

DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**IMPLEMENTATION OF PLC CONTROLLED
PRESS MACHINE WITH SAFETY
PRECAUTIONS**



by
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October, 2019
İZMİR

IMPLEMENTATION OF PLC CONTROLLED PRESS MACHINE WITH SAFETY PRECAUTIONS

**A Thesis Submitted to the
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In Partial Fulfillment of the Requirements for the Degree of Master of Science
in Mechatronic Engineering**

**by
Emre ZEYREK**

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İZMİR**

M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled “**IMPLEMENTATION OF PLC CONTROLLED PRESS MACHINE WITH SAFETY PRECAUTIONS**” completed by **EMRE ZEYREK** under supervision of **ASST. PROF. DR. TANER AKKAN** 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.



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IMPLEMENTATION OF PLC CONTROLLED PRESS MACHINE WITH SAFETY PRECAUTIONS

ABSTRACT

Technology is one of the indispensables of today's life. The metal forming process is a process that shapes sheet metals. The metal forming process is used especially in industrial field. The press machines have a wide range of working areas such as production lines, automotive industry, packaging industry, construction industry, and household appliances. Press machines are indispensables of metal forming industry.

Press machines are one of the most dangerous machine types in industry. For that reason, safety precautions must be applied and tested carefully while manufacturing a press machine.

In this study, press machines and their types are introduced. Mechanical press, which is the one common type of presses, is manufactured and implemented with safety precautions. The safety design on press will be implemented. The risk analyze of safety precautions will be made. The standards about safety precautions will be examined.

Keywords: Press types, mechanical presses, light barriers, door switches, cam positioning, safety precautions

PLC KONTROLLÜ PRES MAKİNESİNİN GÜVENLİK ÖNLEMLERİ İLE GERÇEKLEŞTİRİLMESİ

ÖZ

Teknoloji günlük hayatımızın vazgeçilmezleri arasındadır. Metal şekillendirme süreci, metal sacın şekillendirme işlemidir. Metal şekillendirme işlemi genelde endüstri alanında kullanılır. Pres makinesinin çalışma alanları üretim hatları, otomotiv sektörü, inşaat sektörü, ev aletleri ve paketleme sektörü gibi geniş bir yelpazeye sahiptir. Pres makinaları metal şekillendirme işleminin vazgeçilmezlerindendir.

Pres makinaları endüstrideki en tehlikeli makina gurubunda bulunan makinalardan biridir. Bu yüzden güvenlik önlemleri dikkatli bir şekilde uygulanmalı ve test edilmelidir.

Bu projede pres makinaları çalışma prensipleri ve tipleri tanıtılacaktır. Endüstride en çok kullanılan mekanik pres tipinden bir pres güvenlik ekipmanları ile birlikte uygulanacaktır. Presin güvenlik dizaynı yapılacaktır. Bu güvenlik dizaynının risk analizi gerçekleştirilecektir. Güvenlik önlemleri ile ilgili standartlar incelenecektir.

Anahtar sözcükler: Pres tipleri, mekanik presler, ıřık bariyerleri, kapı sensörleri, kam pozisyonlama, güvenlik önlemleri

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CHAPTER ONE

INTRODUCTION

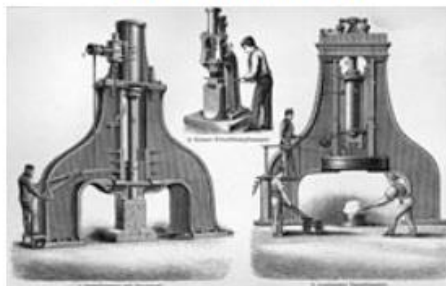
1.1 Press Machines History

In ancient Greece, olive oil was obtained by squeezing grapes. B.C. In the 600's, The Greeks putted the grapes under a board and they squeezed it with a help of arm force or they went on the board and squeezed with help of feet power. 450 years later, they thought of making the pole in the middle of the board grooved. Thus, their work became much easier. The wood was surrounded with the help of the arms, which squeezed the grapes underneath and extracted the water (Ilk Kim Buldu, 2011).

Metal was shaped with hammer with a help of human force. It was getting hard to shape metals while the metal thickness was increased. The mechanism was developed to shape metals with a help of gravity fall.

In the mid-19th century, manual and rotary-cam hammers began to be replaced in industry by the steam hammer which is shown with Figure 1.1. The possibility of a steam hammer was noted by James Watt (1736–1819) in his 28 April 1784 patent for an improved steam engine (Whitlow, 2011). Nowadays most of press machines uses electrical motor powers or hydraulic oil power to shape materials.

Steam hammer



1894 illustration of various sizes of single- and double-frame steam hammer

Figure 1.1 Steam hammer (Wikipedia - Steam Hammer, n.d.)

1.1.1 Press Shaping

Press forming is the process of forming with machines called press, which are designed and manufactured for all kinds of metal molds. Any kind of metals can be shaped in the press machines by the help of molds. Major pressing operations can be sampled as metal shaping, shaving, ironing, cutting, punching, stretching etc. The major press types are divided into two section:

1- Hydraulic Presses

2- Eccentric Presses

3- Servo Presses

1.1.2 Hydraulic Presses

Hydraulic presses are presses working with oil pressure. They can be single and double acting like mechanical presses. They can also be open body or closed body (straight edge) according to their body structure.

Pressured oil is pumped into the system by the help of pump. This pump is operated with electrical motor. The oil which is inside the system can be controlled with proportional valves. The pressured oil goes into the cylinders by the help of control system. The ram moves up and down with the control system. The pressure of oil which is inside the hydraulic system can be adjusted with control system. Also the distance that ram can move can be adjusted with control system. Example picture of hydraulic machine is shown at Figure 1.2.



Figure 1.2 Hydraulic presses (Uysal Otomasyon, n.d.)

1.1.3 Mechanical Presses

Mechanical presses which are shown at Figure 1.3 as an example, are energy machines. Energy is stored in the flywheel and some part of stored energy is lost in the period of one cycle of press. The most energy is lost during work period of one cycle. The lost energy is stored at flywheel with the help of electrical motor. When the electric motor of the press is started, the flywheel mechanism begins to rotate continuously. The upper die and the ram must have vertical move for forming process. The clutch is controlled with double hand push buttons, pedal or any other control devices. When the clutch is activated the ram starts moving. Grip movement on a mile transmits the movement, and the crankshaft is rotated.

The ram can stop at top death center after a hit or can be operated continuously in the automatic mode. The stop is provided by a brake. Usually brake is in the form of a combination of clutch and brake. However, there are also cases where they are placed separately.



Figure 1.3 Eccentric press line (Ozkurt Otomotiv Press Lines, n.d)

1.1.4 Servo Presses

Servo press which is shown at Figure 1.4 are also energy machines. But the difference with the mechanical presses is the energy is not stored in flywheel. Unlike conventional mechanical presses, the servo press is driven by the servo motor, not by

the normal motor and flywheel. So that the ram movement of press can be changed as required movement by programming.

Due to the ram movement can be programmed, the press works according to the most suitable movement type for many different operations and eliminates the need of different press types.



Figure 1.4 Servo press (Dirinler Mak. San. ve Tic. A.Ş, 2019)

1.2 The Aim of Project

The machines safety and security are important for the machines which are used at industrial field. The machine security can be defined as the machine must work with full functionality for process. The machine safety can be defined that the machine must work with safety conditions. The safety conditions must protect all living beings around machine from the harmful movement.

In this thesis it is aimed that an eccentric press will be installed and worked with safety precautions. What should be considered during the design stage of the press and its application stages will be explained in this thesis.

CHAPTER TWO

MECHANICAL PARTS OF ECCENTRIC PRESS

2.1 Body

The most important features in the presses are body shape, body construction type and construction of the material. The construction of the large tonnage press body is made from cast and steel plate welding. The H type large tonnage press body is shown at Figure 2.1. The press body type and type of materials are chosen due to analyze of press rated tonnage.

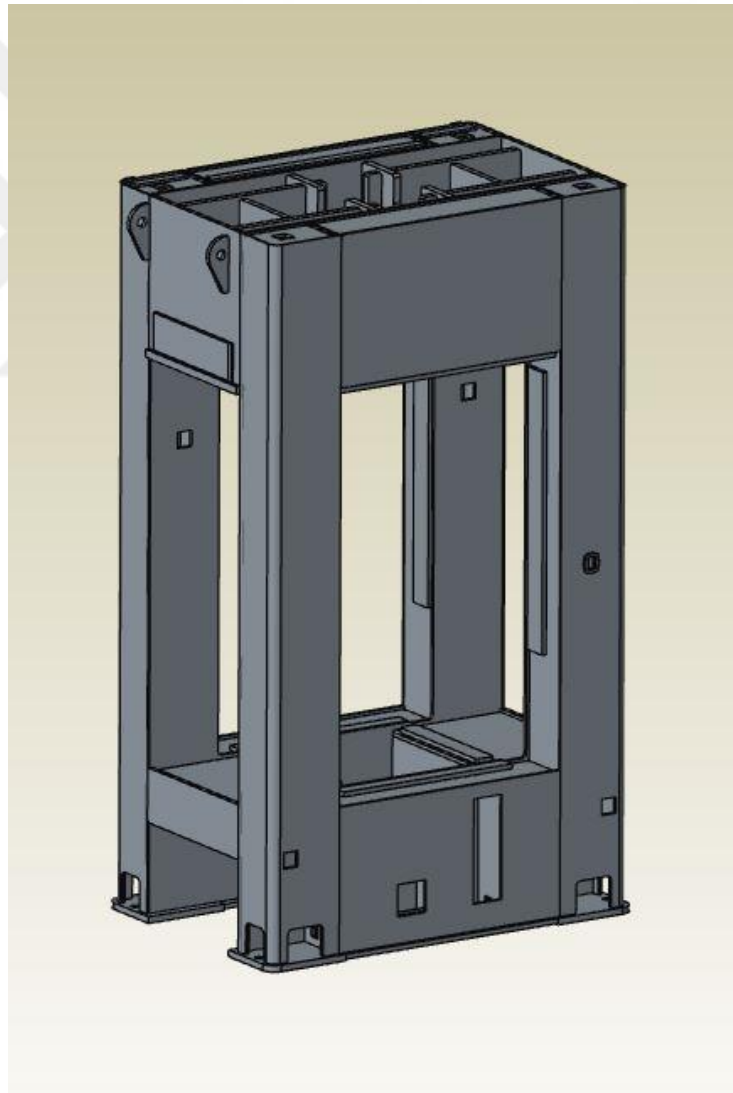


Figure 2.1 Press body

2.2 Electrical Motor

Electrical motor which supplies power for eccentric presses is shown Figure 2.2. Electrical motor power is chosen due to press types, rated tonnage and the force transfer mechanism of press. If the ram is directly moved with electrical motor, the motor power is quite high. The high power motor is much more expensive than the motor with smaller power. Therefore, there is usually a transfer mechanism between the motor and the press movement.



Figure 2.2 Electrical motor of press machine (Dirinler Mak. San. ve Tic. A.Ş., 2019)

2.3 Flywheel

The flywheel which is shown in Figure 2.3, is a mechanical part which stores the rotational energy efficiently. The flywheel has a resistance to the changing of rotational speed because of moment of inertia. The stored energy of flywheel is proportional with the square of rotary speed. For that reason, most of eccentric presses has a flywheel which is connected to the electrical motor with belts.

The capacity of the press, its nominal tonnage and its stroke are important when selecting the flywheel. When calculating the required energy of the press, the tonnage and working distance are calculated. The flywheel size and weight are selected based on these calculations.



Figure 2.3 Flywheel which is connected to motor with belt (Dirinler Mak. San. ve Tic. A.Ş., 2019)

2.4 Mechanism Group

The mechanism group which is shown at Figure 2.4 has two parts. The first part is the crank axis. The second part is transmission axis.

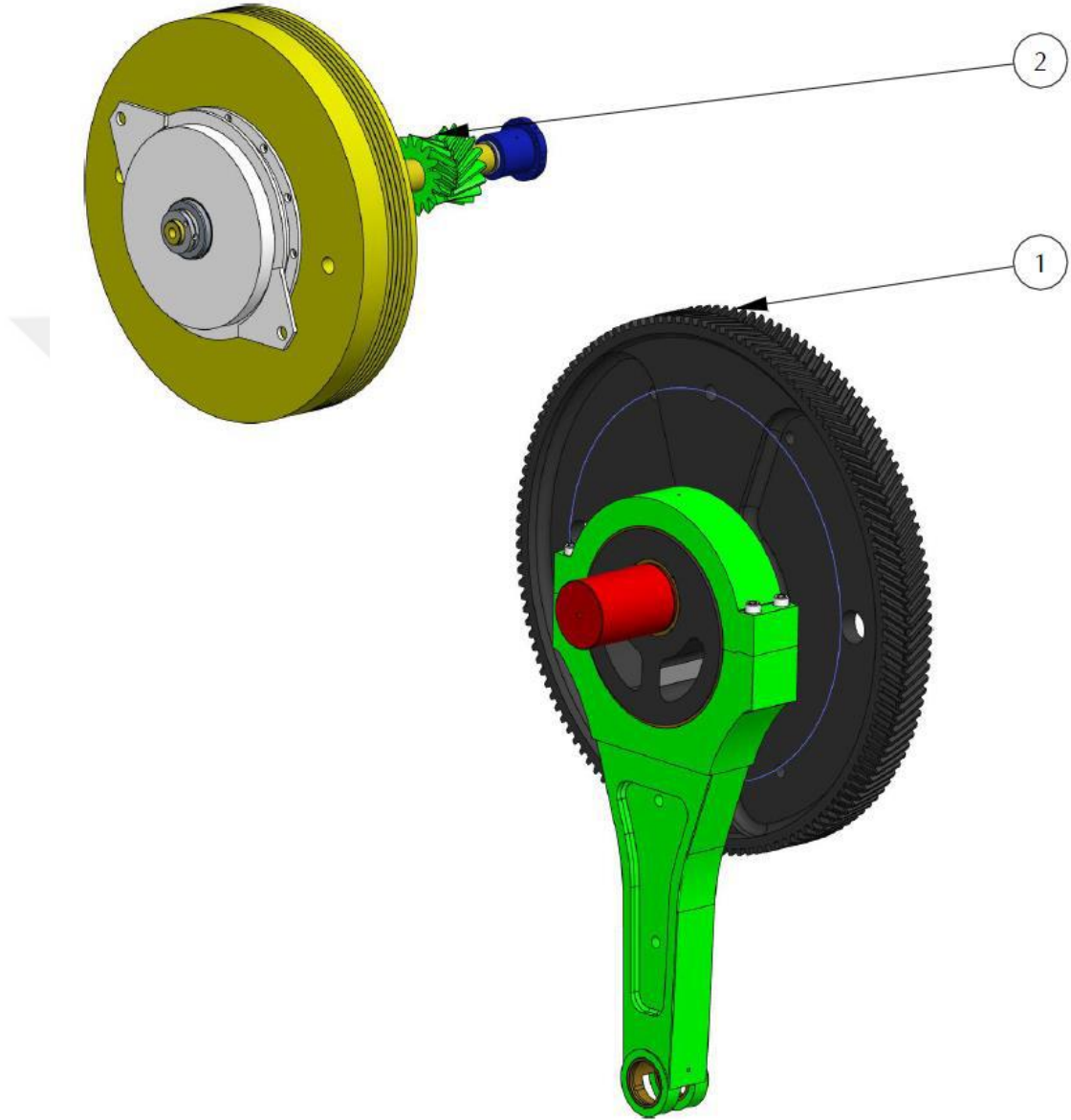


Figure 2.4 Mechanism group (Dirinler Mak. San. ve Tic. A.Ş., 2019)

2.4.1 Crank Axis

The crank axis that is shown at Figure 2.5, is a mechanical part group which transmits the flywheel energy to the ram with a help of eccentric gear, and moves ram horizontally. The Table 2.1 has the crank axis part list. The flywheel energy is transmitted to the eccentric gear by the help of pinion gear. The energy which is stored at flywheel is reduced while transmitting energy to the eccentric gear in proportion as ratio of pinion gear and the eccentric gear. The torque at the eccentric gear is improved in proportion as ratio of pinion gear and the eccentric gear.

The cranks shaft is fixed to the press body by means of wedge. The connection rod which is fixed with red bush on the eccentric gear, makes a half moon movement to move ram.

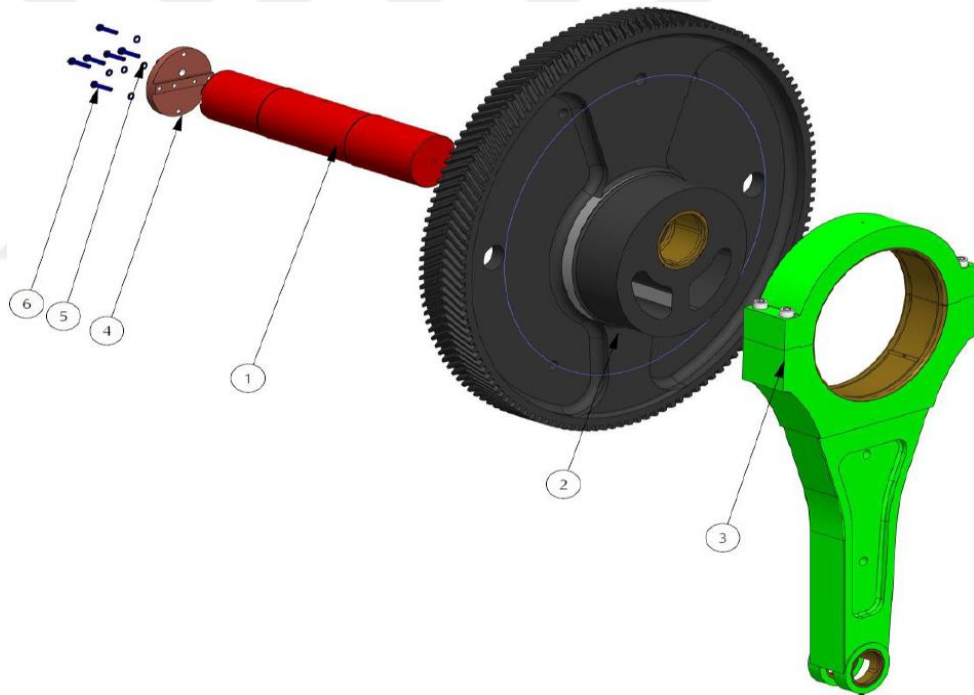


Figure 2.5 Crank axis (Dirinler Mak. San. ve Tic. A.Ş., 2019)

Table 2.1 Crank axis part list

ASSEMBLY NO	PART NAME
1	CRANK SHAFT
2	CRANK HERRINGBONE GEAR
3	CONNECTION ROD
4	CRANKPIN REAR COVER
5	SPRING WASHER
6	SCREW

2.4.2 Transmission Axis

The transmission axis which is shown at Figure 2.6, transmits the stored energy at flywheel to the pinion gear by the agency of clutch group. All parts of transmission axis are listed at Table 2.2. It consists of two groups as clutch and brake. The brake group is fixed to the press body. The clutch is mounted on flywheel. The flywheel bushing which satisfies to rotate flywheel at constant axis, is mounted on the press body by the agency of roller. The transmission shaft is mounted with flywheel and transmission bearings. The transmission is turned with the same axis of the flywheel axis by the agency of bearings and bushings.

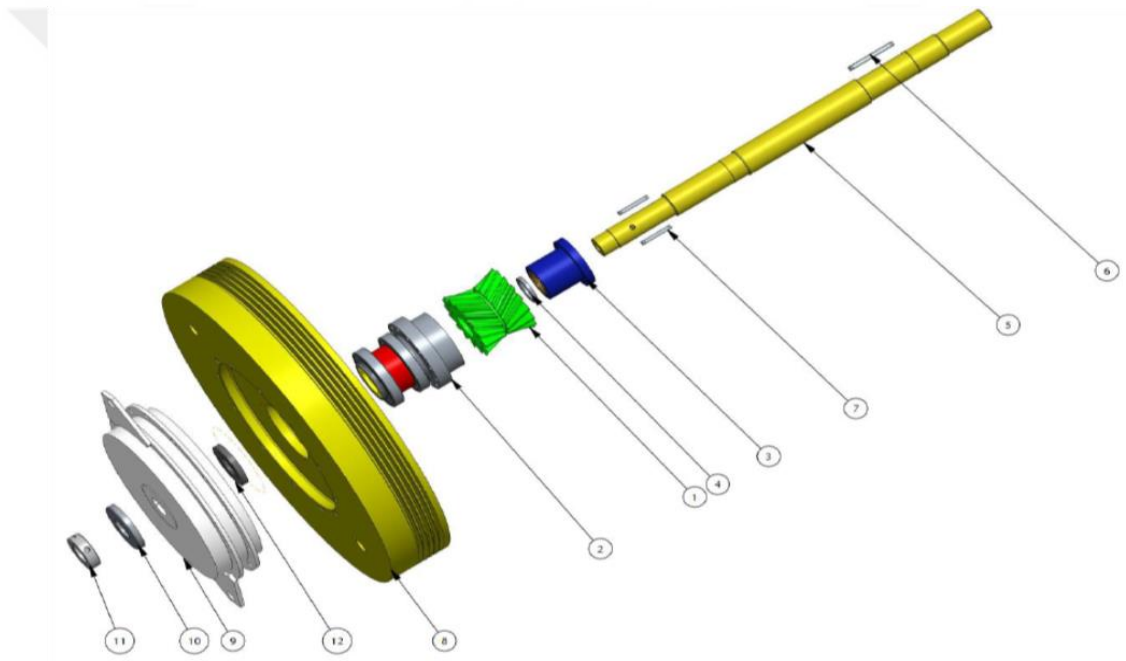


Figure 2.6 Transmission axis (Dirinler Mak. San. ve Tic. A.Ş., 2019)

Table 2.2 Transmission axis parts list

ASSEMBLY NO	PART NAME
1	HERRINGBONE PINION
2	FLYWHEEL BUSHING
3	TRANSMISSION BUSHING
4	TRANSMISSION BEARINGS
5	TRANSMISSION SHAFT
6	TRANSMISSION WEDGE
7	TRANSMISSION-CLUTCH WEDGE

Table 2.2 Continues

8	FLYWHEEL
9	CLUTCH
10	CLUTCH SEALING FLANGE
11	TRANSMISSION CLAMPING NUTS
12	FLYWHEEL SEALING FLANGE

2.4.2.1 Clutch

The flywheel which is turned by the agency of the electrical motor does not operate the mechanism and the ram is at standstill condition at startup. The clutch mechanism which is shown at Figure 2.7 is the mechanism that satisfies movement of transmission axis. All parts of clutch are listed at Table 2.3. When the ram is desired to move, the air entering from the middle core by means of pneumatic system creates pressure in the upper cover with piston. The piston and the piston part which is connected to it are activated with this pressure. In order for the piston to move, the air pressure generated in the system must be able to overcome the spring force. The piston part which is moved towards to flywheel with the air pressure, pushes and tightens the clutch flange towards to lower cover assembly. The clutch flange assembly that is rotating with the flywheel initiates the entire clutch braking combination system to the rotating motion, with the pads on it. The system starts to rotate by the agency of flywheel shaft which is connected to the mechanism by the wedge from the common hub.

The air pressure inside the piston must be cut in order to stop the flywheel mechanism and stop the press. When the pressure is cut, the air in the system will not force the springs. As soon as the pressure is cut, the piston will push the piston insertion and the piston. In this way, clutch brake system will be standstill with the pads.

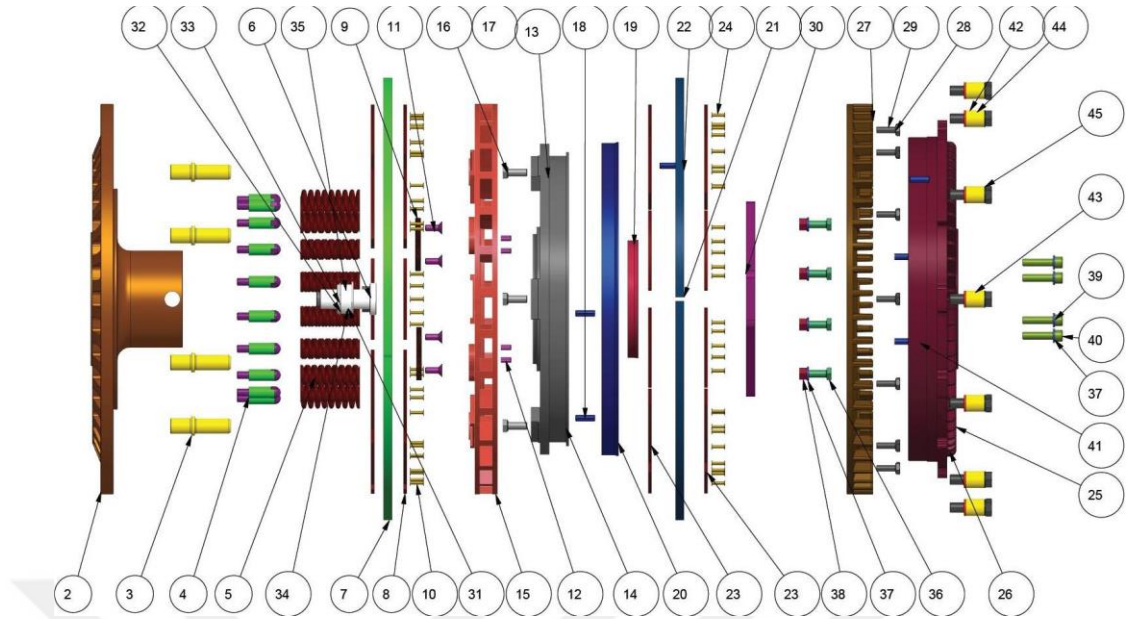


Figure 2.7 Clutch (Dirinler Mak. San. ve Tic. A.Ş., 2019)

Table 2.3 Clutch part list

ASSEMBLY NO	PART NAME
1	10500 NM – D640075 – 1848
2	MAIN BODY
3	CLUTCH PIN
4	SPRING HOLDER PIN
5	SPRING
6	CLUTCH FLANGE ASSEMBLE
7	CLUTCH FLANGE
8	BRAKE LINING
9	BRAKE FLANGE CONNECTION
10	PIPE FASTENER
11	COUNTERSUNK BOLT
12	SPLIT PIN
13	PISTON ASSEMBLE
14	PISTON
15	ADDED PISTON
16	CRINKED SPRING WASHER
17	HEXAGON BOLTS
18	SPLIT PIN
19	SMALL SEAL
20	LARGE SEAL
21	BREAKE FLANGE ASSEMBLE
22	BREAKE FLANGE
23	BRAKE LINING
24	PIPE FASTENER
25	COVER ASSEMBLE
26	CLUTCH COVER
27	COVER CIRCLE
28	CRINKED SPRING WASHER
29	HEXAGON BOLTS
30	CLUTCH EARS
31	LEFT RING
32	RIGHT RING

Table 2.3 Continues

33	HEXAGON BOLTS
34	CRINKED SPRING WASHER
35	FIBERED NUT
36	SHAFT SEGMENT
37	LOCK-WASHER
38	IMBUS ALLEN HEAD
39	SPLIT PIN
40	BUSH
41	CLUTCH BUSH OUT
42	CLUTCH BUSH IN
43	CRINKED SPRING WASHER
44	HEXAGON BOLTS
45	SPLIT PIN

2.4.3 Ram Group

The ram group is a group which consist of ram, sledges and die adjustment group is shown at Figure 2.8. All parts of ram group are listed at Table 2.4. The main body of the ram presses on the mold by making a vertical movement on the sleds and shapes the sheet material. Ram is produced by a welding process of sheet plates. Sledges are the subparts of press which satisfies to move ram in parallel with press table.

Die height adjustment groups stands inside the ram and it is used to adjust the ram height due to the wanted tonnage of press. The hydraulic overload unit is a safety component which limits the tonnage capacity of press. Die height adjustment motor is mounted on the ram body with plate. The motor shaft is connected to the worm shaft in the die height adjustment group by means of the coupling.

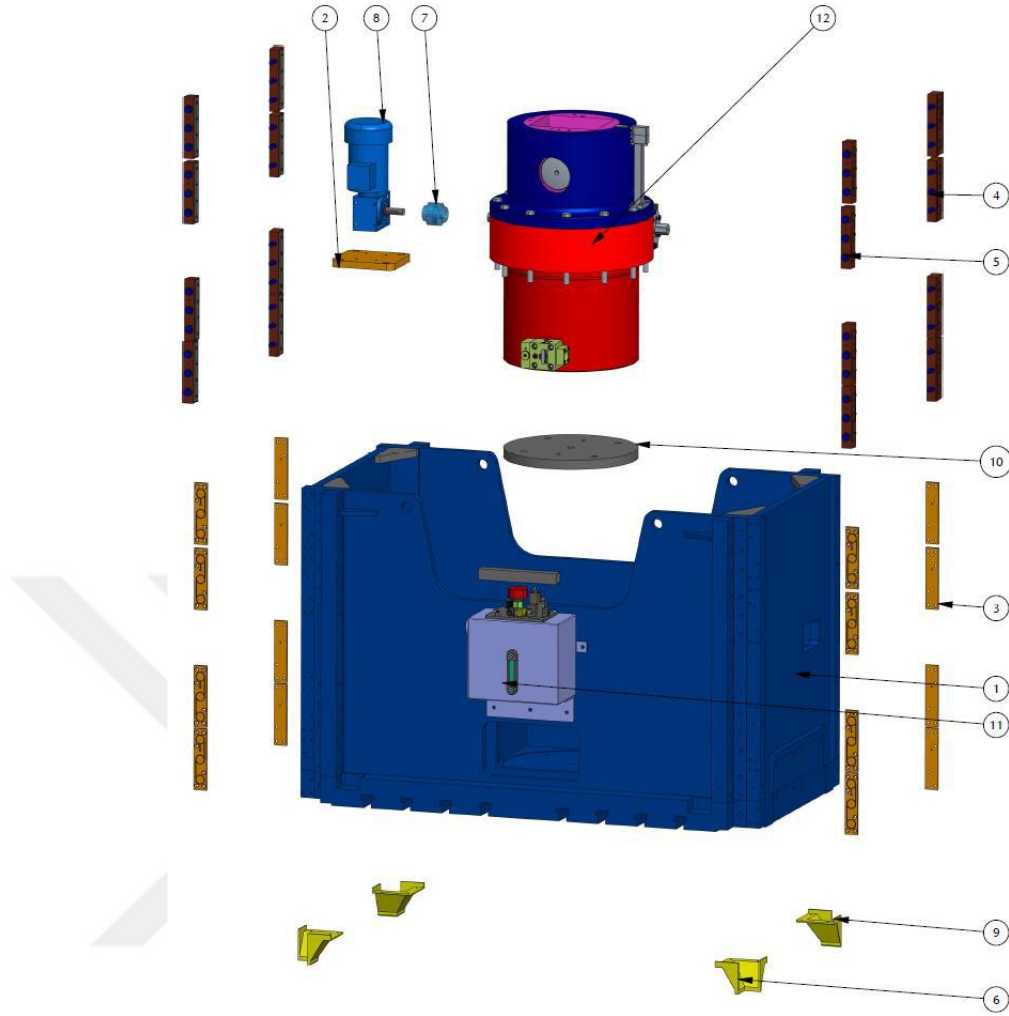


Figure 2.8 Ram group parts (Dirinler Mak. San. ve Tic. A.Ş., 2019)

Table 2.4 Ram group part list

ASSEMBLY NO	PART NAME
1	RAM
2	RAM MOTOR SHEET PLATE
3	RIGHT-LEFT MOVING BODY SLED
4	LEFT MOVING SLED
5	RIGHT MOVING SLED
6	RIGHT SCRAPER
7	DK 378 FLEXIBLE GEAR COUPLING
8	REDUCTOR
9	LEFT SCRAPER
10	RAM BOTTOM TABLE
11	HYDRAULIC UNIT
12	DIE HEIGHT ADJUSTMENT GROUP

CHAPTER THREE

PNEUMATIC SYSTEM

3.1 Pneumatic System

In the eccentric presses clutch brake combination is worked with air. The air coming from the compressor must be filtrated well. The pressurized air is filtrated with a filter. The signal coming from PLC controller operates the valve of clutch and brake system. The ram is operated with when the clutch is operated.

The air pressure of clutch air tank is set from the regulator with number 1 which is placed at bottom body of press is showed at Figure 3.1. The air which goes to clutch is lubricated.

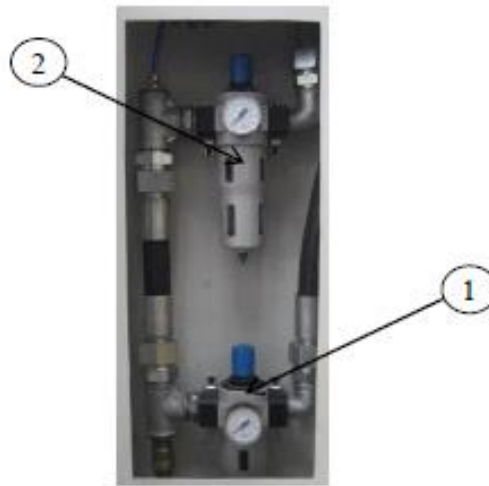


Figure 3.1 Main tank and pneumatic piston air pressure regulator (Dirinler Mak. San. ve Tic. A.Ş., 2019)

In the press also there is an inhibitor which protects the press from over pressurized air. The mechanical valve which is shown at Figure 3.2 with number 5 is opened if the air pressure goes over 7 bar. The clutch air is stored at the air tank to provide constant pressure.



Figure 3.2 Pneumatic system components (Dirinler Mak. San. ve Tic. A.Ş., 2019)

There are two air tanks on the press which provide pressurized air to balancing cylinders are shown at Figure 3.3. The balancing cylinders helps to balance ram and die weight and helps the main motor force which is required to move ram. The balancing cylinder air pressure is set from the regulator which is placed at the bottom body of press with number 2. All the parts of pneumatic system are listed at Table 3.1.

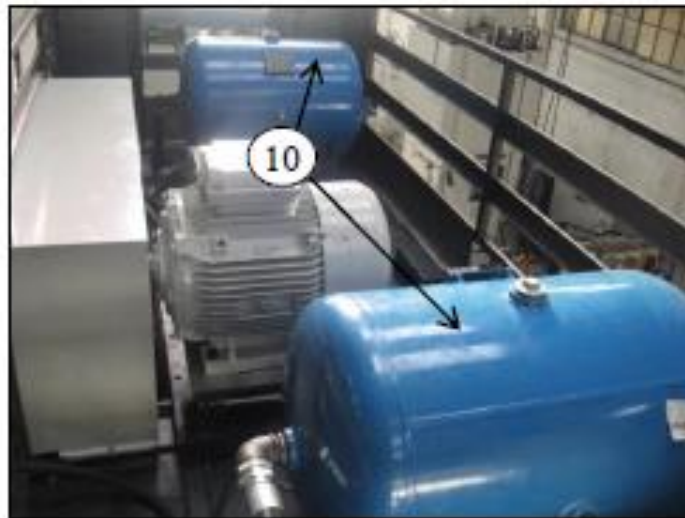


Figure 3.3 Balancing cylinder air tanks (Dirinler Mak. San. ve Tic. A.Ş., 2019)

Table 3.1 Pneumatic system component list

ASSEMBLY NO	PART NAME
1	FILTER REGULATOR (CLUTCH)
2	FILTER REGULATOR (BALANCING CYLINDER)
3	LUBRICATOR
4	PRESSURE SAFETY VALVE
5	PRESSURE CONTROL SWITCH
6	AIR TANK (CLUTCH)
7	CLUTCH CONTROL VALVE
8	MUFFLER
9	QUICK EXHAUST VALVE
10	AIR TANKS BALANCING CYLINDER

CHAPTER FOUR

HYDRAULIC SYSTEM

4.1 Lubrication System

Oil is pumped by oil pump from oil tank through all lubrication points of the press. In case of having clogging in one of the lubrication points it is sensed by pressure sensor at the lubrication system. In different conditions like as jamming in pistons within the distributor, low oil pressure, failure in ultra-sensor or in oil pump; the press will not work by the agency of sensor and the control system. The lubrication system is shown at Figure 4.1 and 4.2

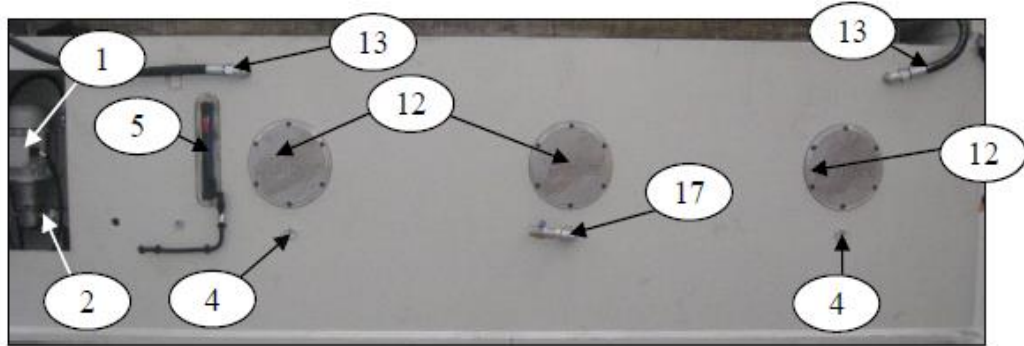


Figure 4.1 Lubrication tank and pump (Dirinler Mak. San. ve Tic. A.Ş., 2019)

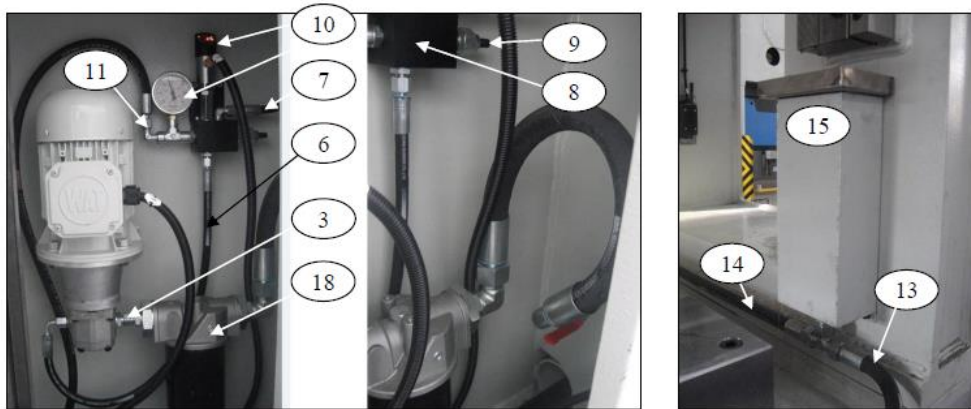


Figure 4.2 Oil container filter – sensors and oil return system (Dirinler Mak. San. ve Tic. A.Ş., 2019)

Efficient lubrication is very important for operation condition that is silent and has high performance. With this aim; oil pressure is controlled for every line, the press will stop in case of oil dirtiness or if the pressure is not enough for lubrication. The condition of oil dirt or lack of pressure are detected with oil filter sensor and with a sensor on oil distribution system that are showed at Figure 4.3. Crank shaft, ram slides, connecting rods, flywheel shaft bearing, flywheel bearing are lubricated while the press is working.



Figure 4.3 Oil dirtiness filter – oil distribution System (Dirinler Mak. San. ve Tic. A.Ş., 2019)

The lubrication system parts are shown at the Table 4.1.

Table 4.1 Lubrication group part list

ASSEMBLY NO	PART NAME
1	PUMP MOTOR
2	GEAR PUMP
3	SUCTION LINE
4	OIL TANK OIL DRAIN PLUGS
5	OIL TANK OIL INDICATOR
6	PRESSURIZED OIL INLET HOSE
7	RETURN LINE HOSE
8	SAFETY BLOCK
9	ADJUSTING VALVE
10	MANOMETER AND SENSOR
11	PRESSURIZED OIL OUTLET HOSE
12	OIL TANK COVERS
13	OIL RETURN PIPES
14	OIL RETURN PIPES
15	OIL RETURN COLLECTION CONTAINERS
16	OIL DISTRUBITION BLOCK
17	BALL VALVE
18	OIL CONTAINER FILTER
19	ULTRA SENSOR
20	OIL DIRTINESS FILTER

The hydraulic overload system that is shown at Figure 4.4 limits the maximum tonnage that press can work. The hydraulic safety unit, is fixed to an adjustment based on nominal tonnage of the press, and its tunes and settings cannot be changed. The user cannot interfere in the hydraulic safety unit. Otherwise, unexpected physical and financial damages might occur.

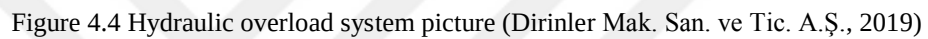
[illegible]

Figure 4.5 Hydraulic overload system diagram (Technofluid, n.d.)

CHAPTER FIVE

PRESS CONTROL SYSTEM

5.1 Description

Press control system gathers the information that are transmitted from the sensors on the press and evaluates the collected information due to the logic on the controller and transmits the signals to the actuators.

Electrical system is a critical system in the press system. The safety category of many presses which are used in industry is at the highest security level. Therefore, the sensors to be used in this system should be selected to ensure the security level. Sensor connections, actuator connections, electrical wiring and programming must be made to meet safety requirements.

The press control system can be divided into two main part as press visualization system and control system.

5.2 Press Visualization System

Press visualization system is a system that make the process easily understandable, shows process sequences and use system ergonomically. It gives opportunity to the user to understand system parts easily, monitor the coming signals and observe the system situation.

Press visualization system should be placed somewhere that can be accessed easily by the operator. The visualization system can be divided from the press and placed an outstanding electrical panel or can be mounted on the moveable place as shown at Figure 5.1 on the press side which can be easily accessed by the operator.



Figure 5.1 Visualization system (Dirinler Mak. San. ve Tic. A.Ş, 2019)

All system faults, sensor conditions, system diagnostics are shown on the HMI screen and some controls of press machine can be made over HMI screen. HMI screen program is developed on TIA Portal 15 programming environment as shown Figure 5.2.

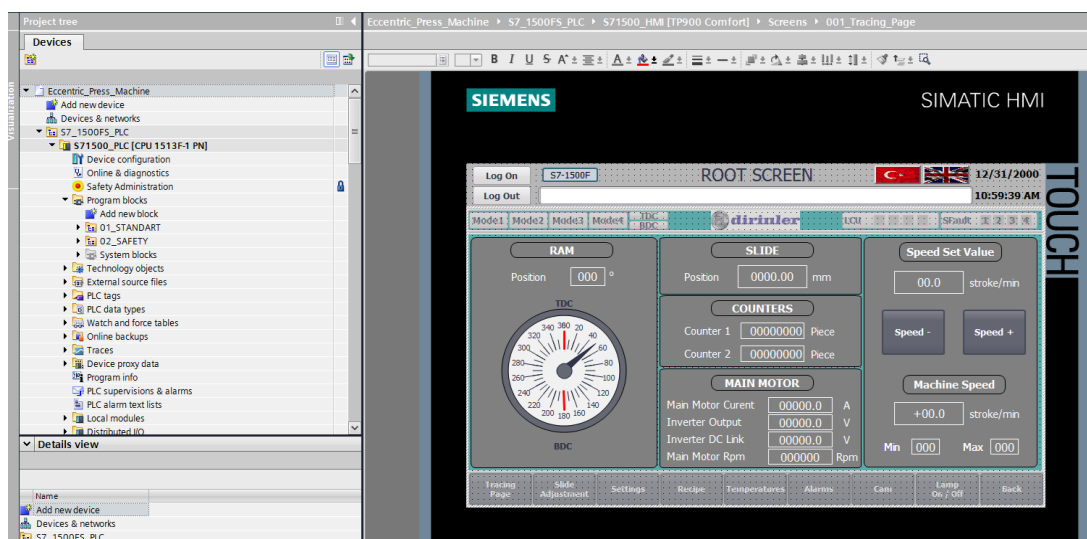


Figure 5.2 Visualization system development environment

5.3 Control System

The control system of press consists of design of system, electrical connections and programming. The electrical control panel which is shown at Figure 5.3 can be divided into two categories as power supply part and the control part.



Figure 5.3 Electrical panel (Personal archive, 2019)

The power supply part consists of main circuit breaker, motor supply circuit, main drive unit, and power supply unit for control system, motor connection terminals and emergency stop contactors as shown Figure 5.4. The power system of electrical panel is designed due to press forces. The main drive unit is selected due to the power of electrical motor. The main circuit breaker is selected depending on the total power of electrical control panel.

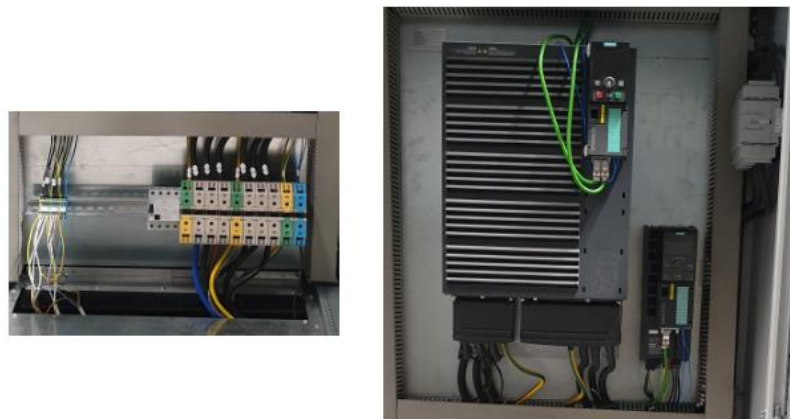


Figure 5.4 Electrical panel – power supply and motor connection (Personal archive, 2019)

The control part of electrical control panel consists of the programmable logic controller, relays, contactors and input/output systems. In this press the controller parts are placed on different places on the press. The main central processing unit is placed in the main electrical panel as shown at Figure 5.5. The input/output systems of controller system are placed both inside the electrical panel and the terminal boxes on the press. This divided system is giving opportunity to user for easy maintenance. In the other hand divided control units are connected each other with an Ethernet cable. This system prevents cabling problems and offer easy wiring.

The controller part must be reliable to prevent non wanted startup of press or running press independent from controller. In case of a failure it should prevents moving press downward.



Figure 5.5 Electrical panel – control system (Personal archive, 2019)

In this project the S7-1500 safety PLC is used as a PLC controller. The ET200SP signal modules are used for divided input output systems. All communication are made over PROFI-safe ethernet communication. The hardware and communications are shown at Figure 5.6.

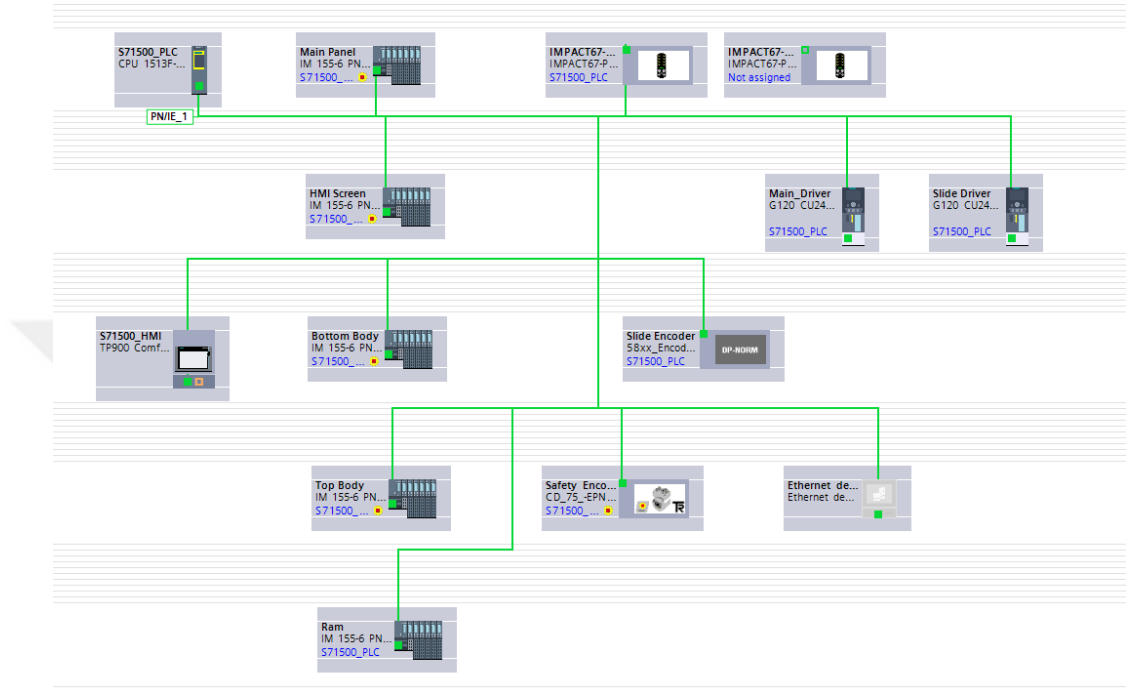


Figure 5.6 Hardware of press control system

5.4 Press Safety Control System Design Components

The safety conditions and precautions that the minimum level of machines have to comply with for a safe operation of machine systems have been discussed by different countries for years. The different standards have been established for machines around the world.

A machine must have the CE marking in order to have the right to move freely within the European countries and must comply with the standards established by the European Union. Therefore 2006/42 / EC Machinery Directive (2006/42 / EC Machinery Directive, 2006) is enacted by Turkey. According to the law that is enacted in Turkey, all produced machines which are covered by 2006/42 / EC machinery directive must comply with CE requirements.

5.4.1 Performance Level (PL)

EN ISO 13849-1 safety of machinery standard is used for the design of safety control systems. This standard describes how electrical safety equipment on machines should be designed. In accordance with EN ISO 13849-1, it is necessary to make various calculations according to machine equipment and connection diagrams. First of all, the class of the hazard is determined according to the Figure 5.7 performance level analyze diagram.

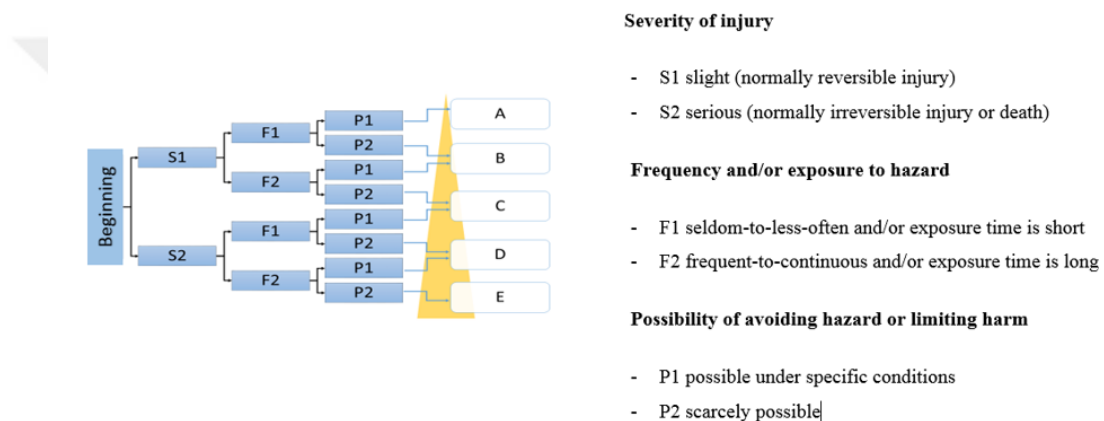


Figure 5.7 Performance level analyze

The risk assessment, starting from the beginning, determines the level of performance required by following the appropriate path according to the risk classification. There is no safe machine according to EN ISO 13849-1. The machines may only be suitable for use according to the place of use and the measures taken. The evaluation results in the PL (performance level) indicating the suitability of each device.

5.4.2 Mean Time to Dangerous Failure (MTTF_D)

It is not difficult to say that the devices we use are a certain time of deterioration because it is known that everything can be corrupted and broken at the end of some time. Mean time to dangerous failure is described as expectation of the mean time to dangerous failure. EN ISO 13849-1 standard describes the relationship between the MTTF_D value and the PL safety level at Figure 5.8.

MTTF _D	
Denotation of each channel	Range of each channel
Low	3 years ≤ MTTF _D < 10 years
Medium	10 years ≤ MTTF _D < 30 years
High	30 years ≤ MTTF _D ≤ 100 years

NOTE 1 The choice of the MTTF_D ranges of each channel is based on failure rates found in the field as state-of-the-art, forming a kind of logarithmic scale fitting to the logarithmic PL scale. An MTTF_D value of each channel less than three years is not expected to be found for real SRP/CS since this would mean that after one year about 30 % of all systems on the market will fail and will need to be replaced. An MTTF_D value of each channel greater than 100 years is not acceptable because SRP/CS for high risks should not depend on the reliability of components alone. To reinforce the SRP/CS against systematic and random failure, additional means such as redundancy and testing should be required. To be practicable, the number of ranges was restricted to three. The limitation of MTTF_D of each channel values to a maximum of 100 years refers to the single channel of the SRP/CS which carries out the safety function. Higher MTTF_D values can be used for single components (see Table D.1).

NOTE 2 The indicated borders of this table are assumed within an accuracy of 5 %.

Figure 5.8 Mean time to dangerous failure of each channel (MTTF_D) (European Standard - EN ISO 13849-1, 2015)

5.4.3 Diagnostic Coverage (DC)

The diagnostic coverage can be expressed “measure of the effectiveness of diagnostics, which may be determined as the ratio between the failure rate of detected dangerous failures and the failure rate of total dangerous failures” (European Standard - EN ISO 13849-1, 2015). The diagnostic coverage estimates can be found at Annex E of European Standard - EN ISO 13849-1:2015. The denotation of DC values is obtained from the Table 5.1.

Table 5.1 Diagnostic coverage (European Standard - EN ISO 13849-1, 2015)

Denotation	Range
None	DC < %60
Low	%60 ≤ DC < %90
Medium	%90 ≤ DC ≤ %99
High	%99 ≤ DC

5.5 Safety System Electrical and Software Program Design

It is hard to make calculations of $MTTF_D$ and DC values of a system by hand for each machines. The SISTEMA software is published by German Social Accident Insurance (DGUV). The calculation of $MTTF_D$ value, DC value and PFH_D values of our system is made by using SISTEMA software. Subsystem elements of machines are added to the program at Figure 5.9. The safety design, program configuration and electrical connection of safety elements of our systems is made one by one at next sections.

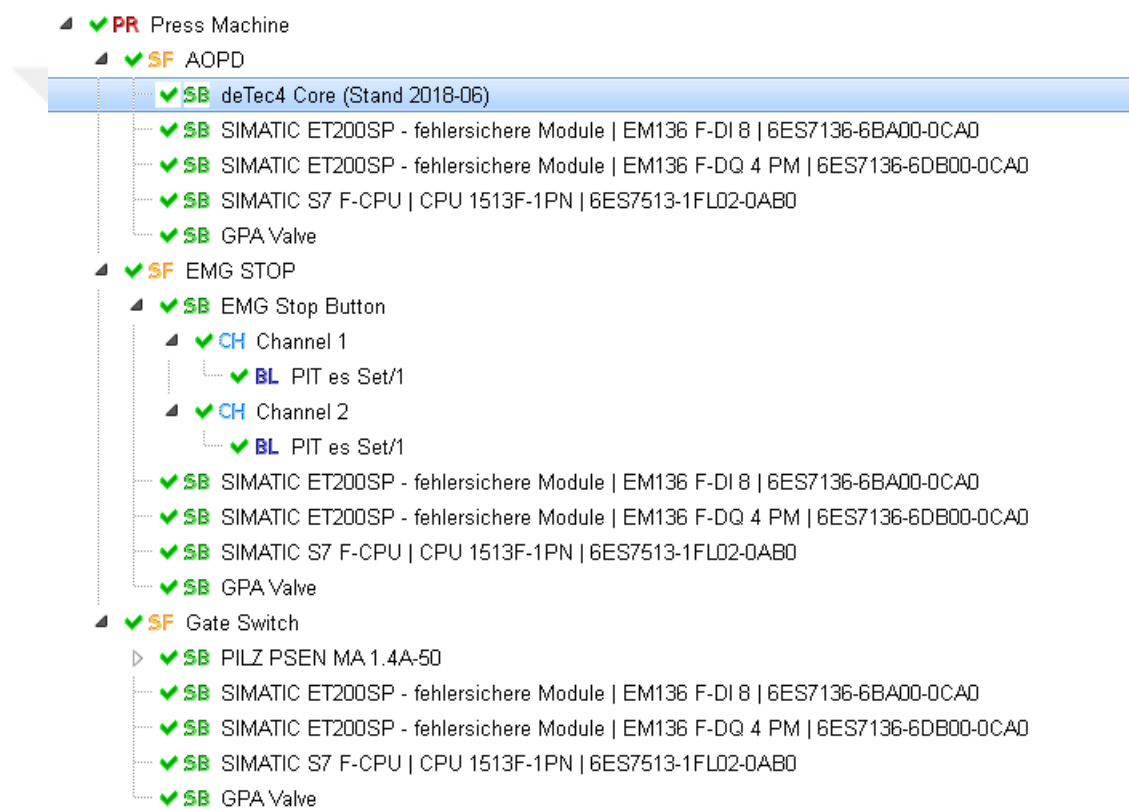
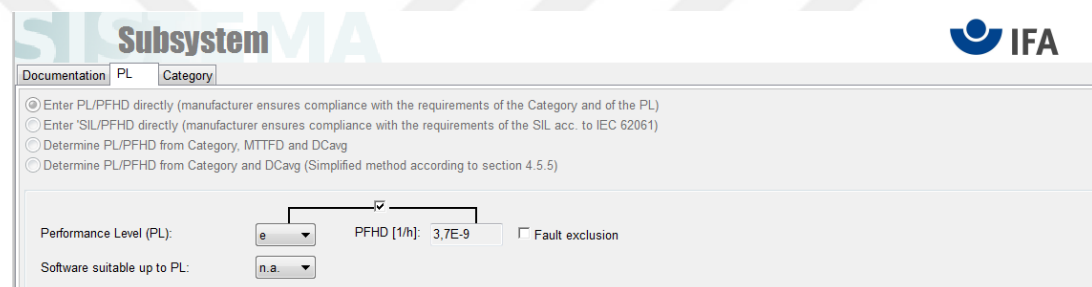


Figure 5.9 Sistema analyze of subsystem elements of press

5.5.1 Light Curtain

The light curtain is mostly used in industrial field where the intervention of operator should be need often. When a light curtain sees an object or a person between the gap of the receiver and the transmitter, it drops the signal off to stop the system.

SICK dete4core is used as light curtain of the press machine. Its library is found and added to the SISTEMA program. When the light curtain is added, its performance level is automatically is shown at the program with PFHD value which is shown at Figure 5.10.



Subsystem IFA

Documentation PL **Category**

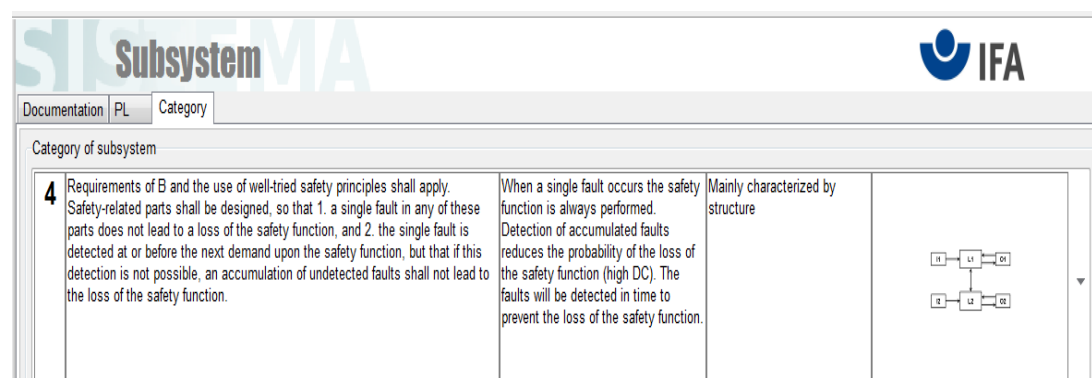
☒ Enter PL/PFHD directly (manufacturer ensures compliance with the requirements of the Category and of the PL)
☐ Enter 'SIL/PFHD directly (manufacturer ensures compliance with the requirements of the SIL acc. to IEC 62061)
☐ Determine PL/PFHD from Category, MTTFD and DCavg
☐ Determine PL/PFHD from Category and DCavg (Simplified method according to section 4.5.5)

Performance Level (PL): e PFHD [1/h]: 3,7E-9 ☐ Fault exclusion

Software suitable up to PL: n.a.

Figure 5.10 PFHD value of light curtain

The light curtain is connected to the safety PLC as a category 4 which means the light curtain should be connected double channel. The category 4 connection of identification is made at Sistema program as shown at Figure 5.11.



Subsystem IFA

Documentation PL **Category**

Category of subsystem

4	Requirements of B and the use of well-tried safety principles shall apply. Safety-related parts shall be designed, so that 1. a single fault in any of these parts does not lead to a loss of the safety function, and 2. the single fault is detected at or before the next demand upon the safety function, but that if this detection is not possible, an accumulation of undetected faults shall not lead to the loss of the safety function.	When a single fault occurs the safety function is always performed. Detection of accumulated faults reduces the probability of the loss of the safety function (high DC). The faults will be detected in time to prevent the loss of the safety function.	Mainly characterized by structure	
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Figure 5.11 Category 4 connection of light curtain at Sistema program

The light curtain return signals are connected the safety PLC as double channel characteristic which is shown at Figure 5.12.

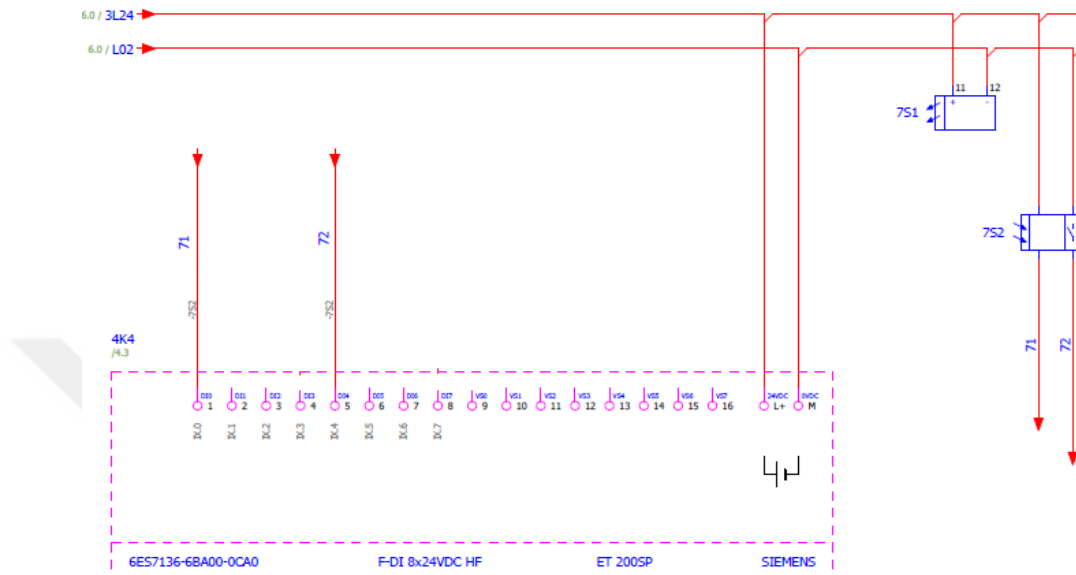


Figure 5.12 Electrical connection diagram of light curtain

The connections of light curtain at the program side defined as double channel. One of the signal of light curtain is connected to the channel 0, the other signal of light curtain is connected to the channel 4 of same safety digital input module. The evaluation of light curtain signals are 1oo2 evaluation, equivalent which means if one of the signal does not come in the discrepancy time the module goes into fault condition. The connections and parameters of light curtain at the program side is shown at Figure 5.13 and 5.14.

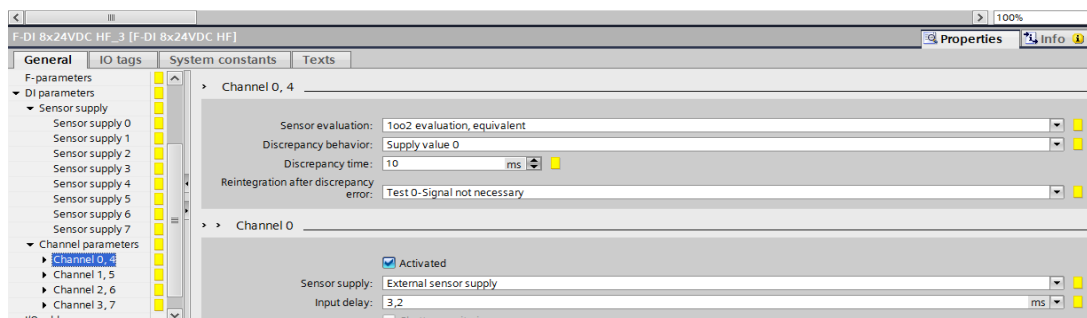


Figure 5.13 The parameter assignment of light curtain at program side

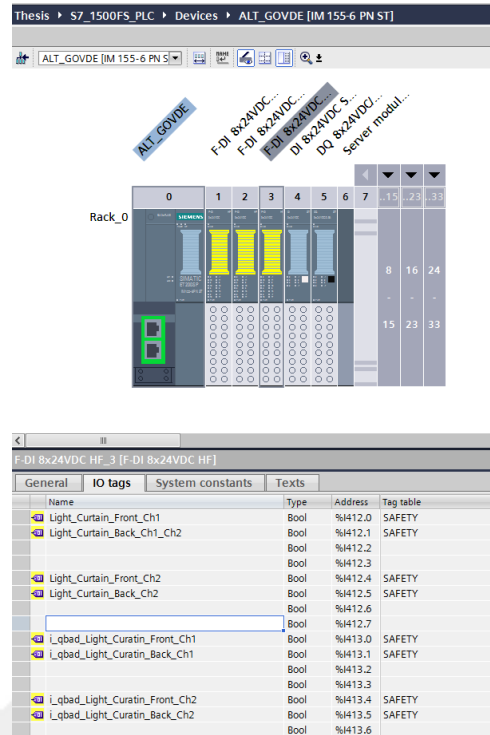


Figure 5.14 Hardware connection of light curtain at the program side

In Sistema program the other compnents that is connected with the light curtain subsystem must be added for a proper calculation. If the light curtain is the input signal of this system that should be at least logic controller and output of the system. The overall subsystem schema of light curtain is shown at Figure 5.15.



Figure 5.15 The overall subsystem schema of light curtain

All the modules of light curtain system are added to Sistema program as shown at Figure 5.16. Their PFH_D values are added automatically when the modules are added. The PFH_D value of light curtain is 3.7E-9 The PFH_D value of safety input module is 1E-9. The safety output module PFH_D value is 1E-9. The safety logic controller PFH_D value is 2E-9. The output valve PFH_D value is as 4.7E-8. The overall PFH_D value is the sum of the other system as 5.5E-8 as shown at Figure 5.17 .

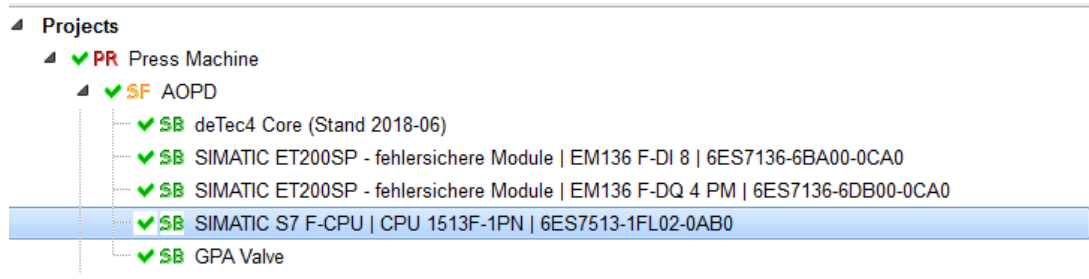


Figure 5.16 The light curtain system design at Sistema

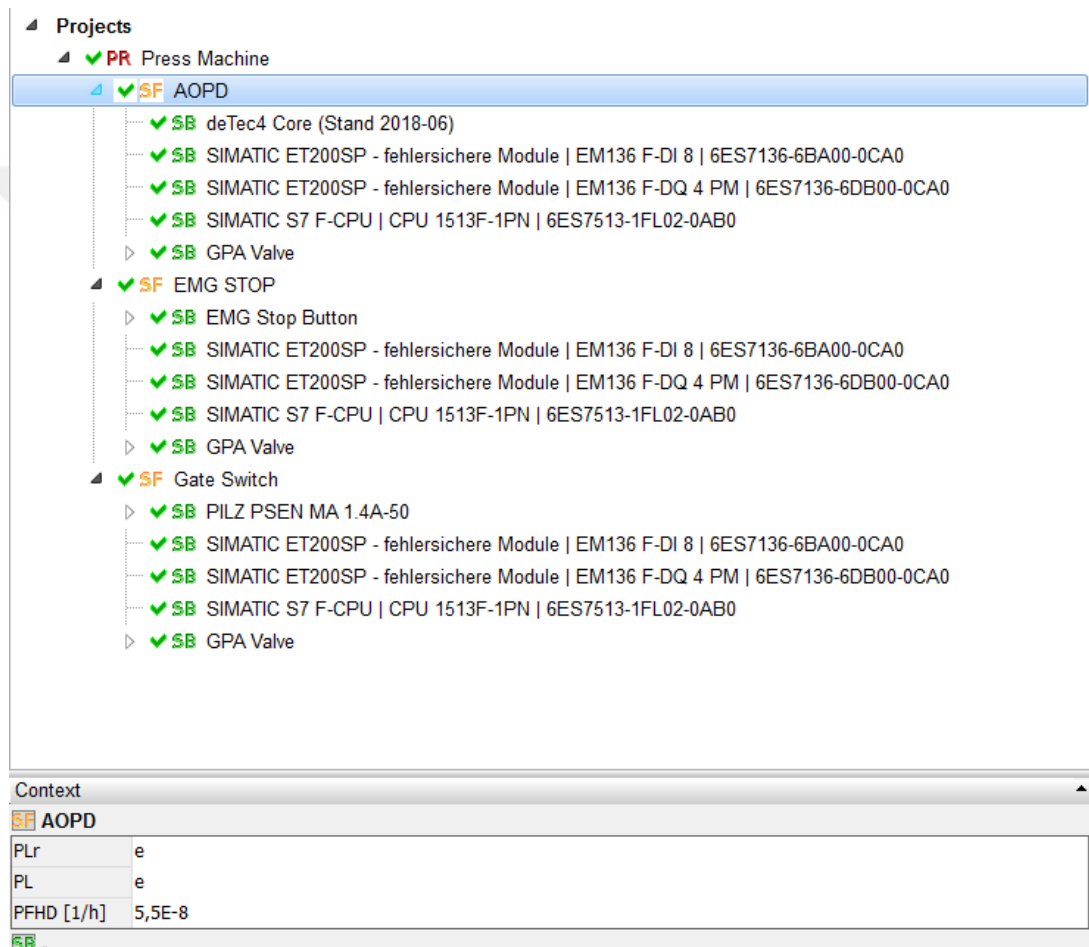


Figure 5.17 The PFH_D value of the light curtain system

The frequency and severity of the hazards that will occur if the safety equipment fails to fulfill its duty in the event of a hazard according to the performance levels is indicated in the Table 5.2. The PFH_D value of light curtain system is obtained as 5.5E-8 from Sistema program. It can be easily seen from the Table 5.2 that the light curtain system satisfies the performance level e.

Table 5.2 Light curtain system performance level (European Standard - EN ISO 13849-1, 2015)

Performance Level (PL)	Average probability of dangerous failure per hour (PFH _D) 1/h
a	$\geq 10^{-5}$ to $< 10^{-4}$
b	$\geq 3 \times 10^{-6}$ to $< 10^{-5}$
c	$\geq 10^{-6}$ to $< 3 \times 10^{-6}$
d	$\geq 10^{-7}$ to $< 10^{-6}$
e	$\geq 10^{-8}$ to $< 10^{-7}$

The Siemens safety press blocks are used for programming. The light curtain input is connected to the LCU_CLK block which is shown at Figure 5.18. The LCU_CLK block communicates with the VALVE_ME (which controls the output of clutch valve) and EN_1_MAN (which controls the modes of press and gives start signal to VALVE_ME block) over datablock variables. In the case of light curtain is blocked the clutch valve output signal is cutted.

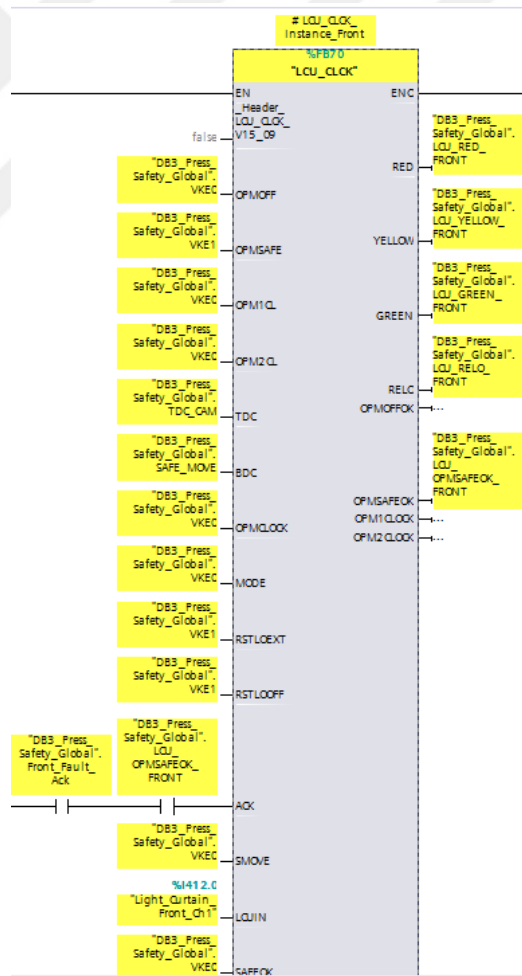


Figure 5.18 The connections of light curtain at program side

The press must be stopped when the light barrier is cut off before any living being reach the dangerous area. For that reason, the placement of light curtain is very important. It can be changed due the parameters of press and light curtain.

There are different types of light curtains like type 2, 3, 4. The response time of the light curtains and aperture angles can be changed due to the types. These types are defined at the manual of the light curtain by manufacturer. The type 4 light curtain should be used for a performance level e system. Also there are different kind of light curtains as finger protection, hand protection and body protection. The protection types do not affect the general type of light curtain. The light curtain can be type 4 and body protection type. The protection type like body protection type affects the minimum distance that the light curtain can be mounted which is shown at Figure 5.19.

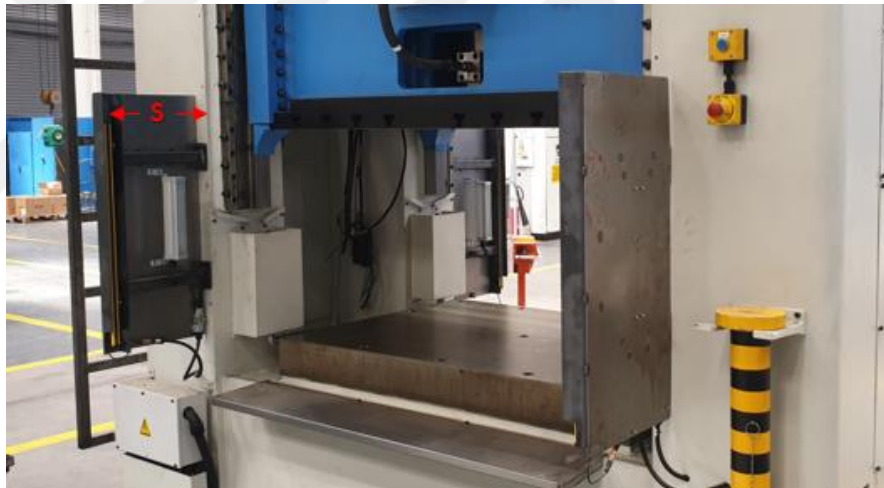


Figure 5.19 Minimum distance (S) for light curtain placement (Personal archive, 2019)

The minimum distance for a light curtain placement is calculated with the formula 5.1.:

$$S = (K \times T) + C \quad (5.1)$$

The S shows the minimum distance that the light curtain will be placed from the dangerous zone. The unit of S is millimeters. K is the speed value of ram movement. The unit of K parameter is millimeters per second. T parameter is the time parameter

that indicates the elapsed time after the stop command is issued in seconds. The C parameter is additional distance based on the type of light curtain. The unit of C parameter is millimeters.

The C parameters of the formula can be changed due to the type of the light curtain. For example, if the light curtain detection capability is 30mm than the C parameter can be taken as 130mm. In the other hand if the light curtain detection capability is equal to 14mm which is the finger protection type than C parameter can be taken as zero.

In this thesis, the minimum distance for the light curtain is calculated with the devices to protect a living being from dangerous area. The distance calculator device is placed near press. The equipment which calculates the speed of the ram is placed under ram with the connection of calculator device which are shown at Figure 5.20 and 5.21.

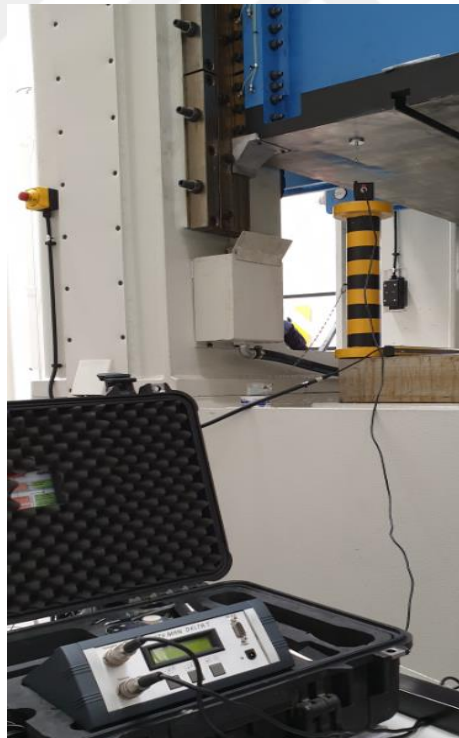


Figure 5.20 The distance calculator equipments of light curtain (Personal archive, 2019)



Figure 5.21 The distance calculator device of light curtain parameters (Personal archive, 2019)

The half of maximum ram travel distance is entered on the device parameter. For this example 200 mm is entered as half of travel distance of ram where the maximum stroke is 400 mm of press.

The device is started for measuring process. Than the ram is moved with the highest speed. When the half of traveling distance is detected by the device the actuator of the measuring device is actuated and blocks the light curtain that is shown at Figure 5.22. After blocking process of light curtain the measuring device continues to measure the traveling distance.

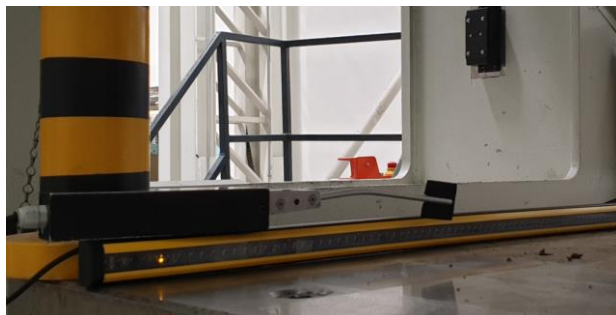


Figure 5.22 The actuator of distance measuring device (Personal archive, 2019)

The distance that is measured by the measuring device after light curtain is blocked is the stopping distance of the ram after light curtain is blocked. The measuring device outputs the S distance as a result that is shown at Figure 5.23. The S parameter shows distance in millimeters as 771 millimeters where the light curtain is placed.



Figure 5.23 The safety distance of light curtain placement (Personal archive, 2019)

5.5.2 Emergency Stop

The emergency stop buttons are very important because if operator see any danger in the working area, the system can be stopped instantly. So the emergency stop buttons must stop all dangerous movement when it is pressed. The emergency stop buttons must be placed somewhere that operator can easily reach at dangerous state. In our project emergency stop buttons are placed at each column, on the operator control panel and on the double hand for easy access. The placement of emergency stop buttons are shown at Figure 5.24 and 5.25 Also the emergency stop buttons must be reset from the place that the operator can see dangerous area. If the emergency stop button is pushed from backside of press it must be reset from backside of press.



Figure 5.24 The emergency stop buttons that are placed at columns (Personal archive, 2019)



Figure 5.25 The emergency stop buttons that are placed are placed for double hand use and control panel (Personal archive, 2019)

The emergency stop system must satisfy performance level e and category 4 for a press machine system. For that reason emergency stop system must be designed as category 4 and performance level e. The performance analyze of emergency stop system is made by using Sistema program.

At first emergency button is added as 2 channel to Sistema program as shown Figure 5.26. The $MTTF_D$ value and DC value cannot be taken from the manufacturer manual because of the emergency stop button is electromechanical component. The $MTTF_D$ value and DC value are calculated and assumed for each channel of emergency stop button.

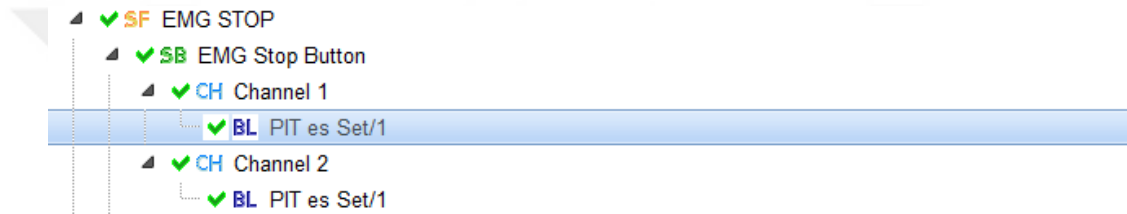


Figure 5.26 The emergency stop button configuration at Sistema program

In our system an emergency stop button mission time is assumed as 20 years. The manufacturer gives the $B10_D$ value of emergency stop button. The manufacturer gives the life of emergency stop button as 104,000 cycle. This value comes from library of Sistema when you added the emergency stop button. It is assumed that the machine will work 360 day and 24 hours of each day. Than it is assumed that the emergency stop button can be pushed every 6000 second in average. The manufacturer gives the life of emergency stop button as 104,000 cycle. From the formula $T10_D$ is calculated as 20.1 year as shown Figure 5.20 which means mission time of emergency stop button is satisfied. For performance level e system the $MTTF_D$ value must be high which means it must be bigger than 100 years. The Sistema program gives the $MTTF_D$ value of emergency stop system as 200.6 year as shown Figure 5.27 which means the $MTTF_D$ value is also satisfied for performance level e system.

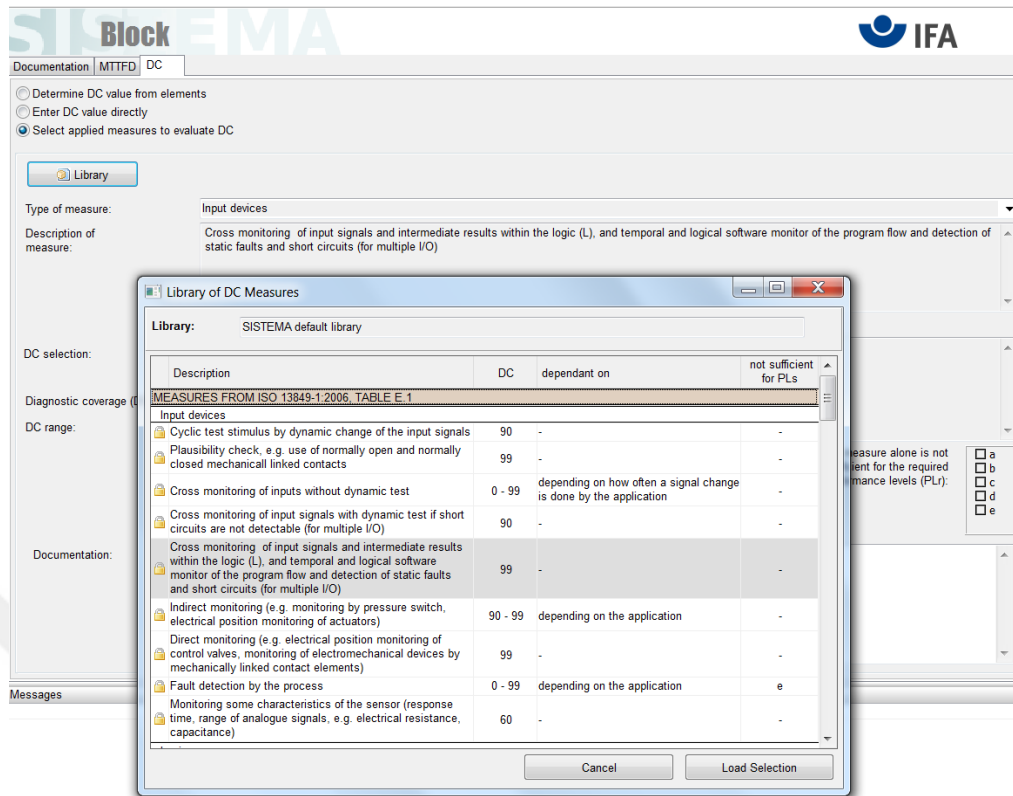


Figure 5.28 The DC value of emergency stop channel

The $MTTF_D$ value of emergency stop button is calculated as 200.6 year as shown Figure 5.20. DC value is selected as %99 based on design parameters as shown Figure 21. It can be seen from Figure 5.29 that DC value and $MTTF_D$ values of the emergency stop button are located at performance level e zone.

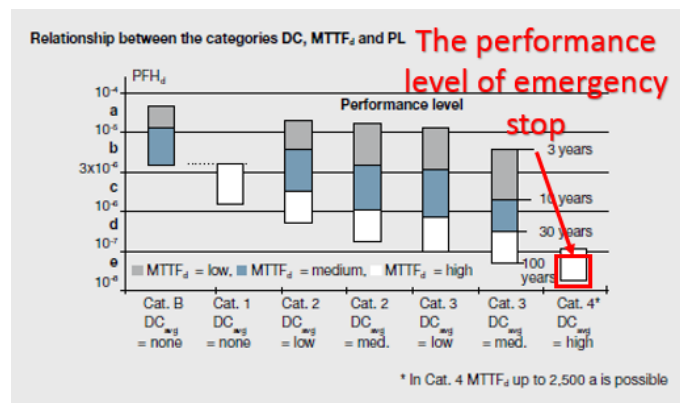


Figure 5.29 Emergency Stop Button Performance Level - Relationship between the categories DC, $MTTF_D$ and PL (TS EN ISO13849-1 Standard Safety of machinery — Safety-related parts of control systems, 2015)

The emergency stop button signals must be connected as double channel closed contact to hardware as shown in Figure 5.30. The signals that are used to control emergency stop button must be the inner signals of control units to satisfy the performance level e. In the controller side these signals are controlled in case of discrepancy.

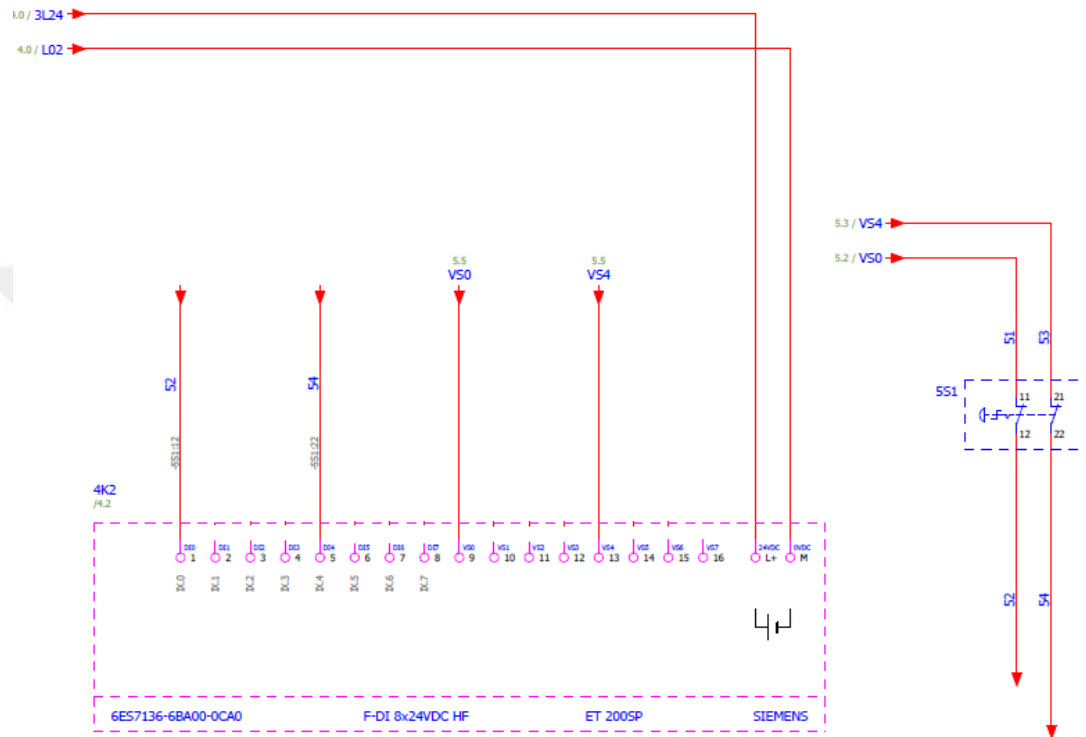


Figure 5.30 Emergency stop electrical connection

The connections of emergency stop button at the program side defined as double channel. One of the signal of emergency stop button is connected to the channel 0, the other signal of emergency stop button is connected to the channel 4 of same safety digital input module. The evaluation of emergency stop button signals are compared as 1oo2 evaluation which means if one of the signal does not come in the discrepancy time the module goes into fault condition. The connections and parameters of emergency stop button at the program side is shown at Figure 5.31 and 5.32.

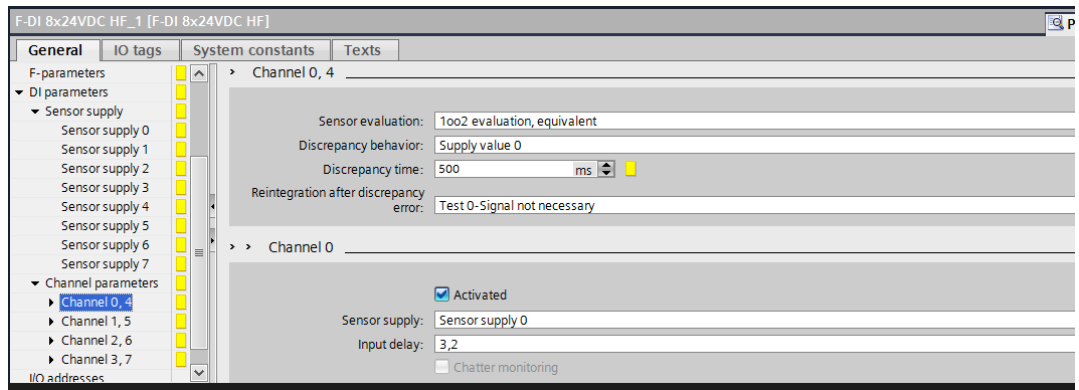


Figure 5.31 The parameter assignment of emergency stop button at program side

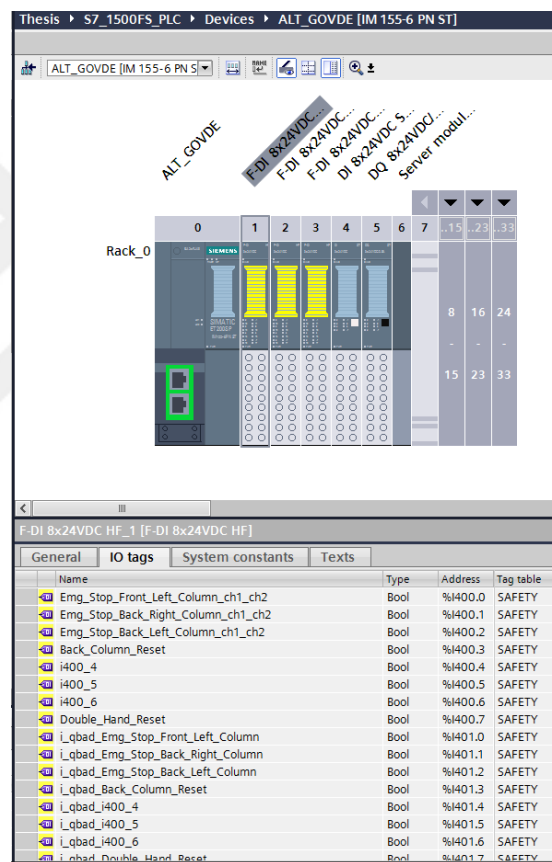


Figure 5.32 Hardware connection of emergency stop button at the program side

In Sistema program the other components that is connected with emergency stop button subsystem must be added for a proper calculation. If the emergency stop button is the input signal of this system that should be at least logic controller and output of the system. The overall subsystem schema of emergency stop is shown at Figure 5.33.



Figure 5.33 The overall subsystem schema of emergency stop system

All the modules of system are added to Sistema program as shown at Figure 5.34. Their PFH_D values are added automatically when the modules are added. The PFH_D value of emergency stop button is $1.2E-8$. The PFH_D value of safety input module is $1E-9$. The safety output module PFH_D value is $1E-9$. The safety logic controller PFH_D value is $2E-9$. The output valve PFH_D value is $4.7E-8$. The overall PFH_D value is the sum of the other system as $6.3E-8$ as shown at Figure 5.35 .

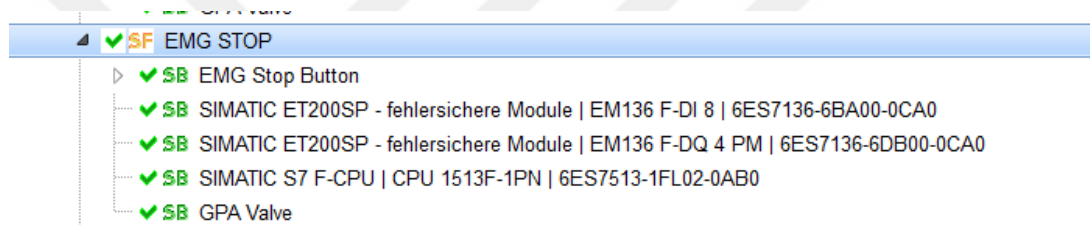


Figure 5.34 The emergency stop system design at Sistema

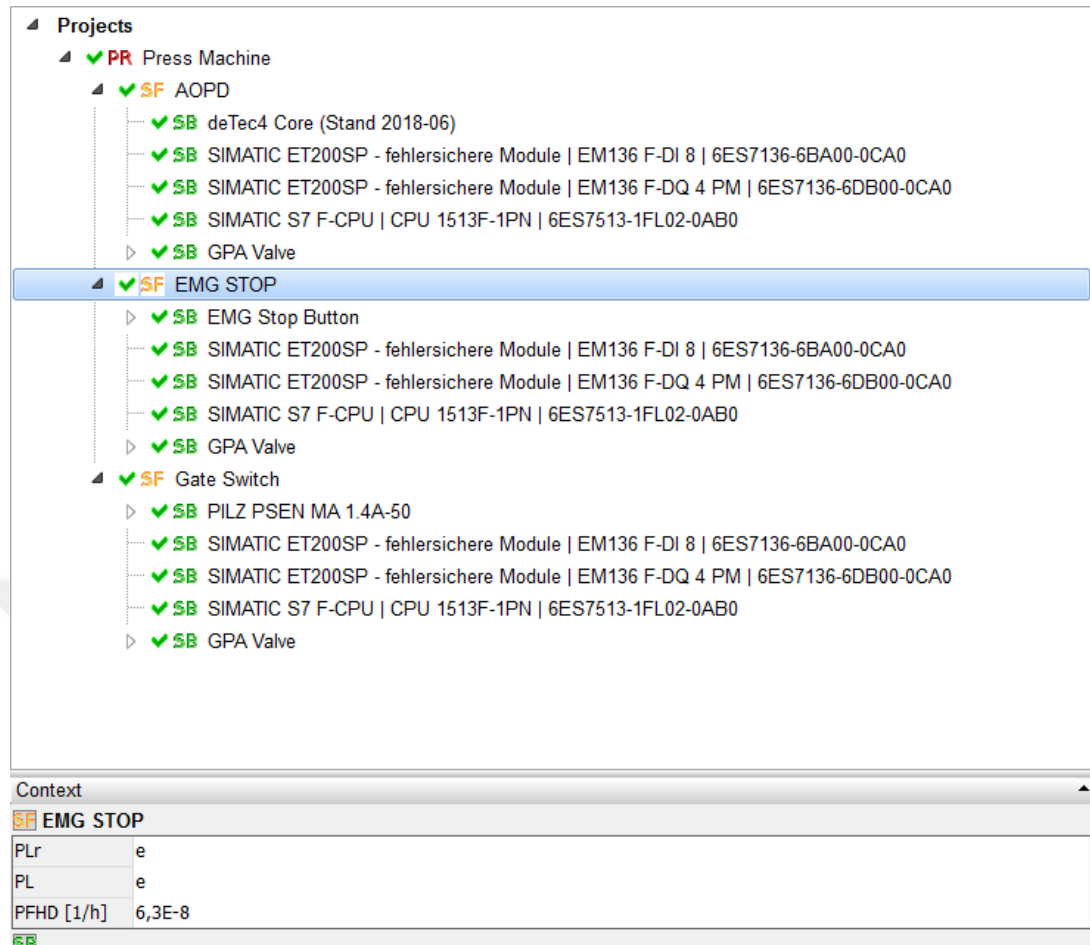


Figure 5.35 The PFH_D value of the emergency stop system

The PFH_D value of emergency stop system is obtained as 6.3E-8 from Sistema program. It can be easily seen from the Table 5.3 that the emergency stop system satisfies the performance level e.

Table 5.3 Emergency stop system performance level (European Standard - EN ISO 13849-1, 2015)

Performance Level (PL)	Average probability of dangerous failure per hour (PFH _D) 1/h
a	$\geq 10^{-5}$ to $< 10^{-4}$
b	$\geq 3 \times 10^{-6}$ to $< 10^{-5}$
c	$\geq 10^{-6}$ to $< 3 \times 10^{-6}$
d	$> 10^{-7}$ to $< 10^{-6}$
e	$\geq 10^{-8}$ to $< 10^{-7}$

The Siemens safety press blocks are used for programming. The emergency stop input is connected to the EM_OFF_Q block which is shown at Figure 5.36. The EMM_OFF_Q block communicates with the VALVE_ME (which controls the

output of clutch valve) and EN_1_MAN (which controls the modes of press and gives start signal to VALVE_ME block) over datablock variables. In the case of emergency stop is pushed, the clutch valve output signal is stopped. After emergency stop signal is came back, reset must be performed from the place that sees the dangerous area, to acknowledge system.

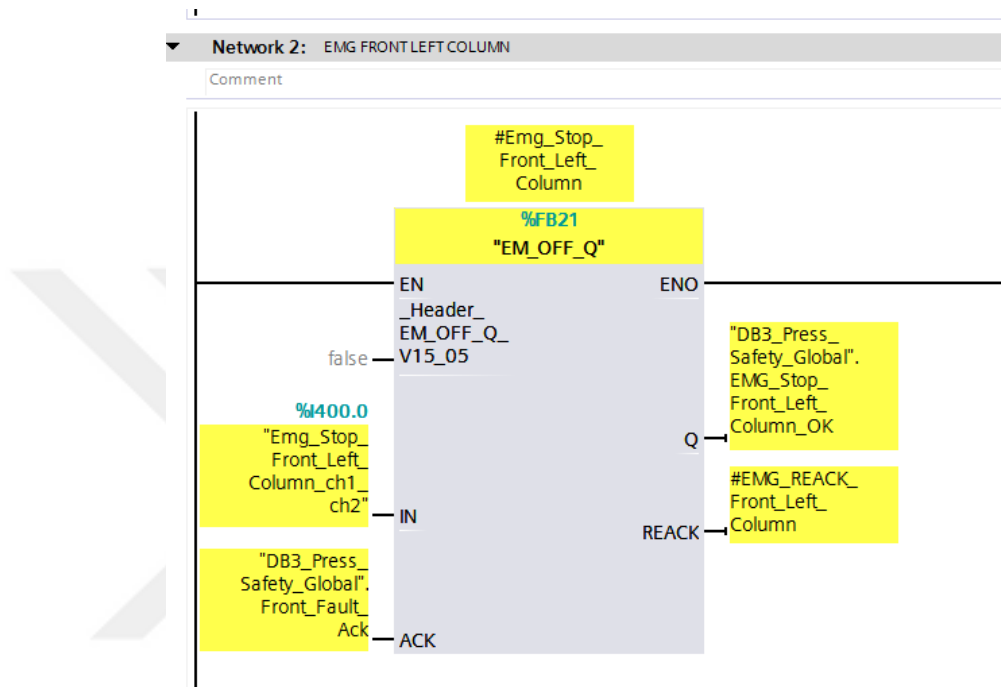


Figure 5.36 The connections of emergency stop button at program side

5.5.3 Safety Switches (Door Sensor)

The dangerous movement of the press is the down movement of the ram. While the ram is moving downward the table area of the press must be the safe area. As it can be seen before the press forward and backward side is protected with the light curtain. In general, if the press is feed by front or backward by hand, the sides of press can be protected with the fixed sheet metal. If the press is feed from side with the feeder or if the side doors are not fixed and can be opened by hand without using a tool, in this case side doors or the fence doors of the fence which surrounds the feeder must be monitored with the safety switches which is shown at Figure 5.37.

If the door is monitored with a safety switch, the safety switch type should satisfy the protection level e for a press application and the connection of the safety switch must satisfy the protection level e. Also if any door is opened, its alarm must be reset from a place that operator can easily see dangerous area.



Figure 5.37 The safety switch (PILZ - Safety Switches, n.d.)

Safety switch is added as 2 channel to Sistema program as shown Figure 5.38. The $MTTF_D$ value and DC value cannot be taken from the manufacturer manual because of the safety switch is electromechanical component. The $MTTF_D$ value and DC value are calculated and assumed for each channel of safety switch.

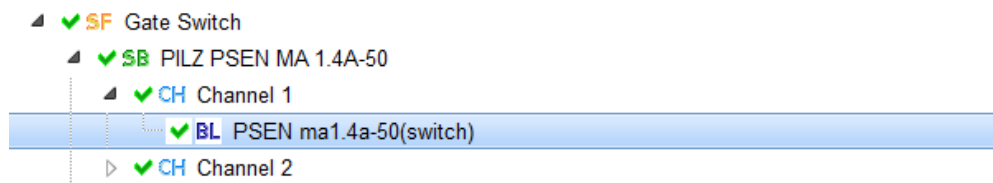


Figure 5.38 The safety switch configuration at Sistema program

The safety switch mission time is assumed as 20 years. The manufacturer gives the $B10_D$ value of safety switch. The manufacturer gives the life of emergency stop as 7,300,000 cycle. This value is emerged when the safety switch is added from the library of Sistema. It is assumed that the machine will work 360 day and 24 hours of each day. Than it is assumed that the safety door can be opened every 600 second in

with each other in case of incompatibility. DC value is selected as %99 based on design parameters as shown Figure 5.40.

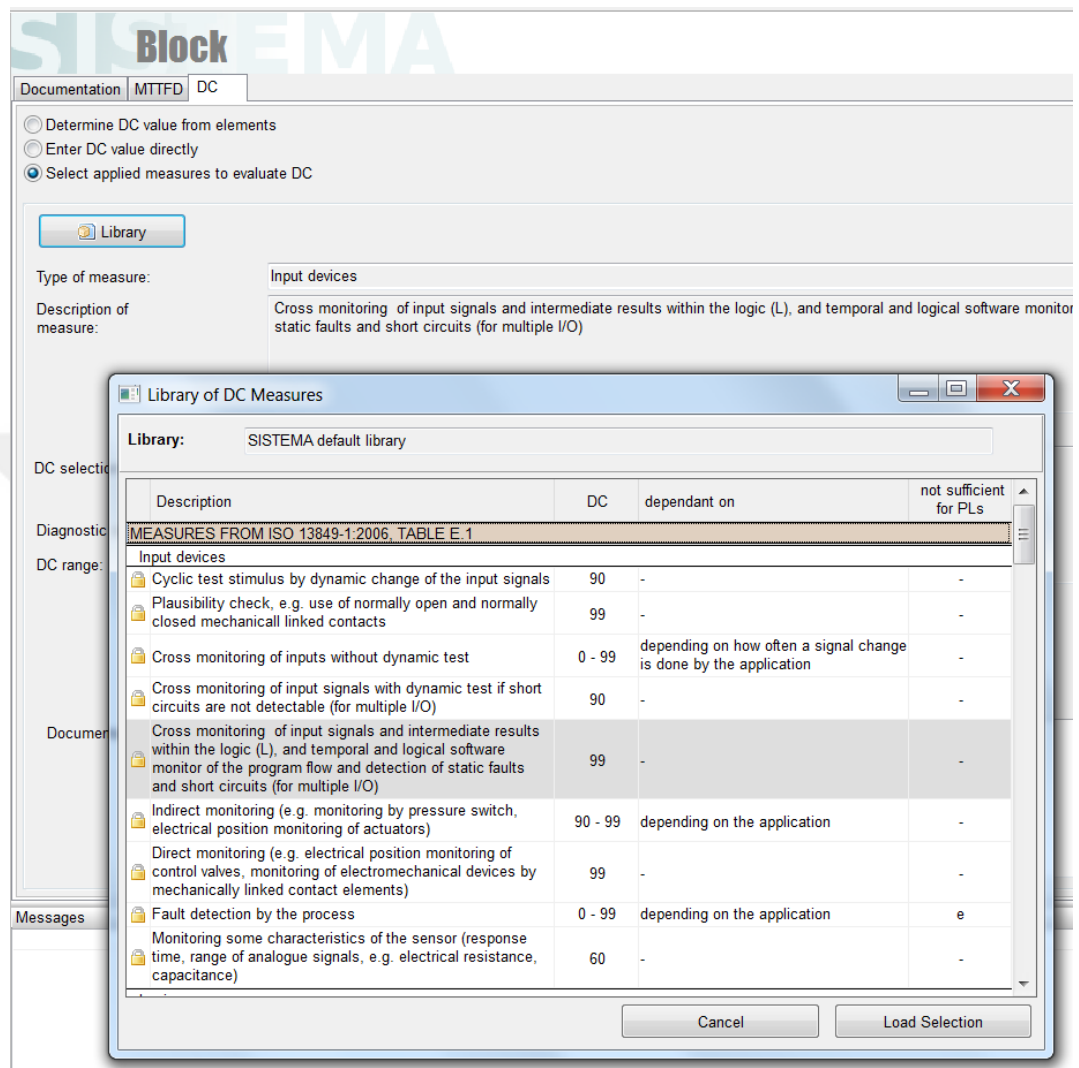


Figure 5.40 The DC value of emergency stop channels

The $MTTF_D$ value of safety switch is calculated as 1400 year as shown Figure 5.39. DC value is selected as %99 based on design parameters as shown Figure 5.40. It can be seen from Figure 5.41 that the safety switch DC value and $MTTF_D$ values are located at performance level e zone.

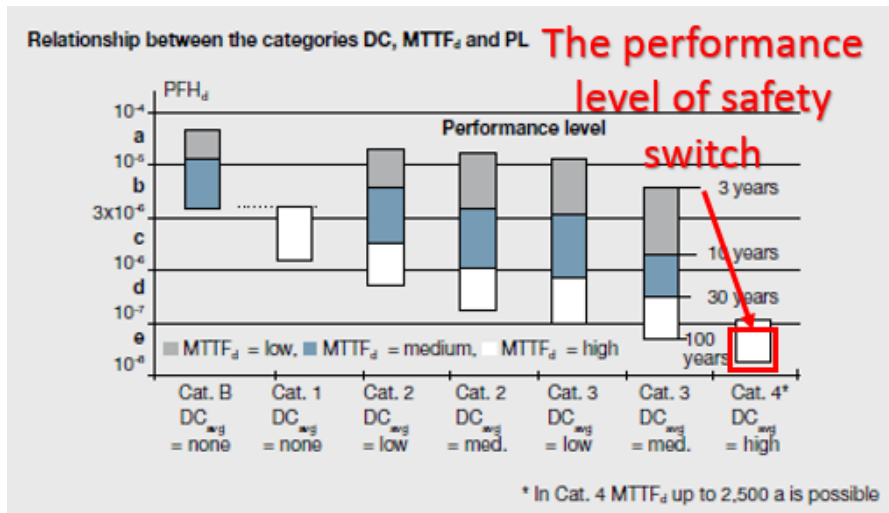


Figure 5.41 Safety switch performance level - Relationship between the categories DC, $MTTF_D$ and PL (TS EN ISO13849-1 Standard Safety of machinery — Safety-related parts of control systems, 2015)

The safety switch must be connected as double channel closed contact to hardware as shown in Figure 5.42. The signals that are used to safety switch must be the inner signals of control units to satisfy the performance level e. In the controller side these signals are controlled in case of discrepancy.

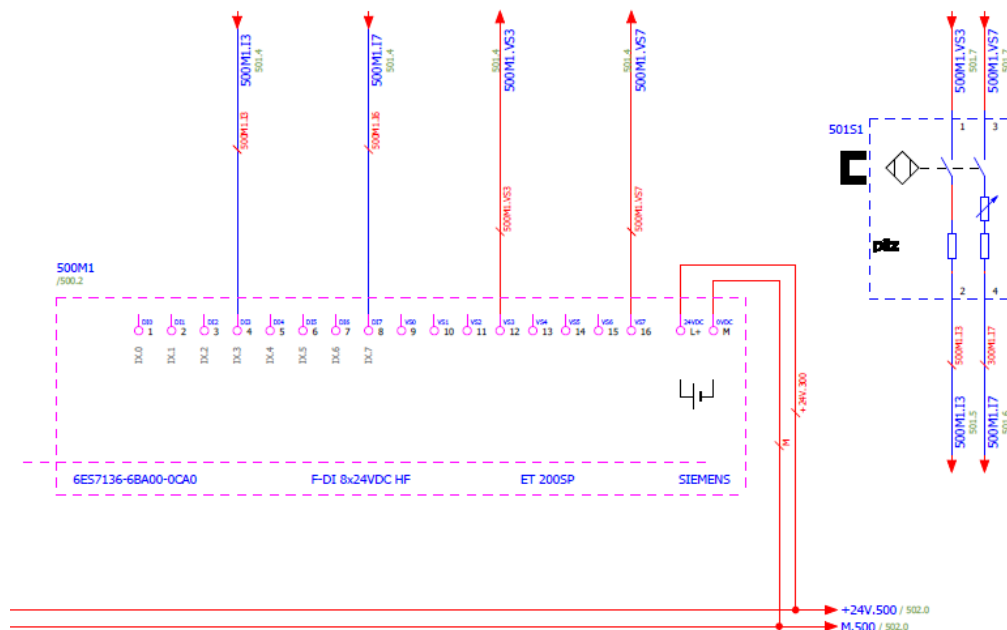


Figure 5.42 Electrical connection diagram of safety switch

The screenshot shows the 'Properties' dialog box for the device 'F-DI 8x24VDC HF_1 [F-DI 8x24VDC HF]'. The 'General' tab is selected. The left sidebar shows a tree view of the device's configuration, with 'Channel 3, 7' expanded. The main area displays the configuration for 'Channel 3, 7'. The 'Sensor evaluation' is set to '1002 evaluation, equivalent'. The 'Discrepancy behavior' is set to 'Supply value 0'. The 'Discrepancy time' is set to '500 ms'. The 'Reintegration after discrepancy error' is set to 'Test 0-Signal not necessary'. The 'Channel 3' section is also expanded, showing 'Activated' checked, 'Sensor supply' set to 'Sensor supply 3', and 'Input delay' set to '3,2 ms'.

[illegible]

Figure 5.44 Hardware connection of safety switch at the program side

In Sistema program the other components that is connected with safety switch subsystem must be added for a proper calculation. If the safety switch is the input signal of this system that should be at least logic controller and output of the system. The overall subsystem schema of safety switch is shown at Figure 5.45.



Figure 5.45 The overall subsystem schema of safety switch system

All the modules of system are added to Sistema program as shown at Figure 5.46. Their PFH_D values are added automatically when the modules are added. The PFH_D value of safety switch is 1.2E-8. The PFH_D value of safety input module is 1E-9. The safety output module PFH_D value is 1E-9. The safety logic controller PFH_D value is 2E-9. The output valve PFH_D value is 4.7E-8. The overall PFH_D value is the sum of the other system as 5.3E-8 as shown at Figure 5.47.

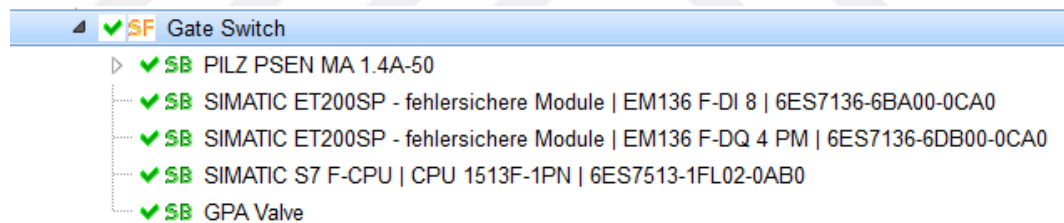


Figure 5.46 The safety switch system design at Sistema

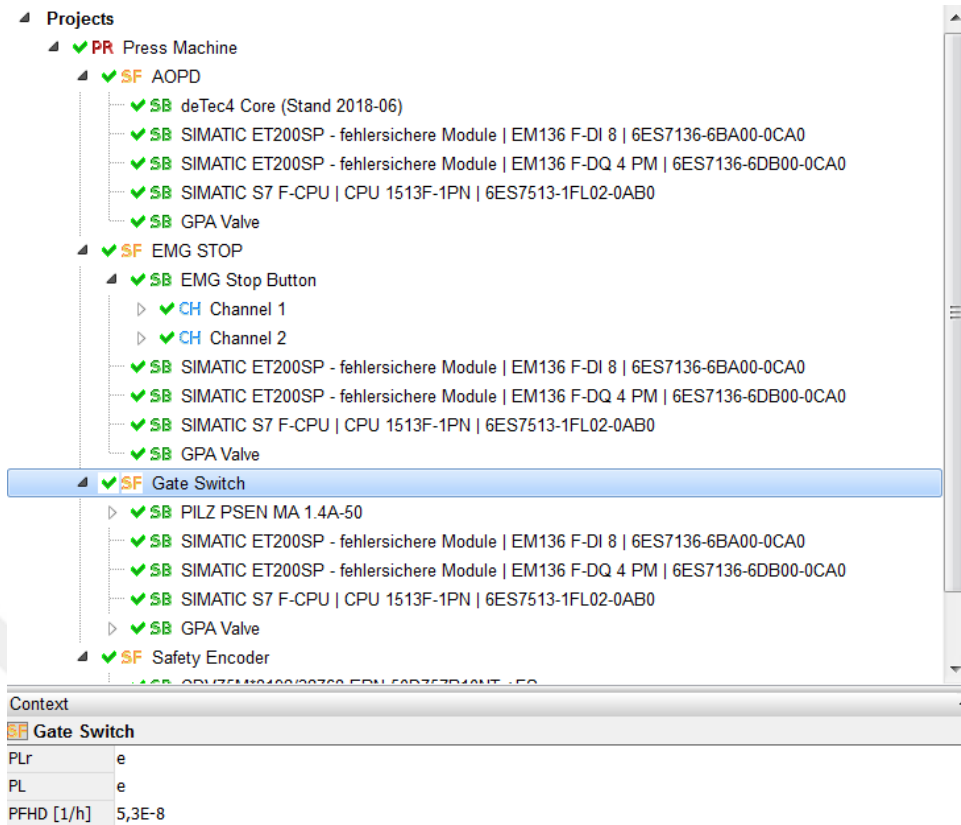


Figure 5.47 The PFH_D value of the safety switch system

The PFH_D value of safety switch system is obtained as 1.6E-8 from Sistema program. It can be easily seen from the Table 5.4 that the safety switch system satisfies the performance level e.

Table 5.4 Safety switch system performance level (European Standard - EN ISO 13849-1, 2015)

Performance Level (PL)	Average probability of dangerous failure per hour (PFH _D) 1/h
a	$\geq 10^{-5}$ to $< 10^{-4}$
b	$\geq 3 \times 10^{-6}$ to $< 10^{-5}$
c	$\geq 10^{-6}$ to $< 3 \times 10^{-6}$
d	$> 10^{-7}$ to $< 10^{-6}$
e	$\geq 10^{-8}$ to $< 10^{-7}$

The Siemens safety press blocks are used for programming. The safety switch input is connected to the EM_OFF_Q block to evaluate safety switch as dual channel which is shown at Figure 5.48. The EMM_OFF_Q block communicates with the VALVE_ME (which controls the output of clutch valve) and EN_1_MAN (which controls the modes of press and gives start signal to VALVE_ME block) over

datablock variables. In the case of safety door opened (safety switch), the clutch valve output signal is stopped. After safety switch signal is came back reset must be pushed for acknowledgement, from the place that sees safety door area and dangerous area.

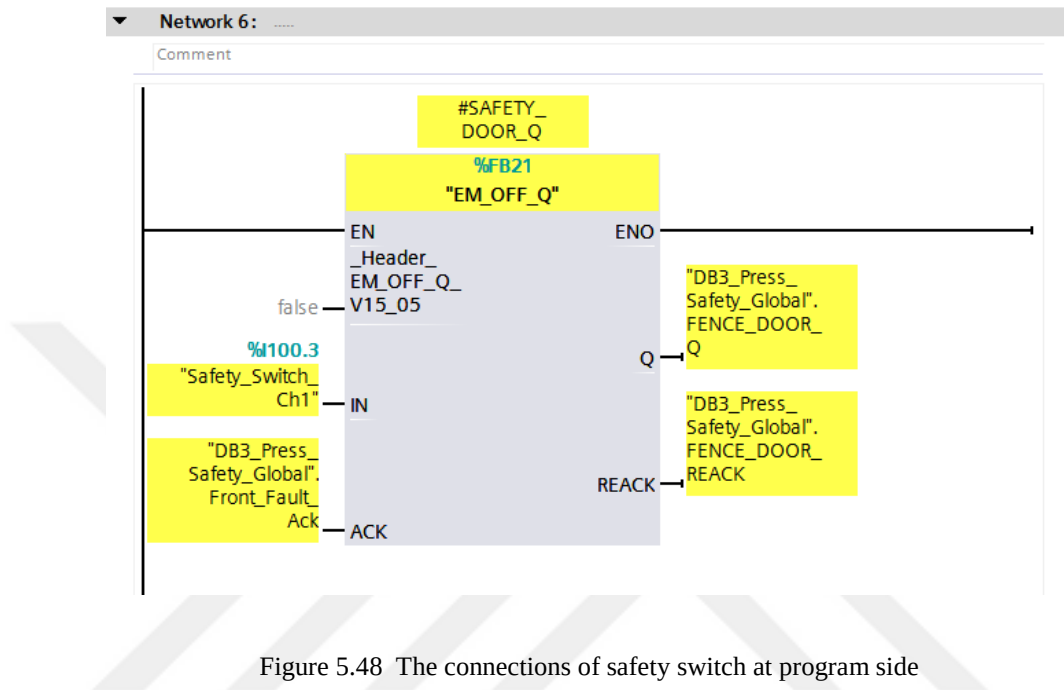


Figure 5.48 The connections of safety switch at program side

5.5.4 Safety Encoder

The movement of press machine depends on the signals which are called over travel cam and run up cam. The over travel cam indicates the area where the press stops which is shown at Figure 5.49. The run up cam indicates the area from pressing start point up to over travel cam area. In old press systems the over travel and run up cams can be adjusted from the cam box by rotating the cam rings which can be seen from Figure 5.50.

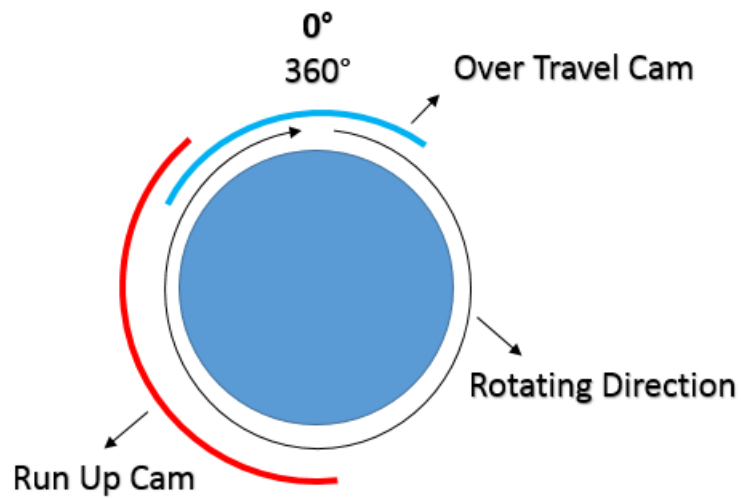


Figure 5.49 Rotary cam arrangement diagram

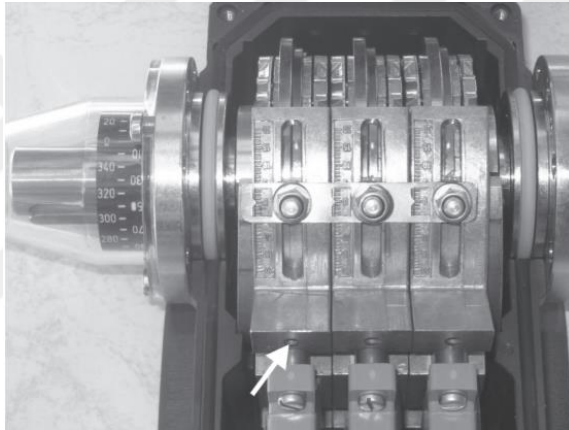


Figure 5.50 Rotary cam switch BSW 819-492 (Balluff BSW 819-492, n.d.)

In this project the over travel cam and run up cam is obtained from safety encoder. The safety encoder which is shown at Figure 5.51, is placed on the cam shaft with the help of chain, gear and timing belt.



Figure 5.51 TR Electronics safety encoder CD_-75 (Absolute Encoder CD_-75, 2019)

The safety encoder is added from Sistema library for safety system inspection as shown Figure 5.52. The PFH_D value is shown as 1.5E-9 automatically which is defined by manufacturer as shown Figure 5.53.

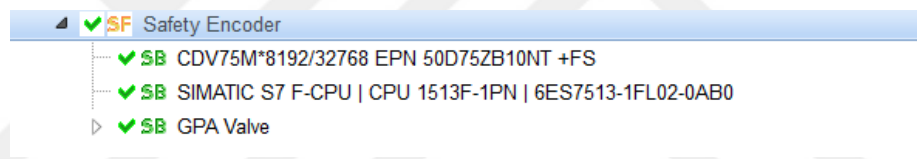


Figure 5.52 Safety encoder system components at Sistema program

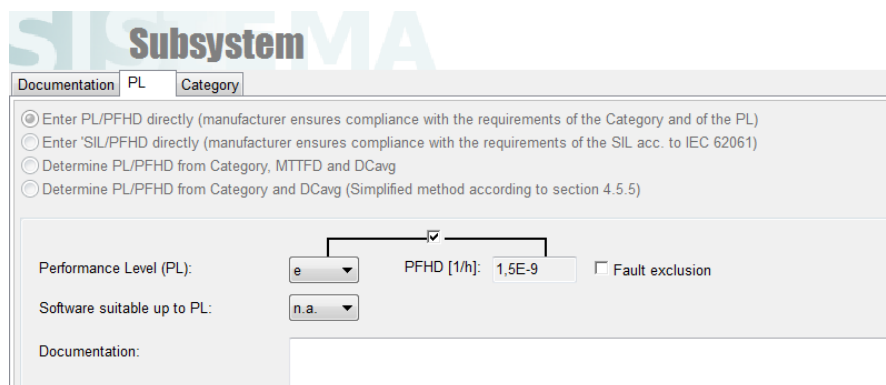


Figure 5.53 PFH_D value of safety encoder

The safety encoder is communicated with the fail safe PLC controller over PROFIsafe communication as shown Figure 5.54.

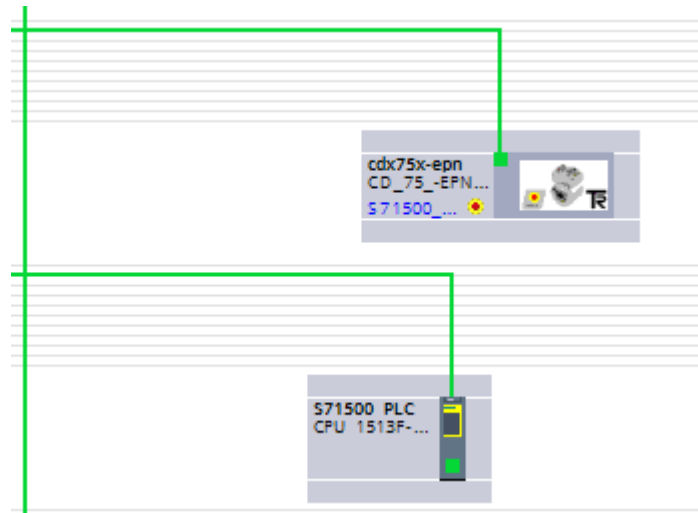


Figure 5.54 The communication diagram of safety encoder

The communication over profisafe is adjusted on the hardware side of programming enviroment as shown Figure 5.55.

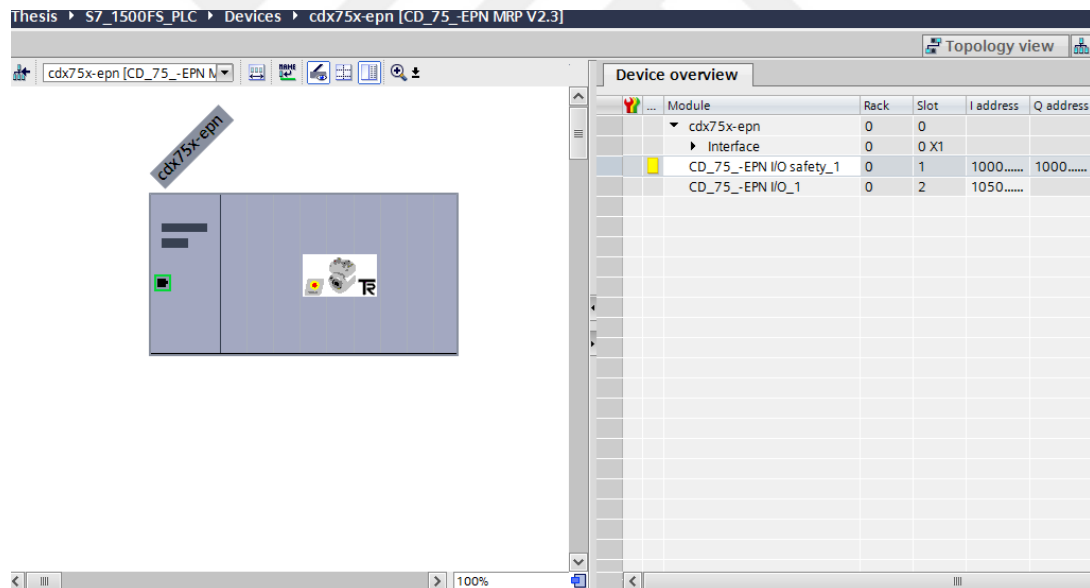


Figure 5.55 The parameter assignment of safety switch at program side

The other compnents that is connected with safety encoder subsystem are added to Sistema program for a proper calculation. If the safety encoder is the input signal of this system that should be at least logic controller and output of the system.The overall subsystem schema of safety switch is shown at Figure 5.56.

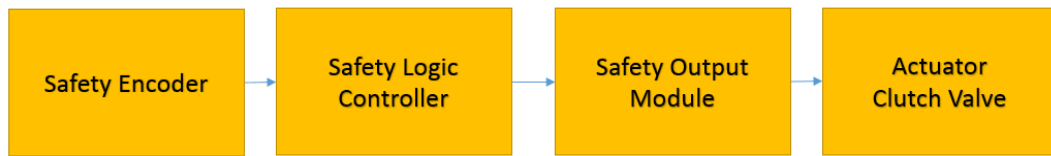


Figure 5.56 The overall subsystem schema of safety encoder

All the modules of system are added to Sistema program as shown at Figure 5.57. Their PFH_D values are added automatically when the modules are added. The safety output module PFH_D value is $1E-9$. The safety logic controller PFH_D value is $2E-9$. The output valve PFH_D value is $4.7E-8$. The overall PFH_D value is the sum of the other system as $5E-8$ as shown at Figure 5.58 .

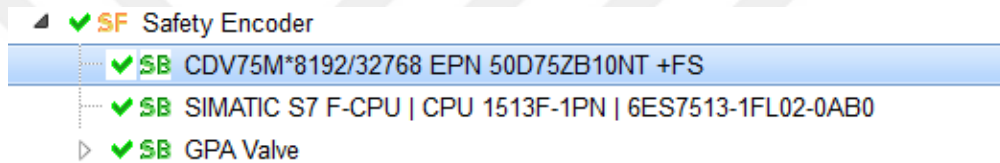


Figure 5.57 Safety encoder system design at Sistema program

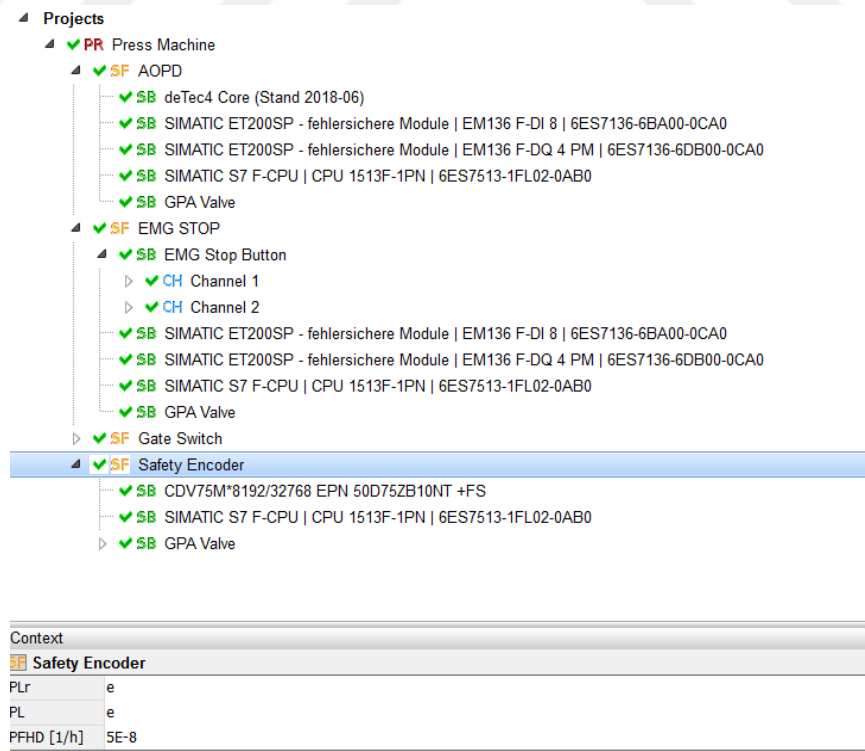


Figure 5.58 The PFH_D value of the safety encoder subsystem

The PFH_D value of safety encoder system is obtained as 5E-8 from Sistema program. It can be easily seen from the Table 5.5 that the safety encoder system satisfies the performance level e.

Table 5.5 Safety encoder system performance level (European Standard - EN ISO 13849-1, 2015)

Performance Level (PL)	Average probability of dangerous failure per hour (PFH _D) 1/h
a	$\geq 10^{-5}$ to $< 10^{-4}$
b	$\geq 3 \times 10^{-6}$ to $< 10^{-5}$
c	$\geq 10^{-6}$ to $< 3 \times 10^{-6}$
d	$> 10^{-7}$ to $< 10^{-6}$
e	$\geq 10^{-8}$ to $< 10^{-7}$

The Siemens safety press blocks are used for programming. The safety encoder input is connected to the SW_CAM block to evaluate safety encoder which is shown at Figure 5.59. The SW_CAM block produces the overtravel and run up cam. The overtravel cam and run up cam are connected to the EN_1_MAN (which controls the modes of press and gives start signal to VALVE_ME block) over datablock variables. The run up cam and overtravel cam defines where the press will stop or will continue to movement.

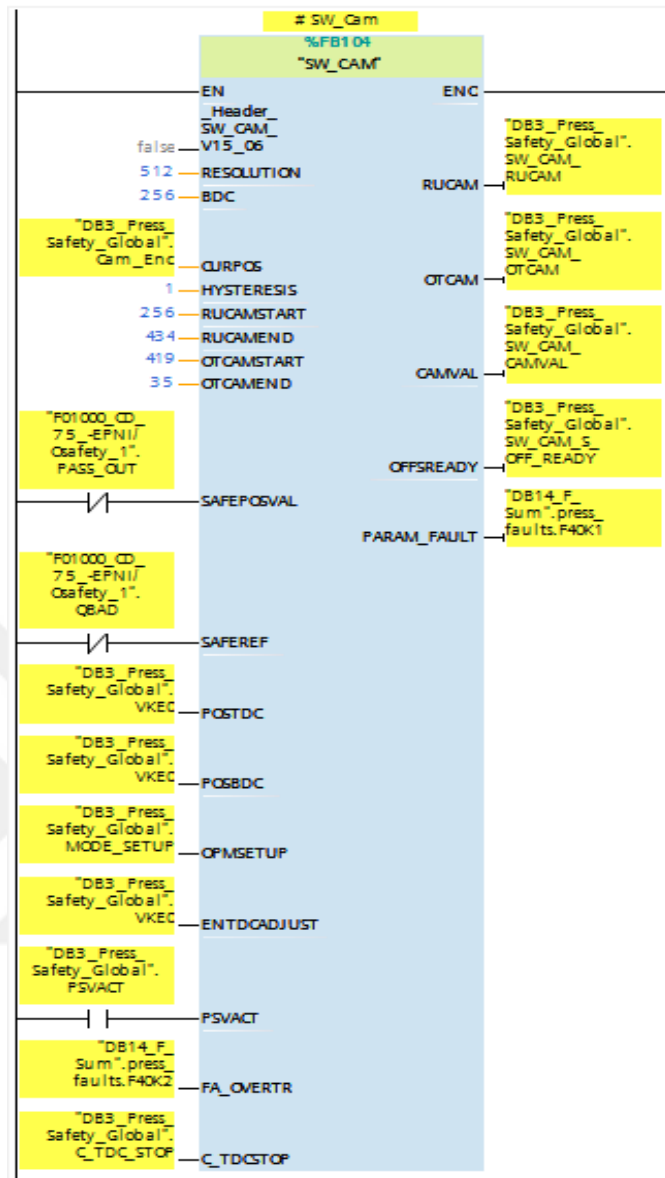


Figure 5.59 The connections of safety encoder at program side

The encoder is set to 0 position when the press is at top position. The angle of the press is read from safety encoder with help of PROFIsafe communication. The over travel cam and run up cam angles are defined in the program.

Using a safety encoder instead of cam box provides us decreasing cost of cable wiring, decreasing labor cost, giving ease of adjustment of cams, easy maintenance and ease of transport.

The over travel cam and run up cam is adjusted for a certain speed of press. This condition is a problem for the presses which has various speeds. Because when the press speed is increased, the press starts to stop outside of the desired condition because of breaking force. Dynamic cam application is developed which is shown at Figure 5.60 to prevent this situation.

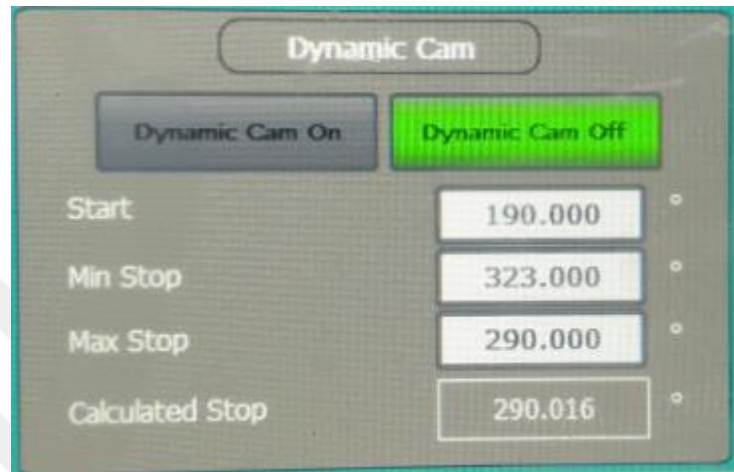


Figure 5.60 Dynamic cam adjustment screen of press

In this project dynamic cam which is shown at Figure 5.61 calculates the stopping angle due to the press various speed. The over travel cam signal and the run up cam signals must be designed in the desired safety conditions in case of failure of dynamic cam.

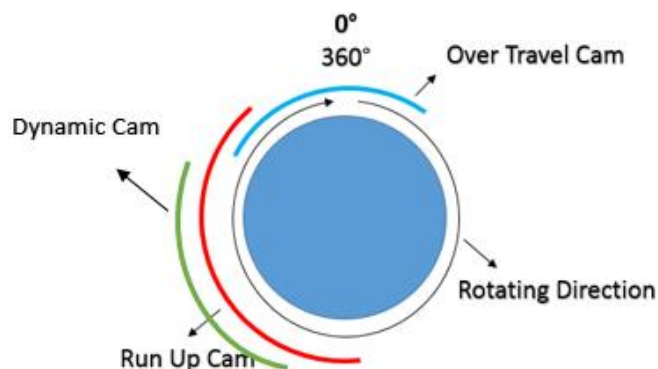


Figure 5.61 Dynamic cam adjustment diagram

5.6 Safety System Programming Schema

The light curtain is evaluated in safety program as an example of program. The clutch valve output signals are cut off when the light curtain signal is gone. The program working diagram is shown at Figure 5.62. In case of light curtain signal is gone the LCU_CLCK module (Solutions for Press Safety SIMATIC S7 F/P, 2018) stops the valve output over C_IMSTOP1 signal. Also mode setup start signal is gone because of light curtain green signal is gone at the same time. The press is protected for unwanted startup of the system until the light curtain signal is came back.

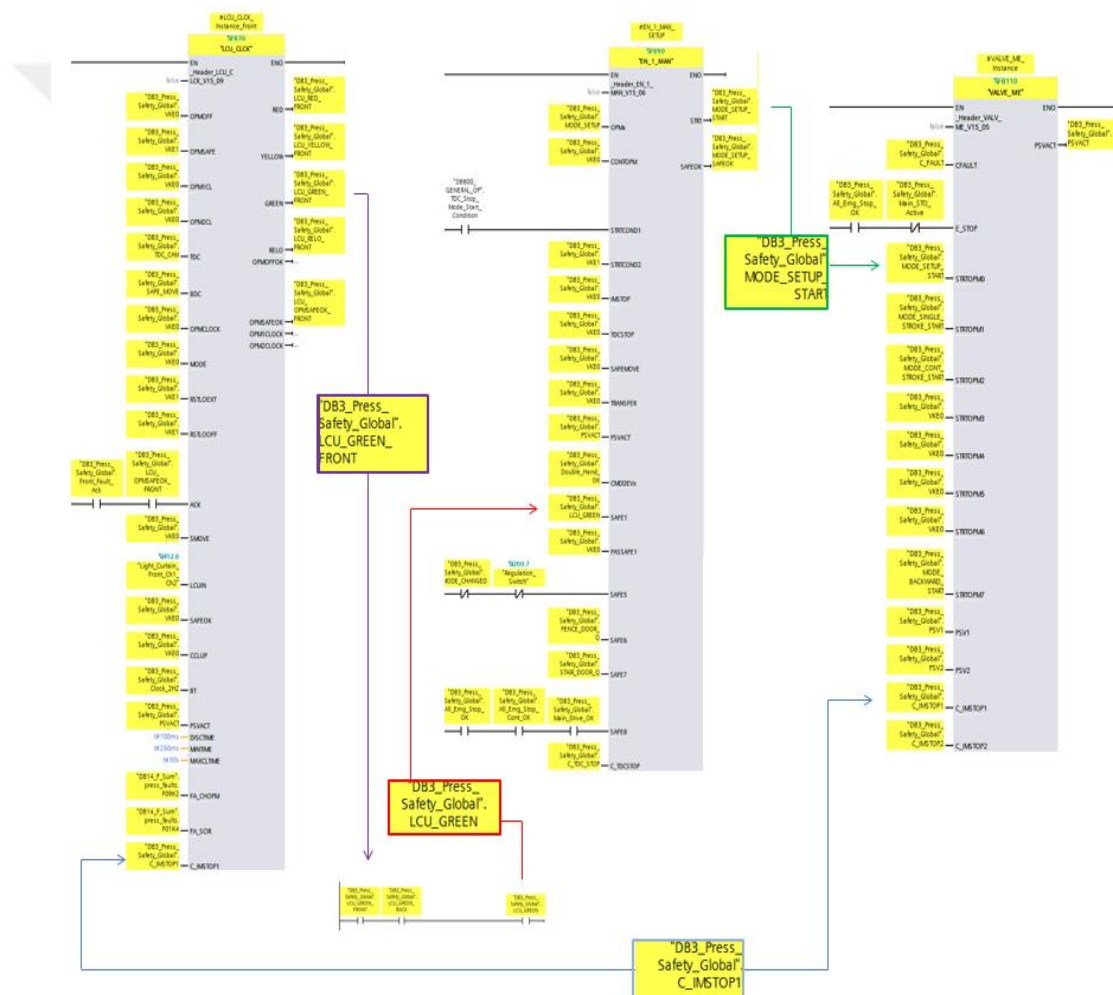


Figure 5.62 Example program of evaluation of light curtain signal

5.7 Standard Press Functions

The standard functions of press are not related with safety functions of the press. But standard functions of press are important for machine safety. Tracking the lubrication pressure can prevent machine working without oil and heating of machine.

5.7.1 Pressure Sensors

Lubrication is required to prevent wear and heating of the mechanical parts which are brushed in the presses. There is a lubrication pump at the bottom of press which pumps filtered oil to the bearings and gears. The pressure sensor that is shown at Figure 5.63, is placed after pump measures the lubrication pressure. If the pressure is lower or higher than the wanted pressure which is set at the commissioning state, it gives information to the PLC controller. PLC controller gives alarm and stops press at the top side. Only adjustment movement of press are allowed while the alarm exist. An example program of error detection of pressure sensor is shown Figure 5.64.



Figure 5.63 Lubrication pressure sensor (BSP Pressure Sensors, n.d.)

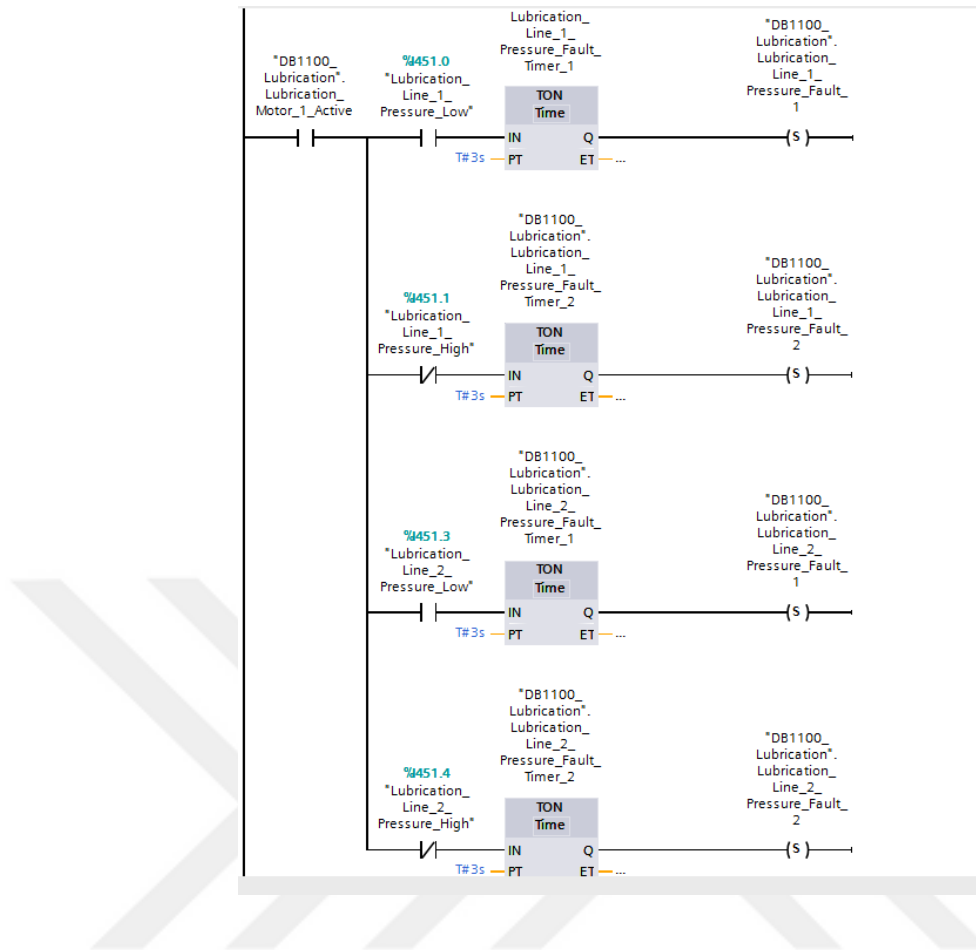


Figure 5.64 Error detection program of lubrication pressure sensor

5.7.2 Temperature Sensors

The temperature of bearings, gears and the other parts are very important for a healthy work of press. For that reason, Pt100 temperature sensors which is shown at Figure 5.65 are placed on different areas of the press to measure the heat of the press parts. The press PLC controller is programmed to measure the heat of the parts and compare the measured values with the required heats. The measured temperatures are shown at visualization system as shown Figure 5.66. If the heat is over the limit heat value or if one of the temperature sensor is broken, then the press is stopped and only adjustment movements of press is allowed for maintenance.



Figure 5.65 Temperature sensor Pt100 (RS Pro - Platinum Resistance Thermometer Pt100, n.d.)

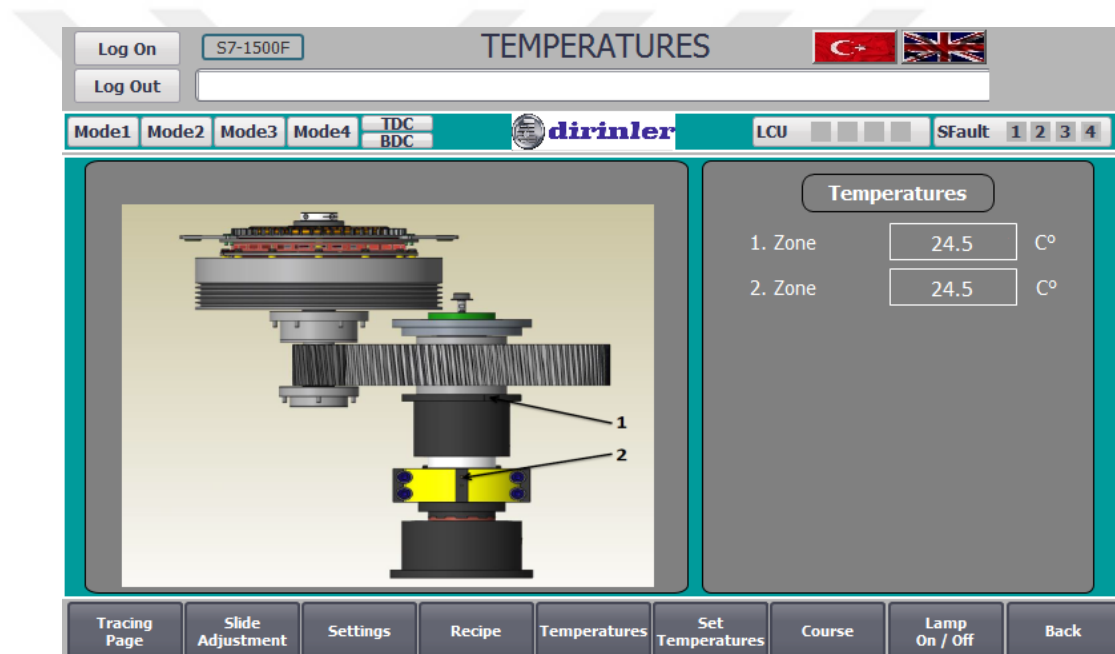


Figure 5.66 Temperature Sensor Page of HMI Screen

CHAPTER SIX

RESULT AND CONCLUSIONS

6.1 Overview of the Project

In this project the general press types are introduced. The mechanical parts for an eccentric press are examined. The hydraulic and pneumatic system of a press are examined. The press system is fully installed and worked. The mechanical parts are produced and assembled by Dirinler Makina San. ve Tic. A.Ş. The press working process and visualization system is developed.

The safety design of electrical components is made. The design requirements for a safe machine are examined. The electrical parts for a safe machine are selected due to the design requirements.

The electrical panel and electrical connections are made on the press machine. The press machine is tested with the safety precautions and the safety program.

6.2 Advantages and Disadvantages of the System

The press system is developed at fail safe PLC environment. This helps to program both safety functions and standard functions at the same PLC controller. The electrical connections are less because both safety program and standard program is developed at the same PLC controller. If two separate controllers are used for safety side and the standard program side than each controller needs same information in some cases like mode selection signals must go each controller for functions which are processed at controllers. On the other hand, the process cycle at the safety PLC controller can be longer than the system which has two separate controllers because of both safety functions and standard functions are ran at the same PLC controller. In some cases, controller price can be increased to have better performance and less program cycle time.

The dynamic cam function is programmed with the PLC controller. It satisfies that the press can stop at the same point while the press has different stroke speeds.

The electrical system is designed to have distributed input and output signal modules. If the all controller modules are placed at the main panel than all sensor and actuator signals must be cabled to the main panel. This situation needs much man power for cabling operation and more cables are used. The system with the distributed input output signal modules satisfies to reduce cost of cabling process and cable cost. The system with distributed input and output controller also satisfies to easy maintenance and diagnostic to user.

The safety encoder is used to determine the cam signals of press instead of mechanical cam switch gear. Safety encoder satisfies to adjust cam signals more easily and gives opportunity to measure system speed in safe conditions. The man power requirement for adjusting safety controller is less than while adjusting mechanical cam. The diagnostic and maintenance of safety encoder is much easier than the mechanical cam switch for the user.

The regenerative driver system is used for controlling main motor of press. This satisfies that the system uses less current to drive main motor. The energy which is obtained from driver as a result of regenerative operation is returned to power network. This means the user will spend less money for producing.

6.3 Future Work

In this thesis an eccentric press is installed and worked with safety precautions. In the future work the press can be equipped with more sensors and can be looked for correlation of each sensor for diagnose faults in advance. For example, the skids can be equipped with temperature sensors. These temperature sensors can be correlated with lubrication pump pressure or can be correlated with the current of lubrication motor. When the skids temperature is getting higher and if the motor current goes upper it can be said that there is a problem with the lubrication. The results from these correlations can tell us future situation of press. It can be possible to have precautions before it breaks down.

Production systems of a factory needs to have information about produced parts, time of production and faults occurred during production. The system which traces all needed parameters of press system and has communication with all production systems can be developed.

The standards safety procedures and safety precautions are enough for a machine can be considered as a safe. But these systems can be depending to human behaviors. For example, a fence area is considered safe when the operator closes door and approves the system that the area is safe from a clear view. A camera system can be developed to identify human if there is a human being in the fence area and can stop all system.

Nowadays workers are replaced by robotic arms at industrial field. The use of humanoid robots in industry is not far away in the near future. With the introduction of humanoid robots, field scanning sensors can be used instead of fixed protection systems. In this way, system security can be provided when a living creature other than humanoid robots is found in the risky area. In addition, moving press table systems are becoming increasingly common. These systems are controlled by remote control, field scanning sensors (3D Lidar Sensor, n.d.) can be placed around the movable press table systems to avoid blind spots that are not seen by the operator. In this context, developing such security measures is aimed as a future work of this study.

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