Speed and force control of a hydraulic press using proportional valve

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Abstract - *In this work, a smart system has been implemented. The system used proportional pressure control valve, proportional directional control valve and also electronic pressure sensor through Arduino controller. It is programmed in a way that performs the relationship between pressure required to bend the material and its parameters. The system of this work was simulated by simulation program (Automation Studio) to make sure the function of it is work properly. Copper alloy with different thicknesses were tested in this work.*

A laboratory system was built to shows the system's work to ensure the performance and design of the system. As a result, a proportional relationship between pressure sensors, ultrasonic sensor with the proportional valves has been obtained. The conclusion of this work the force and speed can be controlled with respect to material thickness and the type of the alloy. Finally it can be design and implement a smart press working with automation system.

Key Words: proportional directional control valve, proportional pressure relief valve, force control, speed control, simulation using automation studio.

1. INTRODUCTION

The hydraulic press is one of the oldest tools that had been used in metal forming. The force of the press is regulated by the pressure relief valve manually. This process need to shut off the hydraulic system and then set the relief valve to the required pressure. The speed of the hydraulic cylinder stroke is regulated using the throttle valve manually. Traditional presses that regulated manually requires the presence of monitoring workers continuously near the press machine, when changing the material that have to be bent.

The objective of this work is to control the speed and force of the press machine and working automatically.

Hydraulics plays a very important role in the lives of people. Its importance can be seen from the fact that it is considered to be one part of the muscle that moves the industry, the place held by hydraulics in modern automation technology illustrates the wide range of applications for which it can be used, Today, hydraulic term was understood as the transmission and control of force and movement by means of fluid.

Press working techniques utilizing large quantities of economical tooling equipment design and it less time, high accuracy and less cost cold working of mild steel and other ductile materials. The component produced range over an extremely wide field and is used throughout industry for economical production of quantities of pressing; consideration has to be given to the rate of production, the cost of the press tool to be employed. Press may be defined as the chip less manufacturing process by which various components are made from sheet. Mostly press use fabricated parts of set shape with thin walls. It uses large force by press tools for minimum time interval of production which result in cutting or shaping the sheet metal work piece in to the desired shape. In the early days, metal forming press use simple crank and lever mechanism that convert rotating motion into linear motion with the help of punch/ram. The rotating motion achieved by motor and linear motion achieved by punch or ram, punch applied on work piece [1].The block diagram of this work is shown in figure (1).

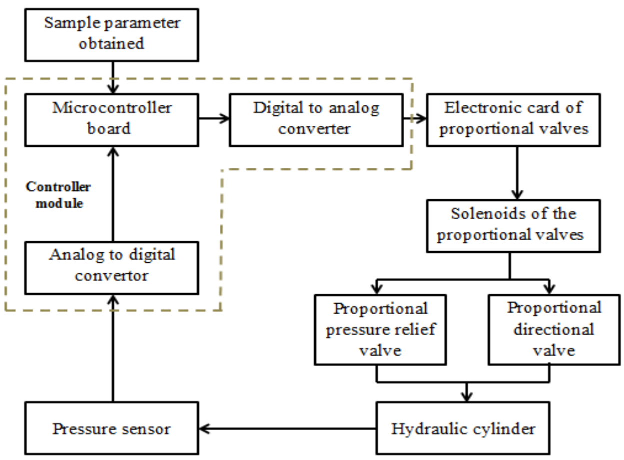

Fig -1: block diagram of proportional control system for speed and force controlling

The required forces that carry out the bend in materials depend on the punch and die geometry, also depending on the thickness, strength and the length of sheet. The required force of bending can be obtained from the following equation [8].

$$F = \frac{K_{bf} TS w t^2}{D}$$

Which F is the force of bending (N); TS is the sheet metal tensile strength (MPa); w is the width of work piece in direction of the bending axis (mm); t is the thickness of the stock (mm); and D is the dimension of the die opening; K_{bf} bending constant, it value chosen depend on the type of die, where for V type bending $K_{bf} = 1.33$ and edge type bending $K_{bf} = 0.33$.

A hydraulic press is a machine using a hydraulic cylinder to generate a compressive force. Frame and cylinder are the main components of the hydraulic press.

In this project press frame and cylinder are designed by the design procedure. Press frame and cylinder are analyzed to improve its performance and quality for press working operation. Structural analysis has become an integral part of the product design [2]. As techniques to control the force of the system, using variable speed drive uses a variable speed electric motor to drive a hydraulic fixed displacement pump. By adjust the rotational speed of the electric-motor to regulate the hydraulic pump flow rate, to produce the required force [3]. Electro-hydraulic pump controlled system was driven by a variable rotational speed AC servo motor to achieve high response and high efficiency. The velocity controlled in a hydraulic injection molding machine. A constant displacement axial piston pump merged with the AC servo motor is developed in this research as the high response electro-hydraulic pump controlled system. A fuzzy control system was used to control the system [7].

In traditional presses the employers has to determine the optimum force and speed required for each sample before bending. The pressure was set manually by using manual relief valve and the speed was selected by using throttle to determine the amount of fluid follow. In this research proportional valve was used with modified control system to determine the force and speed required for each sample. The objective of this research is to design and analysis of electro-hydraulic control system for speed and force control of hydraulic press using proportional valves , to achieve the above objectives .The following points are to be investigated :-

1- Propose variable speed and force of a hydraulic press using proportional technology.

2- To study the performance of the hydraulic press theoretical and practical.

3- Intelligent control system design using sensors to make the works is more safety.

2. SYSTEM DESIGN

In the beginning any hydraulic system works mainly in three stages. It begins with mechanical energy input that will be converted in to fluid power with hydraulic pumps. Then, this fluid with its energy goes through pipes or connectors and necessary hydraulic control valves. Finally the fluid power converted into mechanical power with actuators devices such as cylinders [9]. The hydraulic system is shown in figure (2) and figure (3). It is consisting of: hydraulic power unit, hydraulic cylinder, proportional directional control valve, proportional pressure relief valve, pressure sensors, and ultrasonic sensor.

The system was designed to control the force of the press on the samples by controlling the pressure of the system using the proportional pressure relief valve. And the speed of the stroke of the cylinder is controlled by controlling the amount of the fluid flows to the actuator, the fluid controlled by using proportional directional control valve which controls the direction and the amount of flow at the same time

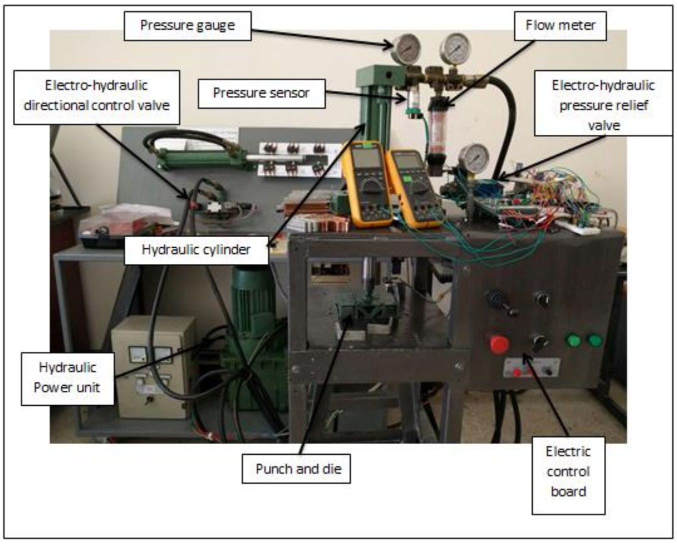

Fig -2: The Electro-hydraulic press machine system

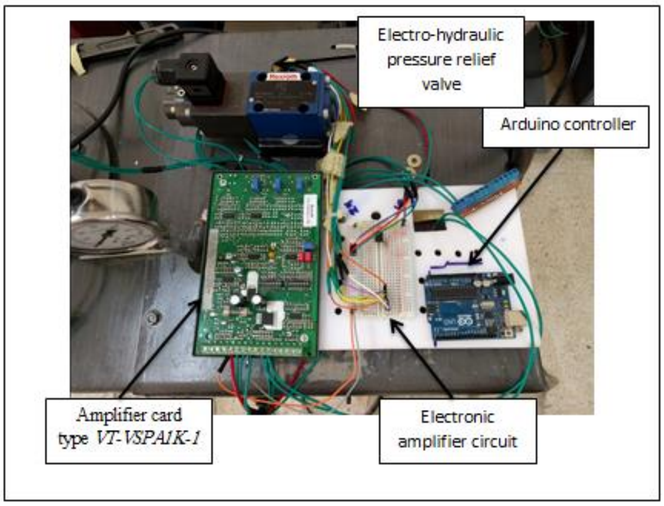

Fig -3: The Electro-hydraulic system

3. SIMULATION ANALYSIS WITH AUTOMATION STUDIO

Automation Studio (AS) package was developed in (2003) by (FAMIC Technologies Inc/Canada) to contain comprehensive libraries of hydraulic, pneumatic, ladder logic, and digital electronic symbols. This package is completely integrated software package that allows the user to design, simulate and animate circuits consisting of various automation technologies [6]. Proportional hydraulic press control system of force and speed control was built and simulated with this program. All components and parameters of the system have been selected and connected as in the actual system in the project work sheet as shown in figure (4).

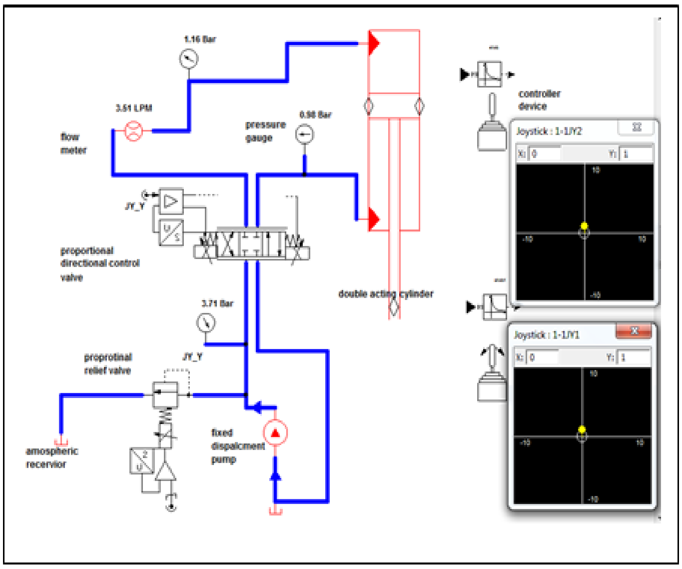

Fig -4: the simulation process of the electro hydraulic control system of the press machine

4. ELECTRONIC CIRCUIT WITH ARDUINO UNO BOARD

The circuits are designed and built experimentally by the researcher using simple electronic components and amplifier cards of the proportional valves. The block diagram of this circuit is shown in figure (4). The circuit connection of Arduino UNO connected with ultrasonic sensor, two pressure sensor, VT-5005 card and VT-VSPA1K-1 card are shown in figure (5).

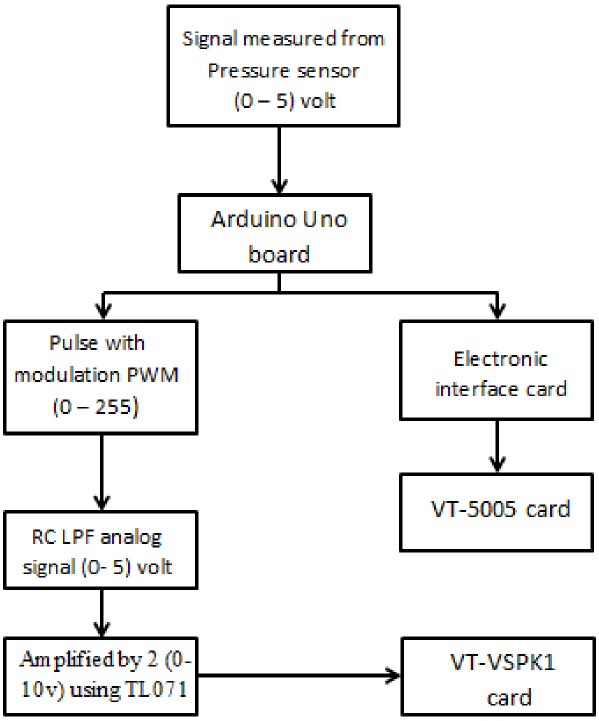

Fig -4: Block diagram of electronic circuit

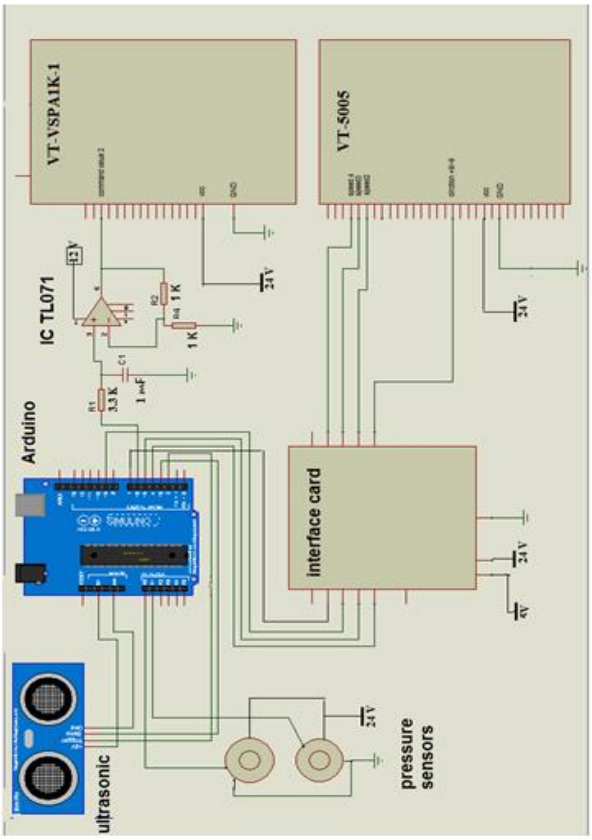

Fig -6: electronic circuit connections

5. PROCEDURE OF THE THEORETICAL AND EXPERIMENTAL WORK

1- Propose the hydraulic system to control the press machine and build it.
2- Design and simulate the hydraulic system using a special program for hydraulic simulation analysis (Automation Studio package V5.2).
3- Calibration of all instruments that are used in the system (pressure gauges, pressure sensors, flow meter, and proportional pressure control valve and proportional directional control valve).
4- Design the electronic circuits that are interfaced with Arduino UNO board.
5- Programming the controlling board (Arduino) using "C" language.
6- Obtaining the result from the Arduino via serial port and then analyzing these results.

6. OPERATION OF THE TEST RIG SYSTEM

1- Firstly, at the beginning the sample which we want to bend in placed on the die under the ultrasonic sensor (thickness sensor) to measure its thickness. The sensor is sending the reading to the controller (Arduino).
2- The material type is selected manually .in this research Copper alloy (C11000) [10] material has been chosen to be studied. The type of material is led to determine the tensile strength which chose to calculate the bending force. The tensile strength of each material is obtained experimentally.
3- After the inputs of points (1, 2) are obtained by the controller calculate the required force which the sample needs to be bent.
4- The speed of the cylinder stroke (speed of bending) is selected for each material.
5- After the bending force is calculated in the controller by the mean of equations we obtain the required voltage to the proportional amplifier **VT-VSPA1K-1** to achieve the required pressure to the system.

7. RESULTS AND DISCUSSION

7.1 Simulation results

Electro hydraulic system has been built with automation studio package V5.2 this result was represented the function of its work. The linear speed of double-acting cylinder at different pressure using and a proportional pressure relief valve and proportional pressure directional control valve at different command values of 10%, 20%, 30% and 40% has been shown in figures (7), (8), (9) and (10) respectively.

Figure (7) represents the linear speed of hydraulic cylinder at different pressure of the system. First case the command value of the proportional directional control valve is set to 10 % of the maximum value. Figure (7) shown the speed of cylinder is seemed to be stable due to changing the system pressure. The difference in speed between the minimum pressure of (3.8) bar mean the command value voltage is (1V) and the maximum applied pressure of (40) bar mean the command value voltage is (10V) is nearly (0.2) in/sec. The pressure applied values is selected depending on the proportional pressure relief valve. The pressure of the system versus command value of (VT-VSPA1K-1) [4] is shown in table (1). And the flow of the system fluid versus command value of (VT-5005) [5] is shown in table (2).

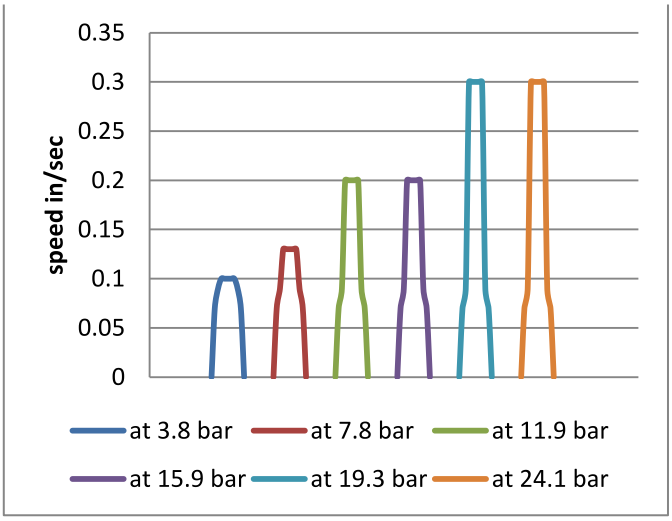

Fig -7 linear speed of hydraulic cylinder with 10% command value

The speed will be constant when the pressure becomes more than (25) bar. The reason of this different in speed due to changing the pressure was because of the flow that returns to the tank from the pressure relief valve. The result is obtained with no load on the hydraulic cylinder.

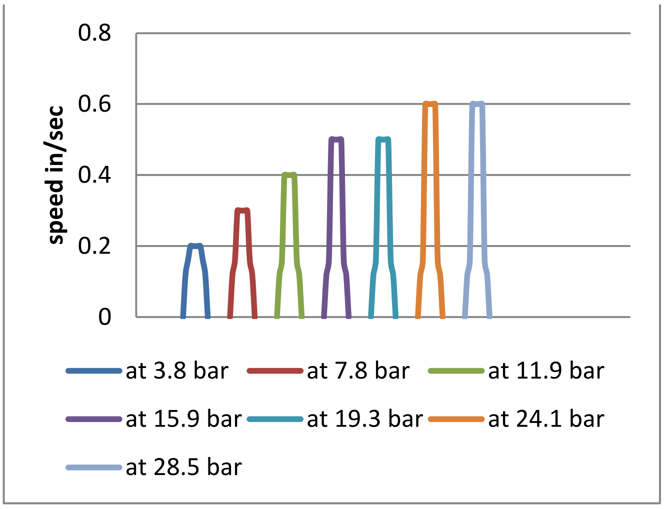

Fig -8 linear speed of hydraulic cylinder with 20% command value

Figure (8) shows the speed of the hydraulic cylinder that increased when increasing the system pressure. Also these results obtained with no load on the hydraulic cylinder.

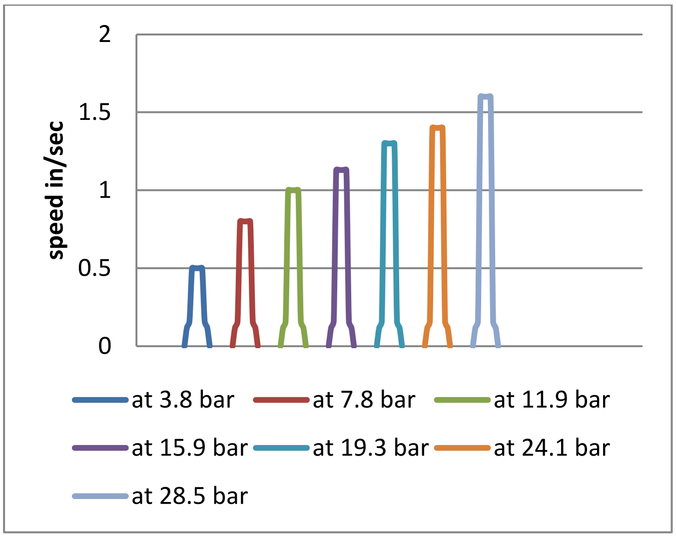

Fig -9 linear speed of hydraulic cylinder with 30% command value

The speed of hydraulic cylinder is increased when increasing the pressure of the system. It is seems from figures (5.1), (5.2) and (5.3) when the command value of the directional proportional control valve change. The difference of the speed increased due to changing the pressure of the system. The increasing of the command value means increasing in flow of the fluid.

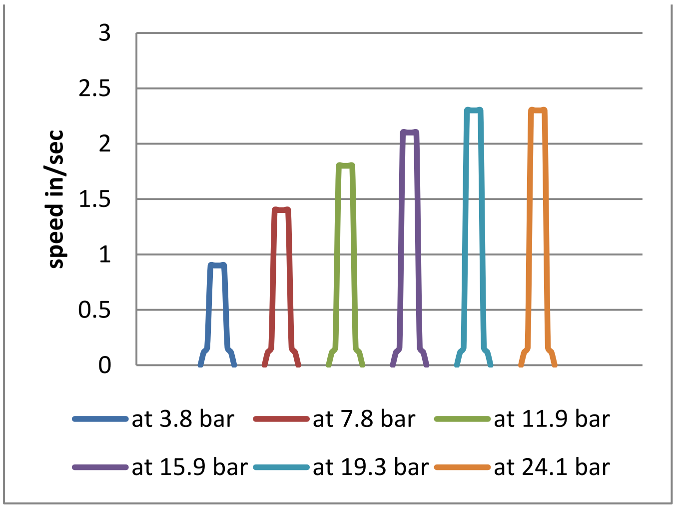

Fig -10 linear speed of hydraulic cylinder with 40% command value

In figure (10) shows that the forth case of 40 % command value of the proportional directional control valve. It shows that the difference of the speed when changing the pressure is slightly more than the previous cases, because the directional control valve is open more than the previous cases. After the pressure increases more than (25) bar the speed will not change when changing the pressure of the system. In the cases more than 40 % of the command value of the directional, the speed of the cylinder will be mostly constant due to changing the pressure of the system.

Table-1 The command value voltage of (VT-VSPA1K-1) with pressure of the system.

Command value (V)	Pressure of the system (bar)
1	3.8
2	7.8
3	11.9
4	15.9
5	19.3
6	24.1
7	28.5
8	32.4
9	36.6
10	40.6

Table-2 The command value voltage of the proportional directional control valve amplifier (VT-5005) with the fluid flow

Command value (V)	Flow (L/min)
1	0.26
2	0.51
3	1.29
4	2.34
5	4.68
6	4.9
7	5.32
8	6.23
9	6.67

7.2 Experimental Results

The results of calibration of the proportional relief control valve, calibration of the directional proportional control valve and the calibration of the pressure sensors that were explained in chapter four, also the behavior of pressure sensor with Arduino board controller will present in the current section. Table (3) shows the relationship between the voltages that input to the amplifier card (VT-VSPA1K-1) and the output pressure of the relief valve.

Table-3 the proportional relief valve calibration

Voltage (V)	Pressure (bar)	Current (A)
0	0	0
1	5	0.11
2.5	9.5	0.18
3	11	0.2
4	13	0.24
5	18	0.31
6	24	0.37
7	29	0.45
8	34	0.54
9	38	0.61
10	40	0.69

The behavior of the directional proportional control valve is represented in table (4). The applied voltages on the command value of the amplifier card (VT-5005) is adjusted using internal potentiometers, which built in the card and then select the required voltage to supply the command value of the card. The amount of the fluid flow is depending on this voltage. The command voltage selected as (2.5, 5, 7.5, 9) volt.

Table-4 proportional directional control valve behavior

Voltage (V)	Flow (L/min)	Cylinder speed (cm/sec)
2.5	2	1.352
5	3	1.783
7.5	4.5	3.183
9	6	4.045

The experimental results were collected from the test rig using two pressure sensors and ultrasonic sensor. These results are shown in table (5) for copper alloy.

Table-5 bending force for copper alloy

Real thickness (mm)	Measured thickness (mm)	Input voltage (V)	Pressure sensor reading	System pressure (bar)	Bending force (N)
2	2.2	0.9	70	2.7	520.65
3	3.34	1.104	127	5.8	1176.46
5	5.17	3.857	329	15.8	2908.77

Figures (11), (12) and (13) showing the system pressure behavior while bending copper alloy 2 mm, 3mm and 5mm in thickness respectively, with 25 mm width, and the ultimate tensile strength equal to 275 MPa.

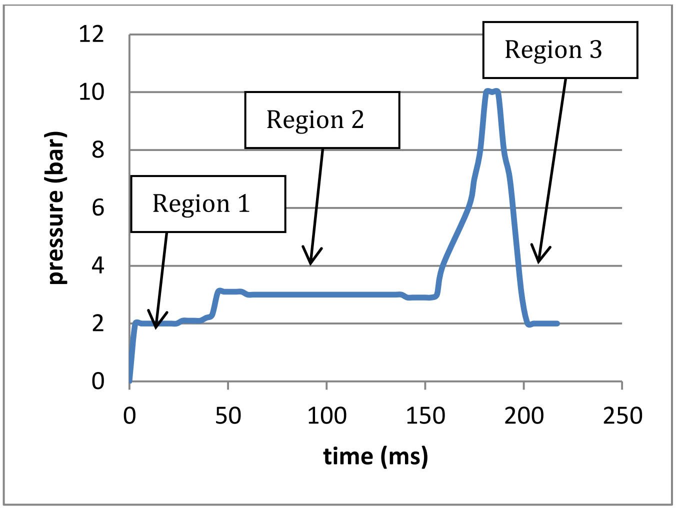

Fig-11 system pressure behavior while bending copper alloy 2 mm thickness

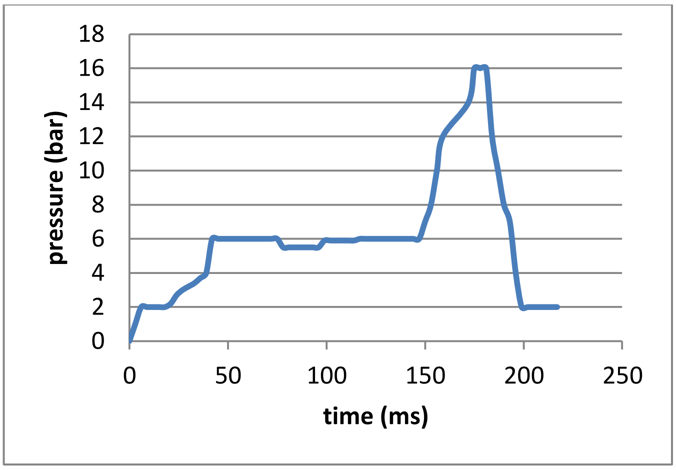

Fig-12 system pressure behavior while bending copper alloy 3 mm thickness

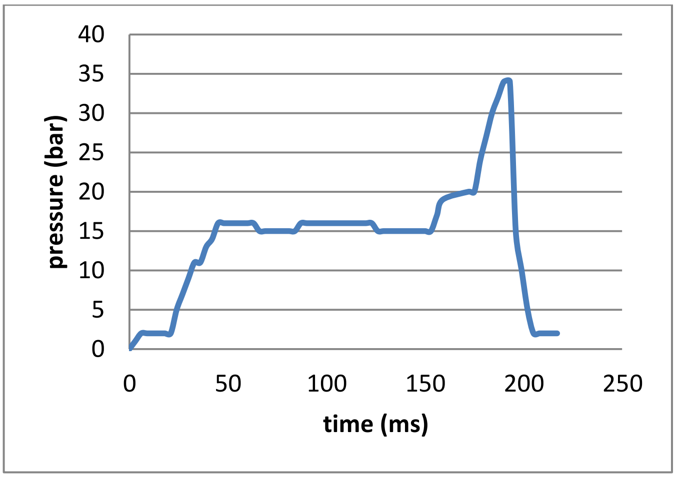

Fig-13 system pressure behavior while bending copper alloy 5 mm thickness

As shown in these figures the behavior of the system during bending for each material with different thicknesses is presented. The bending is done with three region of force. First region is the free zone which the punch moving in air before reaching the sample. This region should have minimum pressure applied on the system and maximum speed. The second region is the bending region which starts when the punch reached the sample the pressure of this region. The pressure of the system is chosen by the system controller depending on the algorithm of the system. Also the speed of this region is selected depending on the type of material. The last region of the operation is start when the punch reached to the final position. In this region the punch returns back with minimum pressure of the system and with maximum stroke speed. The feedback of the system to the controller is the pressure sensor which gives the controller signals to determine the punch position to know in which region it reach and there for controlling the force and speed of the system.

The behavior of the stroke speed of the system during bending is shown in figure (14). The figure shows the behavior of the stroke speed with three regions. First region of maximum speed and the second region represent the bending region of speed 0.3 cm/sec. The third region represents maximum speed with opposite flow direction to let the cylinder to return back.

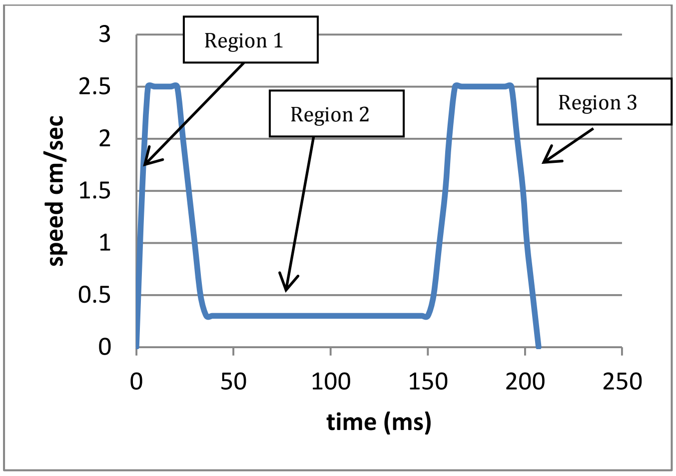

Fig-14 press stroke speed of the system during bending

8. CONCLUSIONS

As a result of this study, the following conclusions are made:

1) The bending force for each material had been determined by the test rig, so that the system will generate the required force for the sample. Un like the other traditional system of fixed applied force, which these systems works under high pressure for each samples and that is lead to losses in power, reduce the life span of the equipment in the system and more noise generated due to high pressure.
2) Automation studio program software can be used to design and simulate the hydraulic system to study the system behavior before building the hydraulic circuit.
3) The bending force required for each sample is determined by the system by using the ultrasonic sensor to determine the sample parameter and then selected the material type, now the force is determined by the controller, then by using the equations of the proportional pressure relief valve which obtained from the calibration of the valve with the amplifier card, and then converting the output of the controller from digital signal to analog signal by the mean of PWM in the Arduino controller, the controller calculate the required voltage to the proportional amplifier to limit the system pressure at a required value.
4) The speed of cylinder stroke while bending is determined by making test of cracks for many samples that had been bent under different speeds, and then chose the optimum speed depending on the number and size of the cracks in each sample.

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