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Two Degree of Freedom PID Controller For speed control of DC Motor

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***Abstract**: In the classical control of PID various versions and variations of PID are exercised. For instance, series and parallel and other is according to degree of freedom for the given process. For a process two main objective of control are set point tracking and load disturbance rejection. A two Degree of Freedom controller has two separate controller units each for set-point tracking and disturbance rejection. However the use of 2-DOF controllers introduces additional parameters that need to be tuned appropriately. One of the most common applications in all mechatronics domains is the control of DC motors. A number of control algorithms have been projected for such motors, ranging from conventional PID algorithms, to most sophisticated advance methods. This paper propose 2-DOF PID controller for speed control of DC motor. 2-DOF PID controller gives better result compare to PID controller.*

***Keywords**: PID, 2-DOF PID, tracking, feedback, feed-forward*

I. Introduction

Control theory is an interdisciplinary branch of engineering and mathematics that deals with the behaviour of dynamical systems. The desired output of a system is called the reference. In the field of control system, various control strategies and methods are implemented, devised and experienced in the process control and other control applications. In control methodology, mostly prefers controllers are proportional, Integral and derivative in parallel and/ or series combinations so far. PID controllers are used for its simplicity and better performance in majority of cases. Tuning of controllers is the main task for better performance of the system.

The degree of freedom of a control system is defined as the number of closed-loop transfer functions that can be adjusted independently [1]. Two-degree-of-freedom (abbreviated as 2-DOF) controller have advantages over one-degree-of-freedom (abbreviated as 1-DOF) controller. Two basic requirements are regulation (disturbance rejection) also called staying at a given set point and command tracking (implementing set point changes) which refer to how good the controlled variable is in tracking the desired value. Specific criteria for command tracking include rise time and settling time. Satisfying these two operating conditions simultaneously is difficult by using 1-DOF Controller. Therefore 2-DOF controller formulation is expected at trying to meet objectives, say good regulation and tracking properties. This second degree of freedom is aimed at providing additional flexibility to the control system design [2].

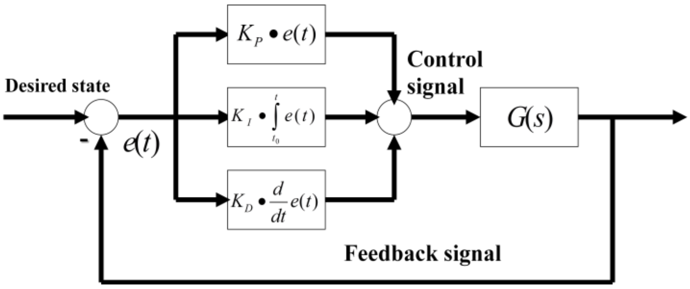
The development of high performance motor drives is very important in industrial as well as other purpose applications such as steel rolling mills, electric trains and robotics. Almost every mechanical movement that we see around us is accomplished by an electric motor. The control of DC motors has been the interest of many researchers, ranging from simple conventional PID controller to more sophisticated algorithms.

II. Control strategies

A. PID controller

In the field of control engineering ultimate aim of any controller is reduction of error in majority of the cases. Generally control engineer prefers PID controller for their application due to its simplicity and better performance in majority of cases. Tuning of PID controller is the main task for better performance. The PID control scheme is named after its three correcting terms, whose sum constitutes the manipulated variable (MV). The output of the PID controller is calculated by summation of the proportional, integral, and derivative terms [3][4], as shown PID structure in figure 1.

Figure 1: PID controller structure



Defining u(t) as the controller output, the final form of the PID algorithm is;

$$u(t) = K_P \cdot e(t) + K_I \cdot \int e(t)dt + K_D \cdot \frac{d}{dt} e(t) \tag{1}$$

Where, K_P = Proportional Gain, K_I = Integral Gain, K_D = Derivative Gain, $e(t)$ = Error Signal, $u(t)$ = control effort.

B. 2-DOF PID controller

The design of control systems is a multi-objective problem, so a two degree-of-freedom (abbreviated as 2DOF) control system naturally has advantages over a one degree-of freedom (abbreviated as 1DOF) control system [3][5]. A general form of the 2-DOF PID controller is shown in Figure 2, where the controller consists of two compensators $G_{ff}(s)$ and $G_c(s)$, which are known as

1. Set point controller transfer function also known as feed-forward compensator which is $G_{ff}(s)$ and given by

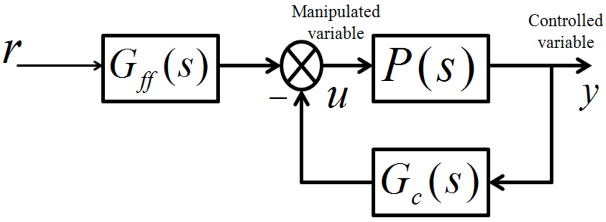
$$G_{ff}(s) = K\left(\beta + \frac{1}{sT_i}\right) \tag{2}$$

2. Feedback transfer function (feedback compensator) which is $G_c(s)$ and given by

$$G_c(s) = K\left(1 + \frac{1}{sT_i} + sT_d\right) \tag{3}$$

Where; β is set point weighting factor or controller parameter $(0 \le \beta \le 1)$ and K, T_i, T_d are PID controller parameter that is Proportional Gain K , integral time T_i and derivative time T_d respectively.

Figure 2: 2-DOF PID controller structure



Where, P(s)= Plant transfer function, u= Manipulated variable, y= controlled variable or output, r= set point. Manipulated variable (u) for continuous controller is given as

$$u(t) = K\left[\beta r(t) - y(t) + \frac{1}{sT_i}(r(t) - y(t)) - sT_d y(t)\right] \tag{4}$$

Many different ways of discretize the continuous controller of equation 4. However here forward difference approximation is used for integral mode and backward difference approximation is used for derivative mode [8]. So after discretizing, final discrete 2-DOF controller equation is

$$u(n)=\frac{T_c(z)}{R_c(z)}r(n)-\frac{S_c(z)}{R_c(z)}y(n) \tag{5}$$

Where; $\frac{T_c(z)}{R_c(z)}$ is feed-forward compensator and $\frac{S_c(z)}{R_c(z)}$ is feedback compensator, and $R_c(z), S_c(z), T_c(z)$ are given by following polynomials.

$$\begin{aligned} R_c(z) &= [1-z^{-1}] \\ T_c(z) &= [\beta+(b_i-\beta)z^{-1}] \\ S_c(z) &= [(1+b_d)+(b_i-1-2b_d)z^{-1}+b_d z^{-2}] \end{aligned} \tag{6}$$

Where $b_i=(T_s/T_i)$ and $b_d=(T_d/T_s)$, T_s is sampling period.

III. System identification

The field of system identification uses statistical methods to build mathematical models of dynamical systems from measured data. System identification also includes the optimal design of experiments for efficiently generating informative data for fitting such models as well as model reduction.

A. Benix DC Motor specification

Here BENIX DC motor kit, that is used for as a system is given in figure 3. For DC motor, transfer function or model is identified using MATLAB tool. This BENIX DC motor kit is consisting of following individual unit:

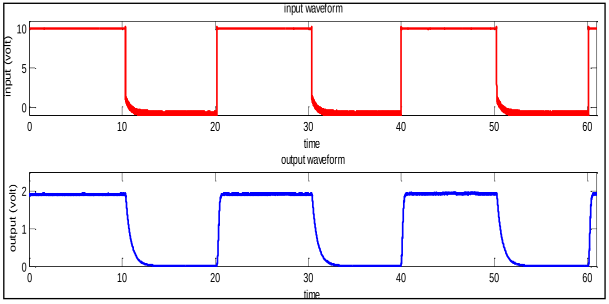
1. DC Motor unit
2. Power Supply unit
3. Optical Encoder Unit
4. Frequency to Volt Converter

Figure 3: Benix DC motor kit

B. System identification

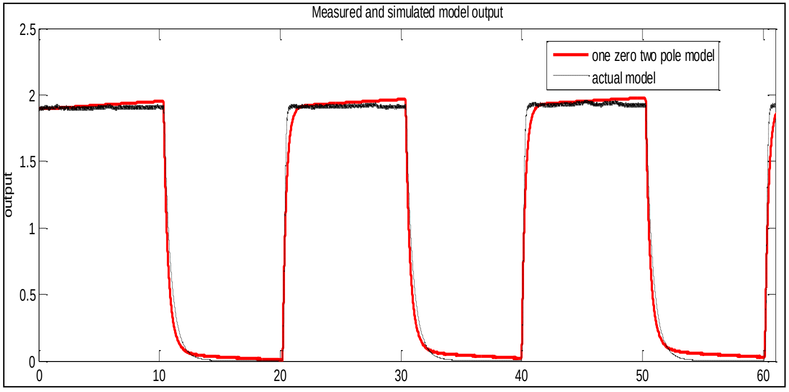
To identify model of DC motor as it is unknown to us we can proceed with identification of system using step change test method as in open loop strategy [9]. With the help of MATLAB system identification toolbox and, data taken at sampling time (Ts) = 0.001sec; control effort u (volt) and output y (volt). Input-output waveform for the DC motor

Figure 4: Input-output waveform of DC motor



Using these input output signals and with the help of MATLAB System Identification Toolbox the system is identified as $G(s)=\frac{0.5957s+0.0683}{(s^2+3.248s+0.339)}$ with one zero and two pole. This estimated transfer function fits to data by 91.15%. Waveform of estimated model and actual model is shown in figure 5.

Figure 5: Estimated and actual model output



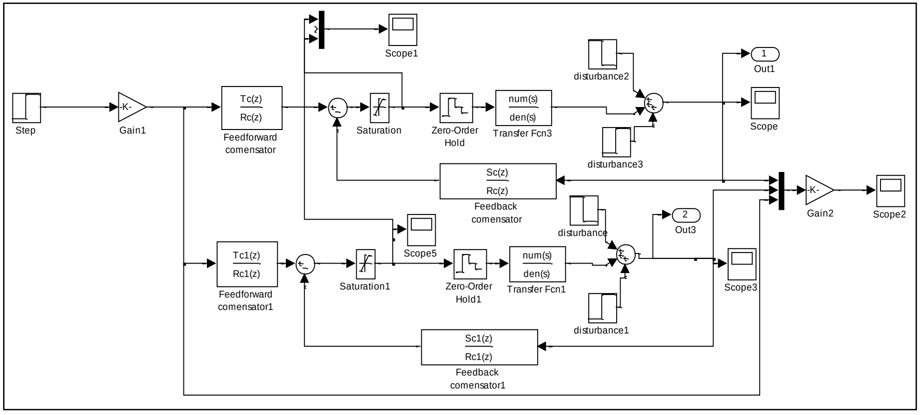
IV. Controller Design And Simulation Result

For DC Motor, using above estimated transfer function 2-DOF PID controller is design. Controller parameter Kp, Ti and Td are calculated using Good Gain method [6]. And these parameter are proportional gain $K_p=16.57$, integral time $T_i=0.22$ sec and derivative time $T_d=0.04$ sec. The set point weighting factor (β) is calculated using equation (7)

$$\beta = \min\left\{\frac{T_i}{T_d * K_p}, 1\right\} \tag{7}$$

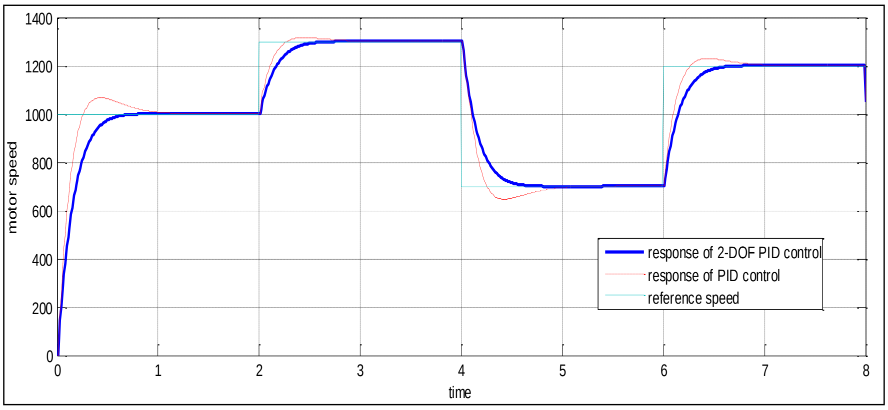
Using the above equation value of set point weighting factor β, *is* 0.3947. A DC motor system is modeled in MATLAB simulation file as shown in Figure 6, for 2-DOF PID controller and PID controller.

Figure 6: DC Motor with PID and 2-DOF PID Controller



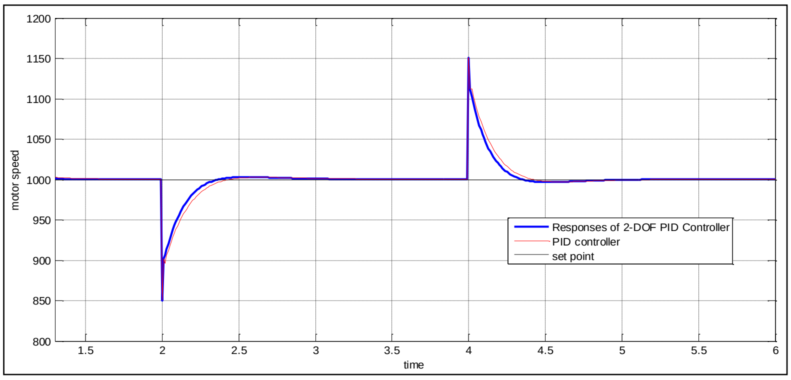
Using this controller setting the system response for set point tracking is shown in figure 7.

Figure 7: Simulation result for 2-DOF PID and PID Controller for tracking



The system response for Disturbance rejection under load changes is shown in figure 8.

Figure 8: Disturbance rejection or system under load changes



V. Analysis

Table I: Comparison table for PID and 2-DOF PID controller

Parameter	2-DOF PID controller	PID controller
Percentage Overshoot %	0.1	4.1
Settling Time sec	0.885	1.3

VI. Conclusion

Here a system actually requires a minimum number of independent controllers equal to the degree of freedom of the system or purpose of the control system. The purpose is tracking as well as disturbance rejection giving the requirement of two independent controllers; and the system is having the degree of freedom two. An effort is made to design a control proposal satisfying the two fold purpose of control. As seen from the analysis and plots the new design having a 2-DOF PID control has far reaching results. Clearly the system performs better under two-DOF PID control with a very less percentage overshoot and good load disturbance rejection with a minimum settling time, all of these compare to PID controller.

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