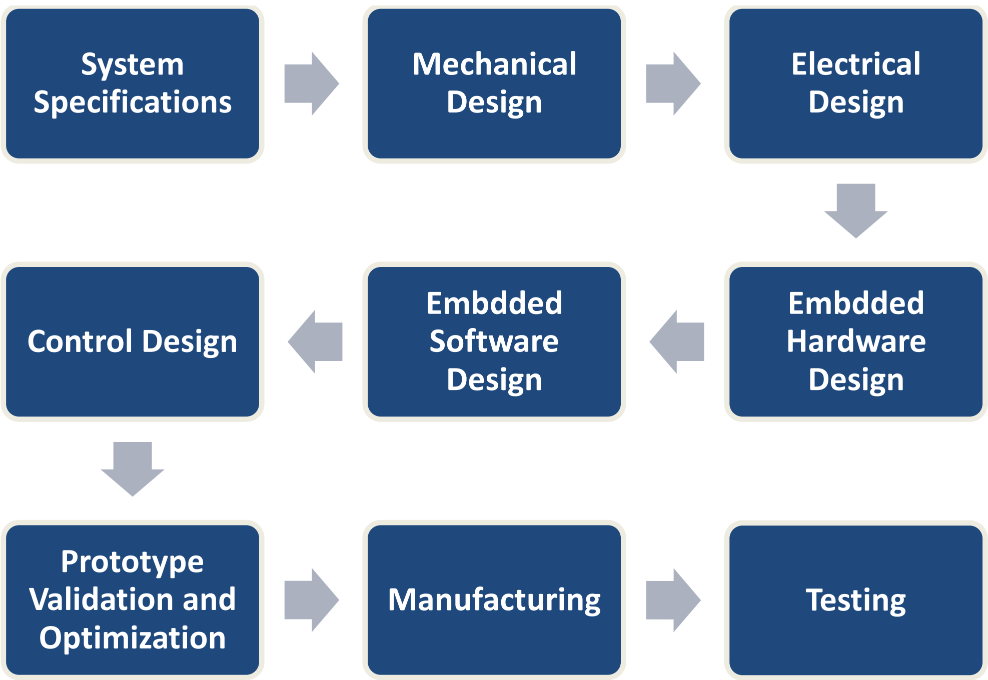


Figure : Traditional Sequential Design Approach

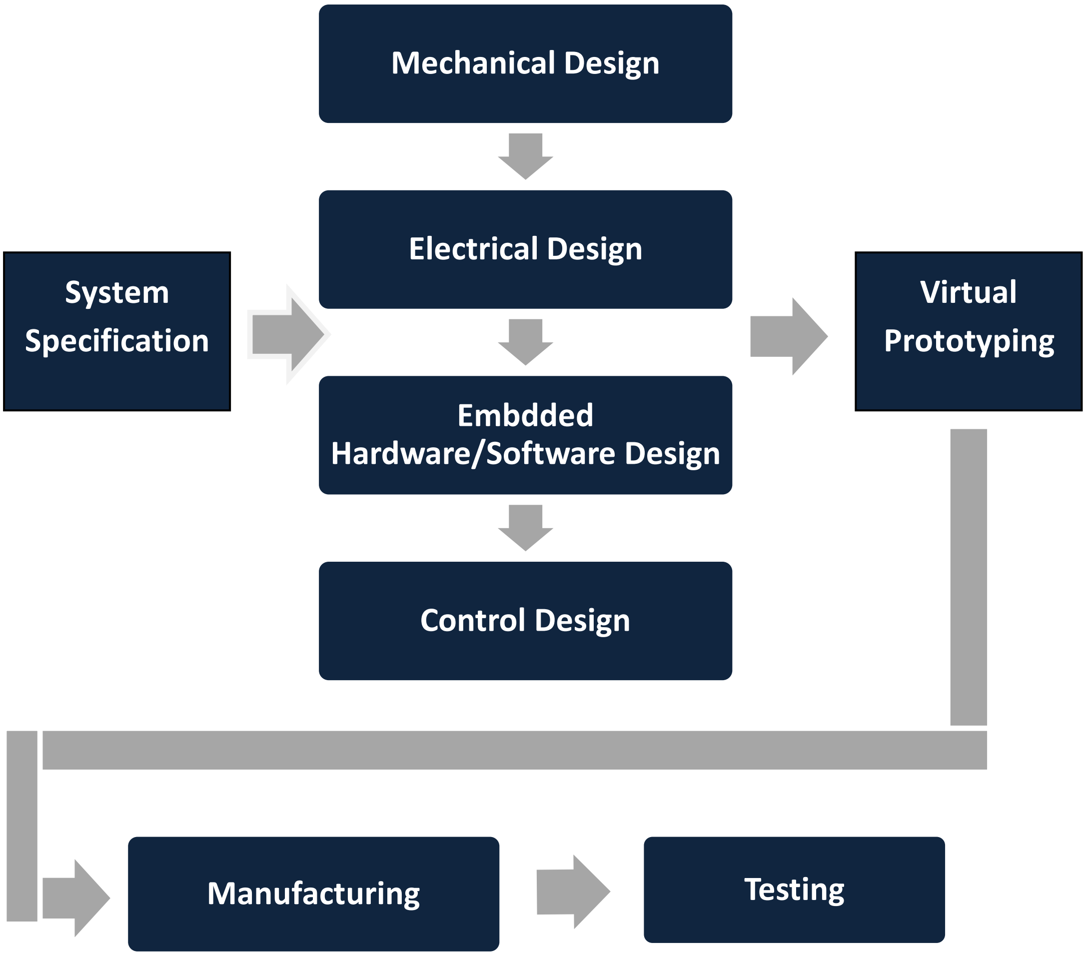


Figure : Mechatronics Parallel Design Approach

III: Skills a Good Machine Designer should possess

A good machine designer possesses some skills that help him/her design the machine elements and machine that meet all the needs of the designer and that helps develop the high quality machine at lowest possible costs. These skills help the machine design engineer consider all the relevant parameters in the broad sense and understand their effects on the machine. The good designer has knowledge of wide range of subjects related to the machine that helps them find out the best solution to the problem. Their communications skills help them communicate their problem to others and find the solution of the problem from different sources.

Here are some important skills that a good machine designer should possess:

1) Inventiveness: This skill is the stone foundation for a good machine design engineer. Any new design starts with the need or some objective. A good designer should have inventiveness, which is the ability to think of or discover valuable and useful ideas or concepts for the things or processes to achieve the given objective. Without inventiveness the designer cannot start the process of machine design.

2) Engineering analysis: Engineering analysis is the ability of the designer to analyze the given component, system or the process using engineering and scientific principles. The designer who possesses this skill will be able to find answer to the engineering related problems very quickly for he or she knows what exactly the problem is and where it is.

3) Engineering science: This is another skill without which the designer will just not be able to do any designing. A good designer is the one who has thorough knowledge and an in depth training in the engineering science. For instance, if the person doesn't know what the refrigerator is and other basics of mechanical engineering how will they will not be able to design the refrigerator?

4) Interdisciplinary ability: A good design engineer is the one who has the ability to solve the problems not only those related to his/her specialty, but also have the ability to competently and confidently deal the basic problems or ideas from other disciplines which are in some or the other manner linked to the machine they are designing.

5) Mathematical skills: All types of designs involve lots of mathematical calculations and iterations. A good designer should have the knowledge of all the basics and advanced mathematical concepts so that they can be applied fruitfully and effectively wherever required.

6) Decision making: During designing many times a number of uncertain situations arrive, in such cases the designer should be able to take the decision with balanced mind considering all the relevant factors involved. If the person doesn't maintain the balance of mind and doesn't consider all the relevant factors there are greater chances of taking the wrong decision.

7) Manufacturing processes: The design engineer should have the knowledge of the manufacturing process like cutting, drilling, milling etc.., and the knowledge of all the machines. They should also have the knowledge of potential and limitations of all the machines and manufacturing processes which may be old or new.

8) Communication skills: Communication skill is the ability of the design engineer to express oneself clearly and persuasively orally, graphically as well as in writing.

These are the important skills that the machine design engineer or rather any designer should possess. Apart from this there are many other skills desired from a good designers, these are: skill in design, good judgment, simulation skill, measurement skill, thought skill, work in team, ability to make conclusion etc.

PART ONE:

MECHANICAL DESIGN

Chapter I:

Overall Design

PART ONE: MECHANICAL DESIGN

Chapter I: Overall Design of the Machine

I.1 Introduction

The mechanical modeling of a machine is a very crucial part of the design procedure because it takes a lot of time and a need a developed knowledge and skills in mechanics, geometry, and material properties, physics of motion. Mechanical design is the use of scientific principles and technical information along with innovations, ingenuity or imagination in the definition of a machine, mechanical device or system (product) to perform pre specified functions with maximum economy and efficiency.

To design is either to formulate a plan for the satisfaction of a specified need or to solve a problem. If the plan results in the creation of something having a physical reality, then the product must be functional, safe, reliable, competitive, usable, manufacturable, and marketable.
Design is an innovative and highly iterative process. It is also a decision-making process. Decisions sometimes have to be made with too little information, occasionally with just the right amount of information, or with an excess of partially contradictory information. Decisions are sometimes made tentatively, with the right reserved to adjust as more becomes known. The point is that the engineering designer has to be personally comfortable with a decision-making, problem-solving role.

I.2: Phases and Interactions of the Design Process

What is the design process? How does it begin? Does the engineer simply sit down at a desk with a blank sheet of paper and jot down some ideas? What happens next? What factors influence or control the decisions that have to be made? Finally, how does the design process end?
The complete design process, from start to finish, is often outlined as in Figure 1.1. The process begins with an identification of a need and a decision to do something about it. After much iteration, the process ends with the presentation of the plans for satisfying the need. Depending on the nature of the design task, several design phases may be repeated throughout the life of the product, from inception to termination. In the next several subsections, we shall examine these steps in the design process in detail.

Identification of need generally starts the design process. Recognition of the need and phrasing the need often constitute a highly creative act, because the need may be only a vague discontent, a feeling of uneasiness, or a sensing that something is not right. The need is often not evident at all; recognition is usually triggered by a particular adverse circumstance or a set of random circumstances that arises almost simultaneously.
For example, the need to do something about a food-packaging machine may be indicated by the noise level, by a variation in package weight, and by slight but perceptible variations in the quality of the packaging or wrap.

There is a distinct difference between the statement of the need and **the definition of the problem**. The definition of problem is more specific and must include all the specifications for the object that is to be designed. The specifications are the input and output quantities, the characteristics and dimensions of the space the object must occupy, and all the limitations on these quantities. We can regard the object to be designed as something in a black box. In this case we must specify the inputs and outputs of the box, together with their characteristics and limitations. The specifications define the cost, the number to be manufactured, the expected life, the range, the operating temperature, and the reliability. Specified characteristics can include the speeds, feeds, temperature limitations, maximum range, expected variations in the variables, dimensional and weight limitations, etc.

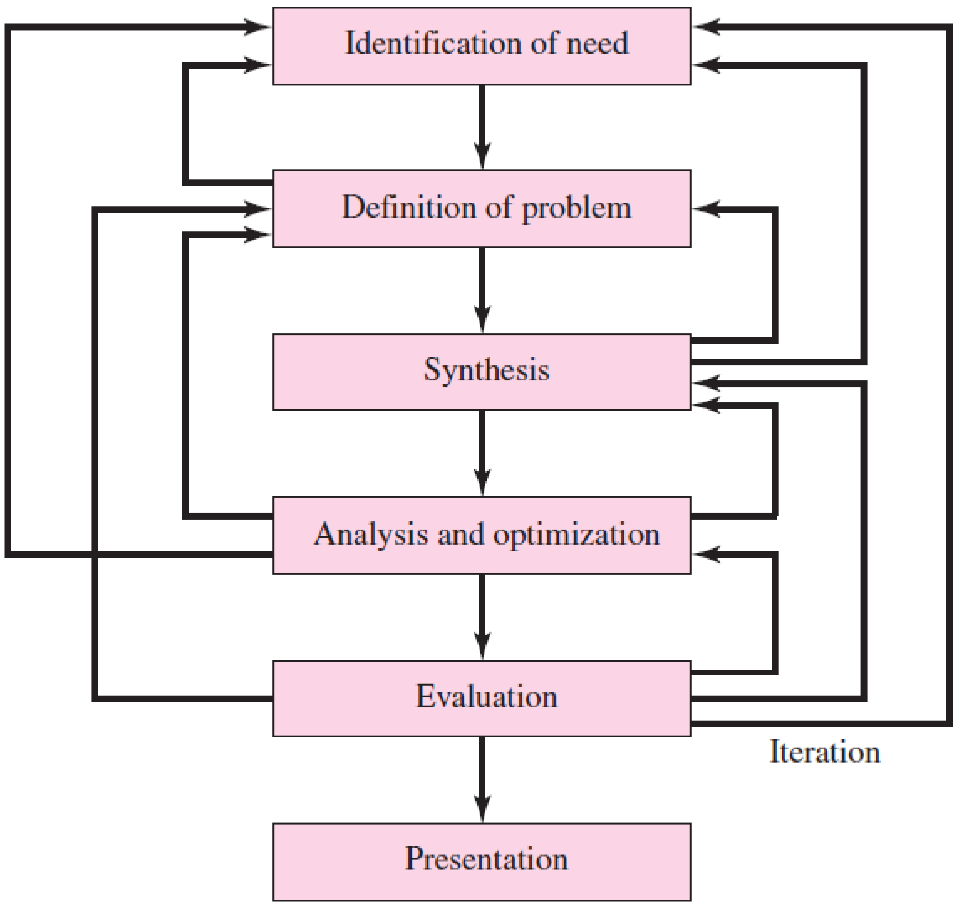


Figure 1.1: The phases in design, acknowledging the many feedbacks and iterations.

The synthesis of a scheme connecting possible system elements is sometimes called the invention of the concept or concept design. This is the first and most important step in the synthesis task. Various schemes must be proposed, investigated, quantified.

Both **analysis and optimization** require that we construct or devise abstract models of the system that will admit some form of mathematical analysis. We call these models mathematical models. In creating them it is our hope that we can find one that will simulate the real physical system very well. As indicated in Fig. 1.1, **evaluation** is a significant phase of the total design process. Evaluation is the final proof of a successful design and usually involves the testing of a prototype in the laboratory. Here we wish to discover if the design really satisfies the needs.

Communicating the design to others is the final, vital presentation step in the design process. Undoubtedly, many great designs, inventions, and creative works have been lost to posterity simply because the originators were unable or unwilling to explain their accomplishments to others. Presentation is a selling job. The engineer, when presenting a new solution to administrative, management, or supervisory persons, is attempting to sell or to prove to them that this solution is a better one. Unless this can be done successfully, the time and effort spent on obtaining the solution have been largely wasted. When designers sell a new idea, they also sell themselves. If they are repeatedly successful in selling ideas, designs, and new solutions to management, they begin to receive salary increases and promotions; in fact, this is how anyone succeeds in his or her profession.

I.3: Design Considerations

Sometimes the strength required of an element in a system is an important factor in the determination of the geometry and the dimensions of the element. In such a situation we say that strength is an important design consideration. When we use the expression design consideration, we are referring to some characteristic that influences the design of the element or, perhaps, the entire system. Usually quite a number of such characteristics must be considered and prioritized in a given design situation. Many of the important ones are as follows (not necessarily in order of importance):

- Functionality
- Strength/stress
- Distortion/deflection/stiffness
- Wear
- Corrosion
- Safety
- Reliability
- Manufacturability
- Utility
- Cost
- Friction
- Weight
- Life
- Noise
- Styling
- Shape
- Size
- Control
- Thermal properties
- Surface
- Lubrication
- Marketability
- Maintenance
- Volume
- Liability
- Remanufacturing/resource recovery

Some of these characteristics have to do directly with the dimensions, the material, the processing, and the joining of the elements of the system. Several characteristics may be interrelated, which affects the configuration of the total system.

I.4: Design Tools and Resources

Today, the engineer has a great variety of tools and resources available to assist in the solution of design problems. Inexpensive microcomputers and robust computer software packages provide tools of immense capability for the design, analysis, and simulation of mechanical components. In addition to these tools, the engineer always needs technical information, either in the form of basic science/engineering behavior or the characteristics of specific off-the-shelf components. Here, the resources can range from science/engineering textbooks to manufacturers' brochures or catalogs. Here too, the computer can play a major role in gathering information.

I.4.1: Computational Tools

Computer-aided design (CAD) software allows the development of three-dimensional (3-D) designs from which conventional two-dimensional orthographic views with automatic dimensioning can be produced. Manufacturing tool paths can be generated from the 3-D models, and in some cases, parts can be created directly from a 3-D database by using a rapid prototyping and manufacturing method (stereolithography)—paperless manufacturing.

Another advantage of a 3-D database is that it allows rapid and accurate calculations of mass properties such as mass, location of the center of gravity, and mass moments of inertia. Other geometric properties such as areas and distances between points are likewise easily obtained. There are a great many CAD software packages available such as Aries, AutoCAD, CadKey, I-Deas, Unigraphics, Solid Works, and ProEngineer, to name a few.

I.4.2: Acquiring Technical Information

We currently live in what is referred to as the information age, where information is generated at an astounding pace. It is difficult, but extremely important, to keep abreast of past and current developments in one's field of study and occupation. Some sources of information are:

- Libraries (community, university, and private): Engineering dictionaries and encyclopedias, textbooks, monographs, handbooks, indexing and abstract services, journals, translations, technical reports, patents, and business sources/brochures/catalogs.
- Government sources
- Professional societies.
- Commercial vendors. Catalogs, technical literature, test data, samples, and cost information.
- Internet.

I.5: The SOLIDWORKS Software

I.5.1: Definition and uses

The main software used in designing and modeling the machine is SOLIDWORKS; this chapter is dedicated to introducing this tool and its basic features

The SOLIDWORKS® CAD (**C**omputer **A**ided **D**esign) software is a mechanical design automation and computer-aided engineering (CAE) application that lets designers quickly sketch out ideas, experiment with features and dimensions, and produce models and detailed drawings. SolidWorks is published by Dassault Systèmes.

Figure 1.2: SOLIDWORKS Logo.

I.5.2: Dassaut Systèms: History and Development of the Company

Dassault Systèmes, the 3DEXPERIENCE Company, provides software applications and services, designed to support companies' innovation processes. The Company's software applications and services span design from ideation, to early 3D digital conceptual design drawings to full digital mock-up; virtual testing of products; end-to-end global industrial operations, including manufacturing management to operations planning & optimization; and in marketing and sales from digital marketing and advertising to end-consumer shopping experience.

The Group brings value to over 200,000 customers of all sizes, in all industries, in more than 140 countries. Dassault Systèmes is the world leader of the global Product Lifecycle Management ("PLM") market (design, simulation, manufacturing and collaboration) based upon end-user software revenue,a position which it has held since 1999.

Dassault Systèmes was established in 1981 through the spin-off of a small team of engineers from Dassault Aviation, which was developing software to design wind tunnel models and therefore reduce the cycle time for wind tunnel testing, using modeling in three dimensions ("3D").

The Company entered into a distribution agreement with IBM the same year and started to sell its software under the CATIA brand.

Through its work with large industrial customers, the Company learned how important it was for them to have a software solution that would support the design of highly diversified parts in 3D.

The growing adoption of 3D design for all components of complex products, such as airplanes and cars, triggered the vision for transforming the 3D part design process into an integrated product design.
The Company undertook a series of targeted acquisitions expanding its software applications portfolio offering to include digital manufacturing, realistic simulation, product data management and enterprise business process collaboration. [2]

I.5.3: SOLIDWORKS Fundamentals

I.5.3.1: Concepts

Parts are the basic building blocks in the SOLIDWORKS software. Assemblies contain parts or other assemblies, called subassemblies.
A SOLIDWORKS model consists of 3D geometry that defines its edges, faces, and surfaces.
The SOLIDWORKS software lets you design models quickly and precisely.
SOLIDWORKS models are:

- Defined by 3D design.
- Based on components.

I.5.3.2: 3D Design

SOLIDWORKS uses a 3D design approach. As you design a part, from the initial sketch to the final result, you create a 3D model. From this model, you can create 2D drawings or mate components consisting of parts or subassemblies to create 3D assemblies. You can also create 2D drawings of 3D assemblies.
When designing a model using SOLIDWORKS, you can visualize it in three dimensions, the way the model exists once it is manufactured.

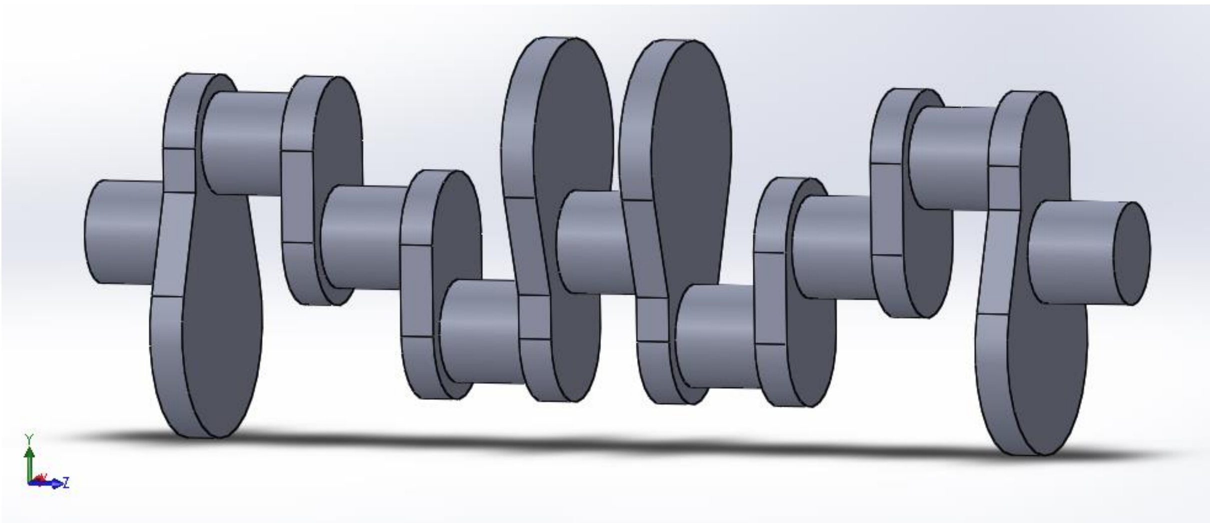


Figure 1.3: SOLIDWORKS 3D part (crank mill)

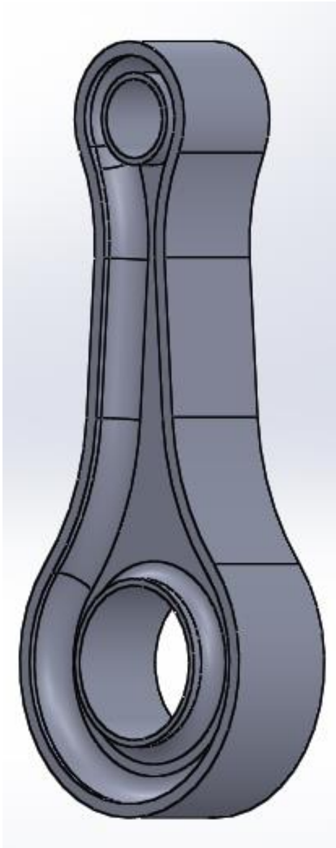


Figure 1.4: SOLIDWORKS 3D part (crank rod).

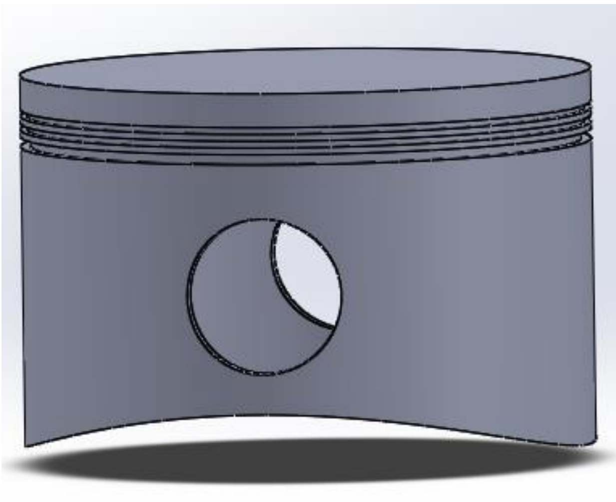


Figure 1.5: SOLIDWORKS 3D part (piston).

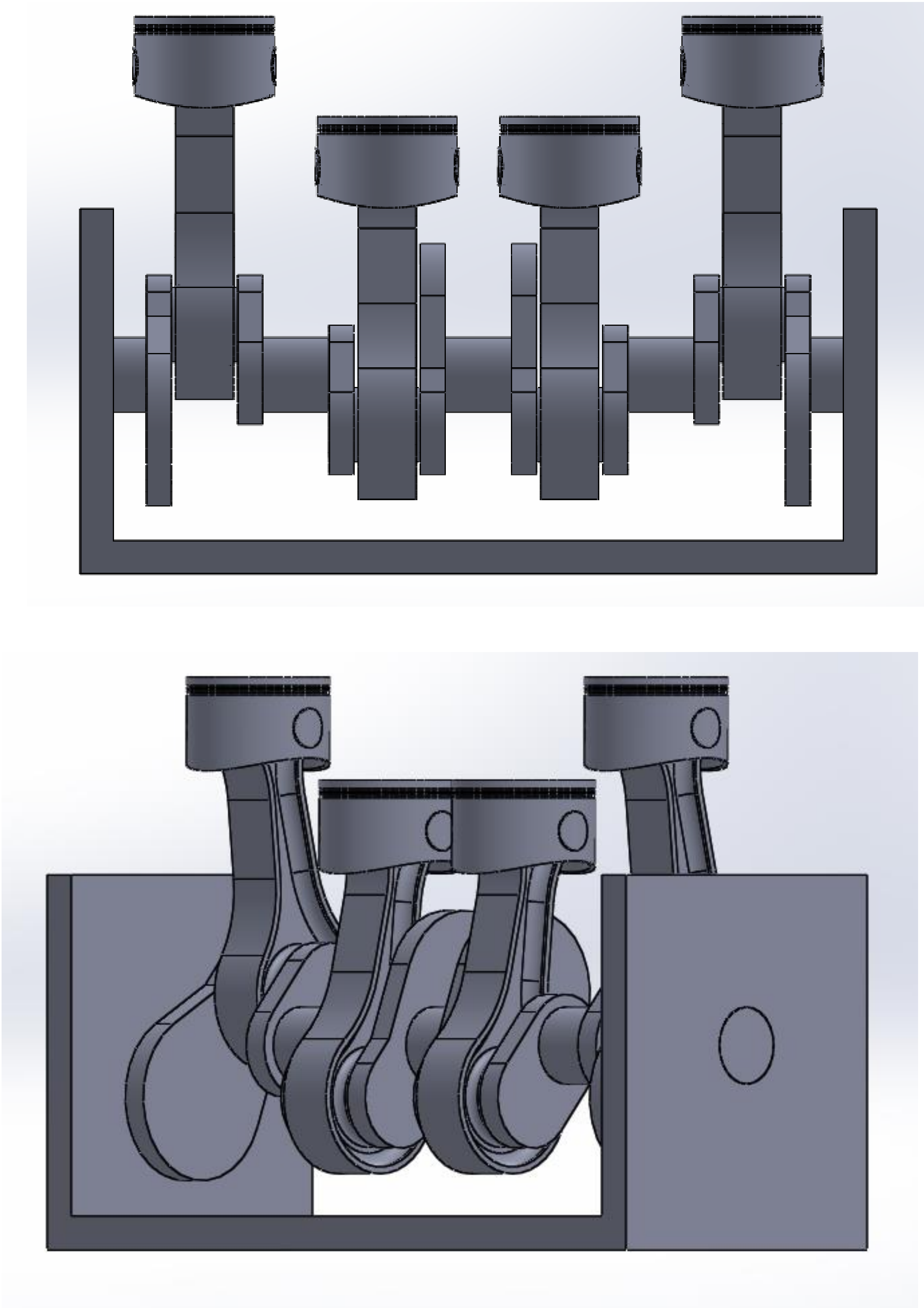


Figure 1.6: SOLIDWORKS 3D assembly.

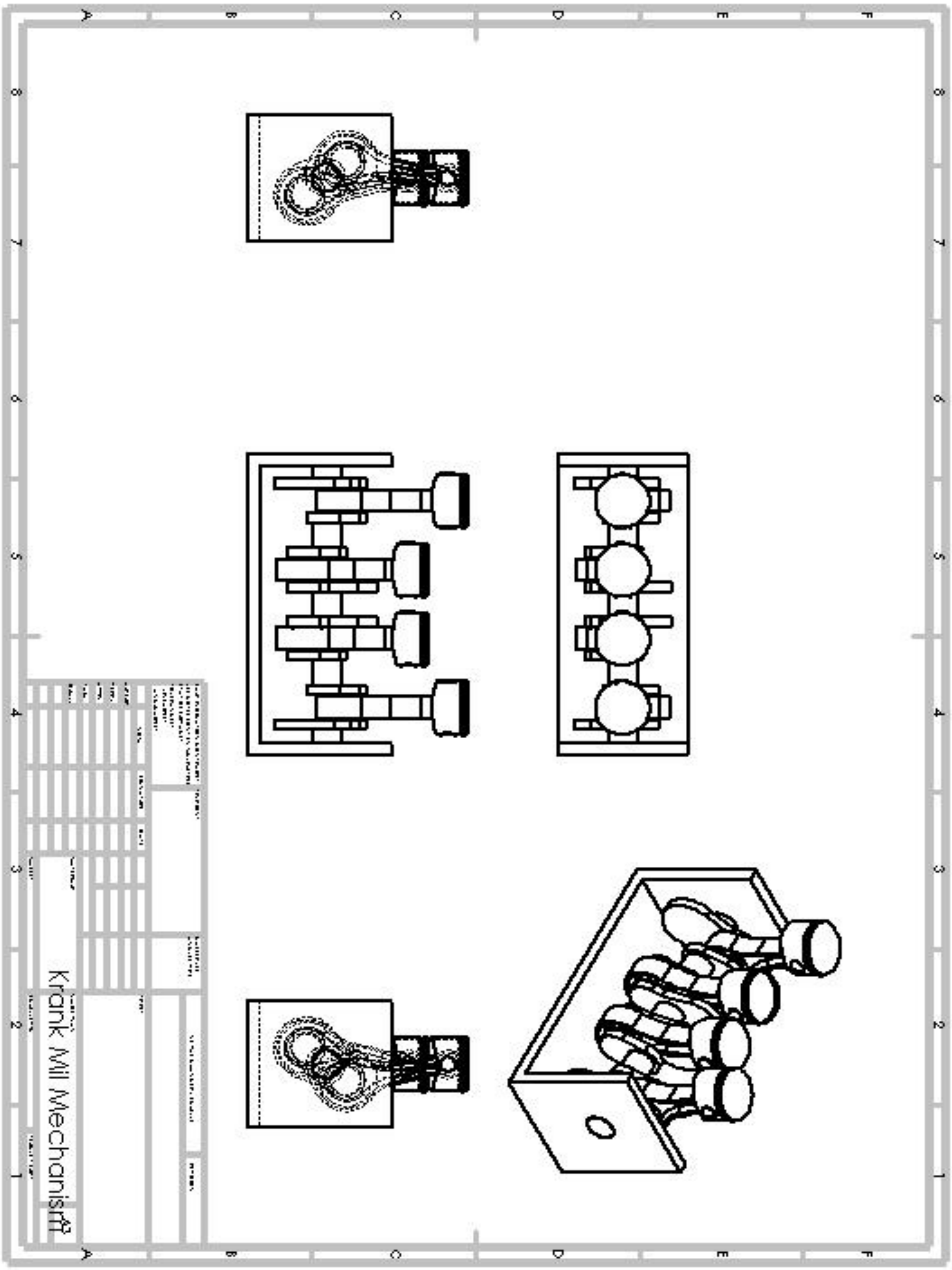


Figure 1.7: SOLIDWORKS 2D drawing generated from 3D model.

I.5.4: Design Process

The design process usually involves the following steps:

• Identify the model requirements.

• Conceptualize the model based on the identified needs.

• Develop the model based on the concepts.

• Analyze the model.

• Prototype the model.

• Construct the model.

• Edit the model, if needed.

I.5.5: Design Method

Before you actually design the model, it is helpful to plan out a method of how to create the model. After you identify the needs and isolate the appropriate concepts, you can develop the model:

- **Sketches**: Create the sketches and decide how to dimension and where to apply relations. The sketch is the basis for most 3D models. Creating a model usually begins with a sketch. From the sketch, you can create features.
  You can combine one or more features to make a part. Then, you can combine and mate the appropriate parts to create an assembly. From the parts or assemblies, you can then create drawings.
- **Features**: Select the appropriate features, such as extrudes and fillets, determine the best features to apply, and decide in what order to apply those features.

Once you complete the sketch, you can create a 3D model using features such as extrude or revolve.

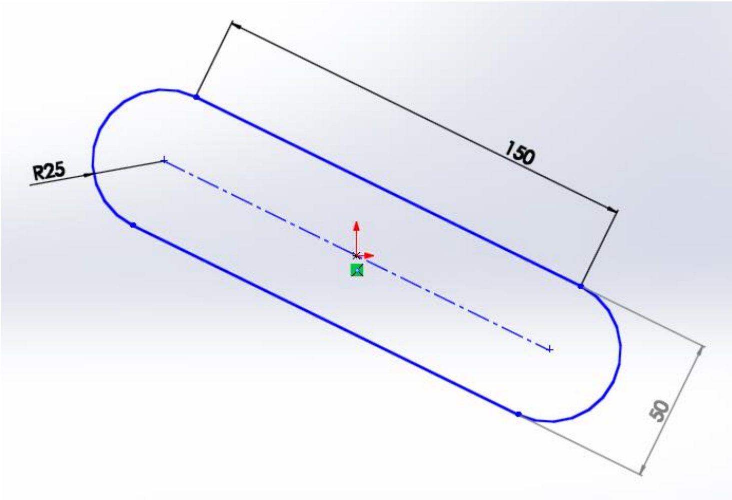


Figure1.8: Drawing sketch with dimensions.

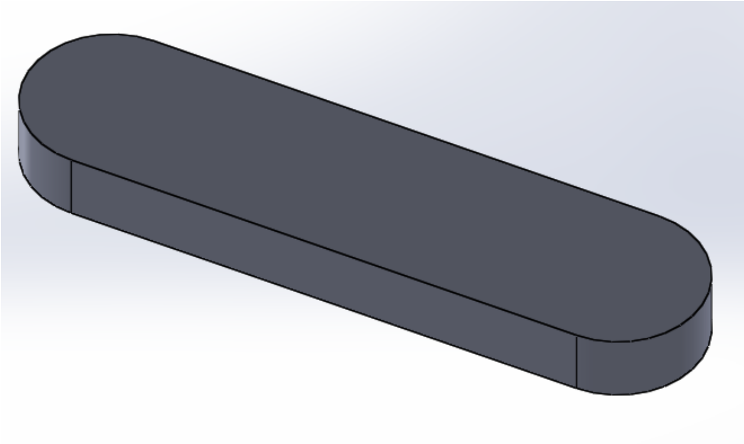


Figure 1.9: Sketch extrusion.

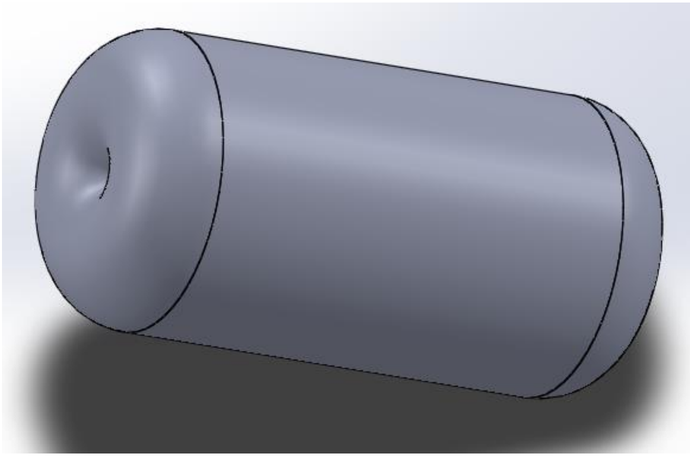


Figure 1.10: Revolution about an axis.

- **Assemblies**: Select the components to mate and the types of mates to apply. You can combine multiple parts that fit together to create assemblies. You integrate the parts in an assembly using Mates, such as Concentric and Coincident.
  Mates define the allowable direction of movement of the components. With tools such as Move Component or Rotate Component, you can see how the parts in an assembly function in a 3D context. [3]

➢ **Engineering Tasks**

The SOLIDWORKS software contains several tools (Toolbox) to help achieving an engineering task such as simulation, animating assemblies, performing stress analysis.
SOLIDWORKS is an essential tool in modern engineering where modeling and prototyping an automated machines is required before proceeding with construction.

I.6: Objectives and tasks of the machine

I.6.1: Introduction

A power strip (also known as an extension block, power board, power bar, plug board, trailing gang, trailing socket, plug bar, trailer lead, multi-socket, multiple socket, multiple outlet, polysocket and by many other variations) is a block of electrical sockets that attaches to the end of a flexible cable (typically with a mains plug on the other end), allowing multiple electrical devices to be powered from a single electrical socket. Power strips are often used when many electrical devices are in proximity, such as for audio, video, computer systems, appliances, power tools, and lighting. Power strips often include a circuit breaker to interrupt the electric current in case of an overload or a short circuit. Some power strips provide protection against electrical power surges.

Figure 1.11: BMS power strip.

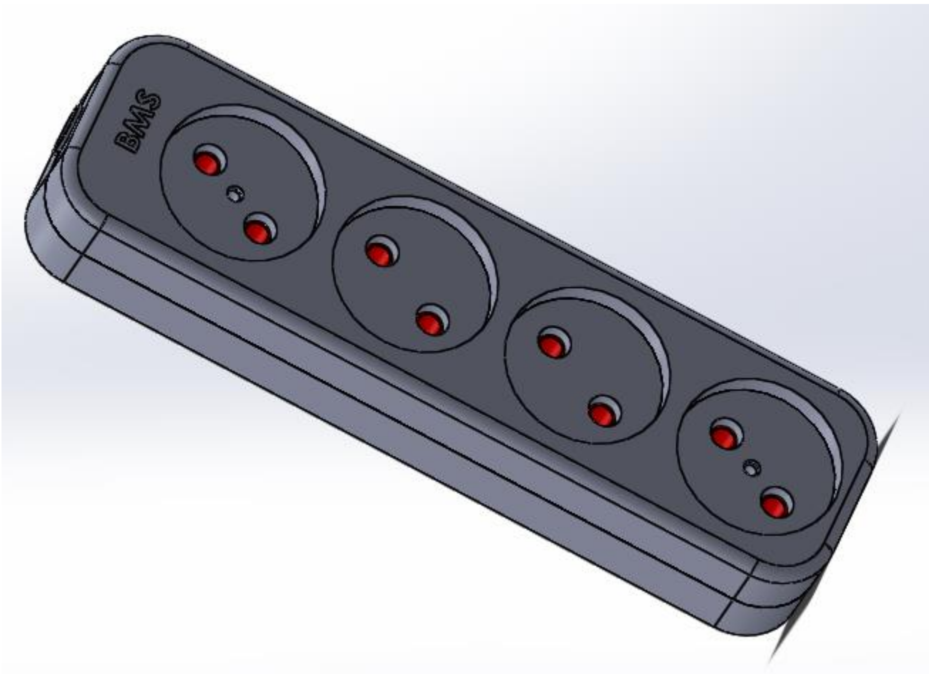


Figure 1.12: BMS power strip SolidWorks model.

I.6.2: Power strip components

A power strip is composed from a bottom cover and an upper cover which contains the sockets (outlets).
Internally is contains a mechanism (housing) that holds copper plates which conducts electricity from the mains, it contains also “plastic spacers” that holds the housing in place to guarantee a smooth conduction and a mechanic strength against chock and vibration, and to guide the plug’s pins.

Figure 1.13: internal components of a power strip.

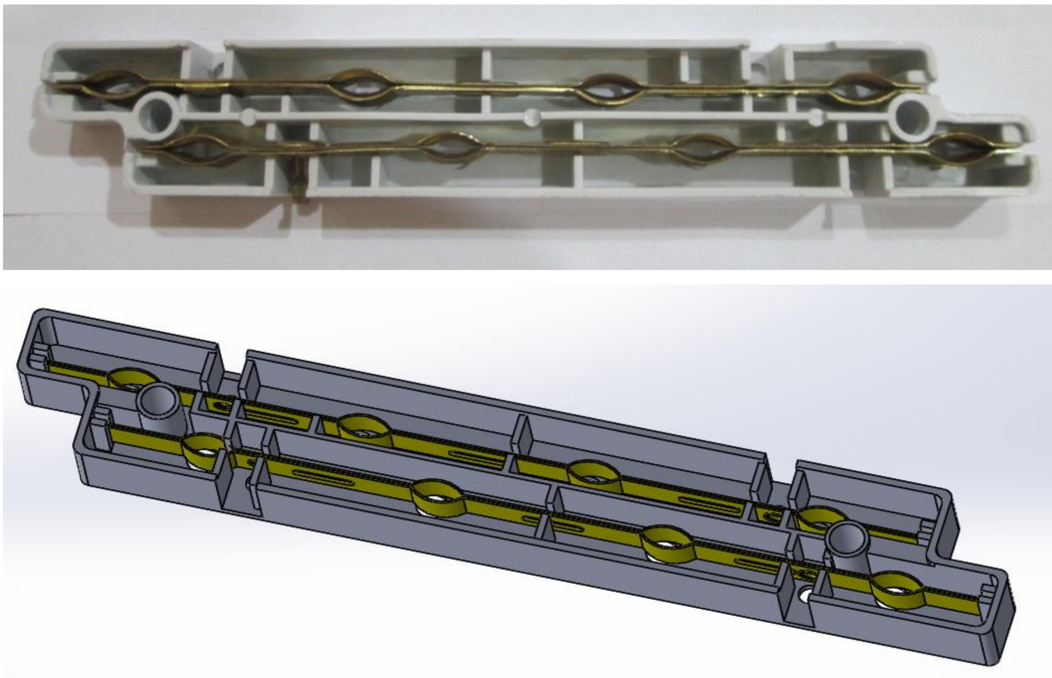


Figure 1.14: Copper plates housing (real and Solidworks model).

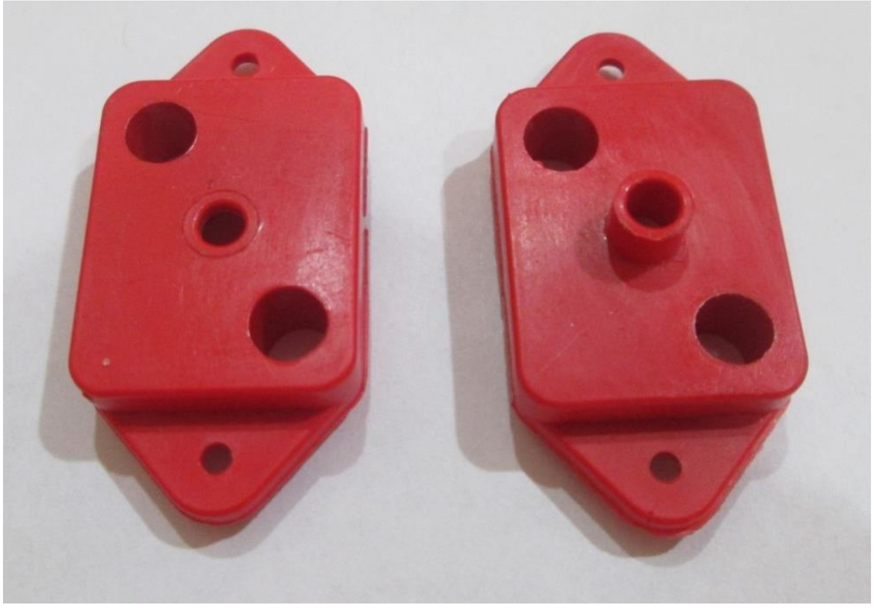


Figure 1.15: Plastic spacers female (right) and male (left).

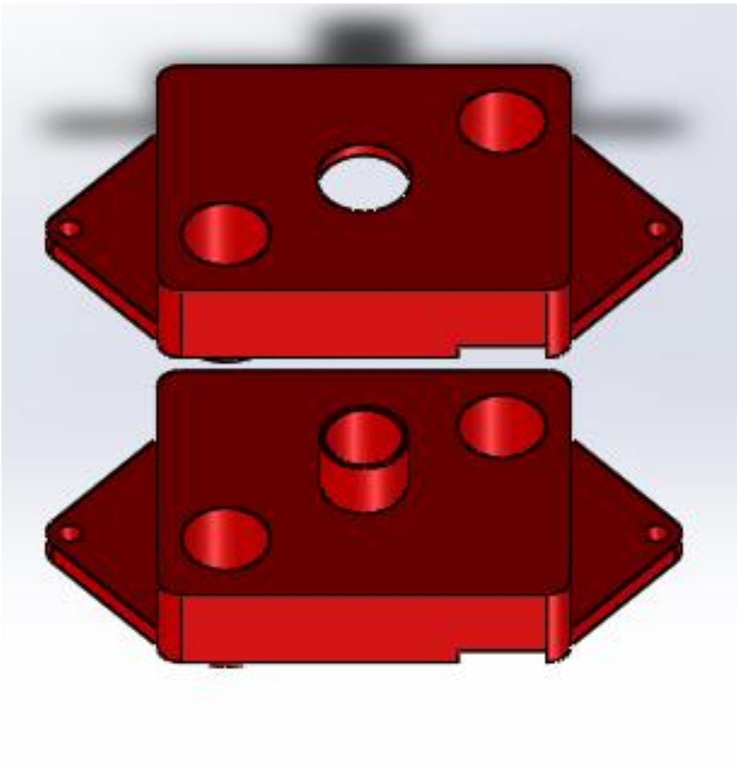
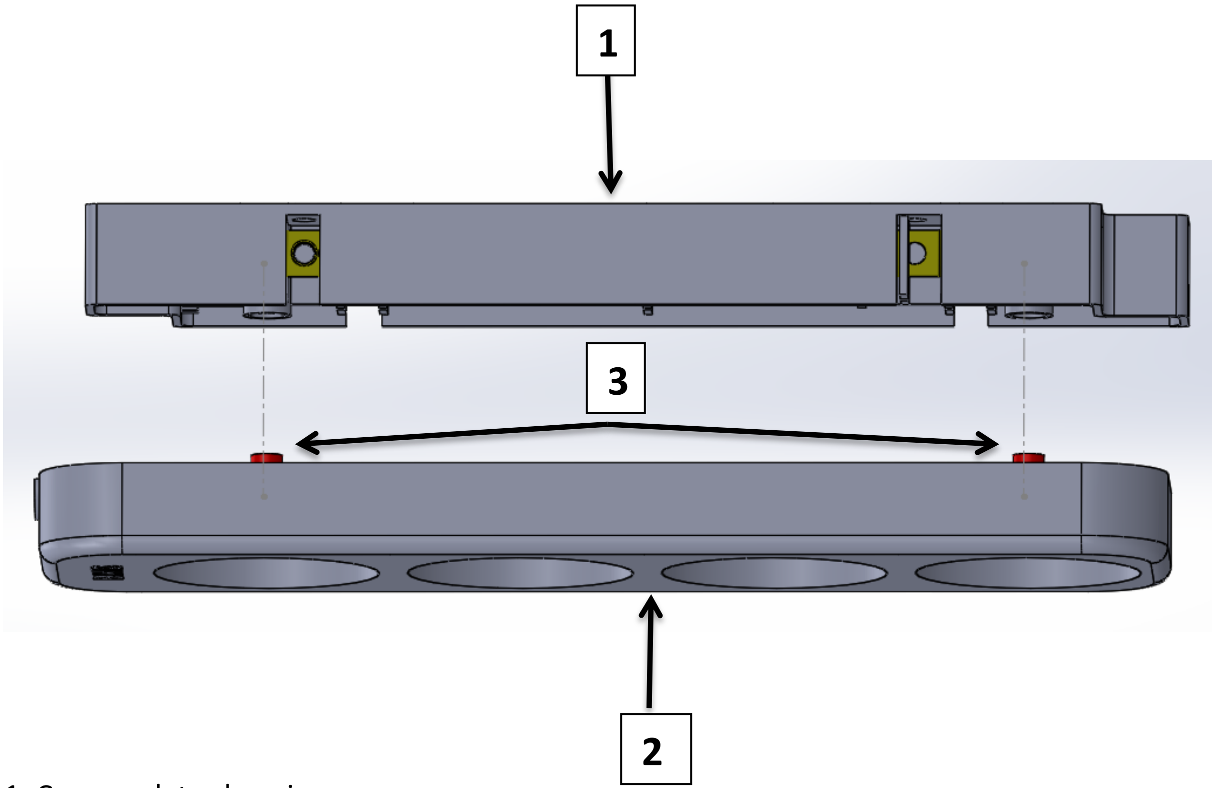


Figure 1:16: Spacers SolidWorks model.



1: Copper plates housing.

2: Power strip’s upper case.

3: Female spacers.

Figure 1.17: housing layout.

Figure 1.18: Housing assembly.

I.6.3: objective

Spacers' assembly is a difficult task and before this project, it was done manually by placing them on the internal surface of the power strip and nailing them with a hammer, this task takes a lot of time and isn't reliable.
The power strip is made of plastic and its internal surface (where the spacers are fixed) contains vertical studs. The side holes of the spacers are aligned with these studs and nailed using a hammer, due to the elasticity of plastic the head of the stud will be deformed and takes the shape of a nail head which fix the spacer.

Our goal is to build an automated machine to replace the manual labor.
I spent days observing the manual procedure and came up with many ideas for the machine stated above. Many of them were erroneous and presented difficulties in their implementation. Due to my lack of experience these ideas were either too complicated or too easy. But after a week of trying out ideas and drawing many sketches and 3D models I ended up with a realistic and implementable design that will be presented in details in the next sections.

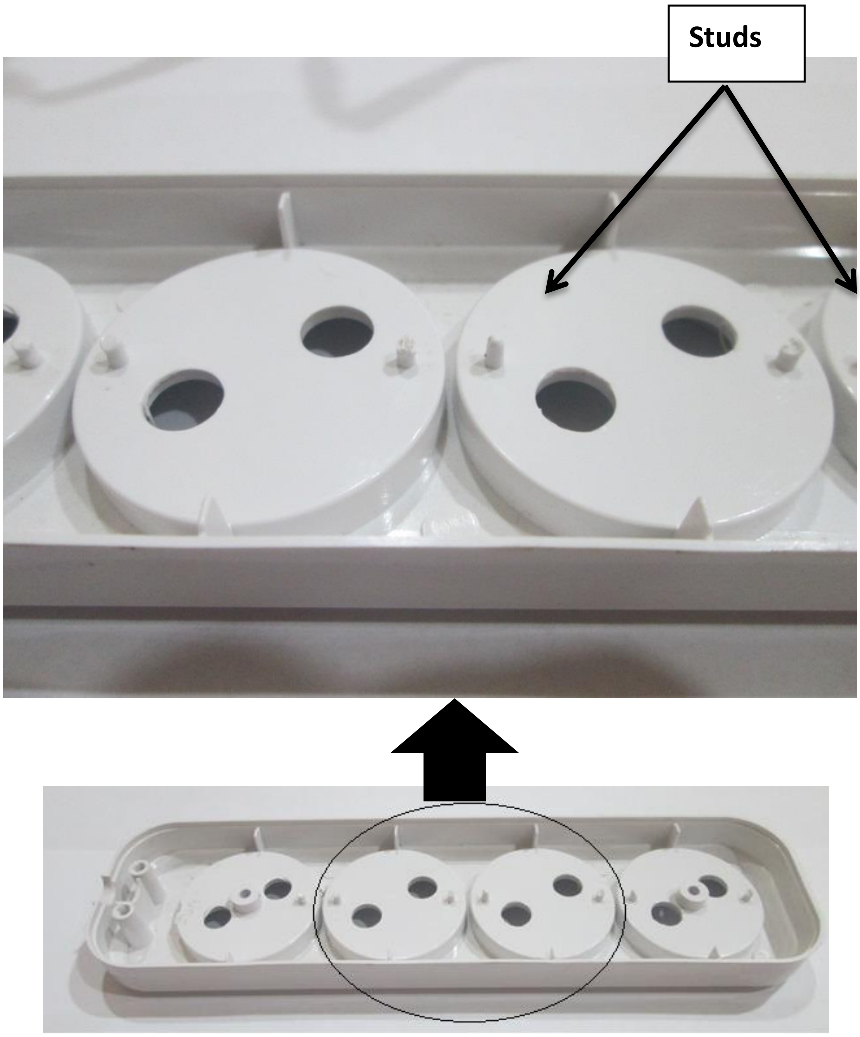


Figure 1.19: Studs and spacers positions

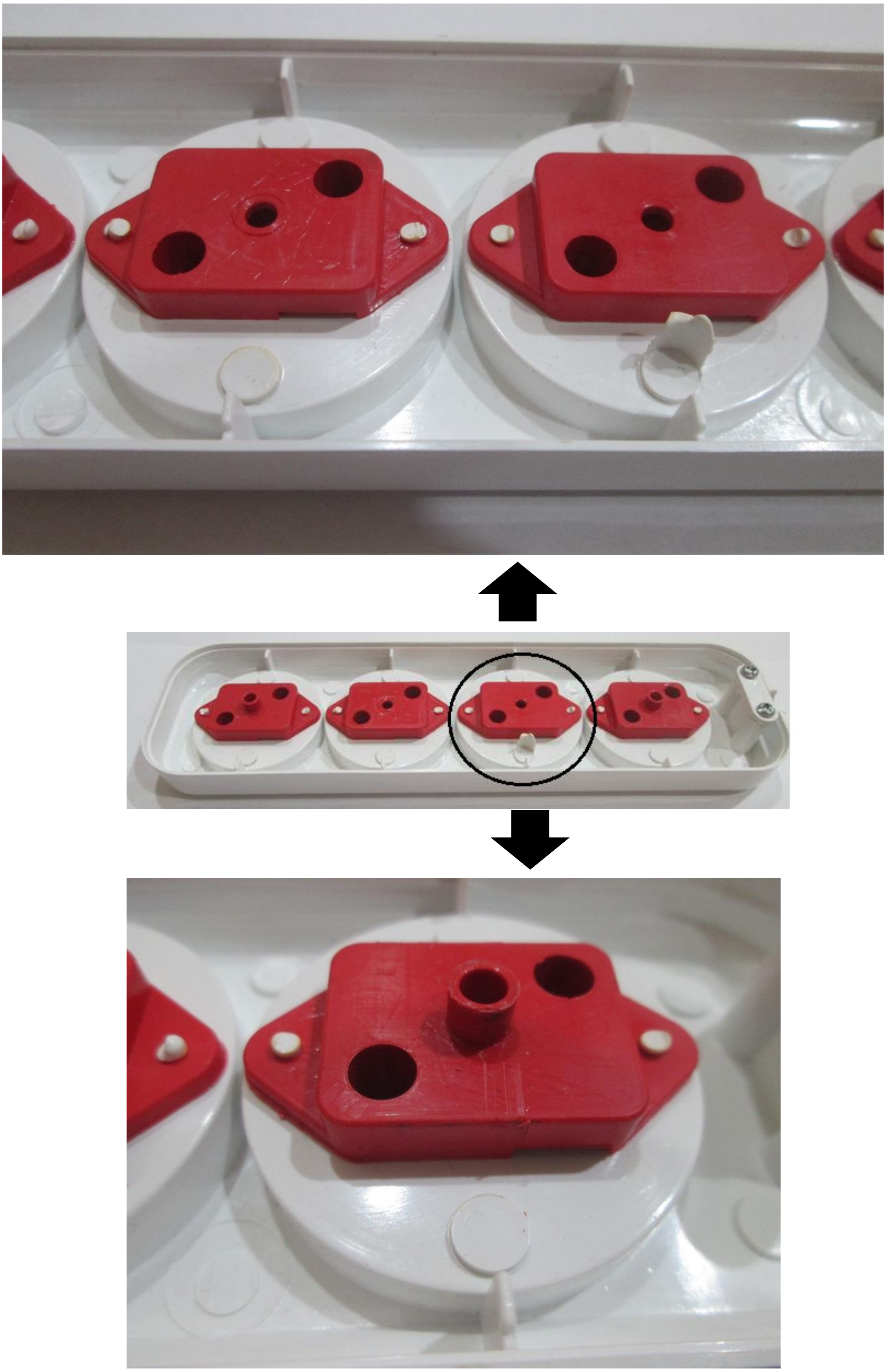


Figure 1.20: Spacer manual assembly.

I.6.4: Machine description

Our machine is linear and consists of a table with 4 workstations on top; each workstation represents 2 degrees of freedom manipulator arm where the assembly procedure is done. The spacers are fed to the machine via two rotational feeders (vibrating bowls) and transported to the pickup spots in two tracks (supply lines).
The spacers will be picked up from specific chambers and placed in a correct position on top of the power strip and fixed later on. The main difference between the manual and the automated procedure is that the fixation in the machine will be thermal which means the plastic studs will be melted using a heat source. These studs will solidify quickly and take the shape of nails which is needed to hold the spacers in place.

Every workstation consists of 3 mechanisms; one for a motion along the x axis and the two others for the y-axis motion.

Every empty power strip injected to the machine by the operator is pushed along the table using a cylinder places beneath the table which moves a T shaped peace and the power strip along with it.
The 4 workstations a regrouped into two main stations, one responsible for placing the male spacers, and the other for placing the female spacers so we used only two bowl feeders instead of four.
An empty power strip in injected by the operator, it’s pushed by the T piece and puts it beneath the first post which places the first male spacer; a second power strip is injected and occupies the previous one’s place by moving it to beneath the second post, now a male spacer is being places on the first power strip and another one on the second power strip. The remaining station remains inactive because there is no power strips supply; the operator keeps injecting power strips until the second station is activated with the presence of power strips (the male spacers being in place), these station is responsible for placing two female spacers on top of the power strip.

Once a power strip and 4 spacers are fully assembled, it will be ejected automatically due to the presence of a rectangular shaped hole in the table.

I.7: Conclusion

The computer aided design phase is the most important step in machine design because it allows engineers to try out different ideas and concepts and perform detailed evaluations and test on models before implementation.
Computer aided design requires an eyes for details, and taking into account every part (moving or fixed) which is referred to as dynamic and static modeling, even screws or bolts and fixation equipment must be modeled, nothing is left to luck.

Material resistance tests must be performed to evaluate the machine’s ability to sustain stress and forces, flexion and torsion test are executed using SolidWorks on every part. Friction between different component and thermal transfer must be limited.

All these essential consideration were thoroughly pursued, we were successful in designing a machine with minimum friction and high strength with a low cost.

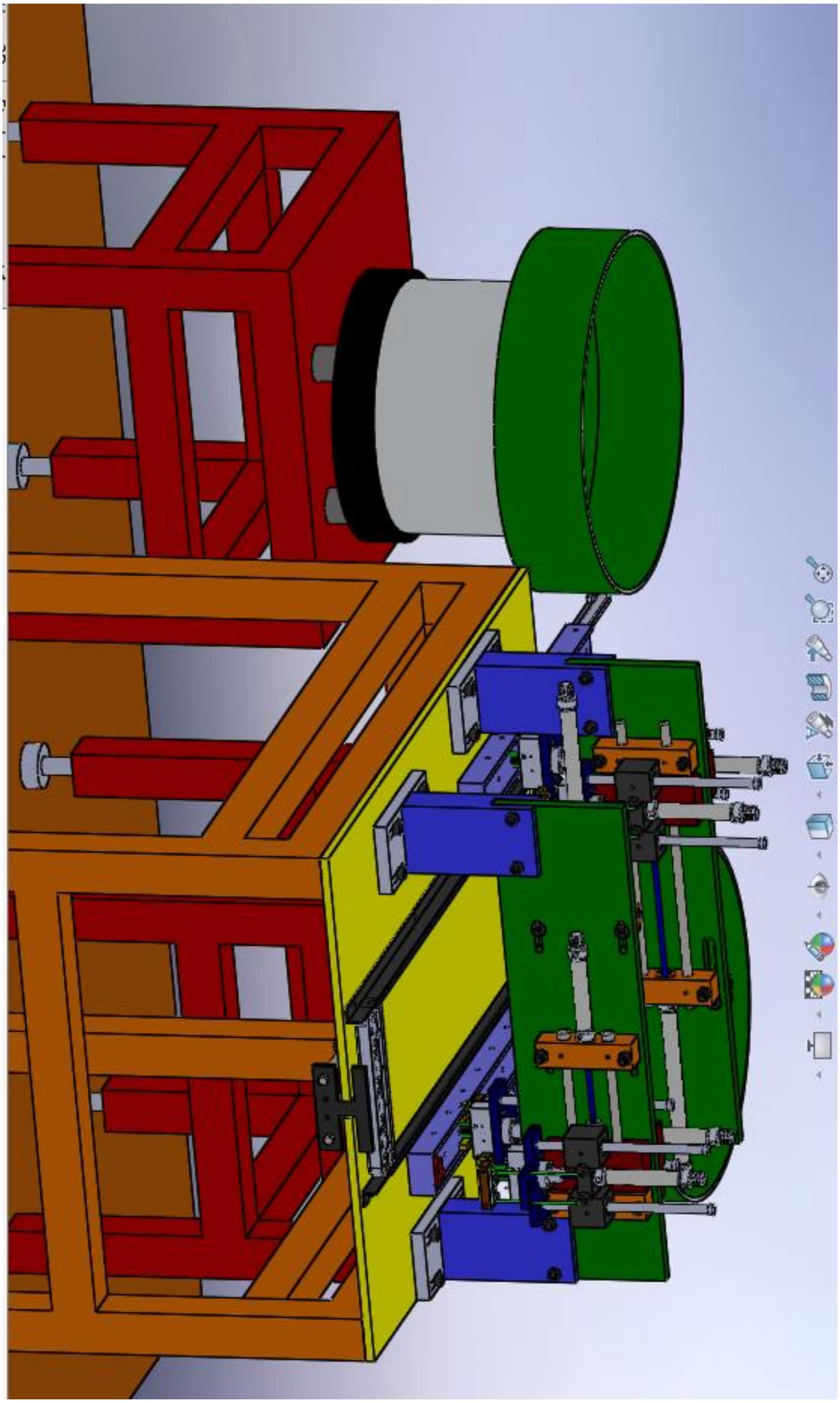


Figure: 1.21: overall design of the machine (Solidworks).

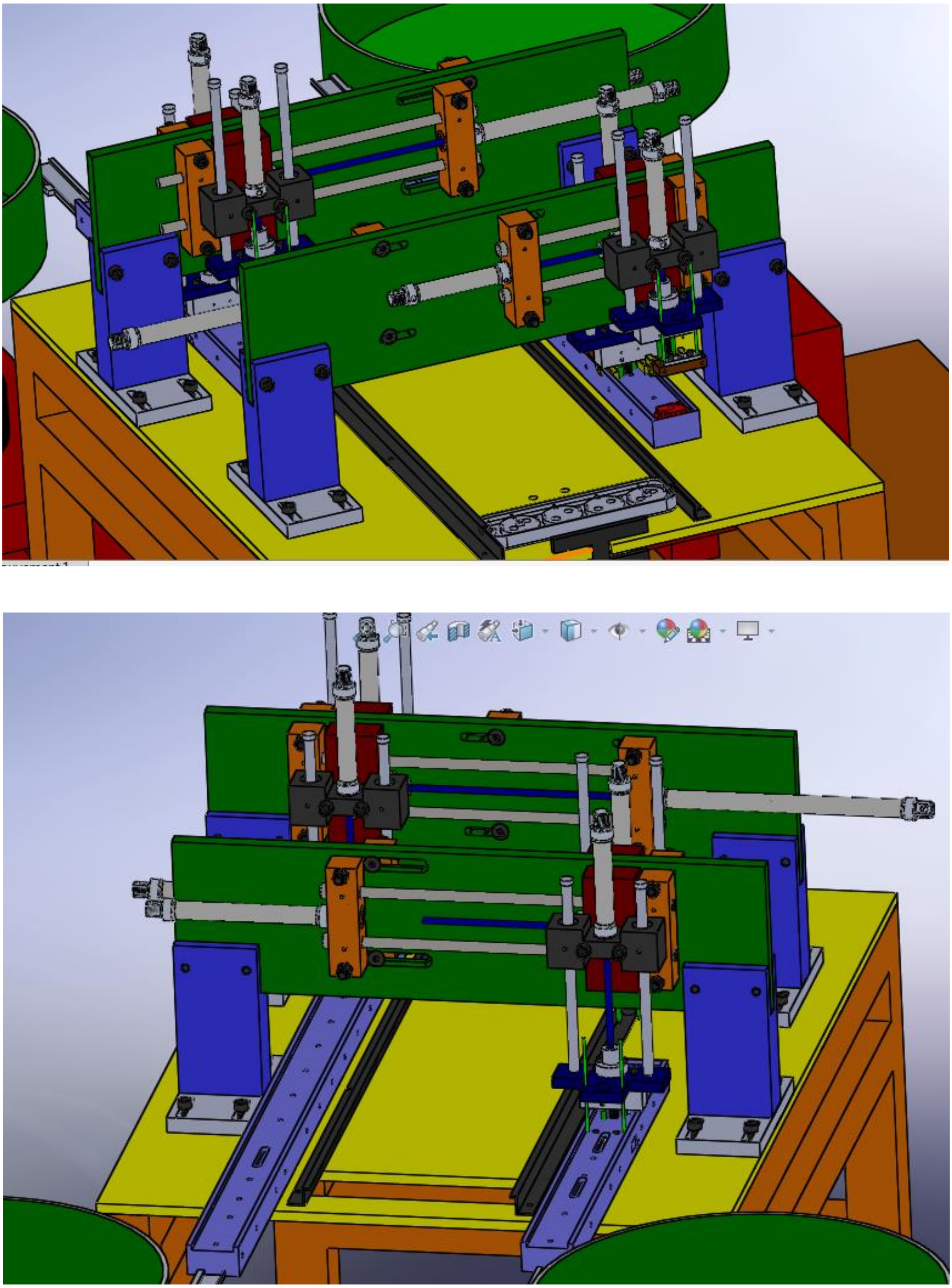


Figure 1.22: overall design (front and back view) in Solidworks.

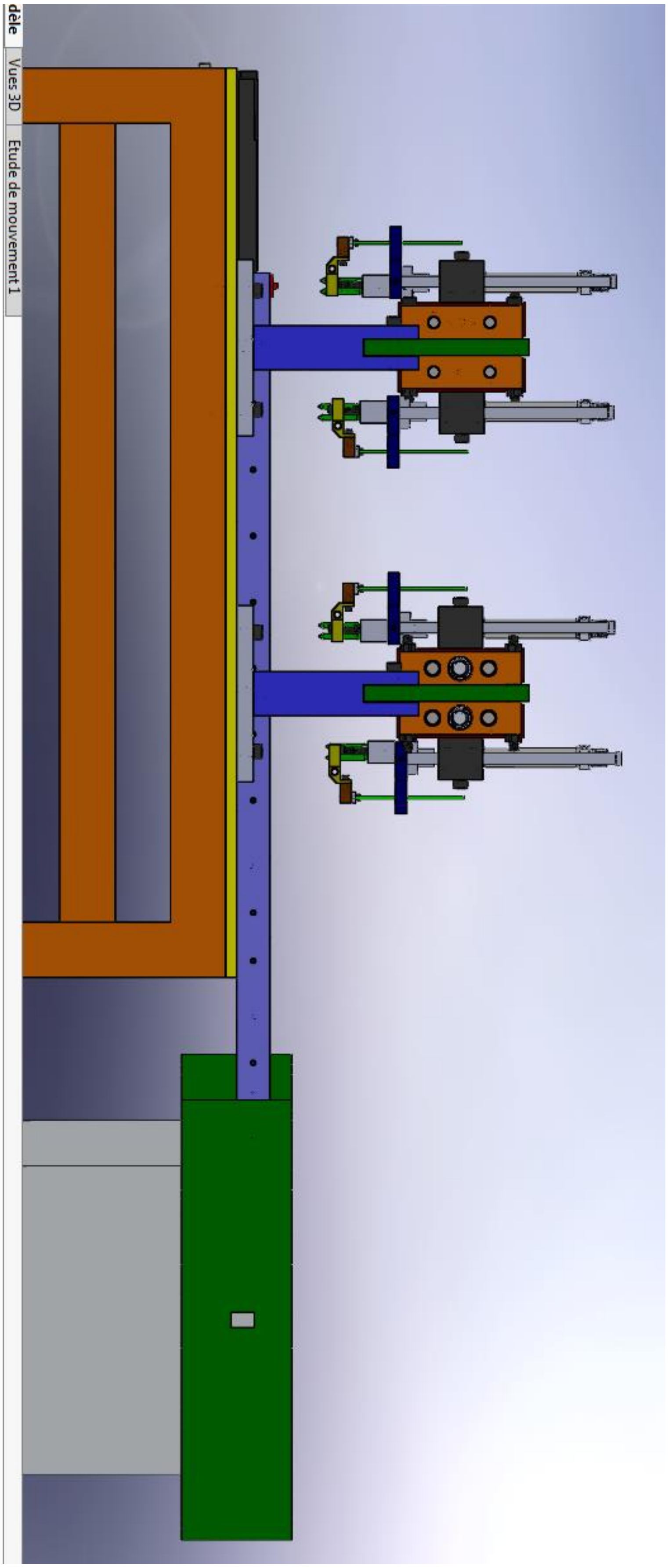


Figure: 1.23 Overall design (side view) in Solidworks.

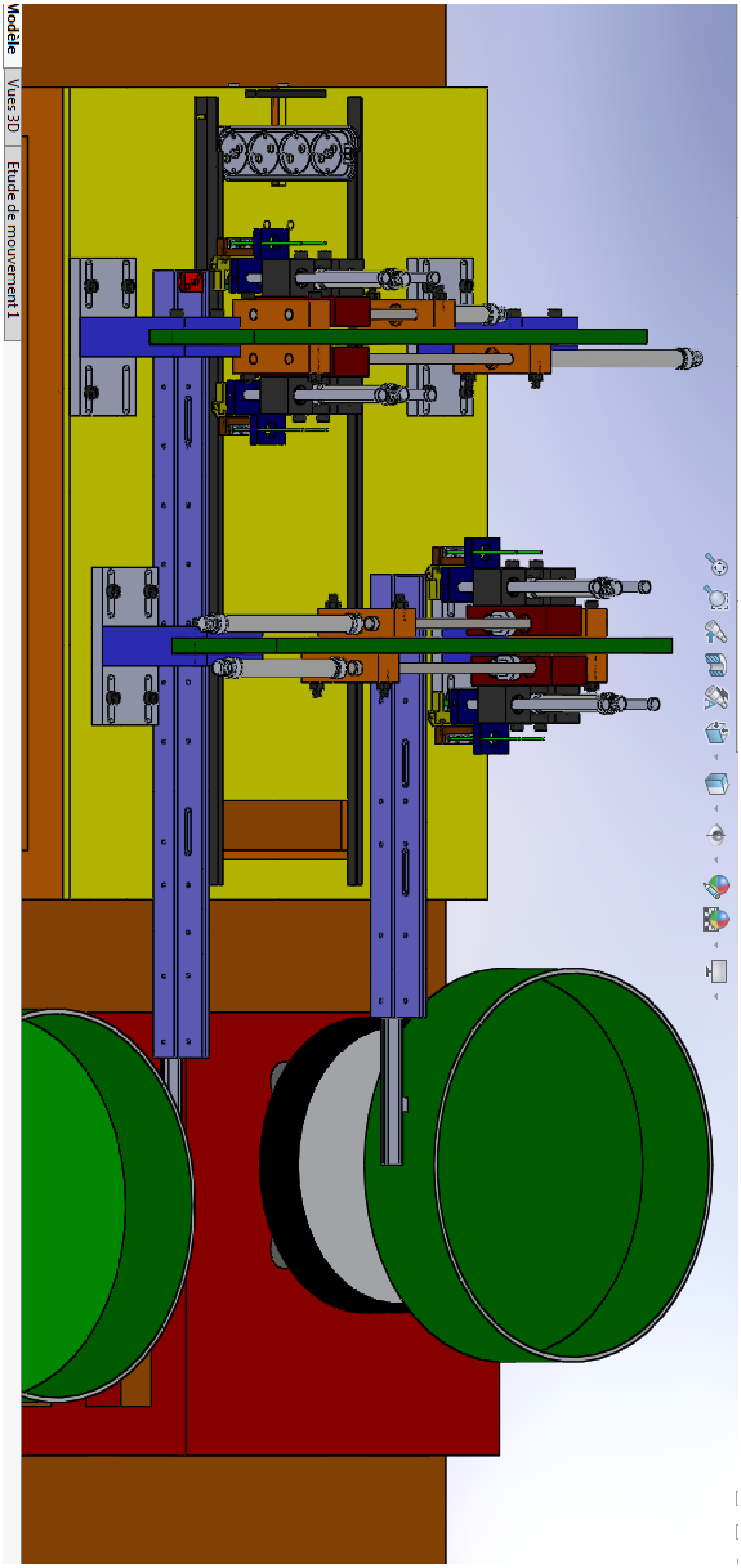
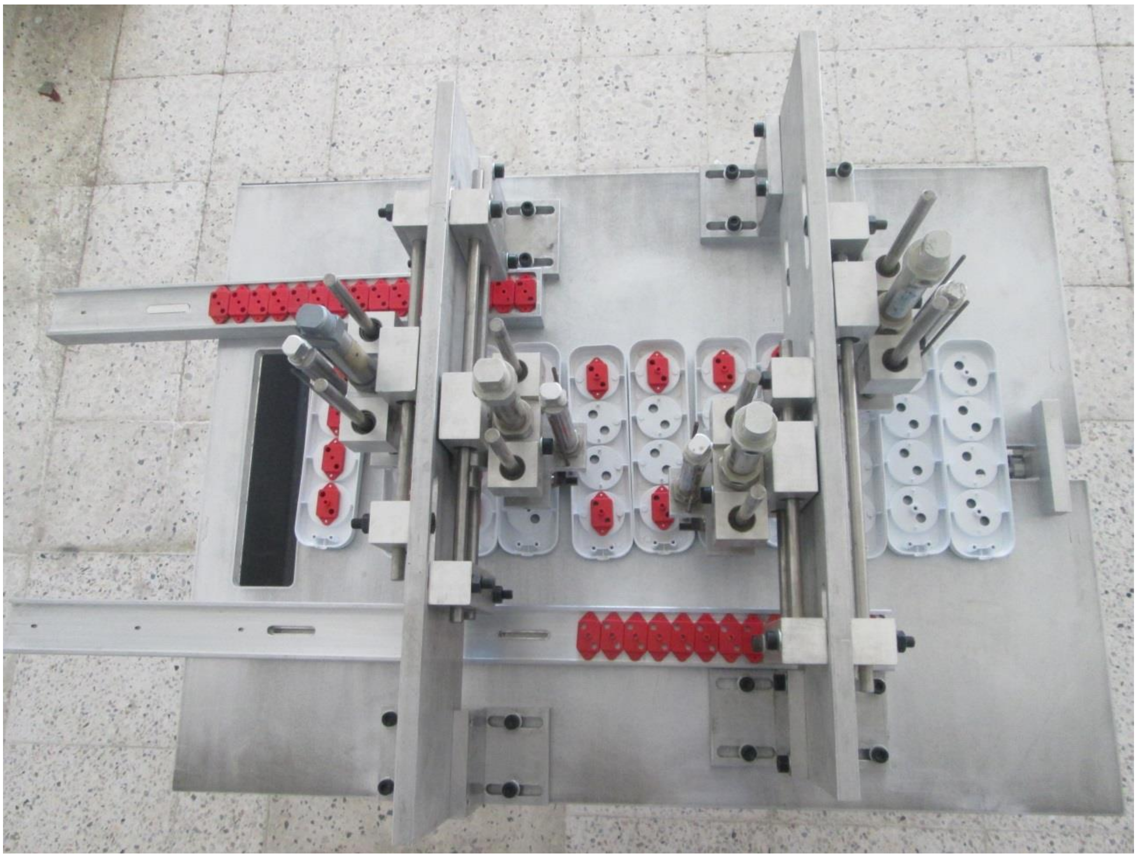


Figure: 1.24 Overall design (top view) in Solidworks.



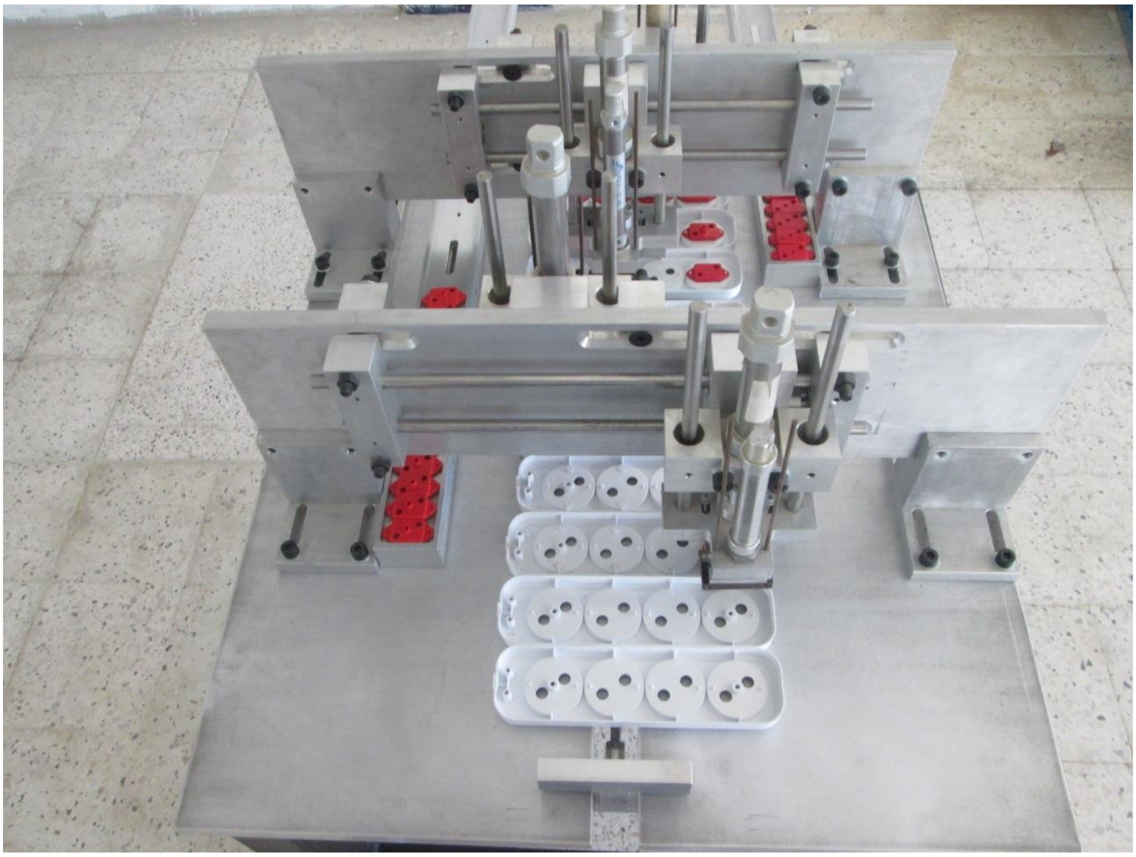


Figure 1.25: Overall design in (real model).

Chapter II: Design of Each Individual Part

This assembly machine consists of 4 main bodies: Support base, worktable, and workstations and accessories.

II.1: Support base

The base has two tasks, the first is to support the worktable and the second is to carry the control cabinet and the pneumatic equipment (solenoid valves manifold).
The base is made by welding together 14 steel square bares (50mm x 50 mm) and painted with a rustproof substance.

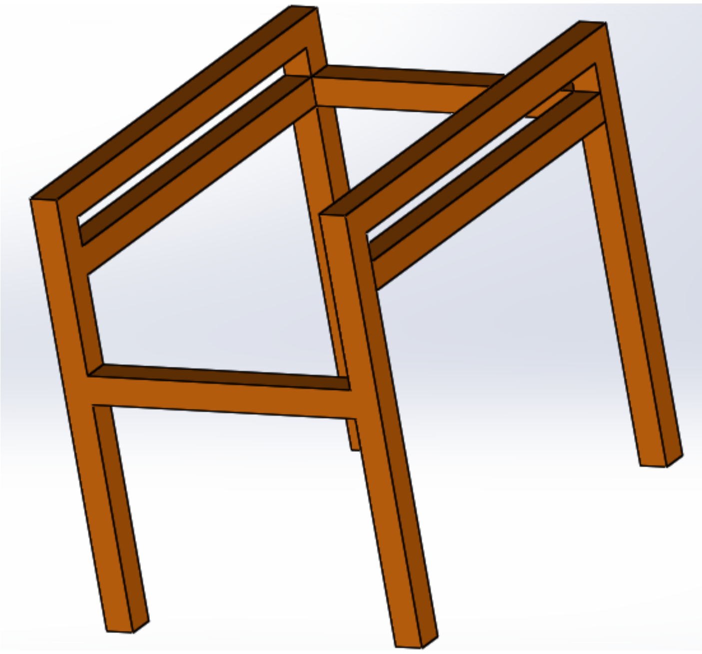


Figure 2.1: Support base Solidworks model.

Figure 2.2: Figure 2.3: Support base (side view).

Figure 2.4: Support base (top view).

II.2: Worktable

The worktable is a rectangular aluminum surface; the worktable supports the two workstations and accessories that are needed for the machine. The surface of the worktable is polished using gasoline and sandpapers so the power strips can slide on top of it smoothly and with minimum friction. Threaded holes are made on the worktable for fixing other parts. The horizontal square shaped cut is for the ejection of the assembled power strips. And the vertical cut is for the T piece (pusher).

Figure 2.5: Worktable.

Figure 2.6: Worktable and Support base assembly.

II.3: Workstations

the machine consists of for two identical workstations and each one has to stations with different tasks and layout, a workstation is s two degrees of freedom manipulator arm e.g. two motions (along x-axis and y-axis) each motion is performed by a special mechanism.

The mechanisms for two motions are supported by a horizontal and a vertical bases which form a “L” shaped support.

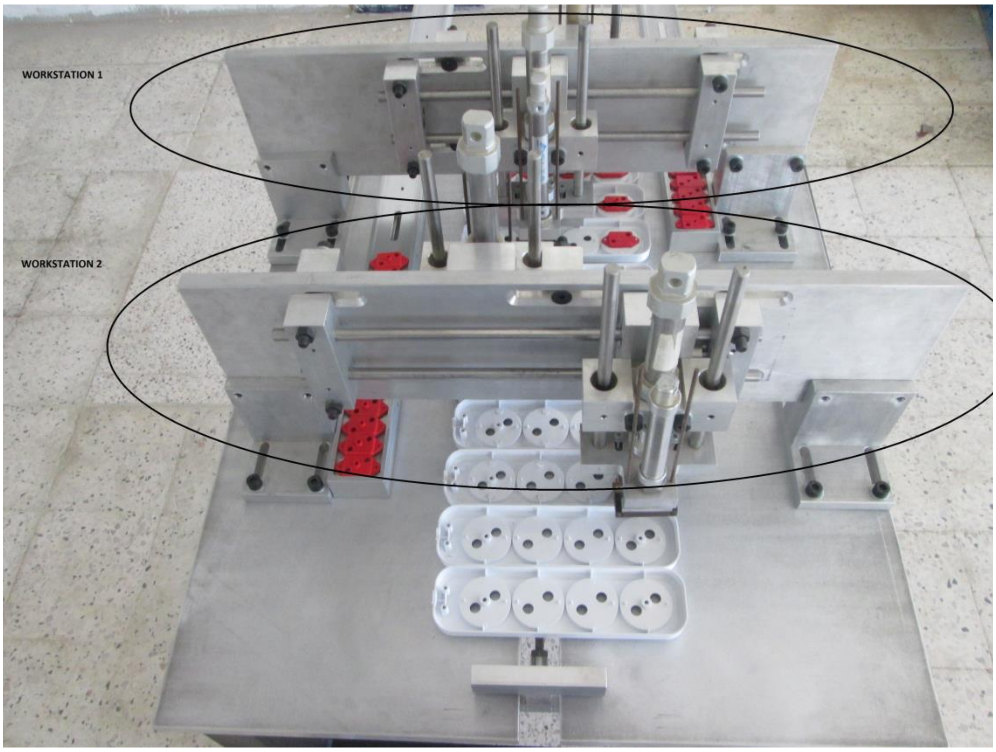


Figure 2.7: Workstations

II.3.1: Supports

- **Vertical :**

The vertical support is an aluminum profile with an adjustable base.

- **Horizontal:**

The horizontal support is responsible for sustaining the weight of both motion mechanisms, and it consists of an aluminum plate with horizontal slots.
Slots are used instead of holes so we can achieve adjustability, if we want to modify the position of a component all we have to do is move it along the slots.

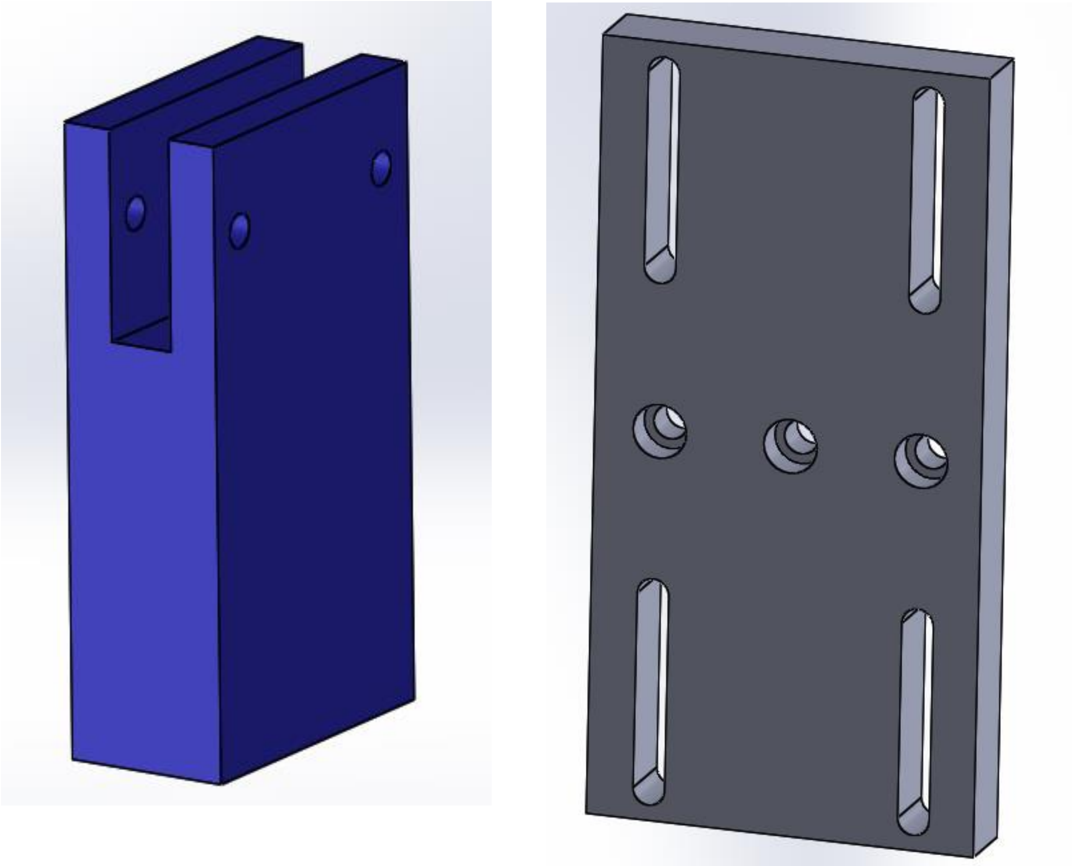


Figure 2.8: Aluminum profile (left) and base (right) SolidWorks model.

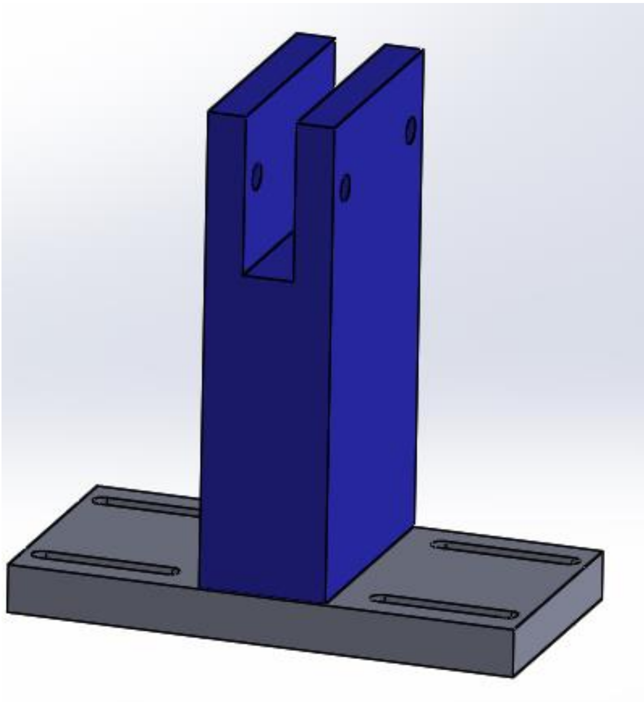


Figure 2.9: Aluminum profile and base assembly (Solidworks model).

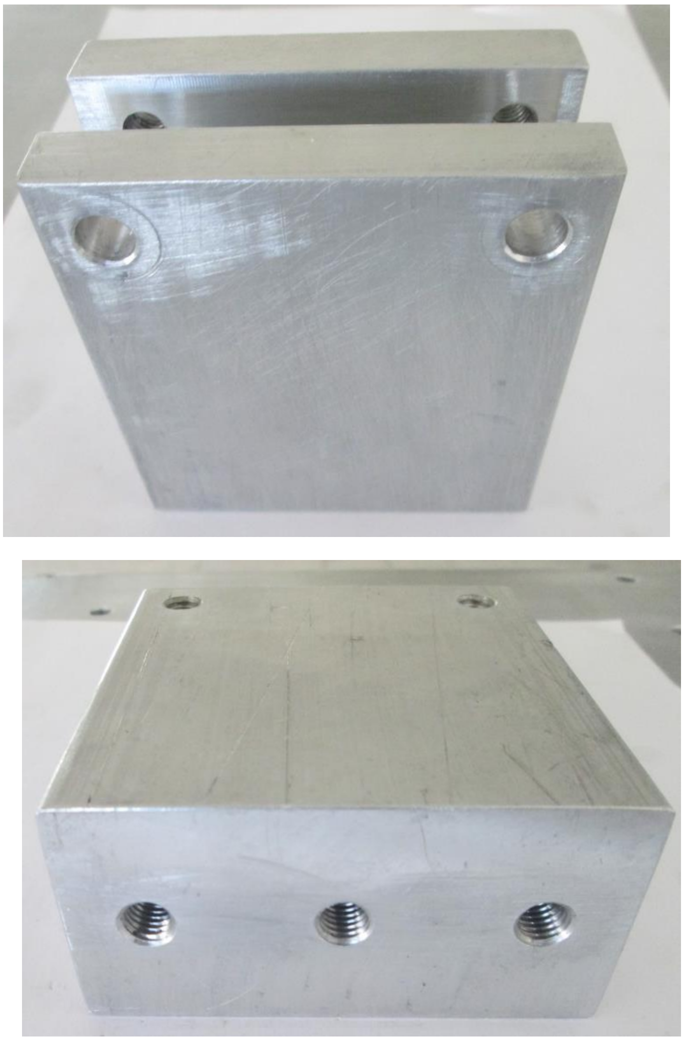


Figure 2.10: aluminum profile (top and bottom view).

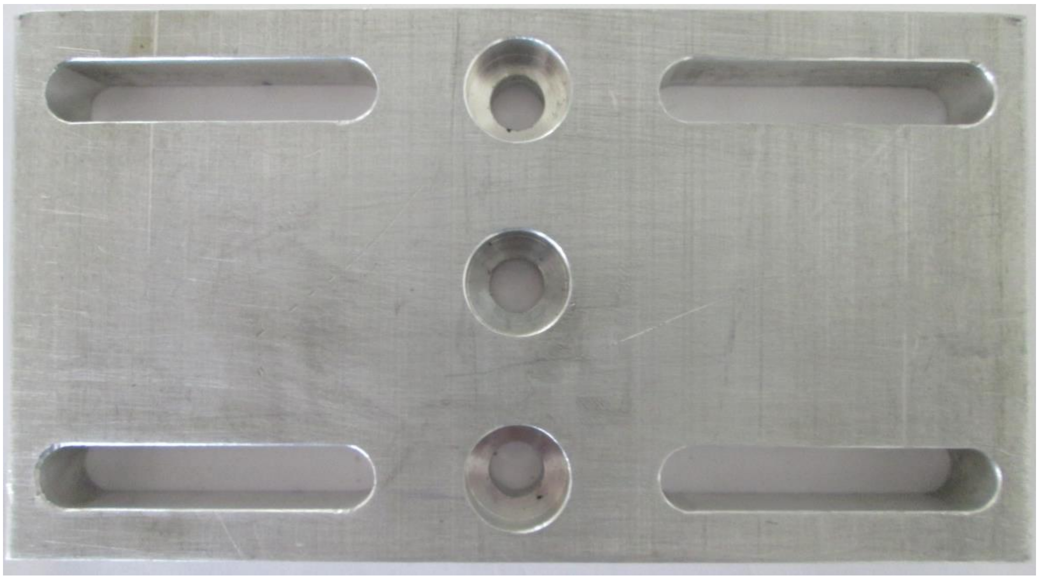


Figure 2.11: Adjustable base.

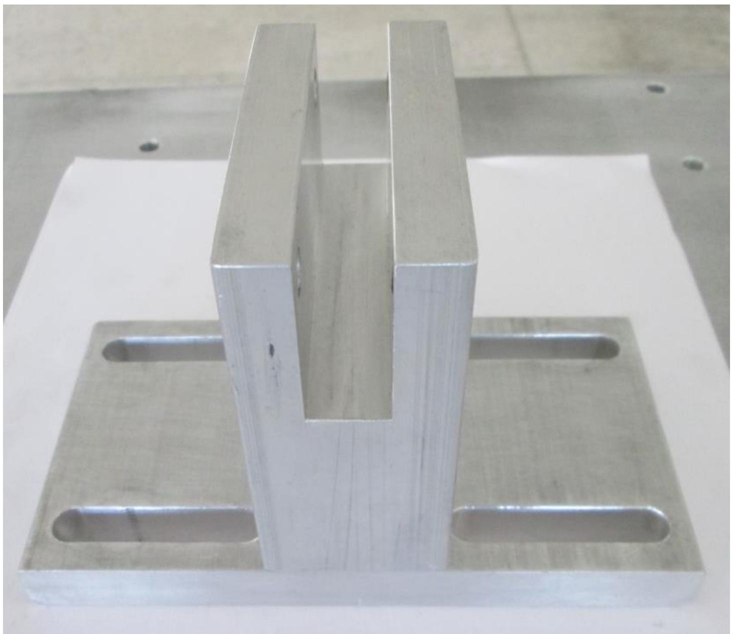


Figure 2.12: Aluminum Profile and base assembly.

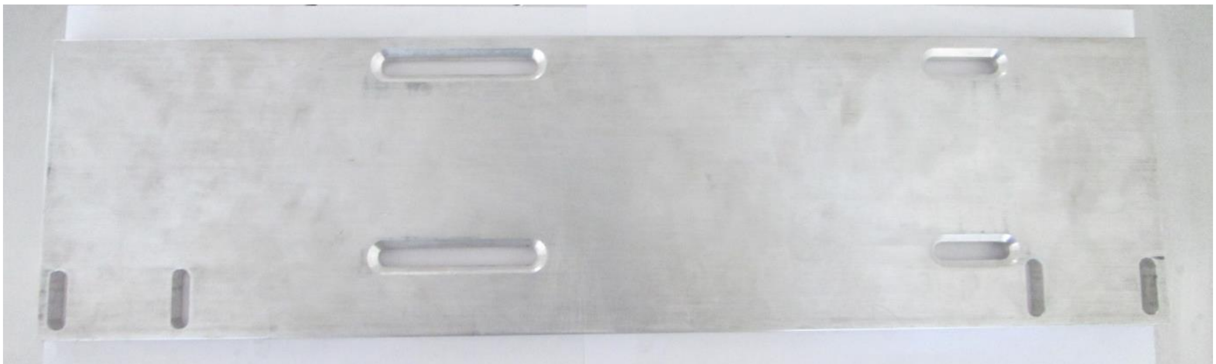


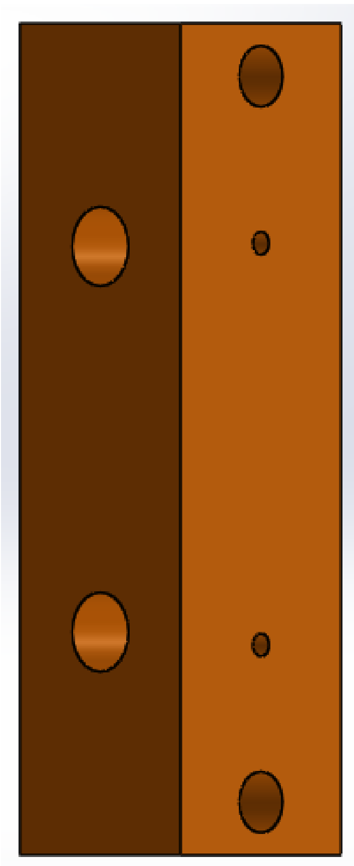
Figure 2.13: Horizontal support.

Figure 2.14: Slots on the horizontal support.

II.3.2: X-axis motion components and sub-assemblies

The mechanism responsible for the x-axis motion is composed of 5 parts, 4 of them are fixed and one mobile. Each part is made of aluminum because it's second most widely used metal in the world. The properties of aluminum include: low density and therefore low weight, high strength, superior malleability, easy machining, excellent corrosion resistance and good thermal and electrical conductivity are amongst aluminum's most important properties. Aluminum is also very easy to recycle. Aluminum is used mostly used in machine's parts manufacturing due to its auto-clamping propriety which means that when screwing two pieces of aluminum together, aluminum assists the fixation screws which prevent screws from getting loose.

The first part is responsible for holding the pneumatic cylinder and two cylindrical ejectors (slides); the second part is parallel to the first and is used for holding the cylindrical ejectors. The third moves or slides along the previously stated ejectors with the force actuated by the pneumatic cylinder.



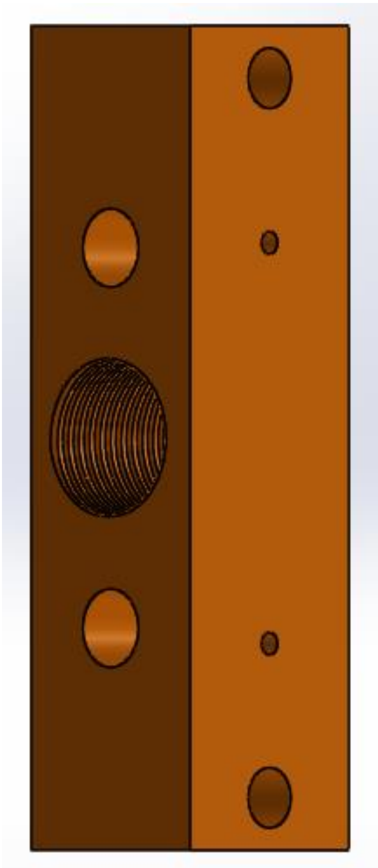


Figure 2.15: Ejectors holder (left) and pneumatic cylinder support (right) on Solidworks.

Figure 2.16: Ejectors holder (left) and pneumatic cylinder support (right) on Solidworks.

Each individual part was manufactured and threaded in BMS machining department with use of multiple lathe machines and with the help of a qualified team.
Technical drawing is critical in the process of part manufacturing, which is essential for communicating ideas in industry and engineering. To make the drawings easier to understand, people use familiar symbols, perspectives, units of measurement, notation systems, visual styles, and page layout. Together, such conventions constitute a visual language and help to ensure that the drawing is unambiguous and relatively easy to understand. Many of the symbols and principles of technical drawing are codified in an international standard called ISO 128.
Engineering drawings are usually created in accordance with standardized conventions for layout, nomenclature, interpretation, appearance (such as typefaces and line styles), size, etc. Its purpose is to accurately and unambiguously capture all the geometric features of a product or a component. The end goal of an engineering drawing is to convey all the required information that will allow a manufacturer to produce that component.

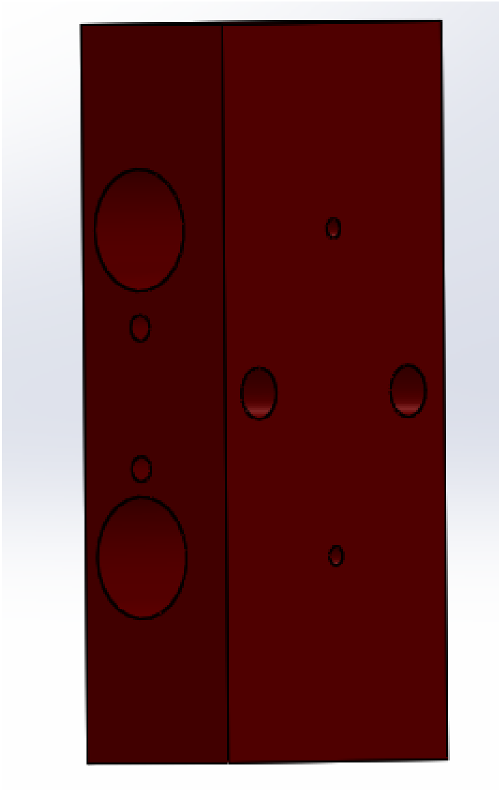


Figure 2.17 : Moving (sliding) part Solidworks model.

Figure 2.18 : Moving part real model.

The last piece slides due the pneumatic cyinder on the cylindrical ejectors back and forth with high speed which can generate heat and material wear beacuase of friction between aluminum and stainless steel ejectors, so we used linear roller bearings (ball bearings) or linear slides which are designed to provide free motion in one direction and low-friction linear movement for equipment. The roller bearing is used is the **lm10uu.**

Figure 2.19: lm10uu linear roller bearing.

Figure 2.20: Dimensions of the lm10uu linear roller bearing.

Figure 2.21: lm10uu linear roller bearing Solidworks model.

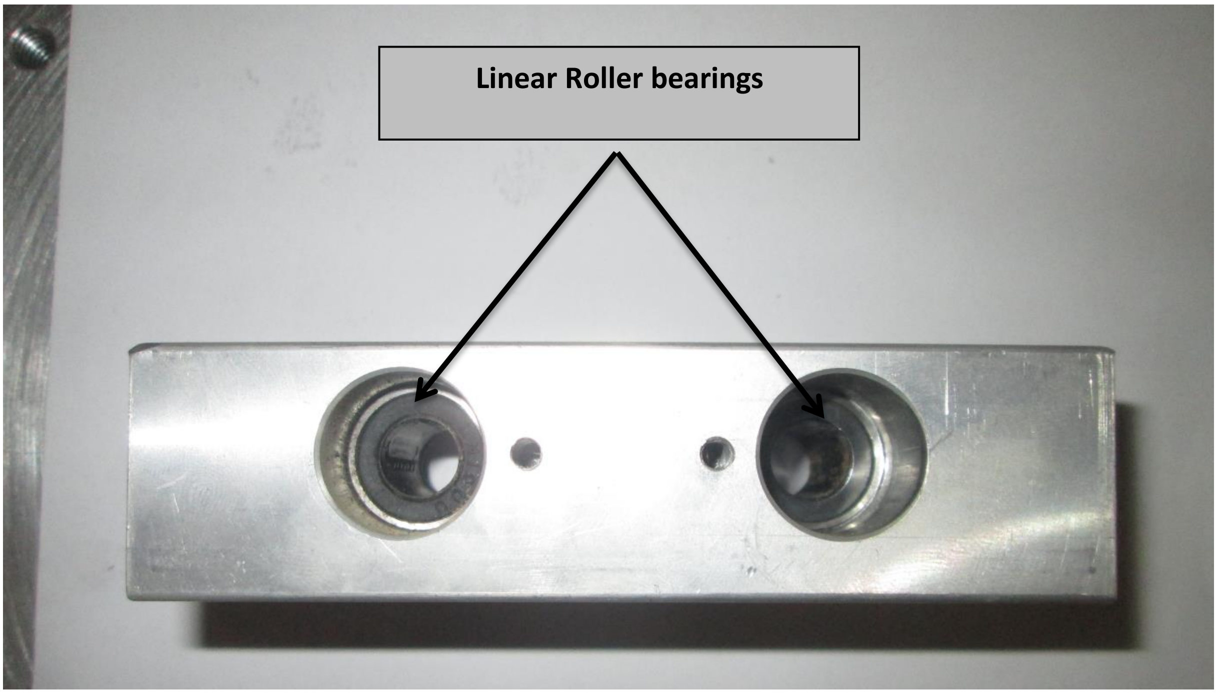


Figure 2.22: Linear bearings mounted on the mobile part.

The next piece is dedicated to fixing the pneumatic cylinder’s rod to the mobile part. The threaded end of the rod is screwed with this piece which is attached to the main body of the moving mechanism.

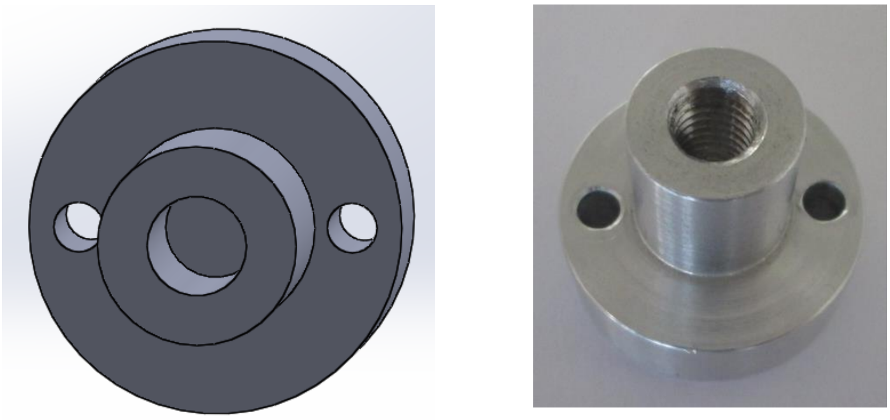


Figure 2.23: Pneumatic cylinder’s rod fixation mechanism.

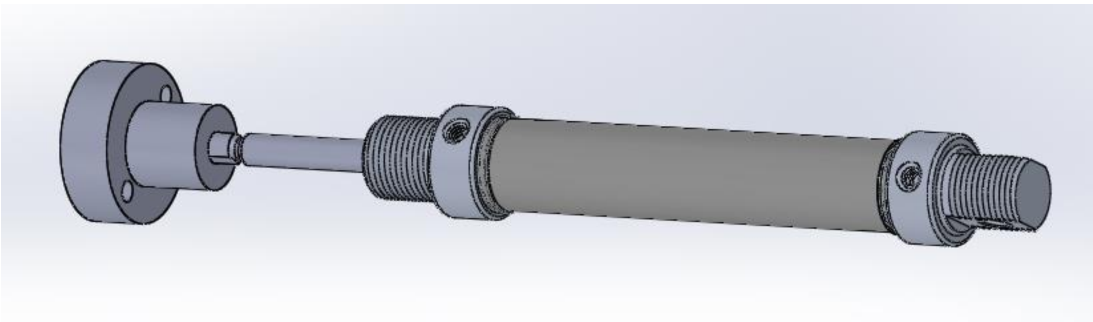


Figure 2.24: Pneumatic cylinder with fixation mechanism assembly.

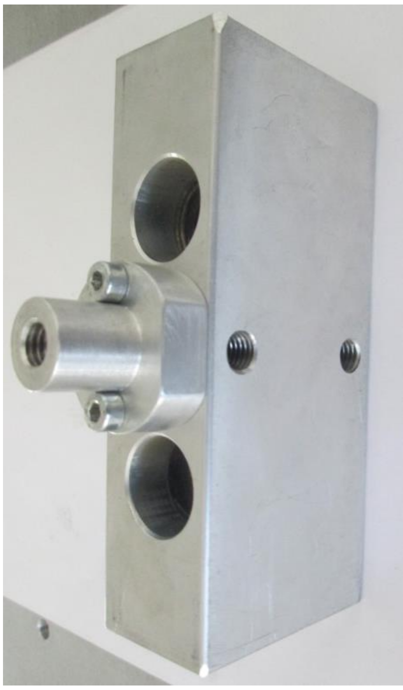


Figure 2.25: Moving piece with rod fixation assembly.

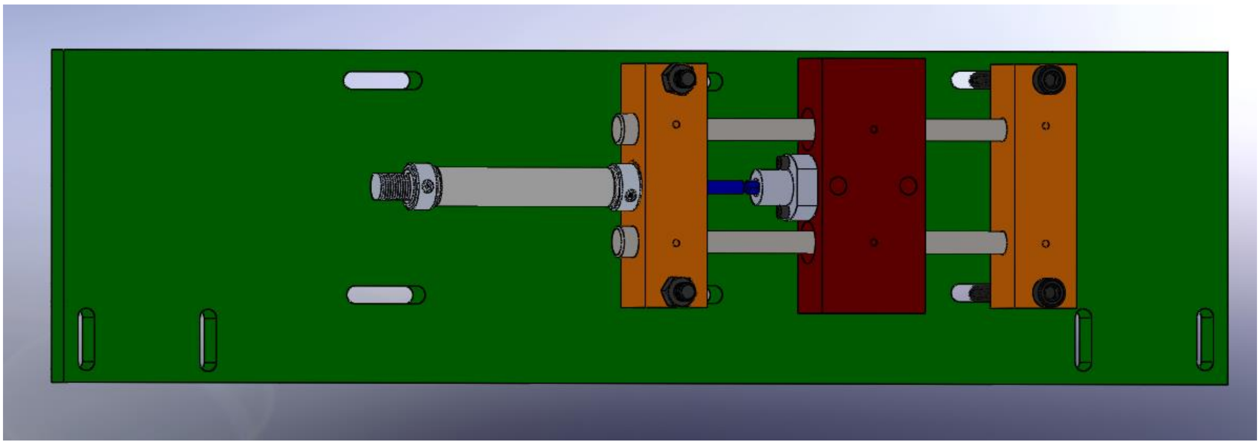


Figure 2.26 : X-axis motion mechanism assembly on Solidworks.

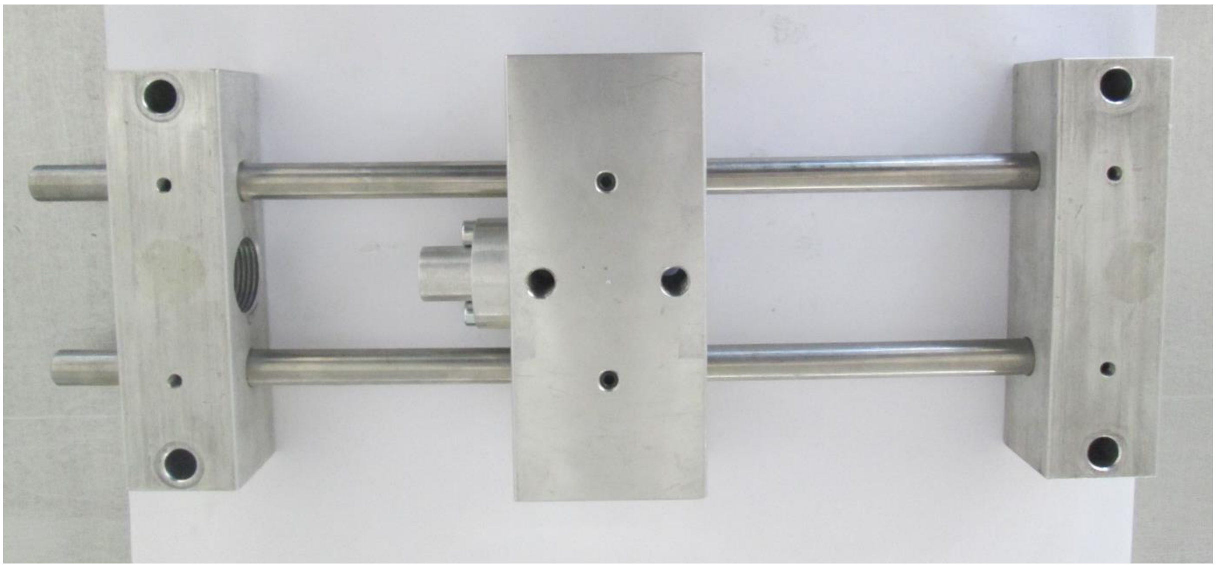


Figure 2.27 : X-axis motion mechanism assembly.

II.3.3: Y-axis motion components and sub-assemblies

The y-axis motion mechanism consists of two parts (one fixed and one mobile) plus the pick-up system (gripper) with the thermal fixation tool.
The first part (fixed) is used for coupling the x-axis motion with the y-axis motion, it's responsible for supporting the vertical pneumatic cylinder.
The second part (mobile) is dedicated to hold the pick-up assembly or the gripper; it slides up and down using cylindrical ejectors which means that the first part must contain linear rollers bearings to minimize friction.

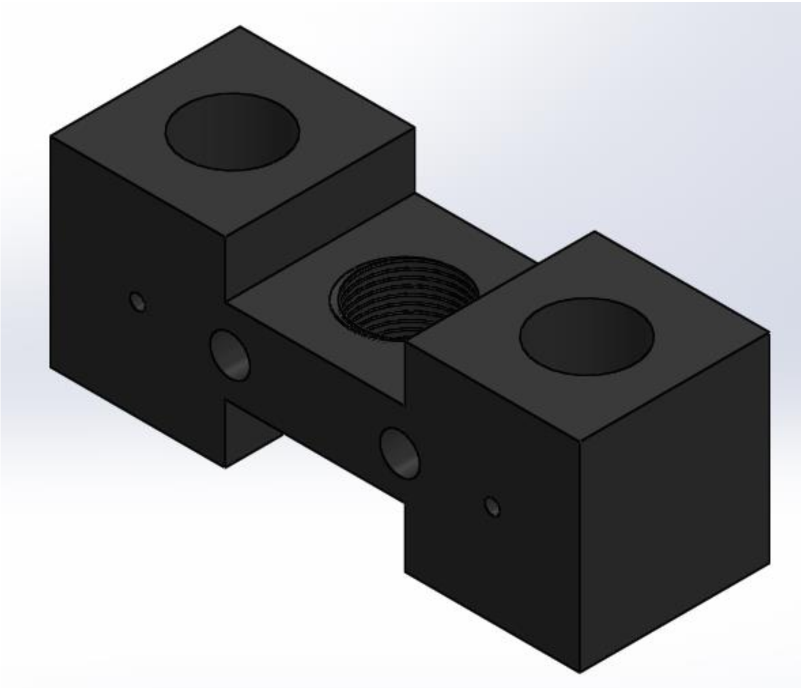


Figure 2.28: vertical cylinder holder (SolidWorks model).

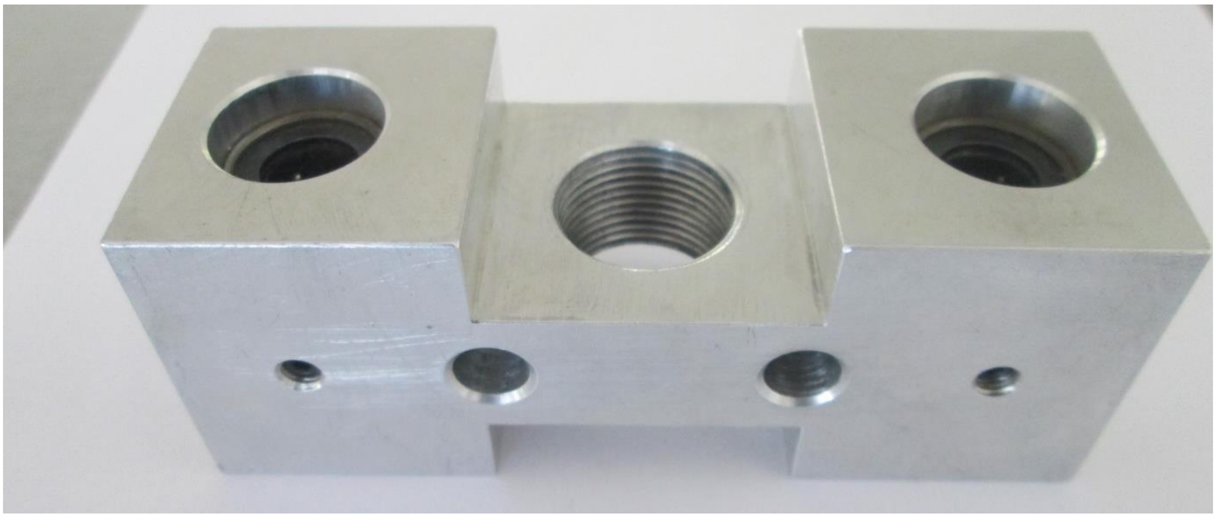


Figure 2.29: vertical cylinder holder (real model).

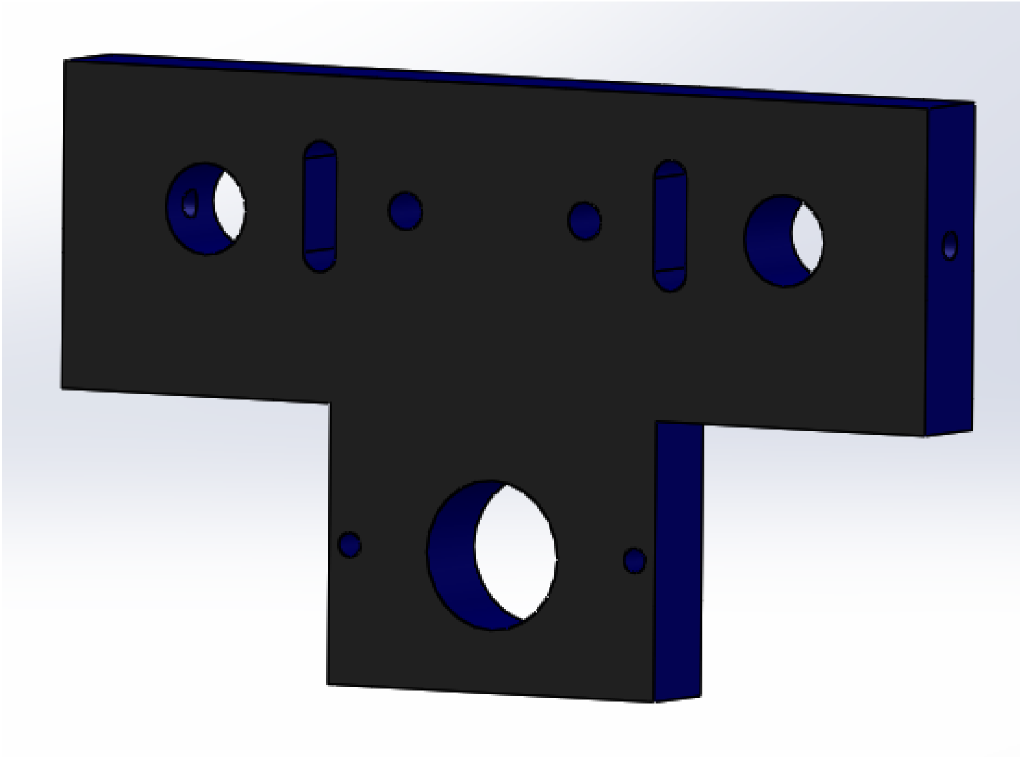


Figure 2.30: Mobile part (SolidWorks model)

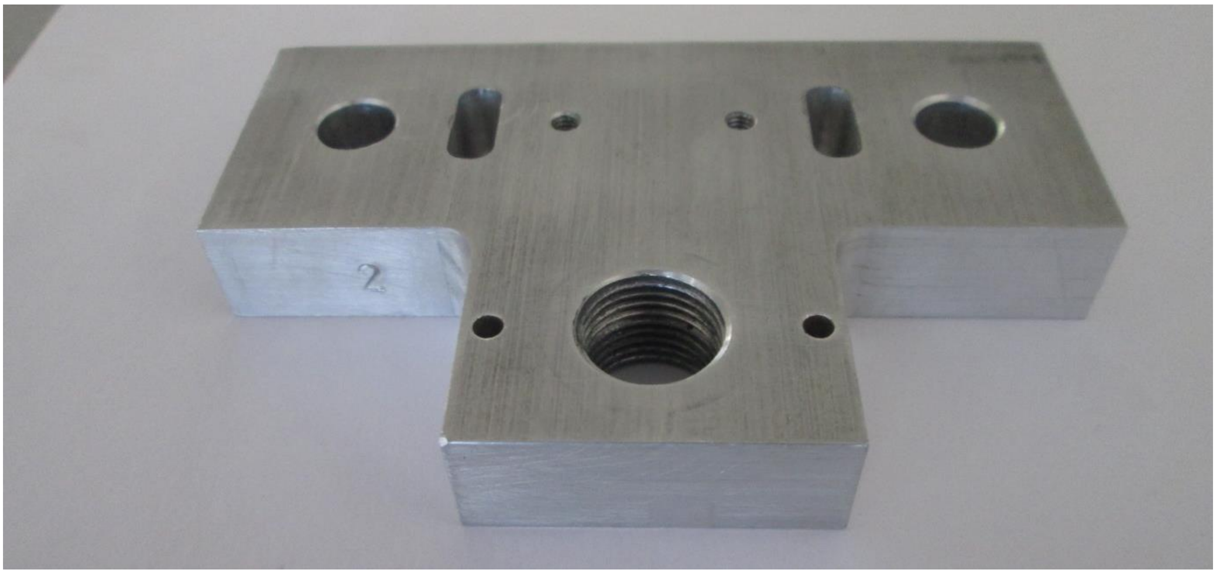


Figure 2.31: Mobile part (real model).

To pick the spacers we had to design a mechanism that lifts the spacers in a correct position and without dropping it, this mechanism consists of two parallel, but slightly inclined pointy rods, with the help of springs that exert lateral forces on them, an efficient pick-up system was designed.

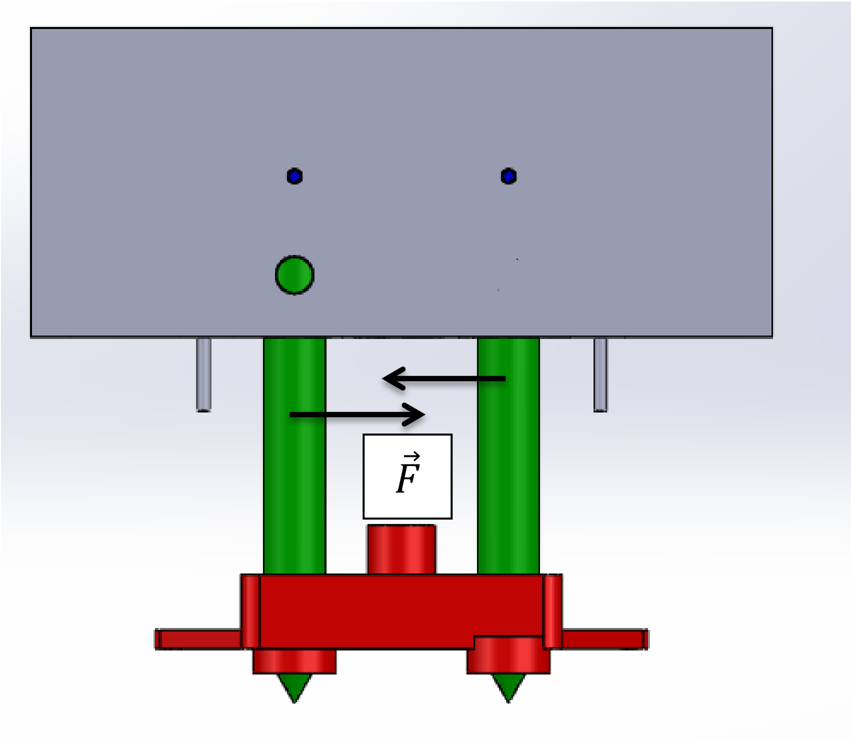


Figure 2.32: Pick-up system (SolidWorks model).

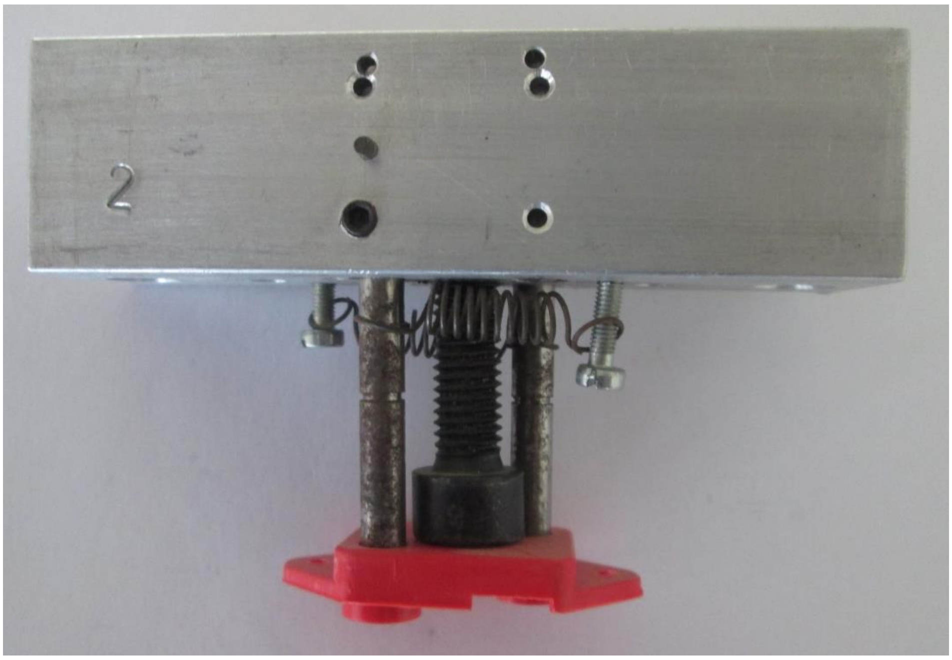


Figure 2.33: Pick-up mechanism (real model).

The spacers need to be fixed on top of the power strip, so instead of using pressure (e.g. hammer in the manual task), we decides to use thermal fixation. A system made of copper (excellent thermal conductor) with a resistance as a heat source; and to isolate the copper and the aluminum we used an isolation layer of bakelite which dissipates the heat from the copper.it contains also al aluminum part that fixes a pneumatic cylinder with the mechanism

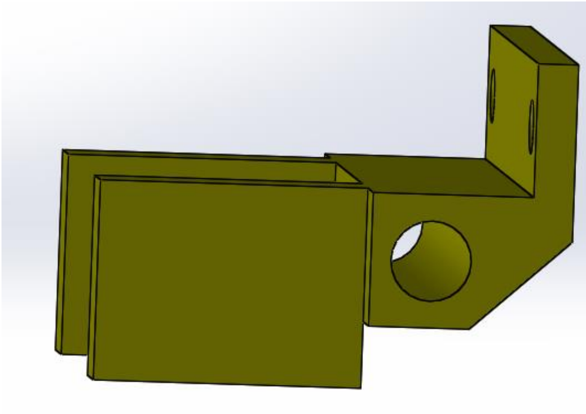


Figure2.34: thermal fixation copper part (SolidWorks model).

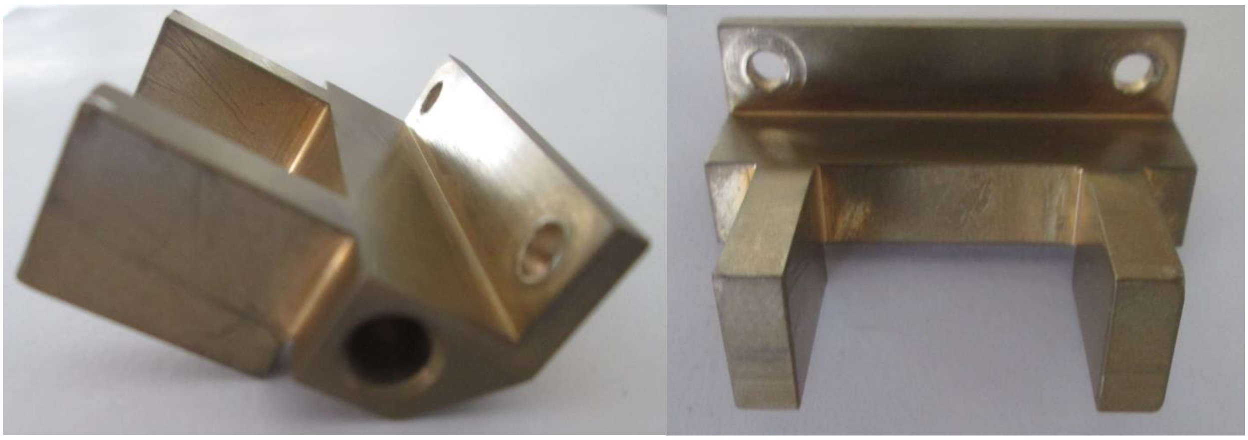


Figure2.35: thermal fixation copper part.

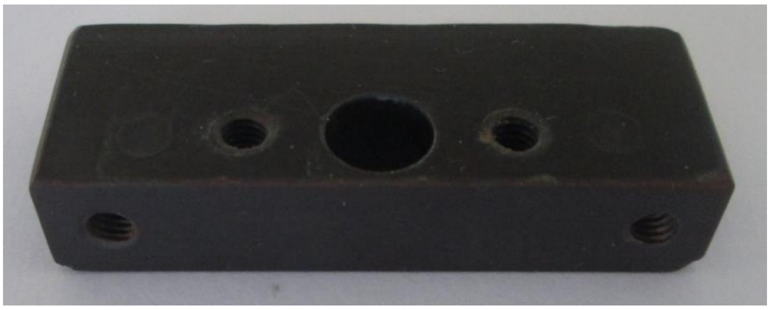


Figure2.36: thermal fixation Bakelite part.

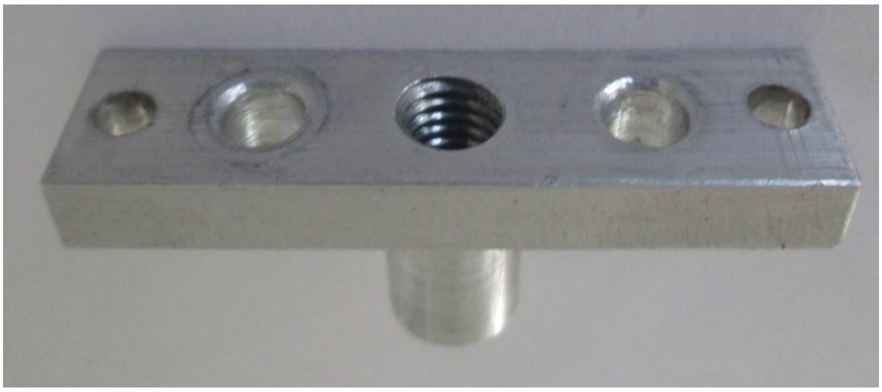


Figure 2.37: Thermal fixation aluminum part.

The assembly of the thermal fixation unit will be shown in next pictures

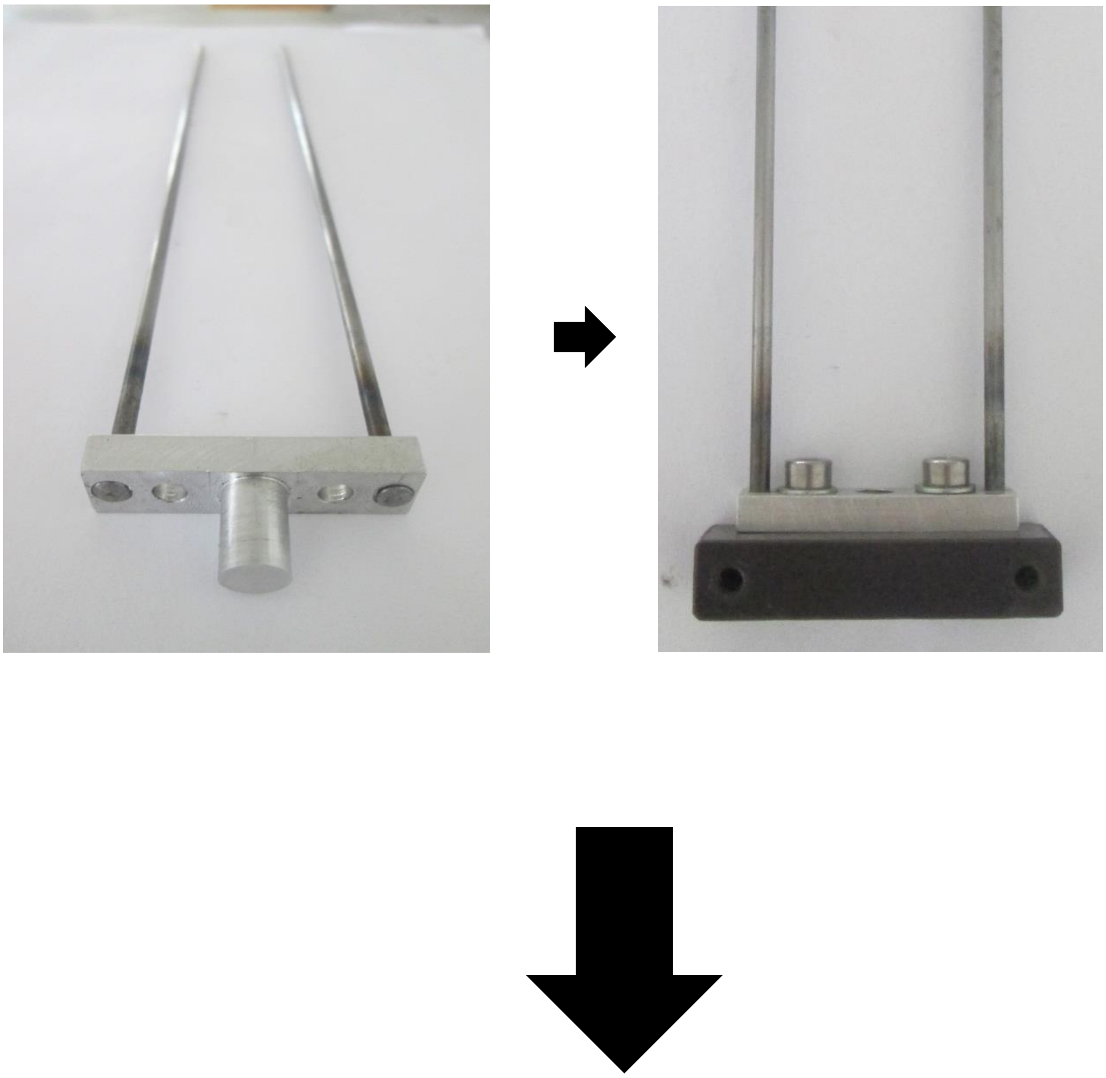


Figure 2.38: Thermal fixation system assembly.

- Working principle:

The y-axis motion system consists of two successive motions, the first responsible for picking and placing spacers, the second is for fixing: so the y-axis motion mechanism consists of two pneumatic cylinders.

When placing a spacer in the right position on top of the power strip, the gripper applies pressure to holds it in place while the thermal fixation mechanism descends and start melting the plastic studs. When the fixation is done the system ascends followed by the pick-up system.

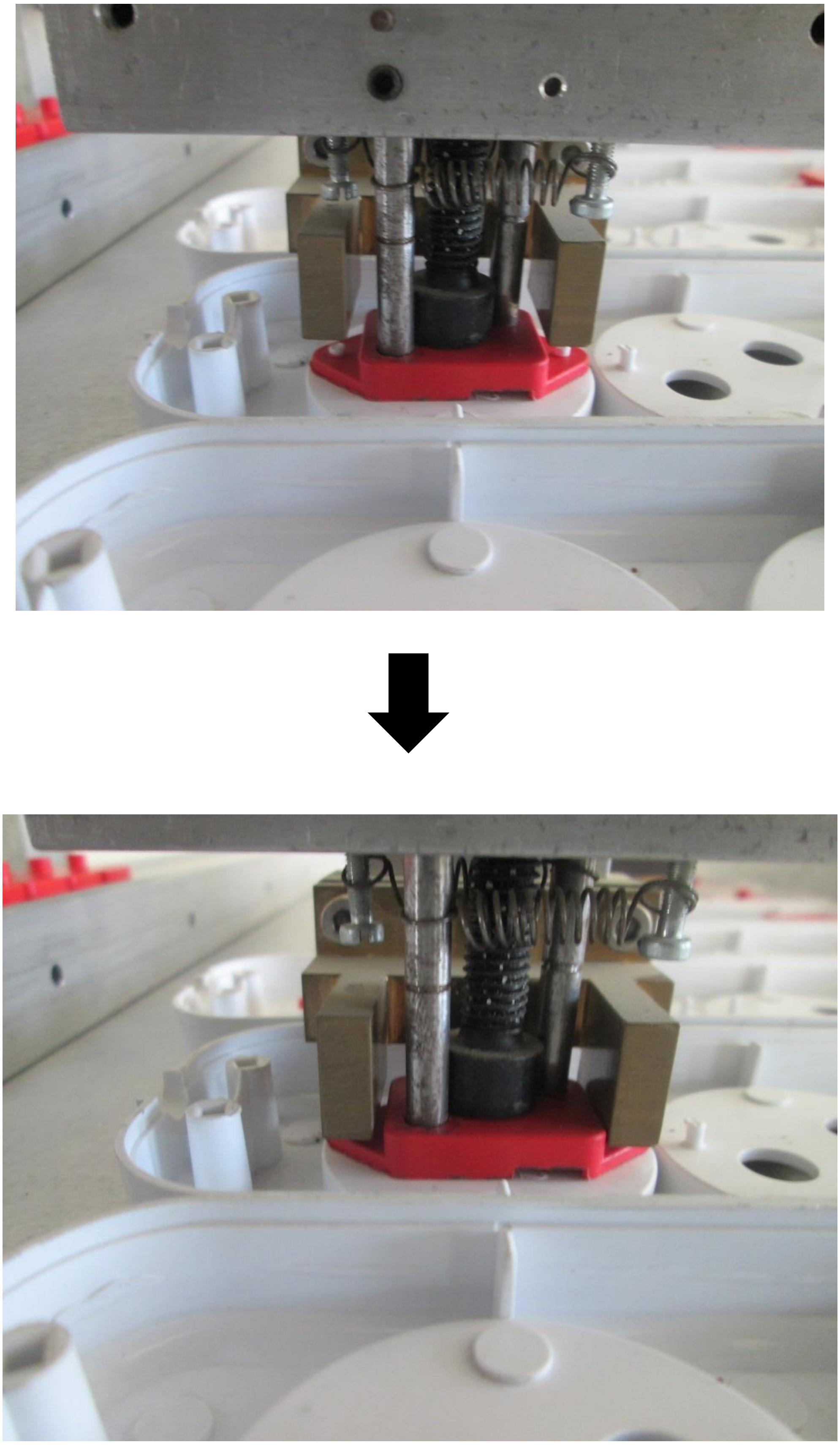


Figure 2.39: Thermal fixation procedure.

Figure 2.40: Y-axis motion assembly with pick-up and thermal fixation assemblies.

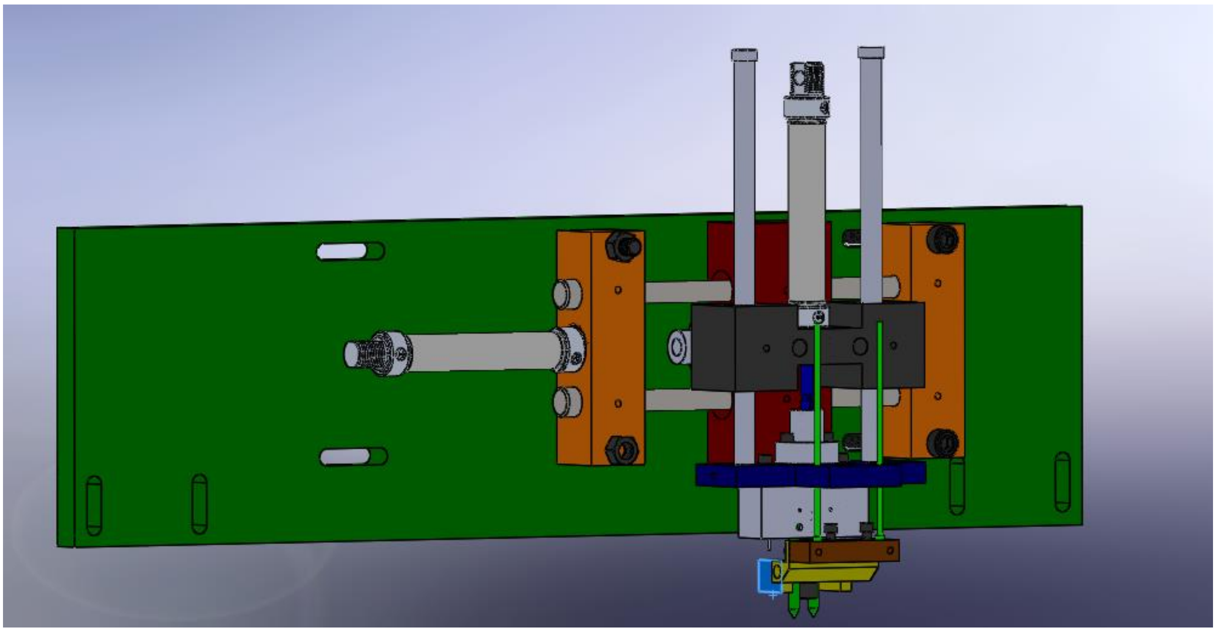


Figure 2.41: X-axis motion and Y-axis motions mechanisms coupled (SolidWorks model).

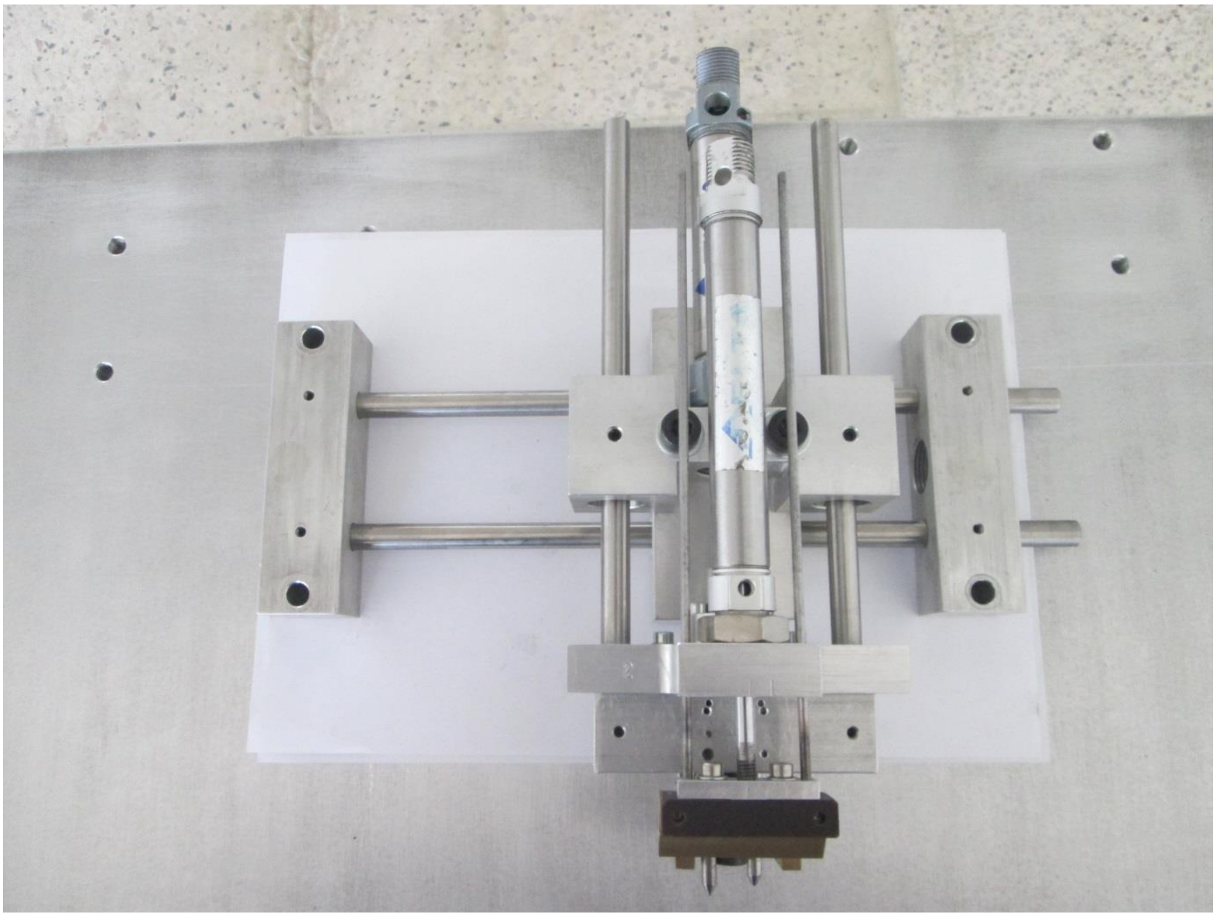


Figure 2.42: X-axis motion and Y-axis motions mechanisms coupled.

II.3.4: Additional components

Accessories are:

- Pusher part: the "T" part that pushes power strips once injected in the worktable, it's controlled by the machine's operator using a pedal switch.
- Spacers' tracks: the machine is continuously fed with spacers, bowl feeders (rotational bowls) move spacers upward to the tracks and moves along these tracks pushed by air coming from the track walls.
- Power strips guides: folded metal sheets, used to keep the power strips aligned.

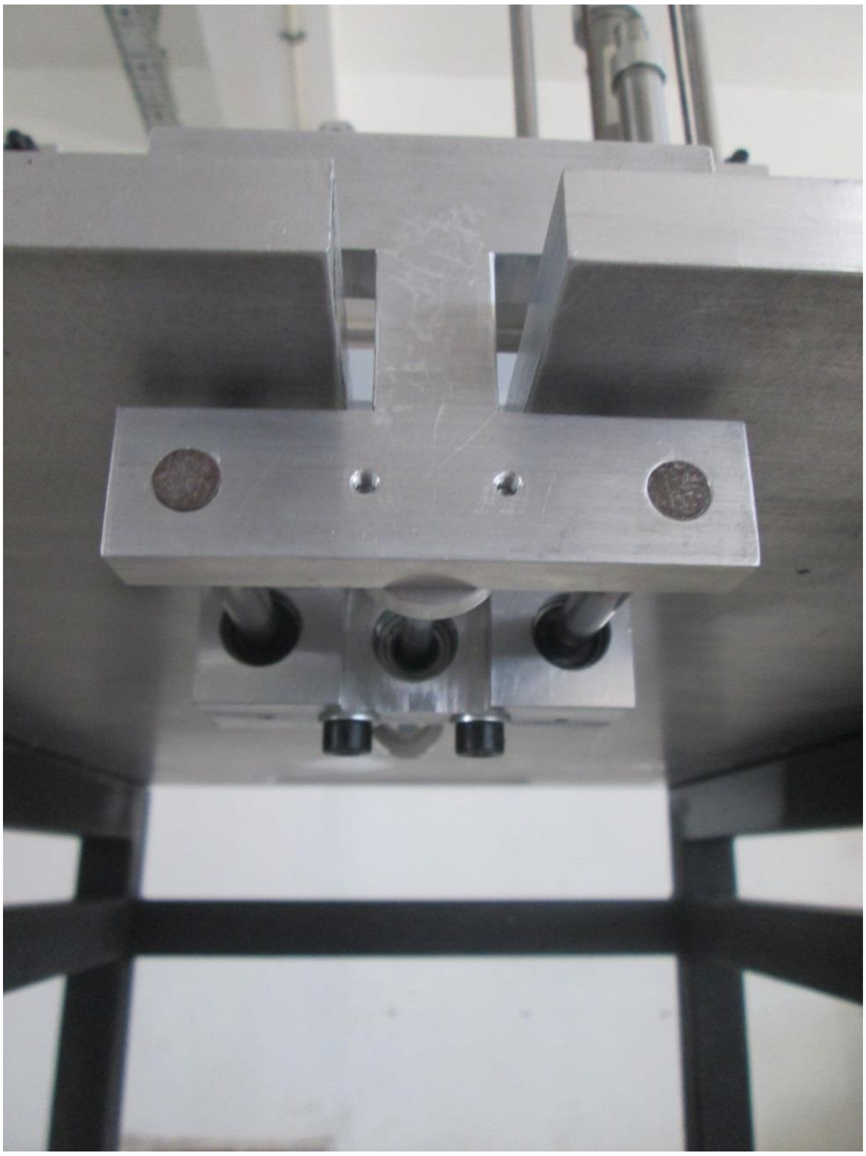


Figure 2.43: Pusher part (bottom view).

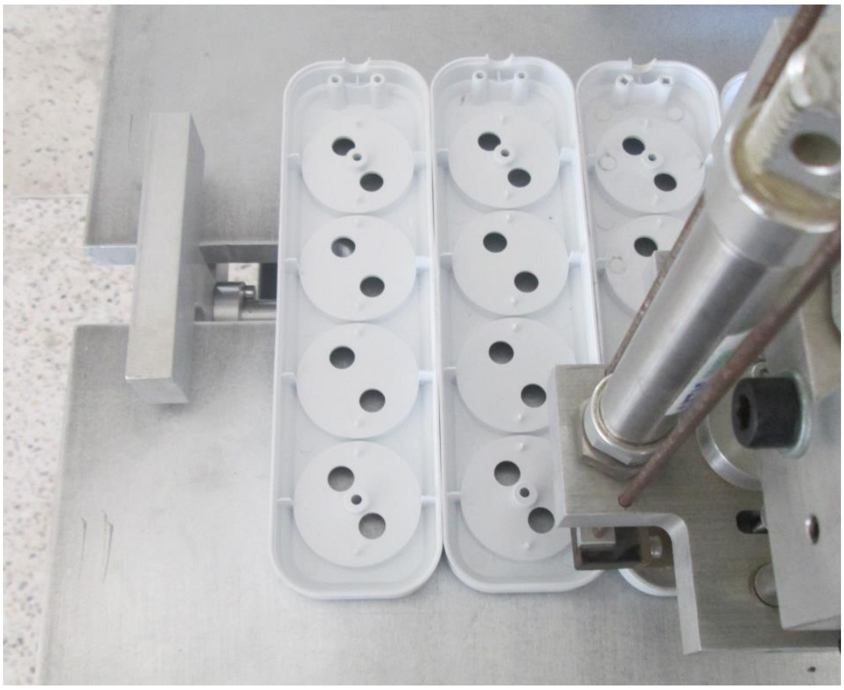


Figure 2.44: Pusher part (top view).

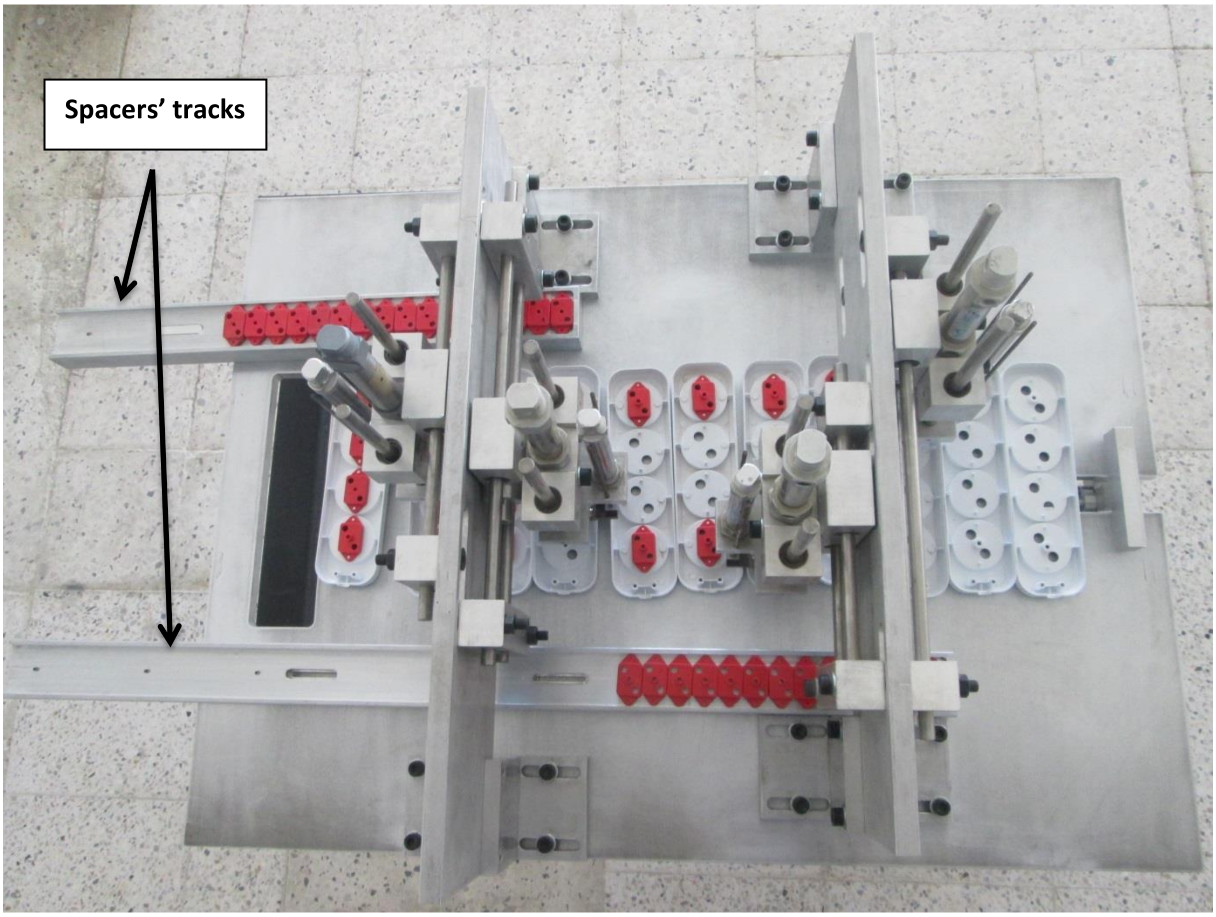


Figure 3.46: Spacers tracks.

II.4: Conclusion

72 parts were machined to achieve the implementation of the previously designed machine, each part was carefully machined with high performance Lathe machines (both mechanical and electrical cutting). The blueprint or the plan of every component was carefully drawn respecting norms and standards for precision and threading.
When designing a part in a machine, an engineer must consider modifications after the manufacturing so parts must be conceived in a way that allows modifications (example: add 10 mm to every dimension).

Threaded holes for screws must follow standards for screw diameters and lengths (dimensions) and threading characteristics (crest, thread angle root and pitch), the same for pneumatics cylinders, bore sizes are standardized.

Finally, skills in lathe machines and CNC machines are essential and required for a control engineer, so when designing parts for automated machines, the manufacturing procedure will run in the background of his mind and the final parts will be easily manufactured.

PART TWO:

CONTROL SYSTEM

and PROGRAMMING

Chapter I:

Control Systems

and Industrial Control Systems

PART TWO: CONTROL SYSTEM and PROGRAMMING

Chapter I: Control Systems and Industrial Control Systems

I.1: Introduction and Definitions

Control System can be defined as subsystems and processes (or plants) assembled for the purpose of obtaining a desired output with desired performance, given a specified input.
In other words, Control System is a device (hardware and software) dedicated to control, manages, commands, directs or regulates the behavior of other devices or systems such as robots, cars, airplanes, assembly machines etc…
Control Systems can be mechanical or electrical but due to the massive development is the field of electronics and power electronics, most Control Systems nowadays are electrical.

Figure 1.1 shows a control system in its simplest form, where the input represents a desired output.

Figure 1.1: simplified Description of a Control System.

An industrial control system (ICS) is integrated hardware and software designed to monitor and control the operation of machinery and associated devices in industrial environments.

Industrial control systems monitor, automatically manage and enable human control of industrial processes such as product distribution, handling and production. The systems have helped bring about an increase in speed, responsiveness to conditions and reliability.
Industrial control system (ICS) is a collective term used to describe different types of control systems and associated instrumentation, which include the devices, systems, networks, and controls used to operate and/or automate industrial processes. Depending on the industry, each ICS functions differently and are built to electronically manage tasks efficiently. Today the devices and protocols used in an ICS are used in nearly every industrial sector and critical infrastructure such as the manufacturing, transportation, energy, and, in extraction resources like mining, oil, gas and coal, as well as factories, water/waste water treatment, power plants, pulp and paper and transport industries. [4]

I.2: Automated Machine Control System

The Control system used to automate our assembly machine is a Control Panel (or: Control Cabinet) which regroups the following elements:

1- Programmable Logic Controller (PLC).
2- Programmable Logic Controller Extension Module.
3- Power Supply Unit.
4- Circuit Breaker.
5- Fuse and Fuse Carrier.
6- Screw Type Terminal Blocks.
7- Wires.
8- Push Buttons and Switches.
9- Cable Raceways (open slot panel trunking).
10- Din Rails.
11- Steel Enclosure.
12- Cable Ties.

With invention of programmable controllers, much has changed in how a process control system is designed. Many advantages appeared.

Figure 1.2: Control Cabinet 1.

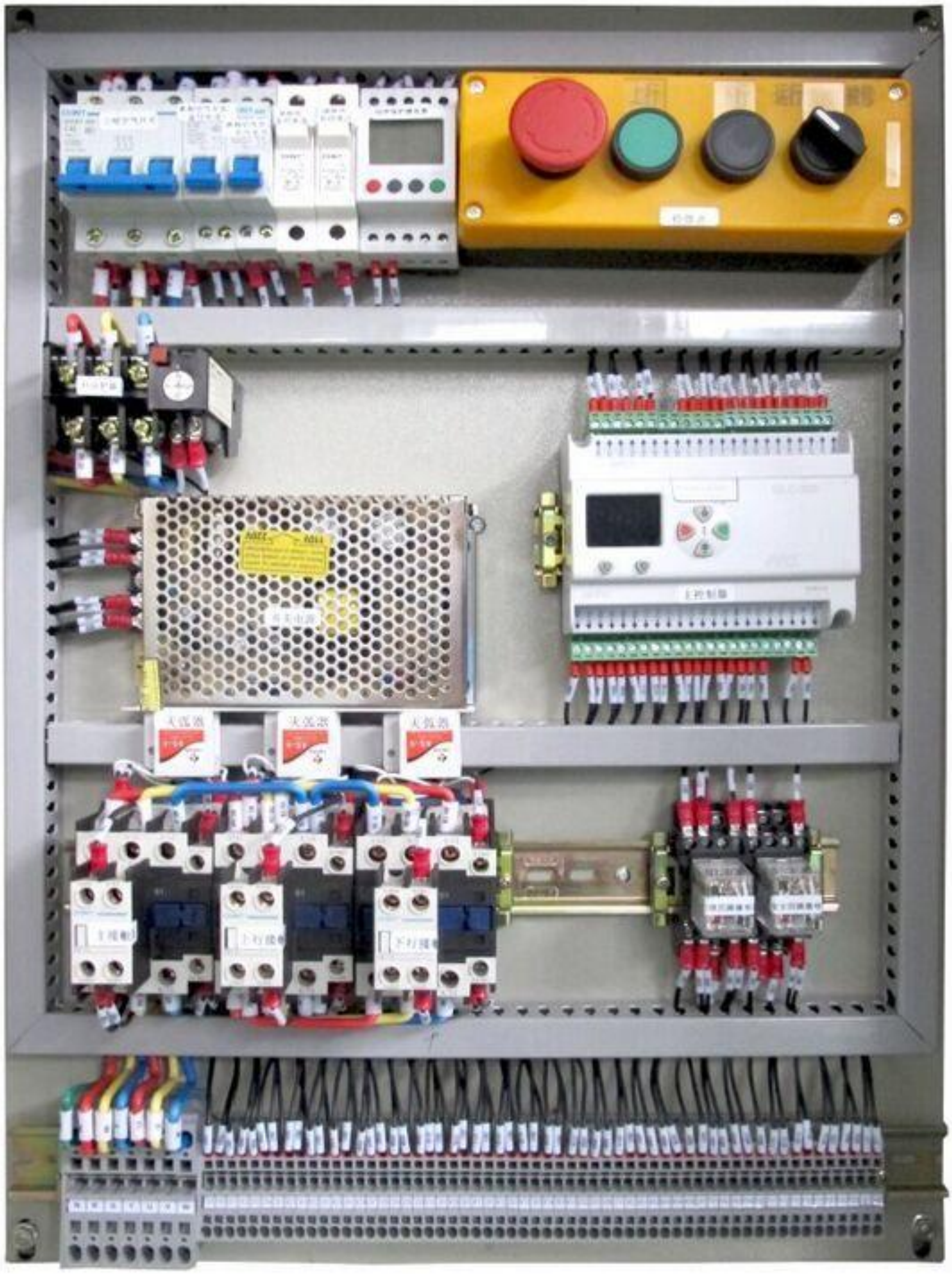


Figure 1.3: Control cabinet 2.

Figure 1.4: the machine's control cabinet.

The following sections present a detailed description of each element in the Control Cabinet and their functions.

I.3: Programmable Logic Controllers

I.3.1: Introduction

Controllers might be required to control a sequence of events, maintain some variable constant, or follow some prescribed change. For example, the control system for an automatic drilling machine shown in figure 1.5 might be required to start lowering the drill when the workpiece is in position, start drilling when the drill reaches the workpiece, stop drilling when the drill has produced the required depth of hole, retract the drill, and then switch off and wait for the next workpiece to be put in position before repeating the operation. Another control system shown in figure 1.6 might be used to control the number of items moving along a conveyor belt and direct them into a packing case. The inputs to such control systems might come from switches being closed or opened; for example, the presence of the workpiece might be indicated by it moving against a switch and closing it, or other sensors such as those used for temperature or flow rates. The controller might be required to run a motor to move an object to some position or to turn a valve, or perhaps a heater, on or off.

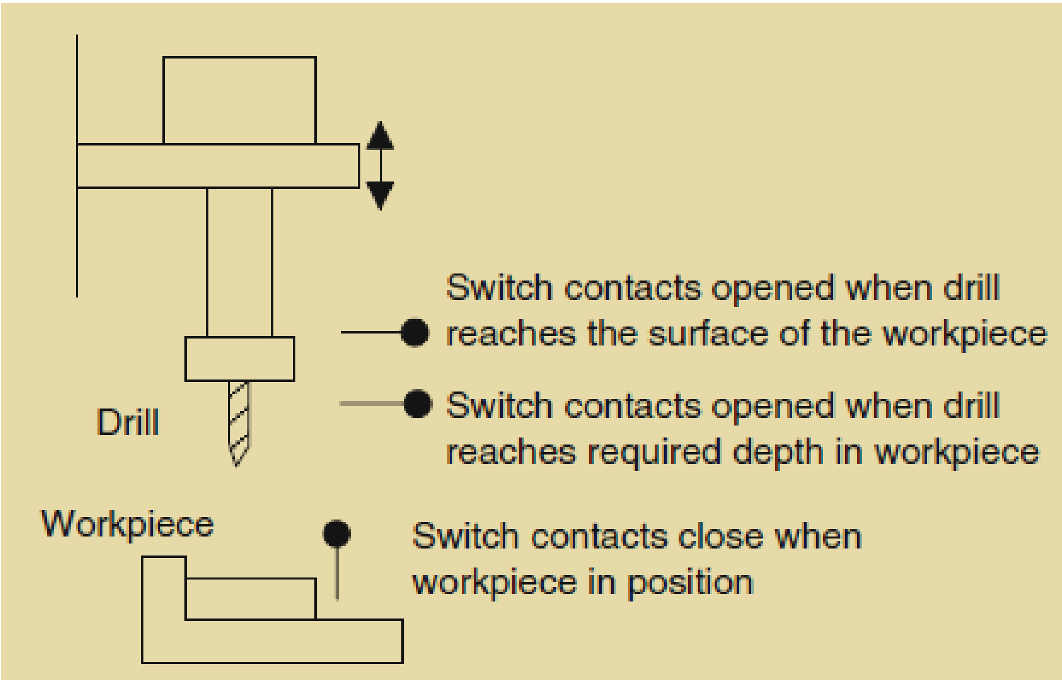


Figure 1.5: An automatic drilling machine.

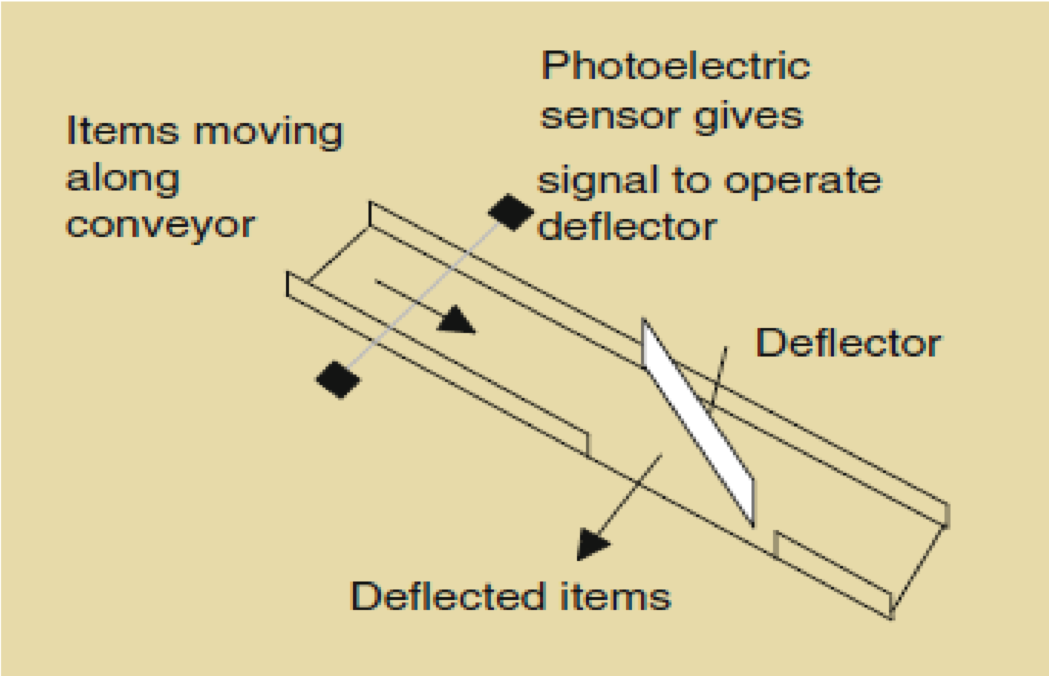


Figure 1.6: A packing system

For the automatic drilling machine, we could wire up electrical circuits in which the closing or opening of switches would result in motors being switched on or valves being actuated. Thus we might have the closing of a switch activating a relay, which, in turn, switches on the current to a motor and causes the drill to rotate. Another switch might be used to activate a relay and switch on the current to a pneumatic or hydraulic valve, which results in pressure being switched to drive a piston in a cylinder and so results in the workpiece being pushed into the required position. Such electrical circuits would have to be specific to the automatic drilling machine. For controlling the number of items packed into a packing case, we could likewise wire up electrical circuits involving sensors and motors. However, the controller circuits devised for these two situations would be different. In the “traditional” form of control system, the rules governing the control system and when actions are initiated are determined by the wiring. When the rules used for the control actions are changed, the wiring has to be changed.

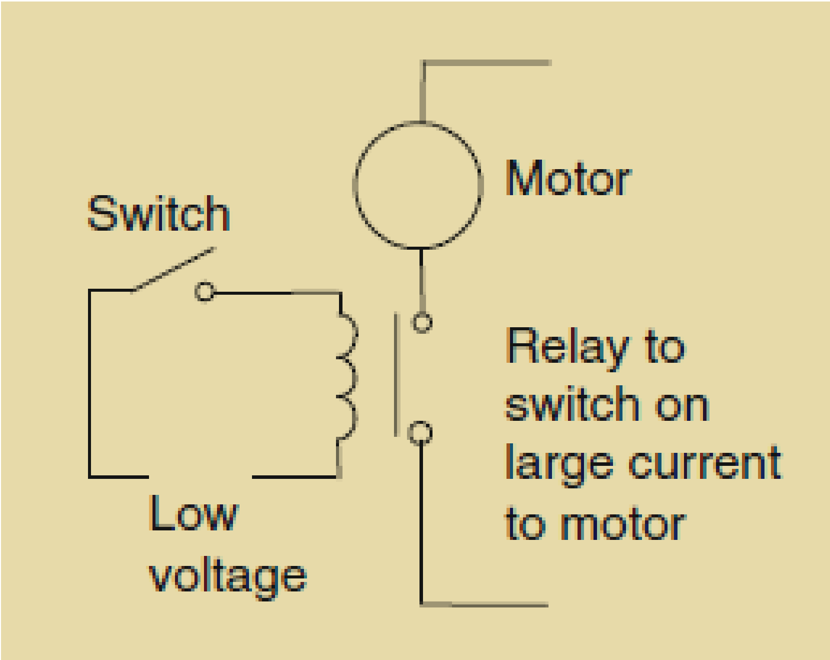


Figure1.7: Basic control system.

I.3.2: Microprocessor-Controlled Systems

Instead of hardwiring each control circuit for each control situation, we can use the same basic system for all situations if we use a microprocessor-based system and write a program to instruct the microprocessor how to react to each input signal from, say, switches and give the required outputs to, say, motors and valves. Thus we might have a program of the form:

If Switch A closes

Output to motor circuit

If Switch B closes

Output to valve circuit

By changing the instructions in the program, we can use the same microprocessor system to control a wide variety of situations.

I.3.3: the Programmable Logic Controller

I.3.3.1: Introduction to PLCs

A programmable logic controller (PLC) is a special form of microprocessor-based controller that uses programmable memory to store instructions and to implement functions such as logic, sequencing, timing, counting, and arithmetic in order to control machines and processes. It is designed to be operated by engineers with perhaps a limited knowledge of computers and computing languages. They are not designed so that only computer programmers can set up or change the programs. Thus, the designers of the PLC have preprogrammed it so that the control program can be entered using a simple, rather intuitive form of language. The term logic is used because programming is primarily concerned with implementing logic and switching operations; for example, if A or B occurs, switch on C; if A and B occurs, switch on D. Input devices (that is, sensors such as switches) and output devices (motors, valves, etc.) in the system being controlled are connected to the PLC. The operator then enters a sequence of instructions, a program, into the memory of the PLC. The controller then monitors the inputs and outputs according to this program and carries out the control rules for which it has been programmed.

Figure 1.8: Mitsubishi FX2N-64MR.

PLCs have the great advantage that the same basic controller can be used with a wide range of control systems. To modify a control system and the rules that are to be used, all that is necessary is for an operator to key in a different set of instructions. There is no need to rewire. The result is a flexible, cost-effective system that can be used with control systems, which vary quite widely in their nature and complexity. Programmable logic controllers are now the most widely used industrial process control technology.

A programmable logic controller (PLC) is an industrial grade computer that is capable of being programmed to perform control functions. The programmable controller has eliminated much of the hardwiring associated with conventional relay control circuits. Other benefits include easy programming and installation, high control speed, network compatibility, troubleshooting and testing convenience, and high reliability.

The programmable logic controller is designed for multiple input and output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs for the control and operation of manufacturing process equipment and machinery are typically stored in battery-backed or nonvolatile memory. A PLC is an example of a real-time system since the output of the system controlled by the PLC depends on the input conditions.

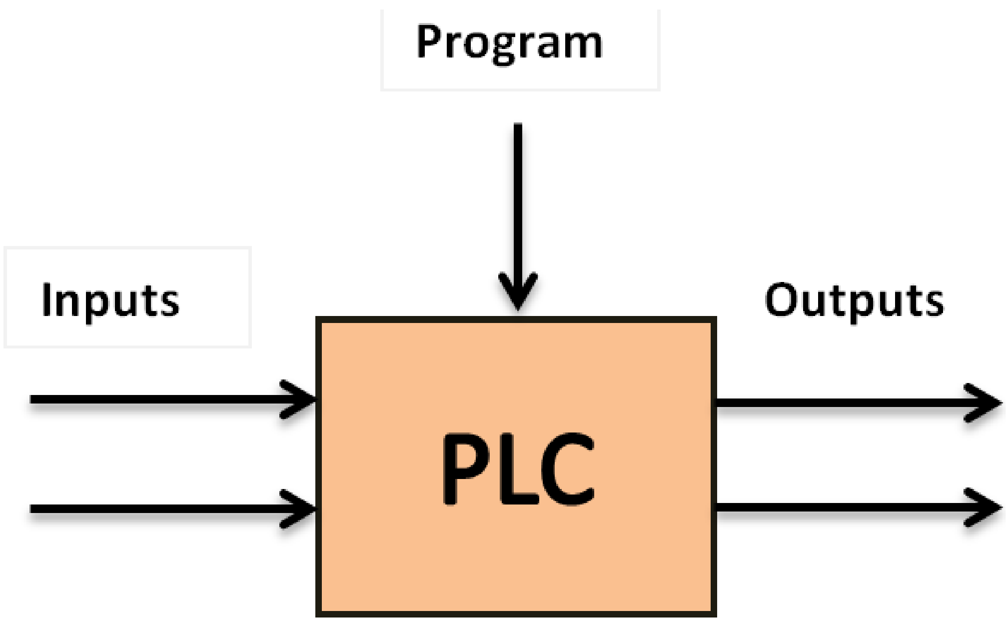


Figure 1.9: A Programmable Logic Controller.

The programmable logic controller is, then, basically a digital computer designed for use in machine control. Unlike a personal computer, it has been designed to operate in the industrial environment and is equipped with special input/output interfaces and a control programming language. The common abbreviation used in industry for these devices, PC, can be confusing because it is also the abbreviation for “personal computer.”

Therefore, most manufacturers refer to their programmable controller as a PLC, which stands for “programmable logic controller.”

Initially the PLC was used to replace relay logic, but its ever-increasing range of functions means that it is found in many and more complex applications. Because the structure of a PLC is based on the same principles as those employed in computer architecture, it is capable not only of performing relay switching tasks but also of performing other applications such as timing, counting, calculating, comparing, and the processing of analog signals.

Programmable controllers offer several advantages over a conventional relay type of control. Relays have to be hardwired to perform a specific function. When the system requirements change, the relay wiring has to be changed or modified (as stated before).
In extreme cases, such as in the auto industry, complete control panels had to be replaced since it was not economically feasible to rewire the old panels with each model changeover. The programmable controller has eliminated much of the hardwiring associated with conventional relay control circuits. It is small and inexpensive compared to equivalent relay-based process control systems. Modern control systems still include relays, but these are rarely used for logic.

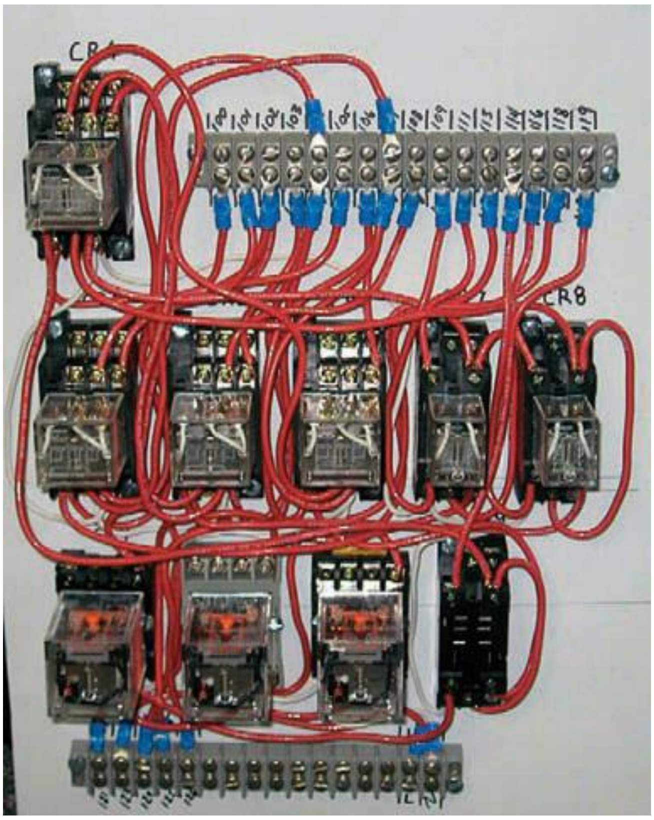


Figure 1.10: Relay based control panel.

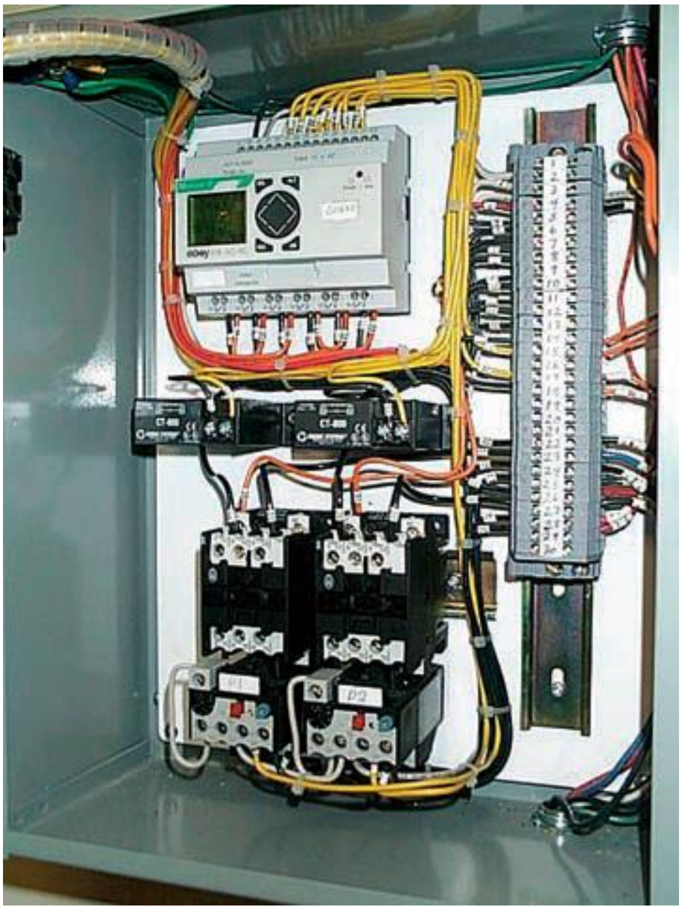


Figure 1.11: PLC based control panel.

In addition to cost savings, PLCs provide many other benefits including:

• **Increased Reliability:** Once a program has been written and tested, it can be easily downloaded to other PLCs. Since all the logic is contained in the PLC's memory, there is no chance of making a logic wiring error The program takes the place of much of the external wiring that would normally be required for control of a process.
Hardwiring, though still required to connect field devices, is less intensive. PLCs also offer the reliability associated with solid-state components.

• **More Flexibility:** It is easier to create and change a program in a PLC than to wire and rewire a circuit. With a PLC the relationships between the inputs and outputs are determined by the user program instead of the manner in which they are interconnected.

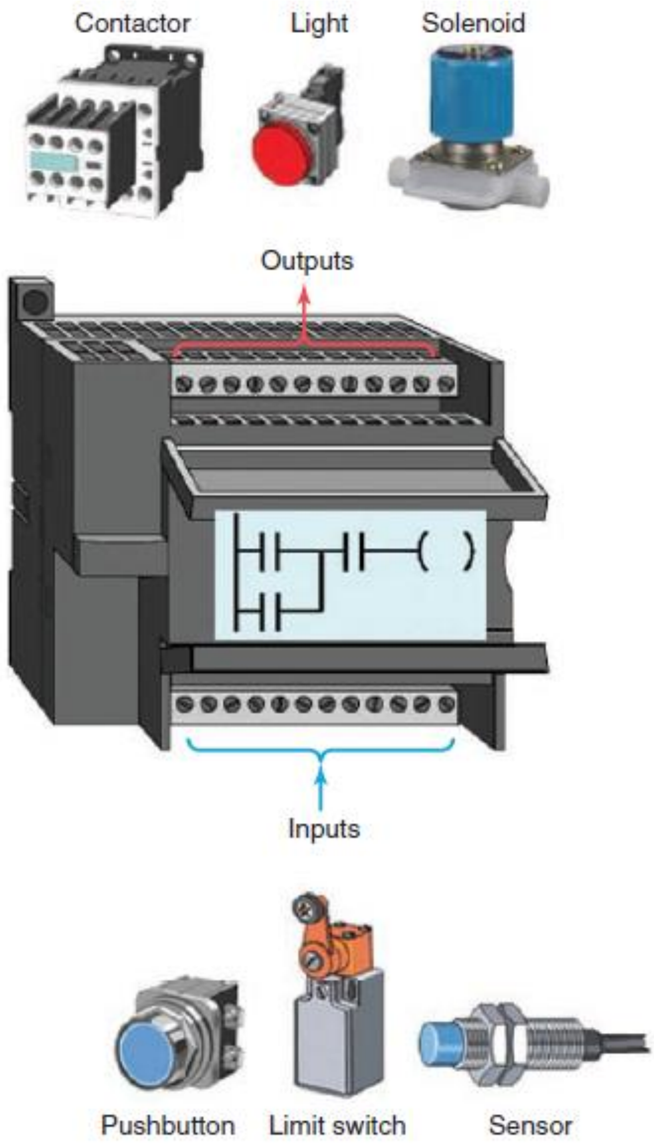


Figure 1.12: Relationships between the inputs and outputs

• **Lower Cost:** PLCs were originally designed to replace relay control logic, and the cost savings have been so significant that relay control is becoming obsolete except for power applications. Generally, if an application has more than about a half-dozen control relays, it will probably be less expensive to install a PLC.

• **Faster Response Time:** PLCs are designed for high speed and real-time applications The programmable controller operates in real time, which means that an event taking place in the field will result in the execution of an operation or output. Machines that process thousands of items per second and objects that spend only a fraction of a second in front of a sensor require the PLC’s quick-response capability.

• **Easier to Troubleshoot:** PLCs have resident diagnostics and override functions that allow users to easily trace and correct software and hardware problems. To find and fix problems, users can display the control program on a monitor and watch it in real-time as it executes.

I.3.3.2: Parts of a PLC

A typical PLC can be divided into parts, as illustrated in Figure 1.13. These are the central processing unit (CPU), the input/output (I/O) section, the power supply, and the programming device.

The term architecture can refer to PLC hardware, to PLC software, or to a combination of both. An open architecture design allows the system to be connected easily to devices and programs made by other manufacturers. Open architectures use off-the-shelf components that conform to approved standards. A system with a closed architecture is one whose design is proprietary, making it more difficult to connect to other systems. Most PLC systems are in fact proprietary, so you must be sure that any generic hardware or software you may use is compatible with your particular PLC. Also, although the principal concepts are the same in all methods of programming, there might be slight differences in addressing, memory allocation, retrieval, and data handling for different models. Consequently, PLC programs cannot be interchanged among different PLC manufacturers.

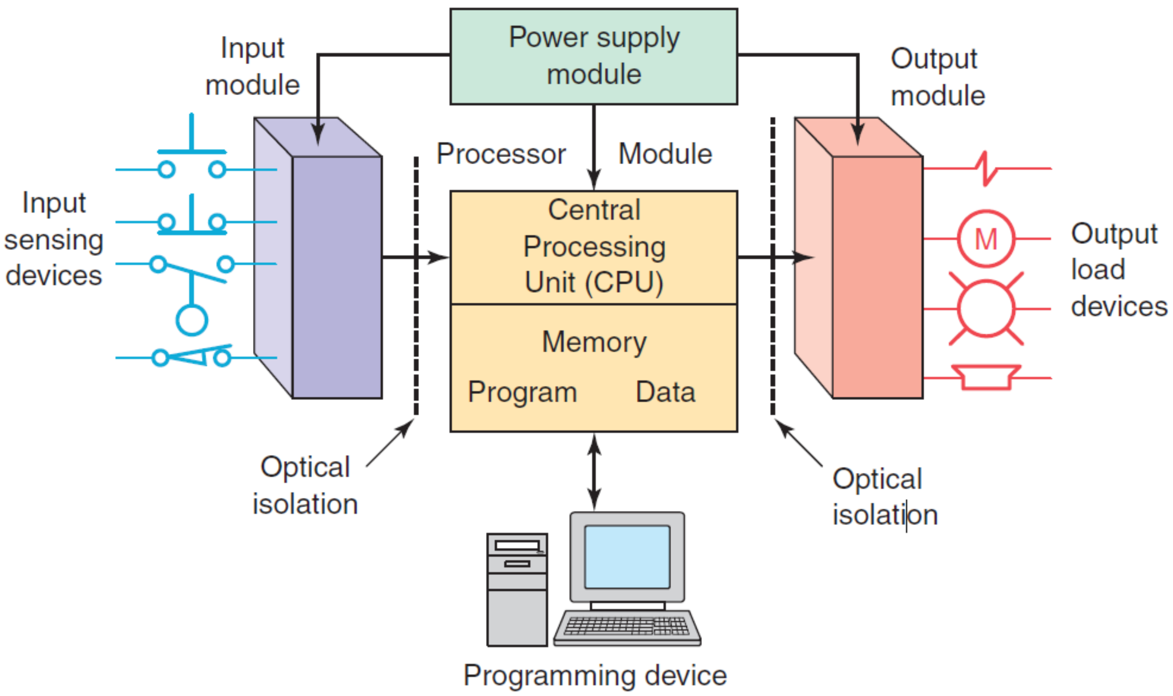


Figure 1.13: Typical parts of a programmable logic controller.

There are two ways in which I/O s (Inputs/Outputs) are incorporated into the PLC: fixed and modular.

Fixed I/O is typical of small PLCs that come in one package with no separate, removable units. The processor and I/O are packaged together, and the I/O terminals will have a fixed number of connections built in for inputs and outputs. The main advantage of this type of packaging is lower cost. The number of available I/O points varies and usually can be expanded by buying additional units of fixed I/O. One disadvantage of fixed I/O is its lack of flexibility; you are limited in what you can get in the quantities and types dictated by the packaging. Also, for some models, if any part in the unit fails, the whole unit has to be replaced.

Modular I/O is divided by compartments into which separate modules can be plugged. This feature greatly increases your options and the unit's flexibility. You can choose from the modules available from the manufacturer and mix them any way you desire. The basic modular controller consists of a rack, power supply, processor module (CPU), input/output (I/O modules), and an operator interface for programming and monitoring. The modules plug into a rack. When a module is slid into the rack, it makes an electrical connection with a series of contacts called the backplane, located at the rear of the rack. The PLC processor is also connected to the backplane and can communicate with all the modules in the rack.

Figure 1.14: Modular type PLC.

Figure 1.15: Fixed type PLC.

The power supply supplies DC power to other modules that plug into the rack. For large PLC systems, this power supply does not normally supply power to the field devices. With larger systems, power to field devices is provided by external alternating current (AC) or direct current (DC) supplies. For some small micro PLC systems, the power supply may be used to power field devices.

The processor (CPU) is the “brain” of the PLC. A typical processor usually consists of a microprocessor for implementing the logic and controlling the communications among the modules. The processor requires memory for storing the results of the logical operations performed by the microprocessor. Memory is also required for the program EPROM or EEPROM plus RAM. The CPU controls all PLC activity and is designed so that the user can enter the desired program in relay ladder logic. The PLC program is executed as part of a repetitive process referred to as a scan .A typical PLC scan starts with the CPU reading the status of inputs. Then, the application program is executed. Once the program execution is completed, the CPU performs internal diagnostic and communication tasks. Next, the status of all outputs is updated. This process is repeated continuously as long as the PLC is in the run mode.

Figure 1.16: Typical PLC processor modules.

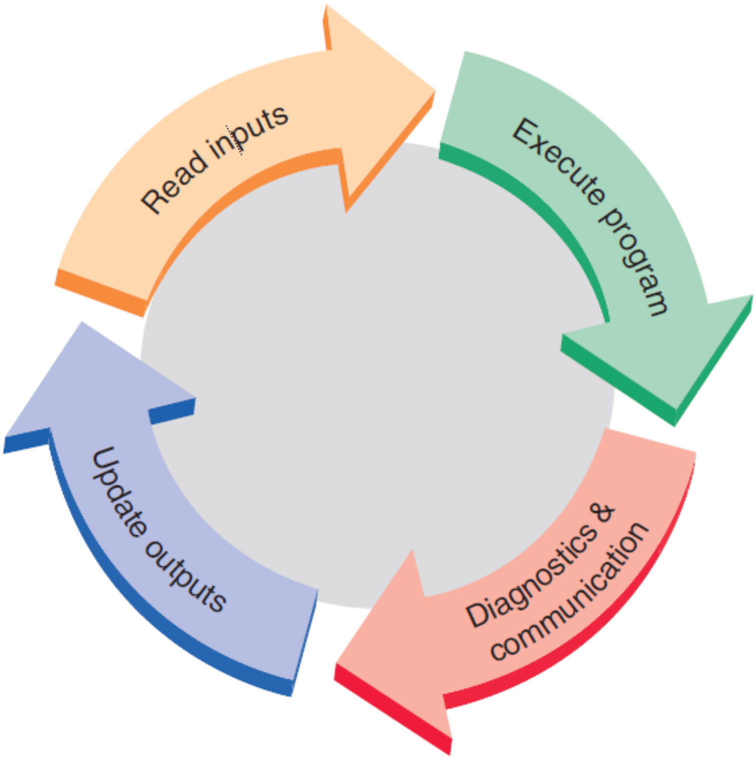


Figure 1.17: Typical PLC scan cycle.

The I/O system forms the interface by which field devices are connected to the controller. The purpose of this interface is to condition the various signals received from or sent to external field devices. Input devices such as pushbuttons, limit switches, and sensors are hardwired to the input terminals. Output devices such as small motors, motor starters, solenoid valves, and indicator lights are hardwired to the output terminals. To electrically isolate the internal components from the input and output terminals, PLCs commonly employ an optical isolator, which uses light to couple the circuits together. The external devices are also referred to as “field” or “real-world” inputs and outputs. The terms field or real world are used to distinguish actual external devices that exist and must be physically wired from the internal user program that duplicates the function of relays, timers, and counters.

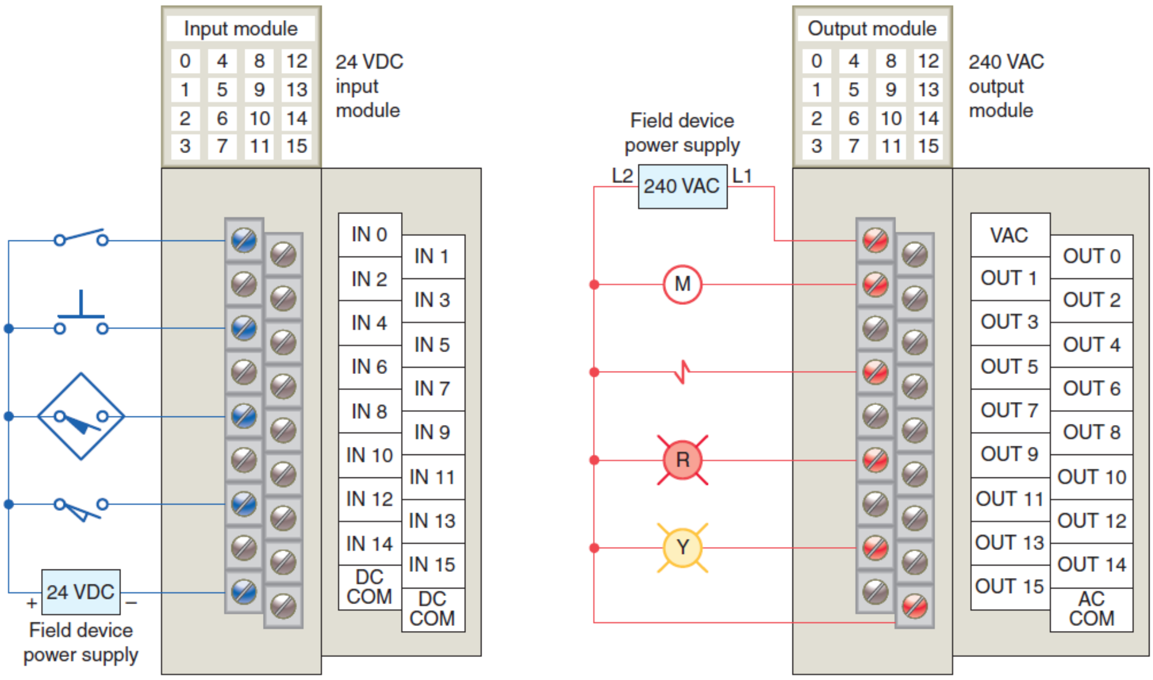


Figure 1.18: Typical PLC input/output (I/O) system connections.

A programming device is used to enter the desired program into the memory of the processor. The program can be entered using relay ladder logic, which is one of the most popular programming languages. Instead of words, ladder logic programming language uses graphic symbols that show their intended outcome. A program in ladder logic is similar to a schematic for a relay control circuit. It is a special language written to make it easy for people familiar with relay logic control to program the PLC.

Hand-held programming devices are sometimes used to program small PLCs because they are inexpensive and easy to use. Once plugged into the PLC, they can be used to enter and monitor programs. Both compact hand-held units and laptop computers are frequently used on the factory floor for troubleshooting equipment, modifying programs, and transferring programs to multiple machines.
A personal computer (PC) is the most commonly used programming device. Most brands of PLCs have software available so that a PC can be used as the programming device. This software allows users to create, edit, document, store, and troubleshoot ladder logic programs .The computer monitor is able to display more logic on the screen than can hand-held types, thus simplifying the interpretation of the program. The personal computer communicates with the PLC processor via a serial or parallel data communications link, or Ethernet. If the programming unit is not in use, it may be unplugged and removed. Removing the programming unit will not affect the operation of the user program.

Figure 1.19: Hand-Held programming device (Automation Direct)

A program is a user-developed series of instructions that directs the PLC to execute actions. A programming language provides rules for combining the instructions so that they produce the desired actions. Relay ladder logic (RLL) is the standard programming language used with PLCs. Its origin is based on electromechanical relay control. The relay ladder logic program graphically represents rungs of contacts, coils, and special instruction blocks.

RLL was originally designed for easy use and understanding for its users and has been modified to keep up with the increasing demands of industry's control needs.

I.3.3.3: Principles of Operation

To get an idea of how a PLC operates, consider the simple process control problem illustrated in Figure 1.20. Here a mixer motor is to be used to automatically stir the liquid in a vat when the temperature and pressure reach preset values. In addition, direct manual operation of the motor is provided by means of a separate pushbutton station.
The process is monitored with temperature and pressure sensor switches that close their respective contacts when conditions reach their preset values.
This control problem can be solved using the relay method for motor control shown in the relay ladder diagram of Figure 1.21. The motor starter coil (M) is energized when both the pressure and temperature switches are closed or when the manual pushbutton is pressed.

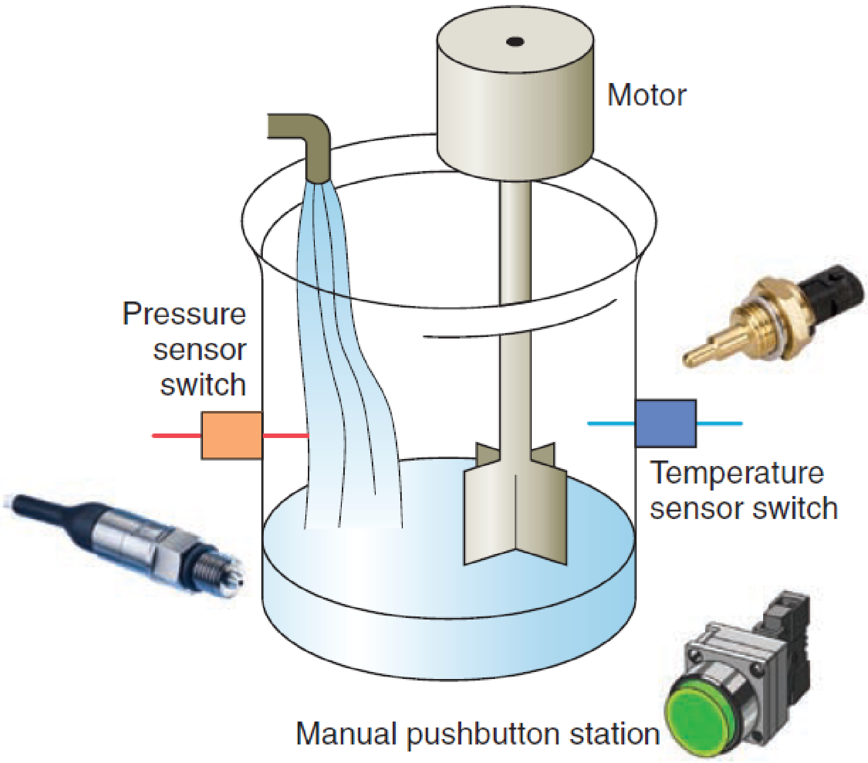


Figure 1.20: Mixer process control problem.

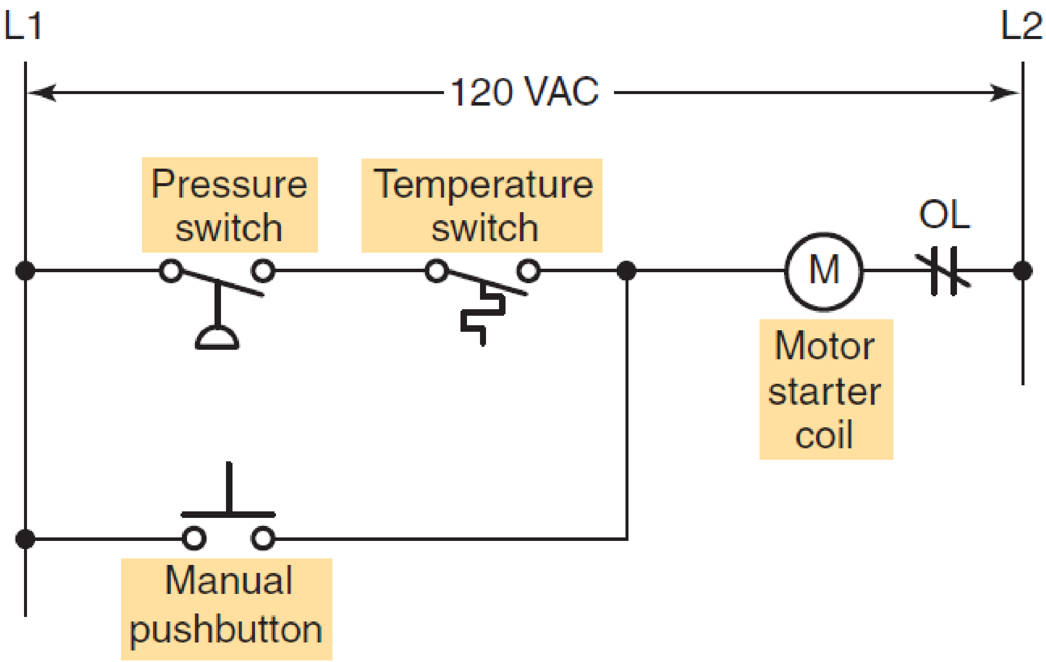


Figure 1.21: Process control relay ladder diagram.

Now let's look at how a programmable logic controller might be used for this application. The same input field devices (pressure switch, temperature switch, and pushbutton) are used. These devices would be hardwired to an appropriate input module according to the manufacturer's addressing location scheme. Typical wiring connections for a 120 VAC modular configured input module are shown in figure 1.22.

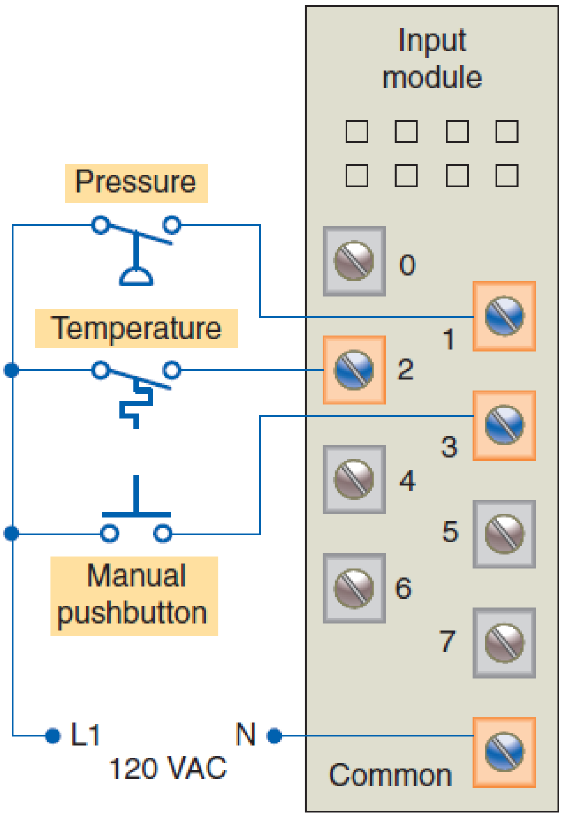


Figure 1.22: Typical wiring connections for a 120 VAC modular configured input module.

The same output field device (motor starter coil) would also be used. This device would be hardwired to an appropriate output module according to the manufacturer's addressing location scheme. Typical wiring connections for a 120 VAC modular configured output module are shown in figure 1.23.

Next, the PLC ladder logic program would be constructed and entered into the memory of the CPU. A typical ladder logic program for this process is shown in figure 1.24. The format used is similar to the layout of the hardwired relay ladder circuit. The individual symbols represent instructions, whereas the numbers represent the instruction location addresses. To program the controller, you enter these instructions one by one into the processor memory from the programming device.

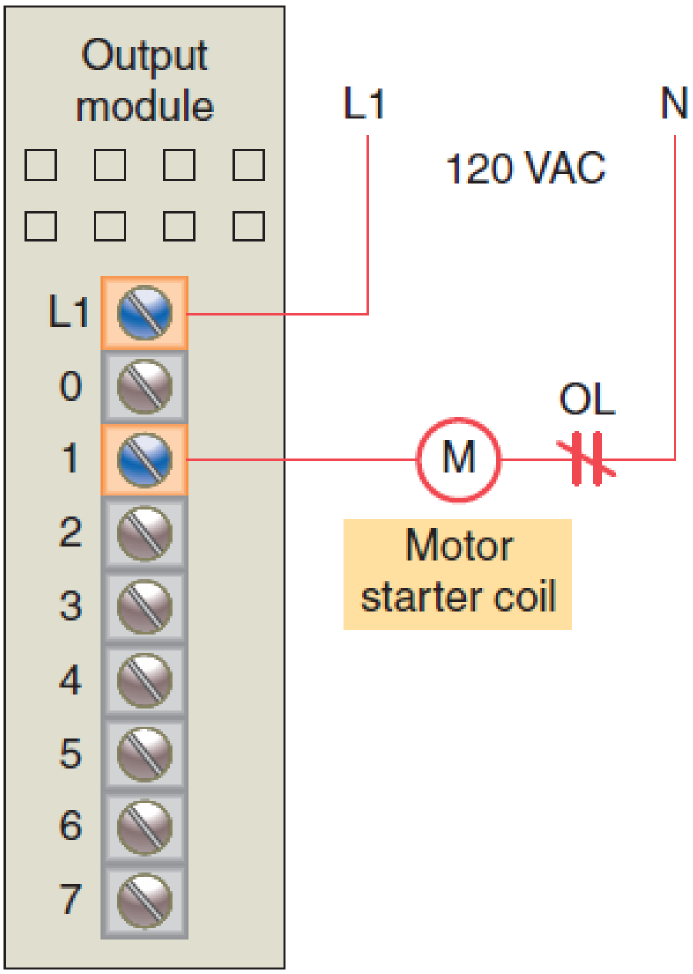
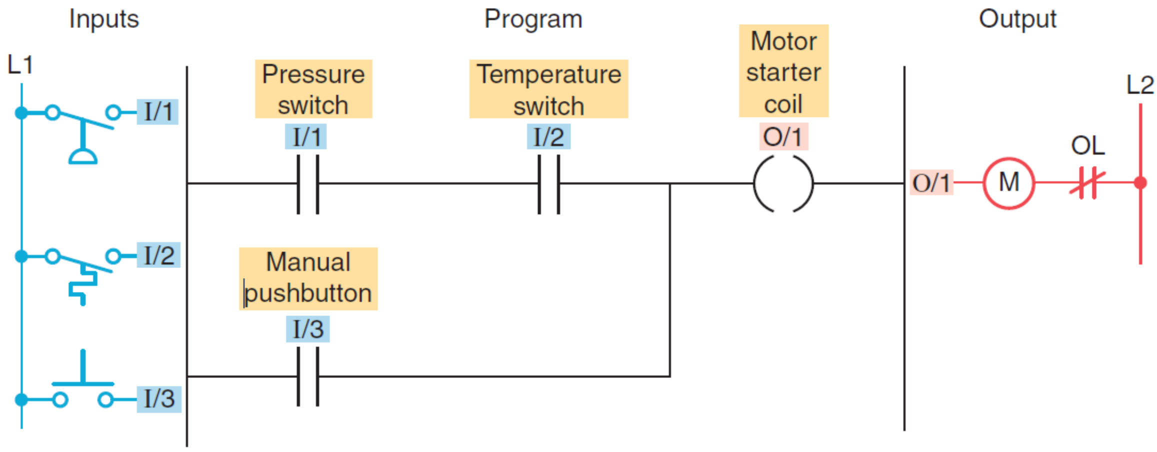


Figure 1.23: Typical wiring connections for a 120 VAC modular configured output module.

Each input and output device is given an address, which lets the PLC know where it is physically connected. Note that the I/O address format will differ, depending on the PLC model and manufacturer. Instructions are stored in the user program portion of the processor memory. During the program scan the controller monitors the inputs, executes the control program, and changes the output accordingly.



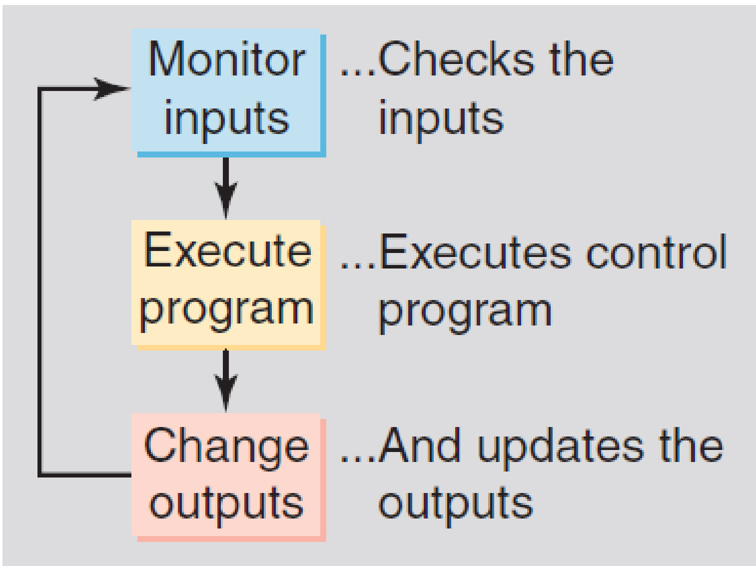


Figure 1.24: Process control PLC ladder logic program with typical addressing scheme.

For the program to operate, the controller is placed in the RUN mode, or operating cycle. During each operating cycle, the controller examines the status of input devices, executes the user program, and changes outputs accordingly. Each symbol can be thought of as a set of normally open contacts. The symbol - ( ) - is considered to represent a coil that, when energized, will close a set of contacts. In the ladder logic program of Figure number, the coil O/1 is energized when contacts I/1 and I/2 are closed or when contact I/3 is closed. Either of these conditions provides a continuous logic path from left to right across the rung that includes the coil. A programmable logic controller operates in real time in that an event taking place in the field will result in an operation or output taking place. The RUN operation for the process control scheme can be described by the following sequence of events:

• **First,** the pressure switch, temperature switch, and pushbutton inputs are examined and their status is recorded in the controller's memory.

• A closed contact is recorded in memory as logic 1 and an open contact as logic 0.

• **Next** the ladder diagram is evaluated, with each internal contact given an OPEN or CLOSED status according to its recorded 1 or 0 states.

• When the states of the input contacts provide logic continuity from left to right across the rung, the output coil memory location is given a logic 1 value and the output module interface contacts will close.

• When there is no logic continuity of the program rung, the output coil memory location is set to logic 0 and the output module interface contacts will be open.

• The completion of one cycle of this sequence by the controller is called a scan. The scan time, the time required for one full cycle, provides a measure of the speed of response of the PLC.

• **Generally**, the output memory location is updated during the scan but the actual output is not updated until the end of the program scan during the I/O scan. [5][6]

I.3.3.4: PLC used for the control of the automated machine

For our project we used the Omron CP1E N40 (24 input and 16 output) with Omron CP1W 16 ER expansion module (16 output).The SYSMAC CP1E Programmable Controller is a package-type PLC made by OMRON that is designed for easy application. The CP1E includes E-type CPU Units (basic models) for standard control operations using basic, movement, arithmetic, and comparison instructions, and N/NA-type CPU Units (application models) that supports connections to Programmable Terminals, Inverters, and Servo Drives.

The E-type Basic CPU Units provide cost performance and easy application with only basic functionality.

- **Features**

• Programming, setting, and monitoring with CX-Programmer.
• Easy connection with computers using commercially available USB cables
• With E30/40, N30/40/60 or NA20 CPU Units, Add I/O by Connecting Expansion I/O Units.
•With E30/40, N30/40/60 or NA20 CPU Units, Add Analog I/O or Temperature Inputs by Connecting Expansion Units.
• Quick-response inputs
• Input interrupts
• Complete High-speed Counter Functionality.
• Versatile pulse control for Transistor Output for N14/20/30/40/60 or NA20 CPU Units.
• PWM Outputs for Transistor Output for N14/20/30/40/60 or NA20 CPU Units.
• Built-in RS-232C Port for N/NA-type CPU Units.

• Mounting Serial Option Boards to N30/40/60 or NA20 CPU Units.
• Built-in analog I/O, two inputs and one output, for NA-type CPU Units.

Figure 1.25: Omron CP1E N40.

Figure 1.26: Omron CP1W 16ER expansion Module.

- **Omron CP1E N40 characteristics:**

- Dimensions (height x depth x width): 90mm x 85mm x 130mm.
- Weight: 660g max.
- Electrical specifications:
  - Supply voltage: 24 VDC.
  - Operating voltage range: 20.4 to 26.4 VDC.
  - Power consumption: 13W max.
  - Current consumption: 0.09 amps.
- Application environment:
  - Ambient operating temperature: 0 to 55 °C.
  - Ambient humidity: 10% to 90%.
  - Altitude: 2000 m max.
  - Shock resistance: 47 m/s2, 3 times in X, Y, and Z directions.
  - Vibration resistance: 5 to 8.4 Hz with 3.5-mm amplitude, 8.4 to 150 Hz.
- Performance Specifications:
  - Program capacity: 8 K steps (32 Kbytes) including the symbol table, comments, and program indices of the CX-Programmer (Software used to program the Omron PLC).
  - Control method: Stored program method.
  - I/O control method: Cyclic scan with immediate refreshing.
  - Program language: Ladder Diagram.
  - Instructions: Approximately 200.
  - Processing speed:
    - Overhead processing time: 0.4ms.
    - Instruction execution times:
      - Basic instructions (LD): 1.19 µs.
      - Special instructions (MOV): 7.9 µs.
  - Number of CP1W-series Expansion Units connected: 3 units.[7]

More performance specifications are given in the datasheet: Built-in input functions, Build-in output functions, communication, number of tasks, clock, memory backup, etc…

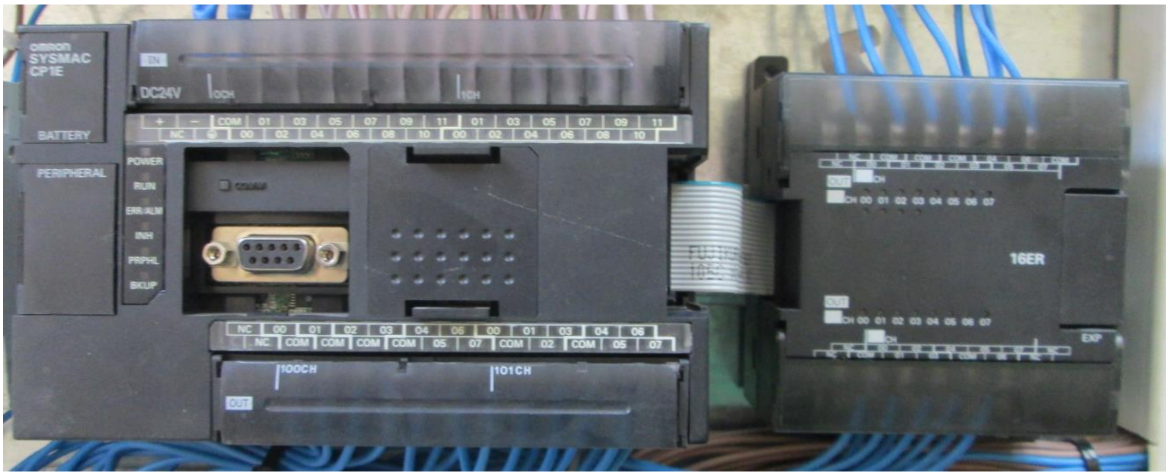


Figure 1.27: CP1E PLC with CP1W expansion module.

I.4: Power Supply Unit (PSU)

I.4.1: Introduction

Electronic equipment is powered from low voltage DC supplies. The source will be a battery, a combination of battery and DC/DC converter or a power supply converting AC mains into one or more low voltage DC supplies. Electronic components require a DC supply that is well regulated, has low noise characteristics and provides a fast response to load changes. AC power supplies, and most DC/DC converters, also provide isolation from the input to the output for safety, noise reduction and transient protection.

As electronic equipment becomes smaller and smaller, the market demands that power converters do the same. Since the introduction of switch mode techniques, this has been an evolutionary rather than a revolutionary process. Conversion efficiency has increased, materials and components allowing higher switching frequencies have become available and packaging techniques have advanced. At the same time, unit cost has fallen as sales volumes have increased. With the global market a reality, power supply systems operate from wide input ranges to cover worldwide AC mains supply variations. There are a number of basic topologies used in power converters, which are suited to various power levels, cost criteria and performance levels.

I.4.2 Electrical design

A simplified consideration of the electrical design of power supplies allows considering them as a device with an input side and an output side. The input side and the output side are electrically isolated against each other.

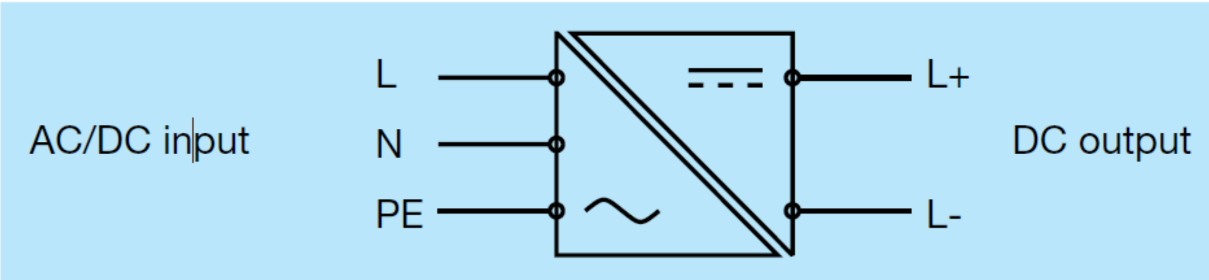


Figure 1.28: Simplified consideration of the electrical design.

The following table lists the most important terms regarding the input side and the output side.

Input side	Output side
Primary side	Secondary side
Input voltage	Output voltage
Primary grounding	Secondary grounding
Current consumption	Short-circuit current
Inrush current	Residual ripple
Input fuse	Output characteristics
Frequency	Output current
DC supply	
Power failure buffering	
Power factor correction (PFC)	

I.4.3: Power supply types and their design

Two major types of power supplies are distinguished: regulated power supplies and unregulated power supplies. Regulated power supplies are further divided into linearly regulated power supplies and switch mode power supplies.

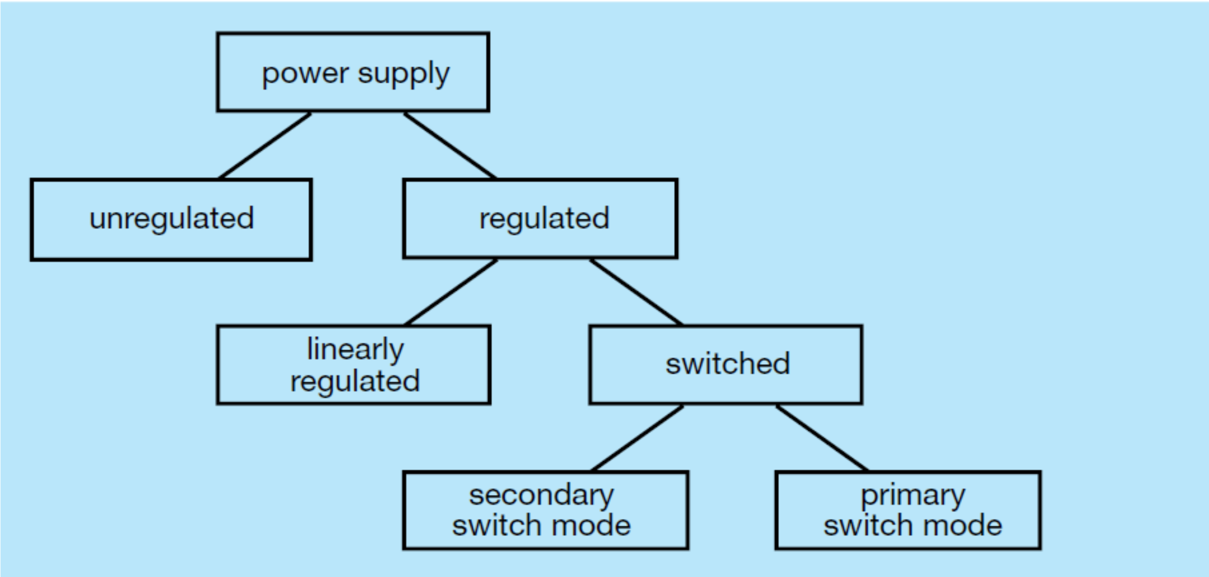


Figure 1.29: Overview of power supply types.

The various power supply types are explained below in more detail. However, the explanations only deal with the basic technology and not with circuit engineering details.

I.4.3.1: Unregulated power supplies

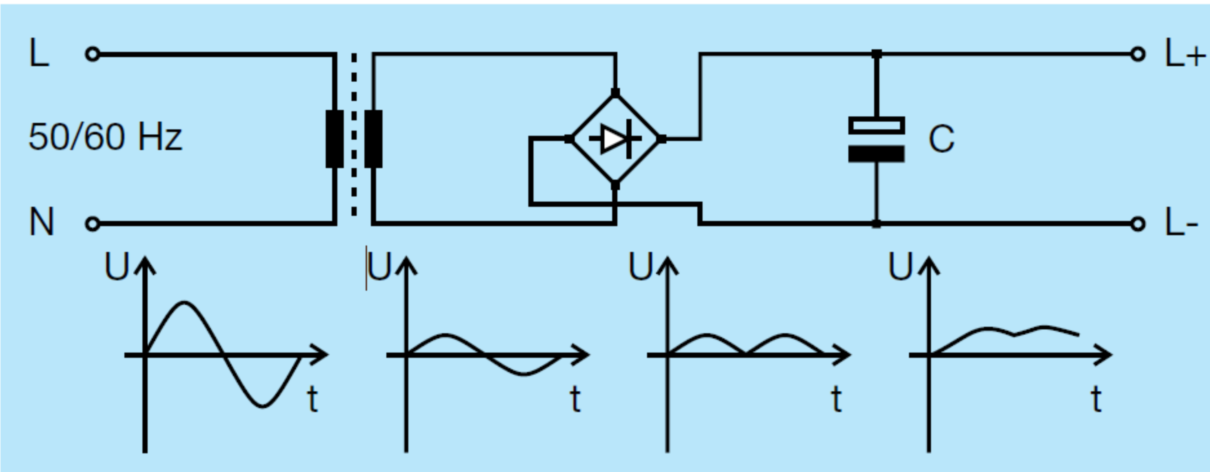


Figure 1.30: Unregulated power supply.

The AC mains voltage (50/60 Hz) applied at the input side is transformed to a lower level and rectified by a subsequent rectifier. Then, a capacitor C smooths the output voltage of the rectifier. The dimension of the transformer depends on the desired output voltage. Due to the design of the electric circuit, the output voltage directly depends on the input voltage which in turn means that variations of the mains voltage have direct effect to the output side. Since no regulation is done on the secondary side, the residual ripple of the output voltage is in the dimension of volts and specified as a percentage of the DC output voltage. Due to their simple design, unregulated power supplies are very robust and durable. Their efficiency is approx. 80 %. Unregulated power supplies are primarily used for simple electromechanical applications that do not require exact output voltages, e.g. for the supply of contactors.

- Advantages:
    - High efficiency.
    - Durable.
    - Cost-efficient.

- Disadvantages:
    - Large size.
    - High residual ripple.
    - No DC Supply.

I.4.3.2: linearly regulated power supplies

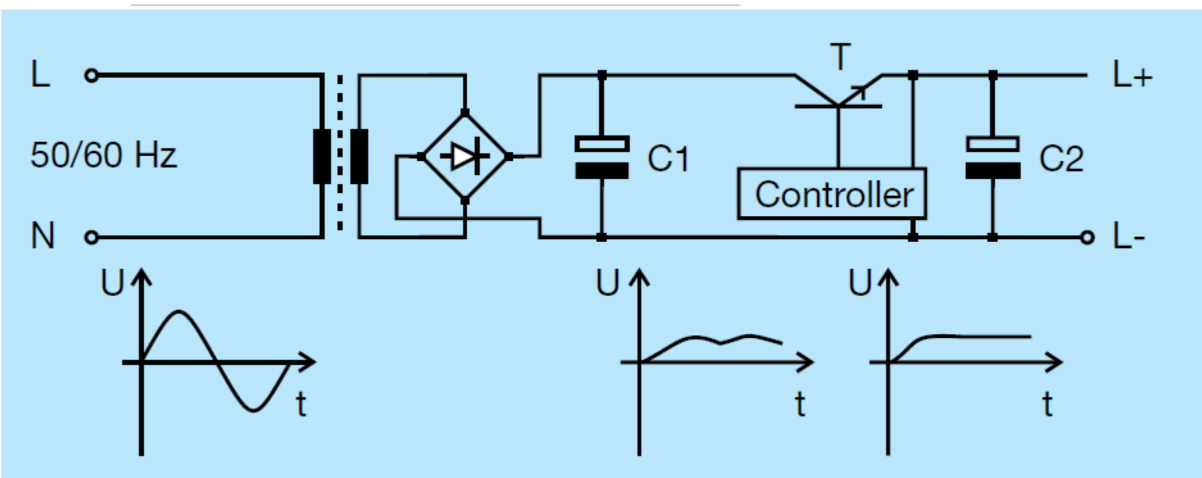


Figure 1.31: Linearly regulated power supply

The AC mains voltage is transformed to a lower level, rectified and smoothed by capacitor C1. Then, voltage regulation is performed, typically using a power transistor. The power transistor acts as a variable resistor, controlled to keep the output voltage constant. The efficiency of linearly regulated power supplies is only approx.50 % due to the high losses inside the power transistor. The remaining energy is emitted in the form of heat. Due to this, sufficient ventilation is required to cool the power supply. Compared with unregulated power supplies, linearly regulated power supplies have a very small residual ripple of the output voltage (in the dimension of millivolts).

Linearly regulated power supplies are used for all applications that require a very exact output voltage, e.g. for highly precise medical devices.

- Advantages:
  - Short regulation times.
  - Small residual ripple.
  - Simple circuitry.

- Disadvantages:
  - Poor efficiency.
  - Large size.
  - No DC supply.

I.4.3.3: Primary switch mode power supplies

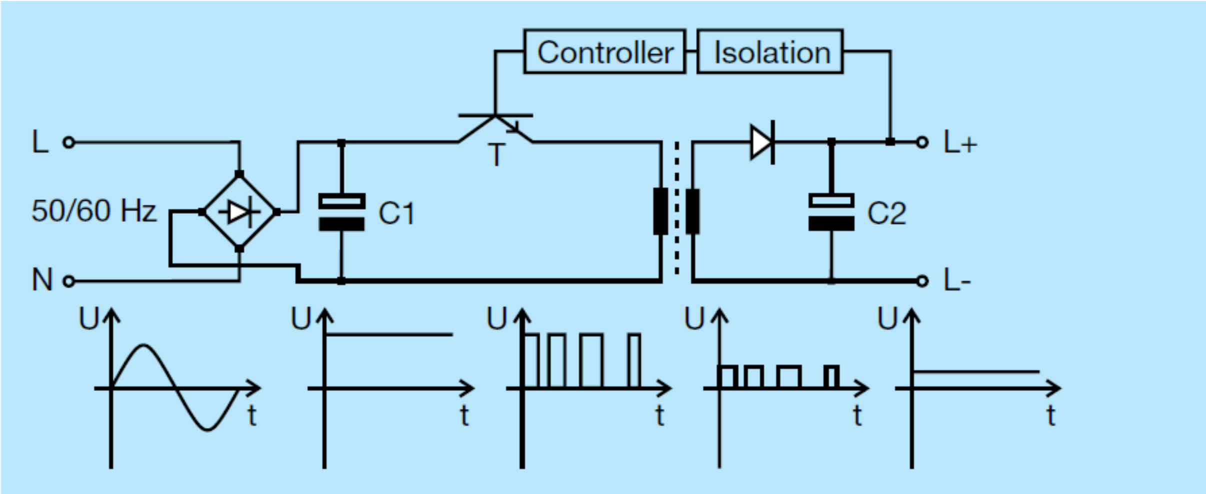


Figure 1.32: Primary switch mode power supply

In primary switch mode power supplies, the AC mains voltage is first rectified and smoothed and then chopped ("switched"). Chopping means that the DC voltage is switched periodically at a frequency of 40 to 200 kHz using a power transistor. In contrast to linearly regulated power supplies, the power transistor does not act as a variable resistor but as a switch instead. This generates a square-wave AC voltage that is transformed to the secondary circuit using a high-frequency transformer. In the secondary circuit, the voltage is rectified and smoothed. The quantity of energy transformed to the secondary circuit is controlled, depending on the load, by varying the chopping rate.

The longer the transistor is conductive, the higher is the quantity of energy transformed to the secondary circuit (pulse width modulation "PWM"). Due to the use of high-frequency AC voltage, primary switch mode power supplies have the decisive advantage that their transformer can be of much smaller size than required for the transformation of low frequencies. This reduces the weight and the dissipation inside the unit. The efficiency of these units is between 85 and 95 %. Since the output voltage does not directly depend on the input voltage, these units can be used for a wide input voltage range and can even be supplied with DC voltage.

Primary switch mode power supplies can be used for all purposes. For example, they are suitable for the supply of all kind of electronics as well as for electromechanical applications.

- Advantages:
  - Small size.
  - Light weight.
  - Wide input voltage range.
  - Easy to regulate.
  - High efficiency.
  - DC supply.

- Disadvantages:
  - Complex circuitry.
  - Mains pollution.
  - High frequency requires interference suppression measures.
  - Expensive.

I.4.3.4: Secondary switch mode power supplies

The design of secondary switch mode power supplies differs in only one detail from the design of primary switch mode power supplies. Chopping is performed on the secondary side. As a result, a much bigger transformer has to be used since it has to transform the mains voltage of 50/60 Hz. However, the transformer also acts as a filter and thus minimizes the mains pollution.

- Advantages:
  - High efficiency.
  - Easy to regulate.
  - Wide input voltage range.
  - Low mains pollution.

- Disadvantages:
  - Large size.
  - No DC supply.
  - Expensive.

I.4.4: Safety and Protection

The safety of persons and installation equipment is a major aspect even for power supplies. The requirements to be fulfilled in order to guarantee this safety are specified by standardized regulations. The most important terms from this field are listed and explained below.

- Input protection

Input protection is implemented in power supplies and DC/DC converters to ensure safe operation. The input fuse fitted within a power supply is not intended to be field-

replaceable; it is rated such that only a catastrophic failure of the power supply will cause it to fail. It will not be cleared by an overload as the power supply will have some other form of overload protection, usually electronic. The fuse will often be soldered into the PCB rather than being a replaceable cartridge type fuse.
The power supply fuse is listed as a critical part of the safety approval process and is used to ensure that the power supply does not catch fire under a fault condition. If the fuse clears the most likely cause is that the converter has failed short circuit presenting a short circuit to the mains supply. In this event the fuse will clear very quickly.
As previously discussed, the fuse in the power supply is not intended to be field-replaceable, and should only be replaced by competent service personnel following repair. When using a component power supply, there will be additional mains wiring within the enclosure before the power supply and its fuse. This is where an additional fuse or circuit breaker as a protection device is fitted to ensure that the wiring and associated components do not present a hazard.
When the end equipment is tested for safety it will also go through fault analysis to ensure that it will not present a fire hazard under a fault condition. If a fault were to occur many hundreds of Amps can flow causing wires to heat up very quickly, causing noxious fumes from the melting plastic insulation and creating a potential fire hazard.

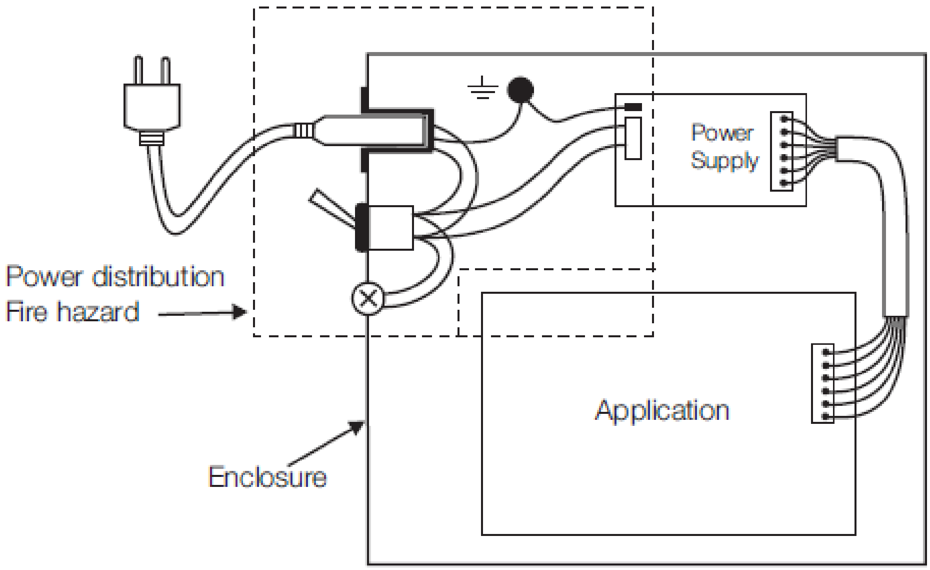


Figure 1.33: Typical Application.

- Inrush Current:

An AC mains system is a low impedance power source meaning that it can supply a large amount of current. In a power supply, at the instant of switch-on, the reservoir capacitor is discharged giving the appearance of a short circuit. Without any additional precautions the input current will be very large for a short time until the capacitor is charged.

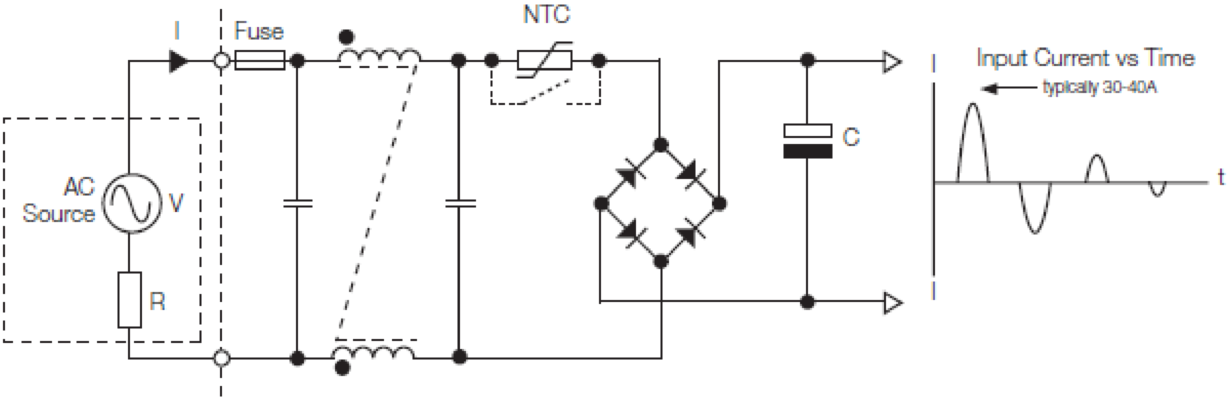


Figure 1.34: Typical power supply input circuit.

Precautions are taken to limit the inrush current as this will cause disturbances on the supply line and could damage any switches or relays and nuisance-blow fuses or circuit breakers. Fuses and circuit breakers need to be of a size and characteristic to cope with this inrush current without nuisance tripping. The most commonly used technique, due to its simplicity and low cost, is the fitting of a Negative Temperature Coefficient (NTC) thermistor. These devices have a high resistance when cold and a low resistance when hot. Inrush current is often specified from a cold start and at 25 °C due to thermal inertia and the time it takes for the thermistor to cool down following switch off of the power supply. In some applications, in order to solve this problem and improve efficiency, the thermistor is shorted by a relay following the initial inrush. There are other techniques using resistors and triacs but these are more complex and less common. A typical value of inrush current in an AC power supply is 30-40 A lasting 1-2 ms but can it be as high as 90-100 A in some products. There is a tradeoff to be made between lower inrush current and higher efficiency due to the power dissipated in the thermistor. [8]

I.4.5: Power supply unit used in the control cabinet

In our project we have used the Omron s8JC-Z05024C power supply with an input voltage from 200 to 240 VAC with a frequency of 50/60 Hz and 0.6A and an output of 24 VDC (2.1 A).

Figure 1.35: Omron S8JC-Z05024C Power supply nameplate.

Figure 1.36: power supply inputs and outputs

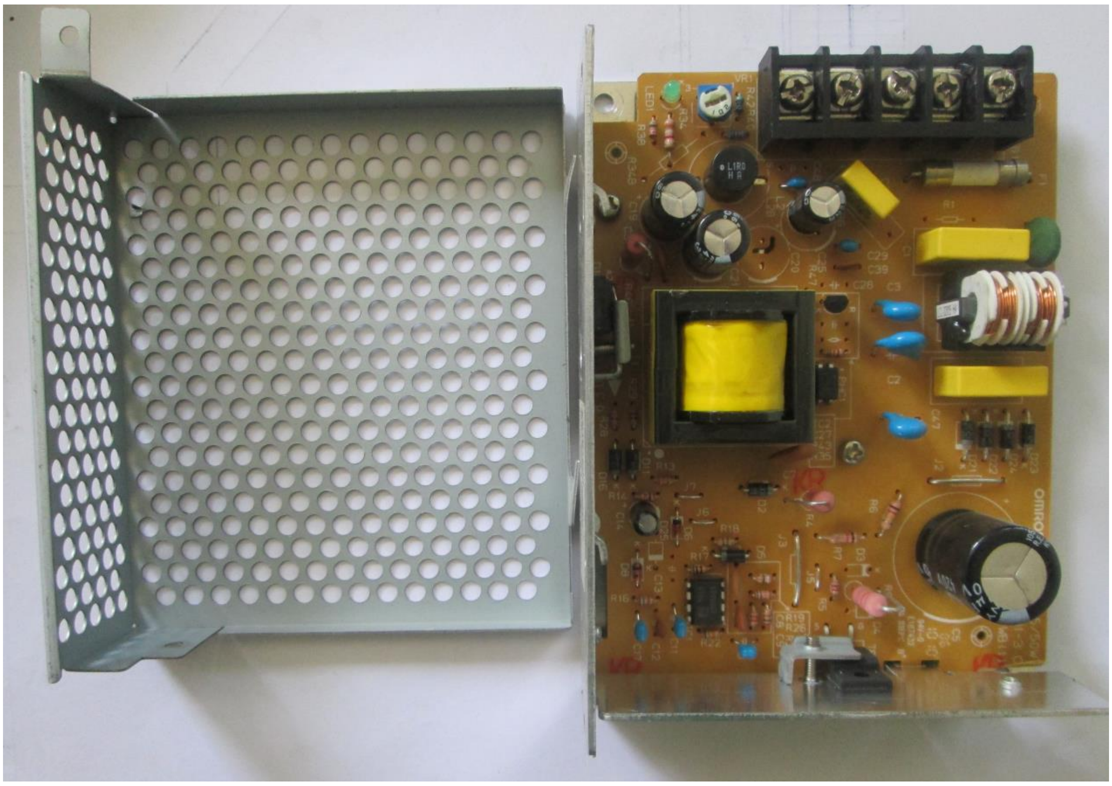


Figure 1.37: Power supply internal circuitry.

I.5: Circuit Breaker

I.5.1: Introduction

The increasing demand for high quality and efficiency in production is leading to the construction of increasingly complex systems. At the same time, the requirements for safety and availability are increasing because the failure of a machine or larger system parts can result in significant costs. A well-planned safety concept for the individual circuits and terminal devices of the entire system makes a significant contribution toward operational reliability. This also includes the selection of a sufficiently strong power supply and suitable protective devices that safely protect against short circuit and overload currents. It is advantageous to provide fuse protection for each piece of equipment. Then, only those circuits affected by overload shut off.

I.5.2: Overload and short-circuit currents

Overload currents and short-circuit currents are usually unexpected. They cause malfunctions and interruptions to the ongoing operation of a system. Production downtimes and repair costs are often the unpleasant consequences. Effects of this type can be minimized by the separate protection of individual devices or with appropriately coordinated device groups. In this way, terminal devices are optimally protected against damage or destruction. System areas not in the affected circuit can continue to operate without interruption, whenever the overall process allows. This ensures high system availability. The different nominal currents of the various loads illustrate the usefulness of separate protection for each individual circuit. Suitable device circuit breakers are available for every nominal current.

- **Overload currents**

Overload currents occur if terminal devices unexpectedly require a higher current than the expected rated current. Such situations may arise, for example, due to a blocked drive. Temporary starting currents from machines are also considered to be overload currents. The occurrence of these currents can essentially be calculated, but can nonetheless vary depending upon the machine load at the moment it starts. When selecting suitable fuses or circuit breakers for such circuits, these conditions should be taken into account. A safe shutdown should be carried out in the seconds to lower minute range.

- **Short-circuit currents**

Damage to the insulation between conductors carrying operating voltage can cause short circuits. Typical protective devices for shutting down short-circuit currents include fuses or miniature circuit breakers with various tripping mechanisms. Short-circuit currents should be shut down safely and reliably in the millisecond range.

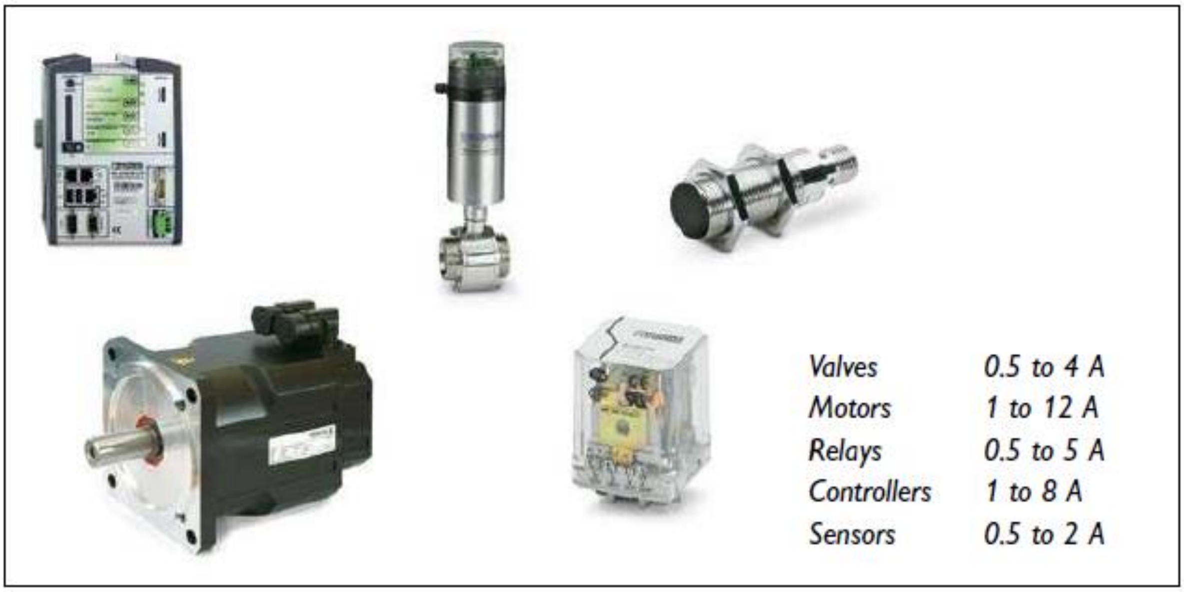


Figure 1.38: Typical nominal currents of electrical loads.

I.5.3: The right protection for a circuit

Selecting the right protective devices for protecting circuits and loads ensures the safe, optimized operation of electrical systems, even in the event of a fault. When talking about circuit breakers, it is important to note the difference between power circuit breakers and device circuit breakers. Power circuit breakers are used in the field of power distribution. They mainly protect power cables in buildings or systems that supply terminal devices, building floors or building complexes with current. However, it is not the task of the circuit breaker to protect loads and terminal devices. It is only in the event of a short circuit in a terminal device that they switch off to protect the power supply line against an overload. They have a high switching capacity of 6 kA or more. As the last protection level for terminal devices, thermo magnetic and electronic circuit breakers offer the most effective short circuit and overload protection. Securing the individual loads or small function groups when a device is disconnected prevents the simultaneous shutdown of unaffected system parts in event of a fault. These areas can then continue working without interruption to the extent that the overall process allows. If a circuit is reinstalled, you must ensure that appropriate protection for the provided terminal device is available. During installation, cable lengths and conductor cross-sections must also be taken into account. The cables must be designed for the expected operating current, but also so that they can deal with any potential overload and short circuit currents. Within the scope of the graded protection of system areas, the selectivity between the individual fuses and protective devices must be maintained. This also ensures higher system availability as only the faulty circuit is switched off. Device circuit breakers should be easily accessible when installed in control cabinets, so that they can be switched on again quickly, easily and without problems after tripping. Moreover, the ambient conditions of the installation should be taken into account.

For example, a control cabinet should not be equipped with too many components, as this can cause an overload in the power supply unit. Furthermore, a sufficient air flow and cooling process should be ensured to prevent accidental activation due to overheating.

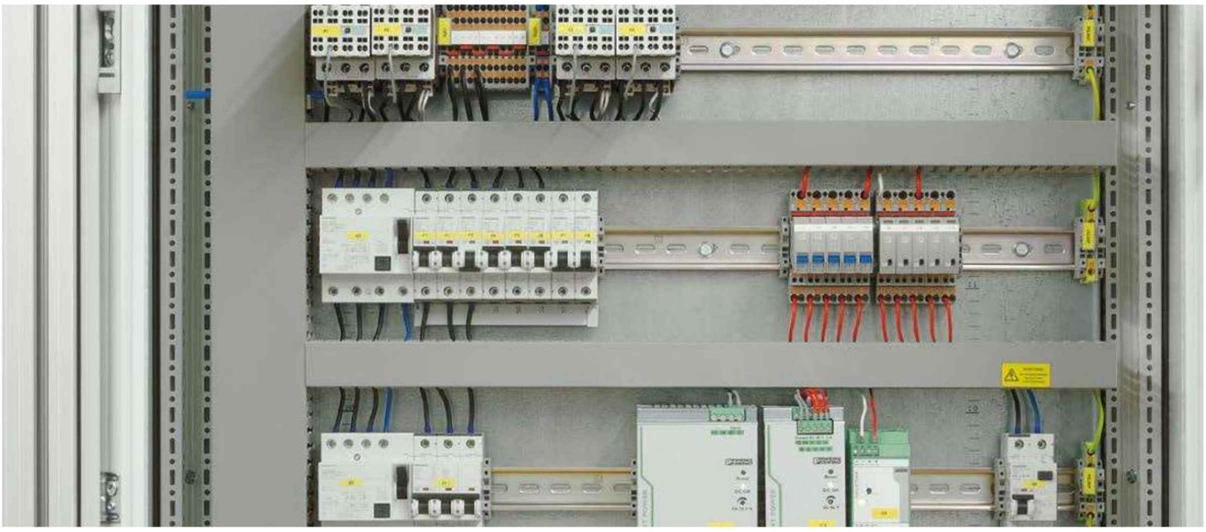


Figure 1.39: Professional installation for problem-free operation and easy maintenance

I.5.4: Definition and components of the circuit breaker

Circuit Breakers are reusable overcurrent protection devices. After tripping to break the circuit, the breaker can be reset to protect the circuit again. There are two accepted definitions for circuit breakers. The National Electrical Manufacturers Association (NEMA) defines a circuit breaker as a device designed to open and close a circuit, by non-automatic means, and to open the circuit automatically on a predetermined overcurrent without injury to itself when properly applied within its rating. The American National Standards Institute (ANSI) states that a circuit breaker is a mechanical switching device capable of making, carrying and breaking currents under normal circuit conditions. Also, it is capable of making and carrying a current for a specified time, and breaking currents under specified abnormal circuit conditions such as those of a short circuit. All circuit breakers have the following common design and functional characteristics:

- **Circuit Breaker Frame:**

The circuit breakers frame provides a method by which all the required components can be mounted and kept in place, ensuring the proper operation of the circuit breaker. The circuit breaker frame provides the rigidity and strength required to successfully deal with the interruption process and achieve the desired Interrupting Ratings. The frame's mechanical strength must be sufficient to withstand the forces created by the square of the current (I^2), which could be quite large and potentially destructive. The frame provides for insulation and isolation of the current path, offering personnel protection near the equipment during operation.

The frame also plays a critical role in the circuit breakers ability to comply with standards. There are two types of frames:

Metal Frame: Metal Frame circuit breakers are assembled from precise metal pieces that are bolted and welded together to form the frame. Older low voltage power circuit breakers and current medium voltage power circuit breakers are of the metal frame design. Historically, all power circuit breakers, both above and below 600 volts, have been referred to as metal frame circuit breakers. The metal frame design is still being used for higher voltages.

Molded Insulating Material: Molded insulated material frames are made from a strong insulating material, such as glass-polyester or thermoset composite resins. Sizes vary according to the Ampere Rating size of the circuit breaker. Molded insulated material frames are primarily associated with low voltage molded case circuit breakers and insulated case circuit breakers. Because of advances in materials and technology, we are now seeing molded insulated case power circuit breakers at 600 volts and higher**.**

Figure 1.40: Metal frame circuit breaker.

Figure 1.41: Molded Insulating Material frame

- **Contacts and Operating Mechanism**

Contacts in a circuit breaker provide a method for connecting the circuit with the system. They also provide a method for isolating a part of a circuit from the rest of the system. A contact set contains a fixed and movable contact. As a circuit breaker opens or closes, the fixed contact maintains its position while the movable contact moves to close (make) or open (break) the circuit. When all is said and done, contacts perform a simple function; they open and close. Circuit breakers require some type of operating mechanism to open and close the contacts. This operating mechanism can be mechanical or a combination of mechanical and power. Depending upon the type of circuit breaker being considered, the operating mechanism could be called upon to:

1- Open and close the contacts manually.
2- Open and close the contacts on demand.
3- Open the contacts automatically.

Circuit breakers by virtue of their size and/or some standards requirements need additional assistance to set the mechanism in motion to open or close the contacts. The additional assistance takes the form of springs. Springs play a big role in the precise functioning of circuit breaker mechanisms. Springs are stretched or compressed to provide the energy necessary to assist with the proper opening or closing of the contacts. There are two types of spring-assisted mechanisms:

- Over Toggle Mechanism: A manual handle on the circuit breaker is operated to set the mechanism in motion. The handle is moved, whether opening or closing the circuit breaker, until a point is reached where the handle goes over-toggle (past the point of no return), and the spring-assisted mechanism automatically opens or closes the circuit breaker. This toggle mechanism is called the Quick-Make, Quick-Break type, which means that the speed with which the contacts open or close is independent of how fast the handle is moved. A motor operator can be used to operate the handle automatically in lieu of manual operation. The design is such that the circuit breaker would trip open when required, even if the manual handle was held in the ON (closed) position.
- Two Step Stored Energy Mechanism: The two-step stored energy mechanism is used when a lot of energy is required to close the circuit breaker and when it needs to close rapidly. The two-step stored energy process is designed to charge the closing spring and release energy to close the breaker. It uses separate opening and closing springs. This is important because it permits the closing spring to be changed independently of the opening process. This allows for an open-close-open duty cycle. The motor can be operated remotely, allowing maximum safety for the operator.

The major advantages of the two-step stored energy mechanism are rapid reclosing and safety.
Rapid reclosing is achieved by storing charged energy in a separate closing spring.
Safety is achieved by providing remote charging of the spring.

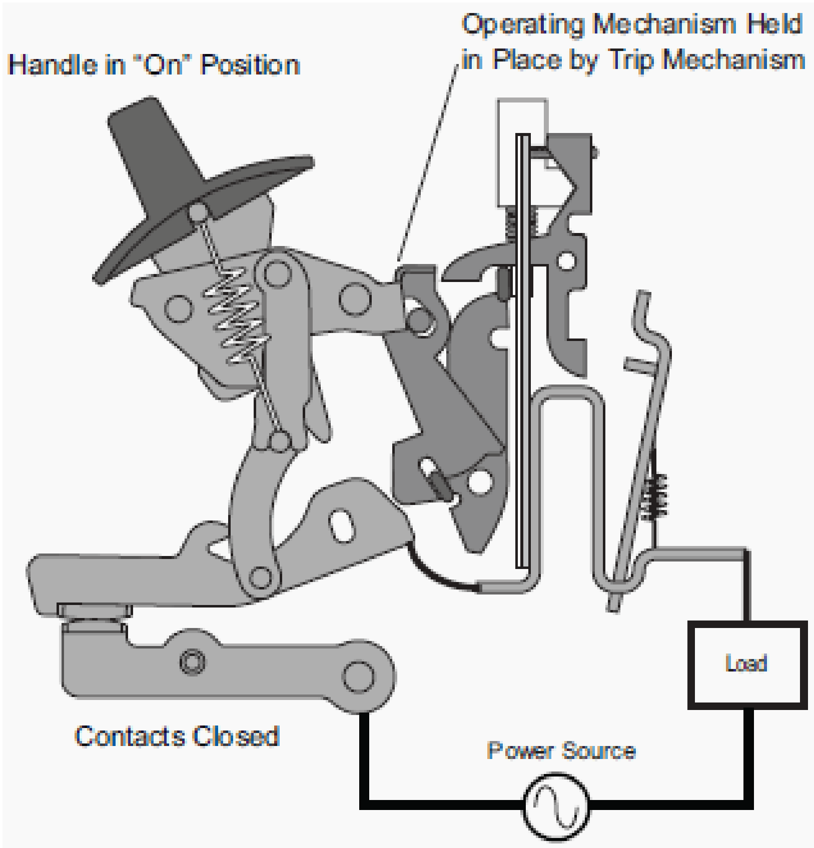


Figure 1.42: Circuit breaker internal structure

- **Trip Unit**

For a circuit breaker to be effective, it needs to have some intelligence to enable it to perform automatically or respond to a command. Without this capability, a circuit breaker would just be a fancy switch. A trip unit is the circuit breakers intelligence. Its function is to trip the operating mechanism (open the circuit) in the event of these overcurrent conditions:

1. Thermal Overload
2. Short Circuit
3. Ground Fault

There are two types of Trip Units:

- Electromechanical: This type of trip unit is generally used in low voltage circuit breakers. It is integrally mounted into the circuit breaker and is temperature sensitive. Thermal magnetic trip units act to protect the conductor (wire), safeguarding equipment under high ambient conditions and permitting higher

safe loading under low ambient conditions. This trip unit utilizes bimetals and electromagnets to provide overload and short circuit protection, which is referred to as thermal magnetic.
The thermal trip portion is used for overload protection. Its action is achieved using a bimetal heated by the load current. On a sustained overload, the bimetal will deflect, causing the operating mechanism to trip. The magnetic trip portion is used for short circuit (instantaneous) protection. Its action is achieved with an electromagnet whose winding is in series with the load current. When a short circuit occurs, the current passing through the conductor causes the electromagnet's magnetic field to rapidly increase, attracting the armature and causing the circuit breaker to trip.

- Electronic: In general, electronic trip units are composed of three components, which are internal to the trip unit. These components include the current transformer, circuit board and flux transfer shunt trip. The current transformer is used in each current phase to monitor and reduce the current to the proper input level. The circuit board is the brains of the system. It interprets input current and makes a decision based on predetermined parameters. A decision to trip sends an output to the flux-transfer shunt trip. The flux-transfer shunt trip is the component that trips the circuit breaker.

- **Arc Extinguishers**

An arc flash from a circuit breaker an Arc Extinguisher is the component of the circuit breaker that extinguishes an arc when the contacts are opened. An arc is a discharge of electric current crossing a gap between two contacts. Circuit breakers must be designed to control them because arcs cannot be prevented. There are four techniques to extinguish an arc and there are several arc control methods. Arcs are formed when the contacts of a circuit breaker are opened under a load. Arcs can be very destructive and vary greatly in size and intensity. The size of the arc depends on the amount of current present when the contacts are pulled apart. The heat associated with an arc creates an ionized gas environment. The more ionization, the better the conditions are for an arc to be maintained and grow. The bigger the arc, the more heat creates an ionized gas environment. Arcing is a condition that must be dealt with quickly and effectively by a circuit breaker. The important thing to remember here is that the ability of the circuit breaker to control the arc is the key to its short circuit interrupting capability. This is a critical factor for selecting circuit breakers. A short circuit is the most devastating overcurrent condition. [9][10]

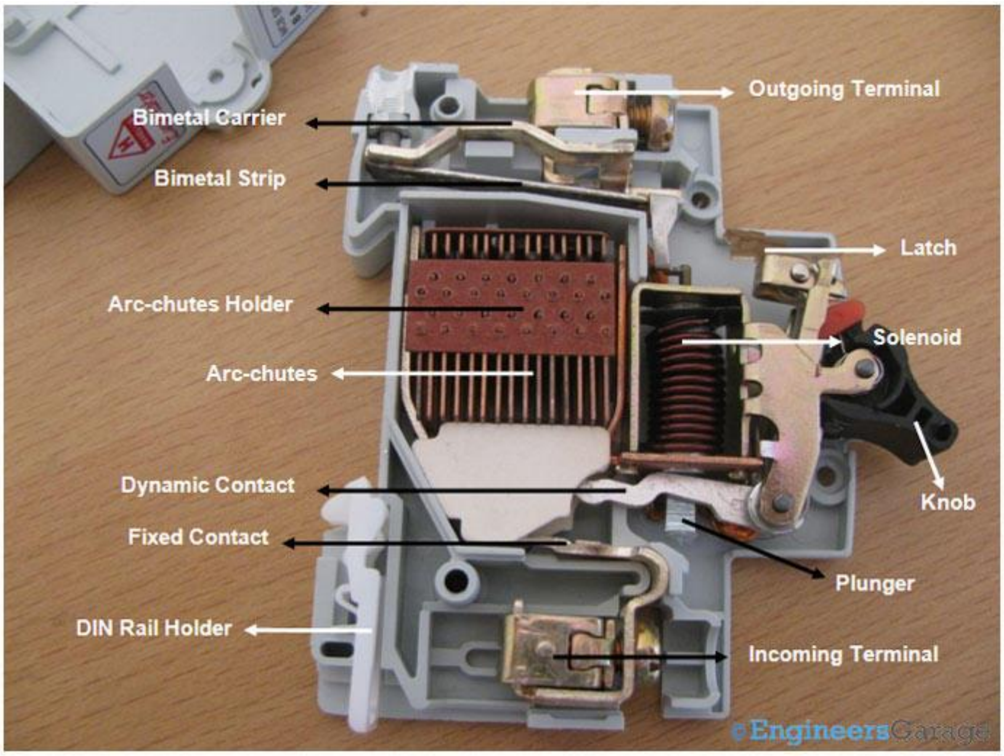


Figure 1.43: Circuit Breaker circuitry

I.5.5: Circuit Breaker used

We have used BMS circuit breaker DZ6000 C10 (tripping current of 10 amps).

Figure 1.44: BMS DZ6000 C10 circuit breaker.

I.6: Fuses and Fuse Carriers

I.6.1: Definition and function

A fuse is a device that protects a circuit from an over current condition only. It has a fusible link directly heated and destroyed by the current passing through it, it contains a current-carrying element sized so that the heat generated by the flow of normal current through it does not cause it to melt the element; however, when an over current or short-circuit current flows through the fuse, the fusible link will melt and open the circuit.
The fuse is a device that protects a circuit by fusing opens its current-responsive element when an over-current passes through it. An over-current is either due to an overload or a short circuit condition. The Underwriter Laboratories (UL) classifies fuses by letters e.g. class CC, T, K, G, J, L, R, and so forth. The class letter may designate interrupting rating, physical dimensions, and degree of current limitation. As per NEC and ANSI/IEEE standard 242 [2]
– A current limiting fuse is a fuse that will interrupt all available currents above its threshold current and below its maximum interrupting rating, limit the clearing time at rated voltage to an interval equal to or less than the first major or symmetrical loop duration, and limit peak let-through current to a value less than the peak that would be possible with the fuse replaced by a solid conductor of the same impedance.

I.6.2: Fuse Construction

The typical fuse consists of an element which is surrounded by filler and enclosed by the fuse body. The element is welded or soldered to the fuse contacts (blades or ferrules). The element is a calibrated conductor. Its configuration, mass and the materials employed are selected to achieve the desired electrical and thermal characteristics.
The element provides the current path through the fuse. It generates heat at a rate dependent on its resistance and the load current. The heat generated by the element is absorbed by the filler and passed through the fuse body to the surrounding air. The filler material, such as quartz sand, provides effective heat transfer and allows for the small element cross-section typical in modern fuses. The effective heat transfer allows the fuse to carry harmless overloads .The small element cross section melts quickly under short-circuit conditions. The filler also aids fuse performance by absorbing arc energy when the fuse clears an overload or short circuit. When a sustained overload occurs, the element will generate heat at a faster rate than the heat can be passed to the filler. If the overload persists, the element will reach its melting point and open. Increasing the applied current will heat the element faster and cause the fuse to open sooner. Thus, fuses have an inverse time current characteristic: that is, the greater the over current, the less time required for the fuse to open the circuit. This characteristic is desirable because it parallels the characteristics of conductors, motors, transformers, and other electrical apparatus. These components can carry low-level overloads for relatively long periods without damage. However, under high-current conditions, damage can occur quickly. Because of its inverse time current characteristic, a properly applied fuse can provide effective protection over a broad current range, from low-level overloads to high-level short circuits.

Figure 1.45: Industrial fuse “LEGRAND”

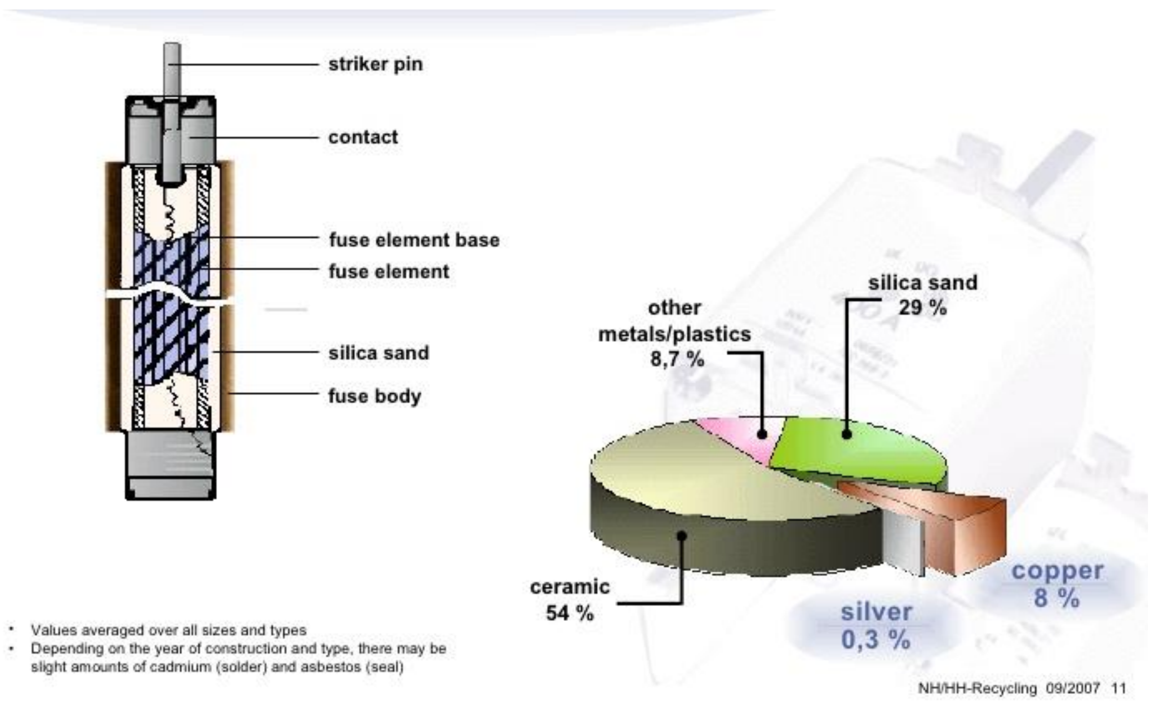


Figure 1.45: Fuse’s internal structure

I.6.3: Types of fuses

A fuse unit essentially consists of a metal fuse element or link, a set of contacts between which it is fixed and a body to support and isolate them. Many types of fuses also have some means for extinguishing the arc which appears when the fuse element melts. In general, there are two categories of fuses:

1- Low voltage fuses.
2- High voltage fuses.

Usually isolating switches are provided in series with fuses where it is necessary to permit fuses to be replaced or rewired with safety. In absence of such isolation means, the fuses must be so shielded as to protect the user against accidental contact with the live metal when the fuse is being inserted or removed.

1- Low Voltage Fuses:

Low voltage fuses are very common in electrical systems and they come in diverse styles, shapes and sizes. Low voltage fuses are defined as fuses with a voltage rating less than or equal to 1500 V. Low voltage fuses can be further divided into two classes namely

- Semi-enclosed or rewireable fuse type.
- Totally enclosed or Cartridge type.

- **Rewirable fuse :**
  The most commonly used fuse in house wiring and small current circuit is the semi-enclosed or rewirable fuse (also sometime known as KIT-KAT type fuse). It consist of a porcelain base carrying the fixed contacts to which the incoming and outgoing live or phase wires are connected and a porcelain fuse carrier holding the fuse element, consisting of one or more strands of fuse wire, stretched between its terminals.
  The fuse carrier is a separate part and can be taken out or inserted in the base without risk, even without opening the main switch. If fuse holder or carrier gets damaged during use, it may be replaced without replacing the complete unit.
  The fuse wire may be of lead, tinned copper, aluminum or an alloy of tin lead.
  The actual fusing current will be about twice the rated current. When two or more fuse wire are used, the wires should be kept. The specification for rewireable fuses are covered by IS: 2086-1963. Standard ratings are 6, 16, 32, 63, and 100A.
  A fuse wire of any rating not exceeding the rating of the fuse may be used in it that is a 80 A fuse wire can be used in a 100 A fuse, but not in the 63 A fuse. On occurrence of a fault, the fuse element blows off and the circuit is interrupted. The fuse carrier is pulled out, the blown out fuse element is replaced by new one and the supply can is resorted by re-inserting the fuse carrier in the base. Though such fuses have the advantage of easy removal or replacement without any danger and negligible replacement cost but suffers from following disadvantages:
  1. Unreliable Operations.

2. Lack of Discrimination.
3. Small time lag.
4. Low rupturing capacity.
5. No current limiting feature.
6. Slow speed of operations.

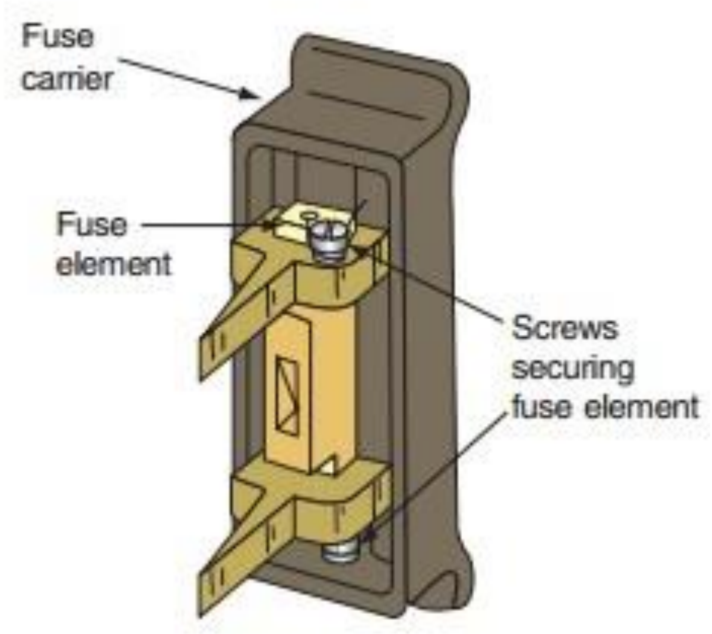


Figure 1.46: Rewirable fuse parts.

Figure 1.47: Rewirable fuse.

- **Totally Enclosed Or Cartridges Type Fuse:**

The fuse element is enclosed in a totally enclosed container and is provided with metal contacts on both sides. These fuses are further classified as

- D-type.
- Link type: (Knife Blade or Bolted)

- D- Type Cartridges Fuses

It is a non-interchangeable fuse comprising s fuse base, adapter ring, cartridge and a fuse cap. The cartridge is pushed in the fuse cap and the cap is screwed on the fuse base.
On complete screwing the cartridge tip touches the conductor and circuit between the two terminals is completed through the fuse link. The standard ratings are 6, 16, 32, and 63 amperes.
The breaking or rupturing capacity is of the order of 4 kA for 2 and 4 ampere fuses the 16k A for 63 A fuses. D-type cartridge fuse have none of the drawbacks of the rewirable fuses. Their operation is reliable. Coordination and discrimination to a reasonable extent and achieved with them.

Figure 1.48: D-type cartridge fuse “Bussmann”

- Link type Cartridge or High Rupturing Capacity (HRC)

Where large numbers of concentrations of powers are concerned, as in the modern distribution system, it is essential that fuses should have a definite known breaking capacity and also this breaking capacity should have a high value. High rupturing capacity cartridge fuse, commonly called HRC cartridge fuses, have been designed and developed after intensive research by manufacturing and supply engineers.

The usual fusing factor for the link fuses is 1.45. The fuses for special applications may have as low as a fusing factor as 1.2. The specification for medium voltage HRC link fuses are covered under IS: 2202-1962. [11]

Figure 1.49: Link type Cartridge Fuse (Knife Blade).

Figure 1.50: Link type Cartridge Fuse (Bolted).

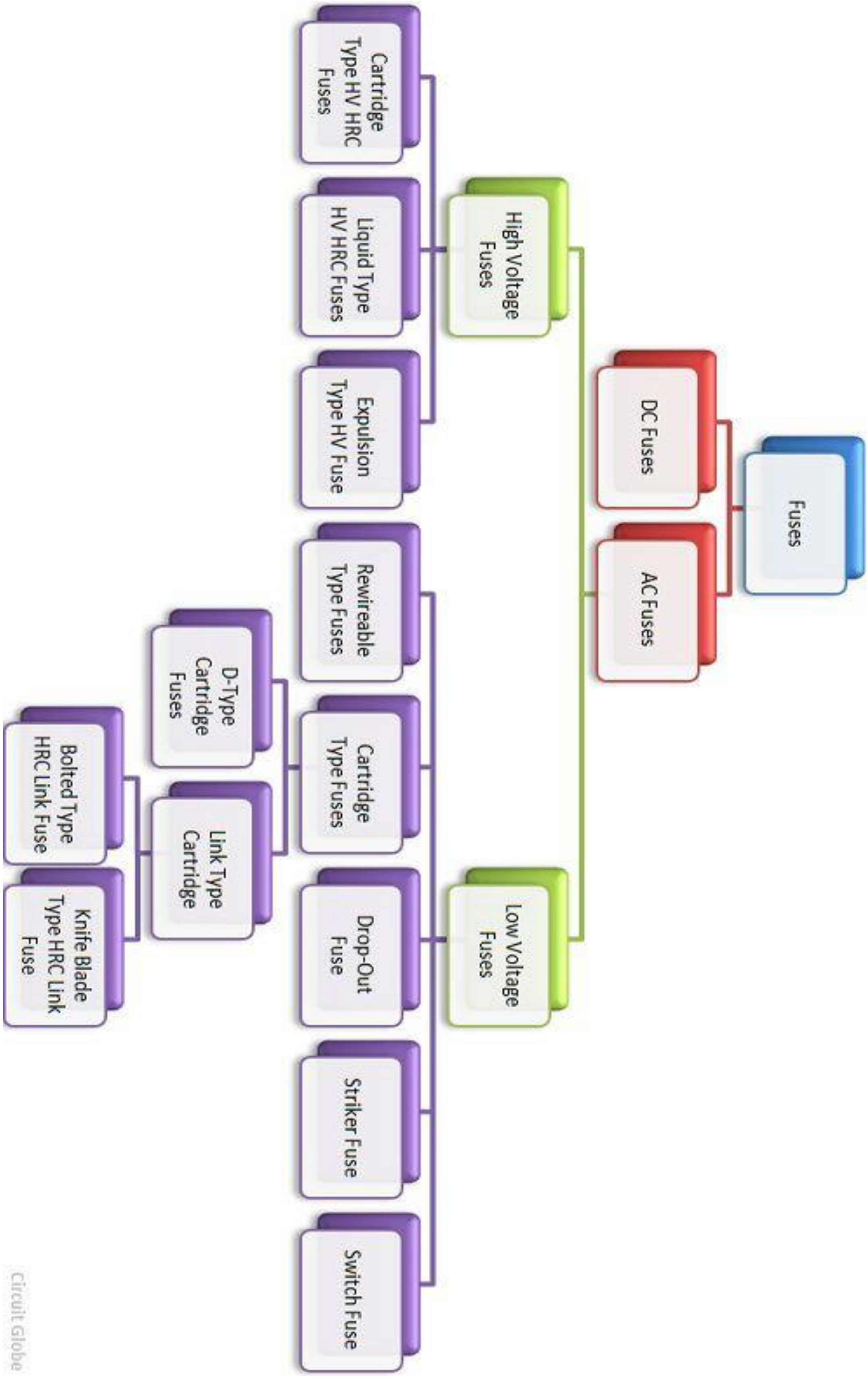


Figure 1.51: Types of fuses.

I.6.4: Fuse Carrier

Fuses carriers are elements that contain and hold fuses; they are used in control cabinets and industrial wiring. The allow ease of removal from the fuse bases allowing significantly improved contact pressure between fuse carrier and fuse base contacts, with a corresponding enhanced electrical performance level. they are used mostly to mount the fuse with the Din rail.

Figure1.52: Fuse carriers with correspondent fuses.

Figure 1.53: Fuse carrier mounted on Din rail

I.7: Terminal Blocks

I.7.1: Definition and function

A terminal block is a screw-type electrical connector where the wires are clamped down to the metal part by a screw. It is a connector which allows more than one circuit to connect to another circuit. It often contains two long aluminum or copper strips that are designed to connect different components. These strips create a bus bar for power distribution that is sent to the connected components. A barrier strip is composed of several screw terminals.

Figure 1.54: Terminal block.

I.7.2: Applications

Terminal blocks are used in control cabinet wiring to ensure secure contact between the PLC and the sensors or actuators, they holds the wires in place in case of sudden shocks.
This feature is achieved by an indirect wiring which means that any wire going out or into the PLC must go through a terminal block which is fixed on the Din rail.

I.7.3: Types

1- Spring type: wire fixation achieved using a spring
2- Screw type :wiring fixation using a screw

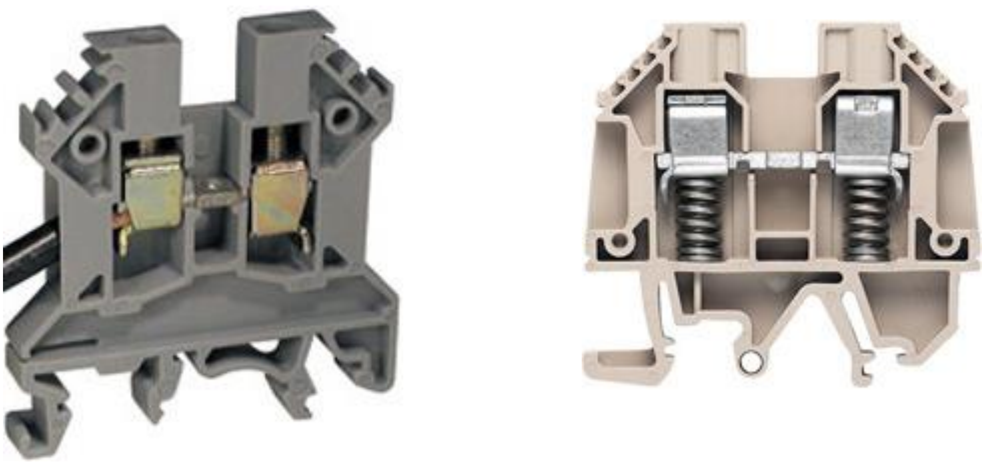


Figure 1.55: types of terminal blocks.

I.7.3: Terminal blocks used in the control cabinet

In our control cabinet we used **Legrand Viking 3 Terminal Blocks** (371 61) with 1 connection (1 entry/1 outlet) and a cross section of 2.5mm, these terminal blocks are reliable and easy to install and provide high contact pressure and excellent mechanical strength.

Accessory: End stops with screw fixing

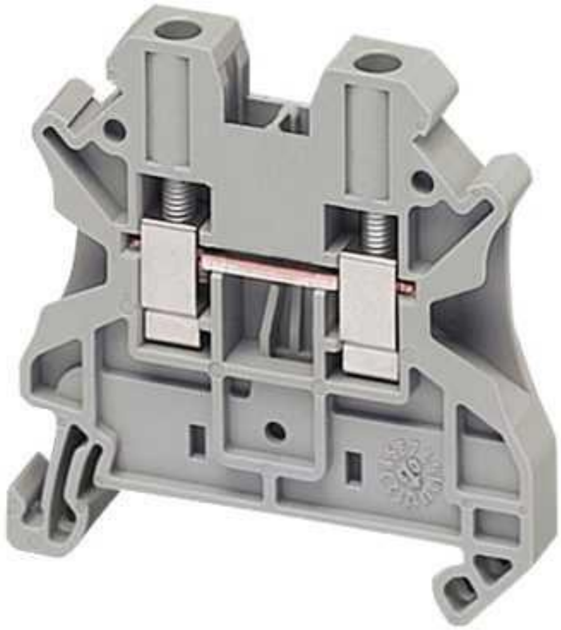


Figure 1.56: Legrand Viking 3 terminal block.

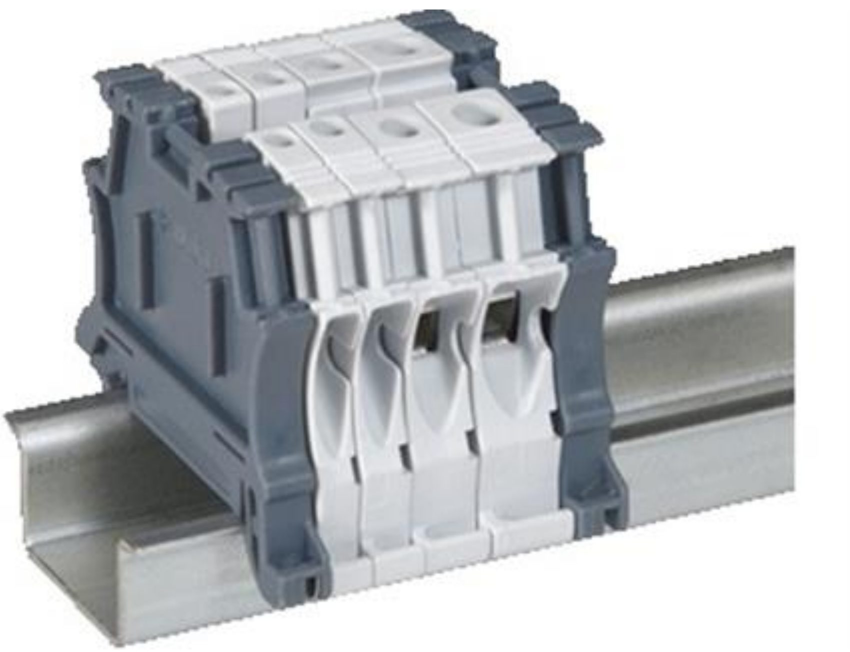


Figure 1.57: terminal blocks with end stops.

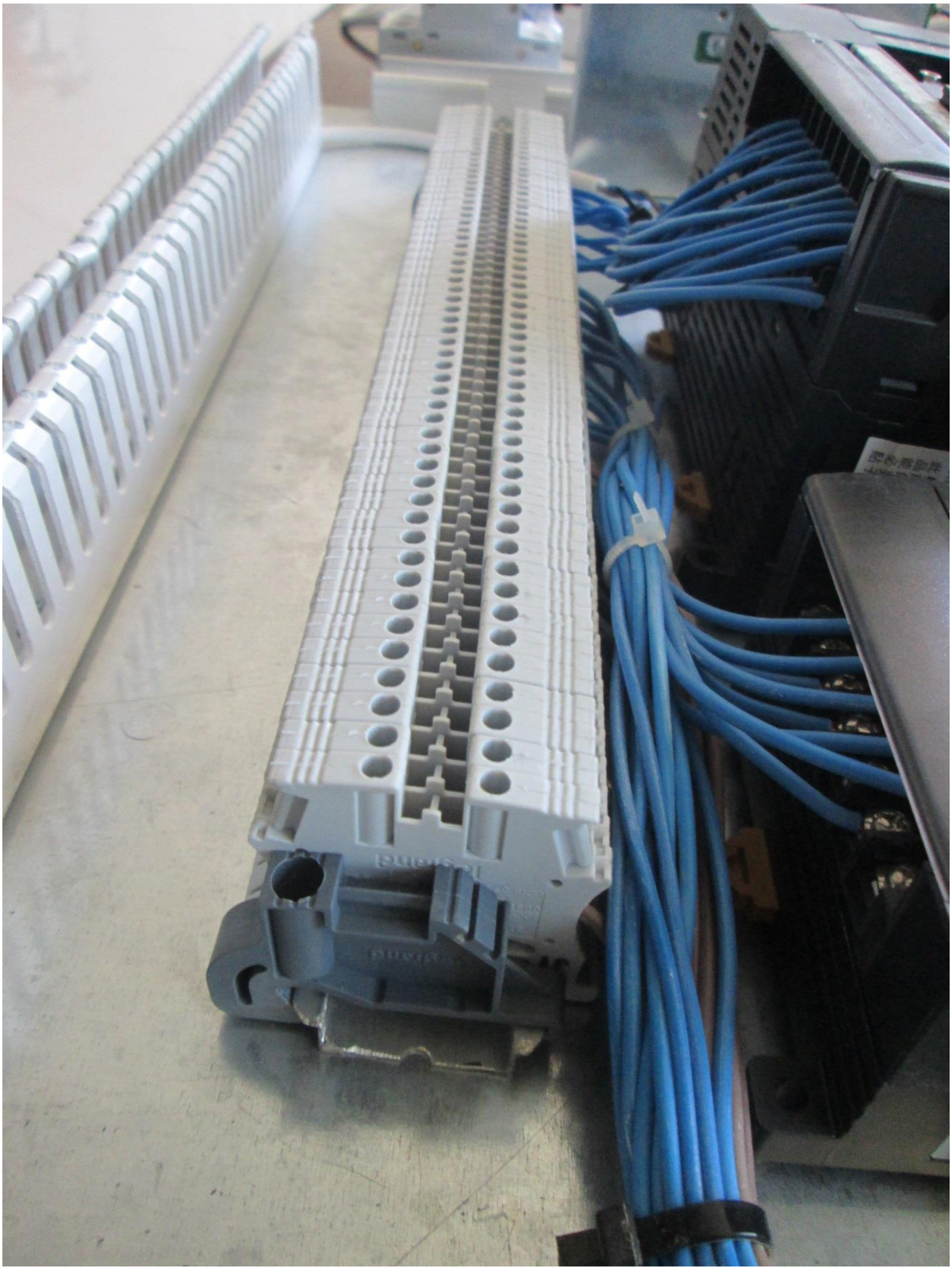


Figure 1.58: Legrand Viking 3 terminal blocks with end-stops

I.8: Din Rails

I.8.1: Definition

A DIN rail is a metal rail of a standard type widely used for mounting circuit breakers and industrial control equipment inside equipment racks. These products are typically made from cold rolled carbon steel sheet with a zinc-plated or chromated bright surface finish. The term derives from the original specifications published by Deutsches Institut für Normung (DIN) in Germany, which have since been adopted as European (EN) and international (IEC) standards. DIN Rails provide a convenient means for mounting electric and electronic devices in a compact and neat manner.
The use of DIN Rail mounting systems saves installation time since all devices just snap onto the metal rails. A complete system can be quickly put together in an organized configuration that provides high density, flexibility, safety and design time savings. Associated devices can be mounted adjacent to each other, thus reducing the length of interconnect wiring.
The DIN Rail concept is widely used in industrial control, instrumentation and automation applications. Today, even DIN Rail mountable micro-computers are available and being used. DIN rail mounted AC-DC power supplies provide a convenient means for powering DC operated devices including sensors, transmitters/receivers, analyzers, programmable controllers, motors, actuators, solenoids, relays, etc., to mention a few. Since these power supplies are convection cooled, no cooling fans are needed. Output voltages from these supplies range from 5V up to 56V with power ratings from 7.5W up to 480W. Many of these supplies can be connected in parallel for higher power applications.

Figure 1.59: Din rail

Figure 1.60: circuit breaker mounted on a DIN rail (front and rear view).

I.8.2: Types

There are three major types of DIN rail:

- Top hat section, type O, or type Ω, with hat-shaped cross section.
- C section.
- G section.

➢ Top hat rail EN 50022:

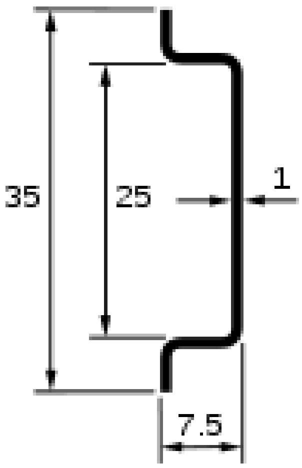


Figure 1.61: Top hat rail dimensions.

Figure 1.62: Top hat rail.

This 35-mm wide rail is widely used to mount circuit breakers. The EN 50022 standard specifies both a 7.5 mm (shown above) and a 15 mm deep version.

- C section type:

These rails are symmetrical within the tolerances given. There are four popular C section rails, C20, C30, C40 and C50. The number suffix corresponds to the overall vertical length of the rail.

Figure1.63: C type rail dimensions.

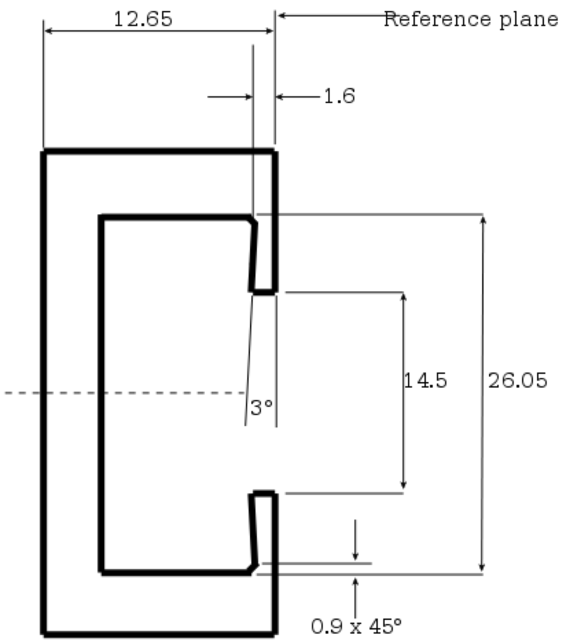


Figure 1.64: C type rail.

- G section type:

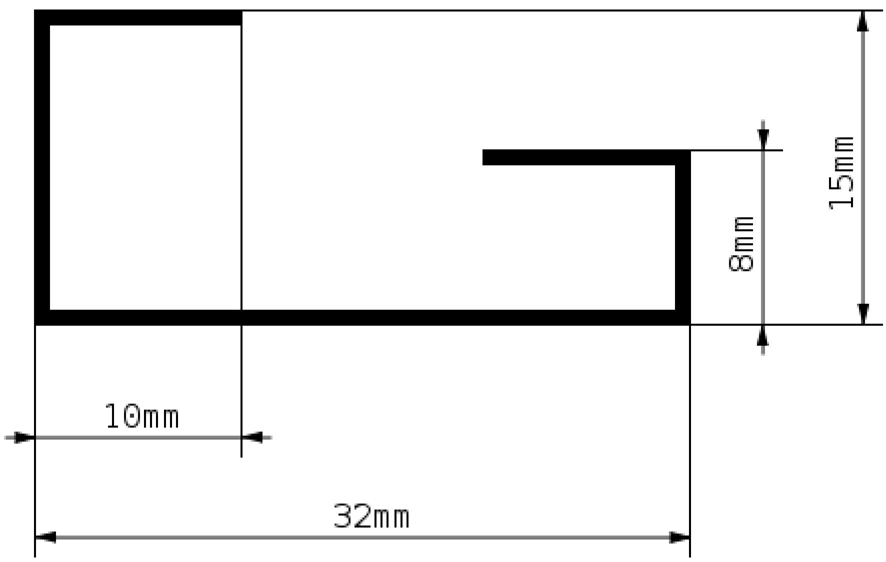


Figure 1.65: G type rail dimensions.

Figure 1.66: G section rail.

I.8.3: DIN rail used

In our project we used a C section DIN-rail due to its simplicity and availability in BMS factory.

I.9: Cable Raceways (open slot panel trunking)

I.9.1: Definition and uses

Cable raceways or open slot panel trunkings are channels to run cables through, that mounts on a wall, or a desk, or some other surface, concealing wires or cables. It's legitimately one of the most useful and versatile cable management tools for both home users and professionals, there are tons of different types of raceway, each suited for a unique application.

I.9.2: Cable raceways used

We have used BMS cable raceways (30 mm wide) with 6mm gaps and 6.5 mm fingers.

Figure 1.67: open slot panel trunkings with cables.

I.10: Pushbuttons and Switches

I.10.1: Definition

An electrical switch is any device used to interrupt the flow of electrons in a circuit. Switches are essentially binary devices: they are either completely on (“closed”) or completely off (“open”). The simplest type of switch is one where two electrical conductors are brought in contact with each other by the motion of an actuating mechanism. Other switches are more complex, containing electronic circuits able to turn on or off depending on some physical stimulus (such as light or magnetic field) sensed. In any case, the final output of any switch will be (at least) a pair of wire-connection terminals that will either be connected together by the switch’s internal contact mechanism (“closed”), or not connected together (“open”).

I.10.2: Pushbuttons

Push Button Switches consist of a simple electric switch mechanism which controls some aspect of a machine or a process. Buttons are typically made out of hard material such as plastic or metal. The surface is usually shaped to accommodate the human finger or hand, so the electronic switch can be easily depressed or pushed. Also, most Push Button Switches are also known as biased switches. A biased switch, can be also considered what we call a "momentary switch" where the user will push-for "on" or push-for "off" type. This is also known as a push-to-make (SPST Momentary) or push-to break (SPST Momentary) mechanism.

Switches with the "push-to-make" (normally-open or NO) mechanism are a type of push button electrical switch that operates by the switch making contact with the electronic system when the button is pressed and breaks the current process when the button is released. An example of this is a keyboard button.

A "push-to-break" (or normally-closed or NC) electronic switch, on the other hand, breaks contact when the button is pressed and makes contact when it is released.

I.10.3: Types of switches and pushbuttons used in control cabinets

- **On/OFF Pushbutton:** used for turning ON /off the machine or for RESET.

Figure 1.68: ON/OFF push button

- **LED pilot lights:** used as indicators of the machine status (running, breakdown, emergency stop).

Figure 1.69: LED pilot lights.

- **Selector switch:** 3 position selector switch for selecting between automatic, manual and cycle modes of operation.

Figure 1.70: 3 positions selector switch.

- **Emergency stop pushbutton (mushroom pushbutton):** used for immediately stopping the machine in case of an emergency.

Figure 1.71: E stop pushbutton.

- **Pushbuttons enclosures:** used to regroup all the previous pushbuttons in a single unit.

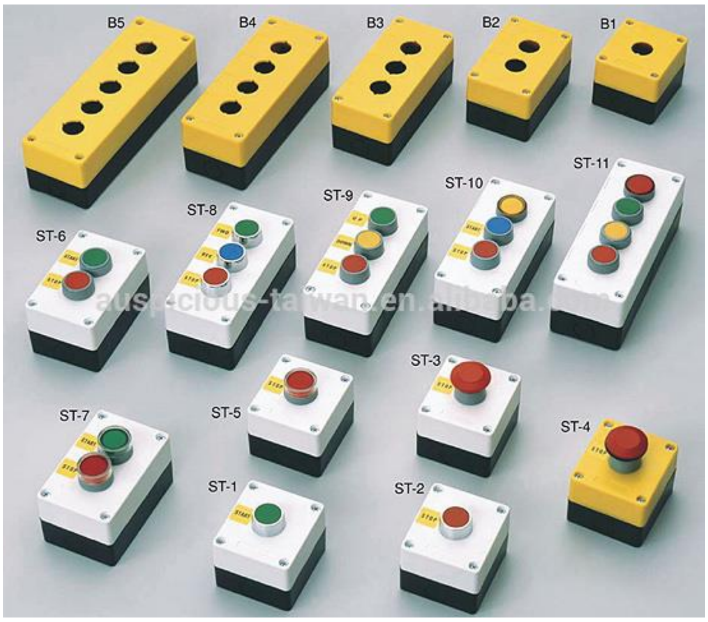


Figure 1.72: Pushbuttons enclosure

I.11: Steel enclosure

Steel enclosures are used to contain and protect all the control cabinet parts, and to prevent electrical shock to equipment users and protect the contents from the environment; the enclosure is the only part of the equipment which is seen by users.

Electrical enclosures are usually made from rigid plastics, metals, particularly stainless steel, carbon steel, and aluminum. Steel cabinets may be painted or galvanized.

Figure 1.73: Stainless steel enclosure.

Chapter II :

Control method

Chapter II: Control Method

II.1: Introduction

Most industrial processes require objects or substances to be moved from one location to another or a force to be applied to hold, shape or compress a product. Such activities are performed by Prime Movers; the workhorses of manufacturing industries. In any control system the use of actuators is essential to lift or cut objects, move components, or a finished product, they convert energy into a motion or force and can be powered by pressurized fluid or air, as well as electricity. The accomplishment of work requires the application of kinetic energy to a resisting object resulting in the object moving through a distance.
In many locations all prime movers are electrical. Rotary motions can be provided by simple motors, and linear motion can be obtained from rotary motion by devices such as screw jacks or rack and pinions. Electrical devices are not, however, the only means of providing prime movers. Enclosed fluids (both liquids and gases) can also be used to convey energy from one location to another and, consequently, to produce rotary or linear motion or apply a force. Fluid based systems using liquids as transmission media are called hydraulic systems (from the Greek words hydra for water and aulos for a pipe; descriptions which imply fluids are water although oils are more commonly used). Gas-based systems are called Pneumatic systems (from the Greek pneumn for wind or breath). The most common gas is simply compressed air although nitrogen is occasionally used.

II.2: Pneumatic, Hydraulic and Electrical control

- **Pneumatic systems**

Pneumatic actuators, for example: tied rod cylinders, rotary actuators, grippers, rodless actuators with magnetic linkage or rotary cylinders, rodless actuators with mechanical linkage, pneumatic artificial muscles, specialty actuators that combine rotary and linear motion (frequently used for clamping operations) and vacuum generators, all the actuators stated above use compressed air as driving force.
The biggest advantage of pneumatic actuator is its simplicity, meaning it's relatively easy to use and install. Their simplicity also results in a low price and small weight. In addition, they have durable components and require little maintenance. Although they are not as precise as electric actuators, they still produce accurate linear motion and high repeatability. Pneumatic actuators are commonly used in extreme temperatures and other hazardous environments. They are really safe to use and also operate without using hazardous materials. They also have no motor, thus they do not create magnetic interference, meaning they are able to meet explosion protection and machine safety requirements.

The disadvantages of pneumatic actuators include for example their low efficiency compared to other actuators. This is because of the pressure losses and airs compressibility. They must also constantly compress air at the operating pressure, even when the actuator isn't moving. The compressed air pneumatic actuators use must also be bought, because the air in the atmosphere can be contaminated. This raises the operating costs. If a pneumatic controller needs to be efficient, it has to be built for the specific purpose and include regulators and valves, once again increasing the costs and lowering the simplicity.

Pneumatic actuators are controlled with valves and different types of measuring devices, which monitor and control the pressure.

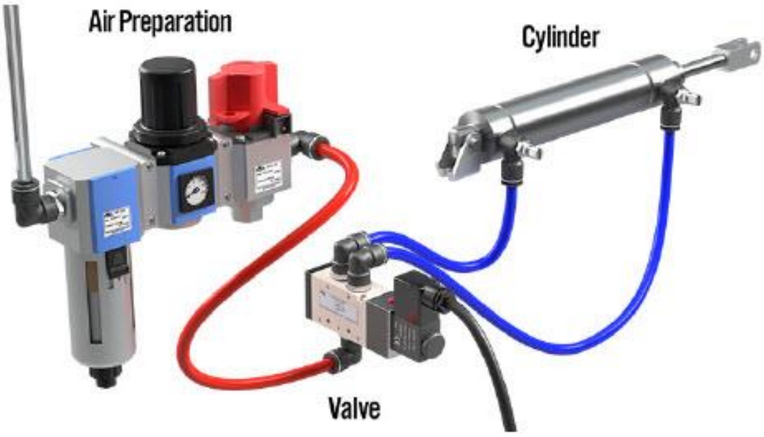


Figure 1C : Basic pneumatic system

Figure 2.1: Basic pneumatic system.

- **Hydraulic systems**

Examples of hydraulic actuators, for example: hydraulic cylinder, hydraulic motor
The most important advantage of a hydraulic actuator is the force it produces, which can be significantly higher than that of a pneumatic or electric one. They also have high stability and hydraulic motors can produce a higher horsepower-to-weight ratio than a pneumatic motor. Also, because of the incompressibility of fluids, they can hold a constant force and torque without the need to pump more fluid or pressure to the cylinder. The motors and pumps of a hydraulic actuator can also be placed from a considerable distance of each other with the minimal loss of power.

One disadvantage of hydraulic actuators is that they leak fluids, which leads to a loss in efficiency. Unlike with pneumatic actuators though, the leaks can damage the surrounding area and components and lead to environmental problems. Also, hydraulic actuators need many other components to operate (a fluid reservoir, motors, pumps, release valves, heat exchangers, noise-reduction equipment), meaning the systems are large and difficult to install.

Hydraulic actuator can be controlled by different types of valves, for example manual, electric, pressure relief, check and shuttle valves. The other control methods include pump control (RPM control, volume per rotation control in the pump), hydraulic transformers (rotary and linear transformer) and actuator control (variable displacement motor, multi-chamber cylinder).

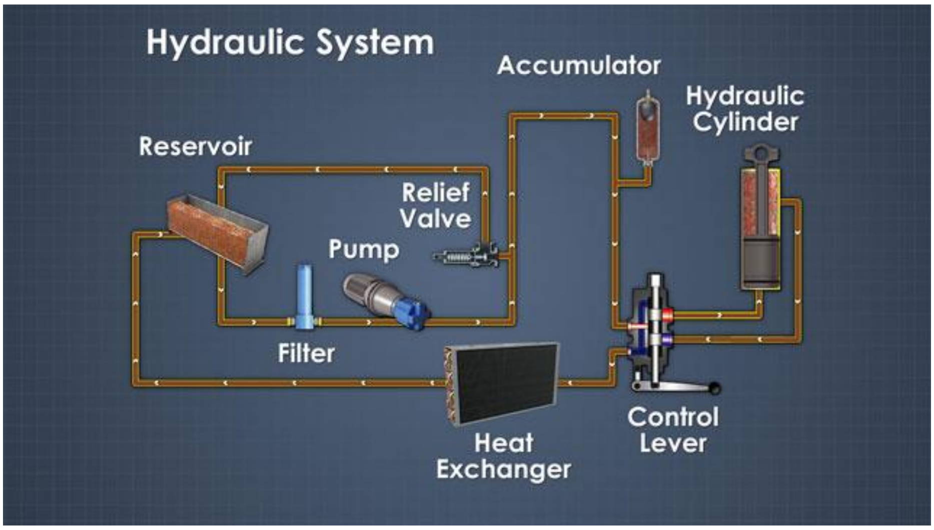


Figure 2.2: Hydraulic system.

- **Electrical systems**

Examples of electric actuators, for example: DC and AC motors, solenoids, voice coils, Active materials (piezoelectric, electrostrictive etc.) and microelectromechanical (MEMS) actuators. There are many advantages in using electric actuators. First, they have the best precision-control positioning of these three options. They can be modified for almost any purpose or force requirement and operate smoothly and with good repeatability. They also produce less noise than pneumatic and hydraulic actuators. They have no fluid leaks, which means they pose no danger to the environment. Also, they offer immediate feedback and can be reprogrammed easily should problems occur. In addition, their motion profiles can be fully controlled and encoders can be implemented for even greater control of for example velocity, position, torque, and applied force.

Electric actuators also have their disadvantages. For example, they are usually more expensive than hydraulic and pneumatic actuators. They can also overheat, which can damage the components. Also, unlike pneumatic actuators, they can’t operate in some hazardous environments. Electric actuators can also be quite large, which may result in installation problems. [12]

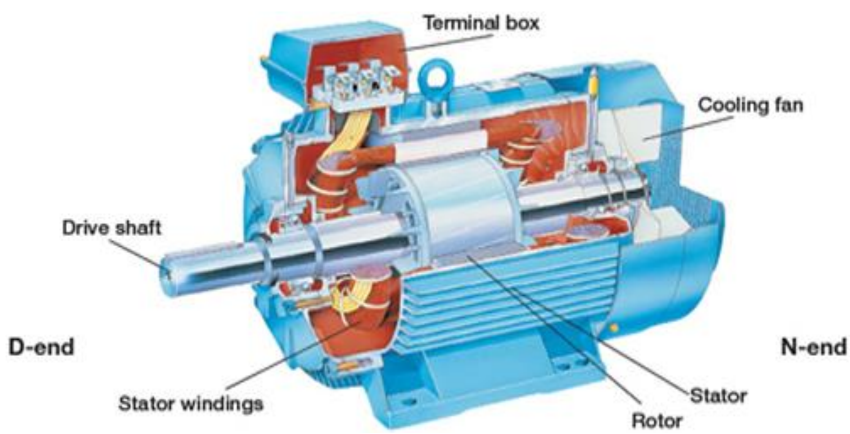


Figure 2.3: Electrical system (AC motor).

- **Comparison of Electrical, Hydraulic and Pneumatic Systems**

Comparison of electrical, hydraulic and pneumatic systems can be done in aspects like energy source, energy storage, energy cost, distribution system, linear actuators, rotary actuators and controllable force.

S.no	Aspect	Electrical	Hydraulic	Pneumatic
1	Energy source	Usually from outside supplier	Electric motor or diesel driven	Electric motor or diesel driven
2	Energy storage	Limited (batteries)	Limited (accumulator)	Good (reservoir)
3	Distribution system	Excellent, with minimal loss	Limited basically a local facility	Good. Can be treated as a plant wide service
4	Energy cost	Low cost	Moderate cost	High cost
5	Linear actuators	Short motion via solenoid. Otherwise via mechanical conversion	Cylinders. Very high force	Cylinders. Medium force
6	Rotary actuators	AC and DC motors. Good control on DC motors. AC motors cheap	Low speed. Good control. Can be stalled	Wide spread range. Accurate speed control difficult
7	Controllable force	Possible with solenoid & DC motors complicated by need for cooling	Controllable high force	Controllable medium force.
8	Problems	Dangers from electric shock	Leakage dangerous and unsightly. Fire hazard	Noisy

Comparison of Electrical, Hydraulic and Pneumatic Systems.

In our project we used pneumatic control due to its simplicity; in addition, our assembly machine consists of only linear motion and no rotational motion, and the pieces handled are light in weight and the course of motion in short.

In the next chapters I will explain in details the structure, properties and components that when come together they compose a well-engineered pneumatic control system.

Chapter III:

Pneumatic Control Systems

Chapter III: Pneumatic Control Systems

III.1: Introduction to world of pneumatics

Pneumatic actuators are still among the most widely used in automation equipment. As a rule, these actuators are direct-drive systems (A direct drive system or DDS is one that takes the power coming from a source without any reductions), pneumatic actuators have been used in devices when lightweight, small-size systems. These actuators are selected for automation tasks as a preferred medium because they are relatively inexpensive (this technology costs approximately 15 to 20% of an electrical system), simple to install and maintain, offer robust design and operation, are available in a wide range of standard sizes and design alternatives, and offer high cycle rates. In addition, pneumatics is cleaner and nonflammable, making it more desirable in certain environments. Furthermore, pneumatic devices are less sensitive to temperature changes and contamination.
Pneumatic actuators are ideally suited to fixed travel applications and the control of force, where precise control of speed is not a prime requirement. In this case, hard mechanical stops are usually positioned along the length of the actuator. Though this adds a certain amount of adaptability, the stops are not truly programmable. They will need to be moved manually should an alternate position be desired.

New technologies today integrate the power of air with electronic closed loop control. The combination of these technologies can provide much higher acceleration and deceleration capabilities than either one used alone. This position, velocity and force-control system technology is typically lower in cost compared with electrical motion systems. Such servo pneumatic systems retain the advantages of standard pneumatics and add the opportunity for closed-loop, controlled, programmable positioning to within fractions of a millimeter in systems in which positions can be approached rapidly and without overshoot, and provide stability under variable loads and conditions and adaptive control for optimized positioning. Generally, servo pneumatic actuators are similar to hydraulic servo actuators and use proportional or servo pneumatic valves, relying on the integration of electronic closed-loop controlled servo techniques.

The development of modern pneumatic actuation systems is to be seen as an evolution in mechatronic systems, when integrated with mechanical and electrical technologies, electronic control systems, and modern control algorithms.

III.2: Properties and mathematical model of Compressed Air

Pneumatic drives use compressed air to store and transmit power or signals. Its properties are therefore significant for the behavior of the drives and a good mathematical model is needed for reliable numerical analysis and simulation.
Clean, dry air is a mechanical mixture of approximately 78 % by volume nitrogen and 21 % oxygen. The remaining 1 % consists of minor quantities of some fourteen other gases.
There are several ways to model the relationship between gas mass, pressure, temperature and volume.

One way is to measure the relevant sets of parameters and use tables and interpolation. This gives the most accurate results but is time consuming; both when carried out with pen and paper or during a simulation. Another way is to use a gas law.

The simplest gas law is based on the assumptions that the molecules are perfectly elastic, are negligible in size compared with the length of their mean free path and exert no force on each other. This gas is called ideal gas and the relation between mass, pressure, temperature and volume is given by:

$$p.V = m.R.T$$

Where:
P: absolute pressure in Pa.
V: volume in m^3.
m: gas mass in kg.
R: gas constant in J/ (kg.K).
T: absolute temperature in K.

- **Definitions Related to Compressed Air**

Pressure is generally defined as "force per area".

$$p = \frac{F}{A}$$

Where:

P: pressure in Pa = N/m2,
F: force perpendicular to surface in N,
A: area in m2.

When analyzing pneumatic systems, the amount of air that is used per unit time is important. This quantity is called *flow rate* and can be given as mass flow rate "$\dot{m}$" or *volume flow rate* qv.

III.3: Structure of Pneumatic Actuating Systems

The pneumatic actuating servo systems used in automatic devices have two major parts: the power and control subsystems. The main part of the power subsystem is the motor, which may be of the rotating or linear type. Basically, this device converts pneumatic power into useful mechanical work or motion. The linear motion system widely uses the pneumatic cylinder, which has two major configurations: single or double action. For the single-action configuration, the cylinder can exert controllable forces in only one direction and uses a spring to return the piston to the un-energized position. A double-action actuator can be actively controlled in two directions. In the case of rotary actuation, the power unit is a set of vanes attached to a drive shaft and encased in a chamber. Within the chamber, the actuator rotates by differential pressure across the vanes and the action transmits through the drive shaft.

Most often, the pneumatic actuator has the direct-drive structure; that is, the output motor shaft or rod is the actuator output link. However, sometimes the transmission mechanisms are installed after the motor; in this case, the output shaft is the actuator output link (e.g., in the rotating actuator where the pneumatic cylinder is used as the motor).

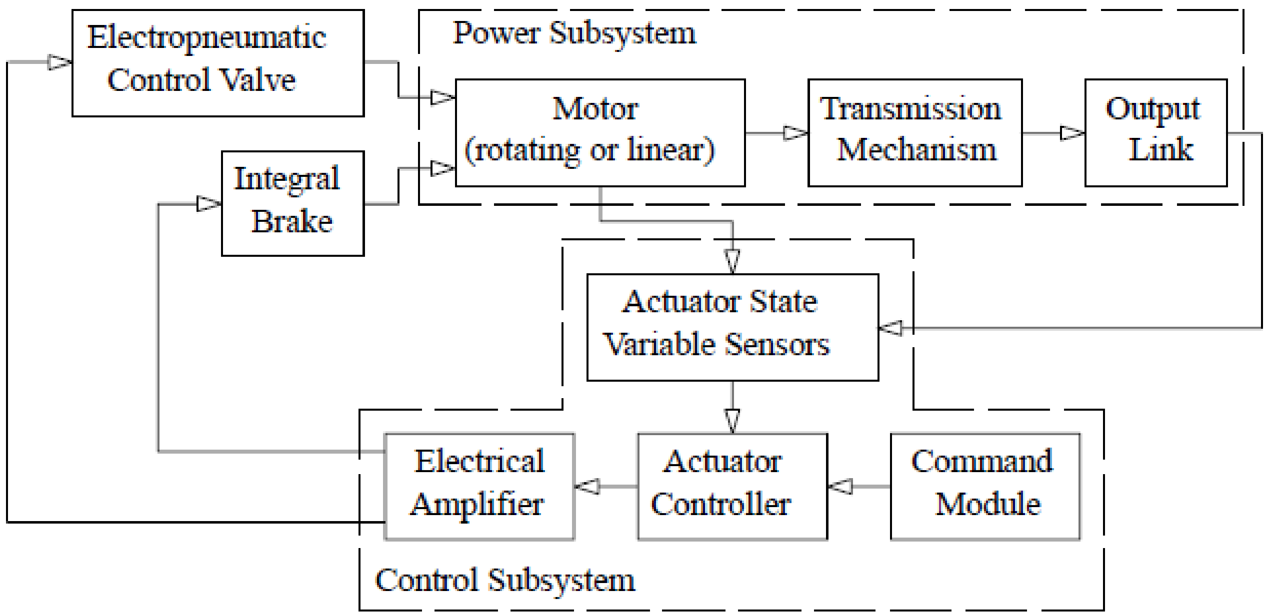


Figure 3.1: Block diagram of the pneumatic actuating system.

Actuator state variable sensors are the input elements of the control subsystems. In general, the displacement, velocity, acceleration, force, moment, and pressure can be measured in the pneumatic actuator. Different sensor designs can read incrementally or absolutely; they can contact a sensed object or operate without contact; and they span a broad range of performance and pricing levels. Linear-position sensors are widely used as feedback elements for motion control in pneumatic actuating systems; there are precision linear potentiometers, linear-variable-differential transformers (LVDTs), magnetostrictive sensors, and digital optical or magnetic encoders.

The important part of the control subsystem is the command module (PLC), which stores the input information (such as desired positioning points, trajectory tracking, velocity, or force value) and selects them via input combinations. For example, in the positioning actuator, the positions can be stored in the command module (as position list records), and move commands can include additional parameters such as velocity and acceleration.

The controller output signals are sent to the electro-pneumatic control valve via the electrical amplifier. In the pneumatic actuator, the control valve is the interface between the power and control subsystems. This device is a key element in which a small-amplitude, low-power electrical signal is used to provide high response modulation in pneumatic power. In general, there are three types of electro-pneumatic control valves: servo, proportional, and solenoid, used in the pneumatic actuator.

Solenoid valves (the type we used) are electromechanical devices that use a solenoid to control valve actuation. These devices are a fundamental element of the pneumatics and have high reliability and compact size. Standard models are available in both AC and DC voltages. The solenoid valve is low cost and universal in pneumatic systems operating with on/off control (e.g., it can be an effective solution for repeated stops in two positions).

Figure 3.2: Linear pneumatic cylinder (FESTO).

Figure 3.3: Rotary pneumatic cylinder.

Figure 3.4: Solenoid valve (FESTO).

Usually, pneumatic actuating systems are connected to compressed air lines with pressure from 0.3 to 1 MPa. Air compressors with pump technologies include positive displacement (piston, diaphragm, rotary vane, and screw styles) and non-positive displacement (centrifugal, axial, and regenerative blowers) and provide air at the necessary pressure. As a rule, the compressor has an integral tank for compressed air storage, a coarse filter, an air dryer, and a pressure regulator.

The removal of moisture from compressed air is important for servo pneumatic systems. Moisture in an airline can create problems that can be potentially hazardous, such as the freezing of control valves. This can occur, for example, if very high-pressure air is throttled to very low pressure at a high flow rate. The Venturi effect of the throttled air produces very low temperatures, which will cause any moisture in the air to freeze into ice. This makes the valve (especially the servo or proportional valve) either very difficult or impossible to operate. Also, droplets of water can cause serious water hammer in an air system, which has high pressure and a high flow rate and can cause corrosion, rust, and dilution of lubricants within the system. For these reasons, air dryers (dehydrator, air purifier, or desiccator) are used to dry the compressed air. Major dryer groupings include refrigerant forced condensation (which removes the water by cooling the air) and desiccants (which adsorb the water in the air with granular material such as activated alumina, silica gel, or molecular sieves). The air can be dried in single or multiple stages.

A compressed air filter is used to remove water, oil, oil vapor, dirt, and other contaminants from the compressed-air supply. These contaminants can have a serious effect on the wear and operation of pneumatically operated machinery. In almost all applications, contamination of the air supply could lead to serious performance degradation and increased maintenance costs in terms of actual repairs and production time lost. The proper use and maintenance of compressed-air filters is one sure way to help cut down on these costs. Porous metal and ceramic elements are commonly used in filters that are installed in the compressed-air supply lines. Most pneumatic filters have a removable bowl in which liquids are separated. The condensate that collects in the filter bowl is drained from time to time, as otherwise the air would entrain it.

Figure 3.5: Industrial air compressor (CHAMPION).

Figure 3.6: Air filter.

Air-pressure regulators are devices that control the pressure in the air lines of pneumatic tools and machines. These regulators eliminate fluctuations in the air supply and are adjusted to provide consistent pressure. The inlet pressure must always be greater than the working pressure. Usually, the regulator has attached gauges. Just as for the filter, the regulator selection process is very important because its parameters, such as pressure drop, standard nominal flow rate, hysteresis, and transient response, have a significant influence on the dynamics and accuracy of the pneumatic device. In particular, if positioning servo actuators are required to behave in a large piston stroke range as designed, the supply pressure should be as constant as possible. It is good if the supply pressure variations remain less than 5% of the designed value.

In some applications, where a few drives are operated, two separate supply lines are used: one with high pressure and the other with low pressure. In this case, the drive that moves on the idling mode may be connected to the low-pressure supply line, and the actuator works with high pressure only for the working stroke. This supply system allows for high efficiency.

Figure 3.7: Air pressure regulator.

In the next sections I will present in details the linear pneumatic cylinder and the solenoid valve due to their excessive use in our assembly machine and to their interesting functionality. [13]

III.4: Cylinders

III.4.1: Definition and internal structure of a cylinder

Cylinders convert pneumatic energy to mechanical work. They usually consist of a movable element such as a piston and piston rod, or plunger, operating within a cylindrical bore. Cylinders are often double-sided, i.e. pressurized air can work on both sides of the piston to extend or retract it, and they have mostly a single-ended piston rod.
The piston rod is case hardened and chrome plated while the barrel is made of stainless steel or – for tie rod cylinders – of an aluminum profile. Most cylinders have a band of magnetic material around the circumference of the piston and are fitted with a non-magnetic cylinder barrel. The magnetic field will travel with the piston as the piston rod moves in and out. By placing magnetically operated switches (sensors) on the outside of the barrel, electronic control of the piston movement with a PLC is possible. Some means of stroke cushioning, i.e. gradual deceleration of the piston near to the end of its stroke are provided by cushioning rings in the end position.

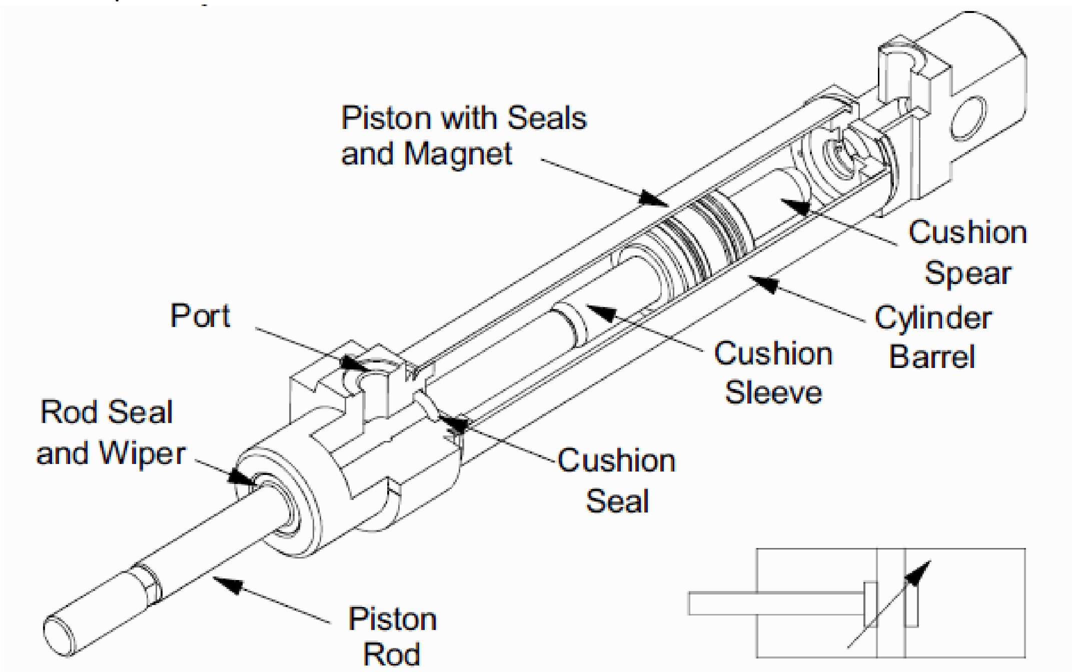


Figure 3.8: Cut-away view of single rod cylinder according to ISO 6432 and symbol.

Today, there are three ISO standards that contain mounting dimensions for cylinders with piston diameters from 8 to 320 mm and a maximum pressure of 10 bars. Cylinders complying with these standards can in most cases be replaced by those from other manufacturers. These standards do not include the attachment of the mountings to the cylinder or the mounting of proximity sensors. The mountings from one manufacturer may therefore not fit with the cylinder from another manufacturer.

When installing a cylinder, care should be taken that no unnecessary lateral forces act on the piston rod, e.g. by an unsupported load to the piston rod. The maximum permissible torque, i.e. the product of lateral force and stroke, depends on the cylinder design and size, e.g. 0.8 Nm for a cylinder with 32 mm bore or 25 Nm for a cylinder with 250 mm bore. An excessive load will increase the wear and can lead to an early end of the service life. If possible, self-aligning rod couplings should be used to minimize the forces from radial and angular misalignment.

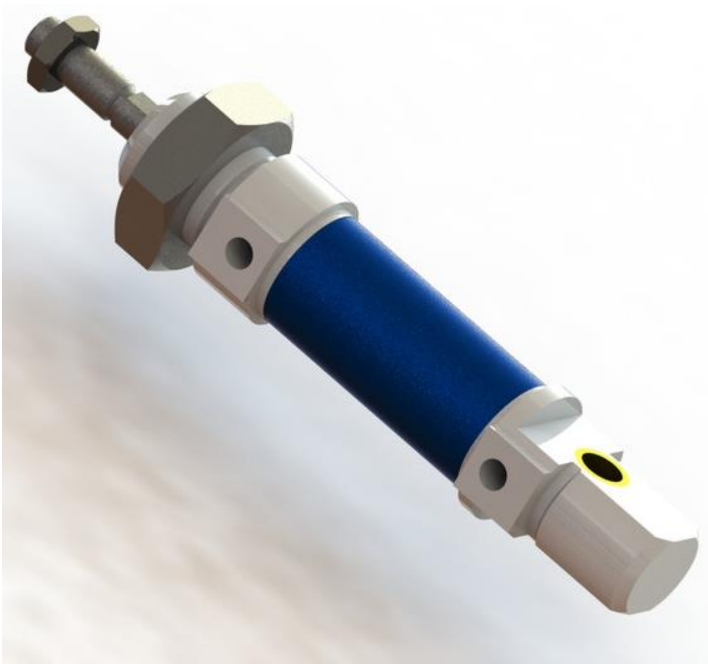


Figure 3.9: Pneumatic cylinder Solidworks model.

III.4.2: Types of pneumatic cylinders

There are three main types of pneumatic cylinders, including:

- Single Acting Cylinders.
- Double Acting Cylinders.
- Telescoping Cylinders.

Each of these cylinders is used for specific applications, meaning the one most suited to purpose, will depend on the job in question. Below we explain the function of these three different types of pneumatic cylinders.

III.4.3: Mathematical model

In order to simulate the piston movement and chamber pressures, a mathematical model is needed. As a result of large changes in pressure and density, the temperature of the air also changes and should be taken into account for a detailed model. A general model of a volume of gas consists of three equations: the energy equation, the conservation of mass equation and an equation of state, e.g. the ideal gas equation of state.
A lumped parameter approach will be taken assuming a homogeneous gas temperature.

Because of the low heat capacity of the air and the high heat capacity of the surrounding material of the barrel and rod, the temperature of the metallic parts can be regarded as constant.

The pressure change rate is rather small compared with the velocity of sound and therefore the pressure in the chamber is assumed to be uniform. Kinetic and potential energy terms will be neglected.
The derivation of the mathematical model starts with the change of the internal energy U of the air in one chamber of the cylinder, given by:

$$\frac{d}{dt}U = \dot{m} * cv * T + m * cv * \dot{T}$$

The change of the internal energy is also given by the energy change of the entering and leaving gas mass, **cp.Ti.$\dot{m}$** , the mechanical work, **p. dV/dt**, and the heat flow from the gas to the cylinder wall**, h.a.ΔT**, which leads to

$$\frac{d}{dt}U = c_p * T_{in} * \dot{m}_{in} - c_p * T_{out} * \dot{m}_{out} - p * \dot{V} - h.a * \Delta T$$

Combining the two previous equations leads to the mathematical model of the gas temperature T in the chamber:

$$\dot{m} * T + m * \dot{T} = \gamma * T_{in} * \dot{m}_{in} - \gamma * T * \dot{m}_{out} - \frac{p * A * v}{c_v} - \frac{h * a * \Delta T}{c_v}$$

$\dot{m} = \dot{m}_{in} - \dot{m}_{out}$ net air mass flow rate in kg/s.
m: Gas mass in kg.
T: Absolute air temperature in K.
T_{in} : Absolute temperature of entering air in K.
γ: Ratio of specific heat capacities (c_v/c_p) .
p: Absolute air pressure in Pa.
A: Piston area in m².
v :Piston velocity in m/s.
c_v : Specific heat capacity at constant volume.
c_p : Specific heat capacity at constant pressure.
h: Heat transfer coefficient in J/(m²·K).
a: Heat transfer surface area in m².
ΔT: temperature difference between air and barrel in K.

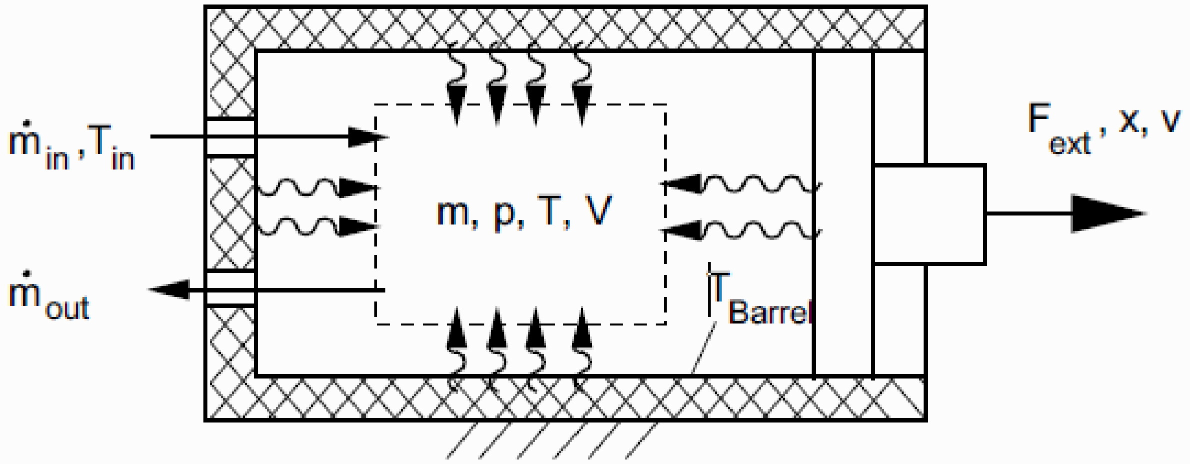


Figure 3.10: Co-ordinate system for the previous equations.

This approach neglects the kinetic energy of the air because it is typically very small compared to the thermal energy.

In the last equation convection is assumed as mode of energy transfer between the air in the chamber and the inside of the barrel. A simple model of that is Newton's law of cooling which states a linear relationship between the rate of heat transfer and the temperature differential " ΔT", the heat transfer coefficient "h "and the surface area "a" $(h * a * \Delta T)$.

The movement of the piston is described by Newton's second law:

$$M * \dot{v} = A * p + F_{ext}$$

Where:
M: lumped piston mass in kg
v: piston velocity in m/s.
A: effective piston area in m².
F_{ext}: net external force in N.

III.4.4: Cylinder Parameters

Two parameters of a cylinder are usually known: the piston or bore diameter and the maximum stroke. For standardized cylinders the diameter of the piston rod and the most relevant mounting dimensions are given in the particular standard. But there is typically no information available about the parameters and characteristics needed for mathematical modeling, e.g. friction, leakage or heat transfer.

Pneumatic equipment manufacturers use universal standards (ISO 15552 for example) in their production lines which allow a wide range of pneumatic equipment with different sizes and parameters; so when designing a machine or any mechanism that includes pneumatics, a design engineer must consider these standards in the design procedure.

A catalog of round pneumatic cylinders from FESTO (leader brand in pneumatics) is attached so you can see how to choose a cylinder.

III.5: Directional Control Valves

III.5.1: Definition and functions

Directional control valves are primarily used to control the direction of flow between the components of a pneumatic circuit. Due to their internal resistance they also throttle the air flow, an effect that is usually not welcome. There are several ways to distinguish between directional control valves:

- Number of ports.
- Number of switching positions or internal stable states.
- Internal design, e.g. spool, poppet or diaphragm.
- Type of operation, e.g. electrical, pneumatically or manual.

Figure 3.11: Directional Control valve.

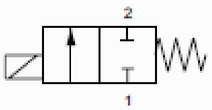
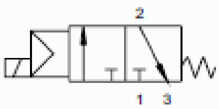
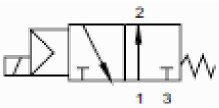
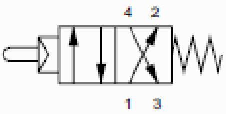
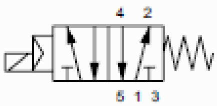
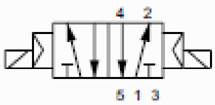
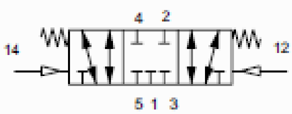
III.5.2: characteristics and types

Directional control valves are often characterized by two numbers: the number of main ports followed by the number of switching positions. The working ports are usually labeled 2 and 4, the exhaust ports 3 and 5 and the supply 1; the control ports of pneumatically operated valves are not counted.
In the directional control valve symbol, the switching positions are represented by squares. Internal connections between ports for a given position are indicated by an arrow or arrows within the square. In circuit diagrams valves are always shown in the neutral position, i.e. valve not actuated.
For 2/2-way and 3/2-way valves it is important to distinguish between those that are open from the supply to the working port when no operating signal is applied and those that are closed. This information is often appended to the valve description as 2/2-way valve NC for

normally closed or 3/2-way valve NO for normally opened. For cylinder drives, 5/2-way valves are often used. The type of actuation, monostable or bistable, depends on the application and the required behavior of the drive during and after an emergency shut-down. If the drive is to remain in the state before the emergency, bistable valves are used.

They (bistable valves) require an electrical signal to change the position of the spool which remains otherwise unchanged due to friction forces. This is a typical situation for horizontal drives. In assembly applications vertical drives are required to move upwards to clear the working space when an emergency occurs to avoid collisions with parts that are out of control. In this case, monostable valves are used that require an electrical signal to move the drive downwards.

The operating signal can be a force applied through a lever, a pressure from another valve or an electric voltage. This signal acts either direct on the main stage or with the help of an additional valve, called pilot valve. This valve is a power amplifier and reduces the required energy of the command signal, e.g. the force of a manually operated valve or the electric current. In the main stage the flow control is often done by a sliding spool that opens or blocks passages between the ports. Other designs use poppets or diaphragms, especially for valves with two positions and two or three ports.

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, monostable
	5/2-way valve, electrically operated, bistable
	5/3-way valve, pneumatically operated

Typical configurations of directional control valves.

III.5.3: Design of Directional Control Valves

A typical design of a pilot valve is shown in Figure 3.12 .It is a 3/2-way directional control valve that connects the working port 2 either to the compressor 1 or the exhaust 3.
If the coil of this valve is not energized, the main spring pushes the moveable armature to the right; the poppet closes the path from 1 to 2 and opens the path from 2 to 3. If the coil is energized, the armature is drawn to the left; the poppet opens a path from 1 to 2 and closes the path from 2 to 3. This kind of valve, a poppet valve, has a low flow resistance when open and gives a good seal when closed. It is robust and does not require lubrication because it has no close tolerance gaps or moving parts. However, it requires a large operating force because of the inherent pressure unbalance on the poppet which in practice limits its use to solenoid or pilot operation.

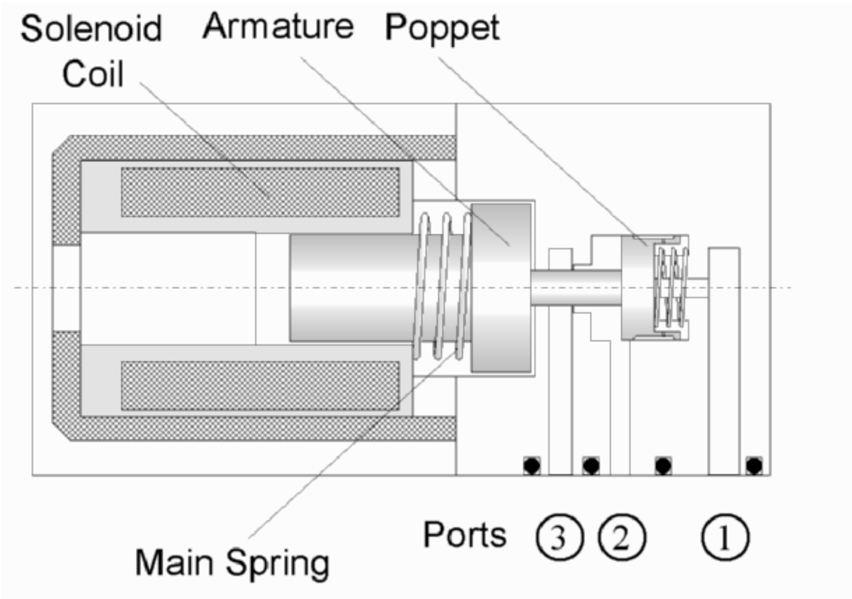


Figure 3.12: Schematic view of a pilot valve as 3/2-way directional control valve, direct operated, normally closed.

Figure 3.13 gives a cut-away view of a 5/2-way directional control valve. On the right side the pilot valve is shown that has a socket for the electric connector and a button for the manual operation of the valve. This pilot valve allows air to flow to the piston side of the spool where pressure builds up and subsequently - either direct or by the use of a piston – a force that moves the spool. The not shown pilot valve on the left side works in the same way. There may also be springs to guarantee a certain position when no pilot valve is activated. The spool opens flow paths from the compressor to the cylinder and the silencers and has in this case two distinct positions.

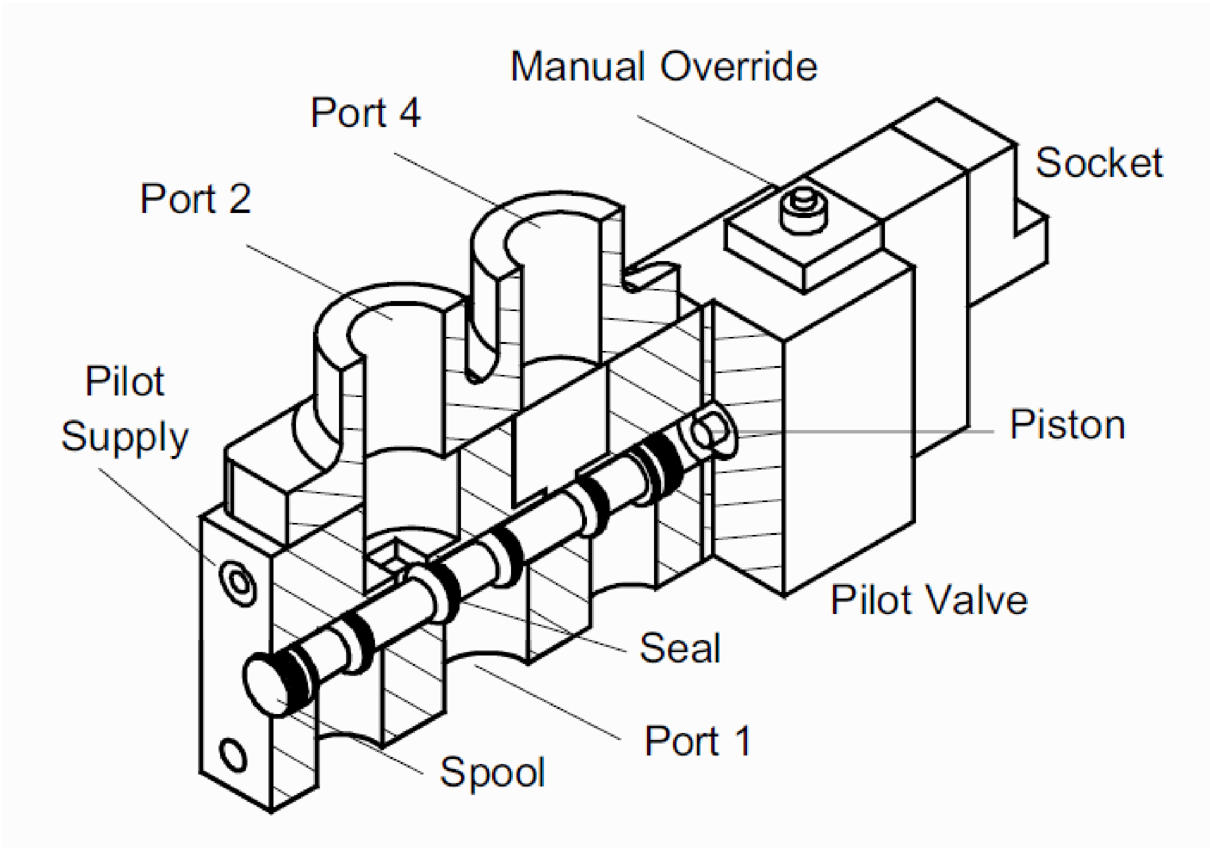


Figure 3.13: Cutaway view of a 5/2-way valve, left pilot valve removed.

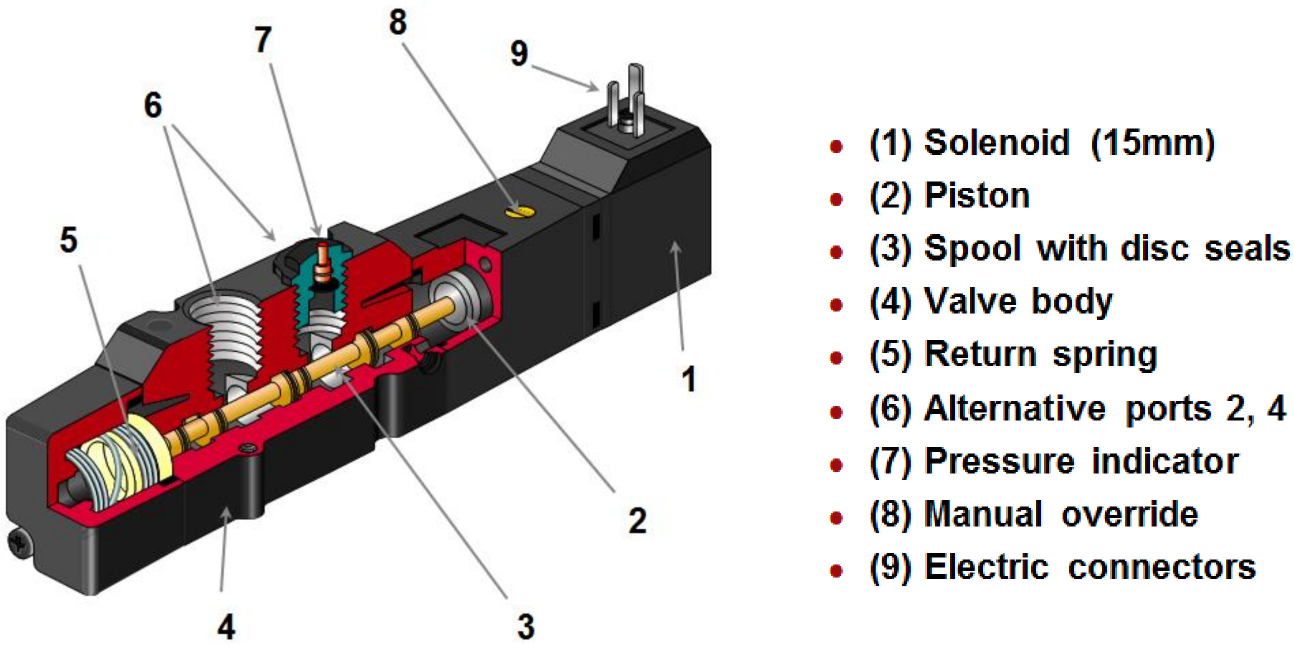


Figure 3.14: Typical 5/2 solenoid valve components.

III.5.4: Operation of Directional Control Valves

The steady-state operation of a directional control valve is simple: if operated, the ports are connected according to the valve symbol. For simple tasks this information is sufficient. When using a drive in a time-critical application or building a dynamic valve model, the transients between the switching positions have to be taken into account.

Figure 3.15 gives the step response of the current through a DC solenoid when the armature is fixed. At t = 5 ms the supply voltage of 24 V is switched on. As described by a first order differential equation, the current “i “rises according to :

$$i = i_{max}(1 - e^{-\frac{t}{\tau}})$$

Where:
i current in A
I_{max}: maximum current in A.
t: time in s.
τ :time constant in s.

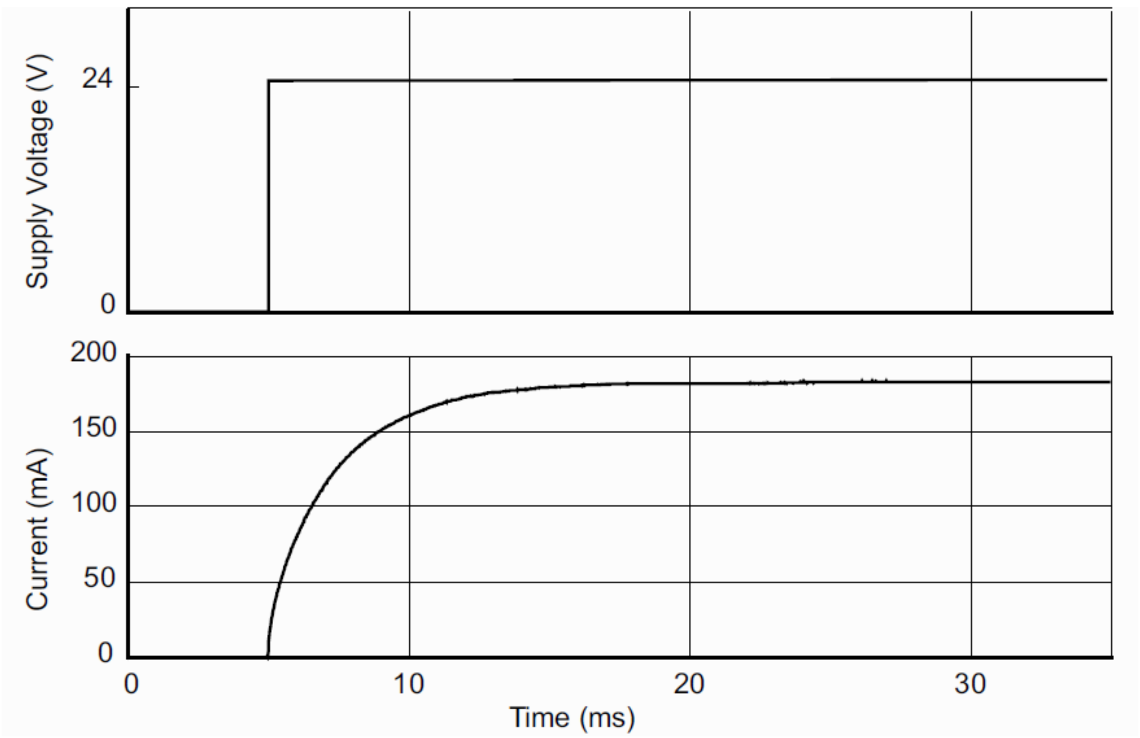


Figure 3.15: Step response of current through DC solenoid, armature fixed.

The current induces a force in the armature. If this force is greater than the opposing spring force and friction, the armature moves. This movement induces an additional voltage in the coil which changes the current curve. A measurement is shown in Figure 3.16 and compared with a solenoid where the armature is fixed. At the moment when the armature starts to

move the two curves separate.
When the armature reaches its final position, the current increases again. [14]

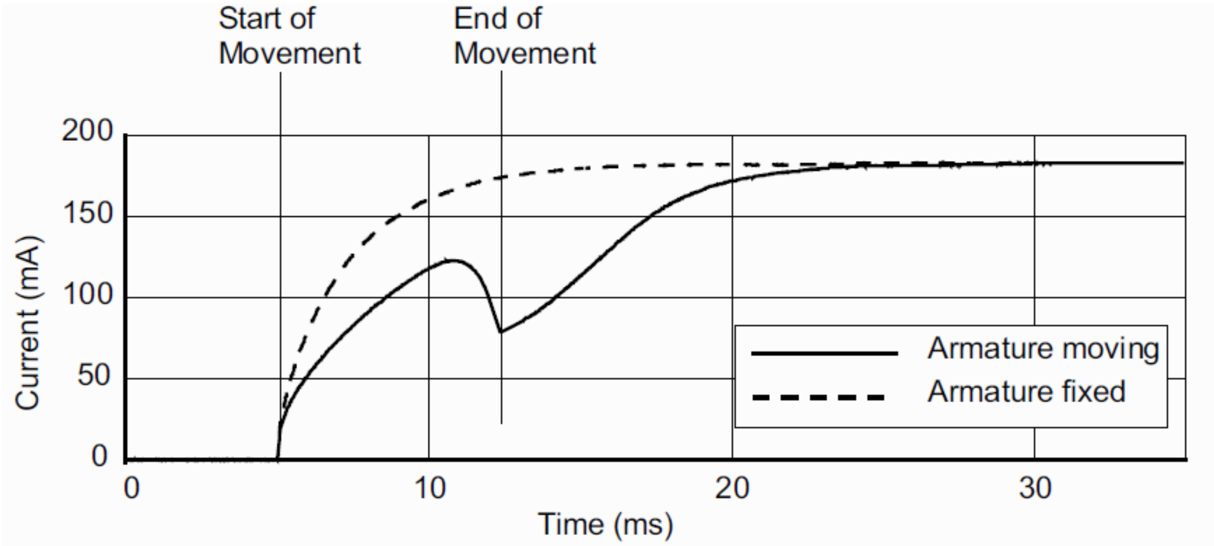


Figure 3.16: Step response of solenoid current, armature moving.

For the pneumatic control of our assembly machine we have used a set 5/2 solenoid valves grouped in a manifold (manifold block) which is slim compact, lightweight and efficient for high density installations.

Figure 3.17: Solenoid valves mounted on a manifold.

III.6: Other pneumatic equipment

- **Tubing**

Plastic tubes with different diameters are used to connect the actuators (cylinders) to the solenoid valves and to connect the manifold block with the compressed air supply.

Figure 3.18: Tubing.

- **Fittings and couplings**

Fittings are used to connect the cylinder's inlet ports or solenoid valves ports with tubes, in general fittings are components used to connect pneumatic elements. They contain two ends, one is threaded to be screwed in cylinders or valves and the other end forms teeth holding mechanism and push to release.

Figure 3.19: Pneumatic fitting.

- **Pneumatic couplings**

Used to connect two tubes or more of different dimensions, or as junction points or nodes in pneumatic circuits, which from one tube other tubes are extracted.

Figure 3.20: 4mm to 6mm diameter coupling.

Figure 3.21: Fittings and coupling types.

- **Distributors**

One inlet and multiple outlets used for size reduction and compact applications.

Figure 3.22: 1/6 distributor.

- **Silencers (Muffler)**

Components to reduce exhaust noise, usually mounted on the manifold block.

Figure 3.23: Pneumatic silencer.

Chapter IV:

Programming the PLC

Chapter IV: Programming the PLC

IV.1: Introduction

Each input and output PLC module terminal is identified by a unique address. In PLCs, the internal symbol for any input is a contact. Similarly, in most cases, the internal PLC symbol for all outputs is a coil. This chapter shows how these contact/coil functions are used to program a PLC for circuit operation. The procedure of programming a PLC is common and standardized for all brands of PLCs, the only difference lies in the instructions set and variable assignment.

IV.2: Processor Memory Organization

While the fundamental concepts of PLC programming are common to all manufacturers, differences in memory organization, I/O addressing, and instruction set mean that PLC programs are never perfectly interchangeable among different makers. Even within the same product line of a single manufacturer, different models may not be directly compatible.
The memory map or structure for a PLC processor consists of several areas, some of these having specific roles. Allen-Bradley PLCs for example have two different memory structures identified by the terms rack-based systems and tag based systems.
Memory organization takes into account the way a PLC divides the available memory into different sections. The memory space can be divided into two broad categories: program files and data fi les. Individual sections, their order, and the sections' length will vary and may be fixed or variable, depending on the manufacturer and model.
Program files are the part of the processor memory that stores the user ladder logic program. The program accounts for most of the total memory of a given PLC system. It contains the ladder logic that controls the machine operation. This logic consists of instructions that are programmed in a ladder logic format. Most instructions require one word of memory.

The data files store the information needed to carry out the user program. This includes information such as the status of input and output devices, timer and counter values, data storage, and so on. Contents of the data table can be divided into two categories: status data and numbers or codes. Status is ON/OFF type of information represented by 1s and 0s, stored in unique bit locations. Number or code information is represented by groups of bits that are stored in unique byte or word locations.

IV.3: Internal Memory in the Omron CP1E CPU Unit

The internal memory in the CPU Unit consists of built-in RAM and built-in EEPROM. The built-in RAM is used as execution memory and the built-in EEPROM is used as backup memory.

The built-in RAM is the execution memory for the CPU Unit where the user programs, PLC Setup, and I/O memory are stored. The data is unstable when the power is interrupted. The user programs and parameters are backed up to the built-in EEPROM, so they are not lost.

The built-in EEPROM is the backup memory for user programs, PLC Setup, and Data Memory backed up using control bits in the Auxiliary Area. Data is retained even if the power supply is interrupted. Only the Data Memory Area words that have been backed up using the Auxiliary Area control bits are backed up but all data in all other words and areas is not backed up.

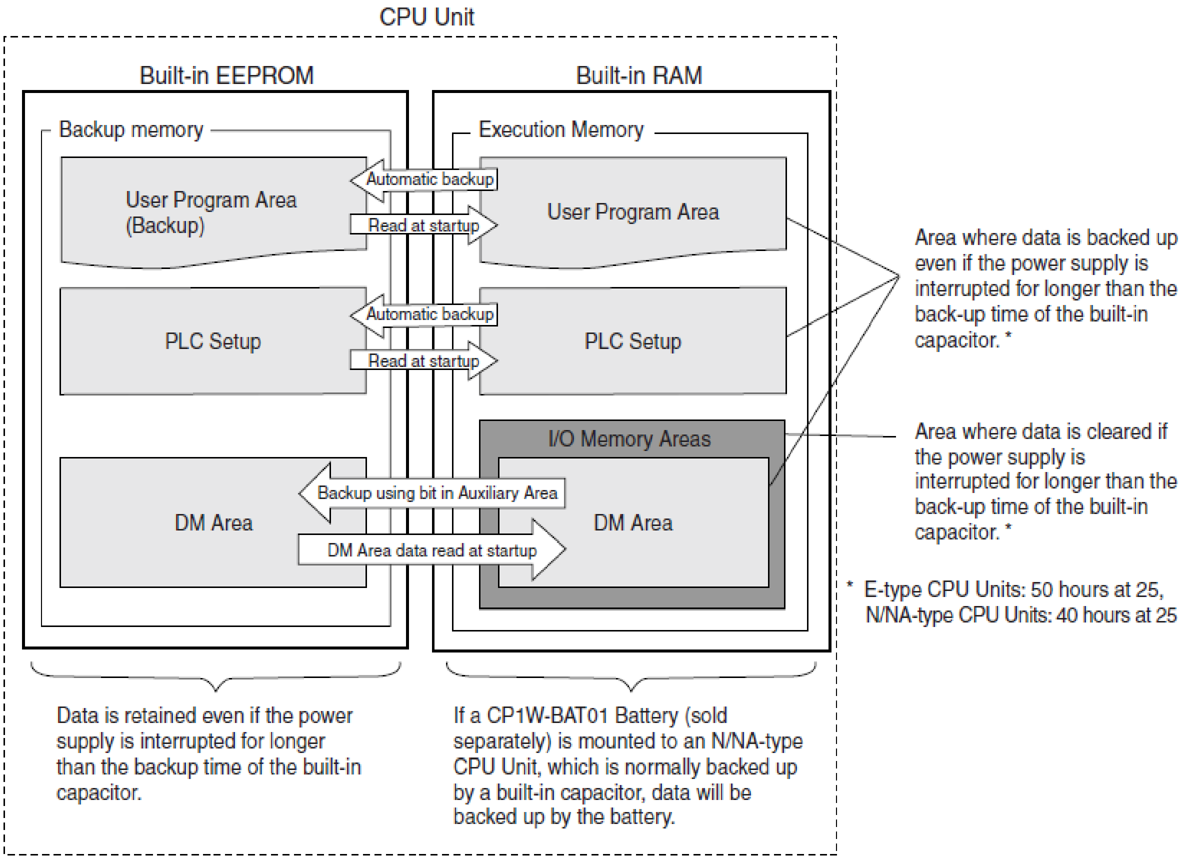


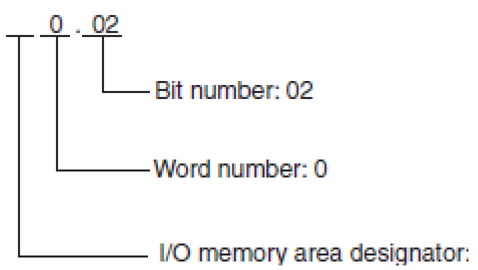
Figure 4.1: OMRON CP1E N40 internal memory organization.

IV.4: I/O Memory

Data can be read and written to I/O memory from the ladder programs. I/O memory consists of an area for I/O with external devices, user areas, and system areas.

- **I/O bits allocation**

These words are allocated to built-in I/O terminals of CP1E CPU Units.



Input bits: CIO 0.00 to CIO 99.15 (100 words)

Output bits: CIO 100.00 to CIO 199.15 (100 words)

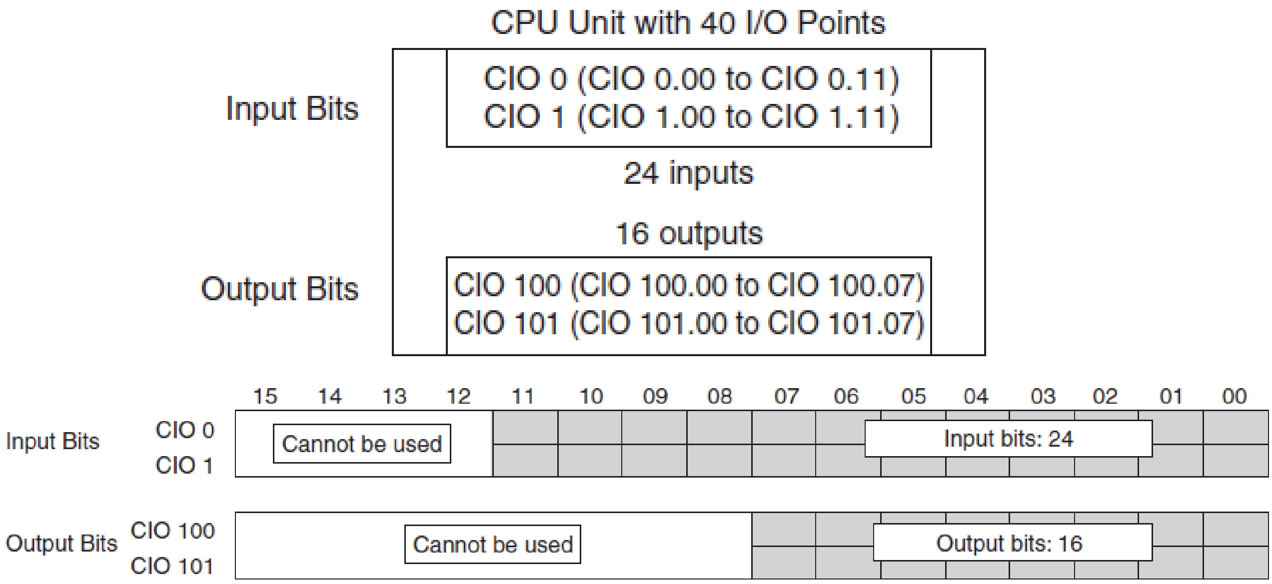


Figure 4.2: Omron CP1E 40 points I/O allocation.

For a CPU Unit with 40 I/O points, a total of 24 input bits are allocated to the input terminal block. The bits that are allocated are input bits CIO 0.00 to CIO 0.11 (i.e., bits 00 to 11 in CIO 0) and input bits CIO 1.00 to CIO 1.11 (i.e., bits 00 to 11 in CIO 1).
In addition, a total of 16 output bits are allocated to the output terminal block. The bits that are allocated are output bits CIO 100.00 to CIO 100.07 (i.e., bits 00 to 07 in CIO 0) and output bits CIO 101.00 to CIO 101.07 (i.e., bits 00 to 07 in CIO 1).
Expansion Units and Expansion I/O Units connected to the CPU Unit are automatically allocated input bits and output bits in words following those allocated to the CPU Unit.
For example, if a CPU Unit with 40 I/O points is used, CIO 0 and CIO 1 are allocated for inputs and CIO 100 and CIO 101 are allocated for outputs. Thus, words from CIO 2 onward for inputs and words from
CIO 102 onward for outputs are automatically allocated to the Expansion I/O Units and Expansion Units in the order that the Units are connected.

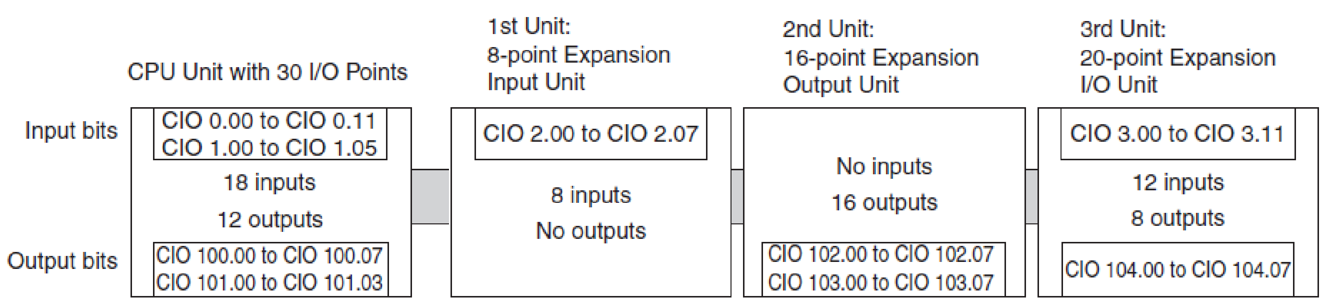


Figure 4.3: Expansion modules I/O allocation.

IV.5: Workflow from Design to Operation

The workflow for constructing a CP1E automated assembly machine control system is shown below:

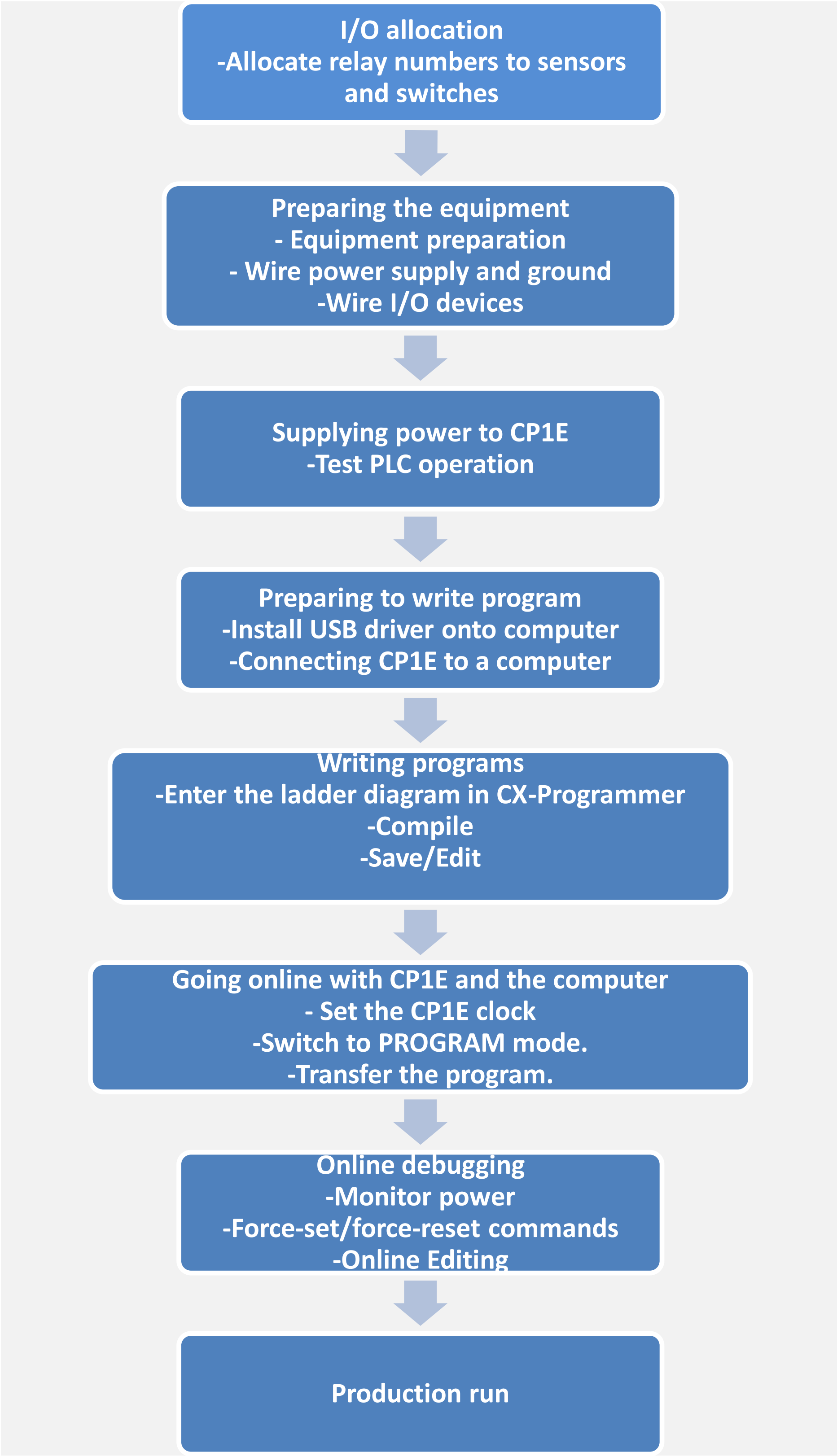


Figure 4.4: Workflow

- **About the assembly machine Control System**

This section defines the operation and components of the assembly machine control system.

➢ **Operation**

- The operator turns on the machine.
- The machine puts the pneumatic cylinders in the appropriate position
  - The vertical cylinders should be retracted and the horizontal ones should be fully extended so the pick-up mechanisms for all four posts are above the spacers tracks.
- The machine detects if the spacers tracks are empty or full by scanning the proximity sensors status, if the tracks are empty it activates the bowls feeders (vibrating bowls) to fill (feed) the tracks and activates the air blowers to put them in the pick-up sections.
- For time optimization, once the machine is turned on, 4 spacers are picked up in all four stations and all and the horizontal cylinders are retracted so the stations are waiting to place them on the power strip body.
- The machine's operator manually places an empty power strip in its appropriate position and pushes a foot pedal (footswitch) .
- Once the foot pedal is pressed the cylinder beneath the table is extended moving along the T piece which is responsible for placing the power strip beneath the first station so the first male spacer is placed and fixed.
- Once the power strip is in correct position a sensor detects its presence and sends signal to the PLC and the first vertical cylinder is activated with the objective of placing the first male spacer in its place.
- Once the previous cylinder completes its course of movement the second vertical cylinder is activated which responsible for the fixation procedure.
- After the fixation task is done, both of the vertical cylinders retract and the horizontal cylinder is extended to pick up the second male spacer.
- All the three other stations remain inactive.
- The operator puts another power strip, press the pedal switch, this power strip moves along the table to take place beneath the first post while pushing the previous one onto the second post, the same steps are undertaken in the second station.
- The operator keeps feeding the machine with power strips until the third post is activated after the 5^{th} power strip is injected into the machine.
- Now all posts are active and the machine is running in a repeated cycle, keeping in mind the rotating feeders and the air blowers to keep feeding the machine with the necessary spacers.

➢ **System Components**

●**PLC:**

CP1E (40-point I/O unit with DC power supply) with CP1W 16ER expansion unit.

●**Equipment and Software for Programming:**

- CX-Programmer
- Computer
- USB cable (A-B)

●**Inputs:**

- Start button: “START”
- Pedal Switch: «PEDAL”
- Emergency stop button : “ES”
- Reset button: “RESET”
- Power socket detection sensor :”PM”
- Spacer detection sensor for station 1: “EN1”
- Spacer detection sensor for station 2: “EN2”
- Spacer detection sensor for station 3: “EN3”
- Spacer detection sensor for station 4: “EN4”
- 1^{st} horizontal cylinder position sensor (extended position sensor): “V1Y”
- 2^{nd} horizontal cylinder position sensor (extended position sensor): “V2Y”
- 3^{rd} horizontal cylinder position sensor (extended position sensor): “V3Y”
- 4^{th} horizontal cylinder position sensor (extended position sensor): “V4Y”

PS: due to the limited number of inputs in the PLC and the simplicity of the machine, we used position sensors only for the horizontal cylinders and we used one sensor for each cylinder to detect if the cylinder is fully extended. For the remaining cylinders we used TIMERS as virtual sensors.

● **Outputs:**

- Solenoid valve coil for the pusher cylinder (T piece): “EVP”
- Solenoid valve coil for station 1,horizontal cylinder: “EVP11”
- Solenoid valve coil for station 1,vertical cylinder 1: “EVP12”
- Solenoid valve coil for station 1,vertical cylinder 2: “EVP13”
- Solenoid valve coil for station 2,horizontal cylinder: “EVP21”
- Solenoid valve coil for station 2,vertical cylinder 1: “EVP22”
- Solenoid valve coil for station 2,vertical cylinder 2: “EVP23”
- Solenoid valve coil for station 3,horizontal cylinder: “EVP31”
- Solenoid valve coil for station 3,vertical cylinder 1: “EVP32”

- Solenoid valve coil for station 3,vertical cylinder 2: “EVP33”
- Solenoid valve coil for station 4,horizontal cylinder: “EVP41”
- Solenoid valve coil for station 4,vertical cylinder 1: “EVP42”
- Solenoid valve coil for station 4,vertical cylinder 2: “EVP43”
- Male spacers pushers (air) on track 1: “SBT1”
- Female spacers pushers on track 2: “SBT2”
- Bowl feeder 1 (male spacers) : “BV1”
- Bowl feeder 2 (female spacers): “BV2”

- **I/O Allocation for the Shutter Control System:**

I/O relays on CP1L are allocated to contacts as defined by following.

- Inputs:

START	BOOL	0.00		In
PEDAL	**BOOL**	**0.12**		**In**
ES	BOOL	0.01		In
RESET	BOOL	0.02		In
PM	BOOL	0.03		In
EN1	BOOL	0.04		In
EN2	BOOL	0.05		In
EN3	BOOL	0.06		In
EN4	BOOL	0.07		In
V1Y	BOOL	0.08		In
V2Y	BOOL	0.09		In
V3Y	BOOL	0.10		In
V4Y	BOOL	0.11		In

-

Figure 4.6: Inputs allocation.

- Outputs

EVP	BOOL	100.00		Out
EVP11	BOOL	100.01		Out
EVP12	BOOL	100.02		Out
EVP13	BOOL	100.03		Out
EVP21	BOOL	100.04		Out
EVP22	BOOL	100.05		Out
EVP23	BOOL	100.06		Out
EVP31	BOOL	100.07		Out
EVP32	BOOL	101.00		Out
EVP33	BOOL	101.01		Out
EVP41	BOOL	101.02		Out
EVP42	BOOL	101.03		Out
EVP43	BOOL	101.04		Out
SBT1	BOOL	101.05		Out
SBT2	BOOL	101.06		Out
BV1	BOOL	101.07		Out
BV2	BOOL	101.10		Out

Figure 4.7: Outputs allocation

- **Creating Programs**

This section explains the necessary preparations, such as connecting CP1E to a computer and installing the USB driver, in order to begin creating ladder programs.

- CX-Programmer:

CX-Programmer is a programming tool (software) for creating the ladder programs that are to be executed by CP1E. In addition to programming functions, it also offers other useful functions for CP1E setup and operation, such as debugging programs, address and values display, PLC setup and monitoring; and remote programming and monitoring via the network.
To use CX-Programmer, you must connect CP1E to a computer, which has CX Programmer installed.
The computer to be connected to must have CX-Programmer Ver.8.2 or later installed.
You will also need a USB cable to connect CP1E to the computer.
Furthermore, a USB driver must be installed for CP1E to be recognized by the computer.

- **Assembly machine's Ladder program**

CX programmer was used to develop the overall ladder program of the assembly machine in hands; the program is divided into 8 sections (Sensors evaluation, Start, station1, station2, station3, station4, alarms, and END section) .
Sensors evaluation section assigns each sensor and pushbutton to a memento which hold the value of the sensor's status.
Start section is executed after previous section and hold the program which is responsible for placing the cylinder in their primary positions as stated before.
Station 1 to 4 sections: contain the operation program of each station.
Alarms section: contain the program which detects malfunctions and breakdown and causes the machine to stop immediately and activates the alarm buzzer.
The overall program will be completed and transferred to the PLC using a USB cable and using the Online debugging tool offered by CX programmer, it will be tested and simulated online.

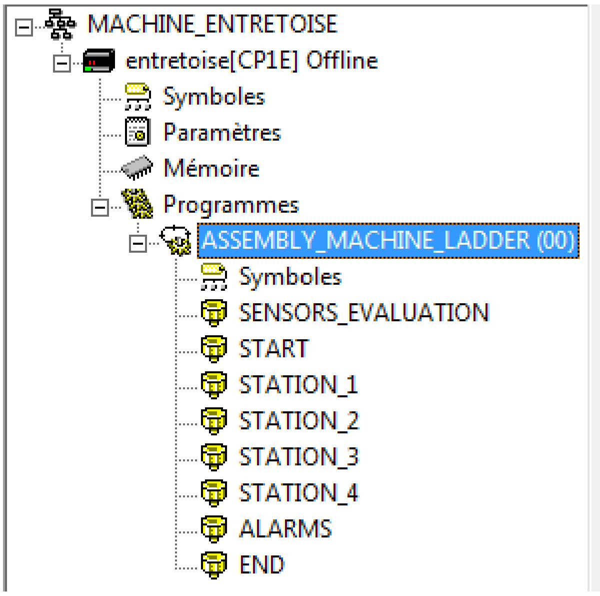


Figure 4.8: Ladder program sections

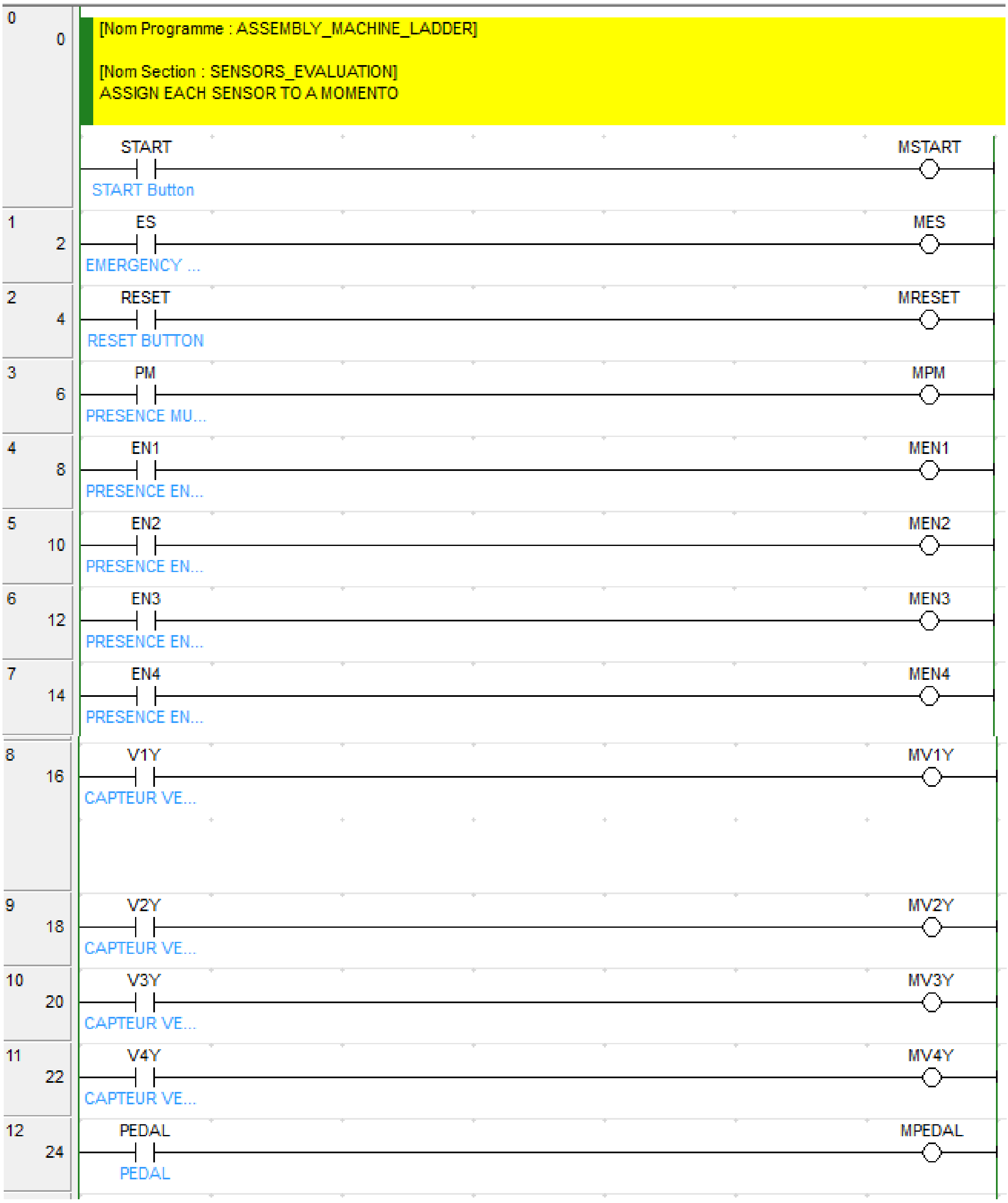


Figure 4.9: Sensors evaluations section ladder program

GENERAL CONCLUSION

General conclusion

This assembly machine is considered as semi-automatic because it needs human interactions to operate e.g.: an operator who turns it on and who is continuously feeding the machine with empty power strips and who is responsible for repairs and maintenance and also inspecting the assembled products.

We can improve the productivity of our assembly machine by making it fully automatic from two points of views: production and maintenance.

The first objective can be achieved by designing an industrial robot responsible for feeding power strips to the machine. In addition, we are planning to add an HMI (Human Machine Interface) which allows more information about performances and gives details about the machine status.

A human machine interface (HMI) is an interface that permits interaction between a human being and a machine. Human machine interfaces vary widely, from control panels for nuclear power plants to the screen and input buttons on a cell phone. Designing such interfaces is a challenge, and requires a great deal of work to make the interface functional, accessible, pleasant to use, and logical. Some engineers specialize in developing human machine interfaces and changing the ways in which people interact with machines and systems.

For the inspection procedure, we can add a visual control system that uses cameras to check that final product is properly assembled.

We are planning also to integrate all assembly and production machines in a SCADA network to make it easy to operate the factory from one control room.

From the point of view of maintenance, we can apply an effective method called Total Productive Maintenance (TPM), it can be considered as the medical science of machines. Total Productive Maintenance (TPM) is a maintenance program which involves a newly defined concept for maintaining plants and equipment. The goal of the TPM program is to markedly increase production while, at the same time, increasing employee morale and job satisfaction.

TPM brings maintenance into focus as a necessary and vitally important part of the business. It is no longer regarded as a non-profit activity. Down time for maintenance is scheduled as a part of the manufacturing day and, in some cases, as an integral part of the manufacturing process. The goal is to hold emergency and unscheduled maintenance to a minimum.

- **Types of maintenance:**

1. Breakdown maintenance:

It means that people waits until equipment fails and repair it. Such a thing could be used when the equipment failure does not significantly affect the operation or production or generate any significant loss other than repair cost.

2. Preventive maintenance:

It is a daily maintenance (cleaning, inspection, oiling and re-tightening), design to retain the healthy condition of equipment and prevent failure through the prevention of deterioration, periodic inspection or equipment condition diagnosis, to measure deterioration. It is further divided into periodic maintenance and predictive maintenance. Just like human life is extended by preventive medicine, the equipment service life can be prolonged by doing preventive maintenance.

3. Corrective maintenance:

It improves equipment and its components so that preventive maintenance can be carried out reliably. Equipment with design weakness must be redesigned to improve reliability or improving maintainability

4.Maintenance prevention:

It indicates the design of a new equipment. Weakness of current machines are sufficiently studied (on site information leading to failure prevention, easier maintenance and prevents of defects, safety and ease of manufacturing) and are incorporated before commissioning a new equipment.

- TPM Targets:

1. Obtain Minimum 90% OEE (Overall Equipment Effectiveness)

2. Run the machines even during lunch. (Lunch is for operators and not for machines!)

3. Operate in a manner, so that there are no customer complaints.

4. Reduce the manufacturing cost by 30%.

5. Achieve 100% success in delivering the goods as required by the customer.

6. Maintain an accident free environment.

7. Increase the suggestions from the workers/employees by 3 times. Develop Multi-skilled and flexible workers.

TPM turned out to be very effective when applied in large factories and can achieve high performances. [15]

Designing and manufacturing automated machines is an interesting field in automation engineering, it allows an engineer to use many disciplines such as mechanics, mathematics physics, materials engineering, and many other branches.

During this project, I leaned multiple skills related to my field of study, beside the theoretical knowledge offered by the university; practical skills are crucial part of an engineer's carrier.

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