Design a Controller Based on Smith Predictor by Direct Synthesis for Speed Control DC Motor

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Abstract: The modified Smith predictor is designed for a speed control DC motor. A speed controller of a DC motor by selection of PID parameters using a direct synthesis method. Here, the model of a DC motor is considered as a second-order system for speed control. The PID and PD controller structure reported recently decouples set-point tracking from disturbance rejection. The aim of this work is to design a speed controller of a DC motor by selection of proper PID. Simulation examples show that improved servo and regulatory performances are achieved by the proposed method as compared to the normal tune PID method, and also check by perturbed performance. When used for regulatory/servo purposes, a controller optimized for servo/regulatory application significantly degrades performance.

Keywords: PID Controller, Direct Synthesis Method, Smith predictor, Maximum Sensitivity, Speed Control DC Motor.

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1. Introduction

DC motors are widely used in industrial applications that require an adjustable speed and good speed limits, as well as frequent reversing, braking, and starting. Rolling mills, paper mills, mine winders, hoists, machine tools, traction, printing presses, textile mills, excavators, and cranes are a few examples of significant applications. Servo motors with fractional horsepower are often used for positioning and tracking. Despite predictions that AC drives will eventually replace DC drives, DC drives nonetheless predominate in variable speed applications today due to their lower cost, reliability, and ease of control. There are numerous techniques available to control the speed and position of a DC motor. A motor speed controller's main function is to take a signal that represents the desired speed and operate a motor at that speed. [1]

Because DC motors are single-input, single-output (SISO) systems, efficient speed control systems may be constructed with ease. characteristic that enables precise adjustment control signals to control motors across a broad speed range. An armature current controlled technique is taken into consideration for speed control in this study. Due to principle, it is possible to use a control structure that removes the delay from the feedback loop and permits controller design based solely on the delay-free portion. [14] There are two noninteger more changeable constants in the FOPID controller in addition to the integer constants proportional (Kp), integral (Ki), and derivative (Kd). parameters: the order of the integral (ʎ) and the order of the derivative(μ). Because it is a generalization of PIDs, this controller technology retains the benefits of traditional ones while having a wider design scope. If the FOPID controller parameters (Kp , Ki ,Kd) are properly calibrated, a better and more reliable performance based on this novel approach can be obtained. Both PID and FOPID controllers for the DC motor plant through obtaining optimum values for their gain parameters. The proportional gain makes the controller respond to the error while the integral derivative gain helps to eliminate steady-state error and prevent overshoot respectively [4]. have provided suitable ranges of the design parameters thereby making difficult the selection of a suitable value for the tuning parameter. The present work is an attempt to propose new tuning rules for IPTD, IFOPTD, and DIPTD processes for the general form of the modified Smith predictor reported in [4] its simplicity and performance qualities, the proportional-integral-derivative (PID) technique is used to implement the controller of speed control system for a DC motor. [2][3].

2. Speed Control DC Motor

A DC motor with a single rigid rectangular coil constituted by a single coil where a current flow, suitably located in a uniform the outside magnetic field (B), then the torque (T) exerted at the coils center is given by:

$$T=ildB \quad (1)$$

Where is the length of the coil perpendicular to the magnetic field (m), is the length of the edge of a coil (m). The flux (φ)flowing through the rotor of the DC motor is proportional to the magnetic field B, the above torque expression can be rewritten as follows:

$$T = K_{\emptyset}\emptyset i \quad (2)$$

Where $K_{\emptyset} = ld / A$. Since in this work, the magnetic field B is taken to be constant, hence K is constant, and then the motor torque can be written as:

$$T = K_T i \quad (3)$$

Where $K_T = K_{\emptyset}\emptyset$ is a constant for motor torque. The back electromotive force (EMF) induced in the coil, as determined by Farady's law, is given

$$E_a = \frac{d\emptyset_c}{dt} \quad (4)$$

where $\emptyset_c$ is the flux that is moving over a closed coil's internal surface (Wb). The reverse EMF can be expressed as follows, which is similar to the cases examined in (2) and (3).

$$E_a = K_a \mathrm{w} \quad (5)$$

Based on the second Newton law, the dynamic system's equation is as follows:

$$J\frac{dw}{dt} + Bw = Ki \quad (6)$$

The following Kirchhoff's voltage law-based formulation of the system's electric equation

$$L\frac{di}{dt} + Ri = E_a - Kw \quad (7)$$

where J is the motor's inertia (kgm^2) , B is the motor's viscous friction coefficient (Nms), w is the motor's angular velocity (rad/s), and L, R, and an E_a are the coil's inductance (H) , resistance (Ω), and voltage (V), respectively. The system dynamic equations (6) and (7) mentioned above can be represented in the s-domain as follows by using the Laplace transform: where w is the motor's angular velocity (measured in m/s) and K_a is the motor's electromotive factor constant. The motor torque and back emf constants are equivalent in SI units, that is, $K_T = K_a$ Consequently, both constants are represented by the constant K, as in

$K = K_a = K_T$.

$$(Js+Bw(s)=KI(s) \quad (8)$$

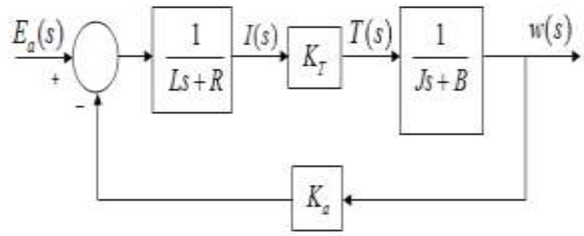

Fig 1: Block diagram of a current-controlled DC motor

$$(Ls+R)I(s)=E_a(s) - Kw(s) \quad (9)$$

Figure 1 in this article depicts the block diagram of the armature-current-controlled DC motor. The open-loop transfer function with the motor voltage E (s) an as the system input and the motor's rotational velocity w(s) as the system output is as follows, based on (8) and (9). [15]

$$\frac{w(s)}{E_a(s)} = \frac{K}{(R+Ls)(Js+B)+K^2} \quad (10)$$

Applying the realistic values of the parameters of the DC motor system listed in Table 1, the final transfer function of the DC motor is approximately equal.

$$\frac{w(s)}{E_a(s)} = \frac{4.6}{s^2+2s+0.1118} \quad (11)$$

Parameter	Symbol	Typical Value
Motor inertia	J	$0.01kgm^2$
Coil inductance	L	0.5H
Coil resistance	R	1Ω
Motor constant	K	0.023Nm/A
Friction	B	0.00003Nms

3. Direct Synthesis Method

Controlling the speed of the DC motor using direct synthesis is proposed in this paper. The mathematical modeling equation are used which used to derive the transfer function of dc motor. The closed-loop transfer function for set-point modifications must be specified to determine the modular aspects. Assume that the process measurement component is

$$\frac{y}{r} = \frac{Gp(s)Gc(s)}{1+Gp(s)Gc(s)} \quad (10)$$

$$Gc(s) = \frac{\left(\frac{y}{r}\right)}{Gp(s)\left[1-\frac{y}{r}\right]} \quad (11)$$

$$\frac{y}{d} = \frac{Gd\ (s)}{1 + Gp\ (s)\ Gc\ (s)} \quad (12)$$

$$Gc(s) = \frac{Gd\ (s)}{\left(\frac{y}{d}\right) Gp\ (s)} - \frac{1}{Gp(s)} \quad (13)$$

. The numerator of the desired transfer function is set equal to the numerator of the obtained transfer function. The tuning parameters λ and τ represent the desired closed-loop time constants for servo and regulatory purposes, respectively. In addition, the authors have provided suitable ranges for selecting these design parameters. [6] Improved robust performance was achieved compared to the tuning method proposed in [7]. Recently, controllers of the above-mentioned double-degree-of-freedom structure have been designed using a two-degree-of-freedom IMC tuning approach for processes with a general transfer function in [8]. Speed control of DC motor has been attracting a considerable interest by many researchers, hence, many studies and researches have been published on this issue. Mickky and Tewari [5] It is observed from the above literature survey that none of the works cited above except [9] and has considered double integration processes with time delay for controller design. In addition, most of the published work is based on the direct synthesis or IMC design approach. It should be noted that no guidelines were provided for selecting the tuning parameters in [8] and [10]. The authors in [11] and [12] have provided suitable ranges of the design parameters, making difficult the selection of a suitable value for the tuning parameter. The present work is an attempt to propose new tuning rules for IPTD, IFOPTD, and DIPTD processes for the general form of the modified Smith predictor.

Table 1. Values of typical parameters for DC motor

4. Controller Design

The modified Smith predictor considered in the present work is shown in Figure 2

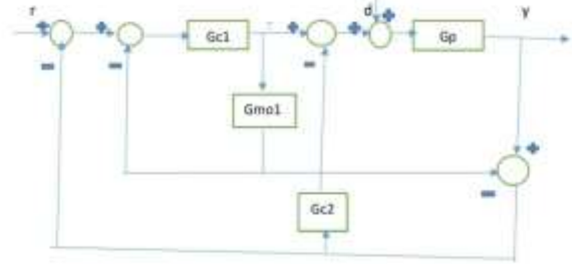

fig 1 Modified smith predictor

where the nominal model of the real process (Gp) that needs to be regulated is represented by Gm = G_{mo}. The two controllers utilised for load disturbance rejection and set point tracking are Gc1 and Gc2. Under nominal conditions (Gp = Gm), the closed loop

Transfer functions between the output and the set point and the input load disturbance are given by

$$\frac{y}{r} = \frac{G_m G_{c1}}{1+G_{mo}G_{c1}} \quad (14)$$

$$\frac{y}{d} = \frac{G_{mo}}{(1+G_{c1}G_{mo})(1+G_{c2}G_{mo})} \quad (15)$$

where, respectively r, y, and d represent for the set point, controlled variable, and load disturbance at the plant input. As shown from the mentioned formulas, y/r only contains Gc1, whereas y/d contains Gc1 and Gc2. The design of Gc2 to reject the load disturbance at the plant input follows after Gc1 has been modified to achieve a suitable set-point tracking in the present study.

4.1 Design of Gc1

The direct synthesis method is used to create Gc1 and is based on the specification of the desired closed-loop transfer function for set-point change. The actual closed-loop transfer function is obtained in order to specify the intended closed loop transfer function. The desired transfer function's numerator is set to be the same as the actual transfer function's numerator. The number of unidentified controller parameters is specified as the order of the denominator polynomial of the intended transfer function. [13] and Gc1 = Kc1 is taken into account for the IPTD process model. For the IFOPTD and DIPTD process models, Gc1 is assumed to be a PD controller with a transfer function of Kc1(1 + Td1s).

$$\frac{y}{r} = \frac{G_m G_{c1}}{1+G_m G_{c1}} \quad (16)$$

$$Gc_1 = Kp(1 + T_{ds} + \frac{1}{T_{is}})$$
(17)

$$G_m = \frac{K}{(S+\tau1)(S+\tau2)}$$
(18)

$$\frac{y}{r} = \frac{\frac{K}{(S+\tau1)(S+\tau2)}\times K_p(1+Td_s+\frac{1}{T_{is}})}{1+\frac{K}{(S+\tau1)(S+\tau2)}\times K_p(1+Td_s+\frac{1}{Tis})}$$
(19)

$$\frac{y}{r} = \frac{KK_p(T_{is}+T_iT_{ds}{}^2+1)/(T_{is})}{T_{is}(S+\tau1)(S+\tau2)+KK_p(T_{is}+T_iT_{ds}{}^2+1)/T_{is}}$$
(20)

$$\left(\frac{y}{r}\right) d = \frac{T_{is}+T_iT_{ds}{}^2+1}{(\lambda S+1)^3}$$
(21)

Desire a closed-loop system

$$K_p = \frac{3-\lambda^2\tau1\tau2}{\tau^2 K}$$
(22)

$$Ti = \lambda(3-\lambda^2\tau1\tau2)$$
(23)

$$T_d = \frac{3\lambda-\tau1-\tau2}{3-\lambda^2\tau1\tau2}$$
(24)

4.2 Design of Gc2

The characteristic equation comprises two elements, which can be seen as (1 $+G_{c2}G_m$) and (1 $+G_{mo}G_{c1}$). Substitute the G_m and G_{c2} in the control equation ($1 + G_{c2}G_m = 0$) and replace with even $(1 + G_{mc1})$, because of $G_{c1}G_{c2}$ required . rules for PI/PID controllers with the following transfer function:

$$\frac{y}{d} = \frac{G_m}{(1+G_{c1}G_m)(1+G_{c2}G_m)} \qquad (25)$$

$$\frac{y}{d} = \frac{G_m}{1+G_mG_{c2}} \qquad (26)$$

$$= \frac{K_{p2}(1+T_{ds}}{(1+T_{fs})}(s+\tau1)(s+2)(1+T_{fs}) + KK_{p2}(1+T_{d2s})=0 \qquad (27)$$

Characteristics for equation $(1 + G_{c2}G_m = 0)$

$$T_f = \frac{1}{3\tau-\tau1-\tau2}$$
(28)

$$K_p = \frac{1}{K}[\lambda^3 Tf - \tau1\tau2]$$
(29)

$$T_{d2} = \frac{Tf}{KK_{p2}}[3\lambda^2 - \frac{\tau1+\tau2}{Tf} - \tau1\tau2]$$
(30)

5. Simulation and Results

Using the Matlab tool, speed motor control system controllers based on PID techniques are developed**.** The controller parameters are tuned with direct synthesis method in maximum sensitivity 1.2, then I have got = 1.38 for first controller and μ= 0.8 for the second controller.

Process model		ISE	IAE
For full system	Smith Predictor	2.12 7	5.309
	Tuning PID	6.39	14.45
Servo	Smith Predictor	0.8512	1.914
	TuningPID	5.223	10.06
Regulatory	Smith Predictor	1.277	3.395
	Tuning PID	1.4	4.91

Table .2 step servo and regulatory

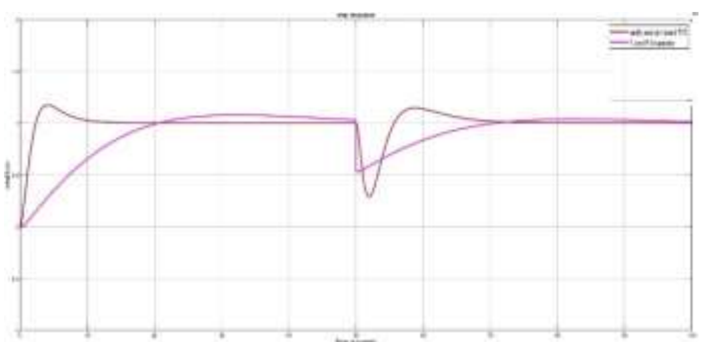

Fig. 2 Step response of DC motor

The step response of the the speed control of DC motor in integral square error (ISE 6.39) and integral absolute error (IAE 14.45) in the tuning of PID and smith predictor (ISE 2.127, IAE 5.309)

Step response of PID controller for speed control of DC motor

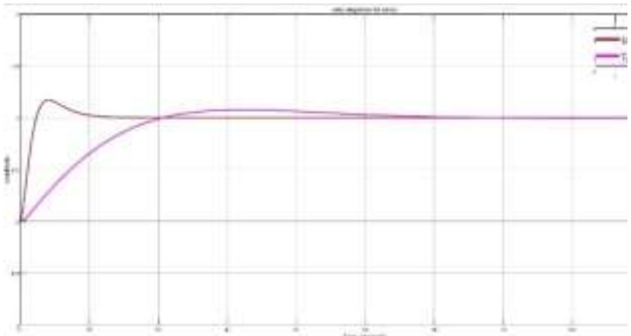

Fig. 3 step response of DC motor for servo

The maximum sensitivity 1.2 in without disturbance normal PID (ISE 5.223, IAE 10.06) and the Smith predictor (ISE 0.8512 IAE 1.914) in graph and the good response Smith predictor in servo speed control DC motor

Step response servo of PID controller for speed control of DC motor

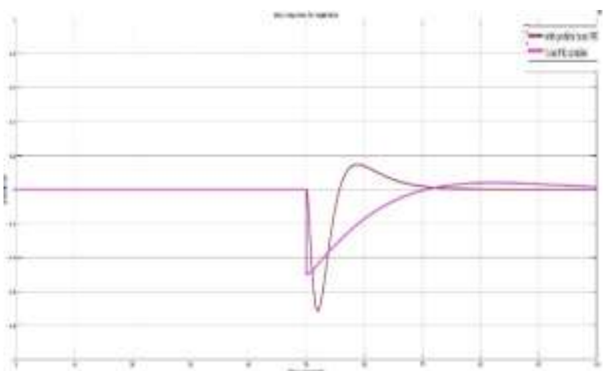

Fig. 4 Step response of DC motor for regulatory

The Maximum sensitivity 1.2 in the normal PID without input step (ISE 1.4, IAE 4.91) and smith predictor (ISE 1.277, IAE 3.395) in graph and the good response smith predictor in regulatory speed control DC motor

PID controller for speed control of DC motor is change in 30% and -30 %.

Process model		ISE	IAE
	Smith Predictor	2	5.195

+30%change in K $T1$&$T2$	Tuning PID	6.625	14.13
-30%change in $T1$&$T2$ -30% in K	Smith Predictor	2.382	5.579
	Tuning PID	6.596	16

Table 3 Performance of perturbation

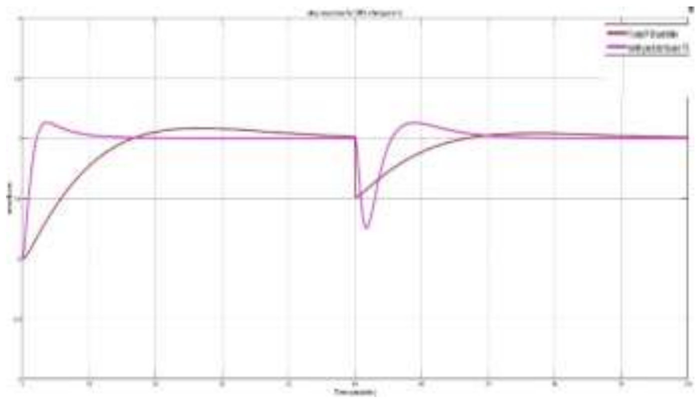

Fig 5 step response perturbation+30 of the DC motor

The perturbation +30% change in the maximum sensitivity of K T1 and T2 1.2 for normal PID (ISE 6.625, IAE 14.13) and the smith predictor (ISE 2, IAE 5.195) step response speed control of the DC motor.

Step response +30 change in K T1&T2 of the PID controller for speed control of the DC motor

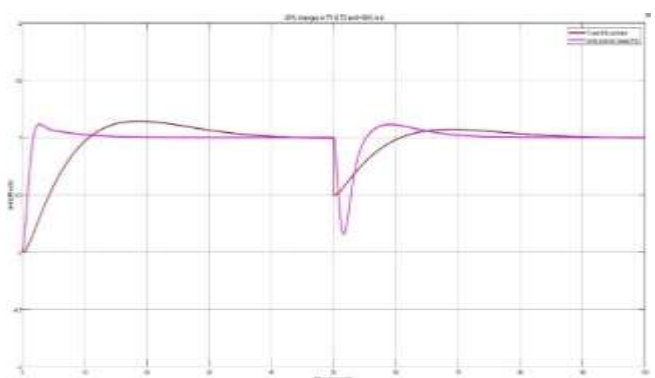

Fig 6 step response of the perturbation -30 % of DC motor

The perturbation -30% change in T1 and T2 -30% change in K maximum sensitivity 1.2 response normal PID (ISE 6.596, IAE 16) and smith predictor (ISE

2.382, IAE 5.579) in better performance smith predictor in speed control of DC motor

Step response -30 change in T1&T2 -30 in K of the PID controller for speed control of the DC motor

6. Simulation study

If the value of this present work, the closed-loop performance of the suggested method is compared with the performance of recently described solutions. All tuning options are compared using the controller settings that produce a maximum sensitivity equal to 2. By cascading a first-order low-pass filter with a time constant equal to 0.1 times the derivative time constant, the pure derivative sections of Gc1 and Gc2 are implemented. The performance metrics ISE, IAE, settling time (st) are used to compare the effectiveness of the various tuning techniques. Fast set-point tracking and disturbance rejection are implied by a small value of ISE/IAE. ISE and IAE in the controlled variable are denoted mathematically by.

$$\text{ISE}=\int_0^\infty e^2\,(t)dt \qquad (31)$$

$$\text{IAE} = \int_0^\infty |e(t)dt| \qquad (32)$$

where $e(t)$ is the difference between the set-point input and the controlled close-loop transfer function. The settlement time is the time it takes for the step response to maintain its ultimate value within $\pm 2\%$

7. Conclusion

This research presents an investigation of the development of speed control system for the DC motor. The set-point tracking controller is tuned using direct synthesis approach, whereas a PID controller is used for rejecting the load disturbance. The system's closed-loop performance is implied by the tuning parameters for servo and regulatory purposes, which are specified to achieve maximum sensitivity equal to 1.2 and compare with the normal tuned PID we got smith predictor best PID/PD control give better response with normal tuned PID control of the best performance smith predictor speed control of DC motor, the rotor performance of the proposed tuning strategy is also improve. The simulation results show that the proposed method improves the system's overall performance.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.