How to Cite:
Anbusagar, N. R. R., Bodupally, R., & Kumar, S. (2022). Design & fabrication of closed loop hydraulic press to control pressure & flow. *International Journal of Health Sciences*, *6*(S4), 5815–5826. https://doi.org/10.53730/ijhs.v6nS4.9417

Design & fabrication of closed loop hydraulic press to control pressure & flow

Dr. N R R. Anbusagar
Professor, Department of Mechanical Engineering, Dhanalakshmi Srinivasan College of Engineering and Technology, Mamallapuram

Rameshchandra Bodupally
Assistant Professor, Department of Aeronauticall Engineering
Dhanalakshmi Srinivasan College of Engineering and Technology, Mamallapuram

S. Kumar
Assistant Professor, Department of Mechanical Engineering, Dhanalakshmi Srinivasan College of Engineering and Technology, Mamallapuram

***Abstract*---**The present paper describes the design and fabrication development of a 250kN closed-loop hydraulic actuated press to control Force, velocity and position during stamping operations as well as mechanical tests. The press has one hydraulic servomechanism: a hydraulic cylinder, driven by a servo-solenoid P/Q valve, to support the operation; The press is equipped with a pressure sensor installed in the cylinder chamber for indirectly measuring the pressing force. On the press it is also possible to measure the position of the upper plate by using a micro-pulse linear transducer, which creates a precondition for the realization of a hybrid force /position /velocity-control algorithm. The control algorithms and monitoring process are implemented on a real-time hardware board. They are programmed in the LABVIEW software. Based on the experimental results, it can be concluded that electrically actuated control components supported by the appropriate computer programs make it possible to improve the characteristics of the hydraulic systems required in modern industrial plants. The software setup allows the implementation of a hybrid controller (force + position + velocity) for the hydraulic cylinder in such a way that it will be easy to switch between force, position and velocity control.

***Keywords*---**closed-loop hydraulic press, electro- hydraulic, servo-solenoid P/Q valve, velocity control, position control, force control, software,

International Journal of Health Sciences ISSN 2550-6978 E-ISSN 2550-696X © 2022.
Manuscript submitted: 27 March 2022, Manuscript revised: 18 May 2022, Accepted for publication: 9 June 2022

Introduction

Hydraulic power systems and actuators have been used for a long time, mainly in circumstances where high loads are encountered or large forces are needed. They present a price and weight benefit over the equivalent electro- mechanical systems needed to generate the same force or torque. Hydraulically actuated systems are used in a wide range of industrial applications, and continue to be a popular and relatively inexpensive power source. These systems provide similar performance to electric motors, including high durability, the ability to produce large forces, and relatively quick response times [1], as well as the benefit of lower costs. Due to the improvement of present technology and the emergence of new technology, hydraulic systems are able of being utilized in an ever-increasing range of applications. Hydraulic systems are essential to the technological processes which need high mechanical power such as stamping, punching, forming or extruding, just to name a few. Most of these processes are performed with hydraulic presses. There are many varieties of hydraulic presses performing many different processes. Most of the presses, used in industry, utilize open-loop motion and are manually or PLC operated. Nowadays, press manufacturers already offer computer controlled solutions with motion and/or force control [2]. However these solutions are usually proprietary and it is difficult, if not impossible, the experimentation of new control algorithms or the integration of new features or new sensors. That is a problem when special equipment is needed, as for example, equipment to be used in mechanical tests. This kind of equipment usually requires special features and need to be developed as an open system that may incorporate new functionalities. This flexibility must also be guaranteed when selecting control and instrumentation software solutions because new experiments or controllers must be setup quickly. This paper reports the design of a computer controlled and operated hydraulic press to perform stamping tasks as well as mechanical tests such as compression, tensile or fatigue tests. In order to achieve this flexibility the hydraulic press is fully instrumented with position and pressure sensors. The Labview package was used to develop all the software.

Automatic Open and Closed Loop System

Nowadays industrial and mobile machines are multi-axis machines. A quite good percentage of them, particularly of large power, are driven electro-hydraulically and controlled by proportional or servo valves. Each axis motion can be operated in an "open loop" or "c1osed loop" control environment, depending on the accuracy level required in the application and the characteristics of the devices implemented in the system. The following introduction is important to clarify some terminologies, which will be used in the text. In many applications the motion cycles are slow; do not require extreme accuracy and the devices used are offering stable and of almost linear characteristics. In such cases, an open loop control system would be a simple and cost effective solution. A closed loop control system is required whenever the system dynamics is nervous and the required accuracy level is high. The accuracy of the closed loop controls is much better than the open loop ones and it is less influenced by the external disturbances.

Both open loop and closed loop control system is working based on a reference "input" signal. Setting the reference signal is generally by one of two ways, manually or automatically. Manual setting of a reference signal is usually by a mechanical lever, conventional potentiometers or joysticks. Automatic setting of the reference signal is usually by a programmable logic controller PLC /microcontroller, central processing units CPU in the computer-based controlled systems or by a mechanical means e.g. cam surface and roller. The Fig 1 represents typical example of an "Automatic Open Loop" control system. As shown in the figure 1, the motion of a hydraulic cylinder "1" is controlled by a proportional valve "2". The proportional valve solenoid is receiving driving electrical current from a driver card, which is generating the driving current based on a reference "input" signal supplied directly by a CPU "3". Such system can be used only for controlling cylinder speed and force. To control a cylinder position automatically, the system must be of closed loop type with a device monitoring the cylinder position on a continuous base.

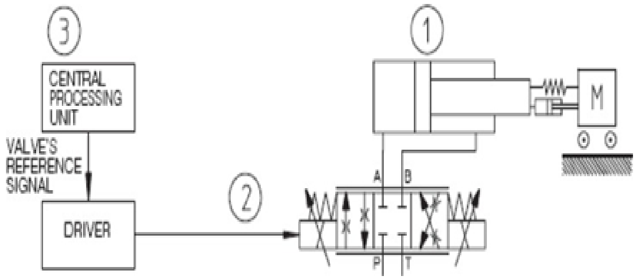

Fig 1. Automatic Open Loop Control of a Hydraulic Cylinder

A closed loop system, whither the reference signal is set manually or automatically, can perform control of cylinder position, speed and force. Figure 2 represents typical example of an "Automatic Closed Loop" control system. As shown in the figure 2, the position of a hydraulic cylinder "1" is controlled by a proportional valve "2". The proportional valve solenoid is receiving driving electrical current from a driver card, which is generating the driving current based on a control signal supplied by an axis controller. The axis controller responsibility is to continuously compare the reference signal set by the CPU "3" to the actual cylinder position fed back by the position sensor "4", then consequently generate the adequate control signal.

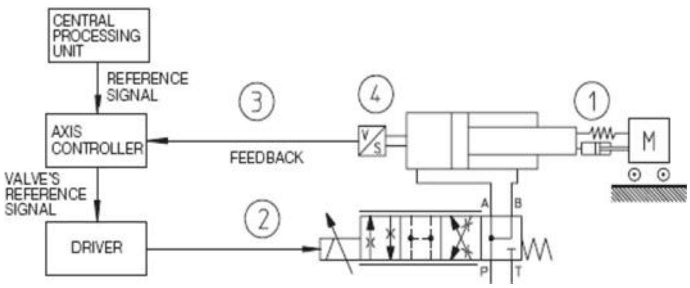

Fig 2. Automatic Closed Loop Control of a Hydraulic Cylinder

Whither the loop is closed or open, manually operated system can be used to control cylinder position since the operator is closing the loop using his eyes as a feedback sensor and his brain as a controller and CPU. Typical example of this situation is an operator is moving an excavator arm. In whole cases, specifying the hydraulic power requirements in terms of flow and pressure to achieve certain acceleration/deceleration rates is an essential part of closed loop control system design. In the following, a systematic calculation approach will be presented and followed by a mathematical modeling and end up with an interactive simulink tool for quick system sizing. Lumped parameter approach will be followed in this project to parameterize the system. As shown in Fig 3. in this text, the cylinder with the attached load is defined as the hydro- mechanical part of the system. The rest of the system is defined as the electro-hydraulic. The mass M represents the equivalent moving mass of the hydro-mechanical part. It is the sum of the mass attached to the cylinder rod plus the mass of the cylinder piston and rod. The stiffness C represents the equivalent stiffness of the hydro-mechanical part. It is the combined stiffness of the physical spring and the cylinder stiffness due to the oil bulk modulus. The friction coefficient K is the equivalent friction coefficient of the hydro-mechanical part. It is the combined friction coefficient due to the piston seal friction and friction between the external moving mass and a fixed surface.

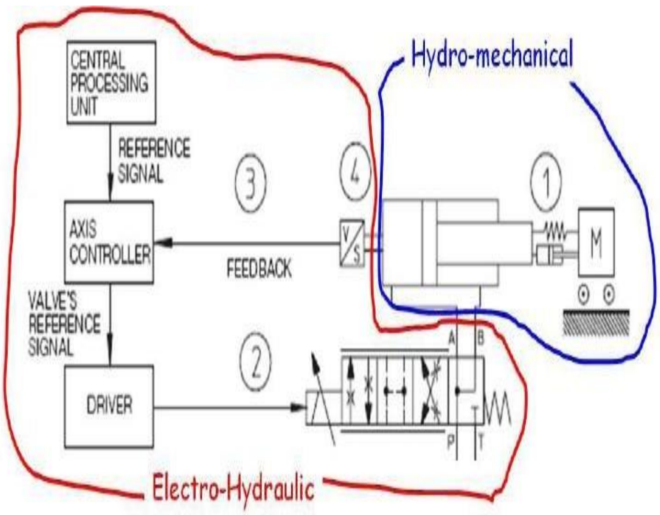

Fig 3. Electro-hydraulic and Hydro-mechanical Part of the System

Natural Frequency

As shown in Fig 4. it is known that the natural frequency ω_n of a stable system is the frequency by which a system freely oscillates after being hit by an of a system can be identified experimentally in different ways. The system can be subjected to an impulsive force and its response is acquired. The system natural frequency will be $\omega_n = 2\pi/T$, where T is the time period of a complete oscillation. Other way is to energize the system with a harmonic input signal, start with low frequency and increase it until the system reaches a resonant condition. Frequency that causes resonance is the system natural frequency.

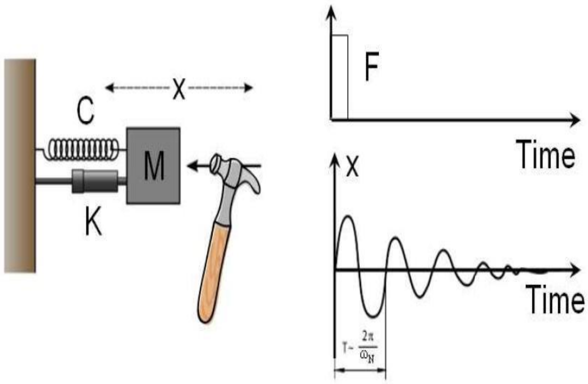

Fig 4. Natural Frequency

Natural frequency can be also calculated based on the system design parameters. Figure 2. shows a number of elements that form a closed loop to control hydraulic cylinder position. Each of these elements has its own natural frequency. The feedback sensor has usually natural frequency 10 times higher than the cylinder. Obviously the valve has higher frequency as compared to the cylinder due its small spool mass. The electronic driver is of the highest natural frequency among these elements. Then the natural frequency for the overall system equals the natural frequency of the hydro-mechanical part since it has the minimum natural frequency among the other system elements. Therefore, an electro-hydraulic controlled system natural frequency will be

$$\omega_N = \sqrt{C/M} = 2\pi f = 2\pi / T$$

(1)

Where C and M are the equivalent stiffness and moving mass of the hydro-mechanical part of the system; respectively and f is the frequency.

Hydraulic Cylinder Stiffness

In order to calculate the natural frequency of a hydraulic cylinder, the hydraulic cylinder stiffness must be found in advance. Figure 5. shows a hydraulic cylinder of differential (unequal area) on both sides of the cylinder piston where A1 is the cylinder bore area and A2 is the annulus effective area at the rod side. As shown in the figure, this cylinder can be simulated by a mass attached to two springs in series arrangement. In such arrangement, the total stiffness of the cylinder is the sum of C1 and C2. Starting with the definition of the stiffness, the hydraulic stiffness of a confined volume of oil under pressure in a cylinder chamber can be deduced as follows:

$$C = \frac{\Delta F}{\Delta X} = \frac{\Delta p \times 10^5 \times A}{\Delta X} = \frac{\Delta p \times 10^5 \times A^2}{\Delta V} = \frac{\beta \times 10^5 \times A^2}{V}$$

(2)

Where b is the oil bulk modulus, A is the effective area under pressure, V is the sum of the dynamic volume of the corresponding cylinder chamber plus the dead volume of thefluid line connected to that chamber.

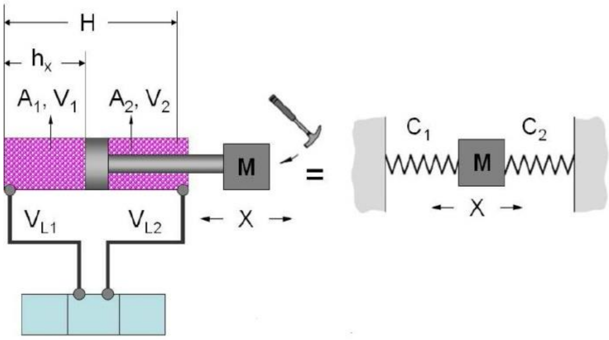

Fig 5. Simulating hydraulic cylinder stiffness

Applying equation 2 to the two cylinder chambers, values of C1 and C2 are found as follows:

$$C_1 = \frac{\beta \times 10^5 A_1^2}{V_1 + V_{L1}}$$
$$C_2 = \frac{\beta \times 10^5 A_2^2}{V_2 + V_{L2}} \quad (3)$$

The total stiffness of a differential cylinder would then be

$$C_H = \beta \times 10^5 \left[\frac{A_1^2}{V_1 + V_{L1}} + \frac{A_2^2}{V_2 + V_{L2}} \right] \quad (4)$$

The volumes V1 and V2 are dynamic volumes based on the cylinder piston position.

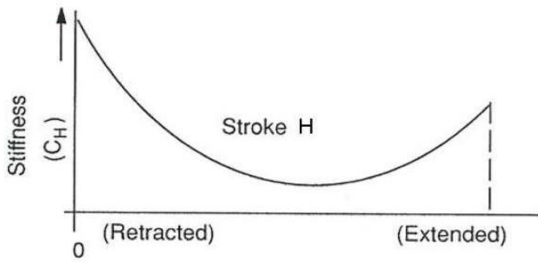

Fig.6 Hydraulic Differential Cylinder Stiffness versus Stroke,

As it can be seen from Figure 6, stiffness is high when the cylinder is dead headed at either end of the strokes. Stiffness reaches a minimum approximately at cylinder travel hx = 0.56 H. substituting value of hx in equation 5, minimum stiffness for differential cylinder will be

$$C_{Hmin} = \beta \times 10^5 \left[\frac{A_1^2}{0.56HA_1 + V_{L1}} + \frac{A_2^2}{0.44HA_2 + V_{L2}} \right] \quad (5)$$

Assuming the hydraulic fluid lines are of small volumes, equations 5 will become 6 and 7, respectively.

$$C_{Hmin} = \frac{\beta \times 10^5}{H}\left[\frac{A_1}{0.56} + \frac{A_2}{0.44}\right]$$
$$C_{Hmin} = \frac{4\beta A \times 10^5}{H} \qquad (6\&7)$$

For performance calculation, only the minimum stiffness will be considered since it has the worst effect on the system dynamics. By substituting the value of the minimum stiffness in equation, the minimum natural frequency will be

$$\omega_{Nmin} = \sqrt{C_{Hmin}/M} \quad (8)$$

Hydraulic Cylinder Maximum Acceleration and Deceleration

The main goal of closed loop system design is to achieve maximum possible acceleration/deceleration rate so that the system will respond very fast to an input signal. On the other hand, the very responsive system may be nervous and unstable. A compromise must be made between the system stability and its speed of response, or in other words minimum acceleration/deceleration time. The rule of thumbs said that the minimum acceleration/deceleration time is to be approximately not less than five times T at the natural frequency. Minimum acceleration/deceleration time would be approximately

$$t_{min} = 35/\omega_{Nmin} \qquad (9)$$

The minimum natural frequency has been used to assure the stability over the whole cylinder stroke. Once the cylinder stroke and the total time for this stroke are known, maximum speed can be calculated, with the aid of Fig 7 , as follows

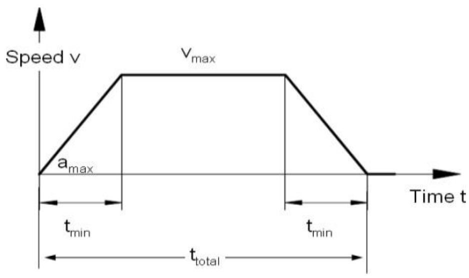

Fig 7. Hydraulic Cylinder Work Cycle

$$H = 0.5\, t_{min} \times v_{max} + v_{max}\,(t_{total} - 2\, t_{min}) + 0.5\, t_{min} \times v_{max} \quad \text{then}$$
$$v_{max} = H/(t_{total} - t_{min}) \qquad \textbf{(10)}$$

a functional bandwidth of 120 hz for inputs of +/- 5% of the maximum valve input signal. The hydraulic power is provided by a fixed displacement gear pump, model 1P3036 from Dowty, along with a 10dm3 capacity accumulator, model IVH

5-330 from HYDAC. The hydraulic system is able to work up to 150bar pressure being the maximum piston force approximately 250KN. The cylinders piston positions xp is measured with linear position sensor with a resolution of 1micronmeter and an operational range of 500 mm. The hydraulic force applied to the piston tool is indirectly measured through two pressure analogue sensors from WIKA, 4-20 mA, installed in the cylinder chambers (P1 and P2).

Consequently, maximum acceleration can be calculated as follows

$$a_{max} = v_{max} \ / \ t_{min} \qquad (11)$$

Hydraulic Power Requirements

Equations 12 through 15 show the calculation of the inertia, required pressure, required flow and required power source size; respectively. Those set of equations must be solved twice to find out the hydraulic power requirements that satisfy both extension and retraction cylinder stroke.

$$\begin{aligned} F_{inertia} &= M \times a_{max} \\ p_{req} &= (F_{inertia} + F_L) / (A \times 10^5) \\ Q_{req} &= v_{max} \times A \times 60000 \\ P_{req} &= p_{req} \times Q_{req} / 600 \end{aligned} \qquad (12\text{-}15)$$

Hardware and software platform

The press has a one hydraulic servomechanisms, servo solenoid P/Q valve which supports the piston rod. Fig.1. presents two images of the press during development and while performing an experiment. The overall hydraulic circuit implemented to operate the press is shown in Fig. 2. The cylinder which is used to actuate the punch tool is a custom built conventional hydraulic cylinder with 140mm piston diameter, a range of motion of 500mm stroke and has low friction hydrodynamic seals to improve dynamic performance. The motion control of the hydraulic cylinder is accomplished using a Bosch-Rexroth® servo-solenoid P/Q valve, model NG6 OBE with integrated electronics, that has

Fig 8 : Photo of the hydraulic press

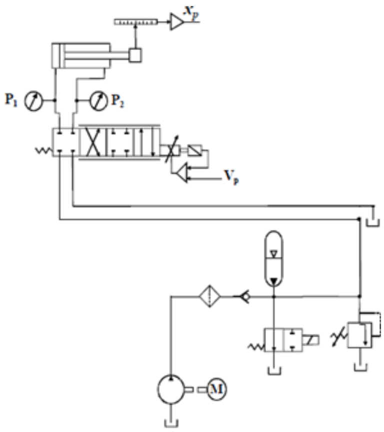

Fig 9. Circuit diagram of hydraulic press

Data acquisition and control of the press are handled by LABVIEW. The control and operation of the press are accomplished by the use of the computer card in conjunction with the LABVIEW platform. This Hardware/software setup allows the simultaneous monitoring and acquisition of data as well as the change of control parameters such as force , velocity and position. All the software to control, operate and monitoring the hydraulic press is implemented in the labview environment.

Controller Implementation

This paper implements PID control in order to control the force, velocity and position. It uses the Set point as PLC analog output, controller is P/Q card, amplifier used is OBE and it utilizes the P/Q valve. Actuator is differential cylinder. Pressure transducer and LVDT are the measuring devices used in this paper. The closed loop control block diagram is shown in the figure.

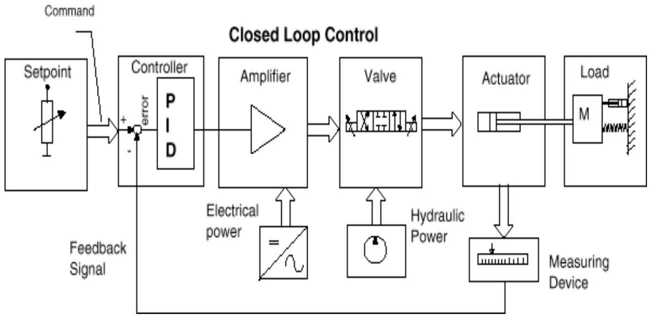

Fig 10. Controller closed control loop

Result and Conclusion

Hence velocity control and pressure control of a hydraulic cylinder with position feedback from linear variable differential transformer is achieved. The system also incorporates PID concept for precise control. The system is commission and about 18% of error due to the data acquisition and it can be overcome with the use of servo cylinder. The velocity and versus stroke response is shown in figure 11. Pressure versus stroke response is shown in figure 12.

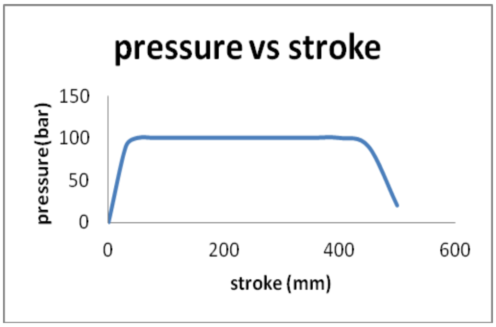

Fig 11. Pressure vs stroke response

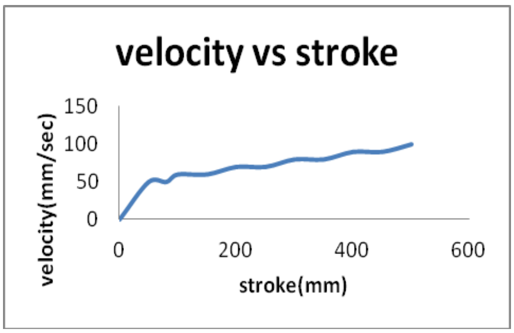

Fig 12. Velocity vs stroke response

References

[1] Murrenhoff, H.: Trends in Valve Development, O+P oil hydraulic and Pneumatic, Vol. 46, Nr. 4., pp. 1-36, (2003).

[2] Smith, D.: Hydraulic Presses, Smith & Associates, www.smithassoc.com/

copyrighted-white- papers/papers/C07.pdf, Monroe, Michigan, pp.1-20, (1993).

[3] Nguyen, Q.H., Ha, Q.P., Rye, D.C., Durrant-Whytel, H.F.: Force/Position Tracking for Electro hydraulic Systems of a Robotic Excavator, Proc. of the 39th IEEE Conf. on Decision and Control, Dec. 12-15, Sydney, Australia, pp. 5224–5229, (2000).

[4] Dunnigan, M.W., Lane, D.M., Clegg, A.C., Edwards, I.: Hybrid position/ force control of a hydraulic underwater manipulator, IEE Proc. of Control Theory Application, Vol. 143, No. 2. pp. 145–151, (1996).

[5] Sun, P., Gracio, J.J., Ferreira, J.A.: Control System of a mini hydraulic press for evaluating spring back in sheet metal forming ,Journal of Materials Processing Technology, Vol. 176,pp. 55–61, (2006).

[6] Choux, M., Hovland, G.: Design of a Hydraulic Servo System for Robotic Manipulation, Proc. Of the 5th FPNI Ph.D Symposium, Krakow, 1-5 July, pp. 391– 400,(2008).

[7] Šitum, Ž., Bačanek, M.: Hydraulic System Control Using Proportional Valve, Transactions of FAMENA, Vol. 29, No. 2; pp.23–34, (2005).

[8] Šitum, Ž., Essert, M, Žilić, T., Milić,V.: Design and Construction of Hydraulic Servomechanisms for Position, Velocity and Force Control, CD–ROM Proc. of the 8th ASEE Global Colloquium on Engineering Education, Buda-pest, Hungary, 12-15 October,GC- 2009-62, (2009).

[9] Šitum, Ž., Milić, V., Essert, M.: Throttling and Volumetric Control Principle to an Electro hydraulic Velocity Servomechanism,7th Int. Fluid Power Conf.(7th IFK), Aachen, Germany, 22-24 March, Vol. 2 – Workshop, pp. 379-390, (2010).

[10] Šitum, Ž., Milić, V., Žilić, T., Essert,M.: Design, Construction and Computer Control of a Hydraulic Press, The 12th Scandinavian Conference on Fluid Power, May 18-20, Tampere, Finland, Vol. 3, pp. 93- 103, (2011).

[11] A. Alleyne, R. Liu. Systematic control of a class of nonlinear systems with application to electro-hydraulic cylinder pressure control. IEEE transactions on control systems technology, 2000, 8(4): 623–634.

[12] J. Ferreira, P. Sun, J. Gracio. Close loop control of a hydraulic press for spring back analysis. Journal ofMaterials Processing Technology, 2006, 377–381.

[13] R. Fung, Y. Wang, et al. A variable structure control with proportional and integral compensations for electro hydraulic position servo control system. Mechatronics, 1996, 7: 67–81.

[14] H. Khan, S. Abou, N. Sepehri. Nonlinear observer- based fault detection technique for electro-hydraulic servo positioning systems. Mechatronics, 2005, 1037– 1059.

[15] C. Lin, L. Ren. The integrated Simulation Analysis on 6-DOFElectrohydraulic Servo-Control Parallel Platform .JSME International Journal, 2005, 48(9): 234–239.

[16] H. Merritt. Hydraulic Control System. John Wiley & Son, Inc, 1967.

[17] Moog. Industrial control division. Http://www.moog.com.

[18] V. Product. Proportional Directional valve with Feedback.

[19] M. Sirouspour, S. Salcudean. On the Nonlinear Control of Hydraulic Servo System. in: International Conference on Robotics & Automation, San Francisco CA, 2000.

[20] P. Sun, J. Gracio, J. Ferreira. Control system of a mini- hydraulic press for

evaluating spring back in sheet metal forming. Journal of Material ProcessingTechnology, 2006, 55–61.

[21] Rinartha, K., & Suryasa, W. (2017). Comparative study for better result on query suggestion of article searching with MySQL pattern matching and Jaccard similarity. In *2017 5th International Conference on Cyber and IT Service Management (CITSM)* (pp. 1-4). IEEE.

[22] Rinartha, K., Suryasa, W., & Kartika, L. G. S. (2018). Comparative Analysis of String Similarity on Dynamic Query Suggestions. In *2018 Electrical Power, Electronics, Communications, Controls and Informatics Seminar (EECCIS)* (pp. 399-404). IEEE.

[23] Kadir, Y. R., Syarif, S., Arsyad, M. A., Baso, Y. S., & Usman, A. N. (2021). Female's reproductive health application design on the school teacher knowledge: an android-based learning media. *International Journal of Health & Medical Sciences*, *4*(2), 189-195. https://doi.org/10.31295/ijhms.v4n2.1686