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Design & Analysis of 2-Dof PID Controller for Speed Control of DC Motor

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Abstract— To design and analysis 2-Dof PID controller I have done many exercise over the reference paper. In this paper I have work on the 2-dof PID controller. 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.

In which I make a mainly focus on 2 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. The use of good gain method through us get fast set-point tracking and also load disturbance rejection. . However the use of 2-DOF controllers introduces additional parameters that need to be tuned appropriately. This paper propose 2-DOF PID controller for speed control of DC motor. 2-DOF PID controller gives better result compare to PID controller.

I. Introduction

In spite of all the advances in control over the past 50 years the PID controller is still the most common controller Even if more sophisticated control laws are used it is common practice to have an hierarchical structure with PID control at the lowest level, . A survey of more than 11,000 controllers in the refining, chemicals, and pulp and paper industries showed that 97% of regulatory controllers had the PID structure. Embedded systems are also a growing area of PID control. Because of the widespread use of PID control it is highly desirable to have efficient manual and Automatic methods of tuning the controllers. A good insight into PID tuning is also useful in developing more schemes for automatic tuning and loop assessment.

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

Proportional-integral-derivative controller (**PID controller**) is a control loop feedback. Commonly used in industrial control systems. A PID controller continuously calculates an "error value" as the difference between a measured processes. Variable and a desired set point. The controller attempts to minimize the error over time by adjustment of a control variable, such as the position of a control

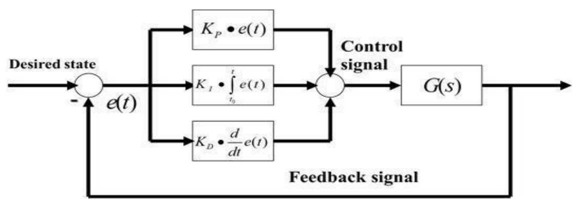

Figure 1: PID controller structure

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

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 degree of freedom of a control system is defined as the number of closed loop transfer functions that can be adjusted independently. 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.

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

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

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

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

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.

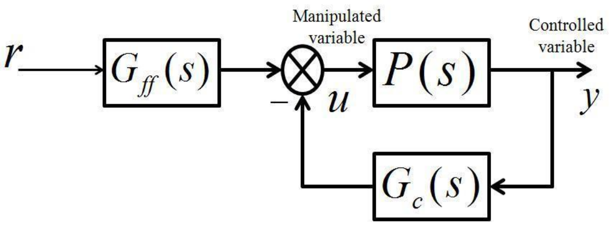

Figure 2: 2-DOF PID controller structure

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

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

So after discretizing, final discrete 2-DOF controller equation is:-

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

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.

$$u(n) = \frac{K[(\beta r - y)(z^2 - 1)z + b_i (r - y)z - (z - 1)^2 b_d]}{z(z - 1)}$$

$$u(n)(z^2 - z) = K[(br - y)(z^2 - z) + bi(r - y)z - (z^2 - 2z + 1)ba]$$

$$u(n)(1 - z^{-1}) = K[(br - y)(1 - z^{-1}) + bi(r - y)z^{-1} - (1 - 2z^{-1} + z^{-2})ba]$$

$$u(n)(1 - z^{-1}) = K[(\beta r - y)(1 - z^{-1}) + b_i z^{-1} r - (1 - z^{-1}) y - b_i z^{-1} y - (1 - 2z^{-1} + z^{-2} b_d y)]$$

$$u(n)(1 - z^{-1}) = K[\beta + (b_i - \beta) z^{-1}]r - [(1 + b_d) + (-1 + b_i - 2b_d) z^{-1} + z^{-2} b_d]y$$

$$R_c(z) = [1 - z^{-1}]$$

$$T_c(z) = [\beta + (b_i - \beta) z^{-1}]$$

$$S_c(z) = [(1 + b_d) + (b_i - 1 - 2b_d) z^{-1} + b_d z^{-2}]$$

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

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 .D.C Kit specification

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

TOOLBOX THE SYSTEM IS IDENTIFIED AS $G(s) = \frac{0.5957\, s + 0.0683}{(s^2 + 3.248\, s + 0.339)}$ WITH ONE ZERO AND TWO POLE. THIS ESTIMATED TRANSFER FUNCTION FITS TO DATA BY 91.15%. WAVEFORM OF ESTIMATED MODEL AND ACTUAL MODEL

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. And these parameter are proportional gain $K_p=18$, integral time $T_i=0.3$ sec and derivative time $T_d=0.04$ sec. The set point weighting factor (β) is calculated

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

Using the above equation value of set point weighting factor *β, is* 0.6. A DC motor system is modeled in MATLAB simulation file as shown in Figure 6, for 2-DOF PID controller and PID controller.

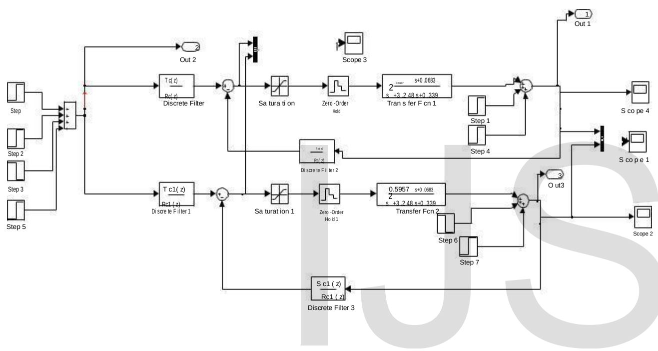

Figure : DC Motor with PID and 2-DOF PID Controller

Using this controller setting the system response for set point tracking

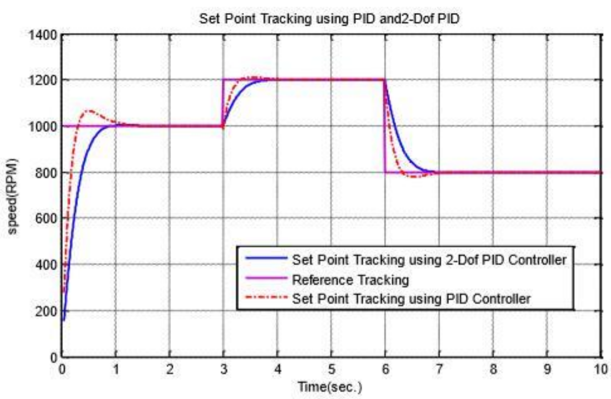

Figure: Simulation result for 2-DOF PID and PID Controller for tracking

The system response for Disturbance rejection under load changes is shown in
Disturbance Rejection Using PID

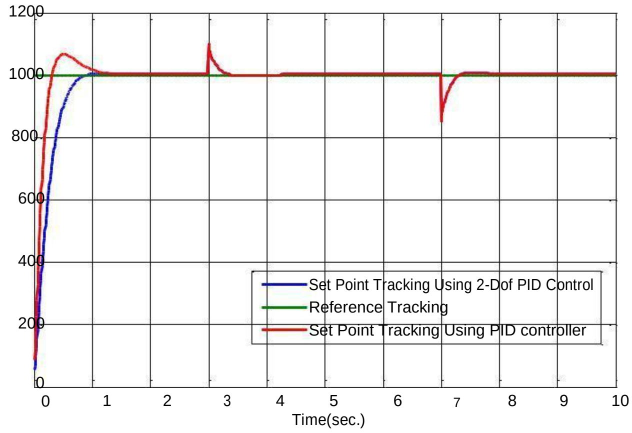

Table I: Comparison table for PID and 2-DOF PID controller

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

III. 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.. 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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