DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DESIGN OF A SMALL-SCALE PIEZOELECTRIC SENSOR PRODUCTION SYSTEM BY USING PROGRAMMABLE LOGIC CONTROLLER (PLC)

by
Hussein Sayid Omar HAMZA

November, 2016
İZMİR

DESIGN OF A SMALL-SCALE PIEZOELECTRIC SENSOR PRODUCTION SYSTEM BY USING PROGRAMMABLE LOGIC CONTROLLER (PLC)

A Thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fullfilment of the Requirements for the Degree of Master of Science
In Electrical and Electronics Engineering

by
Hussein Sayid Omar HAMZA

November, 2016
İZMİR

M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"DESIGN OF A SMALL-SCALE PIEZOELECTRIC SENSOR PRODUCTION SYSTEM BY USING PROGRAMMABLE LOGIC CONTROLLER (PLC)"** completed by **HUSSEIN SAYID OMAR HAMZA** under supervision of **AŞSOC.PROF.DR. ÖZGE ŞAHİN CİHANBEĞENDİ** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Assoc.Prof.Dr. Özge ŞAHİN CİHANBEĞENDİ
Supervisor

Asst.Prof.Dr. Levent BARALI
Co-Supervisor

Prof.Dr. Uğur Can
(Jury Member)

Doç.Dr. Hasan ÖZTÜRK
(Jury Member)

Yrd.Doç.Dr. Mevlüt Karaer
(Jury Member)

Prof.Dr. Emine İlknur CÖCEN
Director
Graduate School of Natural and Applied Sciences

ACKNOWLEDGMENTS

There are many people who I would like to thank for their support while I was writing this thesis.

At first I want to articulate my deep gratitude to the Almighty Allah, who gave me the ability to carry on the thesis.

I would like to thank all the teachers, students and specially my first supervisors Assoc. Prof. Dr. Özge Şahin CİHANBEĞENDİ and also my co-supervisor Asist. Prof. Dr. Levent Parali for their endless help and encouragement to do work on this thesis.

Then I want to thank my respected head of EEE department, Prof. Dr. Üğur Çam, and Prof. Dr. İlknur Cöcen the diractor of Graduate School of Natural and Applied Sciences, those doors was always kept open for me and helped with their kind suggestions and guidance.

I also want to thank to administrator and teachers in Celal Bayar University, Vocational School of Electronics and Automation department for their support and help during my thesis research.

Finally, I would like to thank my parents who have always been there for me, and above all who made this amazing thesis possible. Thank you Mom, Thank you Dad and Thank you my older brother Hassan.

Hussein Sayid Omar HAMZA

DESIGN OF A SMALL-SCALE PIEZOELECTRIC SENSOR PRODUCTION SYSTEM BY USING PROGRAMMABLE LOGIC CONTROLLER (PLC)

ABSTRACT

The world is in demand of consistent supply of electricity due to population expansion and industrial development. This thesis describes the new design of a small scale piezoelectric Sensor production system using Programmable Logic Controller (PLC), based on hydraulic press.

Piezoelectric elements are used to construct transducers for a vast number of different applications. Piezoelectric materials generate an electrical charge in response to mechanical movement, or vice versa, produce mechanical movement in response to electrical input.

A Programmable Logic Controller or Programmable Controller is a digital computer used for automation of electro-mechanical processes, such as control of machinery on factory assembly lines, amusement rides, or light fixtures. PLCs were used in many industries and machines, different general purpose computers, the PLC were designed for numerous input and output arrangements, extended temperature ranges, protection to electrical noise, and resistance to vibration and impact. Programs which controlled machine operations are typically stored in battery backed-up or non-volatile memory. A PLC is an example of a hard real time system since output results must be produced in response to input conditions within a limited time.

Programmable logic controllers along with easy-to-use support software, those are available to flexibly handle applications from small-scale equipment to entire production lines with PLC.

PLCs offer other advantages over traditional control systems, these advantages will be including increased reliability, flexibility, lower cost, communications capability, easier to troubleshoot and high efficiency and time saving for the operating system.

The thesis also shows an industrial solution for hydraulic press control using a programmable logic controller (PLC) as a control device by applying a SIEMENS S7-1200 model. Based on the experimental results, it can be concluded that electrically actuated control components supported by the suitable computer programs make it possible to improve the characteristics of the hydraulic press systems required in modern industry.

Keywords: Piezoelectric sensors, Programmable Logic Control (PLC), Siemens S7-1200, Hydraulic press.

KÜÇÜK ÖLÇEKLİ BİR PİEZOELEKTRİK SENSÖR ÜRETİM SİSTEMİNİN PROGRAMLANABİLİR LOJİK KONTROLU İLE TASARIMI

ÖZ

Nüfus artışı ve endüstriyel gelişme dolayısıyla dünyada sürekli bir elektrik temini talebi olmaktadır. Bu tezde Programlanabilir Lojik Kontrolu (PLC) kullanan küçük ölçekli bir pizoelektrik sensör üretim sisteminin yeni tasarımı anlatılmaktadır.

Piezoelektrik elemanları çok sayıda farklı uygulamalar için dönüştürücü imal etmek amacıyla kullanılır. Piezoelektrik malzemeler mekanik harekete karşılık bir elektrik yük üretirler veya tam tersi olarak elektrik girişine tepki olarak mekanik hareket üretirler.

Programlanabilir Lojik Kontrolu fabrika üretim hatlarındaki, eğlence amaçlı olarak binilen lunapark oyuncaklarındaki veya aydınlatma armatürlerindeki mekanizmaların kontrolü gibi elektromekanik süreçlerin otomasyonunda kullanılan bir tür dijital bilgisayardır. PLC’ler birçok sanayide ve makinede, farklı genel amaçlı bilgisayarlarda kullanılmıştır. PLC çok çeşitli giriş ve çikiş düzenekleri, geniş sıcaklık aralıkları, elektriksel ses koruma ve de vibrasyon ve darbeye direnç amaçlı olarak tasarlanmıştır. Makinenin çalışmasını kontrol eden programlar genellikle akü yedeklemesi olan veya kalıcı belleklerde depolanır. Sınırlı bir süre içinde input koşullarına yanıt olarak output sonuçları üretilmek zorunda olduğu için, PLC faal bir gerçek zaman sisteminin bir örneğidir.

PLC kullanımı kolay destek yazılımı ile birlikte küçük ölçekli aletlerden tüm üretim hattına kadar uygulamaları esnek bir şekilde idare edecek şekilde mevcuttur. PLC’ler geleneksel denetim sistemlerine karşı diğer bazı avantajlar sunarlar. Bu avantajların içinde şunları sayabiliriz: arttırılmış güvenilirlik, esneklik, düşük maliyet, iletişim kabiliyeti, sorunları kolayca giderme ve de işletim sisteminde yüksek verimlilik ve zaman tasarrufu.

Bu tez ayrıca, bir SIEMENS S7-1200 modelini uygulamak suretiyle, denetim cihazı olarak Programlanabilir Lojik Kontrolu PLC kullanarak hidrolik basınç denetimi için endüstriyel bir çözümü göstermektedir. Deneysel sonuçlara dayanarak şu sonuca varılabilir: uygun bilgisayar programları ile desteklenen elektrik kumandalı denetim elemanları modern sanayide gerekli görülen hidrolik sistem basıncının özelliklerinin geliştirilmesini mümkün hale getirebilir.

Anahtar Kelimeler*:* Piezoelektrik sensörler, programlanabilir lojik kontrolu (PLC), Siemens S7-1200, hidrolik basınç.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Pages

CHAPTER ONE

INTRODUCTION

1.1 Description

The world is in demand of consistent supply of electricity due to population expansion and industrial development.

In recent times, the majority of the research within the energy field is to develop sources of energy for future, with oil resources being over and eventually bound to quit. So that, it is time to discover renewable resources of energy for the new generation in the future.

Piezoelectric sensors are being increasing more studied as they become very unusual materials with very particular and interesting properties. In reality, they have the potential to produce electrical energy from mechanical energy, as an instance it can convert vibrations into electricity. Such devices are generally referred to as energy harvesters and can be utilized in applications where outside power is unavailable and batteries are not a feasible option. At the same time as recent experiments have proven that these materials could be used as power generators, they produce low amount of energy.

This thesis describes the new design of a small scale piezolectric sensor production system using Programmable Logic Controller (PLC).

The PLC is used to write specific propriety ladder logic on a computer, and then downloads the code into the PLC directly through a cable connection. The objective of this experiment is to design a small-scall piezoeletric sensor production system using PLC.

The hydraulic press control was realized by using a programmable logic controller SIMATIC S7-1200, manufactured by Siemens. The control program was built using SIMATIC WinCC flexible software for programming the controller and configuring the Human Machine Interface (HMI) panel. Most hydraulic presses are generally slower than mechical presses, this disadvantage has been addressed with the development of new valve with higher flow capacities, smaller response time and improved control capabilities.

The considered system was actually one of experimental electro-hydraulic systems that have been carried out in the Laboratory of the Automation Department of the Vocational School of Electronics, Celal Bayar University.

This thesis also provides a hydraulic press control by using PLC as a control device, which could be used in practice.

1.2 Motivation of Study

Conventional hydraulic presses replace the mechanical presses which are most frequently used in the production of piezoelectric. This is largely due to the advantages of the hydraulic press over the mechanical presses. However, the hydraulic presses have the disadvantage of being slower thus, opening new ways of improving the hydraulic presses which includes, and the development of new valves with higher flow capacities, smaller response times and improved control capabilities.

PLC is one of the methods that can be used in writing the programmed for the control system of the hydraulic press. This is because of its numerous advantages like:

- Programming a PLC is easier than wiring the relay control panel.
- Maintenance of the PLC is easier, and reliability is greater.
- PLC can be connected to the plant computer systems more easily than a relay.

Hence, the title of this research is “The Design of a small-scale Piezolectric Sensors Productıon System by using Programmable Logic Controller PLC”.

1.3 Aim of the Study

The aim of this study is to design a small-scale of piezoelectric sensor production system by using Programmable Logic Controller (PLC). This experimental study includes the construction of a hydraulic press and the implementation of piezoelectric sensor production system by using programmable logic controller SIMATIC S7-1200.

1.4 Objectives of the Study

To achieve the above mentioned aim the following objectives were adhered:

1. To recognize potential piezoelectric materials.
2. To develop a program for production of piezoelectric sensor using PLC.
3. To fit a PLC control system to the hydraullic press
4. To produce a small scale piezoelectric sensor using the developed system.

1.6 Thesis Outline

This thesis is organized in five chapters. The first chapter covers the introduction and historical of the Piezoelectric.

The second chapter gives a brief background of piezoelectrics, for example, discovery of the piezoelectric effect, invention of piezoelectric materials, and applications of piezoelectric materials. Modern Control Equipment regularly uses Programmable Logic Controllers.

The third chapter describes the use of SIEMENS S7-1200 model in writing and developing ladder Logic programme. PLC system was additionally described which incorporates the fundamental functional mechanism of processor unit, memory, power supply unit, input and output interface section, communications interface and the programming devices.

The fourth chapter describes design of PLC hyrdualic press and production procedure of a piezoelectric sensor.

Finally, the last chapter gives the conclusion of the research work and suggests areas of future researches.

CHAPTER TWO

HISTORICAL BACKGROUND

2.1 Piezoelectric

The name *piezo* is Greek terminology which is means to *press*. In electrical engineering, piezoelectricity refers to the charges that increase in certain solid materials such as biological materials like bones, DNA different protiens and certains ceramics. They fast grew as an original field of research inside the previous part of the 19 century. In 1880, some materials like zincblende, topaz, and quartz, mechanical stresses came with macroscopic polarization property were discovered by the Curie brothers and hence, this lead to the production of electric surface charges (Cady, 1946).

Lippmann in succeding year, from the modynamic perspectives, deduced the converse effect an imposed voltage produces mechanical deformations or strains the material. In the early 1920's it was found in quartz and used to realize crystal resonators for the stabilization of oscillators, thereby leading to the development into the field of frequency control. Piezoelectric materials made by human expanded the field of applications.

The devices based on piezoelectricity can be found in sonar, hydro-phone, micro-phones, piezo-ignition systems, accelerometers, etc. Kawai in 1969 discovered a powerful piezoelectric effect in polyvinylidene fluoride (PVDF) polymer, Today, piezoelectric applications finds its uses in smart materials for vibration control, aerospace and astronautical applications, sensors for applications of the robot, and version vibration reduction application in sports materials. Recently, the latest and exponentially growing areas of utilization are the non-volatile memory and the integral incorporation of mechanical actuation and sensing microstructures into electronic chips.

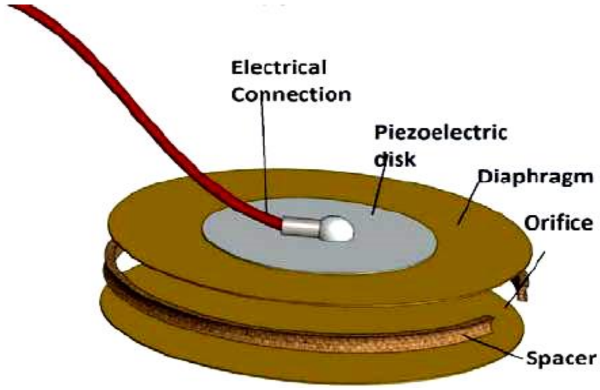


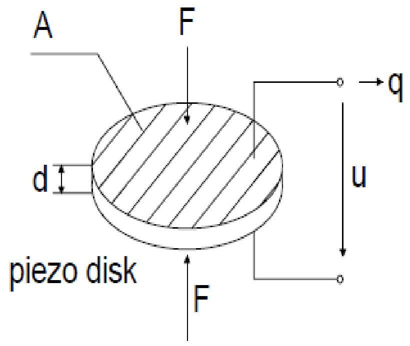
Figure 2.1 Piezoelectric disks (Iklaq et al., 2014)

Ferrelectrics were discovered during the periods of the Second World War (II) and they produced a piezolectric constant much more powerful than natural pizeolectrics. At the same times as quartz crystals were the primary commercially exploited piezoelectric material and still utilized in sonar detection applications, researchers continued to search for better performance materials. Those researches resulted in the development of barium titanate and lead zirconate titanate, materials that had specific properties suitable for specific applications. The capability of positive materials to generate an electric charge rate in response to carried out mechanical strain is referred the piezoelectrıc effect.

One of the important characteristics of this effect is that materials exhibiting the direct piezoelectric impact and additionally exhibit the converse piezoelectric effect. When those materials are located under mechanical stress, a shift in the (+) and (-) charge centers in the substance happens which subsequent results in an external electrical field (Metra Mess-und Frequenztechnik, 2012).

When reversed an outer electrical field both compresses and expands the material. This effect is generally charged within more applications that involve the generation and detection of sound, generation of high voltages, digital frequency generation. It’s also the idea of a number of methodical instrumental techniques with atomic resolution, like scanning probe micro-scopes.

Another one of the majority common place uses can be establish within the explosion supply for cigarette lighters and it shapes the active element of an accelerometer. The below Figure 2.2 explains the piezoelectric effect using a compression disk. A compression disk resembles a capacitor with the piezoceramic matter sandwiched between two electrodes. A force implemented perpendicular to the disk produces a charge and a voltage at the electrodes.



$$q = d_{33}F$$
$$u = \frac{d_{33}.d}{e_{33}.A}.F$$

A	Electrode area
d	Thinkness
F	Force
q	Charge
u	Voltage
d_{33}, e_{33}	Piezo constant

Figure 2.2 Piezoelectric efect basic calculation (Metra Mess-und Frequenztechnik, 2012)

Piezoelectric accelerometers are two main sensing fractions:

- Piezo-ceramic material.
- Seismic mass.

The first surface of the piezo-cermic material might be attached to an inflexible post on the sensor base named the seismic mass and connected to the second surface. Whenever the accelerometer receives targeted on vibration, a force which acts on the piezoelectric material is generated.

As the Newton's Law, the force should be same to the acceleration multiplied by using the seismic mass. The piezoelectric effect an accused output which varies with the carried out force should be generated, due to the seismic mass is permanente, the charge output signal and the acceleration of the mass are proportional.

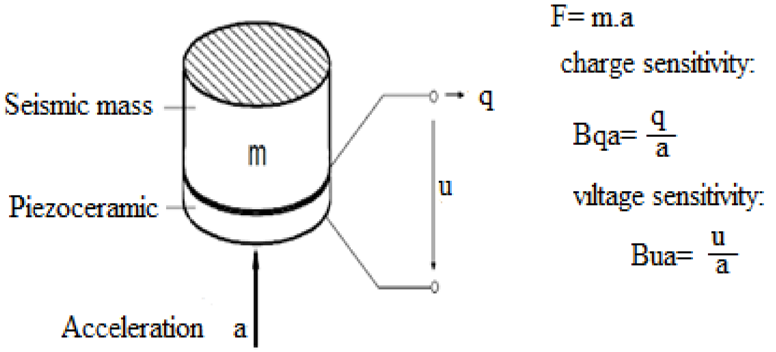


Figure 2.3 Principle of piezoelectric accelerometer

Besides a wide frequency variety, sensors base and seismic mass both have the same acceleration magnitude. The piezoelectric element is attached to the sensor socket through a pair of electrodes. A number of accelerometer features an integrated electronic circuit which converts the high impedance charge output into a low impedance voltage signal. The sensitivity does not dependent on frequency as long as the frequency falls in the useful operating frequency range. It can consider a piezoelectric accelerometer as a mechanical low pass with resonance peak.

A spring mass system is formed by the seismic mass and the piezoceramics; it explains its characteristics and provided us the higher frequency limit of an accelerometer. To get a much wider operating frequency variety, the frequency of the resonance must be increased. This can be finished through reducing the seismic mass (Metra Mess-und Frequenztechnik, 2012).

Therefore, an accelerometer with high resonance frequency will be at lower sensitivity while a seismic accelerometer with better sensitivity has a low frequency of resonance.

Figure 2.4 shows a frequency response the graph of an accelerometer having a steady acceleration excitation.

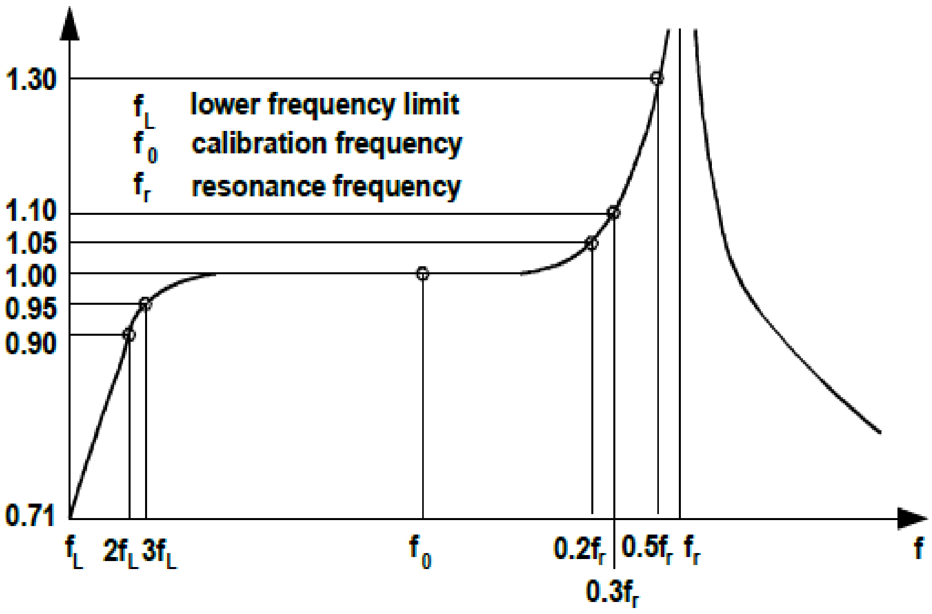


Figure 2.4 Frequency responses curve

So many helpful ranges of frequency may result from this graph:

- Just about 20% of the resonance frequency gives 1.05 of the response of the sensor. This shows that the measured error in comparison with lower frequencies is just 5%.
- At presently about 33% of the resonance frequency, the error is 10%, due to this (linear) frequency variety should be regarded limited to only 33% of the resonance frequency.
- The limit of 3 dB occurring in the region of 30 % error is measured at nearly 50% of the quality frequency.

The lower limit of the frequency relies upon at the pre-amplifier selected. It can continually be adjusted with voltage amplifiers, the lower limit of the frequency varies with the resistance capacitor (R-C) time constant shaped through accelerometer, cable, and amplifier input capacitance collectively with the amplifier input resistance.

2.2 Classification of Dielectric Materials

The majority of dielectric experiences are shift in measurement when they are subjected to an external field. This development is proportional to the uprooting of positive and negative charges in the material. At the point that an external electric field gets attached to the material, a displacement in the direction of the electric field occurs in the cations and gets uprooting the anions in opposite direction happens, giving as a clear deformation of the material.

A dielectric crystal may comprises of a cation and anion joined together by springs and a change dimension of the material might be little or very significant, depending upon the crystal class to which the dielectric belongs to. Thirty two crystal classes exist, out of which eleven possess a center of symmetry or inversion center and twenty one don't have a centre of symmetry, “Centro-symmetric and Non Centro-symmetric”

At the point, when these materials with a symmetrical center are subjected to an external electric field, because of the symmetry. The cations and anions move in such a manner that the estretching and contraction gets cancelled among springs (chemical bonds) near to them and the clear deformation in the crystal to be preferably zeros. But the chemical bonds are not enharmonic, there will be 2nd order consequences ensuing in a small net deformation of the lattice which varies with the square of the electric field. That is the deformation does not dependent upon the direction of the carried out electric field. The impact is stated to be electrostrictive impact. The enharmonic effect exists in all dielectrics, so these points out that all dielectrics are electrostrictive (Vijaya, 2012).

Whenever a dielectric material having a place with a non centro-symmetric category is subjected to external electric field, there will be a motion asymmetrical to the neighboring ions, inflicting important deformation of the crystal that is in direct proportion with the implemented electric field. Those materials are symptoms of an electrostrictive effect due to the enharmonicity of the bonds; therefore, it is included by various important asymmetric displacements. These materials are stated to be piezoelectric materials. The arrangement of dielectric materials based on their response to external shown in Figure 2.5

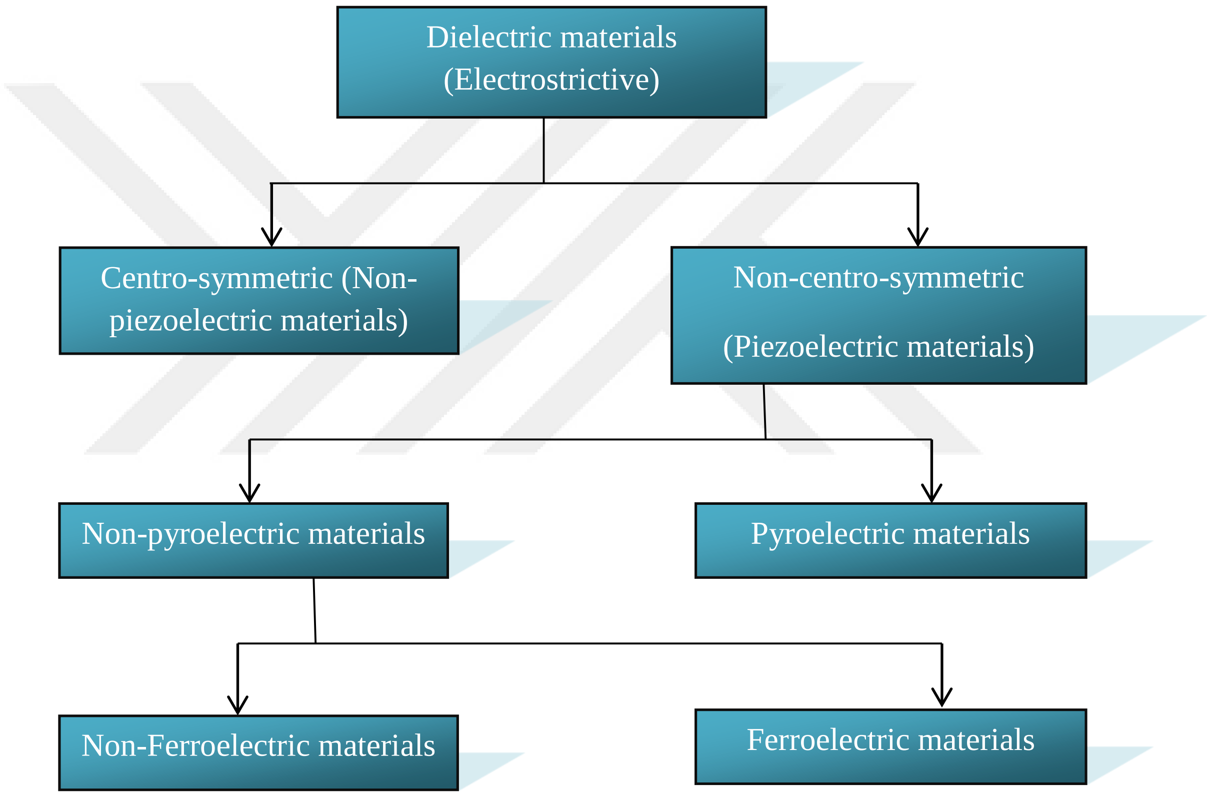


Figure 2.5 Classifications of dielectric materials (Vijaya, 2012)

Each one of those collections of materials indicates certain distinguished characteristics that make them essential to engineering materials. Because they exhibit inherent transducer characteristics materials, they are classified as smart materials.

2.3 Poling Process of Piezoelectric Material

Piezoelectric materials can be standard or man-made; the most generally recognized common piezoelectric material is quartz. But man-made piezoelectric materials are strong and frequently ceramics. Because of their complex crystalline frame, the process made by them is constant and has to follow only specific steps. The elements were thrown up according to an exact temperature and time program, for the duration of the piezo powder particles sinter and the crystalline frame. The elements were cooled and then formed to specifications and electrodes were applied to surfaces that are appropriate (Prewitt, A.D. 2012).

However, electric performance is a sign of piezoelectric material which goes about as a dipole simply lower a specific temperature recognized as Curie temperature. The crystalline arrangement will get a easy cubic symmetry so no dipole instant. On the contrary to the Curie point, the crystal will get quadrangular or rhombohedra symmetry, for this reason, on this connecting dipoles structure areas are recognized as Weiss domains and effects a larger dipole instant as each dipole within the domain has nearly the similar direction, as a result a clear polarization. The alternate direction of polarization among neighboring domains is random, forming the complete material as neutral with no overall polarization.

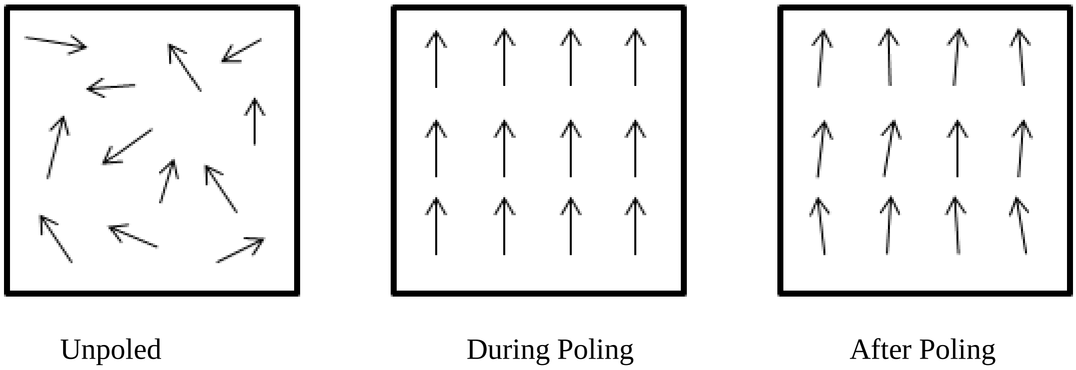


Figure 2.6 Poling of piezoelectric material (Prewitt, A.D. 2012)

For the material to be polarized, it is showing to a complicated and DC electric field whose aim is to line up all dipoles inside the material. Finally this transformation has to be made below the Curie point so that dipoles are usually there.

The material obtains its dipoles nearly aligned with the electric field and now has a permanent polarization which performs as the remnant polarization after the electric field is displaced; due to a hysteretic character and it also receive longer in the direction of the field, for the same hysteretic reason.

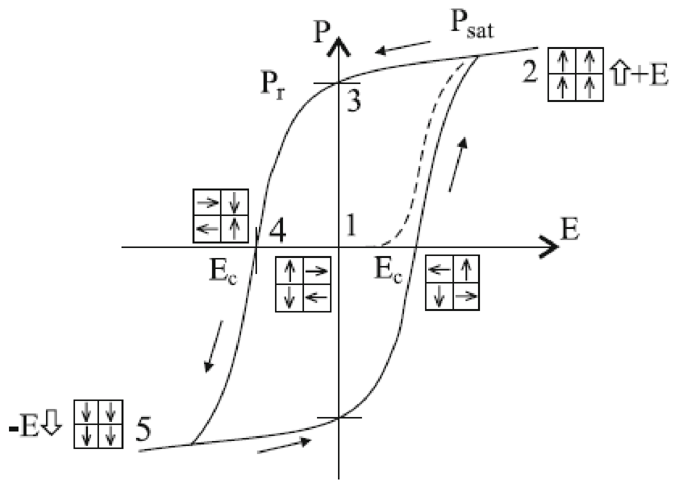


Figure 2.7 Hysteretic curve of polarization (Prewitt, A.D. 2012)

The piezoelectric material which is commonly known is quartz. But piezoelectric materials are many.
Below are the most used ones**:**

- Quartz *(SiO2):* Quartz has a physically powerful piezoelectricity because of its crystalline structure. When a force is applied on a quartz crystal an electrical polarization may be shown along side the pressure direction.
- Berlinite (AlPO4): Gallium orthophosphate *(GaPO4)*: Gallium orthophosphate has usually the similar to crystalline configuration as quartz and also has the similar properties.

However its piezoelectric effect is mostly two times as considerable as the quartz, building it a precious asset for mechanical application. It is an artificial element, it needs to be synthesized.

- *Tourmaline*: Crystal is able variety from violet to green and pink, it is generally black.
- *Barium Titanate ($BaTiO3$)*: This element is made of electrical ceramics; it is substituted with lead zirconate titanate (PZT) for piezoelectricity. It is utilized for microphones and transducers.
- *Lead Zirconate Titanate (PZT)*: It is considered today one of the most in exclusive piezoelectric elements, therefore it is used in several of applications.

2.4 Piezoelectric Effect

The existence of an external mechanical pressure, the internal reticular can be distorted, as a result bringing about the division of the positive and negative focuses of the particle and creating little dipoles as pointed out in the Figure 2.8 (b). Analysis of that, the inverse confronting posts inside the material drop each other and settled charges show at first surface. This is represented in Figure 2.8 (c). That means the material is polarized and the effect is called direct piezoelectric effect. An electric field result from this polarization can be used to change the mechanical energy and utilized as a part of the material's deformation into electrical energy.

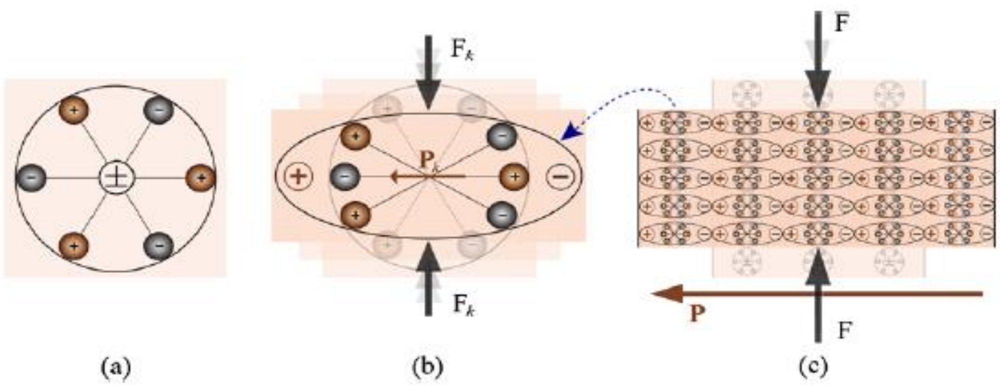


Figure 2.8 Piezoelectric effect explained with a simple molecular model (Dahiya, 2013)

The piezoelectric material between two metal electrodes is placed on opposite surfaces. If the electrodes are externally short circuited with a galvanometer linked to the short circuiting cable and force is useful the outside of piezoelectric material and charge density comes into viewpoint on the surfaces of the crystal in linked with the electrodes. This polarization generates an electric field that sequentially causes the flow of without charges offered in the conductor. Supplying on their sign, the free charges can shift toward the ends where the fixed charges generated by polarization to the opposite sign (Vijaya, 2012).

This flow of free charge keeps on the free charge deactivated the polarization effect, as shown in Figure 2.9(a).

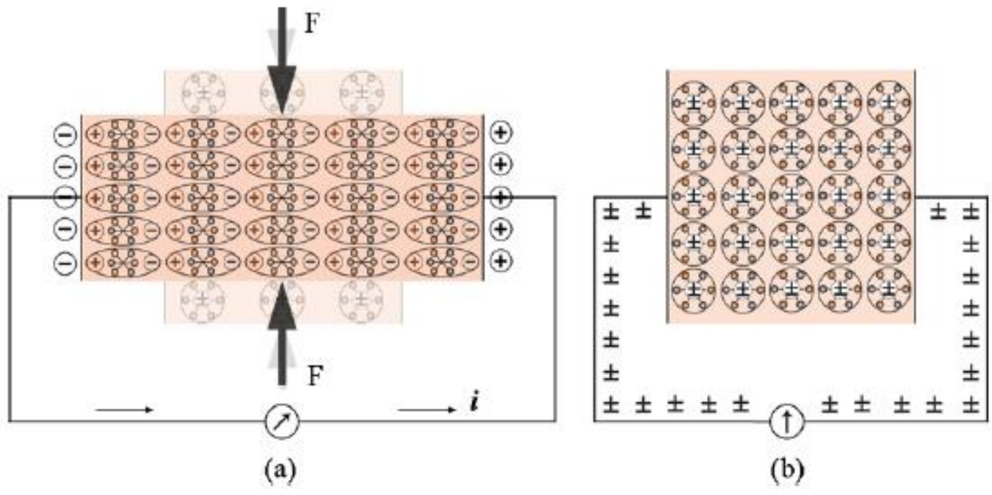


Figure 2.9 Piezoelectric phenomenon (Dahiya, 2013)

This implies that no charge flows within the steady state or in the untroubled state regardless of the presence of external force. The polarization also disappears once the force on the material is removed; the flow of with no charges opposite and typically the material approaches to its original state as indicated in Figure 2.9 (b). This process would be proven on the galvanometer, which may have marked opposite sign current peaks. If short circuiting cable becomes replaced with a resistance load, this would flow through it and mechanical energy would be changed into electrical energy. This method is essential for various energy harvesting systems, those ambient mechanical energy which include vibrations and transfer it into usable electrical shape (Dahiya, 2013).

A number of materials shows the opposite piezoelectric effect, a mechanical strain that made inside of the material when a voltage is carried across the electrodes. The strain generated in this technique could be used to displace a coupled mechanical load. This way of fixing the electrical energy into functional mechanical energy is basic to the applications of nano-positioning devices.

2.5 Piezoelectric Materials

Piezoelectrics are the group of dielectric materials which should be polarized, in similarly to an electric field, additionally with application of a mechanical pressure as established in Figure 2.10 this individual property exhibited through a few dielectric materials is named piezoelectricity, or, literally, pressure electricity. Piezoelectric materials can be divided into polar and non polar piezoelectric. A detailed description of the piezoelectric effect is known in following sections.

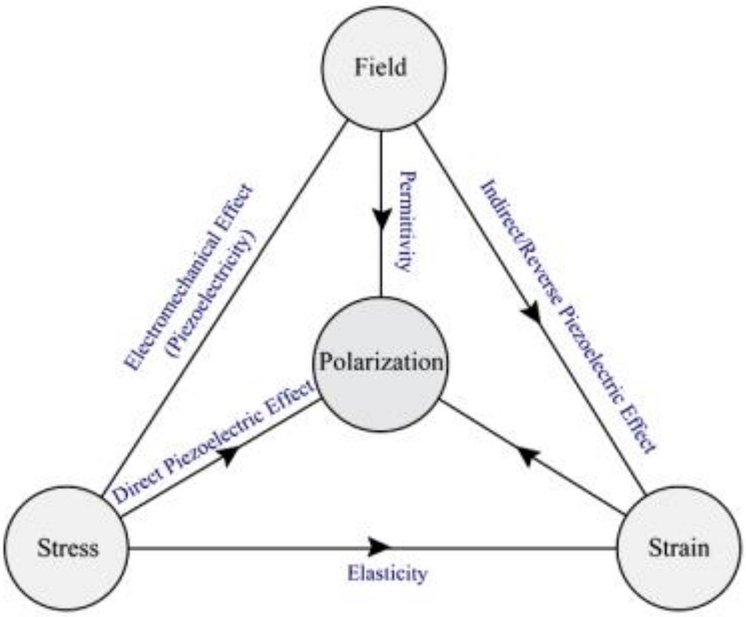


Figure 2.10 Piezoelectric, combination of electric and elastic phenomena (Dahiya, 2013)

The piezoelectric materials are anisotropic in nature and therefore their electrical, mechanical, and electro-mechanical properties are special for the electrical and mechanical excitations along specific instructions, making use of them in numerous sensing or actuating applications needs a systematic tabulation of their properties for which, a standardized means for identifying directions is very important.

Wherever crystals are involved the orthogonal axes at first assigned with the aid of crystallographers are used for this reason. A general examine to recognize the axes is to assign them the numerals. 1 correspond to *X* axis 2 corresponds to *Y* axis, and 3 corresponds to *Z* axis. Those axes are set for the duration of Poling, the process that makes piezoelectric properties within the piezoelectric material. The orientation of the DC poling field determines the orientation of the mechanical and electrical axes.

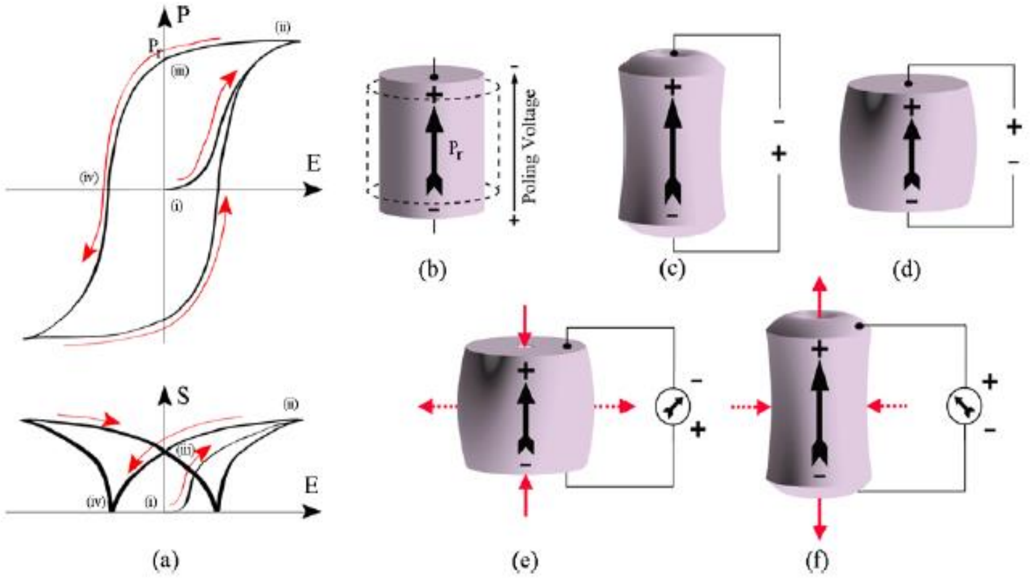


Figure 2.11 Piezoelectric materials in sensing (Dahiya, 2013)

The direction of the poling field is on the whole recognized as one of the X. The poling field is frequently applied in same to way that the material exhibits piezoelectric responses in different directions.

The poling method for completely transforms the dimensions of a piezoelectric material, Figure 2.11 (b) the dimension between the poling electrodes will increases and the dimensions parallel to the electrodes decrease. In different materials the poling step is additionally necessary for the introduction of piezoelectricity.

When the poling method is complete, and then a voltage lowers than the poling voltage transforms the dimensions of the piezoelectric material for as long as the voltage is applied. A voltage with identical polarity as the poling voltage causes further expansion along the poling X and contraction perpendicular to the poling X, in Figure 2.11 (c). One may also take in this from the P-E and S-E plots shown in Figure 2.11 (a).

After poling process, if a procedure a compressive and tensile force is applied to the piezoelectric material, a voltage is generated as exposed in Figure 2.11(d). With an argument comparable to that presented in previous paragraph it is able exposed that the generated voltage may have the similar polarity because the poling field after a compressive force is applied along the poling X or a tensile force applied perpendicular to the poling X.

This is illustrated in Figure 2.11 (e). In the same way, as designated in Figure 2.11 (f), a voltage with the alternative polarity can result as soon as a tensile force is implemented on the poling X or once a compressive force is applied perpendicular to the poling X.

2.6 Different Vibration Modes in Piezoelectric Material

The piezoelectric crystal vibrates in one of a kind manner at exceptional frequency which in different phrase may be term as vibration mode, different vibration modes can be recognized by building crystals of different shapes. To realize cost successful and far performance products, many modes had been to function over numerous frequency levels. Those modes permitted us to make items running inside the low kHz variety as much as the MHz variety.

Absolutely diverse vibration modes and frequency is shown on Figure 2.12.

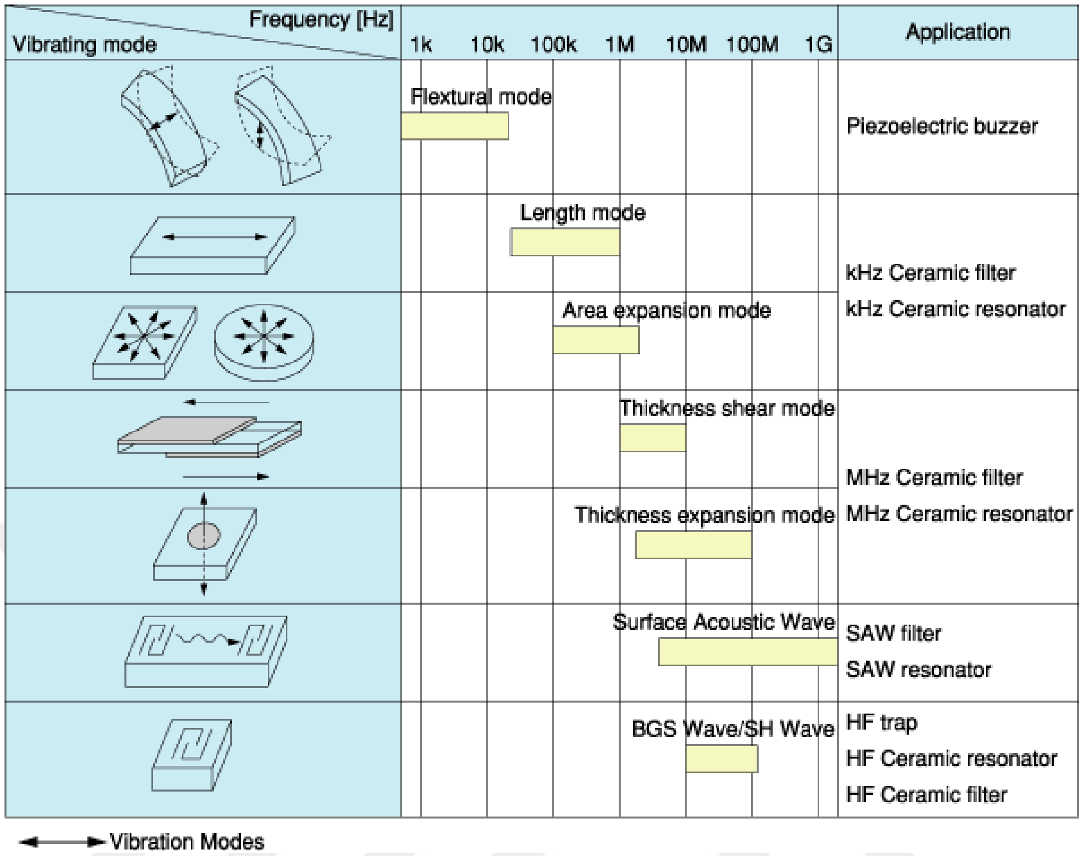


Figure 2.12 Different types of vibration modes of piezoelectric materials

2.7 Piezoelectric Characteristics

Piezoelectric materials may be categorized as direct piezoelectric effect and indirect piezoelectric effect, within the direct piezoelectric effect, the input is mechanical energy and the output is electrical energy. Mechanical input may be within the shape of external stress (*X*) or strain (*x*). Electrical output is inside the form of outside charge density (*D* or *P*), electric field (*E*), or voltage (*V*) Figure 2.10. The indirect piezoelectric effect, the input is electrical energy and the output is mechanical energy. The electrical input can be in the shape of outside charge density (*P/D*) or electric field (*E*) or voltage (*V*), and also the mechanical output is inside the shape of strain (*x*) or stress (*X*) on the material. The parameters that specify the sensitivity of a piezoelectric material are the piezoelectric coefficients that transmit the input and output parameters (Vijaya, 2012).

Piezoelectric Coefficients:

In the direct piezoelectric effect, those equations that relate the mechanical input strain x to the electrical output (D/E) are:

$$D = ex$$

$$E = hx$$

The equation that relate the mechanical input stress X to the electrical output (D/E)

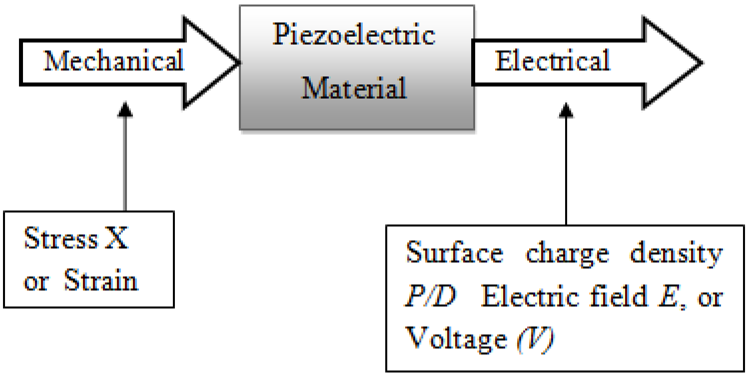


Figure 2.13 Direct Piezoelectric Effects, Input is Mechanical and output is Electrical

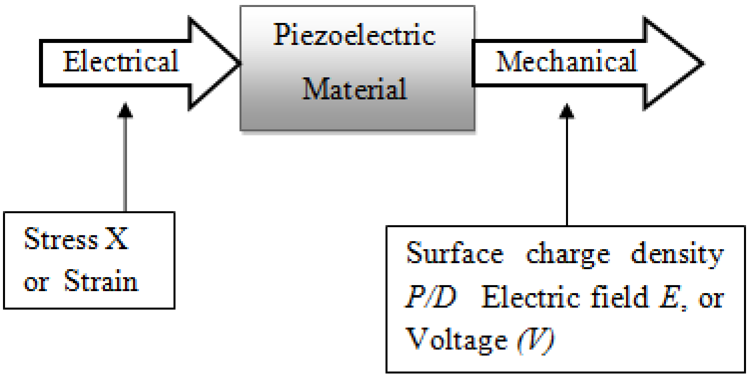


Figure 2.14 Indirect piezoelectric effects, ınput is electrical and output is mechanical.

Imagery of the piezoelectric coefficients and its units are summarized in table 2.1

Piezoelectric materials are characterized by using the following parameters:

- Piezoelectric coefficients: *d*, *g*, *e*, *h*.
- Electrical parameter -permittivity ε
- Elastic parameter- compliance constant *s* and stiffness constant *c*

Table 2.1 Piezoelectric coefficients.

Piezoelectric Coefficient	Definition	Unit
d	$\frac{\text{polarization}}{\text{stress}}$	C/N
g	$\frac{\text{electric field}}{\text{stress}}$	$V.\text{m}/N$
e	$\frac{\text{Polarization}}{\text{Strain}}$	C/m^2
h	$\frac{\text{electric field}}{\text{strain}}$	V/m
d^*	$\frac{\text{strain}}{\text{electric field}}$	$\text{m}/volt$
g^*	$\frac{\text{strain}}{\text{polarization}}$	m^2/C
e^*	$\frac{\text{stress}}{\text{electric field}}$	$N/V.m$
h^*	$\frac{\text{stress}}{\text{polarization}}$	N/C

2.8 Applications of Piezoelectric Materials

2.8.1 Gas Lighter

This is a normal device which makes use of the direct piezoelectric effect to generate electric sparks. In a gas lighter, a high voltage pulse is required to be generated throughout a narrow electrode gap. It includes a Lead Zirconate Titanate (PZT) cylinder this is concentrated to a stress pulse with using a spring mechanism. While the switch is pressed, a stress pulse is functioned on the piezoelectric cylinder which generates excessive and formed to show across a small air gap among two strongly spaced electrodes. The voltage developed is excessive enough to motive breakdown of the air gap linking the two electrodes, resulting in a spark (Vijaya, 2012).

Table 2.2 Engineering applications of piezoelectric materials.

Piezoelectric Effect used	*Energy Conversion*	*Applications*
Direct effect	Input: *Mechanical* output: *Electrical*	Gas lighter Pressure, sensor Accelerometer, Gyroscope (rotation sensor), Piezoelectric microphon, Ultrasonic detecto Hydrophone (SONAR), Tactile sensor, Energy harvesting.
Indirect effect	Input: *Electrical* Output: *Mechanical*	Low-frequency applications, Electronic buzzer Tweeters (high-frequency speakers) Actuators, *High frequency applications*, Piezoelectric motor, Piezoelectric pump,Ultrasonic drill Ultrasonic cleaner, Ultrasonic generator Projector (SONAR).
Both direct and indirect effects	Input: *Electrical/Mechanical* Output: *Mechanical/Electrical*	Quartz crystal oscillator, Quartz crystal balance Quartz crystal AFM probe, Piezoelectric transformer, Ultrasonic nondestructive testing noise and vibration control, Structural health monitoring smart devices and robots.

A stress pulse of amplitude *X*3 generates an electric field *E*3

$$E_{33} = g_{33}\ X_3$$

The electric field is generated across the length *l* of the cylinder. The open circuit voltage generated will be:

$$V = lE_3 = lg_{33}\ X_3 = lg_{33}\,\frac{F}{A}$$

Where (F) is the force pulse amplitude and (A) is the space of pass section of the cylinder, taking the g_{33} value of piezoelectric material PZT as 22 × 10−3 Vm/N, the voltage generated pass through a cylinder of length 1 cm and radius 5 mm for an implemented force of 4.5 × 103 N could be concerning 12.5 KV, that is excessive surfficient to purpose a spark.

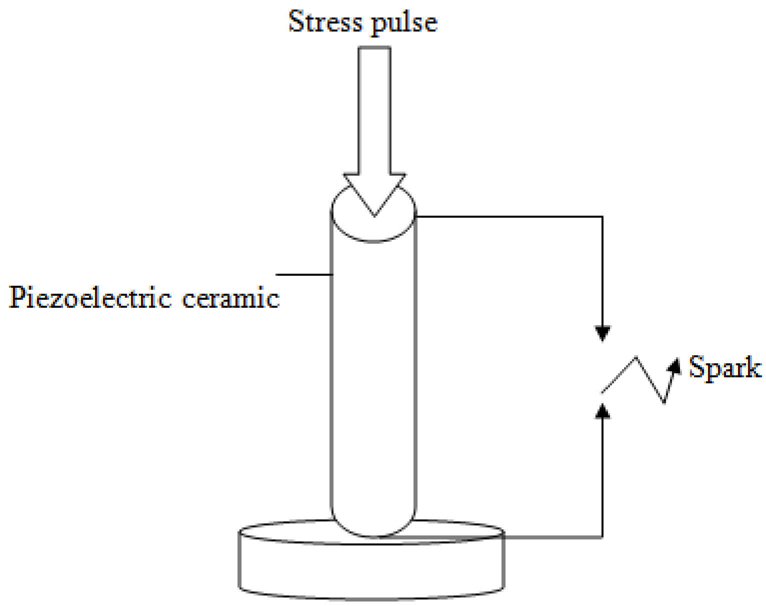


Figure 2.15 Piezoelectric gases lighter.

2.8.2 Accelerometer

Those accelerometers are used for measurement of vibrations in varied purposes, this effect acceleration levels experienced by using cars for all through crash, shock experienced through space vehicles and load in period of separation, trying of shock resistance of packaged products, vibrations in mining activities and seismic vibrations during earthquakes.

(a) Principle of Piezoelectric Accelerometer

A piezoelectric accelerometer instrument essentially consists of a piezoelectric disc clamped between a base plate and a seismic mass *M*.

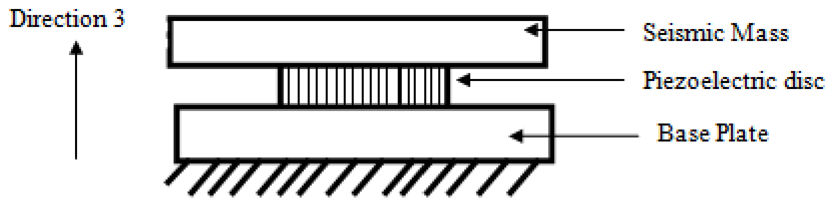


Figure 2.16 Basic parts of a typical compressive type piezoelectric accelerometer

While the system is subjected to acceleration, the seismic mass exerts a force *F* on the piezoelectric disc given by:

$$F = \mathrm{Ma} \qquad (2.1)$$

Where *a* is the acceleration practiced by the disc. The mechanical stress in direction three on the piezoelectric disc is given by:

$$X_3 = \frac{F}{A} = \frac{Ma}{A} \qquad (2.2)$$

Where *A* is the area of the disc, the mechanical stress causes an electric field *E* to be generated across the thickness of the disc given by (Equation 2.1)

$$E_3 = g_{33} X_3 \qquad (2.3)$$

The open circuit voltage across the piezoelectric disc of thickness *t* will be:

$$V = E_3 t = g_{33} X_3 t \qquad (2.4)$$

Alternating for *X*3 from Equation 2.1:

$$V = g_{33} \frac{t}{A} Ma \qquad (2.5)$$

The output voltage is proportional to the acceleration. The proportionality consistent is concluded with the aid of seismic mass M, the piezoelectric coefficient $g33$, and also the dimensions of the piezoelectric disc.

$$C_a = C_o + C_m \tag{2.6}$$

Then the accelerometer output changed into related to a preamplifier, the open circuit voltage will be continued if the input capacitance C_E and the resistance R_E of the amplifier fulfill the conditions.

$$C_E << C_a \tag{2.7}$$

Therefore,

$$R_E >> \frac{1}{\omega C_a}$$

The output of the pre-amplifier is determined of the acceleration; the sensitivity of the accelerometer is expressed like the output voltage consistent with unit of input acceleration. The unit of acceleration is use as g, the acceleration outstanding to gravity. Sensitivity is expressed as millivolts per g of acceleration. The output voltage could be RMS voltage or peak voltage (Vijaya, 2012).

(b) Types of Piezoelectric Accelerometers

There are three types of piezoelectric accelerometers:

(a) Shear design.
(b) Compression design.
(c) Bending design.

A compression design accelerometer includes a piezoelectric disc with a middle hole fitted to a shaft, the disc is connected to an inflexible base and a seismic mass is placed on upper of the disc. The disc and the seismic mass are firmly bonded to each other. The method is raised in unbending framly with a spring as shown in below

Figure 2.17. The external force due to vibration causes compressive forces to act on the piezoelectric disc along its thickness.

The most important components of the three accelerometer designs are:

(a) Shear design

(b) Compression design

(c) Bending design

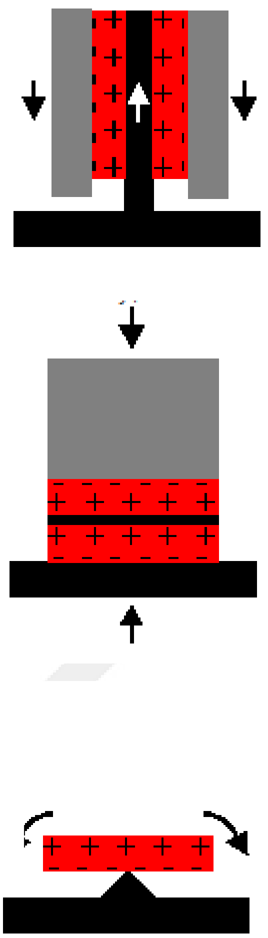


Figure 2.17 Types of accelerometers. (a) Shear design accelerometer cylindrical configuration, (b) Compression design accelerometer (c) Bending design accelerometer.

The purpose of using different piezoelectric systems and their quality of suitability, for some measuring reasons and their different sensitivity to environmental impacts (Vijaya, 2012).

Table 2.3 explains advantages and drawbacks of three designs:

Table 2.3 Piezoelectric accelerometers.

	Shear	***Compression***	***Bending***
Advantage	Low temprature transient Low base Train sensitivity	High sensitivity-to-mass ratio Robustness technological advantages	Best Sensitivity to mass radio
Drawback	Lower sensitivity tp mass ratio	High temperature transient High base strain Sensitivity	Fragile Relatively High Temperature Transient sensştivity

Shear design is good designed within the fire component of modern accelerometers because it's better performance. Excluding, compression and bending kind of sensors are still used in several applications.

CHAPTER THREE

PROGRAMMABLE LOGIC CONTROL (PLC)

SIEMEMS S7-1200 PLC

3.1 Programmable Logic Control (PLC)

A PLC should be a particular group of microprocessor based controller that uses a programmable memory to store instructions and to realize functioning like logic, sequencing, timing, counting and arithmetic so as to control machines and procedures and area unit designed to be worked through engineers with presumably an confined data of computer systems and PC languages. So, it was not designed in order that solely PC programmers will place or changed the programs. Thus, the designers of PLC have before programmed it within order that the control program are frequently entered utilizing a basic, rather resulting structure of language. The Figure 3.1 shows input and output of programmable logic controller. The word logic is used as a result of programming is generally involved with implementing logic and switching operations (Paralı, 2015).

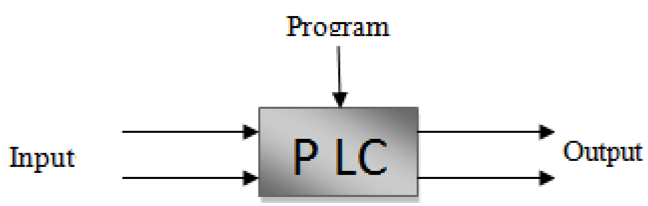


Figure 3.1 Programmable logic controllers

PLCs have the high advantages that constant fundamental controller is regularly used with a good quality of control systems, to improve a control system and therefore the system which is to be used, all that required is for an operator to key through a different position of directions. There’s no need to be forced to wire again; the result's a versatile, charge effective, system which might be used with control systems that modify quite thick in their nature and quality.

The original PLC was built in 1969, they are at present commonly used and extend shape small self contained units for use with possibly 20 digital input/output to modular systems which can be used for large information of input and output, switch of digital or analogue input and output and also holding out proportional integral derivative control modes (Paralı, 2015).

PLCs are utilized to several industries and machines, different common purpose PC; the PLC is supposed for many inputs and output plans, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to manage computer operation square measure usually keep in non-volatile memory.

PLCs were designed to recharge relay logic systems, those PLCs have been programmed in "Ladder Logic" that powerfully resembles a schematic diagram of relay logic. This program in order was selected to decrease preparation demands for the existing technicians.

Farther early PLCs make use of a shape of instruction listing programming, placed a load primarily based logic solver. The current PLCs are programmed in a different type of ways from the relay derived ladder logic to programming languages like especially adapted language of basic and C programme.

Another method is logic an actual high stage programing language designed to program PLCs based on shape change the diagrams. More newly, PLCs are programmed making use of application software program on PCs.

The Computer is connected to the PLC through Ethernet connection, RS-232, RS-485 or RS-422 wiring. The programming software allows access and arranging of the ladder method logic. In the main, the software gives functions for correcting and trouble shooting the PLC software, the high lighting portions of the logic to shown current status throughout operation or using of simulation (Berger, 2013).

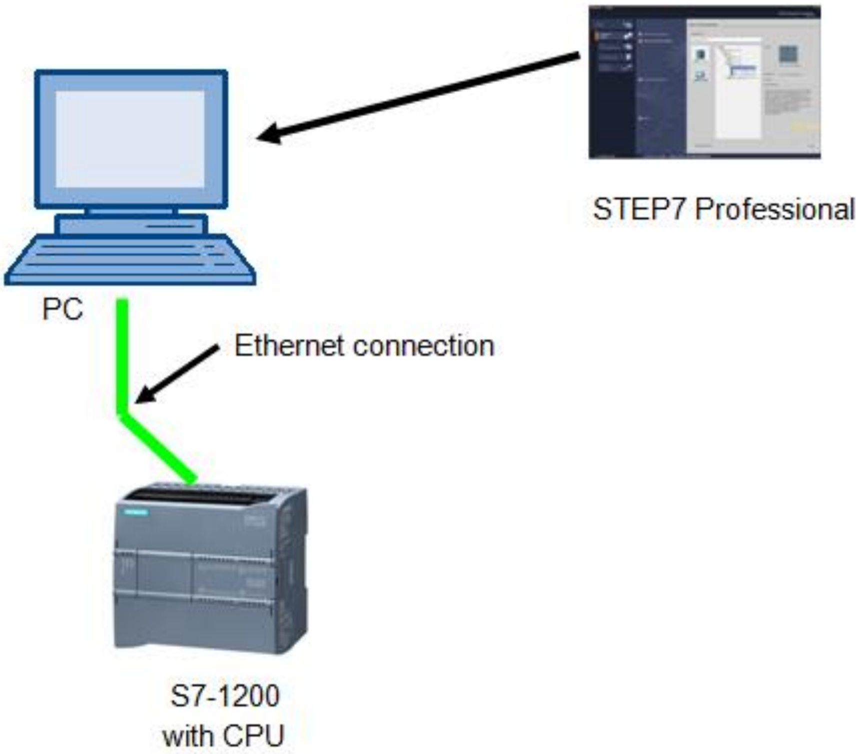


Figure 3.2 Programming (Software/Hardware) of PLC Connection to PC

The software upload can transfer and download the PLC program, designed in support and rebuilding functions. In various models of programmable controller the program is transformed from PC to PLC during the programming board which that writes the program into a removable chip such as an EPROM (Erasable Programmable Read-Only Memory) or EEPROM (Electrically Erasable Programmable Read-Only Memory).

PLCs have constructed in communications ports, normally nine pins, however the optionally EIA-485 or Ethernet. Modbus, BACnet or DF1 is typically contained joined of the communications protocols. Different selections include of numerous field buses (Berger, 2013).

This allows divide components of a complex process to have individual control while permitting the sub-systems to co-ordinate over the communication link.

These communication links are also are usually used for HMI devices such as keypads or PC-type works stations.

Discrete signals work as binary switches, flexible easily an ON or OFF signal. Press button limit switches and photoelectrical sensors are samples of devices provided that a discrete signal. Discrete signals are sent utilizing voltage or current, wherever a selected range is designated as ON and another as OFF. A PLC may use 24 V DC of input and output, with values above 22V DC representing ON, values below 2V DC representing OFF, and Intermediate values undefined intially, PLCs had only discrete. Analog signals are same to amount controls with a range of values among zeros and full scale.

This area unit regularly interpreted as integer counts by means the PLC with totally different ranges of accuracy providing the tools and the amount of bits realizable to store the data. As PLCs usually use 16 bits signed binary processors, the integer number values are restricted between -32,768 (-) and +32,767 (+). Pressure, temperature, flow, and weight are usually represented by analog signals. Analog signals could be use voltage or current with a magnitude proportional to the value of the method signal. An analog (0-10) V input or (4-20) mA would be replaced into an integer value of (0-32767). The structure of a PLC will be divided into 4 components. They are input and output modules, Central Processing Unit (CPU), Memory and Programming terminal.

3.2 Internal Architecture

The basic internal design of a PLC shows the below figure 3.3. It consists of a CPU holding the microprocessor, memory, and Input and output circuit. The CPU controls and processes all the procedures within the PLC. It is prepared a clock with a frequency of generally between 1 and 8 MHz.

This frequency concludes the operational speed of the PLC and offers the timing collection and synchronization for every one of elements in the system.

The information of the PLC is accepted within digital signals, the internal method along of digital signals flow are described the buses, in the physical sense, a buses are simply variety of performers on the electrical signal be able to flow. It can be tracks on a printed circuit board.

The CPU make use of the data buses for transfering data linked the constituent components, the address bus is sends the addresses of positions for contact keeped data and the control bus for signals linking to the internal control actions.

The system buses are applied for communications between the input and output ports and the input and output unit (Berger, 2013).

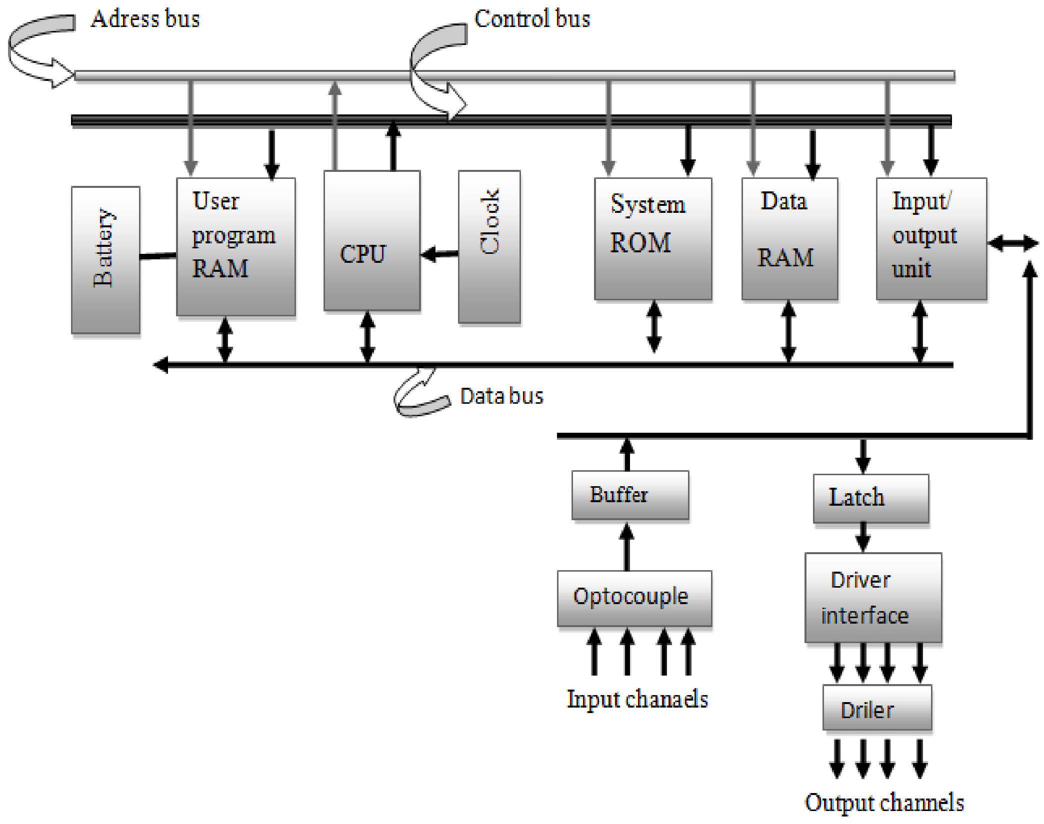


Figure 3.3 Architecture of a PLC

3.2.1 The CPU

The structure of the CPU depends on the microprocessor involved. In normally it has:

a) Arithmetic and Logic Unit (ALU) that is dependable for data manipulation and moving out arithmetic operations of adding, calculation with logic operations of AND, OR, NOT and EXCLUSIVE-OR.
b) Memory, registers, located within the microprocessor and used to store information connected to the program implementation.
c) A control unit which is used to manage the timing arrangement of operations

3.2.2 The Buses

The buses are the methods which it could be used for communication within the PLC, the information is converting to binary form as a grouping of bits being a binary digit of 1 or 0, when digit is one means ON, and also when the digit is zero means OFF states. The expression word applied for the group of bits composing same information. Therefore, 8 bits word may be the binary number 00100110. Each of the bits is communicated at the same time in parallel wire. The system has four buses:

- The ***data bus:*** carries the data used in the process applied through the CPU. A microprocessor termed as being 8 bit has an internal data bus which can handle 8 bit numbers. It can be perform operations between 8 bit numbers and deliver results as 8 bit values.
- The ***address bus:*** used to hold the addresses of memory locations, thus, every term can be positioned in the memory, every memory position is given a single *address*. Just like houses in a town are each given a different address so that they can be located, so each word location is given an address so that data stored at a particular location can be accessed by the CPU either to read data located there or put, i.e. write, data there. It is the address bus which carries the information representing which address is to be accessed. If the address bus consists of 8

lines, the number of 8-bit words, and hence number of distinct addresses, is 2^8 = 256. With 16 address lines, 65536 addresses are possible.

- The ***control bus:*** brings the signal utilized through the CPU for control.
- The ***system bus:*** is made use for communications connecting the input and output ports, and the input and output unit.

3.3 Siemens S7-1200 Programmable controller

3.3.1 S7-1200 PLC

The Siemens S7-1200 controller offers the flexibility and power to control a large selection of tools in maintain of the automation needs. The compact design versatile configuration and effective training set connected to make the S7-1200 an excellent resolution for organizing a wide choice of applications. The CPU combines microprocessor an integrated power supply input and output circuits built in PROFINET, high speed motion control input and output. Therefore, the board analog inputs during a compact housing to get a robust controller.

When the downloaded program in to CPU has the logic needed to monitor and control the devices in our application. The CPU monitors the inputs and changes the outputs in keeping with the logic of program, which consist of Boolean logic, counting, timing, complex math operations, and communications with different intelligent devices. Further modules are obtainable for communicating above PROFIBUS, GPRS, RS485 and RS232 networks.

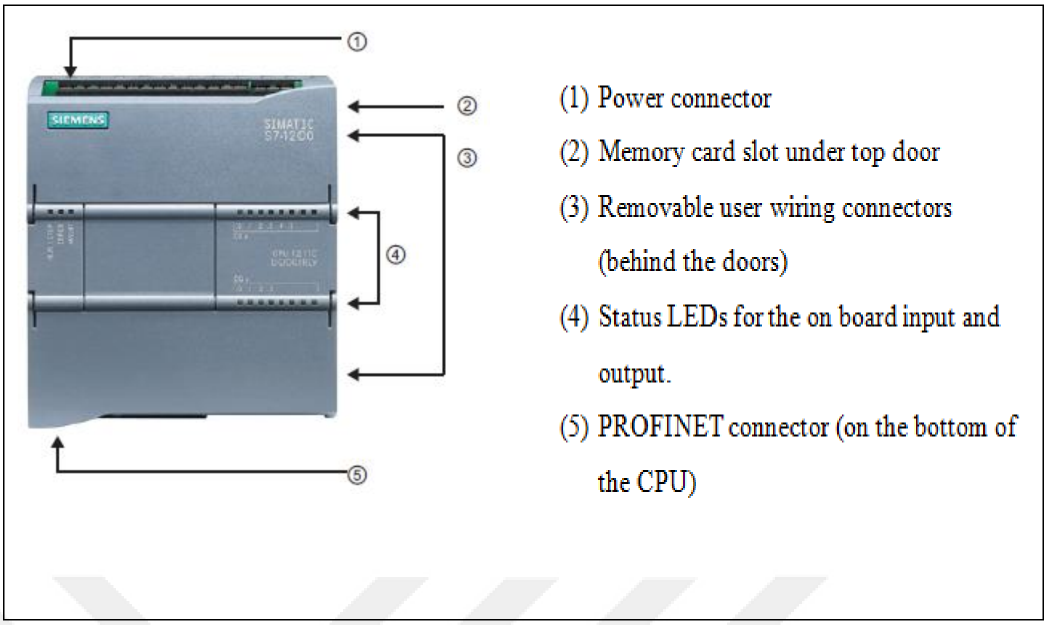


Figure 3.4 PLC of SIEMENS S7-1200 (Berger, 2013)

The memory card can be constructed for different operations:

a) *Program card (P-Card)* : to use the memory card as outside load memory for the CPU and to supply a larger load memory holding area for use with data logging and user.
b) Transfer card (T-Card): to copy a program to the inside load memory of one or more CPUs without using the STEP 7 Basic engineering system.
c) Firm-ware update card (F-Card): to update the firmware of the CPU and all connected S7-1200 hardware.

3.3.2 S7-1200 Station Components

A full programmable controller with all input/output modules is refered to as a station; this also includes distributed input and output modules connected to the CPU by bus system. An S7-1200 station includes at least the CPU. Depending on the version, it has digital and analog input/output channels and can be fixed with additional input and output channels using a Signal Board (SB).

Figure 3.5 S7-1200 Stations with CPU (right) and (left) (Berger, 2013)

Depending on the type of CPU up to eight (8) signal modules can be plugged in which expand the station by digital and analog input/output channels. A two-line design is possible using a two-meter long extension cable. The programming device is connected over Industrial Ethernet. Industrial Ethernet also can be used to connect further SIMATIC stations or HMI devices to the CPU. Up to three communication modules take over the connection to additional bus systems or to a point to point link. Integral technological functions for calculating and counting tasks, closed loop control and motion control permit the CPU 1200 to be used in many complex machine controls (Berger, 2013).

The *SIMATIC Memory Card* can be used to download configuration data, as an external load memory, or for a firmware update. Mounting is a standard 35 mm DIN rail either horizontally or vertically, installation without a mounting rail is also possible. An extension cable (2m long) enables a two-line design without changing the number of connectable signal modules.

Available accessories include an external power supply module, a connection multiplier (Ethernet switch), a *TS* Adapter and two simulator modules. SIMATIC S7-

1200 is also available as a *SIPLUS* version for mostly harsh environmental conditions.

3.3.3 SIEMENS S7-1200 CPU Modules

There are four types of CPU (CPU 1211, CPU 1212, CPU 1214, and CPU 1215), available in each case in the versions DC/DC/DC, AC/DC/RLY, DC/DC/RLY. The first item of data refers to the module power supply (DC = 24 V, AC = 120/230 Volts). The central (middle) item of data refers to the operating voltage of the on board digital inputs (DC = 24 Volts).

The last item of data refers to the type of digital outputs (DC = 24 V direct current electronic, RLY = up to 30 V direct current or up to 250 V alternating current with relay).

The four CPU versions mostly are different in the supply voltage, the number of on board inputs and outputs, the memory size, and the expansion capability with signal modules (Table 3.3). The CPU 1215C can be integrated in STEP 7 Basic V11 with a Hardware Support Package (HSP).

Table 3.3 Selected data of a CPU 1200

	CPU 1222C	CPU 1212C	CPU 1214C	CPU1215
User memory Internal load memory RAM Retentive memory	1MB 30 KB 10KB	1MB 50 KB 10KB	4MB 75 KB 10KB	1MB 100 KB 10KB
Integrated I/Os Digital inputs (DI) Digital output (DO) Analog inputs (AI) Analog outputs (AO)	6DI, 24 V DC 4 DO, 24 V DC or relay 2 AI (10 bit) –	8DI, 24 V DC 6 DO, 24 V DC or relay 2 AI (10bit) –	14 DI, 24 V DC 10 DO, 24 V DC or relay 2 AI (10bit) –	14 DI, 24 V DC 10 DO, 24 V DC or relay 2 AI (10 bit) 2 AO (10 bit)

3.3.4 *Integrated Input/Output*

The Digital inputs (DI) on the CPU module work with an operating voltage of 24 V DC. Different numbers are available depending on the CPU version. The status of the input signals is displayed by means of LEDs. The Digital outputs (DQ/DO) are available in electronic form (24 V DC and 0.5 A output current with a resistive load of 5 W) and as relay outputs (up to 30 V DC and 2 A output current with a resistive load of 30 W or up to 250 V AC and 2 A output current with a resistive load of 200 W). Different numbers of digital outputs are available depending on the CPU version. The status of the output signals is displayed by means of LEDs. Each one of CPU has two Analog Input channels (AI) for 0 to 10 V. The resolution is 10 bits. The analog value can be processed in the user program in the numerical range from 0 to 27 648.

The CPU 1215 has two additional Analog Output channels (AO) for 0 to 20 mA. The resolution is 10 bits. The analog value can be processed in the user program in the mathematical range from 0 to 27 648. The terminal blocks for the inputs and outputs can be removed from all modules without having to disconnect the wiring. The CPU module does not have a mode selector for switching ON/OFF. The operating modes (RUN-STOP) are set online using the programming device.

3.3.5 *PROFINET Connection*

The CPU is connected to an Ethernet network over the PROFINET interface. The connection (port) takes the form of an RJ45 socket. The protocols Transmission Control Protocol (TCP) in according with RFC 793, ISO Transport over TCP (ISO-on-TCP) in accordance with RFC 1006, and User Datagram Protocol (UDP) in accordance with RFC 768 are supported. The connection is able to automatically recognize a transmission rate of 10 or 100 MBit/s (autosensing). Either a standard Ethernet cable or a cross over cable can be used for the network. The CPU can be connected, for example, to a programming device, an HMI device, or other SIMATIC stations over the PROFINET connection. The CPU 1215C has two RJ45 sockets, which are connected with a switch. Figure 3.6 shows the PROFINET connections.

Figure 3.6 PROFINET Connections (Berger, 2013)

The next device can be connected directly to the Ethernet network from the second connection. The additional CPUs have only one RJ45 socket. Here an external switch (connection multiplier) such as the CSM 1277 Compact Switch Module is required when networking several devices. As of firmware version 2.0; a PROFINET input and output controller is integrated in the CPU working system. The CPU can consequently control distributed Input-output input/output by the use of Industrial Ethernet with PROFINET input and output.

3.3.6 *Status LEDs*

The current operating mode of the CPU is indicated by LEDs on the front of the module.

RUN/STO	Constant yellow light in *STOP* mode Constant green light in *RUN* mode Flashing light in *STARTUP* mode.
ERROR	Flashing red light in event of *Error* Constant red light if hardware is faulty
MAINT	Constant yellow light with maintenance request.

Figure 3.7 LED displays on the CPU

After switching on the CPU is in STARTUP mode, it runs during test routines, carries out parameter settings and executes the startup program. Then the CPU changes to the RUN status and executes the user (main) program; this is the “normal” operating status. The CPU returns to the STOP mode if it notice a “serious” error, if it executes a corresponding program statement, or if it is particularly set to this state e.g. by the programming device. The user program is not executed in the STOP mode, but the CPU is still able to communicate, facilitating downloading of parts of the user program, for example.

The ERROR LED flashes when an error has been detected. It lights up permanently if the hardware is faulty. The MAINT LED lights up continuously to indicate that a before configured maintenance request is now present. All LEDs flash if the firmware of the CPU module is faulty.

Figure 3.8 SIMATIC memory cards

3.3.7 Automation System SIMATIC S7-1200

The SIMATIC S7-1200 automation system is a modular mini-control system for the lower and medium performance range. An extensive module spectrum is available for optimum adaptation to the automation task. The S7 controller consists of a power supply, CPU and input and output modules for digital and analog signals. If essential, communication processors and function modules are used for special tasks, such as step motor control. With the S7 program, the programmable logic controller monitors and controls a machine or a process; the input/output modules are polled in the S7 program by means of the input addresses (%I), and addressed by means of output addresses (%Q) (Berger, 2013).

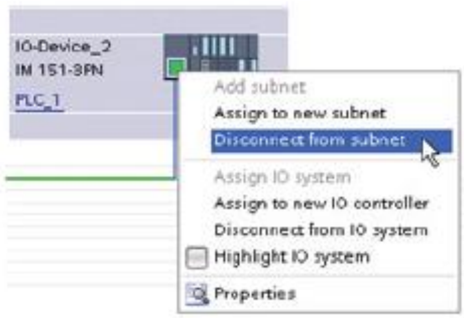
The system is programmed with the software STEP 7 (Berger, 2013).

STEP 7 offers standard programming languages used for convenience and perfomance in developing the control program for the application.

- ***Ladder Logic (LAD):*** a graphical programming language. The symbol relies on circuit diagrams.
- ***Function Block Diagram (FBD):*** a programming language that is supported at the graphical logic symbols used in Boolean algebra.
- ***Structured Control Language (SCL):*** a text based mostly high-level programming language.

3.3.8 Temporarily Disconnecting Devices From a Network

The disconnecting individual network devices from the subnet as a result of the configuration of the device is not remove from the Project. Figure 3.9 shows the CPU network connection and disconnection



Select the command from the context menu "Disconnect from subnet" the interface port of the network device.

Figure 3.9 CPU network disconnect

The network connection does not eliminate the disconnected device from the device. As the network connection is deleted, the interface addresses are not changed.

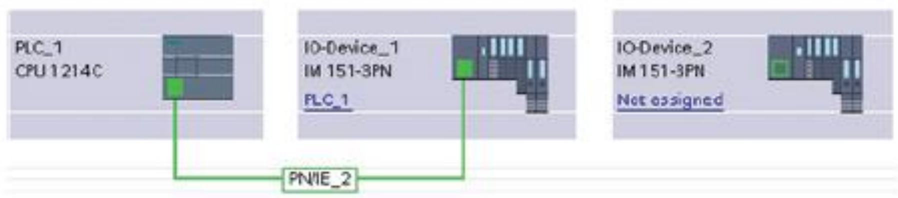


Figure 3.10 CPU Network Connections.

After download the new network connections, the CPU needed to set to STOP mode, and after that reconnect the device again, just create a new network connection to the port of the device.

3.3.9 Virtual Unplugging of Devices from the Configuration

The below Figure 3.11 shows a storage space for "Unplugged" modules, It could draw a module from the frame to save the configuration of that module. These unplugged modules are saved with in device. Single used of this feature for temporary maintenance, it consider a situation which can be remaining for a replacement module and plan to for the time being use in different module as a short-term replacement.

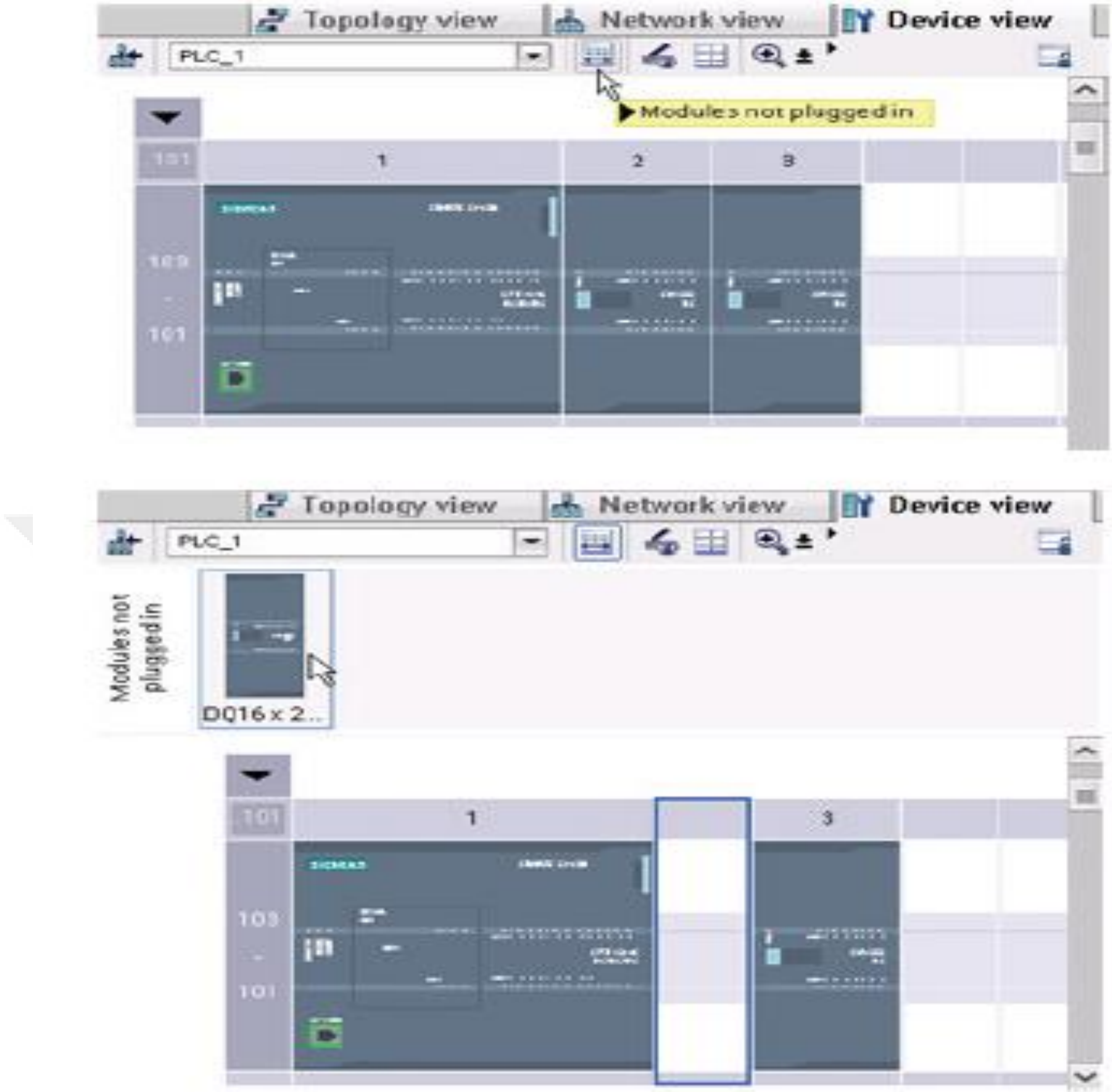


Figure 3.11 CPU unplugging devices (Berger, 2013)

3.4 PLC Software Applications (Programming Language)

The following customary programming languages for S7-1200, once it produce a code block, it should be select the programming language to be utilized by that block, and additionally needed to user program and then draw the code blocks created in the programming languages.

3.4.1 Ladder Logic (LAD)

The drawing block of a circuit diagram, similar to commonly closed and commonly open contacts, and coils are connected to shape networks.

Figure 3.12 LAD Circuit

Drawing the logic for compound operations, it could be insert branches to form the logic for parallel circuits. Parallel branches are opened down-wards or are measure linked to the power rail, the branches up-wards. LAD provides Box directions for a spread of functions; such us mathematics, timer, counter, and move.

The following rules are considering when LAD network drawing:

a) It can not create a branch that could result in a power flow in the opposite direction.

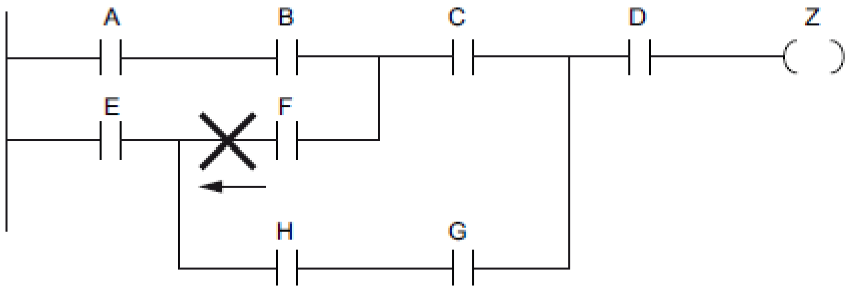


Figure 3.13 LAD opposite direction circuit

b) It can not create a branch that would cause a short circuit.

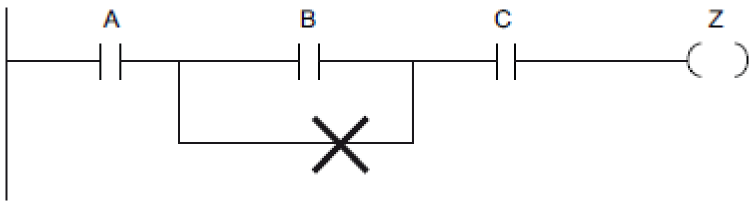


Figure 3.14 LAD short circuits

3.4.2 Local Connection

Communication partners perform the commands to line up and establish the communication connection. It used parameters to specify the active and passive communication end point partners. When the connection is set up and established, it's automatically maintained and Monitored by the CPU.

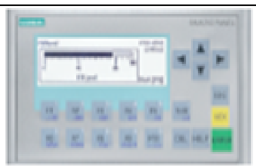
The below Figure 3.15 shows the location connection of CPU. When be connection be finished, the active partner constructs an attempt to re-establish the configured connection. It doesn't require executing the communication instruction once more. The CPU can communicate in alternative CPUs withinm programming devices, with HMI devices and with non-Siemens procedure using regular TCP communications protocols.

Figure 3.15 Local connection of CPU

3.4.3 Human Machine Interface (HMI) panels

HMT panel is converting into a typical component for numerous machine designs; the SIMATIC-HMI Basic Panels gives touch-screen devices for essential operator control and monitoring tasks.

Table 3.2 HMI

Basic HMI Panel	*Description*	*Technical data*
 KP 300 Basic PN	3.6" membrane keyboard with 10 freely configurable tactile keys ✓ Mono (STN, black/white) ✓ 87 mm x 31 mm (3.6) ✓ Backlight color programmed(white, green, yellow or red) ✓ Resolution: 240 x 80	✓ 250 tags ✓ 50 process screens ✓ 200 alarms ✓ 25 curves ✓ 40 KB recipe memory ✓ 5 recipes, 20 data records, 20 entries

CHAPTER FOUR

PLC CONTROLLED HYDRAULIC PRESS SYSTEM

4.1 Hydrualic Press

The hydraulic press is one in all the previously of the fundamental mechanical device tools. Its new descriptor is well adaptedness to energy work zone from coining jewelry to formation aircraft constituent. New hydraulic presses square measure in some cases, higher suited to applications wherever the mechanical press has been historically more popular.

Advantages of hydraulic presses, the mechanical pressure are the primary selection of the many press users for additional years, the making ready of tool, manufacturers and producing engineers has been orientating on the way to applying mechanical presses to sheet metal press working.

New hydraulic press supply large quality execution and dependability, wide spread application of different character of hydraulic power instrumentality in producing needs maintenance technicians to service hydraulic constituent. New quick acting valves, electrical elements and additional efficient hydraulic circuits have increased the capability of hydraulic presses (Lown, 1982).

Force control of hydraulic press, modern industries are marking to bendable result which will be ready to provide some new characteristics of hydraulic systems, in the manner that perform of controlled motion, the feasibility for continuous control of the specified values, simple data transfer and signal process, the feasibility of monitoring and method of conclusion. The speedy developments in electronics in modern years have reduced the price of pc instrumentality to level acceptable for industrial applications program that has allowed the implementation of refined control methods in practice.

Therefore, modern hydraulic arrangement has developed towards electronics and microprocessor controlled electro hydraulic elements so as to realize new control potentialities. In general, due to its complexness, more or less each advanced controller should be implementable on a digital PC, Such as system that has electrically actuated valves will be react the complicated demands display by today's technology. Presses are one among the most usually used machine tools in industry for the forming of various materials. within the past, for the pressing undertaking in industry, mechanical presses were alot of often used, however today hydraulic mechacical press take precedence reached to their varied benefits, such as:

- Full force through the stroke.
- Moving elements that operate with sensible lubrication.
- Force that may be programmed.
- stroke that can be totally adjustable, that contributes to the flexibleness of application,
- safety options that can be programmed and incorporated into the control algorithms,
- Can be created for very large force capacities.

On the hand, hydraulic presses square measure unremarkably slower than mechanical presses, this disadvantage is being overcome with the event of recent valves with higher flow capacities, smaller response times and developed control capabilities. In these styles of applications, the flexibility of force control systems of rules to summarize variable reference signal is commonly needed for the right procedure of the technological method. Additionally, the task of the position control of the hydraulic mechanism is additionally vital.

A replacement quality and vital improvement within the functioning of the press is obtained with a coincidental realization of position feedback.

This thesis describes the development of a hydraulic press and therefore the implementation of electricity sensing element production system by using PLC.

The research also provides an example of hydraulic press control using a PLC as control device, which could be applied in practice.

4.2 Working Procedures

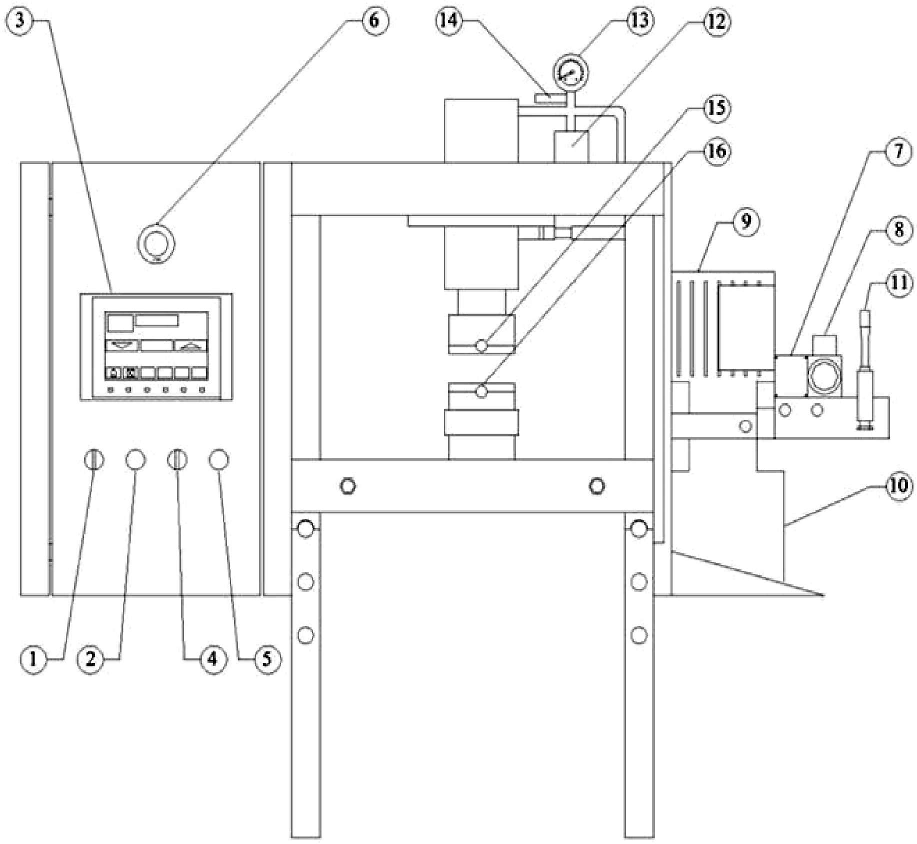
Manual:

It is required in order to allow the plant to start. The PLC does not affect the force selection, but allow selecting the force to start (by using the force change over press on buttons), by this kind, all monitoring functions towards warning light and control are implemented.

Automatic:

According to setup parameter values the system starts working. On the other hand, the software command from control panel, proportional pressure valve (7) and two resistances in top and down jaws are provided (15-16) as electrical.

It provides the pressure values of the hydraulic system. When it reaches the requested pressure value the hydraulic press pressure value reaches stable situation by using check valve (12), for the duration of process, the actual parameter values are visible on the operator panel (3); composite powder material is compressed between top and down jaws with high temperature, when pressure, temperature and process timing values reach to requested values, the hydraulic press working will be stopped by using PLC system. At the end of all processing system piezoelectric composited will be obtained. Figure 4.1 shows the shape of hydraulic press with PLC.



(1) Automatic & Manual Selection Button.

(2) Start Button.

(3) Operator panel.

(4) The upper and lower control of mold

(5) Heater ON/OFF lamp

(6) Emergency Stop Button

(7) Proportional pressure valve.

(8) Direction valve

(9) Electrical Motor

(10) Hydraulic oil tank

(11) Manual Hydraulic press control without Electric.

(12) Check valve

(13) Analogue pressure indicator.

(14) Pressure transmitter (0-10 voltage)

(15) Upper movable mold half

(16) Lower fiexed mold half

Figure 4.1 Hydraulic press with PLC

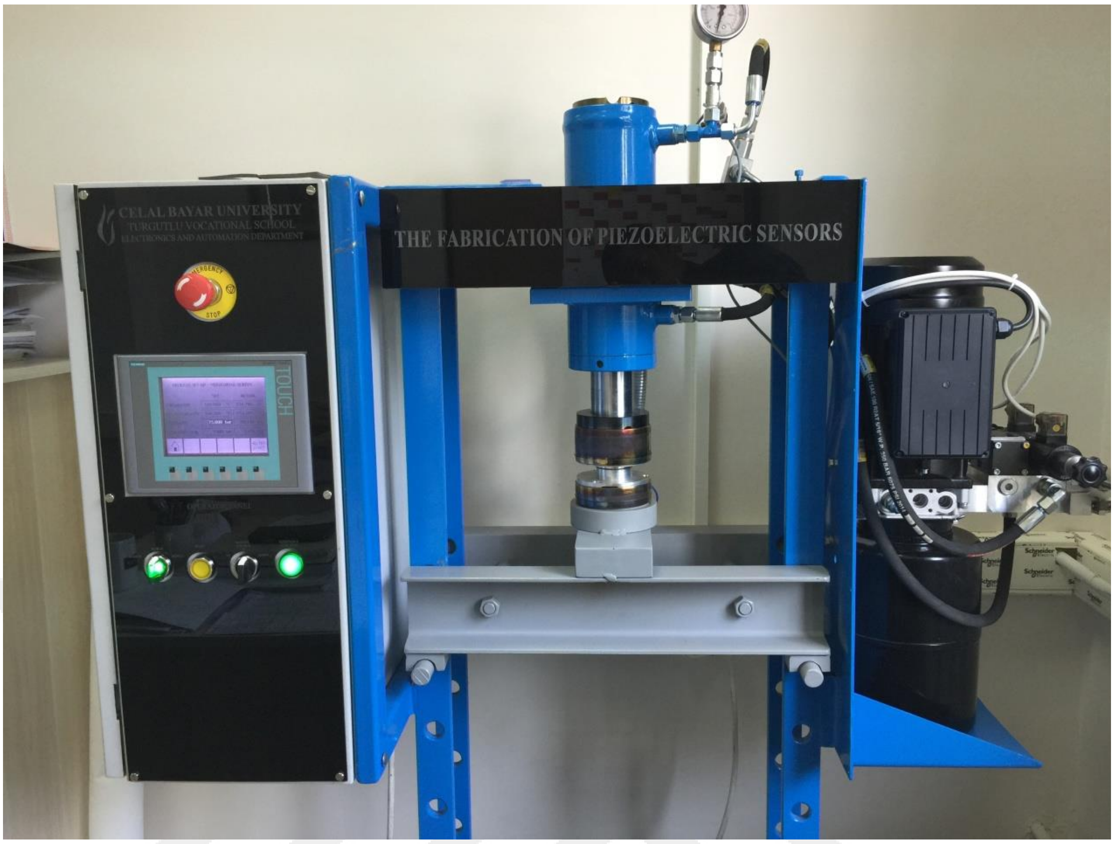


Figure 4.2 Hydraulic press controlled with PLC

An industrial design of the hydraulicl press control is recognized by using a PLC SIMATIC S7-1200, manufactured by Siemens. The control program was built using SIMATIC WinCC suitable software for programming the controller and configuring the HMI panel.

4.3 PLC Software (Ladder Diagram) System of the Work

A normally utilized methodology of programming PLCs is used on the building of ladder diagrams. Writing a program is then comparable to drawing a switching circuit. The ladder diagram consists of two vertical lines in place of to the force rails. Circuits are connected as horizontal lines, the rungs of the ladder between these two verticals. In drawing a ladder, certain conventions are adopted.

PLC run in mode and also it goes through the complete ladder program to the end, the end rung of the program being clearly denoted, so promptly resumes at the beginning, This system of browsing all the rungs of the program is termed a cycle. The end rung could be indicated with a block w and the word END or RET for return, since the program promptly returns to its starting.

4.3.1 Program Blocks

Network 1.

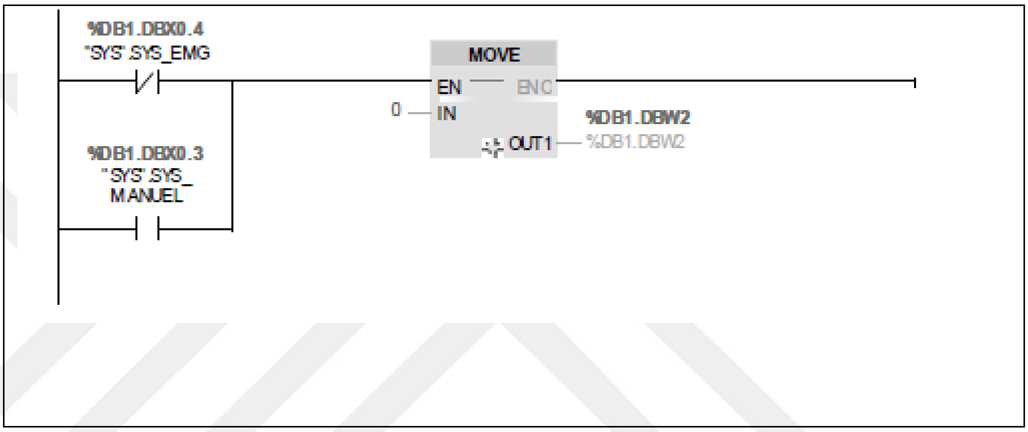


Figure 4.3 System Manual/Emergancy control.

Network 2.

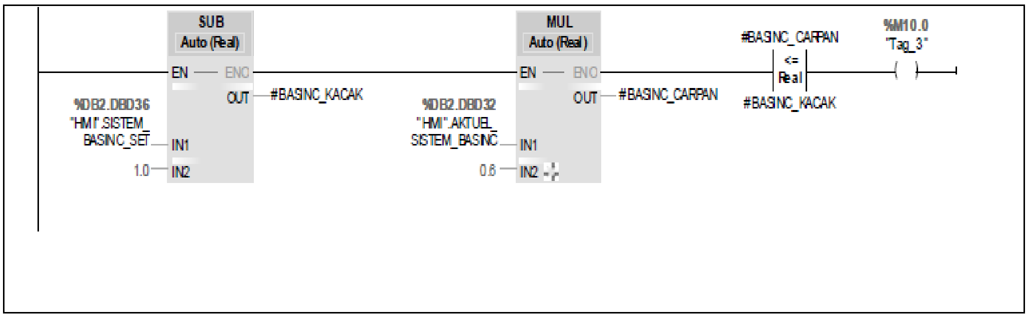


Figure 4.4 HMI is actual system pressure set value.

Network 3.

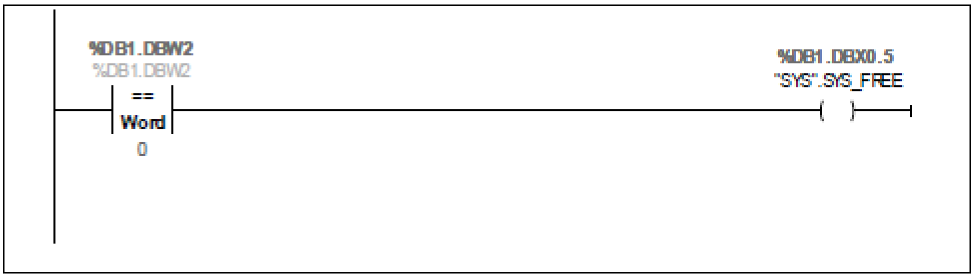


Figure 4.5 Step free control as analog control

Network 4.

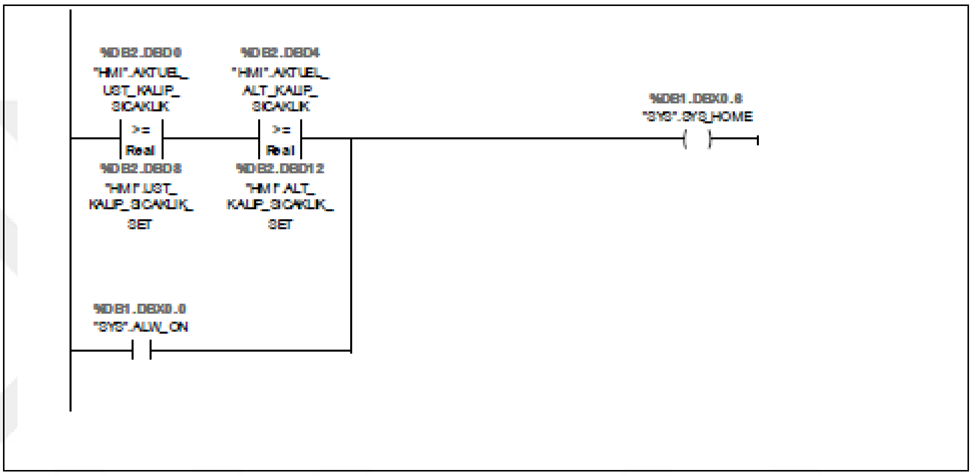


Figure 4.6 Upper mold & lower mold controller set value

Network 5.

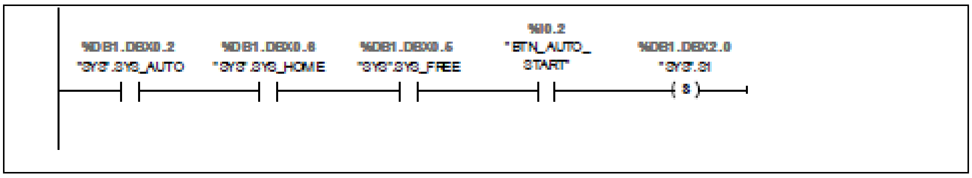


Figure 4.7 Upper mold & lower mold movement

Network 6.

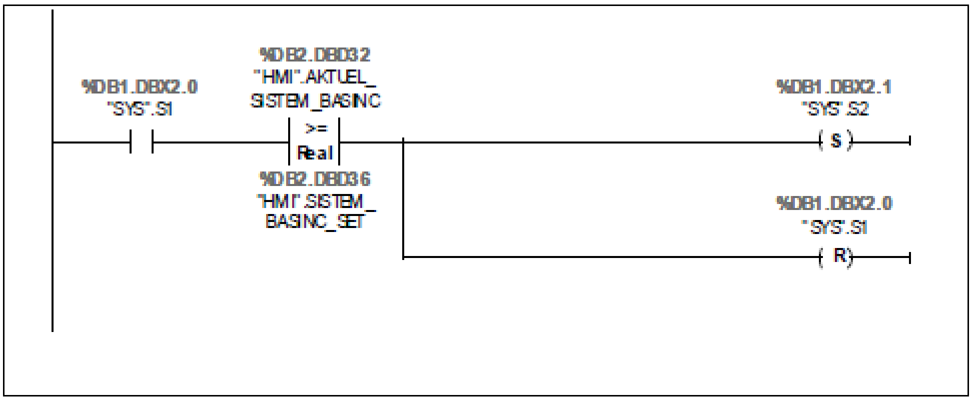


Figure 4.8 Lower f mold half moving stopped and pressure time is working

Network 7.

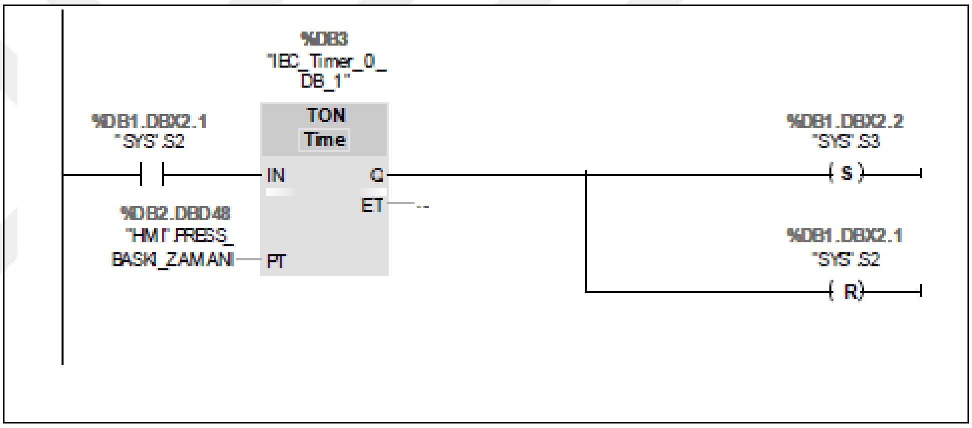


Figure 4.9 The end of timing, upper mold is moving up.

Network 8.

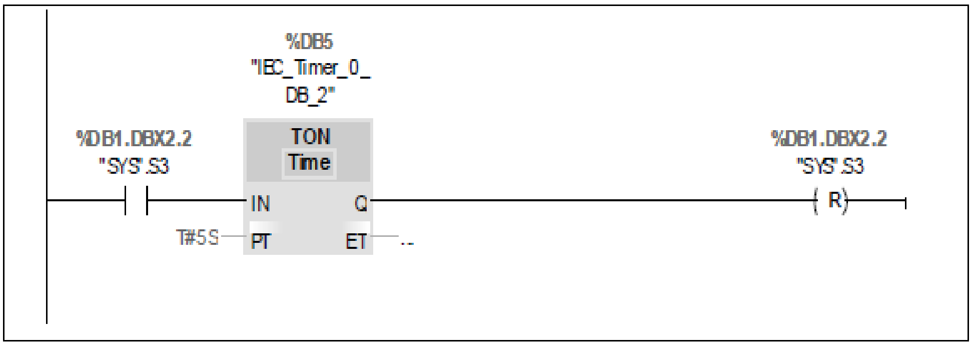


Figure 4.10 Upper mold stabilled satuation then up will be stop

Network 9.

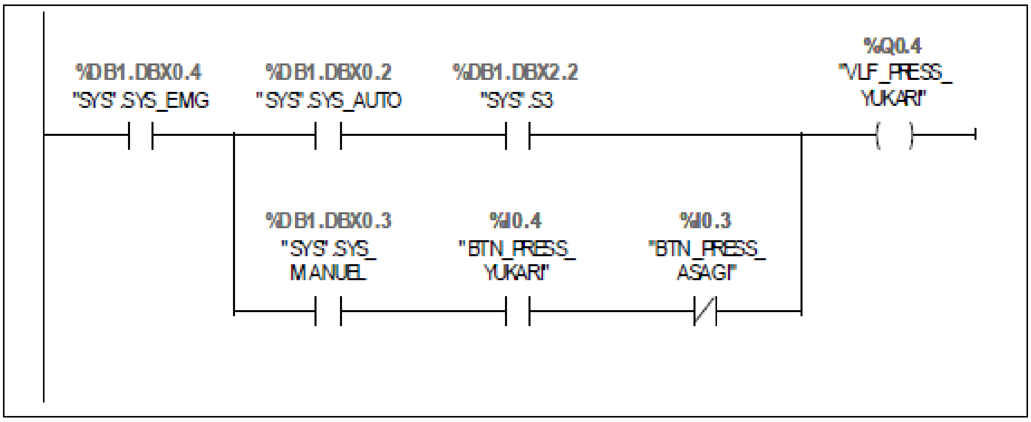


Figure 4.11 Upper movable mold half & lower fixed mold half pressure automatic

Network 10.

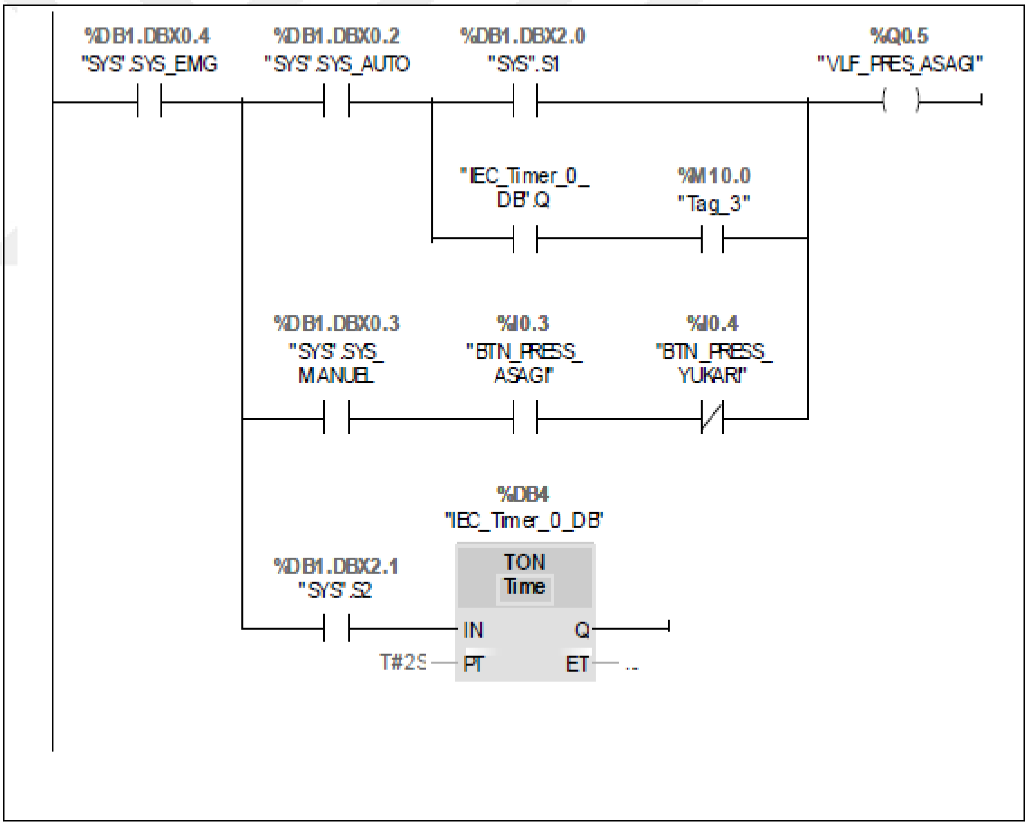


Figure 4.12 Timing control of the hydraulic press

Network 11.

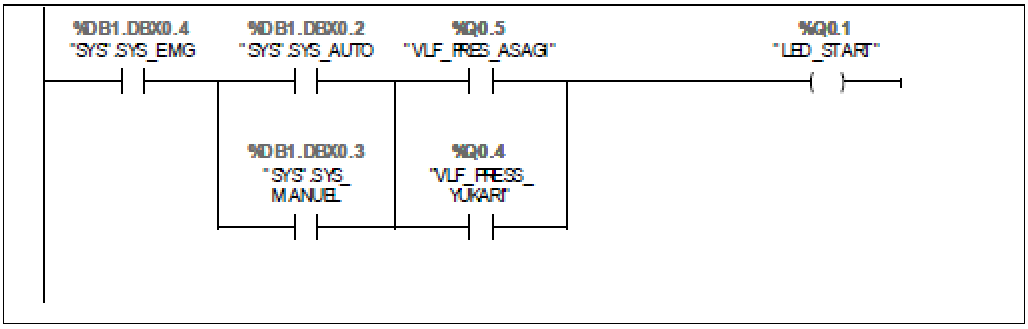


Figure 4.13 According the automatic lamp control

Network 12.

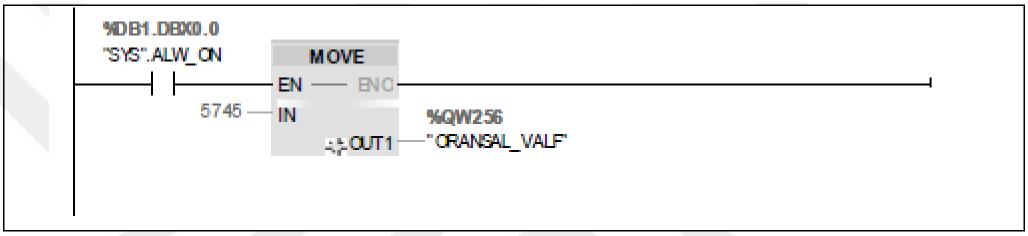


Figure 4.14 Propossional to valve control

Other program blocks:

Network 1 & 2.

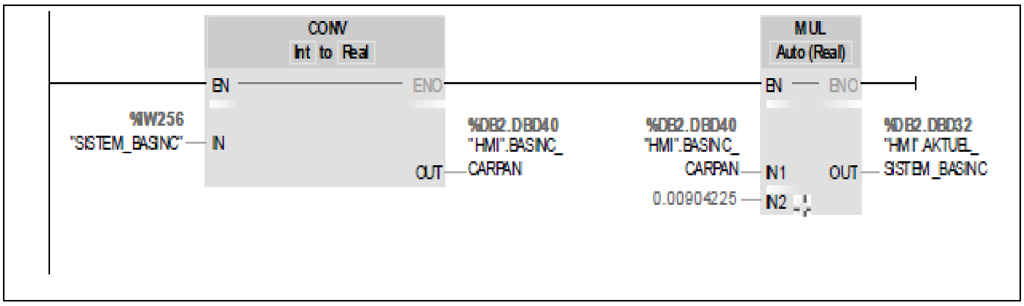


Figure 4.15 It includes some mathmatical parametet divition multiply & conversation

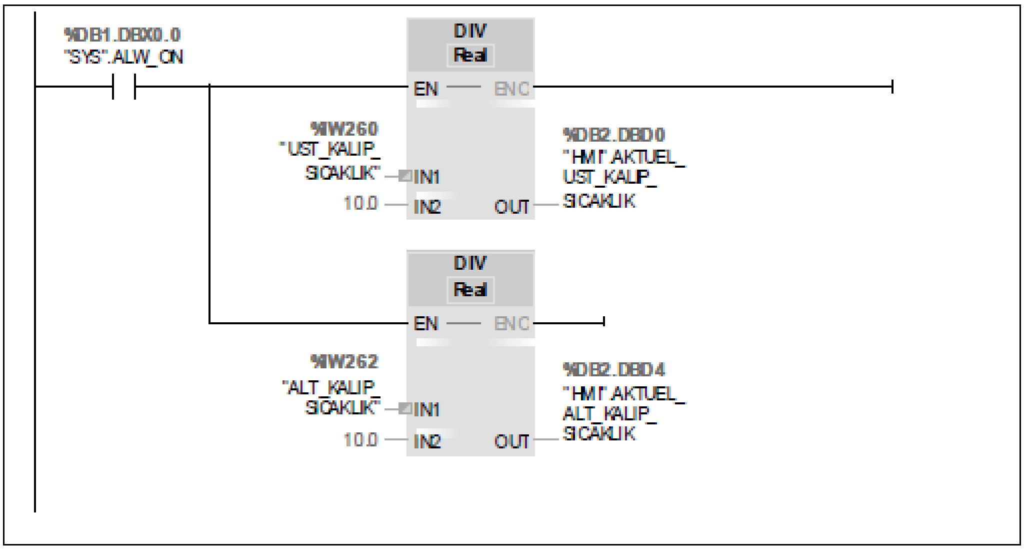


Figure 4.15 It includes some mathmatical parametet divition multiply and conversation (continue).

Network 3.

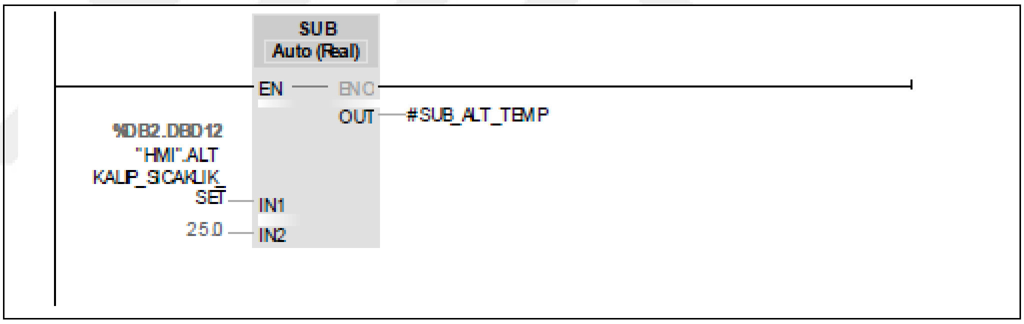


Figure 4.16 The finding of button resistance limits HMI.

Network 4.

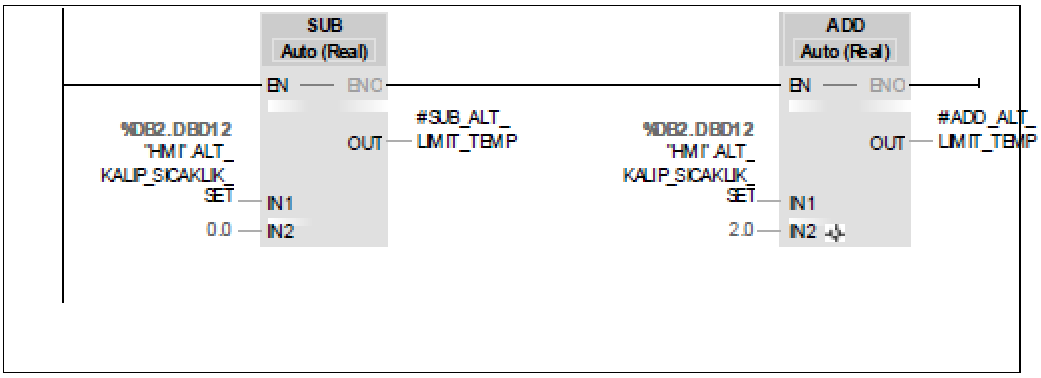


Figure 4.17 Down resistance limit changes

Network 5.

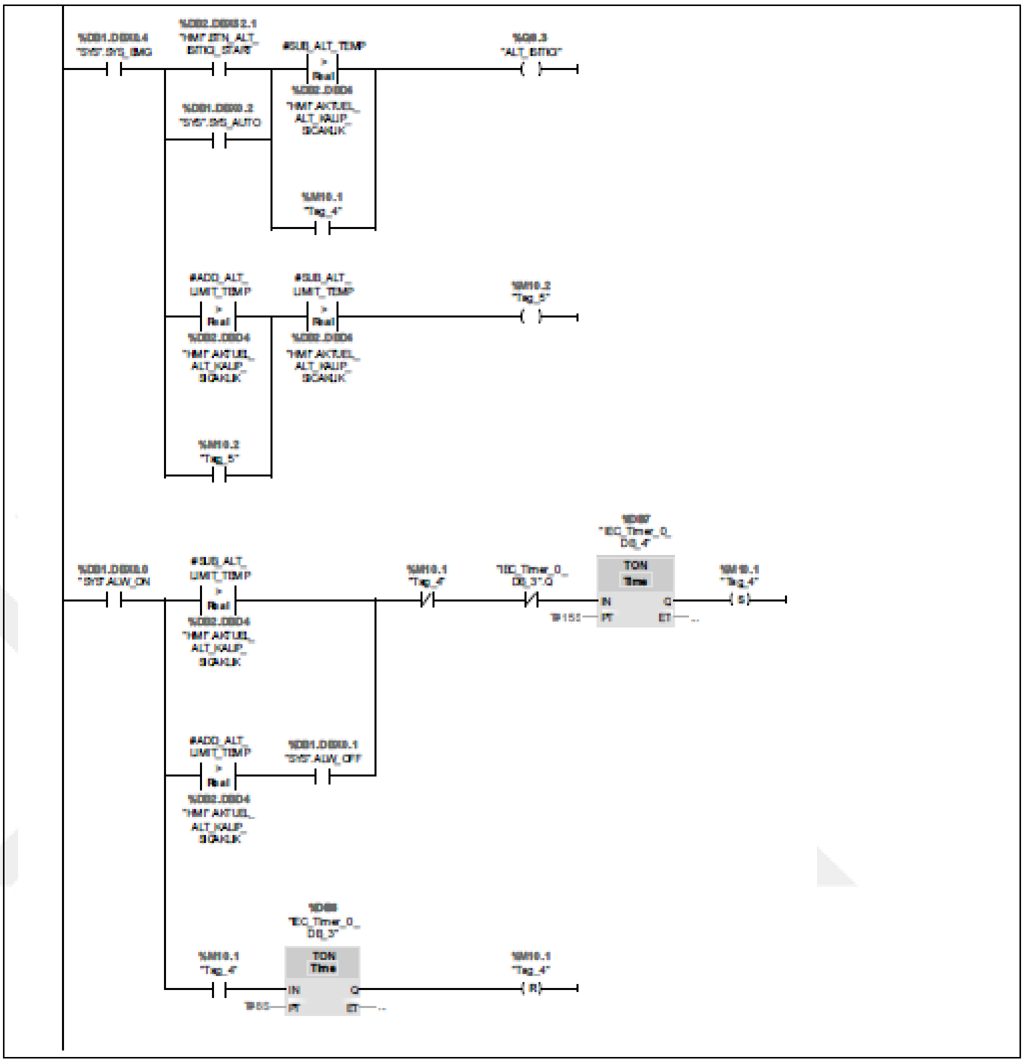


Figure 4.18 Down resistance output changes.

Network 6.

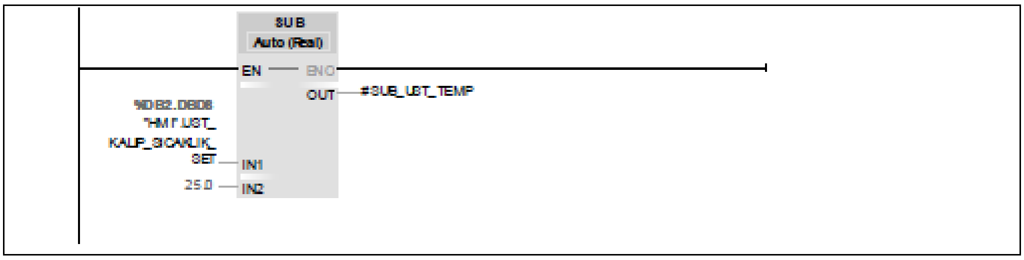


Figure 4.19 Upper resistance limits

Network 7.

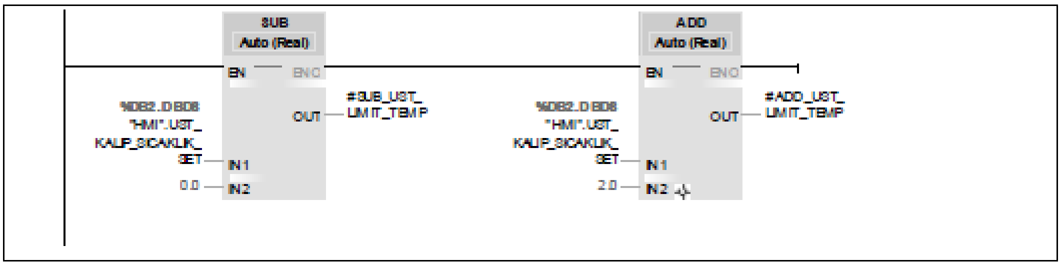


Figure 4.20 Upper resistance limit changes

Network 8.

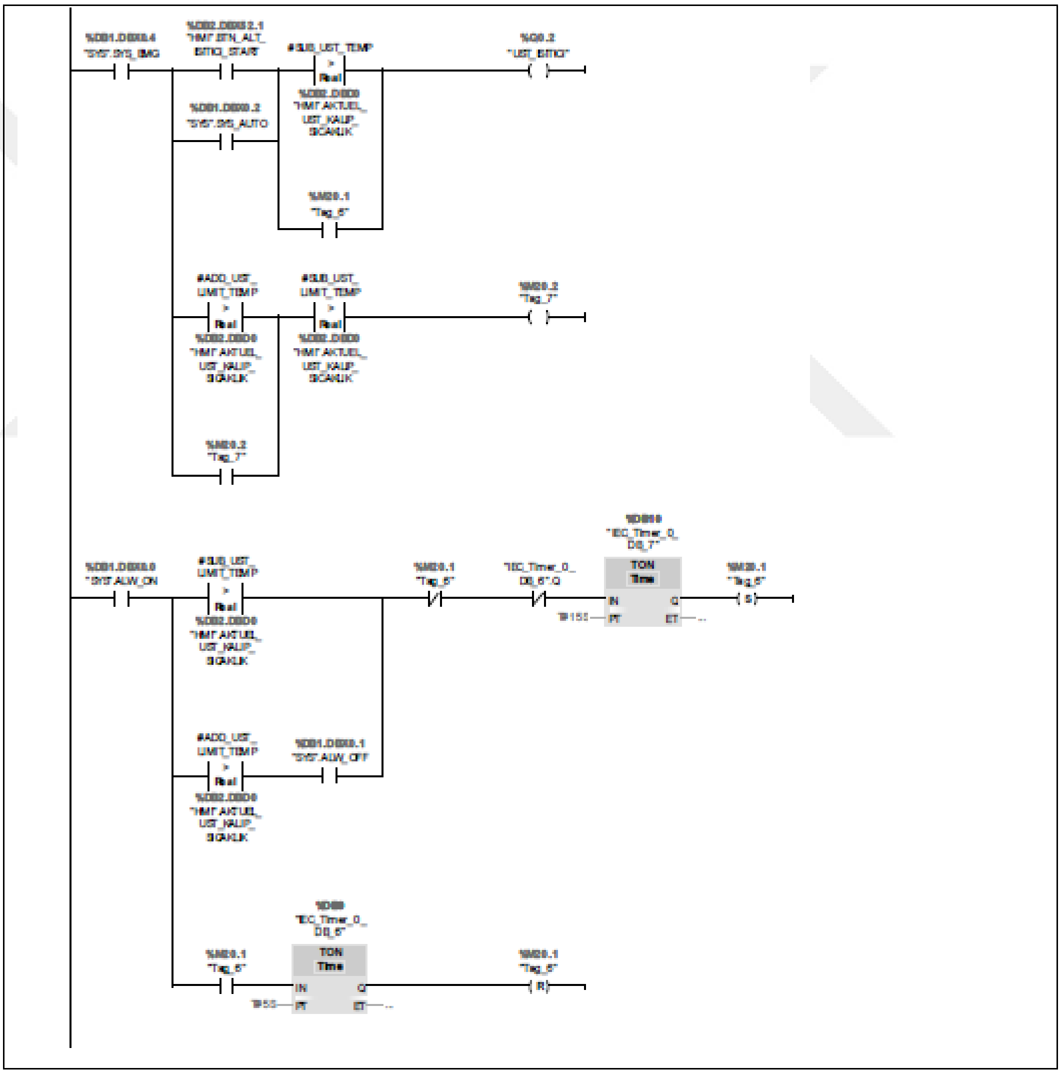


Figure 4.21 Upper resistance output.

Network 9.

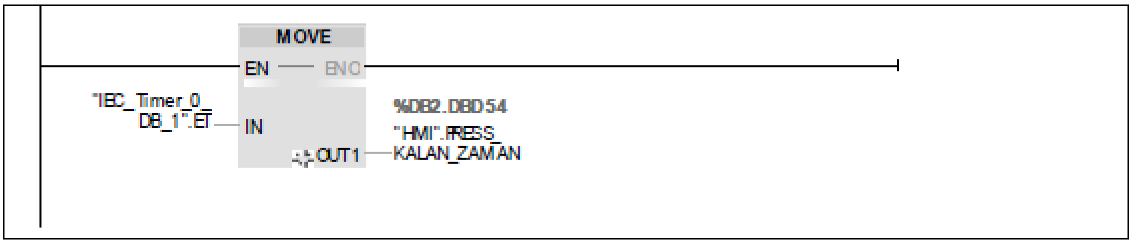


Figure 4.22 Remain timing value

4.4 Preparation of PZT Powder for Piezoelectric Fabrication

The main important composing of piezoelectric ceramic powder is PZT, the ceramic powders are made by adding with a few additives (chemical addition), the powder materials mixed with ZrO2, PbO and TiO2, and taking after by a publication of conscientious and manufacturing procedures**.**

When it reached the finishing part of PZT powders, using the compression instrumentation to apply with pressure the powder into different specifications and forms, then sinter the PZT discs and rings within the temperature around 1350℃. When the polarization, the PZT completed product square measure created.

The unltrasonic preciseness clean up industries has totally different conditions for the performance materials of PZT, the practiced Sunnytec and engineers regularly supply to develop varied ceramic powder formulas to fit in with every customer’s obligation. Figure 4.23 shows a preparation of PZT powder.

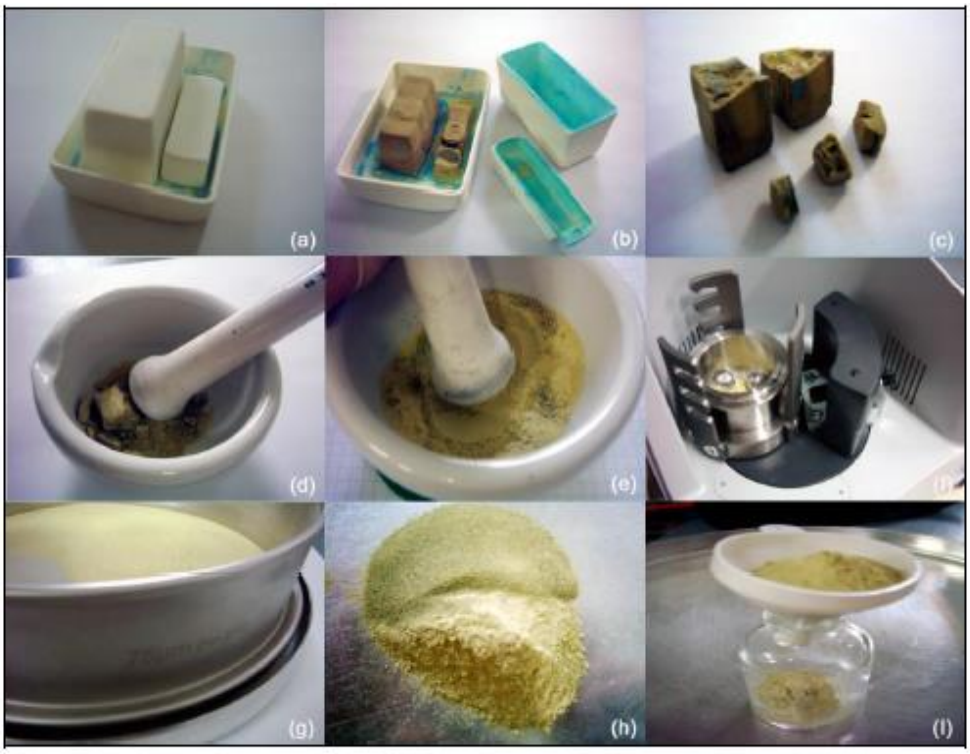


Figure 4.23 Preparation of PZT powder (a-c) Sintered powder, (d-e) Milling Process
(f-i) screening and Storage

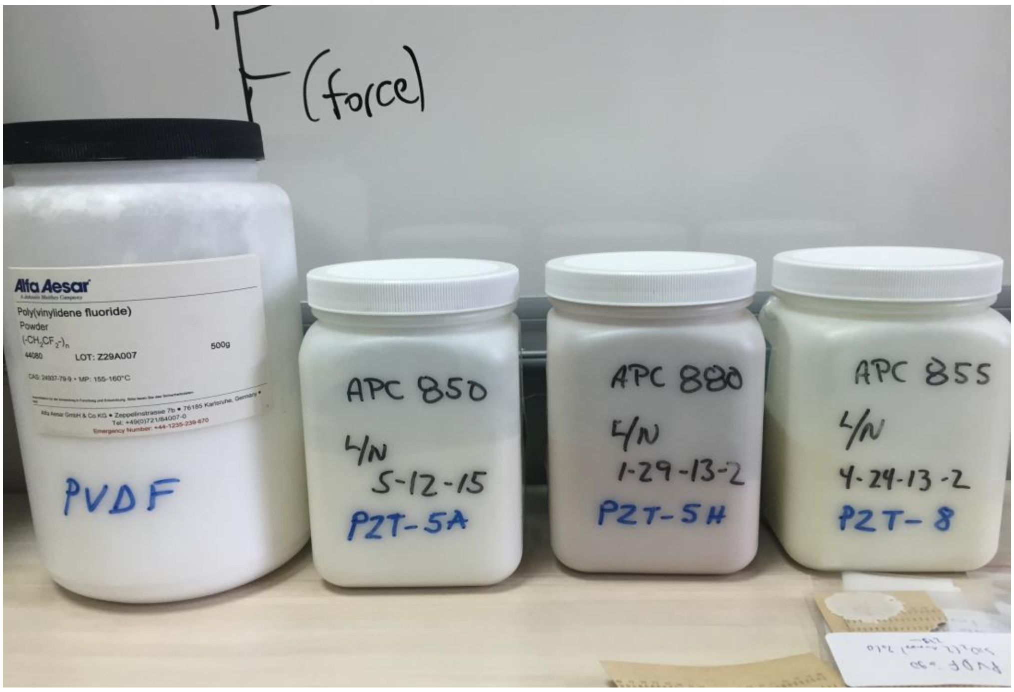


Figure 4.24 Prepared PTZs

➢ ***PZT-5A:*** this material is suggested for hydrophones or implements applications, for the cause of high resistivity at important temperatures, high sensitivity, and high time stability.

➢ ***PZT-5H:*** this material is higher sensitivity and permittivity than PZT-5A. But, limits the functioning temperature vary and results in lower temperature stability.

➢ ***PZT-8:*** is similar to PZT-5H; however it's lower dielectric and mechanical losses under high electrical drive.

4.5 Production Process of Piezoelectric Sensors

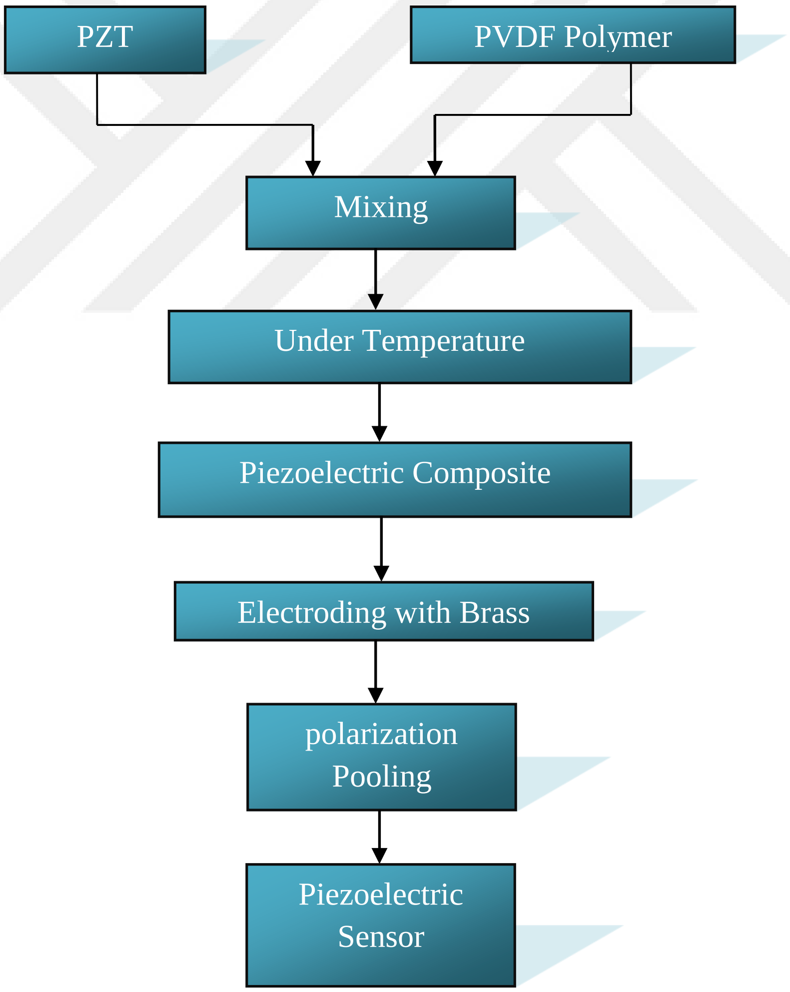


Figure 4.25 Producing of piezoelectric sensors

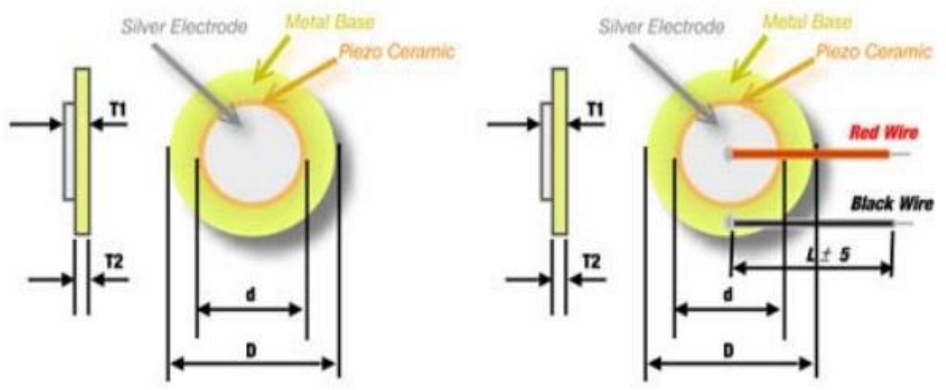
Piezoelectric sensors are made of a structure with at least two groups. One of them is polymer matrix, i.e PVDF (Polyvinylidene Fluoride). The other is the piezoceramic PZT structure like that PZT-8, PZT-5A, and PZT-5H.The process of piezoelectric sensors.

The processing of piezoelectric sensors are as follows:

(a) Formation of the piezoelectric composite by mixing with PZT material and PVDF Polymer then obtaining of piezoelectric composite by pressing them under specific pressure and temperature
(b) Fastening the brass electrodes to both sides of the piezoelectric composite.
(c) Polarization (Pooling) of the piezoelectric sensors under a DC electrical filed 1050 Volt for 30 minutes at 120 C.
(d) After polarization process, produced piezoelectric sensors.

Figure 4.26 Polarizations of piezoelectric sensors

Figure 4.27 Produced piezoelectric sensors



- Silver Electrode
- Metal Base
- Piezo Ceramic
- Red-wire
- Black-wire

Figure 4.28 Piezoelectric sensors wiring

CHAPTER FIVE

CONCLUSION AND FUTURE WORK

This development has proven the concept of design of piezoelectric sensors production system by using PLC, and studied about the basic of piezoelectric. PLC and SIEMENS S7-1200 model were also discussed. Hydraulic press system with PLC was developed, this hydraulic system performed well. This system described in this thesis.

This chapter discusses the future development of these systems and concluding remarks based on the research performed. The discovery of the piezoelectric effect, piezoelectric materials and also the applications of piezoelectric and modern control equipment regularly uses PLC discussed in chapter two. The procedure to pole piezoelectric materials was analyzed and their complex crystalline structure, the elements were fired up according to an exact time and temperature program. The different direction of polarization connected two nearby domains were random, building the full material neutral with out overall polarization. The vibration models in piezoelectric material in different models and frequency was discussed and principle of piezoelectric accelerometer and as well basic mathematic equations of accelerometer.

The third chapter reviews the SIEMENS S7-1200 model in writing and developing ladder logic program. S7-1200 also explained which included the essential components of processor unit, software upload and download from PC to the PLC by using a programming board which writes the program into a removable chip.

In the fourth stage, PLC controlled hydraulic press system is analyzed. This part was described the construction of a hydraulic press and the implementation of piezoelectric sensors production system by using PLC controller. Working procedure, this part was the most important section of the thesis which involved the experimental results that modern hydraulic presses offered good performance. Experiment was also performed using a PLC as a typical control device has completed the design and produced piezoelectric sensors.

A usually utilized method of programming PLCs was used on the make of ladder diagrams. The control methods were designed of ladder diagrams of program blocks.

The final part involves the preparation of PZT powder, the ceramic powder made by adding a few mixed chemical additions.

Piezoelectric crystal can be used to produce electrical output from surrounding vibrations. These materials have the ability to convert mechanical energy into electrical energy that can be used to power other devices.

It was planned to produce actuators numerous of varied of assorted sizes of Piezoelectric sensors and so contribute to technical innovations within the producing industry in various areas. These can embrace industrial machinery, digital home appliances and technology merchandise, that area unit supported our expertience within the world's first sensible implementation of multi layering.

There are few applications that could use a hydraulic system to control and monitor the production of piezoelectric materials. As the size of these piezoelectric continues to get smaller, it will open up even more possible applications.

In this study, the hydraulic system is designed to produce piezoelectric sensors by using PLC, but hydraulic press is normally slower than mechanical press. This disadvantage is being over with the development of new valves with higher flow capacities, small response times and better control potentials.

REFERENCES

Berger, H. (2013). *Automating with SIMATIC S7-1200*, Configuring, Programming and Testing with STEP 7 Basic Visualization with WinCC Basic/2nd enlarged.

Berlincourt, D & Krueger H. A (1987). *Properties of piezoelectricity ceramics*. Technical Publication TP-226.

Bobylev, L. (1963). Distribution of stresses, deformations, and density in soil during consolidation of made ground by tamping plates. *Osnovaniya, Fundamenty İ Mekhanika Gruntov*.

Cady, W.G. (1946). *Piezoelectricity*. New York: McGraw-Hill.

Dahiya, R.S & Valle, M. (2013). Robotic tactile sensing. *Technologies and System* Springer Science, New York, ISSN: 1070-9932.

Giap, H. & Hale, J.M. (2013). Sensitivity of piezoelectric sensors fabricated with various types of commercial PZT powder. *Journal of Systems and Control Engineering*, Hong Duc University, Thanh Hoa, Vietnam.

Hale, J.M. (2004). Piezoelectric paint thick-film sensors for structural monitoring of shock and vibration. *ASME 7th Biennial Conference on Engineering Systems Design and Analysis*, Manchester, United Kingdom.

Iklaq, M, Ghafferi, O. & Arik, M. (2014). Effect of actuator deflection on heat transfer for low and high frequency synthetic jets. *Thermal and Thermo-mechanical Phenomena in Electronic Systems*, IEEE, Orlando, USA.

Kuoni, A. (2003). Polyimide membrane with ZnO piezoelectric thin film pressure transducers as a differential pressure liquid flow sensors. *Journal of*

Micromechanics and Microengineering, Institute of Microtechnology, University of Neuchatel, Switzerland.

Lown, R. (1982). *Hydraulic presses.* Based on SME Technical Paper, MF82-918, The Society of Manufacturing Engineers. Dearborn Michigan, USA.

Mauck, L.D & Lynch, C.S. (1999). *piezoelectric hydraulic pump optimization*. and *10th International Conference on Adaptive Structures and Technologies ICAST*. Paris, France.

Mauck, L.D, Oates, W.S & Lynch, C.S. (2001). Piezoelectric hydraulic pump performance. *Proceedings of SPIE.*

Mehraeen, Jagannathan S. & Corzine S. (2010). Energ harvesting from vibration with alternate scavenging circuitry and tapered cantilever beam. *Industrial Electronics, IEEE Transactions* 57, 820 – 830.

Metra Mess-und Frequenztechnik. (2012). *Piezoelectric accelerometers, theory and applications,* (5th edition). Radebeul, Germany.

Oates, W. (2001). *Piezoelectric pump design and system dynamic model.* Master Thesis, Atlanta, Georgia Institute of Technology.

Paralı, L. (2015). *Programmable logic control*. Retrieved April 13, 2016 from link http://leventparali.com.tr/en/programmable-logic-control.

Paralı, L. Sabikoğlu, İ & Kurbanov, M.A. (2014). *Piezoelectric properties of the new generation active matrix hybrid (micro-nano) composites*, Applied surface science,318,6-9.

Prewitt, A. D. (2012). *Fffect of the poling process on dielectric, Piezoelectric and Ferroelectric properties of lead zirconate titanate.* Retrieved Febraury, 16, 2016 from http://ufdc.ufl.edu/UFE0043951/00001.

Regelbrugge, M., Lindler, J. and Anderson, E. (2006). *Design model for piezohydraulic actuators*. *AIAA Adaptive Structures Conference.*

SIEMENS SIMATIC S7-1200. (2012). *Programmable controller system manual,* eBook 04/2012, A5E02486680-06.

Sunghwan, K. (2002). *Low power Energy harvesting with piezoelectric generators*. *Doctor of Philosophy*i University of Pittsburgh. Retrieved February 27, 2016 from link https://tr.scribd.com/doc/299917953/THESISSHKIMA

Wang, Z. L. (2009). *Energy harvesting using piezoelectric nanowires*. *Advanced Materials*, 21, 1311–1315.

Vijaya, M. S. (2012). *Piezoelectric materials and devices.* applications in engineering and medical sciences, *international Standard Book Number* ISBN-13:978-1-4398.

Zakar, E. (2001). Process and fabrication of a lead zirconate titanate thin film pressure sensor. *Journal of Vacuum Science and Technology,* A19.1,345-348.