Designing a PLC-Hydraulic Base System to Control a Process of Die Casting to Produce a Squirrel-Cage Rotors out of an Aluminum Alloy

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Abstract

Automatic control has been playing a significant role in modern manufacturing and industrial processes. The automatic control provides the necessary tools to obtain the optimal performance of the dynamic systems, improve the quality, lower the cost of production, and increase the production rate. In this paper, A PLC (Programmable Logic Controller)- controlled hydraulic control system was designed and tested for a metal casting system. This system was simulated using Allen Bradly Micrologix 1000 PLC module, and such a system was successfully tested *using the Lab-volt Hydraulic Training system. A need for a developed design was crucial to consider the mechanism of opening and closing the mold. Due that reason, a developed PLC-controlled die casting machine was simulated using TLP(LogixPro Simulator) instead of Micrologix 1000 due to its limitation in the inputs and outputs jacks. Moreover, the mold of the squirrel cage rotor was designed using the Solid work software to prepare it for the manufacturer to be fabricated.*

Keywords*: PLC applications, Die Casting system, Automatic control systems, Hydraulic Power.*

Introduction

There is a consistent need for procedure control frameworks in the assembling manufacturers to create a superior item more skillfully and easily. This necessity has led to the growth of the automated system. History has illustrated that the fluid power called hydraulic is a crucial as modern method of transferring energy (Bill, 2005). The growing use of hydraulics in the industry comes from the need for fast, low cost means of production with better quality, less waste, and increased power. (William, 2009)

Hydraulic systems are valuable as a robust and versatile means of performing heavy-duty labor. Engineers have utilized the power of pressurized fluids to perform simple mechanical tasks such as lifting, hauling, and bulldozing. Hydraulic systems are popular due to their ability to easily transfer massive amounts of power. With comparatively little input, this power is multiplied during its transfer. Fluid-based hydraulic systems are known for their strength and agility that make rapid and efficient work of difficult industrial tasks. Die casting machine is among numerus number of machines that relay on hydraulic system technology to complete its task. (Consultants, 2021)

Die casting is characterized as a metal casting process that forces molten metal under high pressure into a mold cavity. The cavity in the mold is made by using tow hardened tool steel dies that are made into shape via machinery, tow hardened tool steel dies run similarly to an injection mold during the process. Die castings are generally made from non-ferrous metals, Specifically Aluminum, Magnesium, Zinc, Copper, Lead, Pewter and Tin-based alloys. Different furnace heating temperatures are needed for the melting and heating process depending on the type of metal being cast. (Bill, 2005)

Large capital costs of the casting equipment and the metal dies tend to limit the process to high-volume production. Manufacture of parts using die casting involves only four main steps, making it a straightforward process, which keeps the incremental cost per item low. Die casting is well suited for large quantity of small-to medium-sized castings and that is the reason die casting has produced many castings other than any process casting another. A particularly good surface finish and dimensional consistency are mainly the characteristics of die casting. (Bill A. , 2005)

The modern world tends to use die casting because it provides complex forms, and the process is efficient and economical compared to any other process. In addition, the mold has a long life, and good accuracy in the dimensions, and access to the good surface and smooth for the cast. Afterwards, they started to use A PLC- controlled hydraulic control system in die casting to save time, effort and increase the productivity and is more effective. (dynacast, n.d.)

The PLC is the digital operation of electronic systems developed for industrial applications. It becomes the central equipment to achieve stand-alone, workshops, and factory automation by combining computer technology, automated control technology, and communication technology. It has the benefits of high reliability, good anti-interference, flexible combination, simple scripting, and easy maintenance. (A, 1997)

Induction motors with aluminum squirrel-cage rotors have been widely used in various electrical applications. Moreover, its high-volume productions demand makes it as an interested product to be considered to assemble automated production line to rise its production rate. (L, 2006)

The Solidification Time is another parameter that should be considered in the casting process. Solidification is change in the material's phase. It depending on the nature of the material i.e., whither it is a pure element or an alloy. A pure metal solidifies at a constant temperature which is the metals melting point. For alloys, the solidification occurs over a temperature range depending upon the composition. The total solidification time is the required time for the casting to solidify after pouring. Total solidification time depends on the shape and size of the casting by an empirical relationship known as Chvorinov's rule. Chvorinov's rule states that under the same conditions a casting with large surface area and small volume will cool more rapidly than a casting with small surface area and a large volume. The relationship can be expressed as: (Bill A. , 2005)

$$\mathbf{T_{ts} = B\,(V/A)^{n}} \qquad (1)$$

Where:

T_{ts} = Total solidification time (min).

V = Volume of the casting (cm3).

A = Surface area of the casting (cm2).

n = is an exponent usually taken to have a value= 2, According to Askeland, The constant n is usually 2, however Degarmo claims it is between 1.5 and 2.

B is the mold constant, (min/cm2); the mold constant (cm) depends on the properties of the metal, such as density, (heat capacity, heat of fusion and superheat), and the mold, such as initial (temperature, density, thermal conductivity, heat capacity and wall thickness), thermal properties of the cast metal (e.g., heat of fusion, specific heat, thermal conductivity), and pouring temperature relative to the melting point of the metal. The value of **B** for a given casting operation can be based on experimental data from previous operations carried out using the same mold material, metal, and pouring temperature, even though the shape of the part may be quite different. The mold constant of Chvorinov's rule, **B**, can be calculated using the formula (2): (L, 2006)

$$\boldsymbol{B} = \left[\frac{\rho_m L}{(T_m - T_0)}\right]^2 \left[\frac{\pi}{4K\rho C}\right] \left[1 + \left(\frac{C_m \quad \Delta T_s}{L}\right)^2\right] \tag{2}$$

Where:

T_m = melting or freezing temperature of the liquid (in kelvins).

T_0 = initial temperature of the mold (in kelvins).

$\Delta T_s = T_{pour} - T_m$ = superheat (in kelvins).

L = latent heat of fusion (in [J·kg−1]).

k = thermal conductivity of the mold (in [W·m−1·K−1)]).

ρ = density of the mold (in [kg·m−3]).

c = specific heat of the mold (in [J·kg−1·K−1]).

ρ_m = density of the metal (in [kg·m−3]).

C_m = specific heat of the metal (in [J·kg−1·K−1]) (L, 2006)

In this paper, Allen Bradly Micrologix 1000 PLC module programmable controllers and other components were utilized to constitute electrical control system for a metal casting system in order to meet the control requirements. In addition, TLP Logic software was used as a simulation software to overcome the limitation of input and output jacks of the Allen Bradly Micrologix 1000 PLC module. The goal of using TLP software was to increase the potential of the controller to consider the mechanisms of opening and closing the mold.

Working Methodology

A metal casting is a piece of machinery made by pouring liquid metal into a mold that will give the required shape to the piece. Typical examples of metal castings are small engine parts, automobile engine, transmission parts, and outboard motor parts. (L, 2006)

The metal casting process is as follows: the metal is first poured into the mold, then it is allowed to cool to form the final piece. When the metal has solidified, the mold is opened to extract the piece and closed again to make another piece. (Bill A. , 2005)

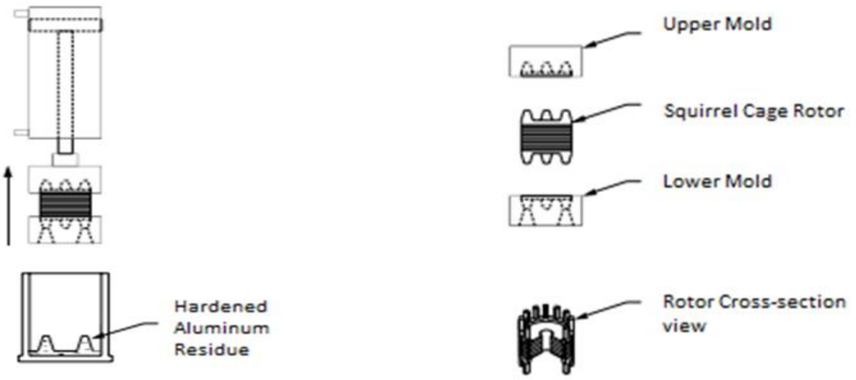
The principal type of metal casting process used in the industry is the die casting process. With this method, metal castings are produced by forcing molten metal into a mold, under high pressures of 700-700 000 kPa (100-100 000 psi). Die casting has the advantage of high production rates, high quality, strength, and good surface finish. (Bill A. , 2005)

The target operation (Die casting Process) that would be Designed and controlled using a PLC through the Lab-Volt hydraulic Training system is described as stated below:

Figure (1) shows a die casting sequences that would be controlled using PLC to produce aluminum squirrel-cage rotors. A stack of rotor laminations is manually injected into the mold. The machine safety door is then closed to prevent molten metal from leaking out during the process. The operator then starts the machine, which causes a hydraulic aluminum-feeding motor to measure and pour molten aluminum into a cylindrical cavity (Figure 1 a). The injection press cylinder then extends and rams the mold assembly into the cavity. When the mold assembly hits the surface of the molten aluminum, the metal is forced upward through the holes of the mold, filling up the mold (Figure 1 b). When the pressure inside the cavity reaches 900 kPa (125 psi), the cylinder stops and dwells for 5 seconds, allowing the aluminum to solidify. The cylinder then retracts and withdraws the mold assembly from the cavity (Figure 1 c). The upper and lower molds can then be pulled apart to release the die-cast rotor (Figure 1 d). (Lab-volt, 2007)

a) Molten aluminum is poured into a cylinder cavity

b) Injection press cylinder extends



c) Injection press cylinder

d) Upper and lower molds are

retracts **pulled away** **revealing the die-cast rotor**

Figure (1): Description of Die Casting Process. (Lab-volt, 2007)

The capability of this design has been raised to add the advantage of control the solidification time for varied materials, and the volume of the molten metal through the PLC program.

Hydraulic Die Casting Machine Design

Design a PLC-controlled hydraulic system that simulates the operation of the die casting machine described in the following steps:

1. A hydraulic circuit has been connected as shown in figure (2).

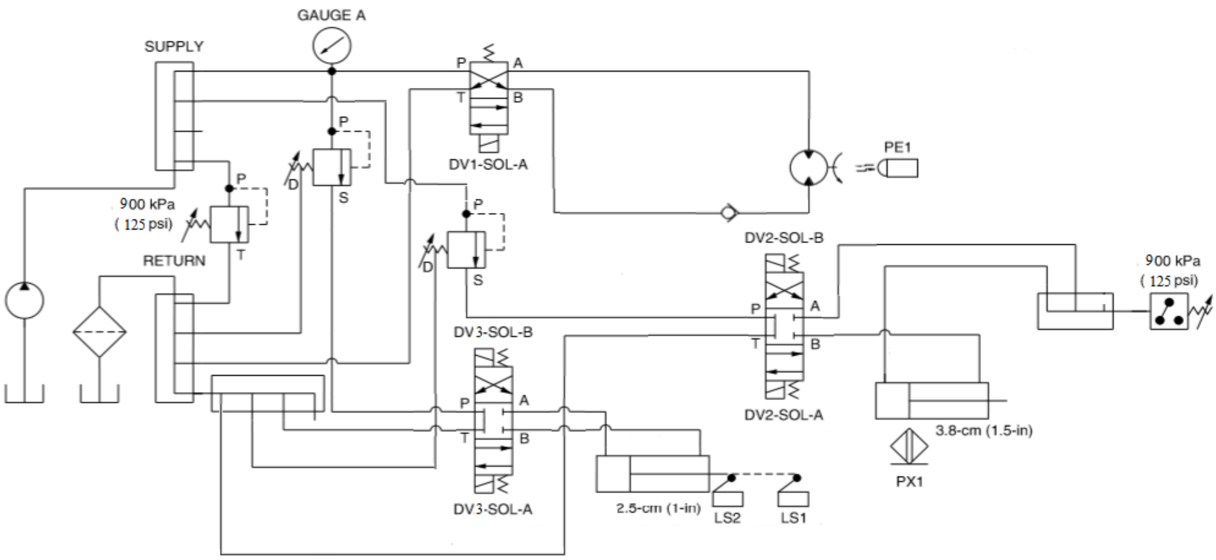


Figure (2) **Die Casting Hydraulic Circuit**

2. The PLC controlled hydraulic system (Inputs and out-puts) had been connected as shown in Figure (3).

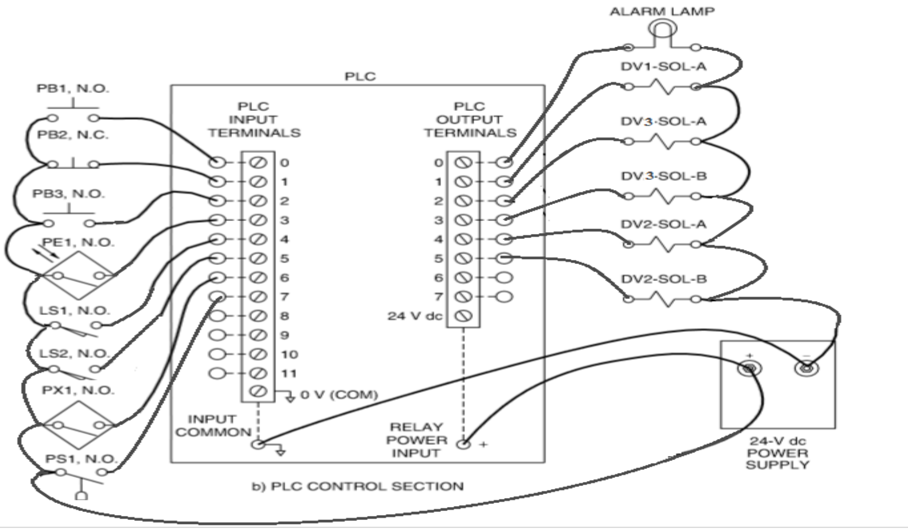
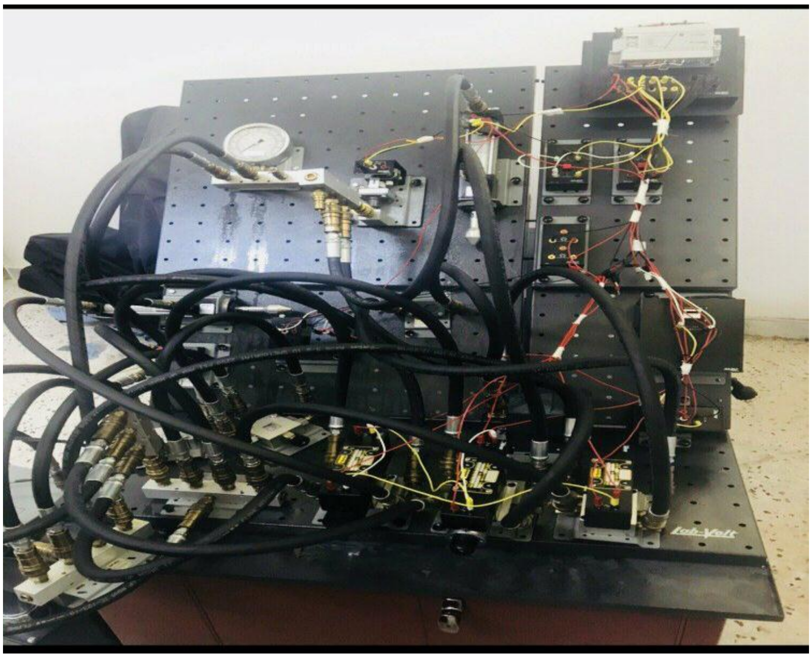


Figure (3) :A PLC Connection.

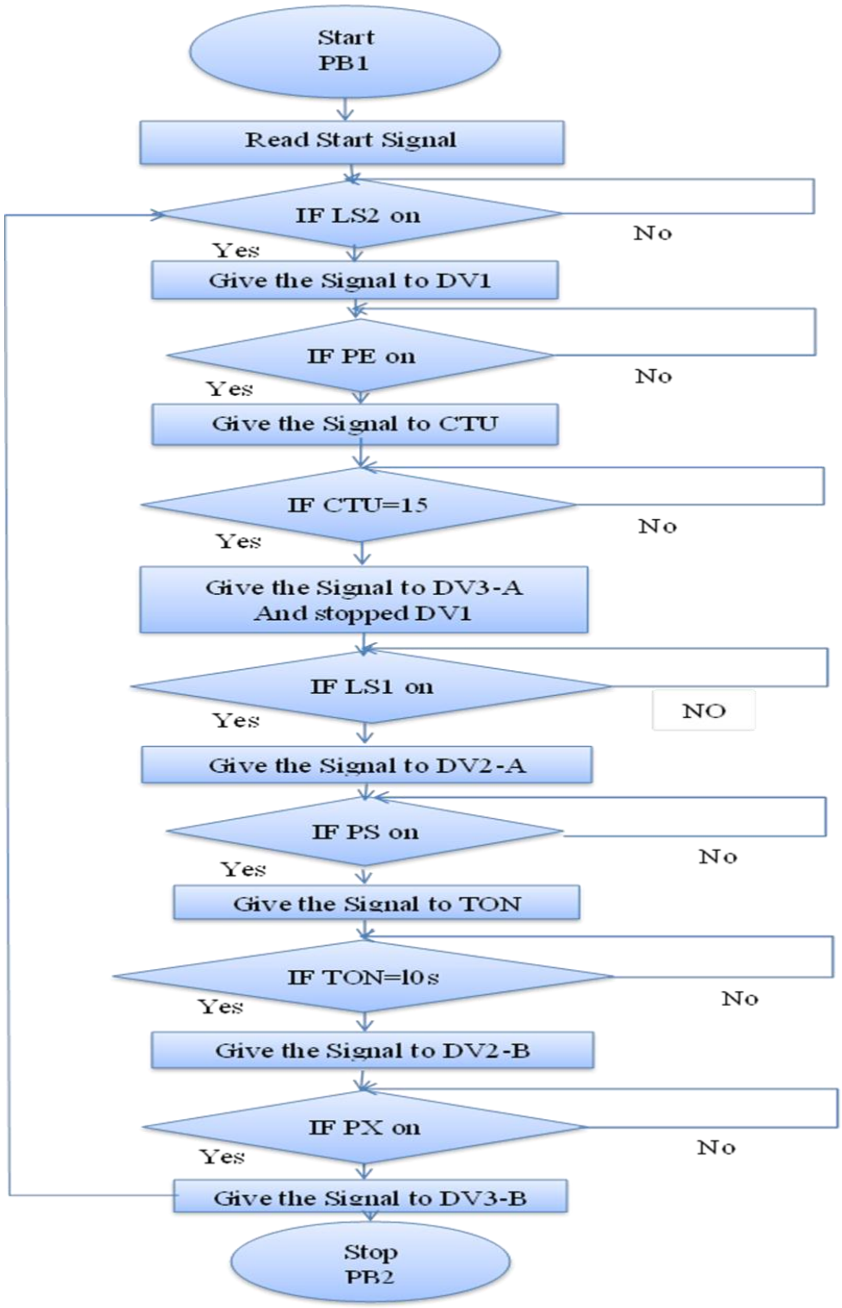
The actual design of hydraulic circuit of the die casting system that is controlled by Programmable logic controller is shown in the Figure (4).



Figure(4): A R**eal model of Die casting m**achine.

Programing

The PLC program of the die casting process has been programmed in RS Logix 500, and is described as follow in the flow chart.



Figure(5): Die Casting Control System Flow Chart

Table (1) has been provided in order to give the needed information that required for understanding the flow chart showing in figure (5).

Table (1) :PLC Ladder Diagram Abbreviations

Code	Description	Type	Using for
PB1	Pushbutton station	Input	Start the system
PB2	Pushbutton station	Input	Shout down the system
PB3	Pushbutton station	Input	Moved the press cylinder backward when any emergency
LS2	Limit switch	Input	Limit the beginning point of the stroke of the safety gate & working of the hydraulic motor
LS1	Limit switch	Input	Limit the end point of the stroke of the safety gate & working of the press cylinder
PE	Diffuse reflective photoelectric switch	Input	Sensing the hydraulic motor & turn on CTU 0
PX	Magnetic proximity switch	Input	Limit the beginning point of the stroke of the press cylinder & open the safety gate
PS	Presser switch	Input	working TON 0 & the press cylinder is stays in the original position
DV1	Directional Control Valve (Single Solenoid)	output	Moved the hydraulic motor
DV2-A	Directional Control Valve (double-Solenoid)	output	Moved the press cylinder forward
DV2-B	Directional Control Valve (double-Solenoid)	output	Moved the press cylinder backward
DV3-A	Directional Control Valve (double-Solenoid)	output	Moved the safety gate forward
DV3-B	Directional Control Valve (double-Solenoid)	output	Moved the safety gate backward
LATCH 0	Latch	Internal relay	Start the system

Code	Description	Type	Using for
LATCH 1	Latch	Internal relay	Working the DV2-A
LATCH 2	Latch	Internal relay	Working the DV3-B
CTU	Up Counter	Internal relay	Stopped of the hydraulic motor & Working the DV3-A
TON	Time Delay	Internal relay	Turn on LATCH 1 & turn off LATCH 2

The next step that had been made to accomplish this design, was downloaded the program to the PLC, then the PLC was placed in Run mode. The machine is started by means of a START pushbutton (PB1).

During the machine operation, a RUN lamp is turned on (LAMP1). The gate should be on the open position. After the gate has been opened the hydraulic motor rotated 15 turns to pour the proper quantity of molten in the cylindrical cavity, so that the motor rotation is read by the diffuse reflective photoelectric switch (PE). After the 15 turns had been accumulated, the diffuse reflective photoelectric switch (PE) gave the order to the gate to close.

The limit switch assembly that fixed on the gate sent order to the cylinder to a press the mold inside the cylindrical cavity, after the pressure reaches 900 kPa in the cylinder. Presser switch gave an order to the cylinder to retain it pressed for 10 seconds through the time delay (TD). After the molten metal had been solidified, the cylinder returns to its original position, and repeats the whole process.

An emergency STOP pushbutton (PB2) was provided to allow the operator to stop the machine at any step of the process. Pressing this pushbutton immediately stops the motor or cylinder. Thereafter, the machine cannot be re-started until the cylinder is returned to the HOME (fully retracted) position.

A RESET pushbutton (PB3) provided to allow the operator to return the cylinder to the home position after the system has been stopped. This pushbutton has a momentary action so that the cylinder retracts when the pushbutton is pressed and stops immediately when the pushbutton is released.

A Developed PLC-Controlled Die Casting System

The Previous design that has been made using the Hydraulic training system has a defect which is the mechanism of the opening and closing the mold. The current mechanism works manually through an operator. As stated before that the goal of this project is to design a system that take into consideration the mass production of the proposed product; therefore, achieving such a goal, a new mechanism has been designed using a Solid Work software. The following figure (6) demonstrates the mechanism of the opening, and the closing of the mold. This mechanism works based on the additional cylinder that was provided to eject the cast out of the mold and dropped it on the projected location (a bag on the conveyer).

The developed design has not been implemented using Hydraulic Training System due to there is not enough inputs and outputs in the PLC module. To overcome this obstacle, a TLP software (simulator) was used to simulate this system and ensure its operation.

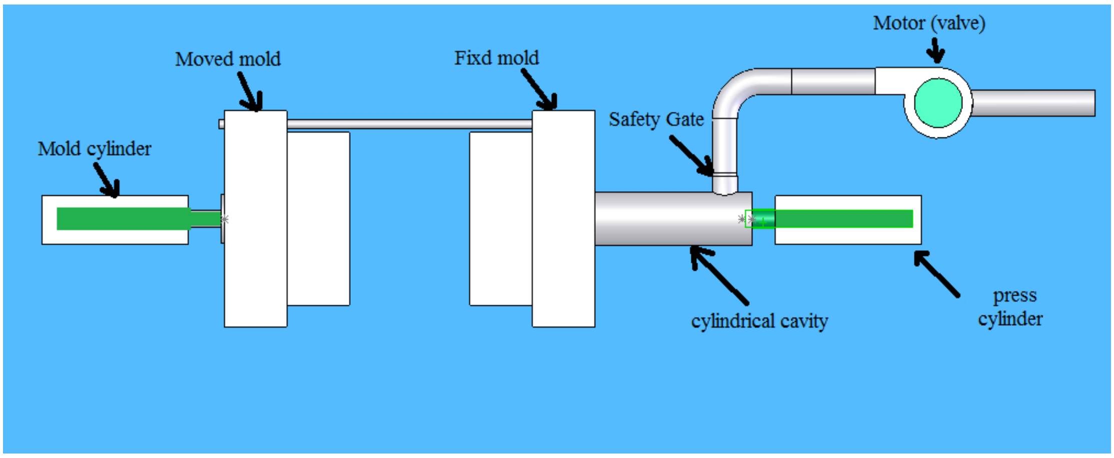


Figure (6): Developed Die Casting System.

A Developed PLC-Controlled Die casting machine Design Steps

The steps of this process are similar to the previous design steps except for some steps that have been modified as following:

1. In the sixth step, the Limit-switch assembly gave an order to the press cylinder to press the movable mold into the fixed mold instead of pressing the mold into the molten metal.
2. In the seventh step, after the molten has been solidified, the press cylinder returns to its original position. Meanwhile, the mold is opened by another cylinder (the new cylinder), and the cast dropped down at projected place, and the process will be repeated again.
3. The PLC program of the developed die casting process has been programmed in the TLP software and is described as follow in the flow chart the showing in figure (7).

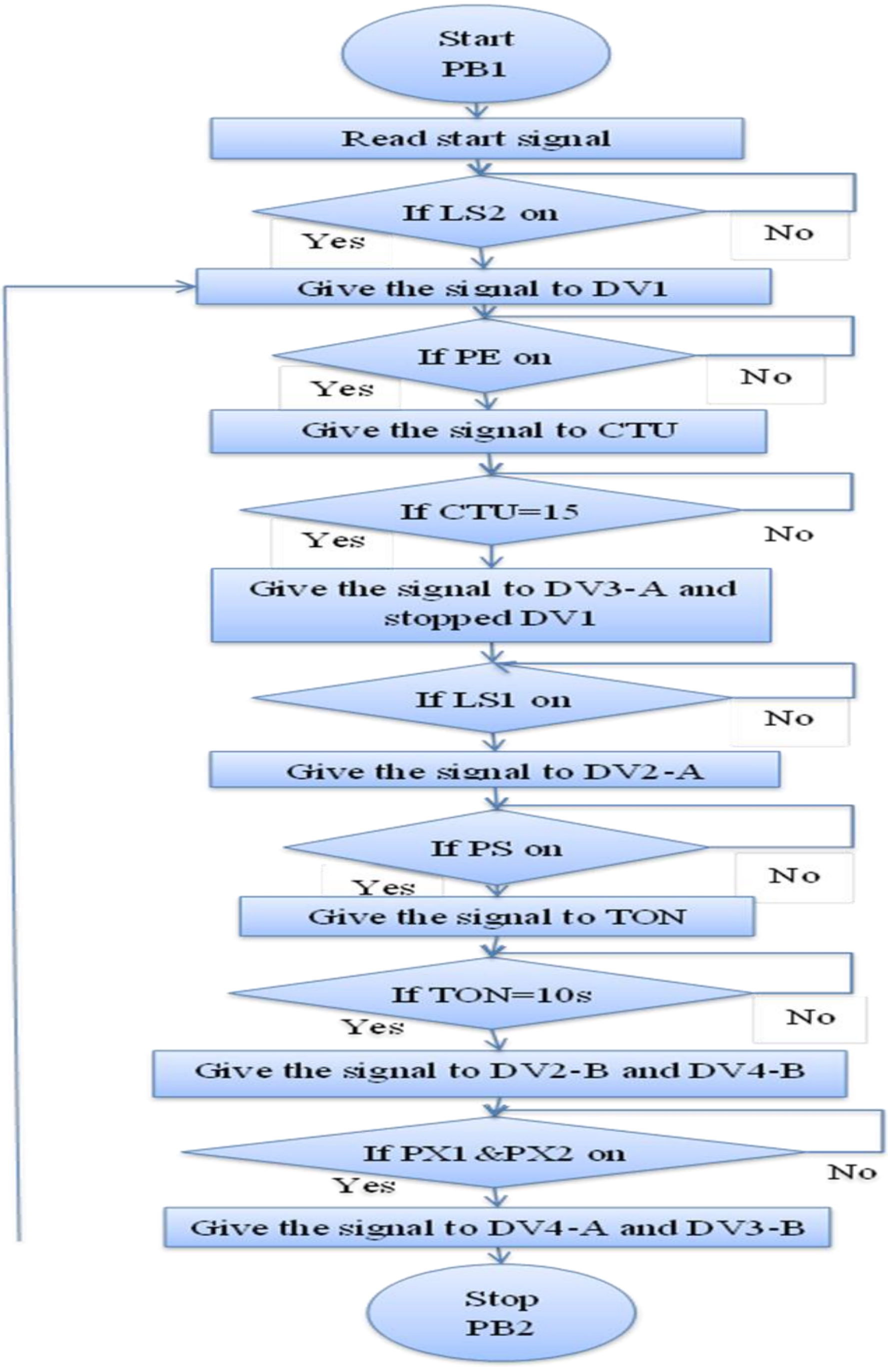


Figure (7): A Developed Die Casting Control System Flow Chart.

PLC Ladder Diagram Abbreviations

In this developed design the abbreviations are the same as those demonstrated in table (1), with addition of the following list:

Table (2): PLC Ladder Diagram Abbreviation

Code	Description	Type	Using for
PX2	Magnetic proximity switch	Input	turn off LATCH 3
DV4-A	Directional Control Valve (double-Solenoid)	Output	Moved the mold cylinder forward
DV4-B	Directional Control Valve (double-Solenoid)	Output	Moved the mold cylinder backward
LATCH 3	Latch	Internal relay	Working the DV4-B

Product Description

The die casting machine was designed to produce any product with any material. The product chosen for this study was an aluminum squirrel cage rotor used in pumps. Figure (8) shows the model of mold.

A squirrel-cage rotor is the rotating part of the motor. It consists of a cylinder of aluminum. In addition, Squirrel-cage induction motors are very prevalent in industry, in sizes from below one kilowatt (fractional horsepower; less than 1 hp) up to a 10s of megawatts (10,000s of horsepower). They are simple, rugged, self-starting, and maintain a reasonably constant speed from light load to full load, set by the frequency of the power supply, and the number of poles of the stator winding.

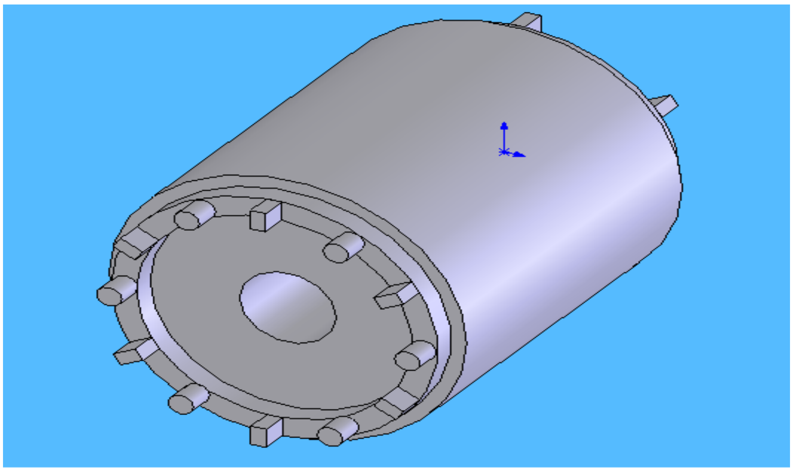


Figure (8): Model design of the Squirrel cage rotor.

The figure (9) shows the dimensions of the product for the purpose of mold design. It should be noted that the dimensions of the die mold will depend on the dimensions of the product. (Bill, 2005)

Note : All the dimensions are in millimeter (cm).

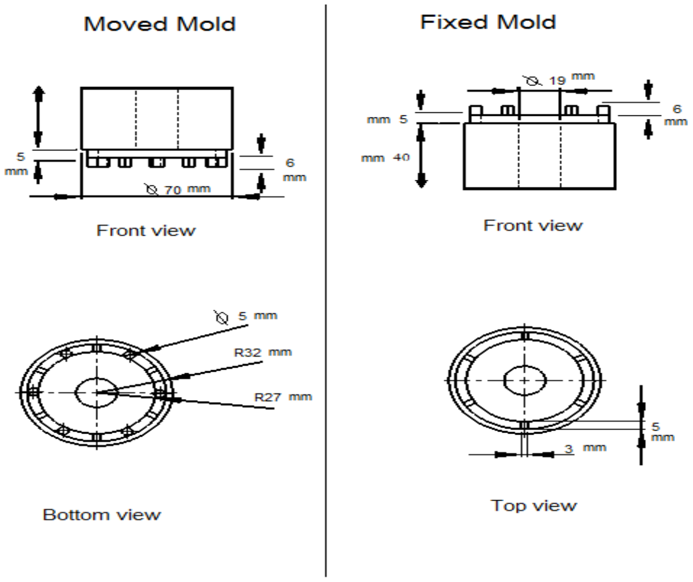


Figure (9): Mold Design Dimensions

Conclusion:

In this paper, A model of the die casting machine for producing squirrel cage rotor was created, simulated, tested, and evaluated using Allen Bradly Micrologix 1000 PLC module. In addition, a developed system was made to overcome the weakness points existing in the current system that affect the functionality, stability, reliability and productivity of the system. Moreover; a product design was accomplished in order to prepare the manufacturer to fabricate the mold with desired dimension.

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