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Fuzzy Logic based Speed Control of Dc Series Motor

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Abstract:- Electrical drives are widely used in many industrial systems. Speed or positions of electric motors are usually controlled to hold the speed/ position under unknown disturbances or to change the speed according to a reference profile. The output of a speed control is a torque demand and electrical drives or called upon to have a good torque control performance. The speed control performance obtained using a PI/PID controller s sensitive to the uncertainties such as plant parameter variation, external load disturbances and unmodelled and non linear dynamics of the plant. Therefore, a robust controller would be attractive in most industrial applications. A controller is said to be robust if it gives satisfactory dynamic response in the presence of parameter variations, external disturbance and unmodelled or non linear dynamics of the plant. The problem of designing robust controller is thus called robust control.

For the robust control of motor drives, a variety of approaches (sliding mode, Fuzzy, two-degree of freedom, torque feed-forward and adaptive control method) has been investigated by many researchers. Although Fuzzy Logic systems are most widely used because of their simplicity and lower computational cost. Fuzzy Logic systems has been used in some control application but these are not have been used for robust speed control of an electric drive system.
In this study a Fuzzy Logic system has been proposed for the speed control of a DC series motor system. The effectiveness of the proposed control scheme under parameter variations and external disturbances were illustrated by simulation results. The performance comparison of Fuzzy controller and PID controller is provided and it has been found that the performance of proposed Fuzzy controller is better with sudden load changes and periodic load changes and also with internal parameter variations due to temperature rise, inter turn faults and aging.

1. INTRODUCTION:

DC Series motors present an exciting field of research and are used in many industrial and household applications. DC Series motors used in many applications such as printing press, food processors, still rolling mills, electric trains, electric vehicles, electric cranes and robotic manipulators require speed controllers to perform their tasks. The speed of the Series motors varies with the variations in the power supply. Thus the speed control of motor is important to achieve maximum torque and efficiency.

2. MOTOR MODEL

The resistance of the field winding and its inductance of the motor used in this study are represented by Rf and Lf, respectively. The resistance of the armature and its inductance are shown by $\mathbf{R_a}$ and La respectively in dynamic model. Armature reactions effects are ignored in the description of the motor. This negligence is justifiable to minimize the effects of armature reaction since the motor used has either inter poles or compensating winding. The fixed voltage **V,** is applied to the field and the field current settles down to a constant value. A linear model of a simple DC motor consists of a mechanical equation and electrical equation as determined in the following equations:

$$J\frac{d\omega}{dt} = K_m \emptyset I_a - b\omega_m - M_{load} \qquad \ldots(1)$$

$$L_a\frac{dI_a}{dt} = V_a - I_a R_a - K_b \emptyset \omega_m \qquad \ldots(2)$$

The various parameters of a DC motor are defined in the table as follows:

Table 1: Parameters of DC Motor

Parameters	Symbol	Value
Field Resistance	R_f	16.2 Ω
Field Inductance	L_f	0.45 H
Reference Voltage	V_{ref}	120 V
Amplifier Gain	K_a	2 V/V
Torque Constant	K_T	0.65Nm/A
Tachometer Constant	K_t	0.1 Vs/rad
Moment of Inertia of Load	J	0.03 kgm^2
Friction coefficient of Load	B_f	0.004 Nm/rad/s

The block diagram of a DC motor can be modeled as follows:

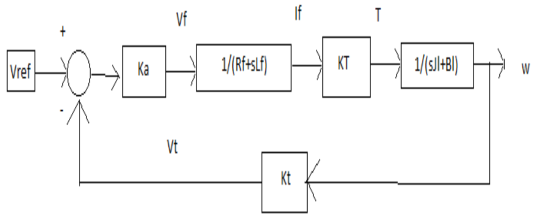


Figure 2: Block Diagram of a DC Motor

The equations of the DC motor can be derived from the block diagram as follows:

$$E = V_{ref} - V_t$$

$$V_f = K_a \times E$$

$$I_f = \frac{V_f}{R_f + sLf}$$

$$\tau = K_T \times I_f$$

$$\omega = \frac{\tau}{sJ + B_f}$$

$$V_t = \omega \times K_t$$

Based on the values chosen, the measured values of field current, I_{ref} and angular speed, ω_{ref} were found to be 3.7895A and 1200 rpm.

2.1 MOTOR MODEL IN SIMULINK

The motor model described in the previous section that was implemented in SIMULINK is shown below:

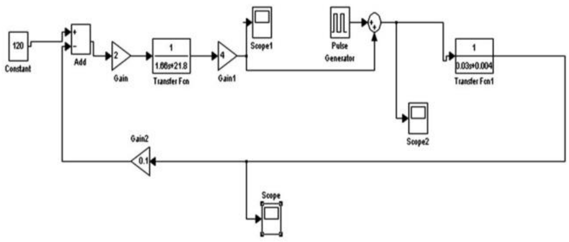


Figure 2: Motor Model in SIMULINK

When the above model is simulated the following graphs are obtained which show clearly that the I_{ref} is 3.7895A and ω_{ref} is 1200rpm.

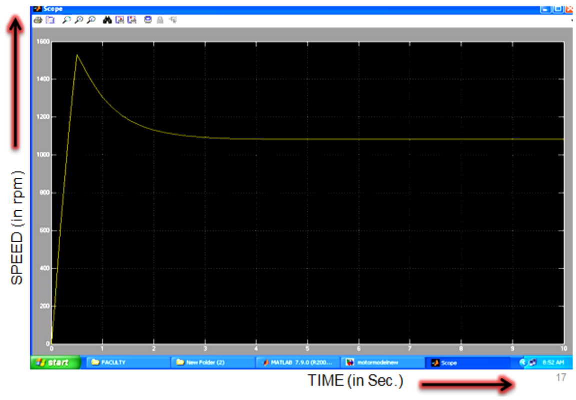


Figure 3: Figure Response of closed Loop Control System with constant disturbance

SPEED CONTROL OF SERIES MOTOR USING PID CONTROLLER

The PD controller could add damping to a system, but the steady-state response is not affected. The PI controller could improve the relative stability and improve the steady-state error at the same time, but the rise time is increased. This leads to the motivation of using a PID controller so that the best features of each of the PI and PD controllers are utilized

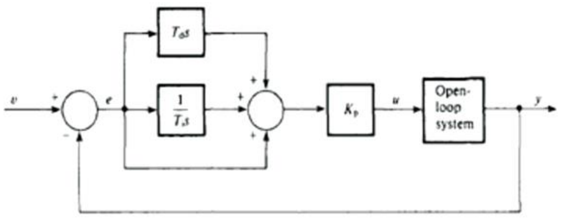


Figure 4: Block Diagram Representation of PID Controller

The PID controllers are the standard tools for the industrial automation. The flexibility of the controller makes it possible to use PID control in many situations. The controllers can also be used in cascade control and other controller configurations. Many simple control problems can be handled very well by PID control, provided that the performance requirements are not too high. The PID algorithm is packaged in the form of standard regulators for process control and is also the basis of many tailor-made control systems. Transfer function of PID controller is as an alternative, the PI portion of the controller can be designed first for a portion of the requirement on relative stability, and, finally, the PD portion is designed. This system can be implemented in simulink as follows:

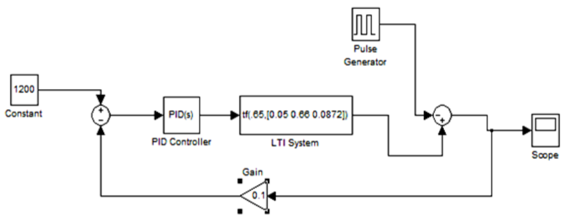


Figure5: PID Controller with pulse disturbance

The response of this model is obtained in MATLAB as follows:

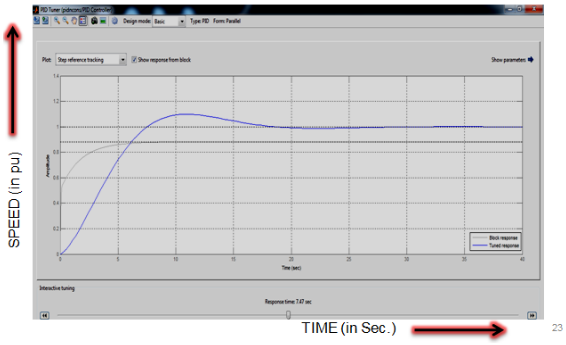


Figure 6: Response of PID Controller with constant disturbance

SPEED CONTROL OF SERIES MOTOR USING FUZZY CONTROLLER

The model presented thus far is a very ideal case. In the real world situation, due to variations in the power supply voltages and other disturbances, there may be random variations in the angular speed which may affect the performance of DC motor. So a controller is required which would track these changes in angular speed. The following diagram shows the basic mechanism of a fuzzy controller [5].

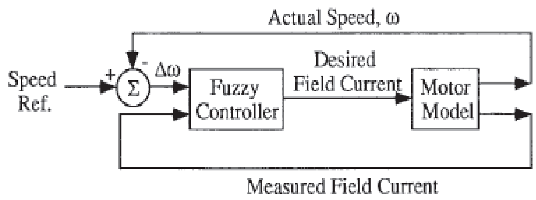


Figure 7: Basic Simulation Model

The following model using Fuzzy Controller was implemented in SIMULINK.

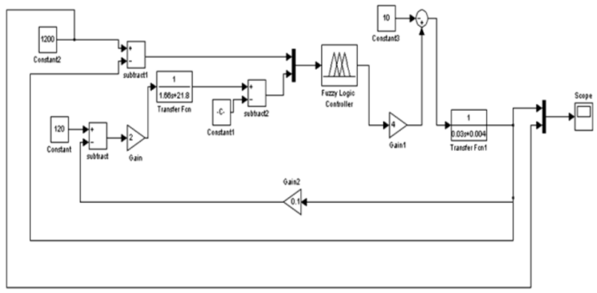


Figure 8 Fuzzy Controller with constant disturbance

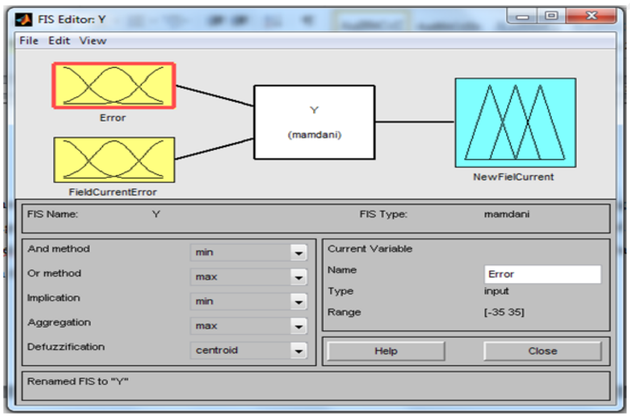
Inputs & Outputs of Fuzzy Logic Controller

Inputs:

- Speed Error [-35, 35]
- Field Current Error [-3.5, 3.5]

Output:

- New Field Current [0.2895, 7.2895]



Membership Functions

Fuzzy Variable 1: Error		
Fuzzy Association	Variable	Range
LN	Large Negative	[-52.5, -17.5]
MN	Medium Negative	[-26.25,-8.75]
SN	Small Negative	[-17.5 ,0]
Z	Zero	[-8.75,8.75]
SP	Small Positive	[0 ,17.5]
MP	Medium Positive	[8.75 ,26.25]
LP	Large Positive	[17.5 ,52.5]

Fuzzy Variable 2: Field Current Error		
Fuzzy Association	Variable	Range
LN	Large Negative	[-5.25, -1.75]
MN	Medium Negative	[-2.625,-.875]
SN	Small Negative	[-1.75 ,0]
Z	Zero	[-.875,.875]
SP	Small Positive	[0 ,1.75]
MP	Medium Positive	[.875 ,2.625]
LP	Large Positive	[1.75 ,5.25]

Fuzzy Rule Base

		Field Current Error						
		LN	MN	SN	Z	SP	MP	LP
Error	LN	LN	LN	LN	MN	MN	SN	Z
	MN	LN	MN	MN	MN	SN	Z	SP
	SN	LN	MN	SN	SN	Z	SP	MP
	Z	LN	MN	SN	Z	SP	MP	LP
	SP	MN	SN	Z	SP	SP	MP	LP
	MP	SN	Z	SP	MP	MP	MP	LP
	LP	Z	SP	MP	MP	LP	LP	LP

The response of these models is obtained in MATLAB as follows:

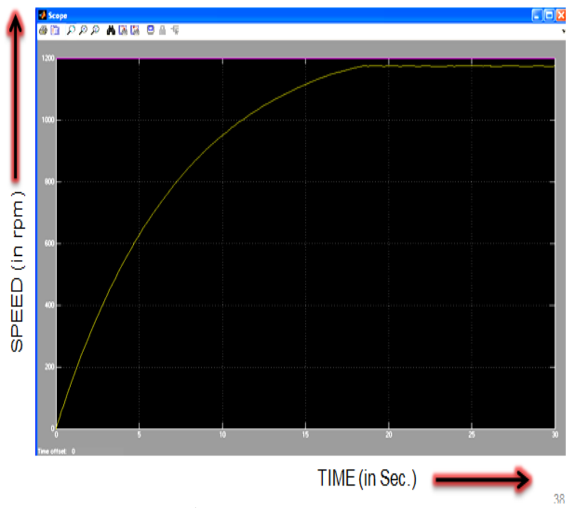


Figure 9:- Response of Fuzzy Controller with constant disturbance

Table 2: Comparison of Results of All Three Controllers

Parameters	Closed loop system	PID controller	Fuzzy Controller
Rise Time (sec)	2	5.32	3
Settling time (sec)	3	16.7	4
Overshoot (%)	10.41	9.8	0.33
Steady state error (%)	9.5	4.16	0.16

The above table clearly shows that system with Fuzzy Controller is more stable and has less steady state error.

EFFECT DUE TO INTERNAL PARAMETER VARIATION

Internal parameters may vary due to many reasons. Some of them are as following:

- Temperature rise
- Inter turn faults
- Aging

Parameter Variation Due To Temperature Rise

When machine is subjected to continuous load obviously the temperature of machine will rise and due to temperature raise the resistance of armature and field windings will increase. Since the machine is of small rating, here we consider 5% change in resistance and inductance. In this condition the model of motor and response will be as following:

5.1.1 Close loop

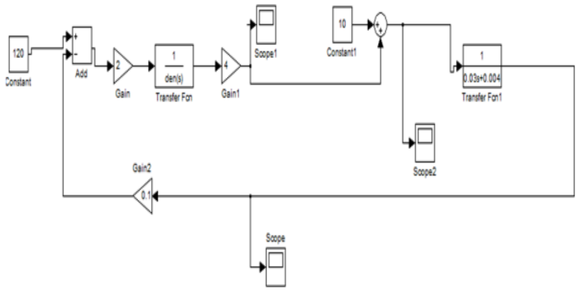
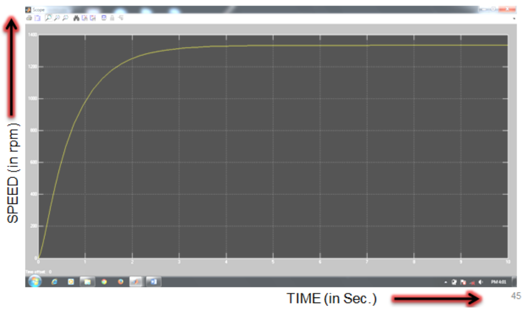


Figure 10: Closed Loop Control System with Constant Disturbance And 5% Change In Internal Parameters due to Temperature Rise

The response of above model is obtained in MATLAB as follows:



5.1.2 PID Controller

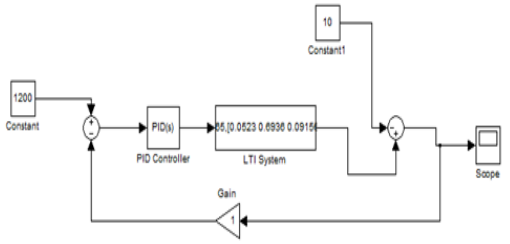


Figure 11: PID Controller with Constant Disturbance And 5% Change In Internal Parameters due to Temperature Rise

The response of above model is obtained in MATLAB as follows:

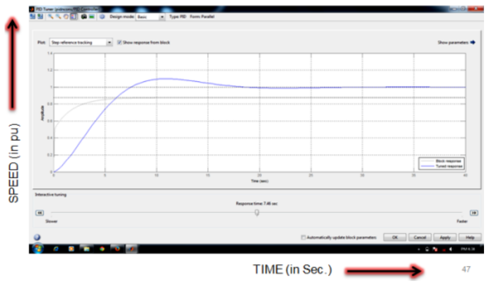


Figure 12: response of PID controller with constant disturbance and 5% change in internal parameters due to temperature rise

5.1.3 Fuzzy Controller

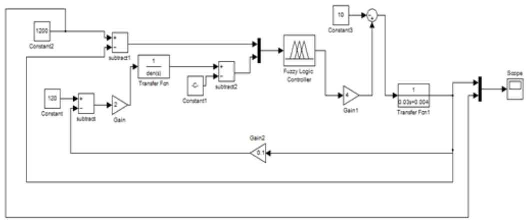


Figure 13: Fuzzy Controller with Constant Disturbance And 5% Change In Internal Parameters due to Temperature Rise.

The response of above model is obtained in MATLAB as follows:

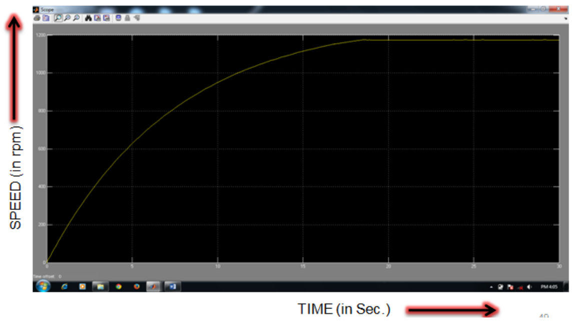


Figure 14: response of fuzzy controller with constant disturbance and 5% change in internal parameters due to temperature rise

Comparison tables for constant disturbances

Table 3: Comparison of results of all three controllers for temperature rise

Parameters	Closed loop system	PID controller	Fuzzy Controller
Rise Time (sec)	2	6	9
Settling time (sec)	4	15	10
Overshoot (%)	8.33	6	0
Steady state error (%)	-8.33	4	0.33

Parameter Variation Due to Inter turns Faults:

Response of Closed Loop Control System with Constant Disturbance And 5% Change in Internal Parameters due to Inter turn Faults is shown in figure 15.

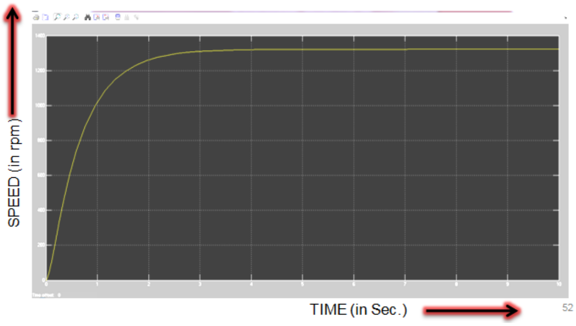


Figure 15: Response of closed loop control system with constant disturbance and 5% change in internal parameters due to inter turn faults

Response of PID Controller with Constant Disturbance And 5% Change In Internal Parameters due to Inter turn Faults is shown in figure16.

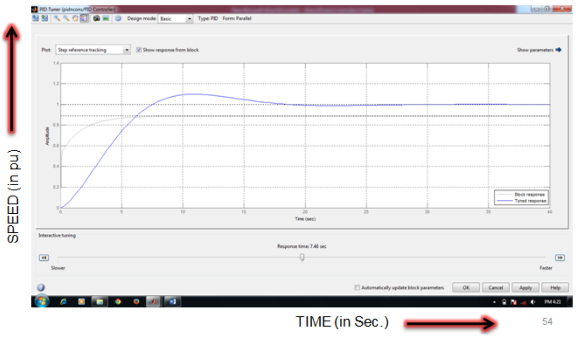


Figure (16)

Response of Fuzzy Controller with Constant Disturbance And 5% Change in Internal Parameters due to Inter turn Faults is shown in figure.

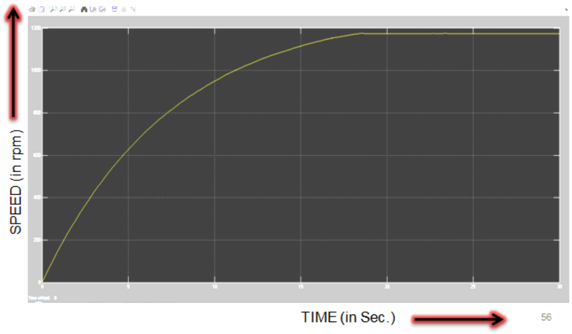


Table 4: Comparison of results of all three controllers for Inter Turn Fault

Parameters	Closed loop system	PID controller	Fuzzy Controller
Rise Time (sec)	2.4	10	16
Settling time (sec)	4.2	18	17.5
Overshoot (%)	12.5	10	0
Steady state error (%)	-12.5	9	0.3

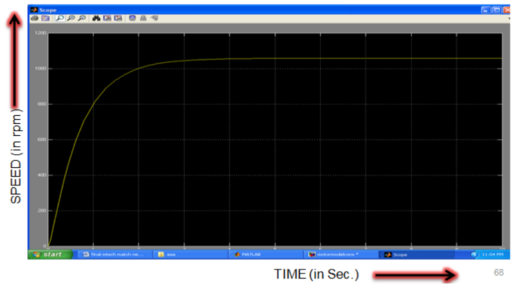
Table 5: Comparison of results of all three controllers for Aging

Parameters	Closed loop system	PID controller	Fuzzy Controller
Rise Time (sec)	2.5	10	16
Settling time (sec)	4	19	17.5
Overshoot (%)	12.5	10	0
Steady state error (%)	-12.5	10	0.33

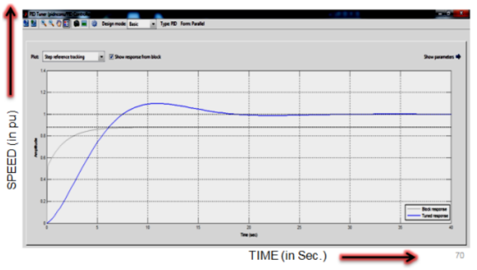
VARIABLE SPEED OPERATION OF DC SERIES MOTOR

Many times it is required to run a machine on different speed. If a machine rated for any specific speed and if it runs on different speed then its efficiency and output may not be desirable and also the external disturbance may affect this mode so this is necessary for robust controller that it should gives desirable result on other speed. Here the reference speed of machine is varied between 600 to 1200 rpm. Now let us observe the model and obtained results.

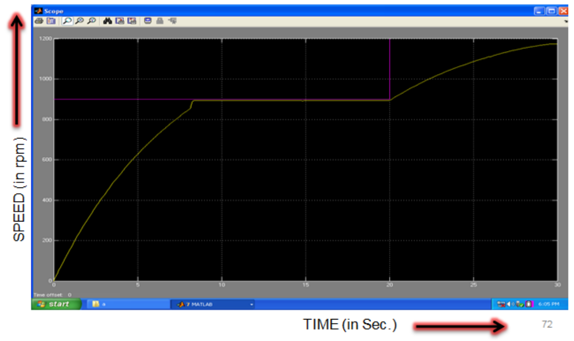
Variable Speed Operation of Dc Series Motor with Closed Loop System



Variable Speed Operation Of Dc Series Motor With PID Controller



Variable Speed Operation Of Dc Series Motor With Fuzzy Controller



Comparison of Results of PID Controllers with Fuzzy Controller

Parameters	PID Controller	Fuzzy Controller
Rise time (Sec.)	5.32	8
Settling time(sec.)	16.7	10
Overshoot (%)	9.79	0
Steady state error	4	0.33

CONCLUSION

Speed response characteristics of DC motor were obtained by mathematical model using MATLAB coding and SIMULINK model .The response is found to be not satisfactory i.e. response doesn't satisfy the desired design requirements like rise time, settling time, peak value, steady state error etc.

To overcome the above drawback we employed PID controller design, by proper tuning of KP, KI and K_d we have improved the characteristics like steady state error. Hence in order to reduce the steady state error modern technique like FUZZY controller is employed. FUZZY controller is proposed to replace conventional PID controller to improve the system characteristics. The corresponding step response is very smooth and ripple free the rule base adopted is of MAMDANI type and its rule viewer is presented .A thorough tuning of rule base may be required for improvement of the response further.

The output waveform closely tracks the input waveform in the results, thereby indicating that the controller designed is quite efficient. The small error is due to the fact that our design is valid for a particular range of inputs. The response of a fuzzy logic controller is much better and faster than a simple feedback control system. The results indicate superior controllability obtained by the use of a fuzzy controller.

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