

# Suppression of Boring Bar Vibration Using Adaptive Fuzzy Logic Control

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## Abstract:

In order to overcome the self-excited vibrations in internal turning (chatter) a new design for boring bar was introduced, which depends on using the workpiece in supporting the boring bar using intermediate rolling elements. The system bears the loads under the action of a hydraulic pressure, which at a certain value prove to have a significant effect on the system chatter tendency. In the present paper, a gear pump driven by a DC motor system is designed to control the pressure of the supporting hydraulic system. The pump-motor system model was created in MATLAB/ SIMULINK simulation and then a fuzzy logic control system (FLC) is designed to control the pressurized oil for keeping it less or equal to 4 bars to save the self-excited vibrations within the desired limits.

*Keywords* — Boring bar – Oil pressure – Fuzzy logic control system

## I. INTRODUCTION

Self-excited vibrations in machining known as chatter [1] is one of the major constraints that limit productivity of the turning process. The source of this kind of vibrations depends on interaction between the machine-tool/workpiece structure and the cutting process dynamics. As a result, chatter is resulted from dynamic instability of the cutting process [2].

Numerous research works have been done for the reduction of vibrations, especially chatter, for the boring bar case. Techniques for reducing or suppressing boring bar vibrations can be classified into two groups as presented by Quintana [3]. The first type is by online or offline change of cutting parameters to fall inside the stability zone in the stability lobes diagram according to the theory of regenerative chatter [4].

The second group focused on changing the system parameters either by passive or active techniques. Online chatter control is applicable

due to the remarkable change in the vibration or acoustic signals at the onset of chatter [5]. Another track of chatter active control uses the stability lobes diagram (SLD) and the theory of regeneration. This is mainly applied by varying the time delay function which means varying the phase difference between the previous and the current cut pass [6] through Spindle Speed Variation (SSV).

Since these vibrations are highly affected by the system dynamic stiffness, therefore, as the system dynamic stiffness increases the system tendency to chatter decreases. An example of chatter suppression systems is using a tuned holder [7]. It is implemented by matching the holder natural frequency to the clamped-free boring bar natural frequency, a new dynamic system is obtained with decreased vibration magnitude and reduced susceptibility to chatter. So, the flexible holder supports the boring bar

and effectively acts as a dynamic absorber for the clamped boring bar as well.

Passive chatter suppression for boring bars was introduced based on a mutual support between the boring bar and the workpiece [8]. The presented support is composed of a hydraulic acting wedge sliding on the boring bar body and forces three circumferentially distributed steel balls against the workpiece inner surface, and thereby imposing a direct contact between the workpiece inner surface and the boring bar body. This technique showed significant suppression values for chatter in internal turning and it is used in this paper through applying an active control action on the hydraulic system pressure value.

Fuzzy logic control system (FLC) used as a type of controller can be used to control the pressure values, it is implemented to improve the pressurized system performance. An adaptive fuzzy control method of airport pipeline pressure control is studied previously [9]. The controller is designed and tested by simulation methods, and it is proved that the fueling outlet pressure stability can be improved. An adaptive fuzzy controller is presented for pressure control of a pressurized in a nuclear power plant [10]. The controller can on-line tune fuzzy control rules and parameters by self-learning in the actual control process, which possesses the way of thinking like human to make a decision. The simulation results for a pressurized water reactor plant show that the adaptive fuzzy controller has optimum and intelligent characteristics, which prove the controller to be effective. Fuzzy logic is applied also on the control of a pump station in a pipeline system [11]. Fuzzy logic technique

is used in order to be able to incorporate the knowledge of the operators of the pipeline system for the eventual implementation. The results show improvement in the operation of the pump station within the pipeline system.

In the present paper, a pressurized oil system is designed to be applied to the previously mentioned boring bar system. It contains a gear pump, which is driven by a DC motor. A fuzzy logic control system is applied to control the oil pump pressure within the desired limits.

## **II. THE PRESSURIZED BORING BAR SYSTEM**

The presented boring bar system is a novel designed boring bar system [8]. It designed to decrease the chatter vibration by increasing the boring bar dynamic stiffness. Its theory is based on converting the boring bar fixation system from fixed-free to fixed-roller system.

This is done by using a wedge contacting circumferentially three spherical steel balls as shown in Figure 1. The balls are in contact with both the workpiece and the boring bar to transfer the reaction from the flexible boring bar to the more rigid workpiece.

When the pressurized oil is pumped to boring bar system through the oil inlet, the pressing wedge forces the balls against the workpiece internal surface due to its tapered wedge shape. When the cutting process is finished, the pressure of the inlet oil is relieved and the wedge moves backwards by the action of the return spring.

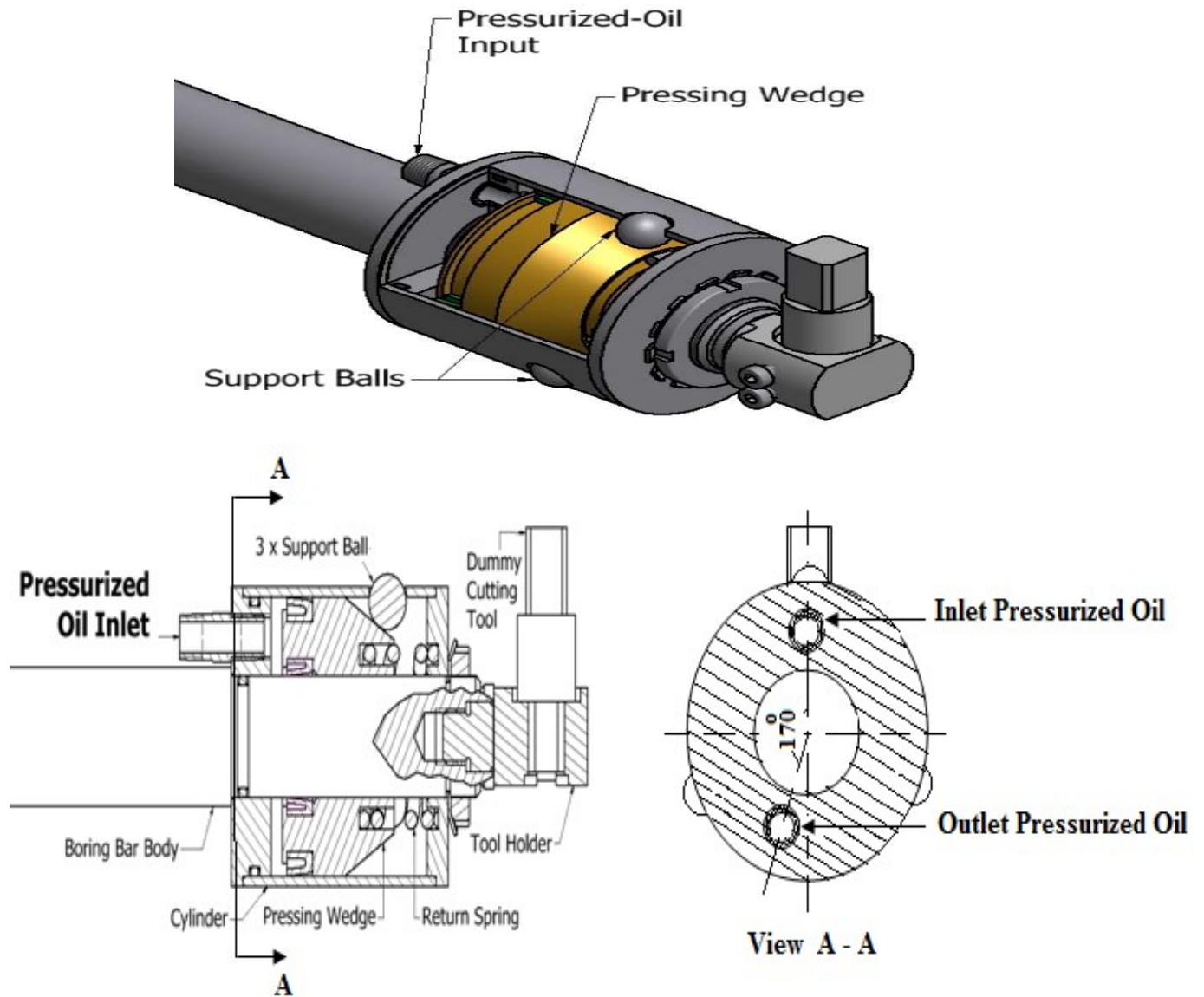


Figure 1: Steel-Balls Boring Bar System

### III. SIMULATION MODEL

The simulation model for the pressurized oil system is shown in Figure 2. It consists of a DC motor coupled with a gear pump. The gear pump is connected with the boring bar through two openings, inlet and outlet, to move the steel balls during cutting process. The motor and pump parameters [12] used in the cycle are shown in Table 1.

Table 1: DC Motor and Oil Gear Pump Parameters

Parameter	Value
Armature resistance = $R_a$	7.31 $\Omega$
Armature inductance = $L_a$	0.831 mH

Back EMF constant= $K_e$	0.0195 Vs/rad
Torque constant= $K_b$	0.044 Nm/A
Rotor inertia= $J$	9.87e-6 kg.m <sup>2</sup>
Friction coefficient= $B$	1.42e-6 Nm s/rad
Motor volt = $V_a$	24 volt
Motor current= $i_a$	4 A
Motor power = $P_m$	52 watt
Motor Torque = $T_m$	0.1834 Nm
Motor speed= $N_m$	3200 r.p.m
Pump oil pressure = $P_p$	4 bar
Pump oil head= $H_p$	0.4m
Pump oil flow rate = $q_p$	4 cm <sup>3</sup> /s
Pump Efficiency = $\eta$	87%
Pump torque= $T_p$	0.0984 Nm
Density of oil= $\rho$	900 kg/m <sup>3</sup>
Steady state time = $t$	15 min

The oil cycle starts with the start of the cutting process where the pump suctions the oil from the oil-tank to inject it into the boring bar through small diameter flexible hoses. After the cutting process finished, the oil gets out from the boring bar back to the oil-tank. Therefore, the oil pressure through the pump should be coupled with the oil tank to be controlled by changing the status of inlet and outlet valves.

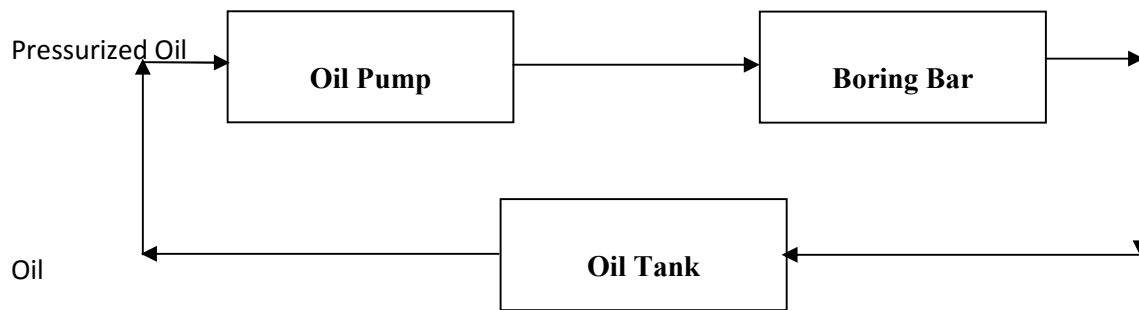


Figure 2: Pressurized Oil Cycle

#### IV. IMPLEMENTED CONTRL STRATEGY

In order to keep the pressure of the oil within the required range, a fuzzy logic control system (FLC) designed. It used for controlling the inlet-outlet oil to the pump to control its pressure.

#### IV. I. FUZZY CONTROLLER DESCRIPTION AND DESIGN

A fuzzy logic control (FLC) system is a control system in which a mathematical system that analyzes analog input values in terms of logical variables. These variables can take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0 (true or false, respectively) [13]. Fuzzy Logic provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. Fuzzy Logic's

approach to control problems mimics how a person makes decisions, only much faster. Characteristic components of a Fuzzy logic include:

- Preprocessing
- Fuzzification
- Rule Base
- Defuzzification
- Post processing

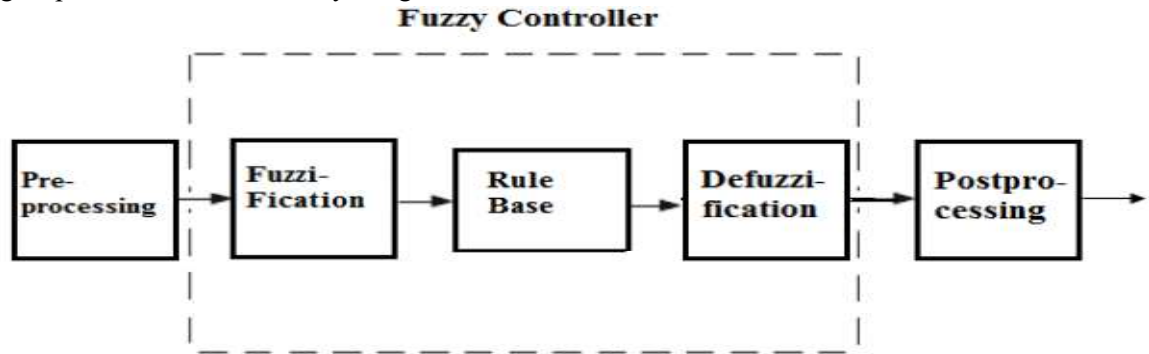


Figure 3: Process Blocks for a Fuzzy Controller

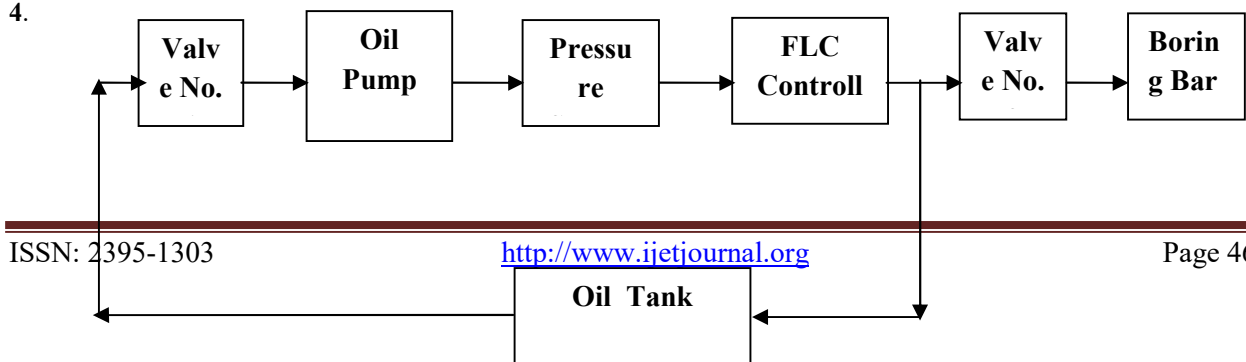
Fuzzification: The first block inside the controller is fuzzification which converts each piece of input data to degrees of membership by a lookup in one or several membership functions. While the collection of rules is called a rule base. The rules are in “If Then” format and formally the If side is called the conditions and the Then side is called the conclusion. The computer is able to execute the rules and compute a control signal depending on the measured inputs error (e) and change in error (Ce).

Defuzzification is when all the actions that have been activated are combined and converted into a single non-fuzzy output signal which is the control signal of the system. The output levels are depending on the rules that the systems have and the positions depending on the non-linearity's existing to the systems. Finally, the

post processing block often contains an output gain that can be tuned and also become as an integrator.

#### IV.II. DEFINING FLC INPUT AND OUTPUT

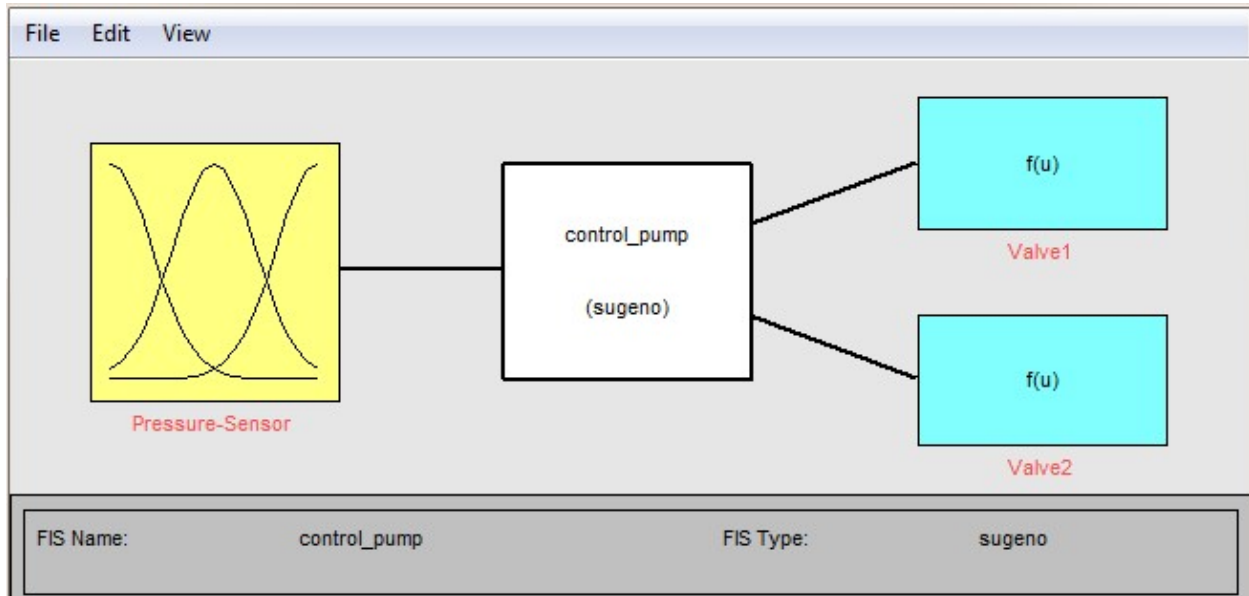
The goal of designed FLC in this study is to keep the pressure of oil pumping through the boring bar within the desired value (4 bar). The fuzzy logic control system controls the pump pressure through change the pump's valves state. The pump has two valves at suction and injection pipes for adjusting the oil pumping process, also a pressure sensor to measure the pump outlet oil pressure. The controlling system cycle can be simplified as shown in Figure 4.



**Figure 4:** Scheme of Pump Control System

The designed fuzzy logic control system has one input and two outputs. The input as the block diagram explain is the pressure sensor measured value, and the output is the valves state (open or close). In other words, when the measuring pressure value less than 4 bar the FLC decision is to open suction valve and close injection

valve, otherwise close the suction valve and open the injection valve in case of the outlet oil has the desired value. The FLC control system structure shown in Figure 5 with membership functions explained as shown in Figure 6, and a part of fuzzy system rules shown in Figure 7.



**Figure 5:** FLC Control System Structure

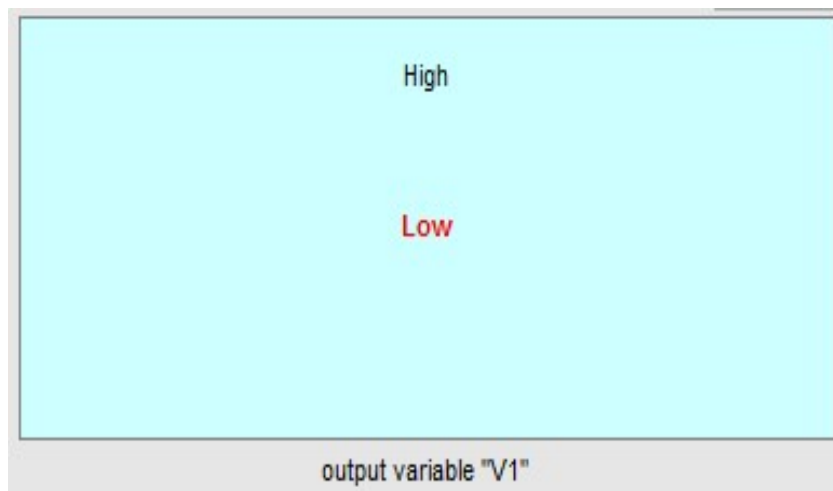
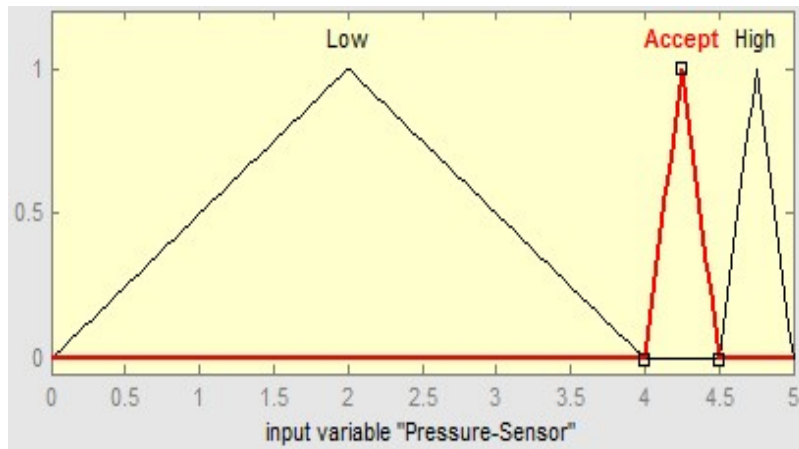


Figure 6: Membership Functions for Input and Output

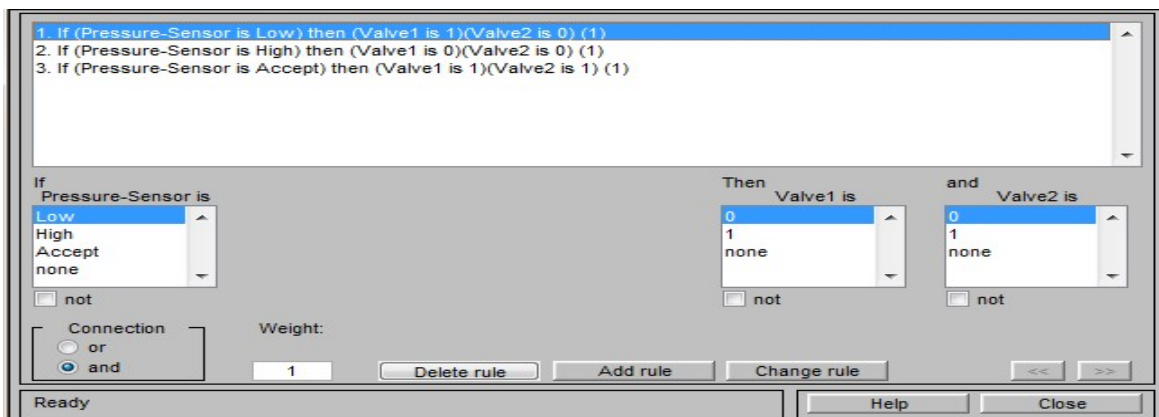


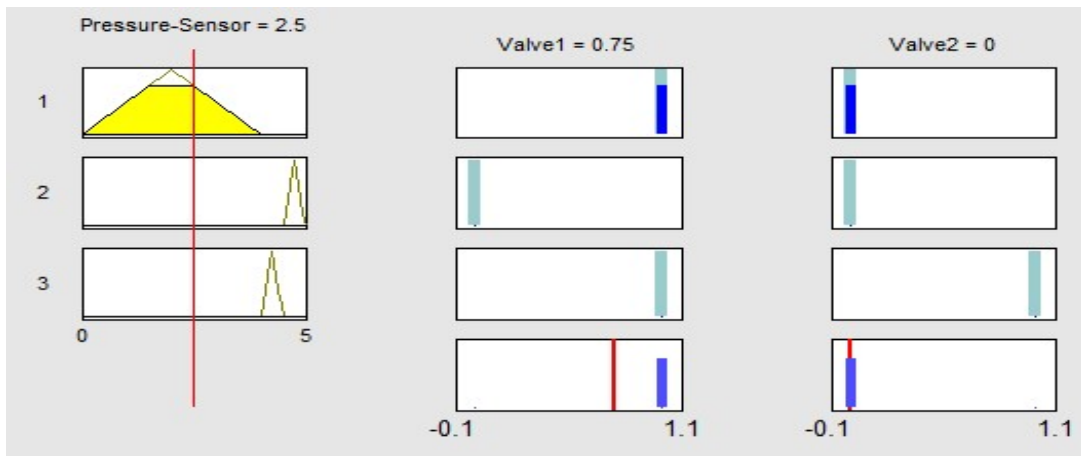
Figure 7: FLC Control System Rules Editor

The rule base is represented as If-Then statements governing the relationship between the inputs and outputs variables in terms of membership functions. There were three rules based on pressure sensor measuring values as shown in Table 2. The low value of pressure value column mean the oil pressure measuring value less than 4 bar, the medium value mean between 4 and 4.5 bar , and the high value mean greater than 4.5 bar.

**Table 2:** Rule Base Parameters

Parameters	Pressure Value	Valve No. 1	Valve No. 2
Case 1	Low	Open	Close
Case 2	Medium	Close	Open
Case 3	High	Open	Close

The rule base and changes done in the valves states related to change the pressure values is presented in **Figure 8**.



**Figure 8:** Rule Base Viewer

The actions of suction valve (valve No.1), and injection valve (valve No. 2) under different values of measured pressure is shown in **Figure 9**.



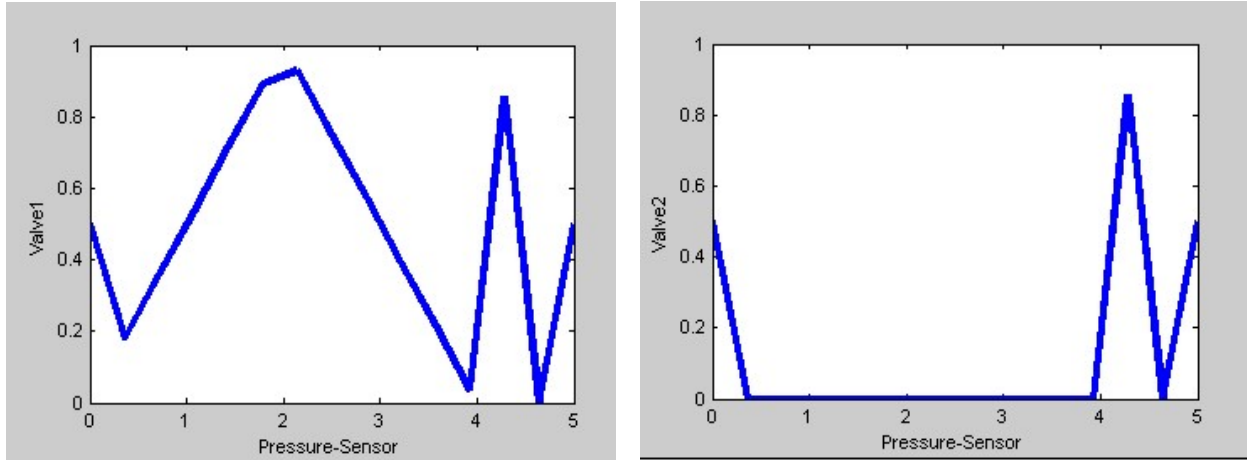


Figure 9: Action of Valves at Change Pressure Values

### IV.III. SIMULINK IMPLEMENTATION

Figure 10 shows the gear oil pump model built in SIMULINK/MATLAB. A sensor is used in measure the pressure value which is input to the FLC system. The output of the FLC is then returned to the suction and injection valves making the open and close actions easy and accurate.

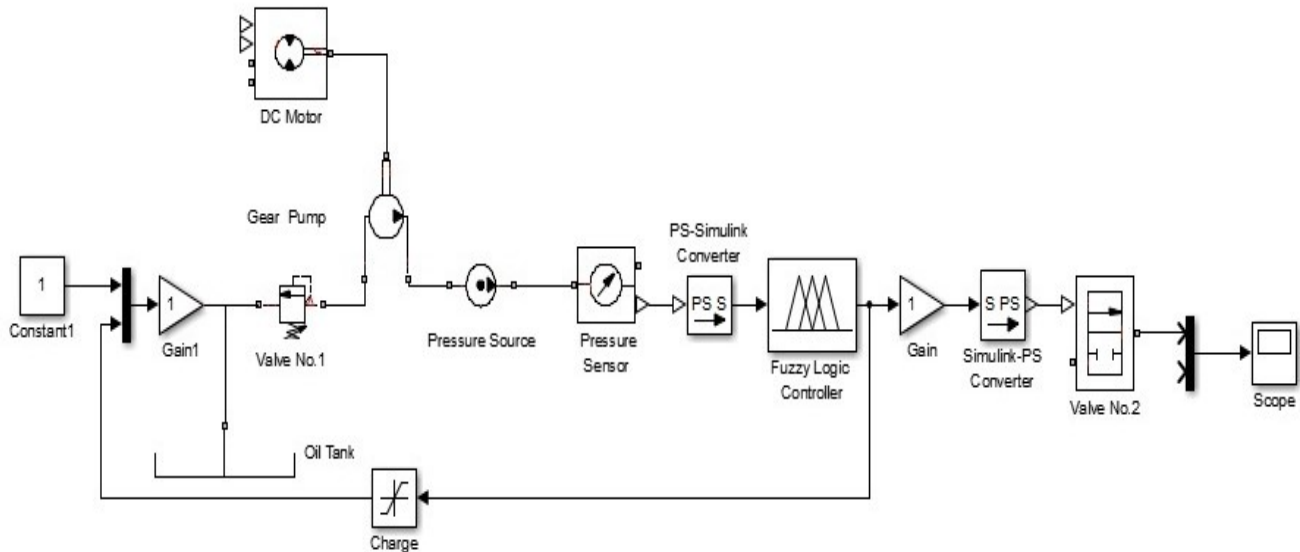


Figure 10: Gear Oil Pump Control System

### V. CONCLUSION

Nowadays the automatic control has played a vital role in the advance of engineering and science. The control of pump pressure is a

common practice thus the implementation of suitable controller for pump pressure is important. In this paper fuzzy logic control have been used to control the pressure of a gear oil pump of boring bar hydraulic system .The proposed fuzzy Logic controller used for control

the pump pressure has more advantages, such as higher flexibility, control, better dynamic and static performance. The results of the fuzzy logic response show that the control performance is significantly improved using the Fuzzy Logic controller. The simulation results are obtained using MATLAB/SIMULINK. Hence, the proposed controller design was proposed and implemented.

#### **V.I. ACKNOWLEDGMENT**

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