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Developing and Simulating a Model using Proportional Integral Derivative (PID) on Matlab/Simulink for Speed Control of DC Motor

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Abstract
This study uses MATLAB/SIMULINK to perform a thorough inquiry of the use of Proportional Integral Derivative (PID) control for accurate speed control of a DC motor. To increase steady-state error, decrease settling time, and improve transient response, the suggested model uses sophisticated PID tuning techniques. The efficacy of the PID controller in preserving the intended speed setpoints is demonstrated by means of comprehensive simulation experiments that assess its performance in a range of operational scenarios. This work creates a useful foundation for DC motor speed control system optimization in addition to offering insightful information on PID-based control techniques.

Keywords: Speed Control, DC Motor, PID Controller, Control System, Transient Response

Introduction

A crucial component of many industrial applications, including robotics and electric vehicles, is DC motor speed control. Optimizing performance and energy efficiency requires accurate and responsive speed regulation. In dynamic systems, proportional integral derivative (PID) control has shown to be a flexible and extensively used method for attaining precise and stable management. This study uses MATLAB/SIMULINK to create and simulate a PID-based speed control system for a DC motor. Improving the motor's dynamic response, cutting down on settling time, and lessening steady-state inaccuracy are the goals. This work seeks to provide useful insights into the application of PID control techniques for DC motor applications through systematic tuning and simulation experiments.

DC motors can be controlled by varying the armature voltage or field current, depending on the type. They are frequently controlled using PID controllers because of their simple architecture. It is necessary to conduct experiments or choose the most appropriate mathematical model of the system in order to modify PID parameters. However, nonlinear, complicated applications where the system model cannot be accurately characterized are not well suited for standard PID (Huang, 2008). Temperature, variations in current and voltage, loading circumstances that fluctuate over time, and driving and operating conditions are just a few of the electrical characteristics that affect motors over time. Variations in loading cause variations in the rotor's speed.

The utilization of PID controllers is limited in applications like speed control due to its susceptibility to external disturbances, loading variations, and parametric changes that arise based on its position. Up till now, PID controllers with constant coefficient have not been able to demonstrate good performance. To address these issues, other modified PIDs, including adaptive and self-tuning, have been created. Furthermore, in order to obtain a control structure with improved performance, many techniques such as fuzzy logic, fractional order PID, genetic algorithms, and others are researched for use in DC motor applications control. In a simulation research, fuzzy logic control and PI are used to achieve control of a permanent magnet DC motor (PMDC). Early in the 1950s, the Soviet Union introduced variable structure control, or VSC. Control actions in variable structure systems (VSS) are discontinuous functions of system states, disturbances, and reference inputs since the VSS is made up of a collection of continuous subsystems with appropriate switching logic. Sliding modes play a crucial part in VSS theory, and the basic idea behind creating VSS control algorithms is to enforce this kind of motion in certain system state space manifolds. An adequate control should be created when a system experiences uncertainties and disturbances in order to maintain system stability and provide the intended reactions (Kanojiya and Meshram, 2012). When external uncertainties and disturbances are present, sliding mode control (SMC) is insensitive. In particular, to the corresponding uncertainties. Due to SMC's resilience qualities, a wide range of linear and nonlinear systems can be effectively controlled using this intensive, well-liked, and appropriate technology. Over the past three decades, a variety of SMC approaches—including both theoretical advancement and practical application of SMC-have emerged. PI controllers have been in use for more than 50 years, have a simple control structure, have a fair price tag, and offer a plethora of recommended methodical tuning methods.

Century. PI controllers, however, are not always able to stabilize the system when it is nonlinear but known or has bounded uncertainties. This is especially true when the bound of uncertainty is big or the nonlinearity is very high. Almost flawless disturbance rejection or control performance is needed in many real-world scenarios. To achieve these performances, the system may be subjected to SMCs. The system trajectories are forced to move on a predefined surface and stay there for the duration of their movement by an SMC. Conversely, however, a discontinuous SMC may be approximated by a continuous control. In fact, the trajectories tend to an equilibrium point within a boundary of the sliding surface. When the trajectories move on the sliding surface, the system is internally controlled by a virtual control, the so-called equivalent control. SMCs are insensitive in the presence of uncertainties and unmodeled dynamics.

One method for approaching variable structure control is the sliding mode control. Near-perfect disturbance rejection and set point tracking are necessary in many real-world scenarios. These performances can be obtained for such systems by applying SMC. The feedback in VSC is non-linear and discontinuous in nature. Because the control input rapidly alternates between two or more control limits, the control is referred to as non-linear.

3.1 Mathematical Model of a Typical DC Motor

The mathematical model of the DC motor is modeled on the parameters from table given below. The BLDC motor provided for this work is the EC 45 flat Φ 45 mm, brushless, 30 Watt from Maxon motors. The parameters used in the modeling are extracted from the parameters used. Find below in Table 3.1 the major extracted parameters used for the modeling task.

Table 3.1: Parameters of DC Motor

S. No	No Data	Unit	Value
1	**Nominal voltage**	**V**	**12**
2	No load speed	Rpm	1200
3	No load current	Ma	151
4	Nominal speed	Rpm	1200
5	Torque	mNm	59.1
6	Nominal current	A	2.14
7	Starting current	A	10
8	Max.efficency	%	77
9	Stall Torque	mNm	255
10	Terminal resisitance	Ω	1.1
11	Terminal inductance	MH	0.5
12	Torque constant	MNm/A	24.5
13	Speed constant	rpm/V	35.4
14	Speed/Torque gradient	Rpm/mNm	17.6
15	Mechanical time constant	Ms	16.1
16	Rotor inertia	gcm	82.5
17	No of phase		3

$$GS = \frac{1/K_g}{\tau m \tau e S^2 + \tau m s + 1} \tag{3.1}$$

Where Kg, τm and τe are the constatnts

$$\tau_e = \frac{L}{3R} \tag{3.2}$$

$$\tau_e = \frac{0.5\times10^{-3}}{3\times1.10} \tag{3.3}$$

$$\tau_e = 151.51\times10^{-6} \tag{3.4}$$

τe is calculated using

$$\tau_e = \frac{3R_\phi j}{K_g K_T} = 0.0161 \tag{3.5}$$

Where K_e is

$$K_e = \frac{3R_\Phi J}{\tau_m K_t} = 0.06902 \tag{3.6}$$

Thus, the model for the DC motor in the form of the transformation function is:

$$G(s) = \frac{14.48}{2.44\times10^{-6}s^2 + 0.0161s + 1} \tag{3.7}$$

3.2 Design of Sliding Mode Controller

The sliding surfaces are designed to impose a trajectory tracking of the output with respect to a reference Thus, for each component of, one may choose: y. ref y), (txS

$$S_j(x,t) = \sum_{i=0}^{r_j-1} l_{ji}(y_{jref} - y_j)^{(i)} \quad j = 1,2,..m \tag{3.8}$$

Where *j r* is the relative degree of the output *j y*. The value of *j r* implies that sth is dependent on *S*□. The sliding surface (8) is designed as a linear dynamics of tracking error (*y y*) *ref* □. It is possible to guarantee the sliding surface by an adequate choice of the coefficients *ji l*, so if the system is constrained to remain in surface *S*(*x*, *t*) □ 0, it slides towards the origin, i.e., the error (*y y*) *ref* tends toward zero with the trajectory dynamics constrained by the choice of;

$$\dot{S}(x,u,t) = \frac{dS}{dt} = \frac{\partial S}{\partial x}\frac{dx}{dt} + \frac{\partial S}{\partial t} \qquad j = 1,2,\dots m \tag{3.9}$$

$$\dot{S}(x,u,t) = \frac{\partial S}{\partial x}(f(x,t) + g(x,t)u) + c(t) \tag{3.10}$$

Equation (3.10) can be written in the following form:

$$\dot{S}(x,u,t) = a(x,t) + b(x,t)u \tag{3.11}$$

The control law for (3.11) is defined as:

$$u = \frac{-a(x,t) + u_n}{b(x,t)} \tag{3.12}$$

The result of the application of this control is:

$$\dot{S}(x,u,t) = u_n \quad (3.13)$$

A possible way to design the switching function is to use one dead zone and two linear zones or using the hyperbolic tangent function, in order to smooth the control. For a DC motor with no saturation of the magnetic circuit, the equation 3.13 is obtained. The outputs and are the current(s) of (the) armature and the speed. The goal is to force these outputs to track a given trajectory. According to the presented technique, the sliding surfaces that are selected are

$$\begin{cases} S_1 = (\dot{\omega}_{ref} - \dot{\omega}) + l_1(\omega_{ref} - \omega) \\ S_2 = l_2(i_{aref} - i_a) \end{cases} \quad (3.14)$$

The objective is to force these outputs to trend toward zero to obtain a sliding mode. The dynamic equation of is:), (1 t x S

$$\dot{S}_1(x,u,t) = (\ddot{\omega}_{ref} - \ddot{\omega}) + l_1(\dot{\omega}_{ref} - \dot{\omega}) \quad (3.15)$$

If the load disturbance is taken into account, equation (3.16) becomes:

$$\dot{S}_1(x,u,t) = a_1(x,t) + b_{11}(x)u_1 + b_{12}(x)u_2 \quad (3.16)$$

The dynamics of $S_2(x,t)$ is as follows:

$$\dot{S}_2(x,u,t) = l_2(\dot{i}_{aref} - \dot{i}_a) = a_2(x,t) + b_{21}(x)u_1 \quad (3.17)$$

Finally, the control is written as:

3.3 The PID Controller

PID controllers have the best control dynamics, with faster response times, no oscillations, zero steady state error, and increased stability. In addition to PI controllers, PID controllers use derivative control to remove overshoot. The ability of PID controllers to be employed with higher order processes, such as those involving multiple energy one of their main benefits is that they are storage units. While PID controller tuning seems straightforward in theory, in practice It's a really challenging problem. Incorrect P-I-D parameter selection could result in an unstable control process, either with or without oscillations. Any system should have a stable output and a non-oscillating process under all set point and disturbance conditions. The three fundamental PID controller modes are derivative, integral, and proportional. Rapid manipulating variable adjustment in proportional mode lowers inaccuracy and accelerates dynamic reaction. Zero offset is achieved in integral mode. The derivative mode offers quick correction according to the controlled variable's rate of change. The transfer function of the controller is provided by

$$C_{PID} = K_P\left(1 + \frac{1}{T_{S(S)}} + T_d(s)\right) \quad (3.18)$$

where Kp, Ts, and Td stand for the PID controller's proportional, integral, and derivative constants, respectively. Ziegler-Nichols open loop approach is the foundation of the PID controller tuning methodology. Furthermore, the load disturbance rejection is prioritized.

4. Data Analysis and Discussion

To validate the effectiveness of the designed controller, the simulation results are presented in this section. The system parameters considered for simulation are as follows:

4.1 The parameters of the DC Motor

Parameter	Specification	Value
R_a	Armature resistance	0.6Ω,
R_f	Field Resistance	60Ω,
L_a	Inductance of Armature winding	$12mH$
L_f	Field Inductance	$8mH$
K_a	Motor constant	62,
J	Moment of inertia	$\frac{0.0167\,Kgm^2}{s^2}$
B_d	Damping ratio	$0.00167\,Nms$

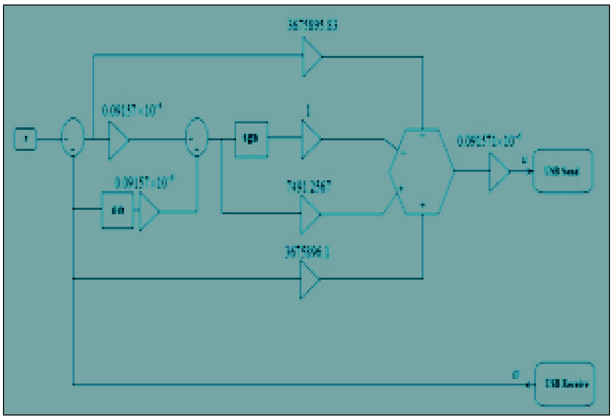

Fig 4.1: Matlab simulink block diagram of the DC motor controller parameters sliding mode control method

4.1.1 Case 1:

The speed is increased from 0 to 150 rad/s at t=0.5s and then decreased to 50 rad/s at t=1.5s. The armature current and load torque are constant (ia 10Nm= 1 τ 8 A,=). The controller has reacted satisfactorily to variations in the reference speed, as seen in Fig. 4.1. The highest armature current divergence from the reference value in the steady condition is 0.55%, as shown in Fig. 4.2. As a result, our wishes are realized and control inputs have adjusted correctly. Va and V f control inputs are displayed in Fig. 4.3.

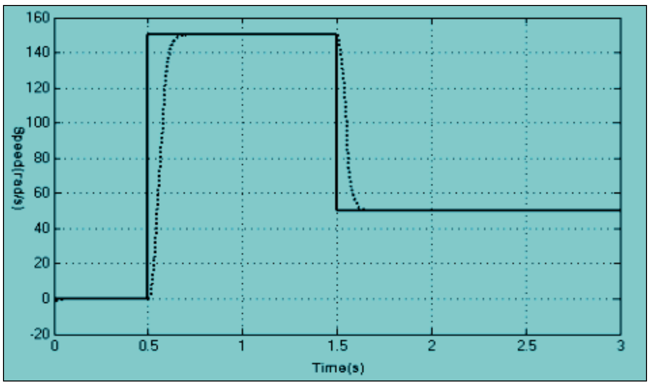

Fig 4.2: Speed changes tracking by the controller

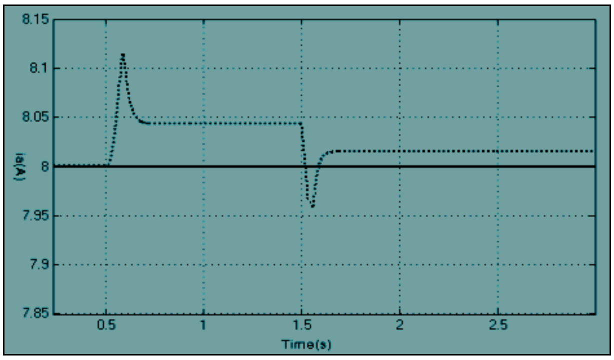

Fig 4.3: Current of the armature when the speed is changed

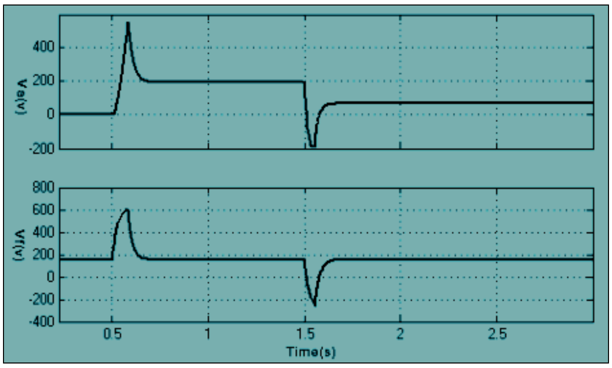

Fig 4.4: Control inputs of Va and V f when the speed is changed

4.1.2 Case 2:

In this instance, it is assumed that both the armature's current (i.e., 8 A, 150 rad/s) and the reference speed are constant. a = ω = the the load torque varies as seen in Fig. 4.3. Figures 4.8 and 4.9 display the armature's speed and current. In contrast to substantial variations in load torque, it is observed that variances are quite small and the controller is operating as intended. The armature's maximum variations in speed and current are 0.1% and 0.5%, respectively. Moreover, Fig. 10 displays control inputs. Because load torque fluctuates a lot and has minimal effect on outputs, the sliding mode controller can be said to be very resilient to disruptions.

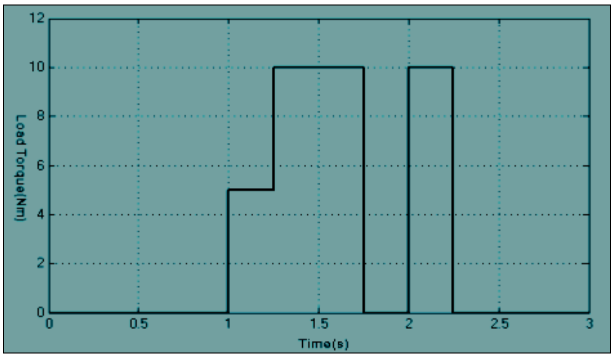

Fig 4.5: Load torque changes

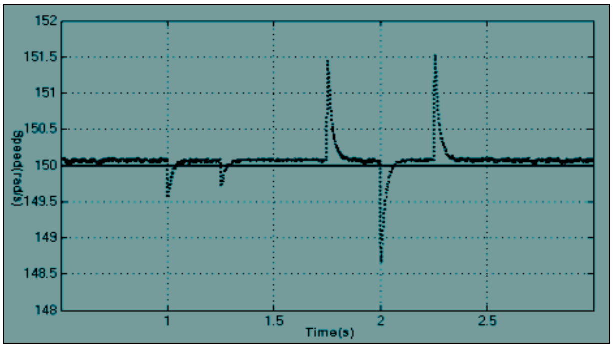

Fig 4.6: Shaft speed when the load torque is changed

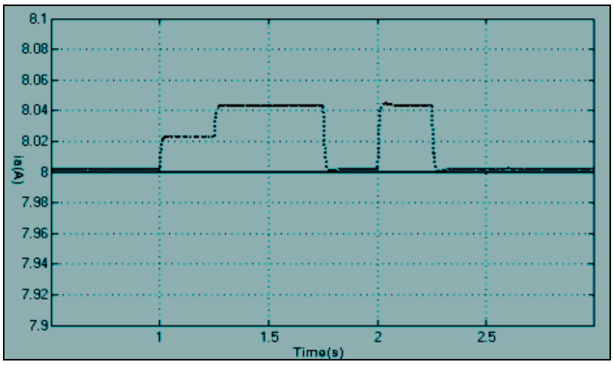

Fig 4.7: Armature current when the load torque is changed

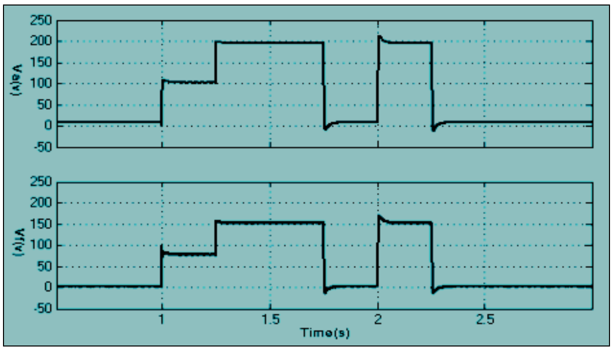

Fig 4.8: Control inputs of Va and V f when the load torque is changed

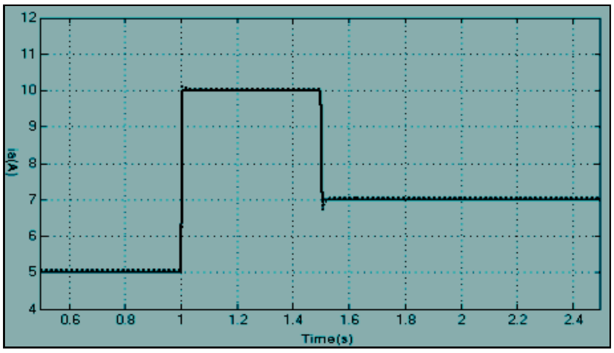

Fig 4.9: Changes of the armature current tracking by the controller

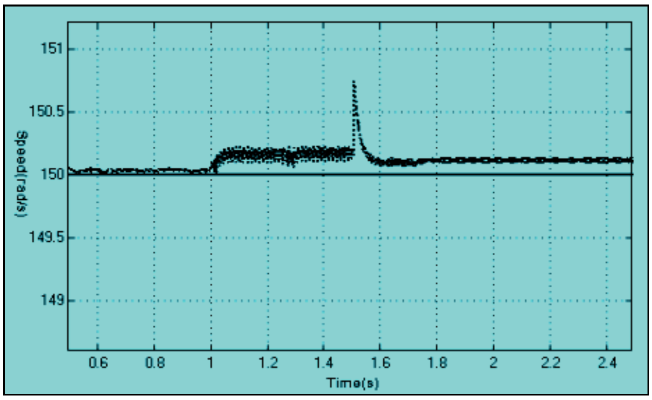

Fig 4.10: Shaft speed when the current of the armature is changed

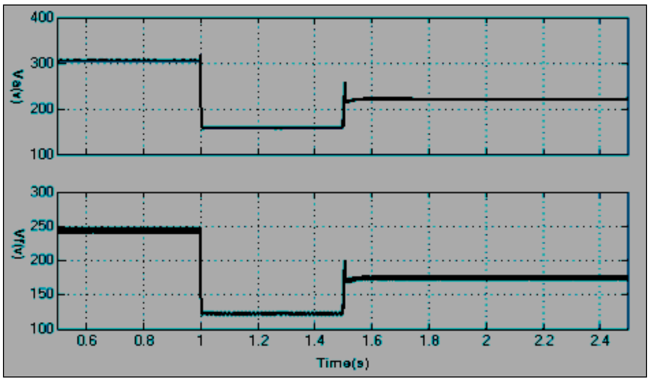

Fig 4.11: Control inputs of Va and V f when the current of the armature is changed

Conclusion

In summary, this study has effectively shown how to use MATLAB/SIMULINK to precisely regulate a DC motor's speed through the use of Proportional Integral Derivative (PID) control. With its PID settings carefully adjusted, the created model demonstrated excellent transient response, settling time, and steady-state error reduction. The simulation results demonstrate the adaptability and efficacy of the suggested PID controller in real-world scenarios and prove its robustness under a range of load conditions.

The knowledge gathered from this research not only advances PID control applications but also provides engineers and researchers working on DC motor speed control systems with useful recommendations. This paper presents an optimized PID controller that is a useful tool for improving the overall performance and dynamic response of DC motors in many industrial applications.

To further confirm the suggested PID controller's functionality in real-world settings, future research may entail experimental validation of the system. Furthering the scope of this research could involve examining sophisticated control mechanisms and integrating machine learning methods for adaptive tuning. All things considered, the study's conclusions advance the field of control systems and lay the groundwork for future research and development in the area of DC motor speed control.

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