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Robust Controller Design for Fixed field-DC Motor Speed Control

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Abstract: The speed and position control of DC motor is an important task in spinning machines, Fans, Blowers, Conveyors, Centrifugal Pumps, Lifts, Weaving Machine based real time applications. In this proposed manuscript various robust controller design has been implemented for fixed field DC motor speed control with various desired set speed and position values , which provides quicker settling time, minimum peak overshoot, minimum rise time and low steady state error while its dynamic transient change with respect to load characteristics. Based on first principle method, modeling of DC motor has been carried out as both Transfer function and state space model. Model based robust feedback controller design (LQR, H-Infinity) provides optimum set point tracking results when compared to conventional controller. The open loop response, Time domain and Disturbance handling analysis have been encountered in MATLAB simulation and then the experimental results are validated by conducting closed loop feedback control test with different load characteristics.

I. INTRODUCTION

DC motors give an attractive other option to AC servo motors in superior movement control applications. DC motors are specifically well known in low-power and high exact servo applications because of their sensible cost and simplicity of control. Generally motor controls [1], [2] in modern applications utilize a course control structure. The external speed and inward current control circles are composed as PD or PI controllers. In any case, the fell control structure expects that the internal circle flows are significantly quicker than the external one (Chevrel et al. (1996)). As of late a few distributions propose elective approaches to recognizable proof and control of DC motors. Umeno and Hori (1991) portray a summed up speed control outline procedure of DC servomotors [3], [4] in light of the parameterization of two-degrees-of-flexibility controllers and apply the plan technique for a Butterworth channel to decide the controller parameter. Chevrel et al (1996) exhibit an exchanged LQR speed controller, planned from the direct model of the DC motor, and analyze its performance with a course control configuration regarding accuracy, vigor and multifaceted nature. Rubaai and Kotaru (2000) propose an elective method to recognize and control DC motors by methods for a nonlinear control law spoken to by a fake neural network. Yu and Hwang (2004) display a LQR approach to decide the ideal PID speed control of the DC motor.

This commitment proposes an orderly approach to speed controller outline of a DC motor in light of model ID and LQR configuration increased with a nonlinear feed-forward compensator [5], [6].

The electrical and mechanical parameters of the DC motor, i.e., opposition, latency, back- EMF, damping are distinguished from perceptions of the open circle reaction. Coulomb grinding is considered as the fundamental driver of the nonlinear motor behavior and is satisfactorily repaid by a feed-forward control flag. The leftover enduring state error caused by minor nonlinearities and vulnerabilities in the model is remunerated by an essential error feedback flag. The proposed controller is assessed for high and low speed reference profiles including speed inversion to show its effectiveness for elite servo applications. The proposed plot endeavors to connect the present hole between the progress of control theory and the practice of DC actuator frameworks. In Section II, the transfer function model and state-space model [7], [8] of the DC-motor has been derived using first principle method (fundamental equations).The model recognizable proof is portrayed in Section III with open loop speed test. Section IV deals with P+I+D control structure implementation for speed control followed by advanced controller design based on Linear Quadratic Regulator (LQR) based state feedback control with an integrator and the feed-forward loop has been discussed in section V. Section VI provides conclusion about proposed work with experimental result analysis of various controller.

II. TRANSFER FUNCTION AND STATE SPACE MODEL OF DC MOTOR

Equivalent model of armature, free body diagram of fixed field-DC Motor [9], [10] rotor is shown in figure1, Based on first principle method system equations are modeled as transfer function as well as state space representation. The relationship between armature-current, motor-torque, angular-velocity and back emf has been given in equation 1-4.

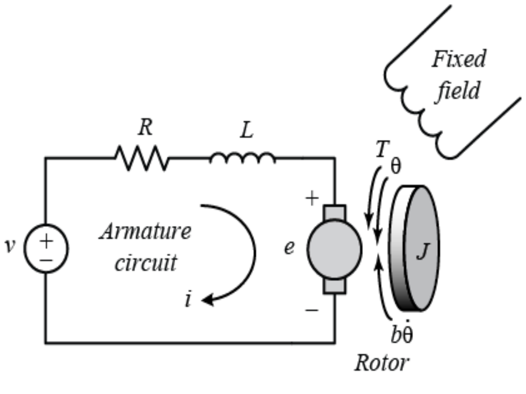

Figure.1. Equivalent Circuit of fixed field DC-Motor

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The armature current and torque relationship is given in equation 1.

$T = K_t\ i$ (1)

The back emf and the angular velocity of the shaft have proportional equality relationship which is given in equation 2.

$e = K_e\ \dot{\theta}$ (2)

From the Figure 1, based on fundamental laws (Newton's and Kirchhoff's laws) the following governing equations are derived.

$$J\ddot{\theta} + b\dot{\theta} = Ki \quad (3)$$

$$L\frac{di}{dt} + Ri = V - K\dot{\theta} \quad (4)$$

The equation 3 and 4 implies the first principle model of DC-motor.

A. Transfer Function Model of DC Motor

The equation 5 and 6 has been obtained taking Laplace transform of equation 3 and 4.

$$s(Js + b)\theta(s) = KI(s) \quad (5)$$

$$(Ls + R)I(s) = V(s) - Ks\theta(s) \quad (6)$$

$$P(s) = \frac{\theta(\dot{s})}{V(s)} = \frac{K}{(Js + b)(Ls + R) + K^2} \quad (7)$$

Where,

$\theta(\dot{s}) =$ DC – motor speed

$V(s) =$ DC – motor Armature voltage

B. State-Space Model of DC Motor

The armature voltage and the rotational speed has been selected as the input and output respectively. The armature current as the state variables. The state space representation [11], [12] is given as,

$$\frac{d}{dt}\begin{bmatrix}\dot{\theta} \\ i\end{bmatrix} = \begin{bmatrix}\frac{-b}{J} & \frac{K}{J} \\ \frac{-K}{L} & \frac{-R}{L}\end{bmatrix}\begin{bmatrix}\dot{\theta} \\ i\end{bmatrix} + \begin{bmatrix}0 \\ \frac{1}{L}\end{bmatrix}V \quad (8)$$

$$y = \begin{bmatrix}1 & 0\end{bmatrix}\begin{bmatrix}\dot{\theta} \\ i\end{bmatrix} \quad (9)$$

The equation 8 and 9 shows the state and output equation of DC-Motor.

C. Design Requirements of DC Motor

The main aim of the design requirement is to control the sped of the DC motor at desired set point or operating condition. Then the additional control outputs should meet the following requirement at any instance.

- Less than 2% of steady state error.
- Less than 2 seconds of settling time.
- Less than 6% of maximum peak-overshoot.

The detailed description of DC motor parameters has been given in Table 1.

Table1. Parameters of DC Motor

Symbol of variables	Description of Parameters	Quantified Value
J	rotor-moment of inertia	0.035Kg.m^2
b	constant value of viscous-friction	0.255N.m.
Ke	Constant of electromotive-force	0.032V/rad/sec
Kt	Constant of motor-torque	0.023N.m/Amp
R	Internal-electrical restriction	1.515Ohm
L	Internal-electrical inductance	0.883Henry

III. DC Motor Speed-Analysis

A. Open loop Test

By conducting open loop test the step response characteristics curve and its time domain specifications has been obtained for equation (7), using MATLAB command- Linear System Analyzer tool

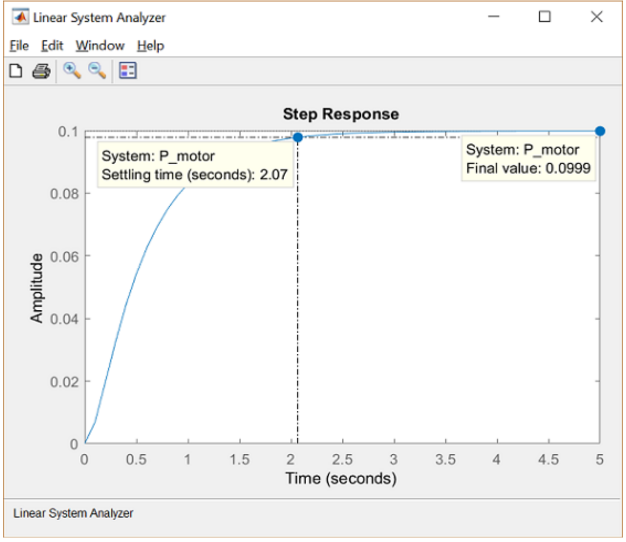

Figure.2. Step Response Analysis

From the figure 2, it is observed that the system model did not attain the desired set speed as 1 rad/sec which attain only 0.1 rad/sec. and also which takes more than 2 sec to settle down. So it is clearly observed that the open loop test will not satisfy the desired design requirements. So the system needs closed loop robust controller in order to achieve the design requirements.

IV. CLOSED LOOP PID CONTROLLER IMPLEMENTATION

The open loop system now modified as closed by introducing feedback to controller. The conventional PID controller takes action after the error occurrence. The closed loop structure is given in figure 3.

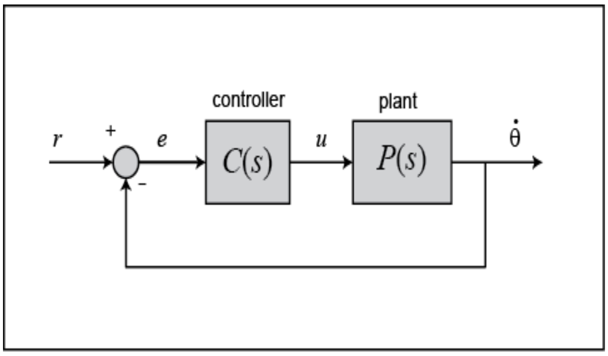

Figure.3. Closed loop structure of DC motor Speed Control

$$C(s)=\frac{u(s)}{e(s)}=K_P e(s)+\frac{K_I}{S}e(s)+K_D e(s)\ldots(10)$$

The equation (10) shows that PID controller output has the effect on error signal.

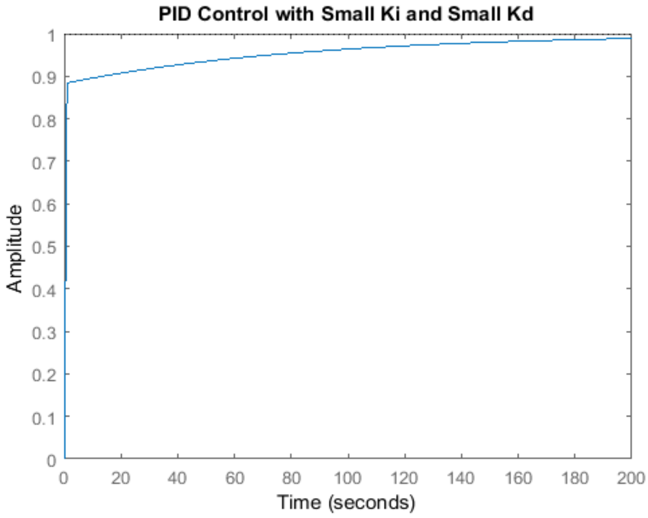

Figure.4. Closed loop PID control Output with K_P=76, K_I=.11, K_D=1.1

Figure 4 shows the closed loop output response with K_P=76, K_I=1.1, K_D=1.1 and there is maximum amount of offset error has been observed. So the system needs to tune effectively with moderate gain parameters.

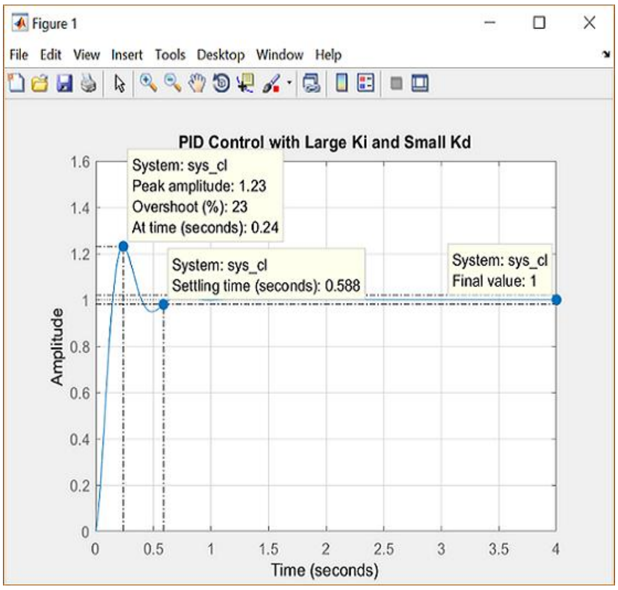

Figure.5. Closed loop PID control Output with K_D=1, K_I=200, K_P=100

Fig.5 shows the closed loop output response with K_D=1, K_I=200, K_P=100 and there is maximum peak overshoot has been observed. So the system needs to further efficient tuning with moderate gain parameters.

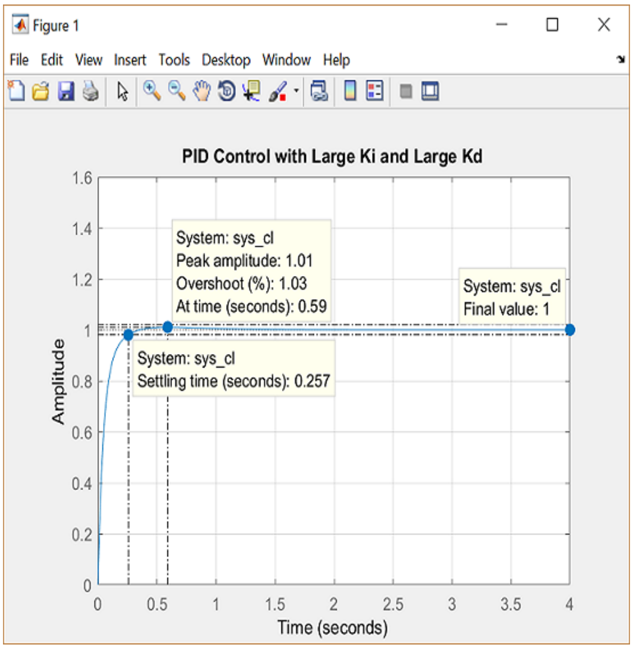

Figure.6. Closed loop PID control Output with K_D=10, K_I=200, K_P=100

Fig.6 shows the closed loop output response with K_D=10, K_I=200, K_P=100and there is no offset error and maximum peak overshoot. So, the controller provides satisfactory output response to control the speed of the DC motor with optimum gain values.

V. ROBUST CONTROLLER IMPLEMENTATION

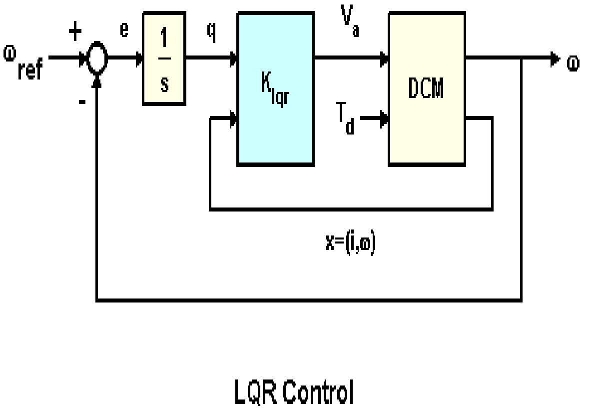

Figure.7. Closed loop Robust LQR controller Design

Figure 7 shows the Linear Quadratic Regulator (LQR) based closed loop control of DC motor speed control [13]. In LQR, the optimum value of gain K_{LQR} provides satisfactory closed loop output without any offset error and overshoot and also LQR handles disturbance effectively [14] when compared to conventional PID based closed loop control strategy.

The final armature voltage of DC motor is given in equation 11 as,

$$V_a = K1 * w + K2 * \frac{w}{s} + K3 * I \qquad (11)$$

The cost function used for better disturbance rejection that penalizes large integral error and it is given in equation 12 and 13.

$$C = \int_0^\infty (20q(t^2) + \omega(t^2) + 0.001V_a(t^2))dt \qquad (12)$$

$$q(s) = \frac{\omega(s)}{s} \qquad (13)$$

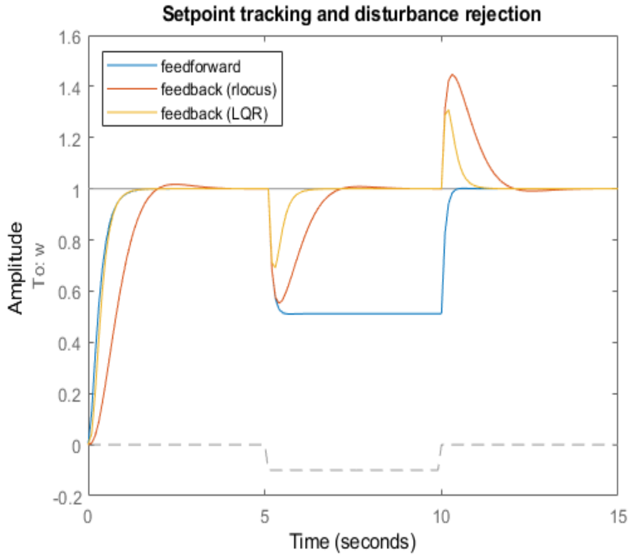

Figure.8. Comparison Result analysis for DC motor Speed Control

From figure 8, it is observed that, the LQR based closed loop control configuration provides superior set point tracking and disturbance rejection performance [15], when compared to existing feed forward and PID based conventional control configuration.

VI. CONCLUSION

From the figure 4, 5, 6 it is observed that the conventional closed loop PID controller does not provides satisfactory response to control the speed of the DC motor. This leads offset error, peak overshoot, large settling time and poor disturbance rejection capability and then, from the figure 7 and 8 it is clearly shows that, the robust LQR based closed loop controller configuration provides ultimate feedback gain which provides satisfactory and optimum closed loop output response with null offset, very minimum peak overshoot and perfect capability of disturbance rejection performance.

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