Experimental PI Fuzzy Controller to Control Pinch-roll Pressure via Hydraulic servo-valves in Continuous Casting Machines in Mobarakeh Steel Company

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ABSTRACT:
In this paper, the Fuzzy PI controller is used to control the hydraulic servo-valves in Saba iron casting facility in Mobarakeh Steel Company. The electronic and control circuitry in the hydraulic servo-valves was damaged and the oil pressure sensor was not working anymore. The roles were bending and slabs were occasionally broken. Any replacement of the whole servo-valve system was not an option. Therefore, a pressure sensor for the oil outlet is installed and using the input to the control unit, the pressure is controlled. Fuzzy membership functions were defined in PLC to implement a PI Fuzzy Controller. The servo-valve was modeled and simulation results shows good controllability of the process in presence of disturbance. The experimental measurements of the slab pressure proved promising application of Fuzzy PI controller for the system under consideration.

KEYWORDS: PI Controller, Fuzzy Logic, Membership Function, Hydraulic Servo-Valves, Iron Casting.

1. INTRODUCTION

Increasing the oil pressure in a hydraulic system, smaller elements can be used in order to achieve the desired production rate. In addition, the oil pipes can be made smaller in diameter to save space and money. However, the increased oil pressure increases the oil temperature and leakage results in elevated friction and corrosion. Therefore, the required maintenance must be more frequent. In addition, noise and pressure overshoots result in poor dynamic performance [1].

The control unit and its elements are the most important parts of a hydraulic system. In-depth knowledge of the responsibilities of the hydraulic system and the way the elements are ought to function are main job of the hydraulic system designer and operator. If the elements are not chosen precisely and accurately, the system fails to meet the required performance. The fluid energy is controlled and directed by control elements known as valves. There are variety of servo mechanism type hydraulic valves.

In a typical servo-valve, the output which is normally pressure, is continuously measured and monitored to follow the command signal. In order to achieve this, the disturbances and load variations should be minimized. The servo-valves can be incorporated to control any physical parameter like location, pressure, force and temperature. The hydraulic servo-valves controls the oil flow in response to an input electrical signal and can be used to control pressure, location, velocity or force. The hydraulic servo-valve is an actuator which has internal closed loop control system. They have three types of one-stage, two-stage and three-stage.

Servo-valve is always under command signal and based on the feedback signal it receives, can control location, pressure, flow and velocity of the system under control. The valves can be configured to achieve infinite number of positions. Fig. 1 shows the internal structure of a typical servo-valve. As it can be seen, the feedback loop consists of two oil nozzle and a flapper. Above the flapper, there is a coil and a permanent magnet. The flapper and the force inserted by the coil and permanent magnet brings the spool to a stable position which defines the oil outlet flow. Servo-valves and proportional valves are electro-hydraulic valves that accept analog or digital electrical signal and convert it to a hydraulic output like pressure and flow [2].

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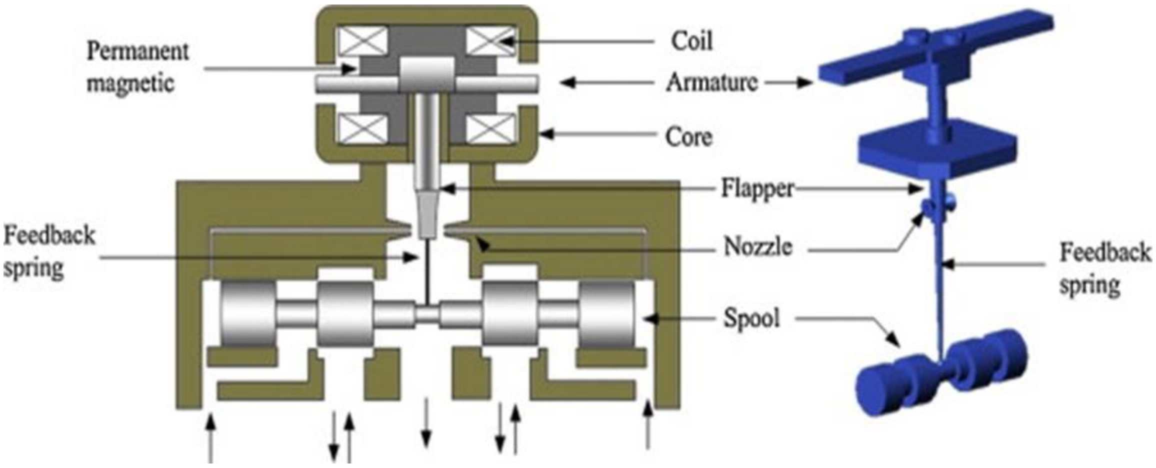

Fig. 1. The internal structure of a servo-valve [2].

Furthermore, the choice of proper controller for industrial systems is a crucial task. Among the list of controllers, the most important one in industrial systems is Proportional + Integral + Differential (PID) controller. It can be easily set up, the structure of the controller is simple, it can easily be tuned and most importantly it requires no knowledge of the system under control [3]. The PI controller is usually used for process control in which parameters like pressure, temperature, force and flow are to be controlled. On the other hand, PD controller is used for servo systems where the system set point is rapidly varying and the output should follow the position, velocity or acceleration of the input [4]. For the servo-valve hydraulic system where the oil pressure is to be controlled, PI is used. In these systems any introduction of differentiate action, introduces noise in the process control loop. PI has proved for many years the most versatile process controller.

However, in a simple PI controller, the proportional and integral parts are fixed and if the system undergoes any variation or disturbances, the control performance slightly varies. Introduction of Fuzzy logic and its associated membership functions to better adjust the proportional and integral coefficients gives more flexibility to the controller to reject the nonlinearities and disturbances [5]. The membership functions are adjusted using knowledge base data which is derived from experts in the field. The membership functions are achieved using rule-base programing which can be implemented in a computer or PLC. The rule-base consists of essentially some if and then commands which works on the controller input. In a PI controller, the error signal which is generated from difference in the set-point and measured sensor value, is fed back into the controller and the fuzzifier. Then, rule-base commands and defuzzifier based on the expert knowledge decide on the output of the controller. The controller output is input to the servo-valve and the oil pressure is controlled [6].

This paper is organized as follows, in section 2 the structure of the pinch-roll and servo-valves are explained, the simulation results of the PI controller is discussed in section 3, experimental results are shown in section 4 followed by a conclusion in section 5.

2. THE EXPERIMENTAL SYSTEM

As it can be seen from Fig. 2, the molten steel from tundish enters the mold and gradually steel phase converts from liquid to solid. When the steel exits the mold, the steel cross section is rectangular and it is named slab. The idle rollers then slightly decrease the slab thickness and cool it down. At the end of casting machine, the pinch rolls pull the slab out of casting machine and the hydraulic cylinders which are controlled by servo-valves adjust the pressure to the designed value and electrical motors rotate the cylinders. The hydraulic oil which flows through the servo-valves controls the oil pressure in cylinders. The servo-valves, themselves, has electrical connection to the PLC which runs expert commands to control the whole production line. A very important parameter is dependency of the pinch roll pressure to the casting machine speed. The whole process parameters are controlled such that the pinch roll pressures follow a specific trajectory regarding the casting speed. The more casting speed is the less withdrawal curve pressure is.

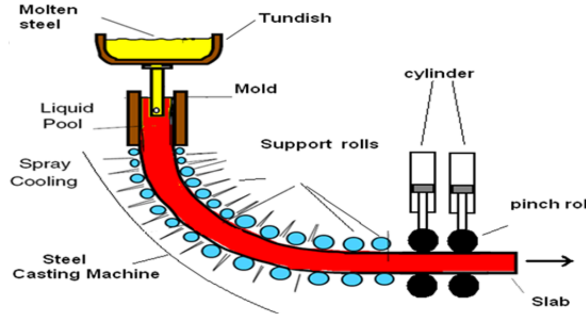

Fig. 2. The continuous steel casting machine.

The servo-valves used in this process is MOOG servo valves [6]. The Servo-valve is a D691 MOOG series proportional valves with integrated electronics. The valves modulate a fluid flow and in closed loops control the pressure. The control electronics for the spool position and control loops and pressure transducer are integrated in the valve. These hydraulic servo-valves can accurately and rapidly adjust its output in response to the electrical control signal. The output is either oil flow or oil pressure. The oil pressure in the servo-valve under study is measured using an internal pressure sensor and a PI internal controller receives the command from a computer or PLC. Fig. 3 shows the servo-valve internal electronics including control loops. The control command signal in the PLC computes from calculations of production line parameters and it is the operator who adjusts the line speed. The line speed affects the pinch-roll pressure and the required oil pressure command is fed back to the servo-valve and the control loop adjusts the oil pressure. The malfunction of electronic control loops causes breakage of slab pinch rolls.

In the servo-valve under study, the PI control loop and the pressure sensor were damaged and replacement of the whole servo-valve system was not an option due to the sanctions. Therefore, only the input to the internal control loop which was the flow command was accessible. So, a conventional PI and a PI fuzzy controller is designed and adjusted to control the pressure and the results are compared.

In the next section, the simulation results of the conventional and fuzzy PI controller are shown for the servo-valve.

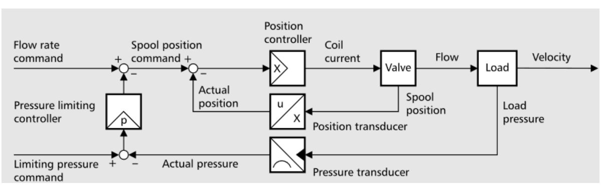

Fig. 3. Servo-valve Internal control loop.

3. THE CONVENTIONAL AND FUZZY PI CONTROLLER SIMULATION RESULTS

In order to simulate the system, a type two degree transfer function for the MOOG servo-valve is considered.

A step function input to the system is considered for simulation of the system under normal operating condition. The Ziegler-Nicoles method for adjastment of the controller coefficient is considered. Intentional disturbances are introduced through the system. Fig. 4 shows the results of controlling action on the MOOG transfer function. As it can be seen, the output shows small overshoot and it traces the input in the conventional PI controller.

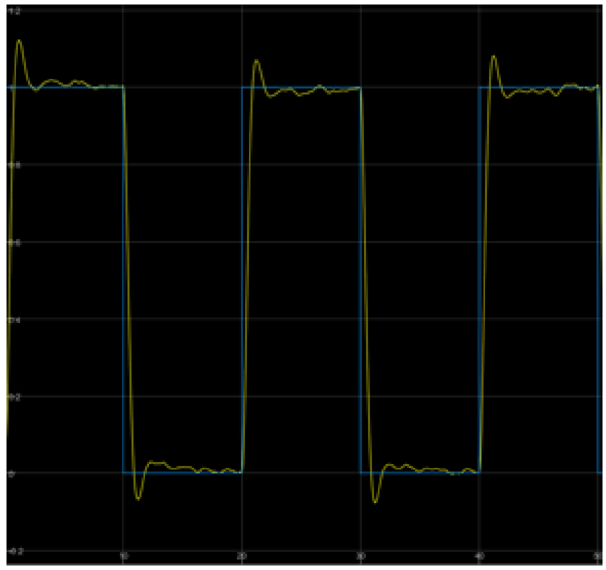

Fig. 4. Simulation response to the step input for the conventional PI Controller

The controller parameters are chosen such that the best settling time is achieved.

For the next step, the Fuzzy membership functions and corresponding PI controller is chosen. Three membership functions are considered. The rule knowledge base is considered. Fuzzification and defuzzification of the input and output signals based on the Mamdani [7] method is chosen. Fig. 5 shows the simulation results of step response of the system. As it can be seen, small overshoot and settling time are achieved compared to the conventional PI controller.

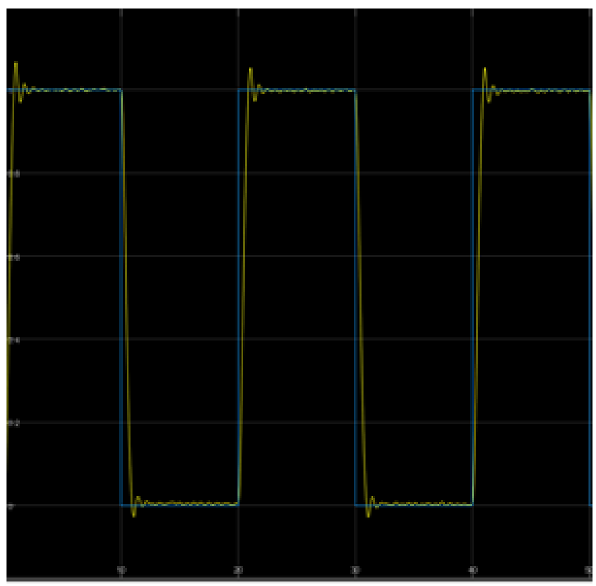

Fig. 5. Simulation response to the step input for the Fuzzy PI Controller.

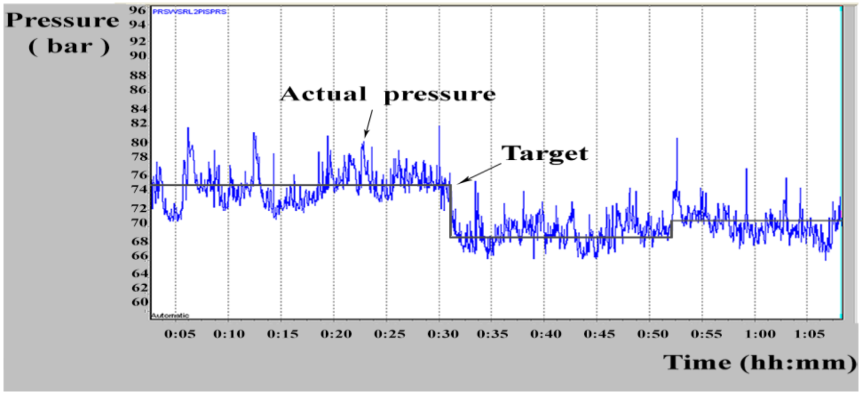

Fig. 6. The experimental step response output for the conventional PI Controller.

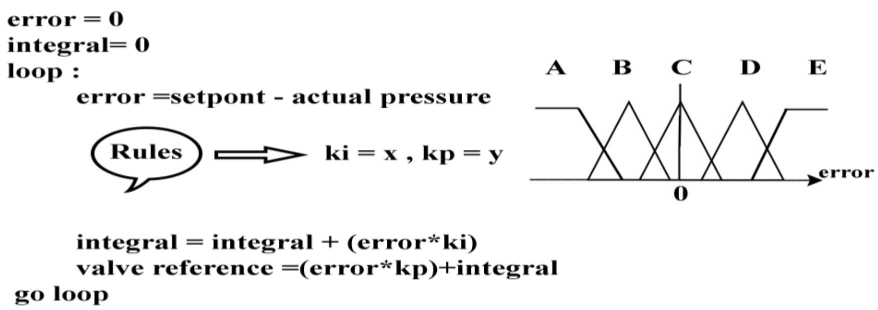

Fig. 7. The Actual PI commands implemented in the PLC.

4. THE REULTS OF EXPERIMENTAL FUZZY PI CONTROLLER

In order to control the experimental system using PI controller, a pressure transducer is installed on the output of hydraulic servo-valve. A PLC program to implement the PI controller is written and the PI parameters are chosen to achieve the best output performance. An industrial data logger is used to record the output. Fig. 6 shows the system step response. As it can be seen, the experimental step response is undergoing lots of overshoot and undershoot and the response is showing lots of disturbances. Maximum overshoot of 10% is measured. Therefore, a poor step response in experimental system output response is observed.

A PI fuzzy controller adds more flexibility to the controller structure and using expert knowledge base, the controller is capable of rejecting the undesired undershoot, overshoot and disturbances when the speed of line changes. The simulation results in the previous section also verifies the comments. Therefore, the same procedure mentioned in the last section is followed to design a rule based controller. In order to do that the fuzzification, defuzzification, knowledge driven rule base and proper membership functions are accomplished. Fig. 7 shows the actual commands which are used in PLC to achieve the Fuzzy PI controller. The knowledge base is written with the aim of experts on the field who have proper knowledge of servo-valve mechanism and the requirements imposed on the servo-valve from the process. The proper membership functions are defined. By fuzzification of the fuzzy controller output, the proportional and integral parameters of the PI are proportionally varied to obtain the required response. The output of PLC program is further scaled and sent through an Analog to Digital PLC internal board to the reference value of servo-valve. The flow reference signal is used for this purpose.

Fig. 8 shows the experimental system step response to the fuzzy PI controller. The response is achieved by well-tuning the membership functions and the corresponding PLC codes and rules. The experts on the field helped out to adjust the speed of line with the pressure requirements and to define proper rules. As it can be seen from Fig. 8, maximum overshoot of 2% is measured at the same time the pressure signal output which is the pinch-roll output pressure not only follows the steps in the required pressure, but also rejects the unwanted undershoot, overshoot and disturbances which we already saw in the response of the system to the conventional PI controller.

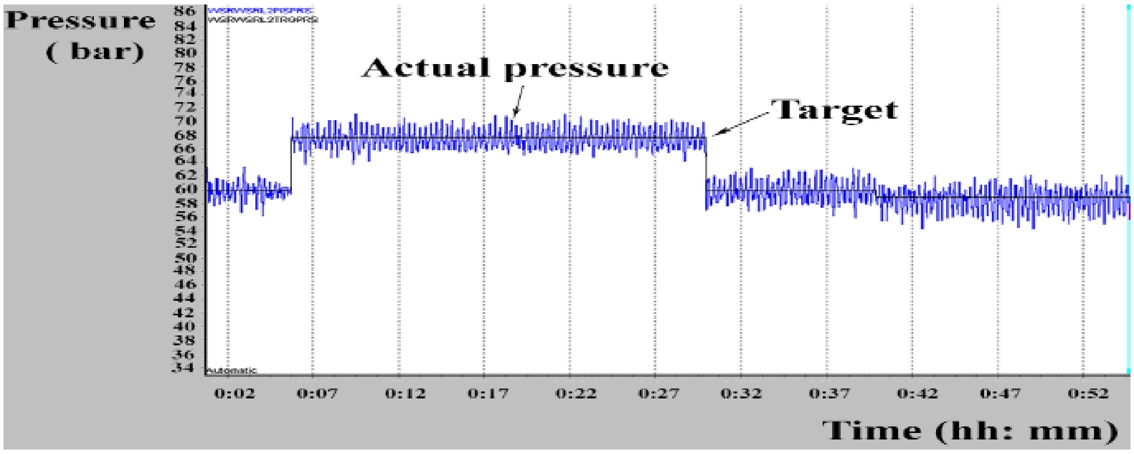

Fig. 8. The experimental step response output for fuzzy PI Controller.

5. CONCLUSION

A PI fuzzy controller and a conventional PI controller are designed both theoretically and experimentally. The simulation results and experimental findings of the fuzzy PI controller proved the advantage of the fuzzy logic in controlling experimental systems. The control of complicated industrial process using Fuzzy PI controller in this paper presents small overshoot, undershoot and disturbances in comparison with the conventional PI controller.

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