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Comparison and Speed Control of DC Motor and DC Servomotor Using IMC Based PID Controller

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ABSTRACT

IMC based PID controllers are being used to speed control of DC motor and DC servomotor in industry. As this controller offer good performance comparitive to conventional controllers like PI, PID and Ziegler Nichols frequency method controllers. This paper presents the speed control of the DC motor and DC servomotor using PI, PID, Ziegler Nichols method and IMC-PID controllers, to realize the optimization of control action. A mathematical calculation of DC motor and DC servomotor has developed and simulations are carried out in MATLAB/ Simulink environment.

From the results, it is observed that time domain parameters like rise time 0.6 secs, settling time 2 secs, speed for peak over shoot 1450, peak amplitude 1, with no oscillations using IMC-PID controller on DC motor. And for DC servomotor its rise time is 0.3 seconds, settling time is 1 second, speed for peak overshoot 1450 rpm, peak amplitude 1 with absence of oscillations by using IMC-PID controller

KEYWORDS:*DC motor, DC servomotor, IMC based PID controller, PI controller, PID controller, Ziegler-Nichols controller.*

I. INTRODUCTION

One of the most widely used industrial applications is DC motor, because of low cost, its high reliability, and its high flexibility. These DC motors are mostly in robot manipulators, home appliances, including conveyors, cranes, vaccum cleaner, sewing machine and others for which adjustable speed are required with constant or low speed torque are needed`.

DC motors can converts its electrical energy into mechanical energy where the interaction of two magnetic fields, which one of its field that is produced by a magnet of poles assembly, and other field which is produced by an electrical current flowing in the motor windings. These two fields result in a torque which tends to rotate the rotor[5].

One of its advantage of DC motor is it control speed over a wide range of both and above its rated speed, it has large starting torque and best suited for electric traction and free from harmonics. The disadvantage is it has high initial cost, cannot operate in explosive and hazard conditions.

The DC Servomotors are commonly used for high technology devices in industrial applications like automatic technology. It is usually like a transducer that can convert electrical form of energy in to mechanical energy. A servomotor is rotary actuator or linear actuator that allows for actual control of linear position and speed control. The torque developed on shaft of the motor is directly proportional to field flux and armature current.

The heart of many control systems which are automatic in nature is servo motor drive. DC servomotor is treated as heart of the industrial applications. They are widely used in conveyor belts, radars, camera auto focus, solar tracking system and precise control applications. The DC servomotors are very expensive compared with AC servomotor because of its brushes and commutators . Usually, servos can operate in negative feedback, where control input is compared with actual position of the system by some sort of transducer at the output [1].

Any electrical motor can be utilized as servomotor if it is controlled by servomechanism. Although servomotors are not in a specific class of motor, they are proposed and designed to use in a motion control applications which is required for high accuracy positioning, quick reversing and exceptional performance. DC servomotors are used as simple applications because of their low cost, high efficiency and simplicity.

II. WORKING OF DC MOTOR

In this work, performance of DC motor and DC servomotor is observed in Simulink / MATLAB environment. For performing the operation of DC motor and DC servomotor, modelling of the motor is done in this work. These two motors is simulated under different conventional controllers. For PI-controller, steady state error of the system is reduced but less stable. For PID-controller, rise time and steady state error are controlled. Here uncontrolled parameter is overshoot. But in IMC design PID is tuned then rise time, steady state error, settling time are controlled along with peak overshoot.

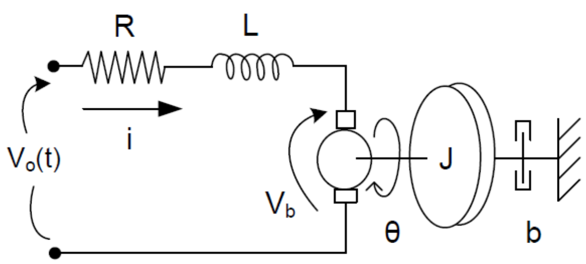

Fig.1. DC Motor Model

The armature voltage is given as,

$$V_a\ (t) = R_a.\ I_a\ (t) + L_a.\frac{dIa}{dt} + E_b\ (t) \quad (1)$$

Equation for back emf of motor

$$E_b\ (t) = K_b\ \omega(t) \quad (2)$$

Torque equation will be

$$T_m\ (t) = J\frac{dw\ (t)}{dt} + B\ \omega(t) \quad (3)$$

Where $K_t = J\frac{dw\ (t)}{dt} + B\omega(t)$ (4)

Combine above equations

$$V_a\ (t) = R_a.\ I_a\ (t) + L_a.\frac{dIa}{dt} + K_b\ \omega(t) \quad (5)$$

Taking Laplace Transform of (5), we get

$$V_a\ (s) = R_a.\ I_a\ (s) + L_a.\ I_a\ (s) + K_b\ \omega(s) \quad (6)$$

$$K_t.\ I_a\ (s) = J\ \omega(s) + B\ \omega(s) \quad (7)$$

Current equation is obtained from above two equation

So, the relation between speed of rotor shaft and armature voltage which is applied is given by transfer function.

$$\frac{W(s)}{V_a(s)} = \frac{K_t}{(JL_a s^2 + (JR_a + BL_a)s + (K_t K_b) + BR_a))} \quad (8)$$

This is transfer function of DC motor.

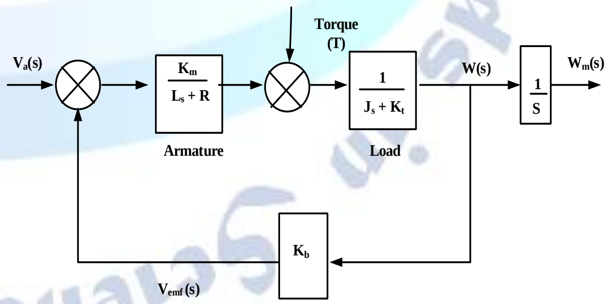

Fig.2. Block diagram of DC motor.

III. MODELLING OF DC MOTOR

The purpose of modelling DC motor is approaching its actual DC motor. To include its parameters, it can get the transfer function of DC motor for controlling the position.

Table 1

DC Motor Parameters and Values

Parameter	**Value**
Armature Voltage (V_a)	220 V
Electrical Inductance (L_a)	0.5 H
Electrical Resistance (R_a)	1 Ω
Moment of Inertia (J)	0.01 Kg. m^2
Friction Coefficient (B)	0.1 N-m/rad/sec
Back emf Constant (K_b)	0.01V/rad/sec
Rated speed	1450 rpm
Torque Constant (K_t)	0.01 N.m/A

By using the above parameters mathematical calculation of transfer function is given as.

$$\frac{W(s)}{V_a(s)} = \frac{K_t}{(JL_a s^2 + (JR_a + BL_a)s + (K_t K_b) + BR_a))} \quad (9)$$

Substitute the above parameter values in equation 9 transfer fiction is obtained as.

$$Q(s) = \frac{0.01}{0.005s^2 + 0.055s + 0.0901} \quad (10)$$

IV.MODELLING OF DC SERVO MOTOR

DC servomotors are most preferable in extensive range of speed control and are used for most variable speed control drives. In this model, Fig.3. represents the DC servomotor model and Fig. 4. Represents schematic diagram of DC servomotor model [1].

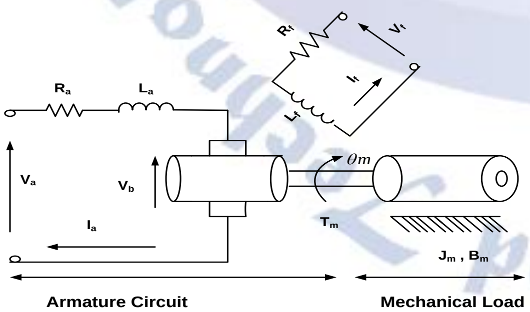

Fig.3. DC Servomotor model

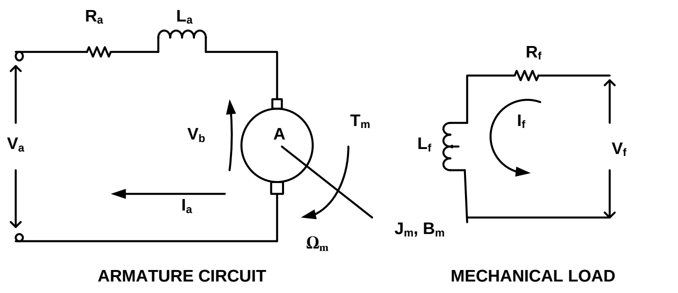

Fig.4. Schematic diagram of DC Servomotor.

Input voltage in Laplace transform is

$$E_a(s) = L.\ s.\ I_a(s) + R_a.\ I_a(s) + E_b(s) \quad (1)$$

$$E_a(s) = (L.\ s + R_a)\ .\ I_a(s) + E_b(s) \quad (2)$$

Equation for output mechanical system is

$$T(t) = J_m\ .\ \frac{dw_m(t)}{dt} + B_m\ .\ w_m(t) \quad (3)$$

Apply Laplace transform to above equation 3

$$T(s) = [\ J_m.\ s + B_m\ ]\ .\ \Omega_m(s) \quad (4)$$

$$\Omega_m(s) = [\frac{1}{J_m.s + B_m}]\ .\ T(s) \quad (5)$$

So, the relation between speed of rotor shaft and armature voltage which is applied is represented as transfer function of DC servomotor.

$$\frac{W(s)}{V_a(s)} = \frac{K_t}{S(JR_a + R_aB + JL_as^2 + BL_aS + (K_tK_b)}(6)$$

The block diagram of DC servomotor is shown in Fig. 4. with load torque at zero value (T_L).

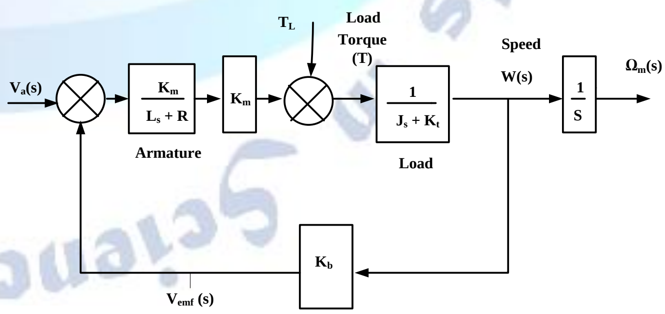

Fig.5. Block diagram of DC Servomotor

V.CONTROL TECHNIQUES COMPARISON

A. PI Controller

The Proportional plus Integral controller which provides output signal of two terms : one is

Proportional to error signal and the other one is Proportional to the Integral of error signal [3]. Fig.5. represents the Simulink model of PI Controller of DC Servomotor.

The one more advantage of PI controller is zero steady state error, Stability and maximum peak overshoot which is better than Integral only controller. PI controller is not suitable to slow moving process variables. Majority of speed control applications are used as PI control actions.

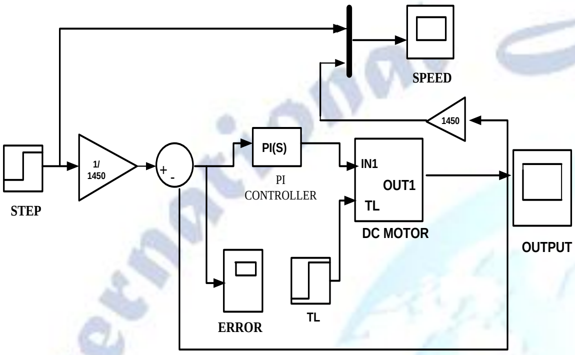

Fig.6. Simulink model of PI controller using DC motor.

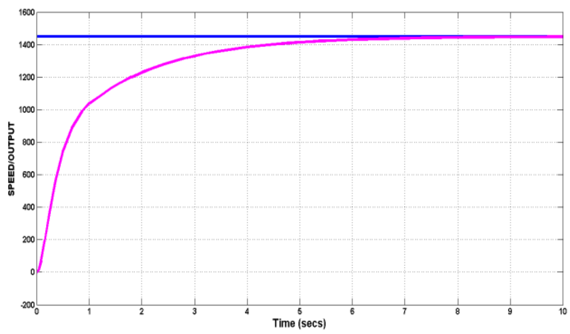

Fig.7. Unit step response of PI controller using DC motor

In this simulation result, it is observed that PI controller provides stability to the system, it has higher rise time and settling time. Larger settling time takes high fault currents which takes place in the system. But it has no oscillations.

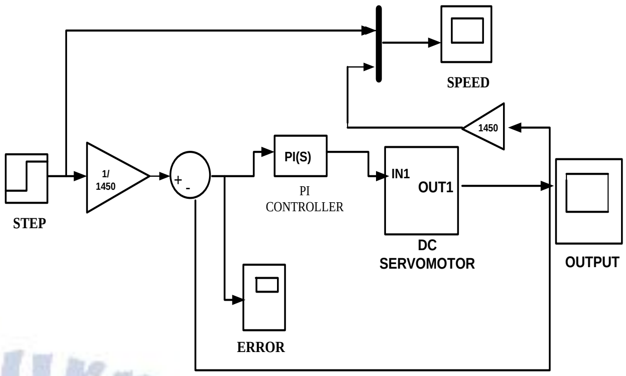

Fig.8. Simulink model of PI Controller using DC Servomotor

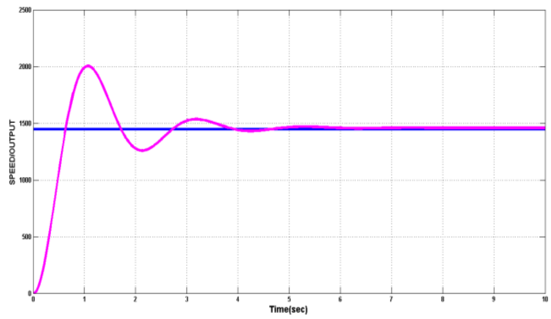

Fig.9. Unit step response of PI controller using DC servomotor

In this simulation result, it is observed that the PI controller provided better stability to the system, and it fully eliminates the steady state error that is offset, good transient response. But it has moderate oscillations and high starting overshoot compared to DC motor.

B. PID controller

The combination of Proportional plus Integral and Derivative can improve all its parameters of the system performance[3]. Fig.9 represents simulink model of PID controller of DC motor.

The Proportional controller which stabilize the gain but produces steady state error. Integral controller decreases or eliminates steady state error. The Derivative controller reduces the rate of change of error. Fig.11 represents unit step response of DC Servomotor using PID controller [5].

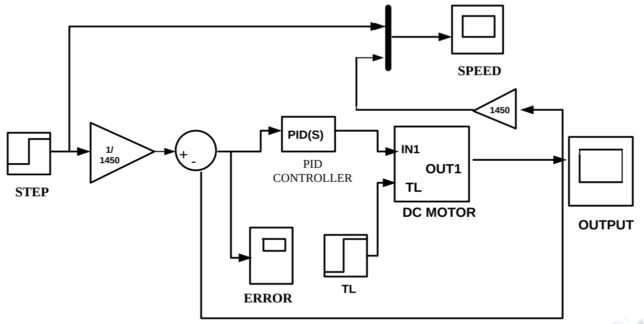

Fig.10. Simulink model of PID controller using DC motor.

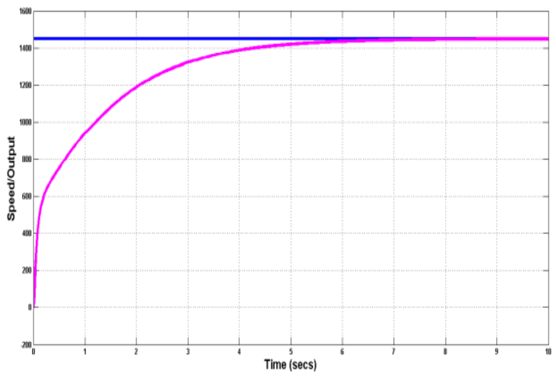

Fig.11. Unit step response of PID controller using DC motor.

This simulation result, it takes more for settling time and rise time. But has no oscillations.

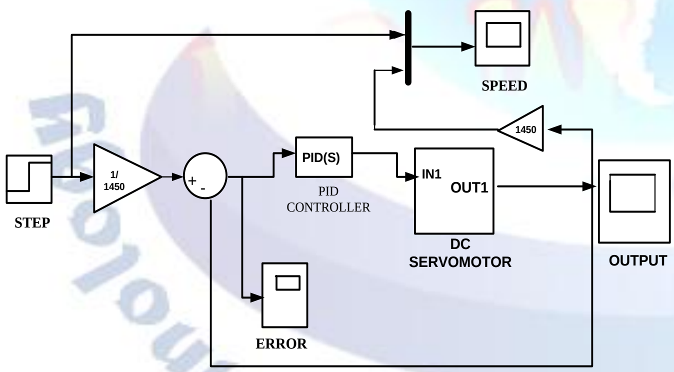

Fig.12. Simulink model of PID Controller using DC Servomotor

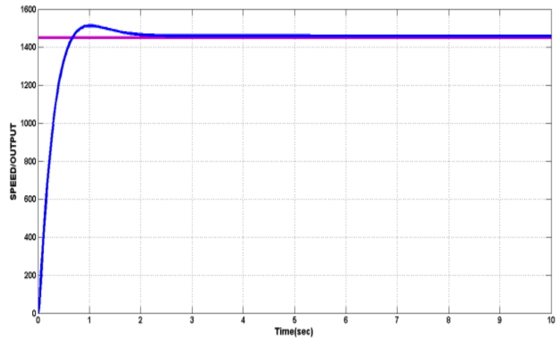

Fig.13. Unit step response of PID Controller using DC servomotor.

Comparing the above two results PID has no oscillations but has faster settling time, reduces peak overshoot. Now a days, PID Controllers are widely used in industrial applications.

The purpose of modeling DC servomotor is approaching actual DC servomotor. Including the parameters, can get the transfer function of DC servomotor for controlling position.

Table 2

DC Servomotor Parameters and Values

Parameter	**Value**
Armature Voltage (V_a)	220 V
Electrical Inductance (L_a)	0.5 H
Electrical Resistance (R_a)	1 Ω
Moment of Inertia (J)	0.01 $Kg.m^2$
Friction Coefficient (B)	0.1 N-m/rad/sec
Back emf Constant (K_b)	0.01V/rad/sec
Rated speed	1450 rpm
Torque Constant (K_t)	0.01 N. m/A

By using the above parameters mathematical calculation in transfer function we can get equation . Here higher order terms are eliminated.

$$\frac{W(s)}{V_a(s)} = \frac{K_t}{(JL_a s^2 + (JR_a + BL_a)s + (K_t K_b) + BR_a))}$$

Substitute the parameter values in above equation gives

$$Q(s) = \frac{0.01}{0.06s^2 + 0.01s + 0.0001}$$

C.ZIEGLER – NICHOLOS CONTROLLER

The Ziegler-Nichols rule is a problem solving PID tuning method that attempts to produce good values for PID gain parameters[5]. Fig.13 represents block diagram of Ziegler-Nicholos controller of DC Servomotor.

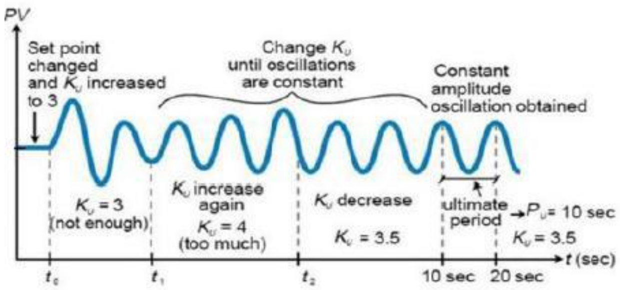

Fig.14. Ziegler – Nichols Controller method.

It is performed by setting the value I (integral) and D (derivative) gains to zero. The P (proportional) gain, K_P is increased from zero to its maximum gain K_u, which is larger gain at the output of control loop to stable and consistent oscillations. Higher gains than the maximum gain K_u have diverging oscillations K_u and the oscillation period T_u are used to set the P, I, D gains depending on type of controller.

From the result, the complete process depends on two variables and the other systematize parameters are determined according to the table. Fig.8 represents speed response of DC Servomotor using Ziegler-Nichols method.

Type of controller	K_p	T_i	T_d
P	$0.5K_{cr}$	∞	0
PI	$0.45\ K_{cr}$	$11.2\ P_{cr}$	0
PID	$0.6\ K_{cr}$	$0.5\ P_{cr}$	$0.125P_{cr}$

Where K_p - Path Gain of controller.

T_i - Integrator time constant.

T_d -Derivative time constant.

From closed loop equation method, $K_c = 13$ and T= 2 sec, that is K_p= 7.8, T_i =1 sec and T_d = 0.5.

In this method DC motor transfer function is used as

$$Q(s) = \frac{0.01}{0.005s^2+0.055s+0.0901}$$

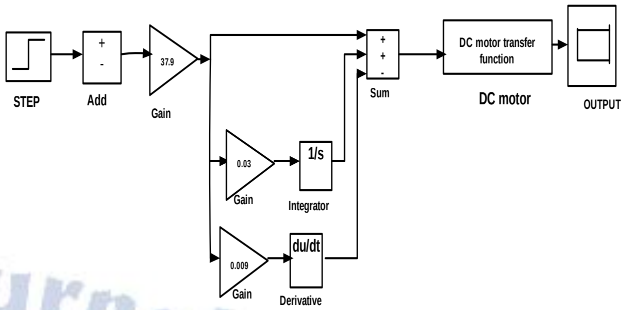

Fig.15. Simulink model of Ziegler-Nicholas Controller of DC motor.

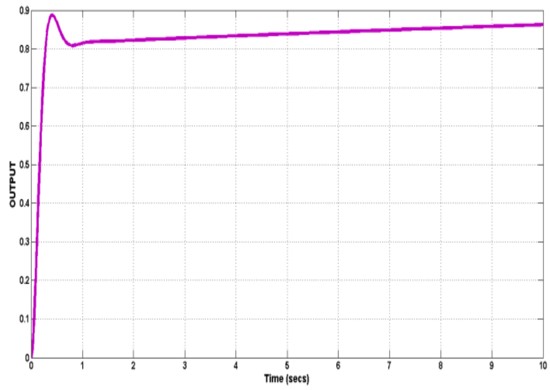

Fig.16. Ziegler-Nichols Controller-Speed response of DC motor.

Comparing the DC motor results of PI and PID controllers, ZNM has faster rise time and settling time and has no peak overshoot.

For this method DC servomotor transfer function is used

$$Q(s) = \frac{0.01}{0.06s^2+0.01s+0.0001}$$

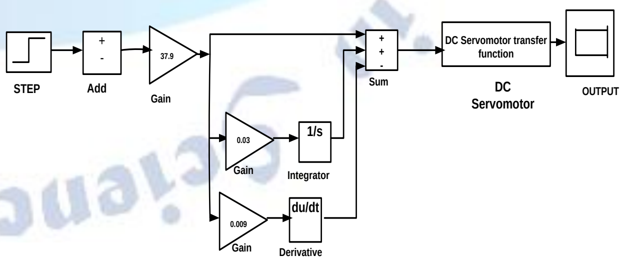

Fig.17. Simulink model of Ziegler-Nicholas Controller of DC Servomotor

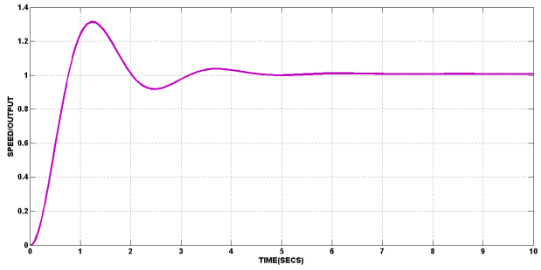

Fig.18. Ziegler-Nichols Controller Speed response of DC Servomotor

From above simulation result of Ziegler Nichols methods of DC servomotor has all the parameters are controlled compared to PI and PID controllers but has moderate oscillations occurred.

D.INTERNAL MODE CONTROL (IMC)

The theory of IMC states that "control can be achieved only if the control system encapsulates, either implicitly or explicitly, some representation of the process to be controlled" [5].

The IMC (Internal Mode Control) controller is based on the inverse of the process model and the gain becomes unity and have a perfect set-point tracking.

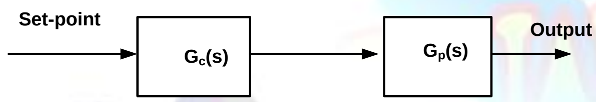

Fig.19. Equivalent block diagram of IMC

$$G_c(s) = \frac{Q(s)}{1-\widetilde{Gp}(s).Q(s)} \qquad (1)$$

Now,

$$G_P\,(s) = \widetilde{Gp}\,(s) \qquad (2)$$

Designed the IMC controller

$$G_{IMC} = Q(s) = [\widetilde{Gp}(s)]^{-1} G_f(s) \qquad (3)$$

$$\widetilde{Gp}\,(s) = 1 - G_p(s) \qquad (4)$$

Where G_f (s) is a low pass function defined as

$$G_f\,(s) = \frac{1}{(1+\propto s)\hat{}n} \qquad (5)$$

Now the DC moor transfer equation is

$$\frac{W(s)}{V_a(s)} = \frac{K_t}{(JL_a s^2+(JR_a+BL_a)s+(K_tK_b)+BR_a))} \qquad (6)$$

Taking α = 0.9 and n = 2 for second order low pass filter.

So finally the equation becomes

$$G_c(s) = \frac{Q\,(s)}{1-\widetilde{Gp}(s).Q(s)} \qquad (7)$$

Substitutute equations 4 and 5 in 6 using the DC motor parameters and values , low pass filter value in above equation we can get equation as follows

$$Q(s) = \frac{0.006s^2+0.030s+0.0801}{0.005s^2+0.055s+0.0901} (8)$$

Simply IMC is nothing but tuning of PID or transfer function of the motor.IMC is tuning with PID along with DC servomotor then we can get better result from above methods.

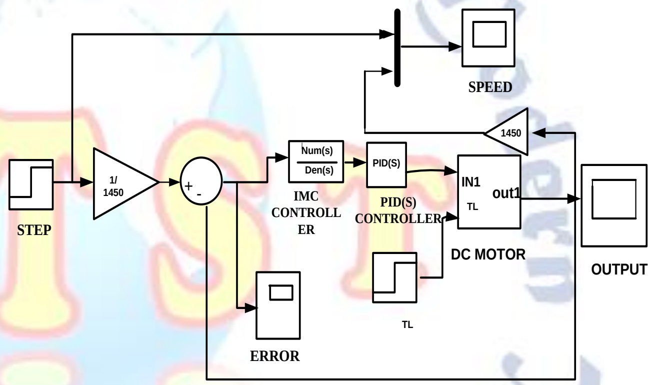

Fig.20. Simulink model of IMC -PID controller using DC motor

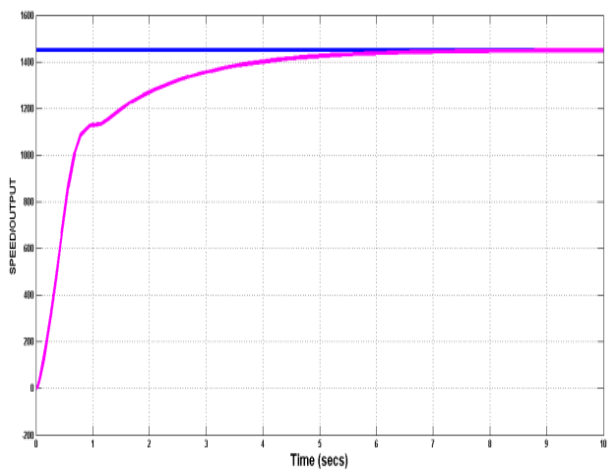

Fig.21. Unit step response of IMC controller of DC motor.

In this IMC-PID based DC motor we observed faster settling time , rise time and has no oscillation and absence of peak overshoot.

In the same manner , for IMC=PID design can be used to DC servomotor

The transfer function of DC servomotor is

$$\frac{W(s)}{V_a(s)} = \frac{K_t}{S(J R_a + R_a B + J L_a s^2 + B L_a S + (K_t K_b)}(6)$$

Substitutute equations 4 and 5 in 9 using the DC servomotor parameters and values , low pass filter value in above equation we can get equation as follows

$$Q(s) = \frac{0.06s^2+0.010s+0.0001}{0.06s^2+0.01s+0.0008} \qquad (10)$$

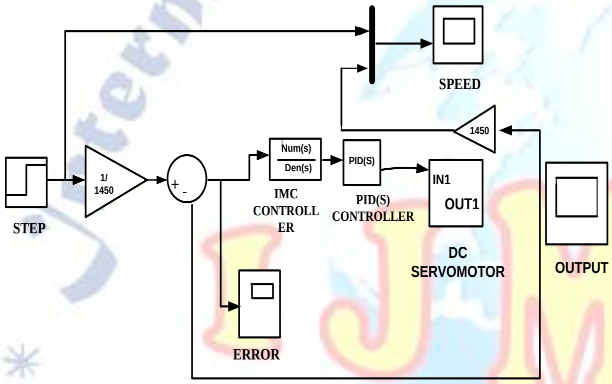

Fig.22. Simulink model of IMC-PID controller using DC servomotor.

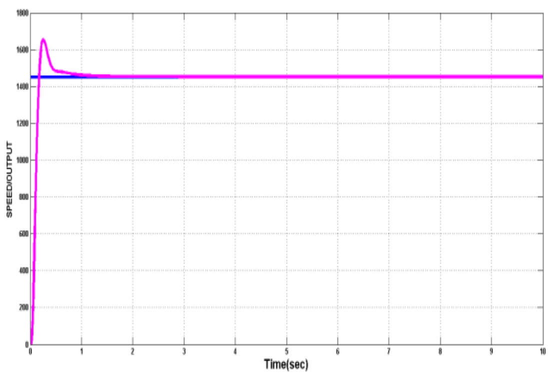

Fig.23. Unit step response of IMC-PID controller using DC servomotor.

Comparing all the results, of DC motor and DC servomotor IMC based PID gives better result like rise time, settling time, peak overshoot and absence of oscillations.

VI.RESULTS

On comparing speed control of DC motor and DC servomotor wit different controllers under same parameters gives better result are as table follows.

Comparing all the conventional controller like PI, PID, Ziegler Nichols method, IMC-PID controllers of DC motor and DC servomotor gives various results under same time domain parameters and gives results as rise time, settling time, overshoot, peak amplitude and oscillations.

Apart from IMC based PID controller of DC servomotor, none of the controller controls the whole parameters.

The final result are as follows in terms of time domain specifications are rise time as 0.3 secs, settling time as 1.0, speed for peak amplitude as 1450 rpm, peak overshoot is 1.0 with absence of oscillations.

Motor	controller	Rise time (T_R)	Settling time (T_S)	Speed	Peak amplitude	oscillations
DC motor	PI	7.2	9.3	1450	1.1	no
DC servo motor	PI	0.8	6.0	1450	1.22	moderate
DC motor	PID	6.9	8.5	1450	1.1	no
DC servo motor	PID	0.7	5.0	1450	1.1	no
DC motor	ZNM	0.9	9.0	1450	1.3	no
DC servo motor	ZNM	1.3	5.0	1450	1.1	moderate
DC motor	IMC-PID	0.6	2.0	1450	1.1	no
DC servo motor	IMC-PID	0.3	1.0	1450	1.0	no

VI.CONCLUSION

In this work, Speed control of DC motor and DC Servomotor is controlled by different conventional controllers method under same parameters gives better performance, on which IMC-PID controller of

DC Servomotor gives better results comparison is shown here in terms of time domain specifications such as rise time 0.3 seconds, settling time 1 second, speed with peak overshoot 1450 rpm, peak amplitude 1.0 and absence of oscillations. Apart from IMC based PID controller of DC servomotor, none of the controller controls the whole parameters.

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