A Comparative Analysis of Controllers Controlling Uncertainty in the Form of 2nd Order Load, Affecting the Robust Position Control of DC Motor

Er. Farhad Aslam, Er. Birendra Kumar Yadav, Ram Sharan Choudhary, Gopal Kumar Choudhary

ABSTRACT--- All the industrial process applications require robust position control of DC motor. The aim of this paper is to design a robust position control of DC motor by selecting different controllers like P, PI, PID and their tuning methods. The model of a DC motor is considered as a third order system with incorporating uncertainty. This paper compares the different kinds of tuning methods of parameter for PID controller. One is the controller design by Zeigler and Nichols method, second is the auto tuning of the controller in basic design mode and third is in the extended design mode. It was found that the proposed PID parameters adjustment in the basic and extended design mode is far better than the P, PI and Zeigler and Nichols method. The proposed method could be applied to the higher order system also.

Keywords: Basic mode, DC motor, PID tuning, robust position control.

I. INTRODUCTION

Due to its excellent speed control characteristics, the DC motor has been widely used in industry even though its maintenance costs are higher than the other motors like induction motor, synchronous motor, brushless dc motor. As a result, robust position control of DC motor has attracted considerable research and several methods have evolved. Proportional- Integral- Derivative (PID) controllers along with their tuning have been widely used for speed and position control of DC motor.

This paper endeavors to design a system using two methods of auto tuning of PID parameters called Basic design mode and Extended design mode. Auto tuning is basically used to tune PID gains automatically in a Simulink model containing a PID controller block. The PID tuner allows achieving a good balance between performance and robustness. It automatically computes a linear model of the plant. The PID tuner considers the plant to be the combination of all blocks between the PID controller input and output. Thus, the plant includes all blocks in the control loop, other than the controller itself.

The main objectives of PID tuner are closed- loop stability (in which system output remains bounded for bounded input),

adequate performance (in which closed- loop system tracks reference changes and suppresses disturbance as rapidly as possible) and adequate robustness (the loop design has enough gain margin and phase margin to allow for modeling errors or variations in system dynamics.

Basic design mode of PID tuner refines the controller design by adjusting response time. It makes the closed- loop response of the controlled system faster or slower. Extended design mode of PID tuner refine the controller design by separately adjusts loop bandwidth and phase margin. The larger the loop bandwidth, the faster the controller responds to changes in the reference or disturbances in the loop. The larger the phase margin, the more robust the controller is against modeling errors or variations in plant dynamics. The objective of this paper is to show that by employing the proposed tuning of PID controllers, an optimization can be achieved. This can be seen by comparing the result of the PID tuner against the classically tuned system.

II. MODELING A DC MOTOR

To be modeling a DC Motor, simple circuit of its electrical diagram as shown in Fig. 1 is considered. To be Modeling and Simulate the DC motor, the following steps are to be made step by step;
Step1: Represent the DC motor circuit diagram.
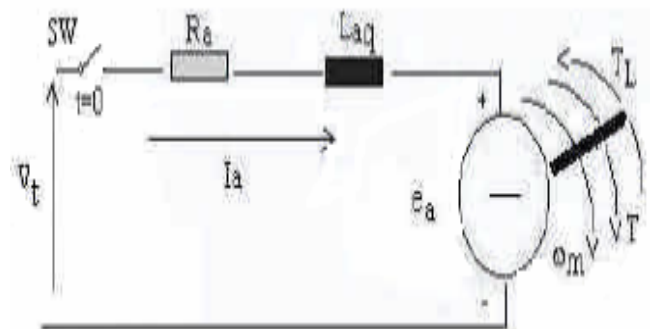Step2: Represent system equations
Step3: Calculate the Transfer function
Step4: Convert to model block
Step5: Run the Simulation
Step6: Analysis

A. Closed-Loop System Consideration
To perform the simulation of the system, an appropriate model needs to be established. Therefore, a model based on the motor specifications needs to be obtained. Fig. 1 shows the DC motor circuit with Torque and Rotor Angle consideration.

Fig. 1 Schematic diagram of a DC motor

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Er. Farhad Aslam, Assistant Professor & HOD, ECE Dept., Amrapali Institute of Technology, Lakhisarai, Bihar, India.
Birendra Kumar Yadav , Assistant Professor, Civil Engineering Dept., Amrapali Institute of Technology, Lakhisarai, Bihar, India.
Ram Sharan Choudhary, Assistant Professor & HOD, Department of Mathematics, Amrapali Institute of Technology, Lakhisarai, Bihar, India.
Gopal Kumar Choudhary, Lecturer, Department of Physics. Amrapali Institute of Technology, Lakhisarai, Bihar, India.

B. System Equation

The motor torque **T** is related to the armature current, **i** , by a torque constant **K**;

$$T = K\,i \qquad (1)$$

The generated voltage, e_a, is relative to angular velocity by;

$$e_a = K\,w_m = K\,d\theta/dt \qquad (2)$$

From Fig. 1 we can write the following equations based on the Newton's law combined with the Kirchhoff's law:

$$J\,d^2\theta/dt^2 + b\,d\theta/dt = K\,i \qquad (3)$$

$$L\,di/dt + R\,i = V - K\,d\theta/dt \qquad (4)$$

C. Transfer Function

Using the Laplace transform, equations (3) and (4) can be written as:

$$J\,s^2\,\theta(s) + b\,s\,\theta(s) = K\,I(s) \qquad (5)$$

$$L\,s\,I(s) + R\,I(s) = V(s) - K\,s\,\theta(s) \qquad (6)$$

Where *s* denotes the Laplace operator. From (6) we can express **I**(*s*):

$$I(s) = \frac{V(s) - K\,s\,\theta(s)}{R + Ls} \qquad (7)$$

and substitute it in (5) to obtain:

$$J\,s^2\,\theta(s) + b\,s\,\theta(s) = \frac{K\,(V(s) - K\,s\,\theta(s))}{R + Ls} \qquad (8)$$

This equation for the DC motor is shown in the block diagram in Fig. 2. From equation (8), the transfer function from the input voltage, **V** (*s*), to the output angle, θ, directly follows:

$$G(s) = \frac{\theta(s)}{V(s)} = \frac{K}{[\,s\{(R+Ls)(Js+b) + K^2\}\,]} \qquad (9)$$

Before any consideration of the above equations, we must know the constant values of data, K, J, b, V, L and R. This is very important to the application of DC motor which we will be used.

Speed N = 1220 rpm = 127.7 rad/sec

Motor inertia J = 1 Kg.m^2 V = 240V

$$i = armature\ current = 16.2\ A$$

$E_O = V - i\,R_a = 230.3$ V   Power $P = E_O\,I_a = 3731$ W = 5 HP

$I_f = V/R_f = 1$ where $R_f = 240$ Ω $E_O = w\,L\,I_{f\,=}\,127.7$ rad/sec

Therefore for the max speed rpm of 1220, it can be calculate the torque constant K;

$$w_m = \frac{V}{K} = \frac{2\pi N}{60} \qquad (10)$$

K = 1.88 N. m/A

By using equation (3), for w = dθ/dt

$$K \times i = J\frac{dw}{dt} + bw \qquad (11)$$

At the steady state (used as analyzed data), both **I** and **w** are stabilized;

$$J\frac{dw}{dt} = 0 \ \ and \ \ T = \frac{P}{w} = 29.2\ Nm$$

Therefore, the total equivalent damping **b** can be chosen the value of;

$$b = \frac{K \times i}{w} = 0.24\ N.m.s \qquad L = mutual\ inductance = 1.8\ H$$

$$R = armature\ resistance = 0.6\ \Omega$$

By calculating and assuming the require data as above, the following value are assigned to be used for our desire DC Motor Model. **V**=240 V; **J**= 1 kg.m^2; **b** =0.24 N.m.s; **K** =1.88 N. m/A; **R** =0.6 Ω; and **L** =1.8 H;
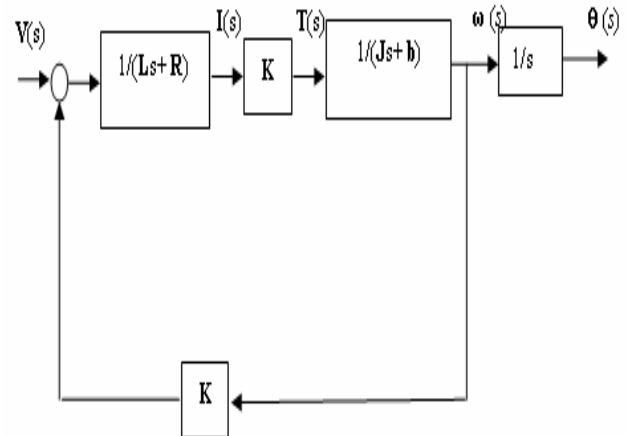

Fig. 2 A closed- loop system that representing the DC motor

III. SIMULATION, TESTING AND RESULTS

There are four cases in which uncertainty in the form of disturbance and load is incorporated to the system.

Our Design requirement

Maximum Overshoot = < 2%
Undershoot = 0
Rise time (t_r) = < 7 sec
Settling time (t_s) = < 12 sec

In the paper, the given system is incorporated with an uncertainty in the form of 2nd order load.
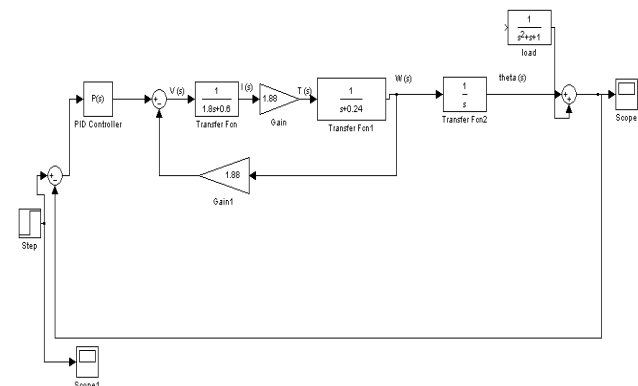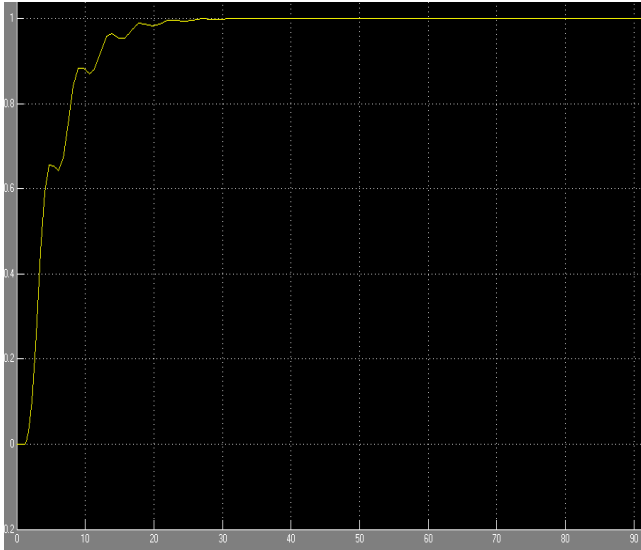

Fig. 3 Process model with P controller
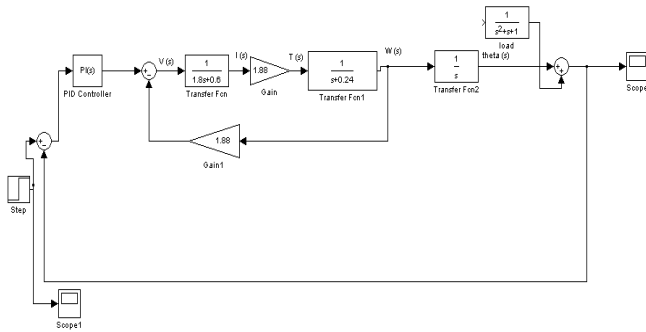
Fig. 4 System output with P controller

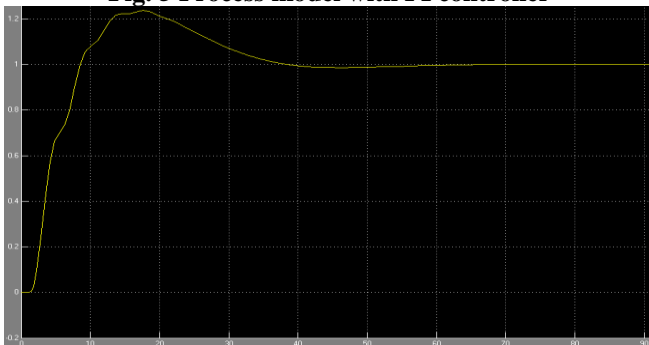**Fig. 5 Process model with PI controller**

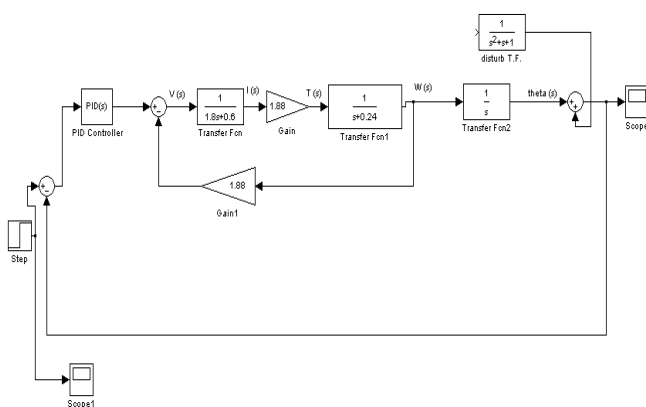**Fig. 6 System output with PI controller**

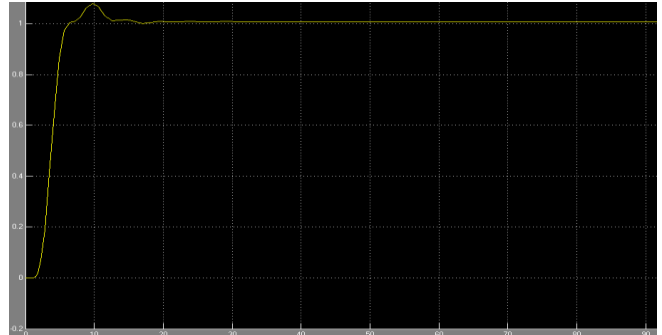**Fig. 7 Process model with PID controller**

Fig. 8 System output with PID controller auto tuning (Basic design mode)
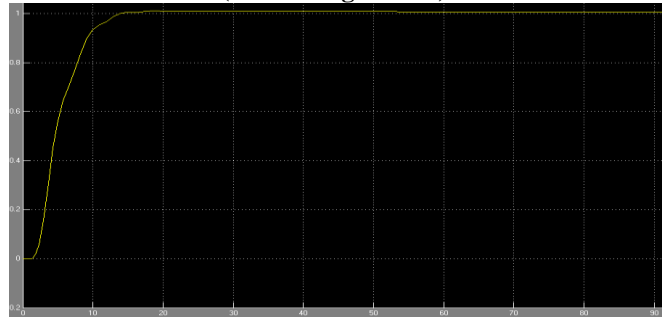

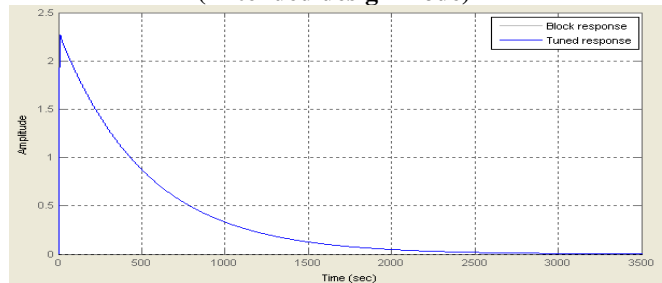**Fig. 9 System output with PID controller auto tuning (Extended design mode)**

Fig. 10 Step disturbance rejection plot with PID controller auto tuning (Extended design mode)
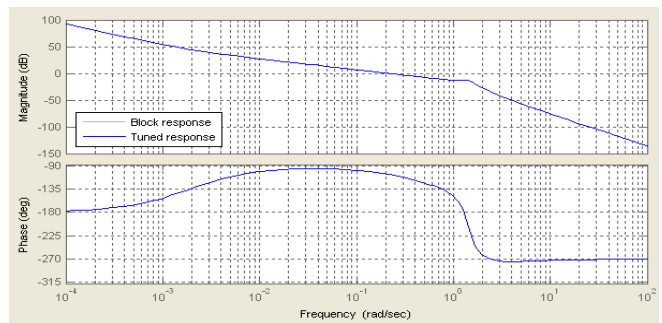

Fig. 11 Open- loop Bode plot with PID controller auto tuning (Extended design mode)

Table 1. Comparative analysis of different controllers under 2nd order load

Controller types	K_P	K_I	K_D	Rise time (t_r in sec)	Settling time (t_s in sec)	Over shoot (%)	Under shoot (%)	Gain margin(db@ rad/sec)	Phase margin (deg@rad/sec)
P	0.43695	0	0	9.6	16.1	0.00758	32	8.19@1.43	86.2@0.229
PI	0.35952	0.037665	0	5.45	34	23.7	0	9.62@1.41	60@0.21
PID(Basic)	0.76098	0.0031897	-1.276	2.65	11	8.05	0	8.88@1.2	60@0.361
PID(Ext.)	0.43964	0.0019183	-1.103	6.53	11.6	1.12	0	13@1.28	73@0.278

After incorporating 2nd order load, the design requirement of the system is achieved in the extended design mode which is shown in table 1.

IV. CONCLUSION

Electric machines are used to generate electrical power in power plants and provide mechanical work in industries. The DC machine is considered to be basic electric machines. The aim of this paper is to introduce Technicians to the modeling of power components and to use computer simulation as a tool for conducting transient and control studies. Next to having an actual system to experiment on, simulation is often chosen by engineers to study transient and control performance or to test conceptual designs.

MATLAB/SIMULINK is used because of the short learning curve that most students require to start using it, its wide distribution, and its general-purpose nature. This will demonstrate the advantages of using MATLAB for analyzing power system steady state behavior and its capabilities for simulating transients in power systems and power electronics, including control system dynamic behavior.

This paper has demonstrated the implementation of auto tuning of PID controller in MATLAB/SIMULINK, both in basic and extended design mode. This is easy to implement and requires a small amount of time. The controller showed robust performance of the system under uncertainty and optimization of the system is achieved which is less complex than other controllers and optimization technique.

REFERENCES

1. Steven T.Karris, 'Introduction to Simulink with Engineering Applications', Orchard Publications,www.orchardpublications.com
2. Tan Kiong Howe, May 2003, Thesis, B.E (Hons.), 'Evaluation of the transient response of a DC motor using MATLAB/SIMULINK', University of Queensland.
3. Math Works, 2001, Introduction to MATLAB, the Math Works, Inc.
4. O. Dwyer, .PI And PID Controller Tuning Rules for Time Delay Process: ASummary. Part 1: PI Controller Tuning Rules, Proceedings of Irish Signals and Systems Conference, June1999
5. Raghavan S. Digital control for speed and position of a DC motor. *MS Thesis,Texas A&M University, Kingsville,* 2005.
6. M. Chow and A. Menozzi, "on the comparison of emerging and conventional techniques for DC motor control," Proc. IECON, pp. 1008- 1013, 1992.
7. SimPowerSystems for use with Simulink, users guide, Math Works Inc., Natick, MA, 2002.
8. S. Li and R. Challoo, Restructuring electric machinery course with an integrative approach and computer-assisted teaching methodology, IEEE Trans Educ. 49 (2006), 16_28.
9. J. J. D'Azzo and C. H. Houpis, Linear control system analysis and design, McGraw-Hill, New York, 1995.
10. S. J. Chapman, Electric machinery fundamentals, 3rd ed., WCB/McGraw-Hill, New York, 1998.

AUTHORS PROFILE

Er. Farhad Aslam, Passed M.E. (EIC) from Thapar University, Patiala. He has Published three national and three international papers. He has life membership of International Association for Engineers (IAENG). He is now working as an Assistant Professor & HOD in Electronics & Communication Engineering, Amrapali Institute of Technology, Bihar,India.

Er. Birendra Kumar Yadav, He has Completed M.Tech from Indian School of Mines, Dhanbad. He has Published one national and two international papers. He has life membership of International Association for Engineers (IAENG). He is now working as an Assistant Professor in Department of Civil Engineering of "Amrapali Institute of Technology", Bihar India.

Mr. Ram Sharan Choudhary, He has Completed M.Sc in Mathematics. And Currently Pursuing Ph.D in Mathemtics. He is now working as an Assistant Professor in Department of Mathematics of "Amrapali Institute of Technology", Bihar India.

Mr. Gopal Kumar Choudhary, He has Completed M.Sc in Physics and Currently Pursuing M.Tech in VLSI. He is now working as a Lecturer in Department of Physics of "Amrapali Institute of Technology", Bihar India.