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Design of Hybrid Controller For Control Valves In Rocket Engine Pump

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Abstract

In this paper a fuzzy PID hybrid controller is designed for process control valves which is used to retain the constant ratio in order to maintain the stability of the rocket engine pump during ground test of engines. The proportional-integral-derivative (PID) controller is widely used in process control application due to its simplicity, robustness. In general, PID controller provides reliable performance for most of the system if the PID parameters are tuned properly. However, in reality, conventional PID controller cannot function as expected because of various reason like complexity of problem, lack of valid input to the controller and finally due to insufficient tuning of PID parameters. Now as technology improves, fuzzy logic controllers have been applied successfully in industrial process when the control system is complex or nonlinear. In this paper, by taking error and error rate of changes as input, design and simulation of fuzzy-PID of control model is proposed. The model has features as online self-tuning of PID parameters using Fuzzy Inference system (FIS). This paper combines the features of PID control methods and the flexibility of Fuzzy control. The transfer function for process is estimated by using system identification tool and the simulation of the model is carry out in MATLAB/SIMULINK environment. Design model will avoid overshoot which normally happens in the conventional PID controller as well as improves response time.

Keywords: PID controller, on line self-tuning, control valves, FIS, booster turbo pump, fuzzy-PID.

INTRODUCTION:

The engine pump consists of three feed circuits namely turbine feed circuit, pump feed circuit and balance disk cavity feed circuit and a common delivery circuit. During ground testing of engine three different DM (demineralized) water tanks are being used to supply DM water to the three feed circuit at different pressure and flow rate.The DM water supplied to turbine feed circuit drives the turbine and the turbine drives the pump coupled with turbine. As the rotor of the turbine rotates it creates an unbalanced force which acts on the bearing of the turbo pump in order to avoid the loading of the bearing a pressure in opposite direction is applied to the rotor. The booster turbo pump should run at constant ratio to maintain the stability. To maintain this constant ratio it is essential to use the control valves in closed loop. Presently, the control valve is controlled by using a PID controller to achieve a constant ratio. The conventional tuning by using mathematical model (via) PID *controller gives* reasonably good results [1].Classical PID controllers are based on precise mathematical models that have assured stability, reliability and controllability. Despite their effectiveness for linear systems, classical PID controllers are not suitable for nonlinear systems.From performance reasoning, deriving a control action from linguistic rules might be a general design approach that avoids some complexities associated with nonlinear mathematic modeling. In a fuzzy logic controller, the control action is determined from the evaluation of a set of simple linguistic rules. Fuzzy logic based controllers have been implemented in the control valves. But, fuzzy controllers raise concern about reliability, controllability and stability of the system. Hence, hybrid systems which are more powerful due to the combined advantages in different control techniques are being implemented.

CONTROL VALVES:

The closed loop system of the control valve in the rocket engine pump is shown in fig1. The error signal which is difference between the set point and the process output is given as input the fuzzy-PID controller which is used to produce the controlled variable to maintain the constant ratio of the system. The controlled variable is given as input to the transfer function of the system. The transfer function of the system is estimated by system identification tool based on the previously collected response of the control valve.

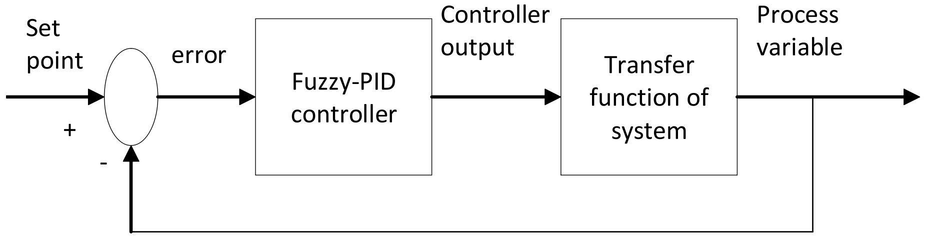

Figure 1: closed loop system of control valves

FUZZY LOGIC CONTROL SYSTEM:
According to this paper, the expected choice for real time tuning of control valves is combining FIS and PID control system. Fuzzy model has an advantage of converting a linguistic control strategy and very good ability to handle imprecise and inconsistent real data[2]. Another important key role of the FIS is that it efficiently synthesis the problem of highly complex and nonlinear. Because of these advantages, fuzzy system has a number of practical applications in control system development. Nonetheless, designing fuzzy controllers is challenging[3]. The primary thrust of fuzzy logic control system is to utilize the human control operator's knowledge and experience to construct controllers [4].The following steps have to be followed to compute the output from the FIS system.

- Determine a set of fuzzy rules.
- Make the inputs fuzzy using input membership functions.
- Combine the fuzzified inputs according to the fuzzy rules for establishing a rule strength.
- Determine the consequent of the rule by combining the rule strength and the output membership function.
- Combine all the consequents to get an output distribution.
- Finally, a defuzzified output distribution is obtained.

The structure of fuzzy logic controller is shown in figure2.

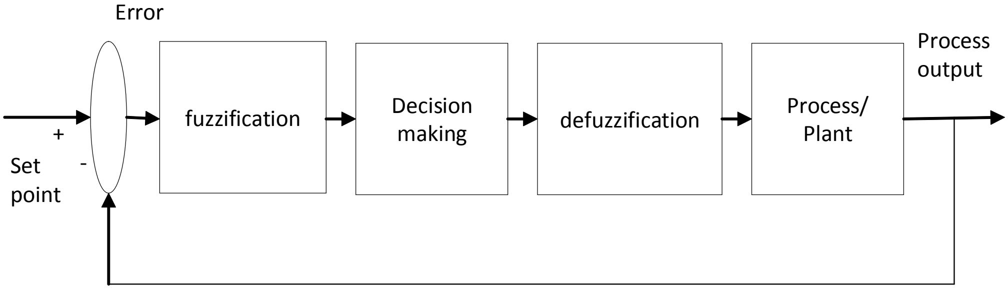

Figure 2: Structure of fuzzy logic controller

MAPPING OF INPUTS THROUGH MEMBERSHIP FUNCTIONS

To design the fuzzy system for control valves, two inputs which have been considered as 'error (E)' which is a deviation from the set point and response of the system and 'rate of change in error (EC)' which is the rate at which deviation occur due to course of the engine operations. Also according to the requirements, two outputs namely ΔK_P, ΔK_I are to be derived from the model which are the self-tuned PID parameters. Figure gives the designed fuzzy inference system in the MATLAB environment.

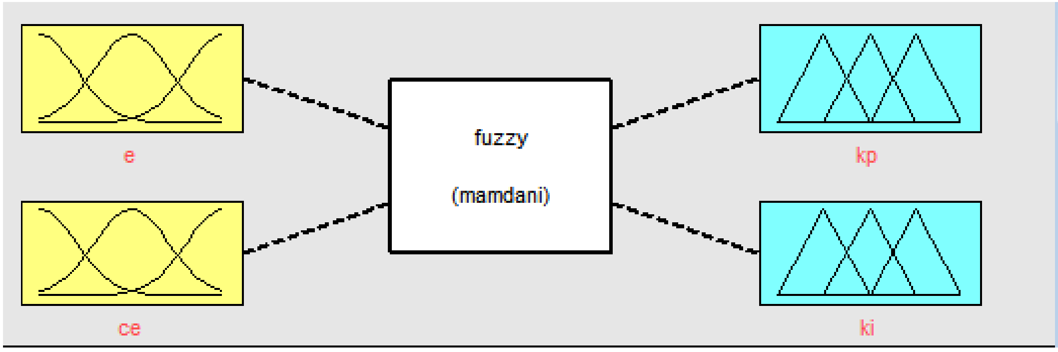

Figure 3: Fuzzy Control System Model

The membership functions are used to map the inputs. The membership of each fuzzy input variable is calculated for the given crisp input based on experience and the resulting value is used in evaluating the rules. In the fuzzification process of membership function, fuzzy subsets for input variables and output variable are defined by the experience. For the self-tuning PID control parameter, inputs fuzzy set is identified as: *{Negative Big (NB), Zero Error (ZE), Positive Big(PB)}*.And the output fuzzy set is:*{zero (ZE), Medium (ME), Very Large (VL)}*.The range of the fuzzy variable is fixed from the intuition as well as from the requirements of error range. For the input variable error and error rate, Gaussian membership function (gaussmf) is chosen. For the output variable, $\Delta K_P$and ΔK_Isame Gaussian membership function (gaussmf) is selected. The membership functions are shown in Figure 4 and Figure 5.

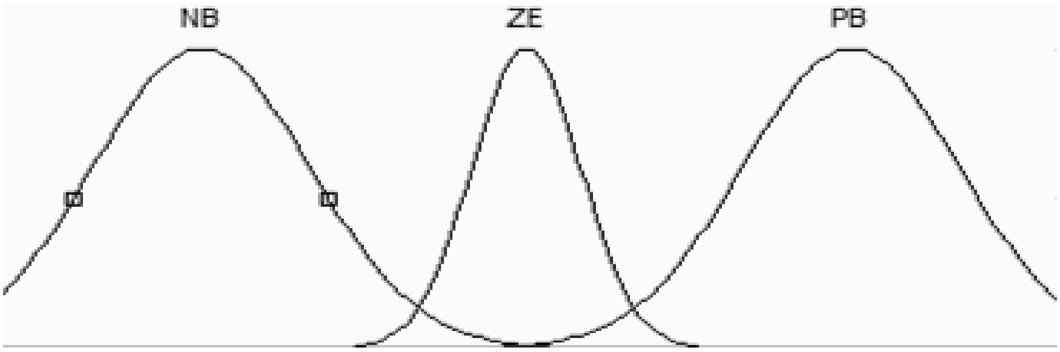

Figure 4: Membership degree function of input variables E and EC

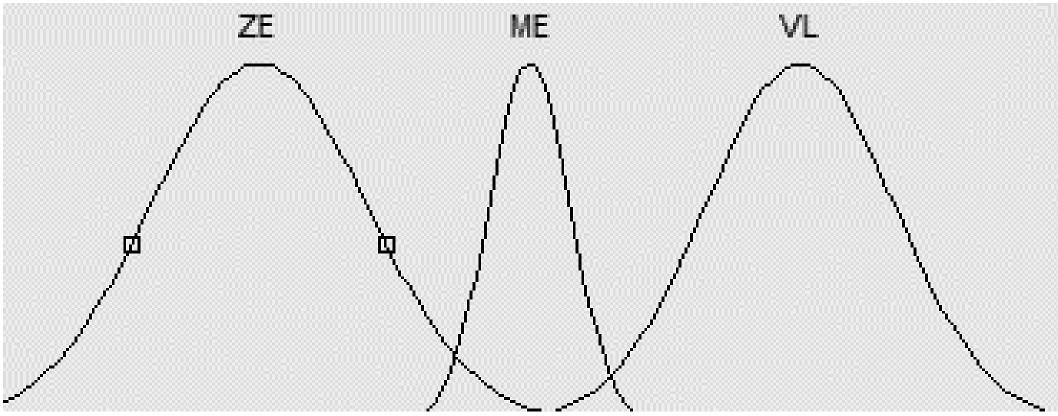

Figure 5: Membership degree function of output variables ΔK_P and ΔK_I

Generation of Fuzzy Rules

The core of the Mamdani fuzzy model is to build proper fuzzy rule chart based on the *designer's knowledge and operator's experience*. Rule chart table preparation is a critical step for developing the model and hence proper care is taken. The table: 1 gives fuzzy rule chart for ΔK_P, and the same way for ΔK_I

Table 1: Fuzzy Rule Chart of ΔK_p

CE \ E	NB	ZE	PB
NB	ZE	ME	ME
ZE	ZE	ME	VL
PB	ZE	ZE	VL

Evaluating the rules and Defuzzification

Using the membership functions, rules are evaluated according to the concept of *compositional rule* of inferences. For the fuzzy set operations, 'AND' with minimum logic and 'OR' with maximum logic is considered. Also for the rules aggregation 'maximum' logic is selected. The result of the Implication and Aggregation operation is an output fuzzy set. Range of the output fuzzy set depends on the combination of membership function. Finally fuzzy outputs are to be converted into a scalar output quantity. This is done by implementing defuzzification techniques. For the development of self-tuning PID parameters, 'centroid' method is adapted for the defuzzification process.

INTEGRATION OF FUZZY CONTROLLER AND PID CONTROLLER

Once the new set of K_P and K_I are obtained, it is integrated with process (via) PID controller and control system for the real time implementation. The structure of Fuzzy-PID control system is given in Figure 6.

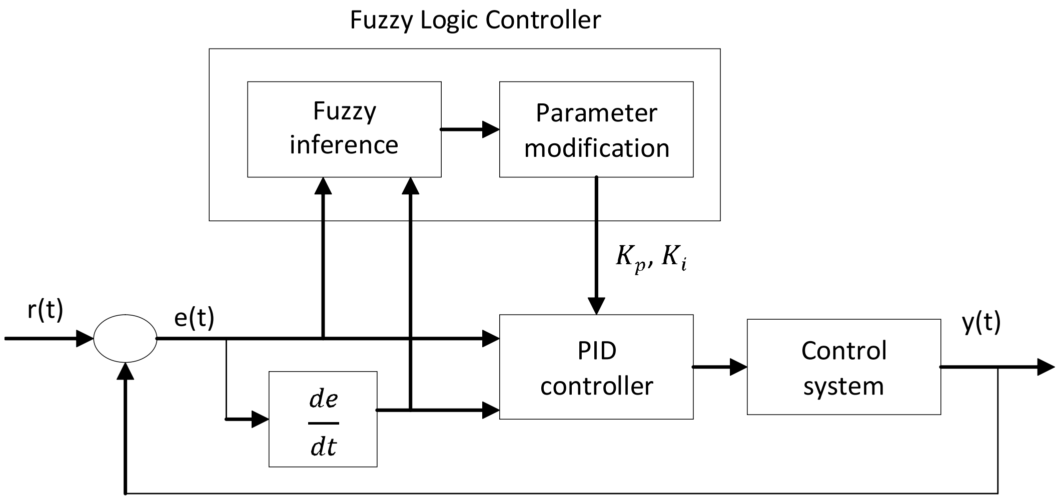

Figure 6: Structure of Self-tuning Fuzzy System

For simulating the problems, the integration of fuzzy, PID controller is done in MATLAB SIMULINK environment [5]. Following steps are involved for the integration:

a) Using system identification techniques and by utilizing the available data, transfer function is to be obtained for the PID controller.
b) Initialization of the process parameters $K_P$and K_I, simulate the control valve plant.
c) The obtained error value and error rate value are checked for the allowable limit. If they do not satisfies with the desire parameter value, the simulation loop goes to the fuzzy inference system for further tuning.
d) The fuzzy controller which is developed with the set of rules and membership functions fine tune the parameters K_P and K_I.

The simulation loop continues in real time by self-evaluating the PID parameters as well as adjusting the parameters with respect to the process requirements.

SIMULATION OF FUZZY-PID CONTROL SYSTEM:
BLOCK DIAGRAM OF FUZZY-PID CONTROLLER FOR CONTROL VALVES.

The basic building block of a fuzzy-PID controller for a control valve which is used to control the constant ratio at which water flow towards the booster turbo pump include the transfer function of control valve based on their response. The block diagram of fuzzy-PID controller for control valve is shown in figure 7. The error value which is a difference between the reference value 32.7 and the actual output of control valve and the rate of change of error is given as input to the Fuzzy-PID controller. The saturation block is used to limit the input value. Anthor input to the controller is the change in error. The fuzzy gain scheduler by using the fuzzy associative control rules computes the value of k_p, $k_i$respectively. The obtained values k_p, $k_i$along with the error and rate of change of error are fed to the PID controller thereby achieving the desired pressure for the flow of water to the tank.

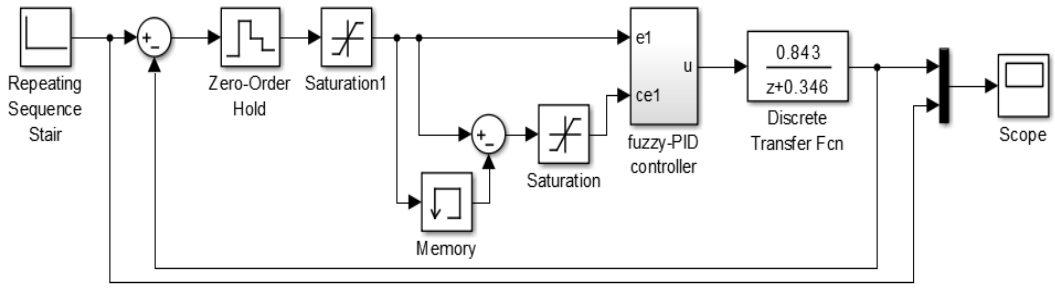

Figure 7: Block diagram of fuzzy-PID controller for control valves

THE SIMULATION RESULT:
SIMULATED RESULT OF k_pANDk_i:

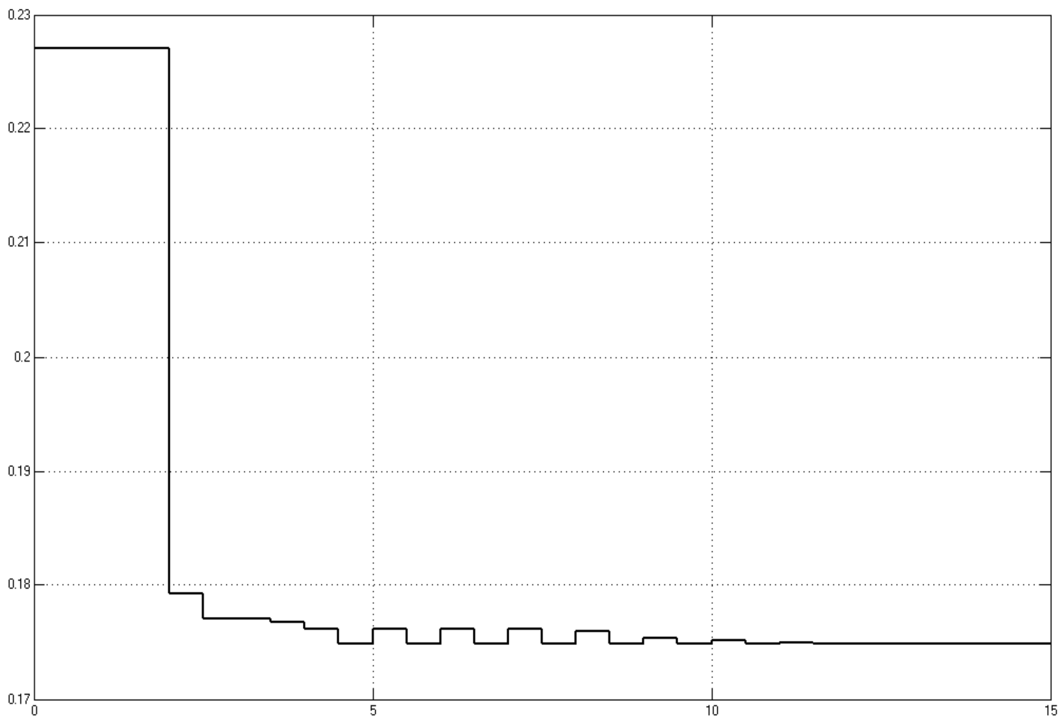

Figure 8: Simulated result of proportional constant (k_p)

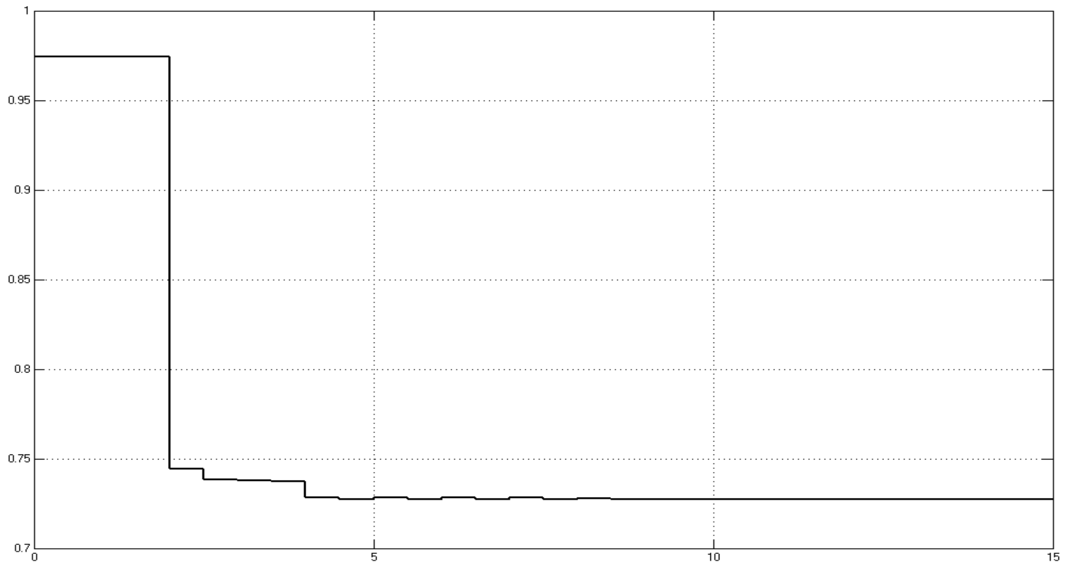

Figure 9: simulated result of integral constant (k_i)

The above figure shows the variation of proportional constant (k_p) and integral constant (k_i) obtained across the control valve.

COMPARISON OF HYBRID CONTROLLER AND PID CONTROLLER:

The simulation result indicates that the settling time for conventional PID controller is high as compared to the fuzzy-PID controller. The hybrid Fuzzy-PID controller has fast response, zero overshoot and higher stability. Since the fuzzy gain scheduler automatically changes the coefficient k_p, k_i when the reference input is change.

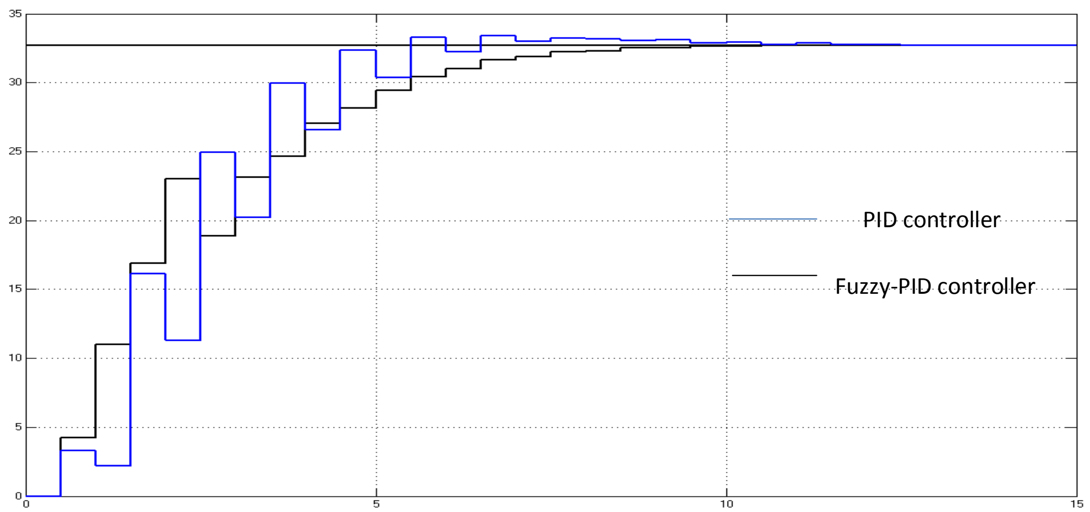

Figure 10: comparison result of fuzzy-PID and conventional PID controller

The hybrid controller has advantages that it can be applied to different operating conditions and produce the controlled output when compare to the PID controller.

CONCLUSION

This paper adopts fuzzy inference method as the self-tuning structure of conventional PID controller, which realizes the non-linear processing to PID and the non-linear mapping between the changes of system characteristics and controlled variables which is applied in the control valves. It can be concluded from the simulation result that self-tuning controller gives a better control than the conventional PID controller, and improves the static and dynamic performance of the system. The fuzzy gain scheduler automatically tunes the PID parameters thereby, improving the transient response for change in load variation. This paper taking the advantage of the traditional control and fuzzy control, has a great practical significance and design of the controller.
Some advantages of the proposed hybrid controller are

1. Robustness to load variations
2. Effective performance under different operating conditions.

The model has great practical significance and major reference value for further application research. Further, the same can be utilized in digital processors for achieving effective performance in process. PID parameter can also be obtained using neural systems.

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