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Speed control of DC servomotor using Chopper based PI Controller

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Abstract: - In industry the most commonly used control strategy is PID. The effectiveness of PI controller is increased by tuning of it (Ziegler-Nicholas Method). Using PID and Ziegler-Nichols controllers, speed control of industrial applications are not controlled in Suggested manner. Fuzzy controller is enhanced than Ziegler-Nichols controller but rise time is high. In this research, DC Servomotor speed control is governed by Chopper-based PI Controller that monitors time-domain variables like as rise time, settling time, peak amplitude, over shoot, oscillations. Simulation results of speed control of DC servomotor using PI, Ziegler-Nicholas controller, Fuzzy controller, Chopper based PI controller are demonstrated.

Key Words: — ***Ziegler-Nicholas controller, Fuzzy controller, DC servomotor, Chopper based PI controller.***

I. Introduction

Industrial systems which are having high Performance and efficiency are playing pivotal role in robot technology. Because of the need of robot technology had made to research and developed control techniques during previous years. Robot manipulation is main pillar of the core fields in industrial manufacturing and healthcare sectors. It works in unforeseeable, risky and difficult to live in conditions where human cannot survive as in the chemical and nuclear sectors [1]. The best example for robot manipulator is DC servomotor. DC servomotor is treated as heart of the industrial applications. They are used in automatic doors, disk drives and precise control applications. These motors extensively used and various control logics has been developed to improve their efficiency but they are suffering from non-linear parameters varying the overall system efficiency. Changing the load connected to the motor or further unexpected change in working condition may introduce more complexity to the application [2]. DC servomotor is used as actuators in servomechanisms. DC servomotor is used in robotic technology because of ability to operate at high torque at any speed. It can hold at any instant static position which play Levant role in robotic mechanism and servomechanism. These motors can change the direction of rotation quickly. As AC servo motor is more complex than DC servomotor, speed controlled DC drive is more economical than speed controlled AC drive [3].

In this work, performance of DC servomotor is performed and observed in Simulink / MATLAB environment. For performing the operation of DC servomotor, modelling of the motor is done in this work. DC servomotor is simulated under different controllers. For PI-controller, steady state error of the system is reduced but less stable. For PID-controller, the parameters like rise time and steady state error are controlled. Here uncontrolled parameter is overshoot. For Ziegler-Nicholas controller, rise time of the system is more but problem occurs with oscillatory response. Could not find overshoot and stable operation for fuzzy logic controller yet rise time varied high. But in chopper based PI controller controls the almost all time domain specifications.

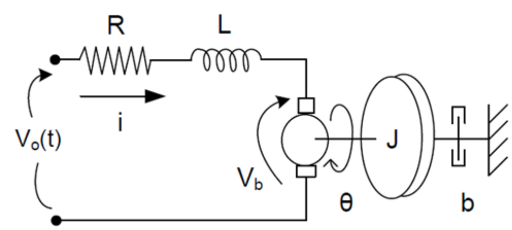

Fig.1. DC Servomotor circuit diagram

II. Modeling of DC motor

DC servomotors are more preferable for extensive speed varying control and are available for a lot of variable speed drives. Simulation for this, Fig. 2. depicts a variant of the DC servomotor. Table.1. displays parameters and values calculated and estimated (For practical conditions) for motor simulation [1].

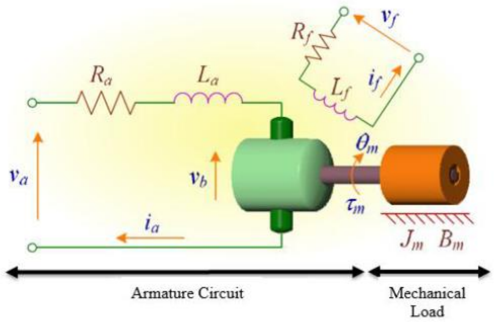

Fig.2. Circuit diagram of DC servomotor

Input voltage in Laplace transform is

$$E_a(s) = L \cdot s \cdot I_a(s) + R_a \cdot I_a(s) + E_b(s)$$
$$E_a(s) = (L \cdot s + R_a) \cdot I_a(s) + E_b(s)$$
$$E_a(s) - E_b(s) = (L \cdot s + R_a) \cdot I_a(s)$$
$$I_a(s) = \left[\frac{1}{L \cdot s + R_a}\right]\left[E_a(s) - E_b(s)\right]$$

Equation for output mechanical system is

$$T(t) = J_m \cdot \frac{d\omega_m(t)}{dt} + B_m \cdot \omega_m(t)$$

Apply Laplace transform to above equation

$$T(s) = \left[J_m \cdot s + B_m\right] \cdot \Omega_m(s)$$
$$\Rightarrow \quad \Omega_m(s) = \left[\frac{1}{J_m \cdot s + B_m}\right] \cdot T(s)$$

DC-servomotor block diagram is shown in Fig.3. With zero-load torque (TL).

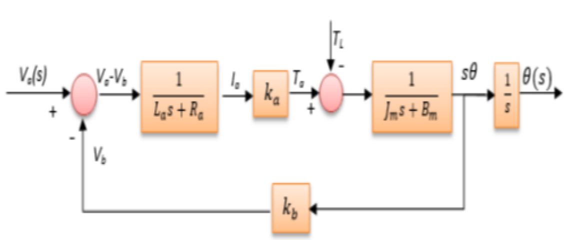

Fig.3. Block diagram of DC servomotor.

Modeling the DC servomotor is intended to mimic the idealistic DC servomotor. Summing up the parameters to the transfer function equation, we can get the DC servomotor transfer function for monitoring position.

Table.1. Parameters and values for DC servomotor

Parameter	value
Moment of inertia (J_m)	0.000052 Kg.m2
Friction coefficient (B_m)	0.01 N.ms
Back EMF constant (K_b)	0.235 V/rad s-1
Torque constant (K_a)	0.235 Nm/A
Electric resistance (R_a)	2 ohm
Electric inductance (L_a)	0.23 H

$$G(position) = \frac{\theta(s)}{V_a(s)} = \frac{19640}{s^3 + 201s^2 + 6290s}$$

III. CONTROL TECHNIQUES COMPARISON

A. PI Controller

The proportional plus integral controller specifies two terms for an output signal: one is proportional to the error signal, while the other is proportional to the error signal integral. Fig.4. depicts the Block diagram of PI Controller of DC Servomotor.

It is known from the closed loop transfer function that the PI-controller adds zero into the system and changes the order by one. Lifting the order of the system results in less stable system than the comparative one because higher orders are less reliable than lower order systems.

From the loop transfer function the PI-controller is found to increase the number of the type by one. The increase in the number of type results in a decrease of the error of the steady state. Fig.5 depicts the Speed response of DC servomotor using PI-controller.

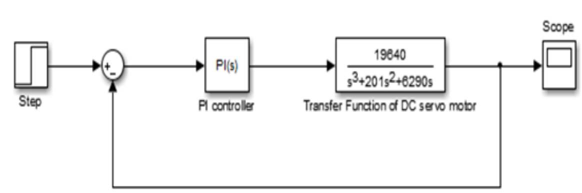

Fig. **4.** Simulink diagram of PI Controller of DC Servomotor

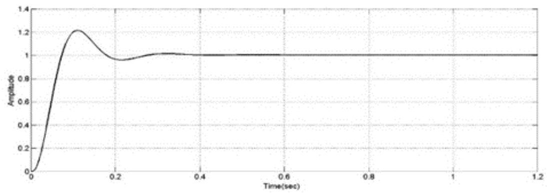

Fig.5. PI Controller-Speed response of DC servomotor

B. PID controller

The best choice of three fundamental relationships: proportional, integral and derivative can improve the performance of the system in all aspects.Fig.6 depicts simulink block diagram of PID-controller to the DC Servomotor.

The proportional controller stabilizes the gain but maintains a steady error in the process. The integral controller decreases the steady state error, or eliminates it. The derivative controller gradually diminishes the rate of change of error. Fig.7. depicts speed response of DC Servomotor using PID controller.

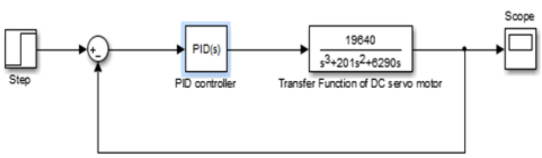

Fig.6. Simulink diagram of PID Controller of DC Servomotor

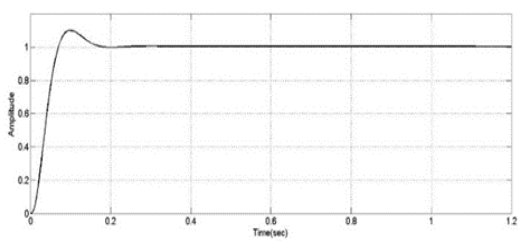

Fig.7. PID Controller-Speed response of DC servomotor

C. Ziegler-Nichols Controller (Z-N controller)

The Ziegler-Nichols rule is a trial and error PID tuning procedure, which aims to produce decent values for parameters of gain of PID-controller. Fig.9 depicts block diagram of Ziegler-Nichols controller of DC Servomotor.

The reasoning comes from the heuristic theory of neutrality. Initially, whether the optimal proportional gain is positive or negative is tested. For this function, step input is increased a bit manually, otherwise if the steady state output rises it is positive otherwise it is negative.

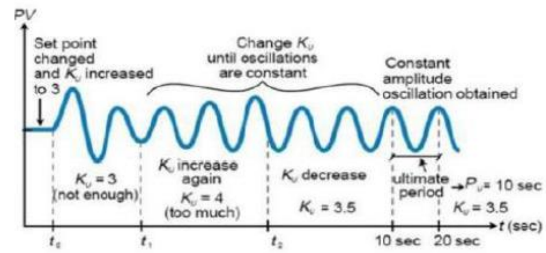

Fig. 8. Parameters values calculation from (Z-N) controller

Fig 8. Depicts the parameters values calculation from Ziegler-Nichols controller. Then, K_i and K_d are set to zero and K_p value is raised until a periodic oscillation is generated at the output response. This critical K_p value succeeds in being the ultimate gain (K_c), and the duration in which the constant oscillation process occurs is considered as the ultimate time (P_c). As a consequence, the whole cycle depends on two variables and the other systematize parameters discussed. Fig.10 depicts speed response of DC Servomotor using Ziegler-Nichols method.

Type of controller	K_p	T_i	T_d
P	$0.5Kcr$	∞	0
PI	$0.45Kcr$	$11.2Pcr$	0
PID	$0.6Kcr$	$0.5Pcr$	$0.125Pcr$

Where K_p implies controller path gain

T_i implies controller's integrator time constant

T_d implies controller's derivative time constant

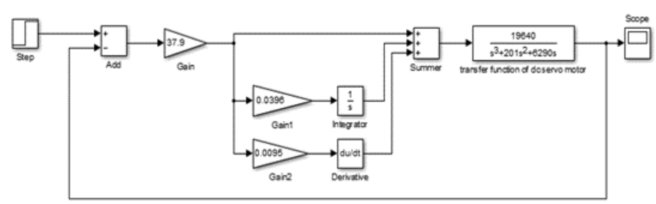

Fig. 9. Block diagram of Ziegler-Nicholas Controller of DC Servomotor

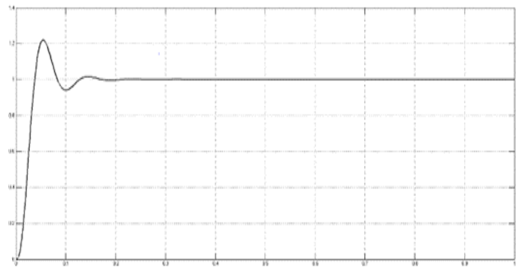

Fig.10. Ziegler-Nichols Controller-Speed response of DC servomotor

D. Fuzzy Logic Controller

Fuzzy logic controller is a control logic which is based on the functions of the member ship. In fuzzy logic controller, human knowledge is converted to automatic control logic. Fuzzy logic controller doesn't need critical mathematical calculations like the others control strategies. On other hand other control methods need mathematic parameters and algebraic expressions, but fuzzy logic controller only need expert knowledge to convert into membership functions. Fig.11. depicts Block diagram of FLC.

FUZZIFICATION: In this controller the measured inputs are called the crisp values. The transformation of these crisp values to the linguistic fuzzificated values is called a fuzzification.

KNOWLEDGE BASE: Gathering the principles of expert knowledge required to achieve the stated goal.

FUZZY REASONING MECHANISM: Using this method, fuzzy logic operations are performed and control action is taken about the inputs of the fuzzy logic controller.

DEFUZZIFICATION UNIT: It transforms the output of the fuzzy reasoning system into the requisite crisp value within this unit

FUZZY CONTROLLER DESIGN: In fuzzy logic controller the very crucial thing is to establish the membership functions for both input and output.

There are 7 rules that used at the controllers which are based on human experience and information are.

1. If E is PL then CONTROL is PL
2. If E is NL then CONTROL is NL
3. If E is Z and DE is N then CONTROL is NM
4. If E is Z and DE is P then CONTROL is PM
5. If E is Z then CONTROL is Z
6. If E is NM then CONTROL is NM
7. If E is PM then CONTROL is PM

After anticipating the rule from the observation, we can get the surface viewer in Figure that depicts the rule of FLC.

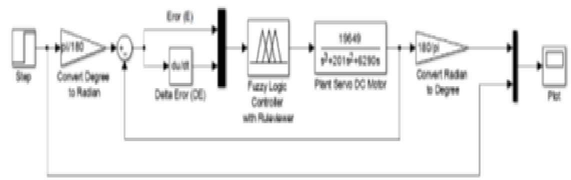

Fig. 11. Simulink model for simulating FLC.

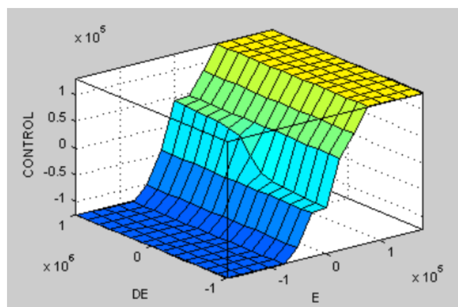

Fig.12. FLC surface

Fig.12 depicts the surface of fuzzy logic controller. Fig 13-15 depicts membership functions of error, change in error and control signals. Fuzzy inference system features two sourced inputs and an expected output regarding inputs. Two sources here are Error (E) and Change in error(DE). One output which is utilises as a control signal input to the plant. The Fuzzy membership functions are depicting in figure for correction, error and control signal. NL implies Negative High, NM implies Negative Small, Z implies Zero, PL implies positive large and PM implies Positive Medium Fig.16 depicts the speed response of DC Servomotor using fuzzy logic controller. [5]

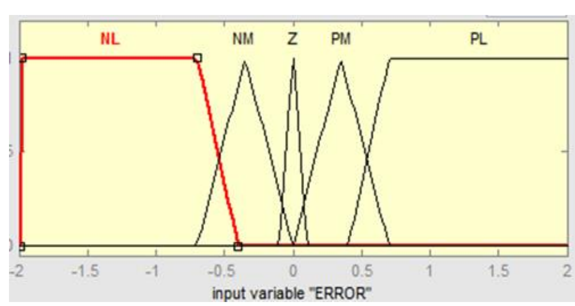

Fig.13. Chosen membership function of error (E) as input

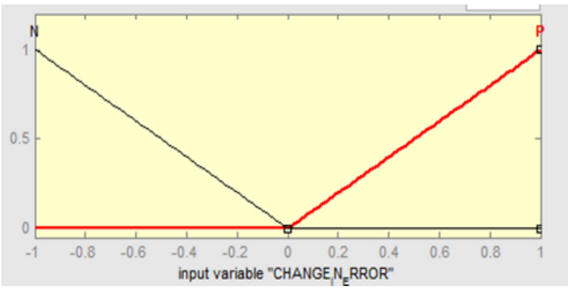

Fig.14. Chosen membership function of delta error (DE) as input.

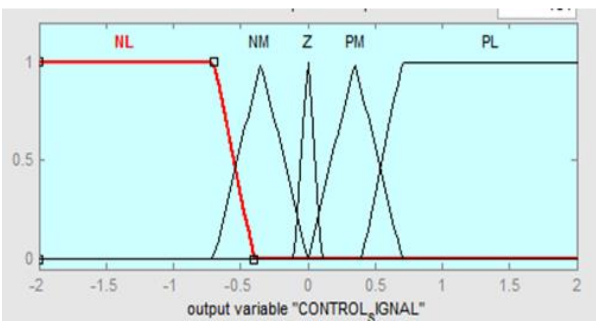

Fig.15. Chosen membership function of CONTROL as output.

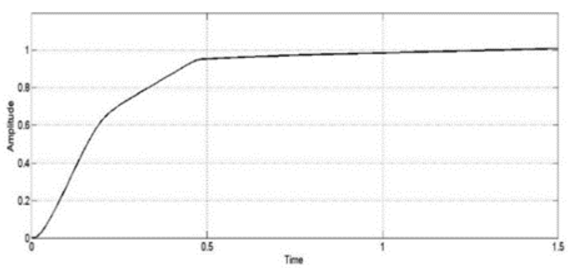

Fig.16. FLC-Speed response of DC servomotor

IV. Proposed Chopped Based Controller

In this proposed controller technique, DC servomotor is controlled by chopper based controller. Fig.17. depicts chopper based PI controller of DC Servomotor.

In this controller, transfer function of DC servomotor is taken as in terms of functional blocks in way to get the signals of input current and speed of DC Servomotor.

Speed of the DC servomotor is compared with reference speed. The compared signal is in terms of error speed signal which is converted to current signal using PI controller. PI controller is used to convert error signal to respected current signal. This current signal which is derived from PI controller again compared with input current signal of the DC servomotor. This error current signal is converted to amplified current signal using PI Controller.

This amplified current signal is used to control the chopper operation. Switching of switches can be done by two relays whose are fed by amplified current signal. The EMF signal developed in the DC servomotor is fed to the chopper load to get the desired load current. This load current is the controlled current signal which is fed to DC Servomotor as input current.

This technique is completely based on closed loop operation which is used to get the desired speed of DC Servomotor with controlled time domain parameters. Fig.18 represents speed response of DC Servomotor using chopper based PI controller.

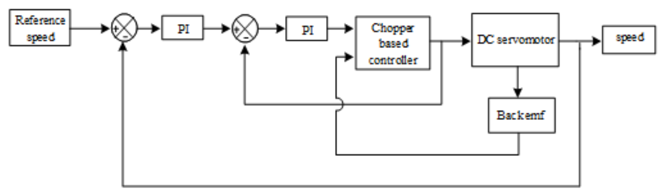

Fig. 17. Block diagram of Chopper based PI Controller of DC Servomotor

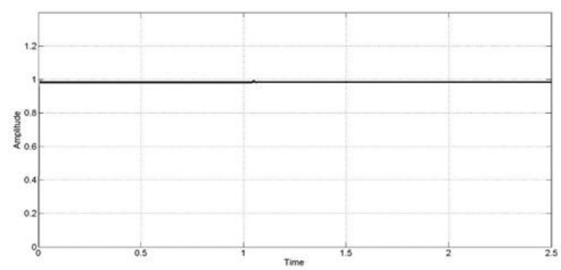

Fig.18. Speed response of DC Servomotor using chopper based PI controller.

V. Results and Discussion

Fig. 19 depicts the comparison among speed control of DC servomotor using different controllers. On comparing DC servomotor with different controllers, the time domain specifications are as graph and table follows. Table 3. Depicts the counterparts of time domain parameters of above discussed controllers.

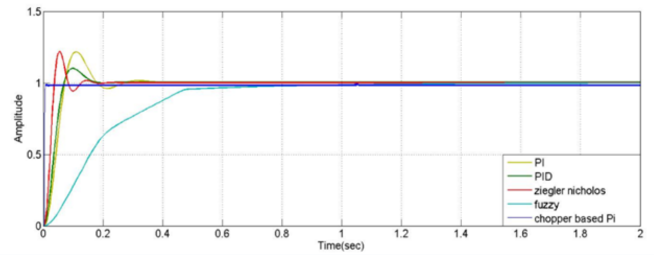

Fig.19. Comparison among speed control of DC servomotor using different controllers

Table.3. Comparison of time domain parameters

Controller	Rise time (sec)	Settling time (sec)	Overshoot (%)	Peak Amplitude	Oscillations
PI	0.056	0.24	21.5	1.22	Moderate
PID	0.049	0.18	10.1	1.1	No
Ziegler-Nicholas	0.044	0.15	21	1.21	Moderate
FLC	1.0	0.9	0	1	No
Chopped based PI Controller	0.01	0.01	0	1	No

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