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*Research Paper*

# DESIGN, MANUFACTURE AND SIMULATE A HYDRAULIC BENDING PRESS

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A small hydraulic press for V-bending operation is designed, manufactured and modeled. The hydraulic bending press consists of hydraulic circuit, punch, die and PLC control unit. Automation studio and SimHydraulic in Matlab/Simulink library are used to model the hydraulic circuit. Using PLC program, the bending operation is controlled. The press had to be capable of withstanding 2 tons of force. The punch and dies are designed to be rigidly fixed and easily removable, changeable to any kind of forming operation with decreasing of spring back effect of the sheet metal.

***Keywords:*** Hydraulic circuit, Bending press, SimHydraulic, Spring-back, PLC

## INTRODUCTION

Bending is a metal forming process in which a force is applied to a piece of sheet metal causing bending of it to an angle and forming the desired shape. Bending is typically performed on a machine called a press brake which can be manually or automatically operated. A press brake contains an upper tool called the punch and a lower tool called the die. The sheet metal is located between them. In automatic press brake the punch is forced into the sheet under the power of a hydraulic ram. The bend angle is determined by the depth which the punch forces the sheet into the die. Precisely, this depth is controlled to achieve the desired bend angle.

Hydraulic bending press has many advantages over other type of press, (1) It may cost less than an equivalent mechanical press. (2) Its production rate is equal to the mechanical press in a small lot of production, where hand feeding and single stroking occur. (3) In addition, the die shut heights variation do not change the force applied. In an attempt to alleviate the problem of the dearth of the equipment in laboratories in most of higher institutions in Nigeria, a 30-ton hydraulic press has been designed and constructed using locally source of material. The machine has been tested for the performance with a load of 10 kN (Malachy and Akii, 2011).

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On the same target, we have been tried to manufacture hydraulic bending press to bend sheet metal from low carbon steel to 90 degrees. This press is part of an automation production line built in automation and design laboratory in mechanical engineering department. The production line consists of three components. The first is a belt conveyor, which loads sheet metal. The second is the hydraulic arm robot, which transfer sheet metal from belt conveyor to the third component (the hydraulic bending press). The production line is shown in Figure 1.

**Figure 1: Automation Production Line**

In this paper, components of the hydraulic bending press, design calculations for the hydraulic circuit and design of punch and die have been illustrated in section two. The work flow of the circuit simulation by automation studies has been given. Modeling of hydraulic circuit with SimHydraulic in MATLAB/Simulink has been presented. Programmable logic controller and Ladder diagram has been illustrated.

## COMPONENTS OF HYDRAULIC BENDING PRESS

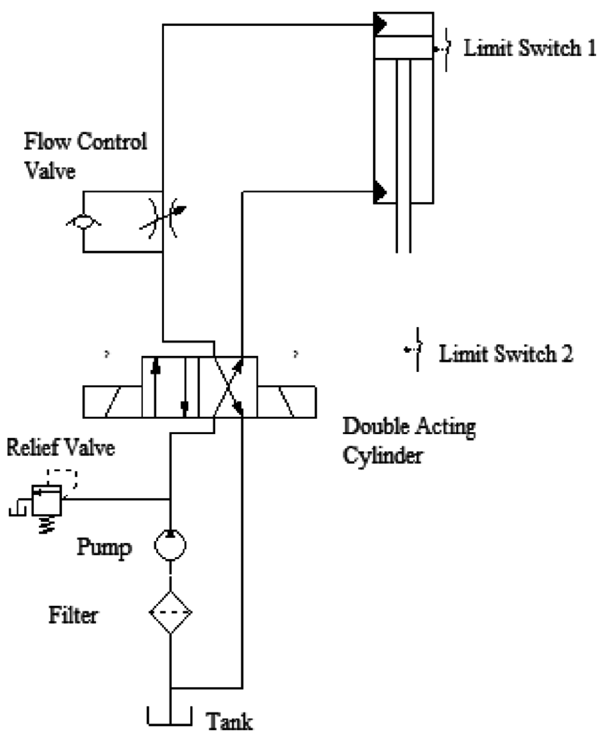
Figure 2 shows the hydraulic bending press consists of a hydraulic circuit, punch and die V-bending and PLC unit.

**Figure 2: Hydraulic Press**

### The Hydraulic Circuit

The hydraulic circuit shown in Figure 3 consists of the following components: (1) Reservoir, which containing oil that supplied to the system as needed and into which the oil from the return line flows. (2) Fixed displacement pump, which supply the fluid to the components in the system. (3) Double acting hydraulic cylinder, which use the hydraulic energy developed in the pump to move the punch. (4) Throttle check valve, which slow the flow in one direction or

**Figure 3: Component of the Hydraulic Circuit**




control the speed of the flow. (5) Pressure relief valve, which used in a pump to prevent overloading. (6) Filter located between the reservoir and the pump intake to remove the contaminant. (7) Hydraulic lines such as pipes or hoses to connect the units to each other.

## *Hydraulic Circuit Calculations*

To design the hydraulic circuit for bending press,

The force needed to bend a sheet of low carbon steel to 90° with dimensions equal to $140 \times 100 \times 3$ mm$^3$ are given in the following Equation (2):

$$F = \frac{k \times Y_S \times L \times t^2}{w} \quad ...(1)$$

where

$F$ = The bending force ($N$)

$k$ = Constant for V-bending = 1.33

$Y_s$ = Yield strength of material (MPa)

$L$ = Is the width of the part in the direction of bend axis meters

$t$ = The sheet thickness (mm)

$w$ = The die opening (mm)

To know the yield strength of low carbon steel, a tensile test for a sheet of 3 mm is applied to universal testing machine and the obtained graph is shown in Figure 3.

The hydraulic press is designed for 0.5 Ton force.

At present many of the valves are limited to a working pressure of 250 bar. Hence we can keep the max working pressure to 200 bar and select other parameters (Mukherjee and Ilango, 1996).

$$\max working\ pressure = \frac{Force}{Bore\ area\ of\ hydraulic\ cylinder} \quad ...(2)$$

The bore area is 7.03 cm$^2$

The cylinder manufacturers follow ISO standards in respect of bore sizes of hydraulic cylinders (e.g.). The preferred bore size can be 40 mm bore diameter cylinder. So, the rod size is 25 mm.

$$Actual\ working\ pressure = \frac{Force}{Bore\ area\ of\ hydraulic\ cylinder}$$

$$= 115 \text{ bar} \quad ...(3)$$

Calculate the flow of the pump required

$$Q\ flow\ rate = Cylinder\ bore\ area \times velocity$$

$$= 12.57 \text{ cm}^2 \times 180 \text{ cm/min}$$

$$= 2.262 \text{ liter/min} \quad ...(4)$$

The pump which can deliver 2.262 liter/min will be the most appropriate at 1400 rpm.

The actual horse power required to drive a pump delivering 2.262 liter/min at 1400 rpm and with pressure of 115 bar can be obtained from:

$$\textit{Fluid power} = Q \times P$$

$$= 200 * 2.26/600$$

$$= 0.75 \text{ kW} \quad ...(5)$$

For overall efficiency of 90%

Power required = 0.75 × 0.9 = 0.678 kW = 0.91 HP

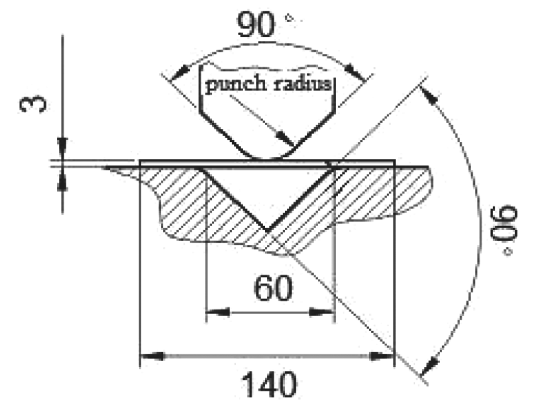
The analysis shows that a motor of 1 HP is sufficient to give the required performance of the pump.

## Design of Punch and Die

Standard tooling in V-bending is often used for the punch and die, allowing a low initial cost and suitability for low volume production. Die and punch are supposed to have clearance equal to the sheet thickness. The punch and die are made of steel. The most important factors, which effects the quality of bending angle and prevent the occurrence of spring-back and spring-forward are bend radius, die angle, punch angle, punch tip radius, die width and punch height. Several researches discussed the most important factors, which effects on bending angle when they design both of punch and die by Zhang *et al.* (2007). These parameters are investigated by using finite element program for V-bending operation with different angles by Florica *et al.* (2007). Also, the effect of changing these parameters on spring-back and spring-forward are discussed in Grizelj *et al.* (2010). The conclusion from these researches is to design punch and die the following constraints must be considered: The size of bend radius is depends on the material thickness and hardness. The punch angle should be made close to the die angle to decrease the influence of spring-back. When the difference between the die and punch angles increases, the spring-back increases. Spring-back and spring-forward are affected by the punch radius; the bend angle of work piece is decreases, spring-back increases and spring-forward decreases when the punch radius is increases.

In the considered hydraulic bending press, both of punch and die are made from steel. After several trails with different punch and die radii and angles (Ivana, 2004), result shows that the best suitable dimensions are; the punch radius is equal to 2 times of thickness, the die radius is equal to the punch radius plus the thickness of sheet metal, while the die opening is 20 times of the material thickness as shown in Figure 4. The punch is fixed to the cylinder rod while the die is fixed on the table.

**Figure 4: Punch and Die Dimension**




A sheet metal used in this study is made of low carbon steel, has the mechanical properties with 3 mm—thickness material given in Table 1.

**Table 1: Mechanical Properties of Experimentally Used Sheet Metal**

| Young's Modulus E(GPa) | Yield Stress $\sigma_y$ (MPa) | K(MPa) | Poisson's Ratio $\gamma$ | *n* |
|---|---|---|---|---|
| 125 | 185 | 480 | 0.29 | 0.225 |

## WORKFLOW OF THE CIRCUIT SIMULATION

The hydraulic circuit has been simulated by using Automation studio 5.3 (http://www.automationstudio.com). The bending process has two speeds; rapid approach, and a feed speed (lower speed compared to rapid speed and rapid return).

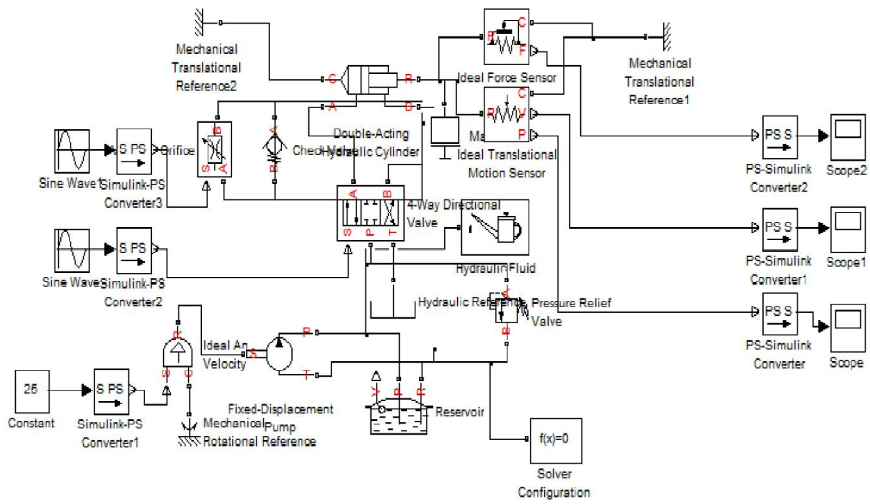
**Situation 1:** Solenoid *X* is energized; flow is through Flow Control Valve (FCV) to port A1 in the cylinder. This allows the cylinder to extract until bend the sheet metal. As the oil has to go through the FCV (free flow is not allowed by the check valve of FCV) the rate of oil flow through part A1 is controlled and hence desired reduced feed speed can be obtained. Oil from port A2 flows freely to the tank. The punch reaches the die at about 1.2 sec. When the punch reaches the die, the pressure at port A1 increases rapidly to produce the forcing force.

**Situation 2:** Solenoid *Y* is energized; FCV is by passed and rapid return is possible in the opposite direction. This is allow the rod of cylinder to be retracts because the oil flow through part A1 comes through the check valve lifting the check valve and to the tank, when the piston rod of cylinder retracts, it reaches the LS2. This gives pulse to solenoid *X* to change the direction.

## SIMULATION OF A HYDRAULIC CIRCUIT IN MATLAB

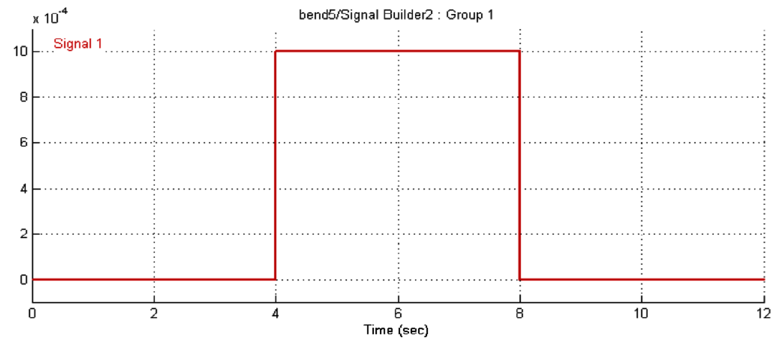
SimHydraulic in MATLAB was used to simulate the hydraulic circuit for the bending press (http://www.mathworks.com/products/simhydraulics/). To draw the hydraulic circuit choose library menu. This menu has various components needed to construct a diagram. By choosing the right component; the hydraulic symbol can be assembled. Figure 5 shows the

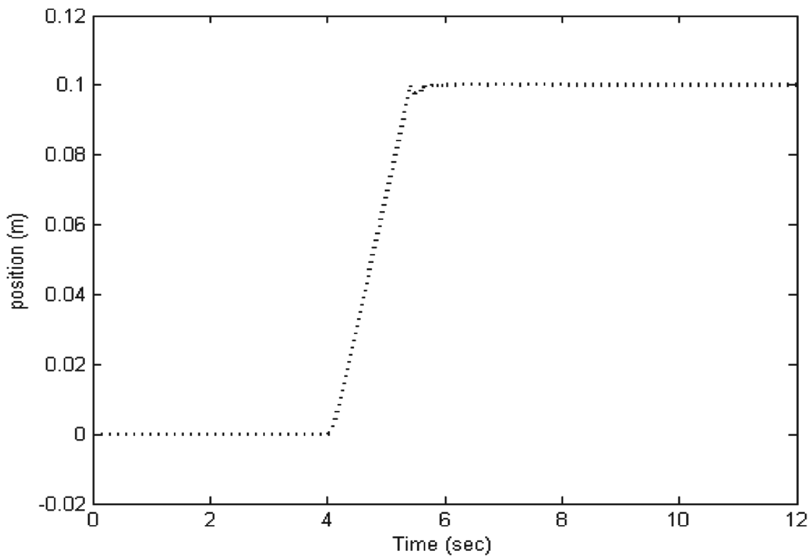
**Figure 5: Simulation of Hydraulic Circuit with SimHydraulic**



simulation of the hydraulic circuit. The piston position and velocity are shown in Figure 6. It is shown that the piston position depends on a valve position.

**Figure 6: (a) Input Signal, (b) Rod Position, (c) Rod Velocity, and (d) Flow Rate**



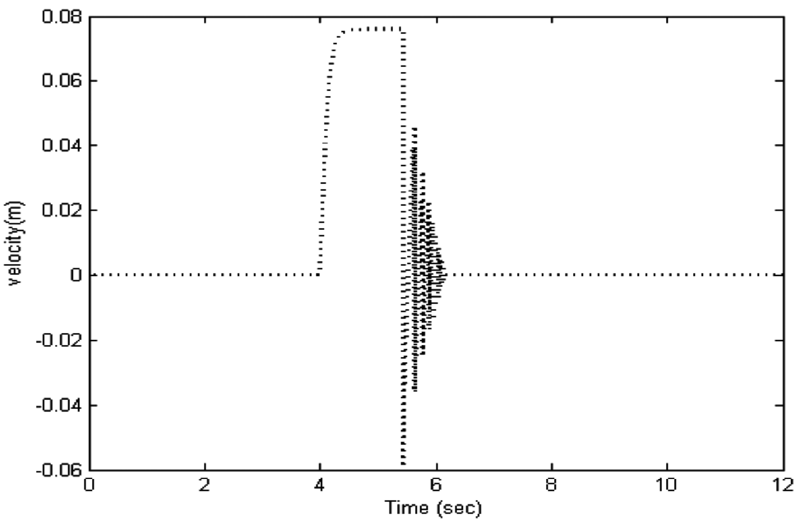
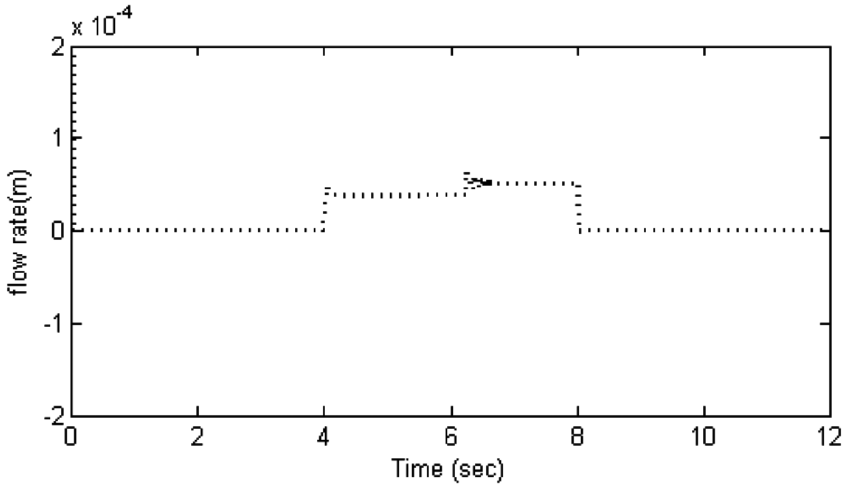



Figure 6 (Cont.)




## PROGRAMMABLE LOGICAL CONTROLLER

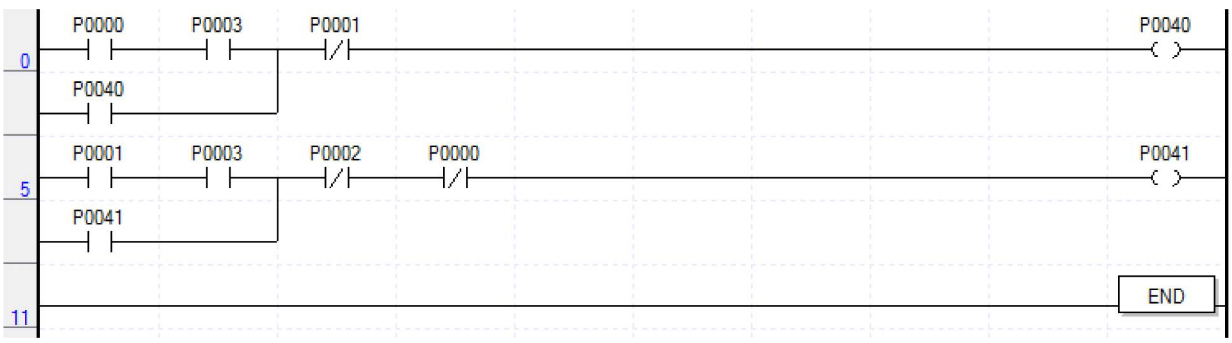
Programmable Logical Controller (PLC) is well adapted to a range of automation task. This is typically industrial process in manufacturing, where the cost of developing and maintaining the automation system is high relative to the total cost of the automation (Kelvin, 2005). PLC contains input and output devices compatible with industrial pilot devices and controls; little electrical design is required and the design problem center on expressing the desired sequence of operations. PLC applications are typically highly customized systems, so the cost of a package PLC is low compared to the cost of a specific custom-built controller design.

A ladder diagram was designed and drawn according to the sequence of operations as shown in Figure 7. The circuit causes the punch, which connected to the rod of the cylinder to automatically extend and retract one time after a push button is pressed.

A detailed description of the operation sequence performed by the PLC program follows:

**Step 1:** When the start push button P00 and the inductive sensor P003 are activated, the solenoid valve P40 is activated, which makes

**Figure 7: Ladder Diagram**



the oil flows to the cylinder. Then the rod is extracted until the punch reaches the fully closed position and close to the die. When the piston is fully extended, the normally closed limit switch P01 opens.

**Step 2:** When the limit switch P01 and the inductive sensor P003 are activated, the solenoid P41 is activated. This moves the directional control valve downward causing the piston to retract until normally closed limit switch P02 open, the push button P00 is inserted as normally closed for stopping this step and starting the new cycle.

## CONCLUSION

A small hydraulic bending press has been designed and manufactured. Both of punch and die have been designed to reduce the spring back and the spring forward. The hydraulic circuit was simulated using both of an automation studio 5.3 and a SimHydraulic programs. SimHydraulic is an extension from Matlab/Simulink library. The bending press is tested by using a low carbon steel sheet metal with 3 mm thickness. Results show that, there is a little amount degree in the spring back and there is no defects on the work piece surface. Therefore in the future, we can design and manufacture a large scale hydraulic bending press with saves in the production cost.

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