Pressure Pattern Improvement of Proportional Valve Application on Hot press Machine Using PID

Widianto Stevanus
Department of Mechanical Engineering
Swiss German University
Tangerang 15143, Indonesia
Email: widianto.stevanus@gmail.com

Hanny J. Berchmans
Department of Mechanical Engineering
Swiss German University
Tangerang 15143, Indonesia

Aulia A. Iskandar
Department of Mechanical Engineering
Swiss German University
Tangerang 15143, Indonesia

***Abstract*—The purpose of this study is to develop a control scheme for the hydraulic proportional system using PID function on Mitsubishi PLC Q series, which can rapidly control the pressure in a hydraulic cylinder with very short stroke. The mathematical model of the control system is established according to the principle of the electro-hydraulic system. Considering the mentioned characteristics, simulation of the system modelling will be established to know the system response. In order to improve the control precision of the hydraulic hot-press system, the Mitsubishi PID controller are designed by selecting appropriate tuning parameters. Their control performances are analysed in time domain respectively. The variation of PID controller configuration will be conduct to know the better model for this system controller. The validity of the proposed control scheme is confirmed through the experiments to verify the rationality of the theoretical model. The results show that the Mitsubishi PID and the ideal PID give the same result for the tuning parameter resulted from simulation. And also the experiment give the better stability in the 3 different pressure set value that conduct by author.**

I. INTRODUCTION

Brake pads systems in automotive industry must have good wear resistant, stable coefficient of friction during service life, high thermal conductivity, and low thermal expansion properties. Asbestos composite are considered as a unique material and is mainly used to produce light weight high strength and also used to reduce cost of technical applications. Production of brake pad consists of a series of unit operations including mixing, cold and hot pressing, cooling, post-curing and finishing.

Hot pressing is a process of metallurgy for forming the powder friction material that already preform in the previous process. By applying high temperature and certain value of pressure to achieve some quality parameter of the product. This is can be done by apply simultaneous of heat and pressure pattern. To optimize the machine operation and capability one machine must be able to running with various type depend on customer needs. Each type consist of different formula and process condition. In hot press machine two parameter must be full fill are temperature and pressure pattern. Pressure come from hydraulic pump unit. For changing the pressure value we must adjust manually with remote relief hand valve that need time because we must trial by press and release the ram cylinder while change the remote hand valve rotary position.

Reduce the setup and change over time will increase the machine capacity, increase manufacturing flexibility, and increase overall product output. While our operators or technicians are scurrying around to change tooling and process condition from one job/type to the next, that machine or assembly operation is idle. We focus on setup times because most of the customers will continue to demand new features, options, and customized applications of our products. It is impossible to attempt to make and hold these all various products in storage field. Lot sizes will also decrease because the customers are managing their businesses more efficiently. So the increasing development of product features and options convert into more job changes/setups, and that leads to more lost production time between jobs. To reduce setup/change over time, proportional valve was applied to adjust pressure value automatically based on selected type (process condition). Unfortunately the pressure pattern did not match with the requirement. The pressure pattern produce more ripple and slowly decrease while hold for many second. This condition making crack on brake-pad friction side, that one of S marking in the quality inspection Hydraulic Hot-press system

II. SYSTEM DESCRIPTION

The hot-press machine use hydraulic power source to produce the pressure that required by process condition. Operational start with heating up temperature from room temperature till certain point. After the temperature stable (shown by graph in HMI) operator start measuring real temperature using temperature calibrator. After temperature ready operator start adjust the pressure (before apply proportional valve) based on product process condition. All timer sequence already input in HMI for each product. This timer is use for determine the pressure pattern between pressing and breathing. After all the process condition conform the operator start to loading friction preform material to dies and also the pressure plate. After all dies full filled with the raw material the operator switched start and machine will operate automatically. The sequences will repeatable apply press and breathing. In this sequence the pressure pattern will be important and will be monitor every time. All the sequence and parameter condition control by PLC.

A. Working principle of the system

The hydraulic Hot-press system is used to press up the number of dies which is made up of series with the preform material inside the cavity. The pressure range is between 0-20 MPa and its equivalent to 0- 90 tons load. This system consists of a fuel tank, motor, axial piston pump, proportional valve, accumulator, cooler, digital display temperature controller, valve group (electromagnetic directional valve, direct-acting relief valve, oil filter, and so forth). The specific hydraulic principle is shown in Figure 1.

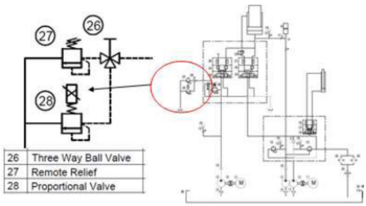

Fig. 1. Simplified diagram of hydraulic system.

The hot-press machine used hydraulic for apply certain value of pressure with the certain pattern (pressing and breathing in time series). The hydraulic system adjusts the pressure automatically by the electro-hydraulic proportional relief valve. The pressure value is given by the upper computer. The analogue output module of the PLC outputs control current. The proportional amplifier amplifies the control current to drive the open degree of the electric-hydraulic proportional relief valve. Real-time load is collected through pressure sensors. The core components of the whole hydraulic loading system include a controller, proportional relief valve and pressure sensor, which jointly complete the pressure setting, control and detection of the system. Figure 2 show the schematic of PLC control hot-press machine.

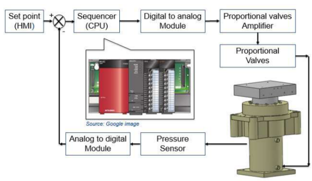

Fig. 2. Control system of hydraulic hot-press machine.

In a current controller method the sensing value of the actual pressure will be compare with the set point value in ladder diagram. The comparator decide what operation that would be conducted. If the sensing value lower than the set value the PLC ladder give the instruction to slightly increase the digital value of the set point buffer with the 0.2 second clock incremental value. When the set point value reached the clock will be disable and keep the pressure during the pattern time. If the sensing value higher than the set value, the set point buffer value will be decrease with the 0.2 s clock also till the set point pressure and the actual pressure giving the same. The set value and corrective value will be converted to analogue value and transfer to proportional amplifier to drive the proportional electromagnetic valve to adjust the valve mouth open. During the process monitoring and the observation this method produced ripple on the pressure pattern

B. Model of Hydraulic hot-press system

In order to facilitate the simulation and application of the control algorithm, the mathematical model of the current system needs to be established. The test rig adopts NACHI proportional valve. It is the core component that transforms the system pressure from the electrical signal to the actual pressure. The concrete structure is shown in Figure 3.

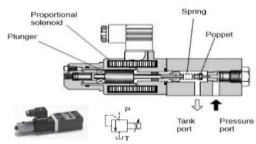

Fig. 3. Proportional relief valve hardware.

The valve is used for constant pressure. When the control signal is certain, stable system pressure can be obtained. The change of control signal can adjust the pressure of the system smoothly, so that the hydraulic impact on the system is small. The high-pressure fluid acts simultaneously on both ends of the main valve, so the force balance is maintained because of the same effective area on the main valve. If the pressure continues to increase, the force balance will be broken. When the hydraulic pressure reaches the thrust of the proportional electromagnet, the pilot conical valve opens. The fluid pressure will be fed through the pilot valve core. Pressure drop will be produced on the upper end of the main valve. The main valve core overcomes the rise of the spring force, and the P and T oil roads will be connected. The excess flow of the system flows back to the tank, so the pressure will not continue to rise and the reconstruction force will be balanced. Meanwhile, this proportional relief valve is equipped with a pressure relief valve. When the electrical or hydraulic system fails (due to excessive current, or excessive pressure in the hydraulic system), the safety device acts to limit the rise of system pressure.

III. Control System Design

In this study PLC used to control the size of the relief valve mouth by proportional electromagnetic current. When the system program or relief valve failure, the system cant be unloaded in time, the system pressure rose sharply, when to secure value, the hydraulic controlled pilot valve action, by mechanical unload valve to uninstall, guarantee the system pressure is not too large. This system adopts the electro-hydro proportion relief valve instead of electro-hydro machinery relief valve. Electro hydraulic proportional relief valve was as the execution element of the system, the system uses the electro-hydraulic proportional electromagnetic valve to control the system pressure. System control diagram in figure 4 is as follows:

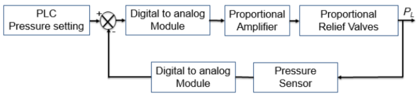

Fig. 4. Current control system block diagram.

In the full pressure control system, the pressure sensor as the signal collector of control system, testing the pressure of the cylinder ram, the signal directly be input into PLC analogue module, than the signal be transferred from the simulation module of the signal to PID controller of PLC processor, comparing PID operation between the acquisition signal and the set value in PID controller, by the simulation output module the result signal be transferred to the electro-hydraulic proportional relief valve electromagnet, through the current size of the input electromagnet, controlling the size of the relief valve mouth. The pressure sensors collect the pressure signal, the signal value with the set value subtracting. When calculating value is positive value, electromagnet pick up current, the valve open mouth, the mouth open degree and the calculated value of proportional to unload system, the system pressure drop. When calculating value is negative, the electromagnet without action, the mouth closed, the system pressure rise or remains the same. According to the overall control diagram of the system, all aspects formed the system can be obtained: proportional amplifier, proportional control components, and detection feedback element. PID controller is a software controller combined with PID algorithm in PLC. Equation 1 shows the transfer function. K_P is the scale factor; T_I is the integration time constant; T_D is the derivative time constant.

$$G_c(s) = \frac{U(s)}{E(s)} = K_p(1 + \frac{1}{T_I s} + T_D s) \qquad (1)$$

Because the system using 2 different Pressure supply one is low press and 2nd is high pressure that would be handle by proportional valve. Low press supply used for initial pressure at the minimum point. After the value reach the high pressure work by the proportional valve. So we assume here while proportional work the cylinder is no moving or closed to zero ($y = 0$). The transfer function can be simplified as Figure 5.

Pressure sensor: due to the pressure sensor bandwidth is higher than the system's, usually can be regarded as approximate proportion. So the transfer function of the pressure sensor is K_a According to the working principle of the system and the mathematical model of control system, the system dynamic chart was shown in Figure 6

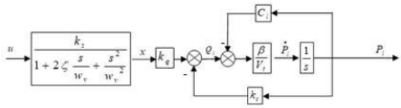

Fig. 5. Pressure control block diagram

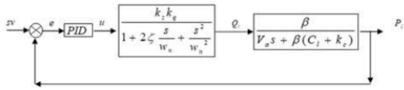

Fig. 6. Pressure control block diagram with PID

IV. Control System Simulation and Analysis

In the actual site, the working pressure of Hot-press machine is between 5 MPa and 20 MPa. When the system pressure is higher than the 20 MPa, the relief valve discharge. Therefore, this rated pressure of the system is set at 11.2 MPa According to the system hardware, the suitable parameter were selected, and they were be plug into dynamic equation, In this paper, simulation models of MATLAB software is built for deeper theory analysis. Also, we can conclude that the ideal PID help to improve the rising time and settling time. The system getting stable after 5 second and the overshoot is around 10 bar. The PID parameter chose by auto tuning in MATLAB with the guidance of process condition and setting tolerance.

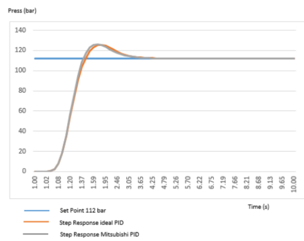

Fig. 7. Comparison between two PID form.

According to the vertical axis changes of the simulation curve graph (Fig.7), these can be seen that the system is stable at 11.2 MPa. When the constant pressure signal of 11.2 MPa is input, the system pressure response will fluctuates up and down as the pressure goes on, but quickly stable at the 11.2 MPa, that proves the system is stable. Based on the system pressure wave range, the system pressure is not more than 20 MPa, it proves that the pressure of the pressure control system can not surpass the maximum pressure value; if the pressure valve is not lower than 24 MPa, that proof the pressure of the pressure control system cannot below safety limit, the system wave in the security range, the system will not appear hydraulic shock, accord with the safety requirement of the control system at working conditions on site. Observe the horizontal axis change of the curve, something can be seen, that change of the curve in time is very quick, the system can be stable in 4 seconds, and less fluctuations in frequency, the system will not have the too big burden, no apparent vibration and noise. Overall, in control of the hydraulic proportional relief valve, pressure change slowly in safety, rational scope. The system won't be hit by hydraulic shock which can be caused by the general mechanical relief valve suddenly opened or closed, that play a good protection for the system structure and implement sealing elements, make certain the miss operation never start. The system is very suitable for coal mine which characteristic is higher safety factor.

V. Result and Discussion

From the Figure 8 we can see the part of the pressure pattern as a single graph for to be compare with the simulation result. In these figure show the response of the system or the pressure control by time domain using Mitsubishi PID control function the system response doesn't have an overshoot (undershoot) different with the simulation. But the settling time is almost the same, the system became stable after 5 second.

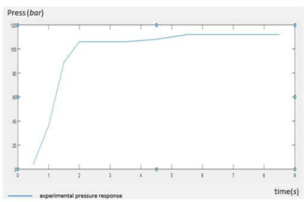

Fig. 8. Experimental step response using Mitsubishi PID.

The difference simulation and experiment graph may cause by the limitation of the experiment such as some parameter not measured directly but calculated from datasheet or just taken from reference, an external factor like temperature, etc. The temperature will affect to the sealing system because the system applied with high temperature. The dynamic of the seal will be different in certain temperature and may effected leakage and the flow rate value.

The experiment graph is not smooth because of the sampling rated from the PLC maximum is 500 ms this sampling rate is enough practically, but for deeper analysis the higher sampling rate is needed. After we compare the simulation and the experiment using PID function, we will analysed the full pattern of the system running. The previous controller system will be compare with Mitsubishi PID controller as one graph. As reminder the previous control built from the 0.2 s clock increment and decrement function based on the comparison the present value of the pressure with the set value

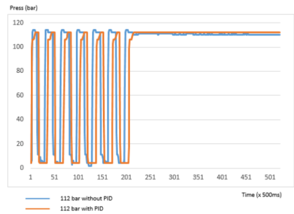

Fig. 9. Proportional relief valve hardware.

Figure 9 show the comparison of two graph in one coordinate, for the detail pressure pattern improvement. Applying Mitsubishi PID controller help to remove the ripple in short time experiment. The cycle time of Mitsubishi PID controller longer than previous controller but it is still in the range. The monitoring will be continue to know the reliability of this controller. For make sure the PID control work not only in this certain value, we also established experiment with different pressure setting. The pressure chose based on the product process condition. The set pressure that has been chose are 93 bar and 140 bar (Fig.10—11).

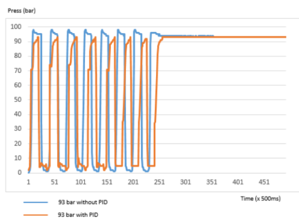

Fig. 10. Comparison before and after apply PID 93 bar.

The comparison at 93 bar, the experiment result show the previous controller give the overshoot around 2-5 bar. This overshoot is still in the range (±5 bar) but the ripple make the problem happened to the product quality. For this pattern from 93 bar the cycle off press and breathing different with previous sett value the time less than before but the cycle higher than 112 bar pattern.

From Figure 11 above the total cycle is much more different, we can see the significant different. This thing happened cause by the cycle press from the 140 bar set value is longer than others two set pressure, but have less time for last holding pressure.

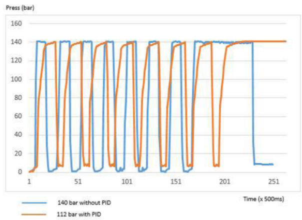

Fig. 11. Comparison before and after apply PID 140 bar.

VI. Conclusion and Recommendation

A. Conclusions

This thesis work have a purpose to improve the pressure pattern for the system. This work start from the analysis of the system stability from the dynamic equation. The simulation in MATLAB shown that the system is stable. The ideal PID and Mitsubishi PID giving the same step response in the simulation, because the different of the two model is in the operation of Td "+" for ideal PID, "-" for Mitsubishi PID) and the value of Td resulted from the auto tuning is small so it doesnt effected very much. Using Mitsubishi PID as a pressure control can improve the stability of the system and increase the rising time compare with the result of the open loop system. The total time achieve in experiment show that using Mitsubishi PID function take time longer than previous control. And higher press cycle the difference total time will be increasing.

B. Recommendations

More complex stability analysis is needed to know the reliability of this controller to keep the pressure pattern. This proportional valve is open loop device and become closed loop with the pressure sensor, we can try another proportional valve like a servo valve that have a linear scale sensor inside the valve, so we can directly measure the displacement of the poppet or the spool for better control. And finally this control system need to be monitoring for long time and see the pattern changing due to the machine dynamics and environment changing.

References

[1] Walters, R. B., *Hydraulic and electric-hydraulic control systems* second Enlarged Edition., Springer Science Business Media Dordrecht, Wembley, U.K. 2000

[2] Merritt, Herbert. E., *Hydraulic control system.* : John Wiley & Sons, Inc. New York, USA. 2000

[3] Choux, Martin. Hovland, Geir., Design of a hydraulic servo System for robotic Manipulation. : Proceedings of the 5th FPNI Ph.D. Symposium. Grimstad, Norway, 2008

[4] Zhang, Chuan. Zhao, Sihai, *Modelling and Simulation of Emulsion Pump Station Pressure Control System Based on Electro-hydraulic Proportional Relief Valve.*, Applied Mechanics and Materials Vols. 190-191. pp 860-864, Switzerland. 2012

[5] Dasgupta, K., Watton, J., *Dynamic analysis of proportional solenoid controlled piloted relief valve by bond graph.*, Simulation Modelling Practice and Theory 13. 2138. Wales, U.K. 2004

[6] Wilber Acuna-Bravo, *Position control of proportional electro-hydraulic valves: an Embedded Model Control solution*, Proceedings of the 34th Chinese Control Conference July 28-30, 2015, Hangzhou, China. 2015