Design a Controller Based on Smith Predictor by Direct Synthesis method 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 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. This work aims to design a speed controller of a DC motor by selecting 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 checked 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.

Received: March 11, 2023. Revised: November 21, 2023. Accepted: December 23, 2023. Published: January 30, 2024.

1. Introduction

DC motors are widely used in industrial applications requiring adjustable speed, 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 frequently used for positioning and tracking. Despite predictions that AC drives will eventually replace DC drives, DC drives nevertheless predominate in variable speed applications today due to their lower cost, reliability, and ease of control. There are numerous techniques available for controlling 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 the motors across a broad speed range. An armature current-controlled technique is taken into consideration for speed control in this study. Due to principle is 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 non-integer more changeable constants in the FOPID controller in addition to the proportional (Kp), integral (Ki), and derivative (Kd) integer constants. parameters: the order of the integral (λ) 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 of 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 a speed control system for a DC motor. [2][3].

1.2 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 outside magnetic field (B), then the torque (T) exerted at the coils centre is given by:

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

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

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

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:

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

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

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

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).

$$E_a = K_a w \qquad (5)$$

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

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

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

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

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 =$K_a = K_T$.

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

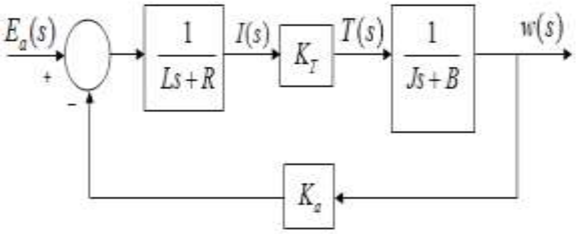

Fig 1: Block diagram of a current controlled DC motor

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

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]

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

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

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

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

To control speed of DC motor using direct synthesis is proposed in this paper. The mathematical modeling equation are used which used to derive the transfer function of the 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

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

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

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

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

. The desired transfer function’s numerator 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. Also, the authors have provided suitable ranges for selecting these design parameters. [6] Improved robust performance was achieved as compared to the tuning method proposed in [7]. Recently, controllers of the above said double two 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 motors has been attracting considerable interest by many researchers, hence, there are many studies and research have been published in this issue. Mickky and Tewari [5] It is observed from the above literature survey that none of the above-cited works except [9] and has considered double integrating processes with time delay for controller design. Also, most of the published works are based on the direct synthesis or IMC design approach. It is to 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 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

Table 1. Typical parameter values for DC motor

3.1 Controller Design:

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

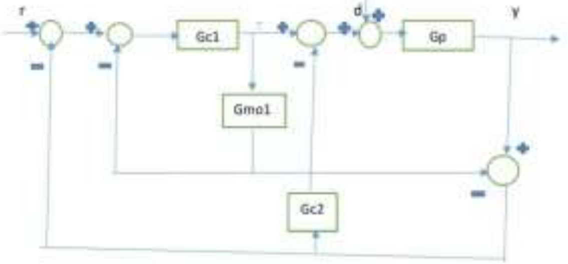

fig 1 Modified smith predictor

where the nominal model of the real process (Gp) that needs to be regulated is represented by Gm = G_{mo}. The two controllers utilized 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

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

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

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 comes after Gc1 has been modified to achieve suitable set point tracking in the present study.

3.2 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 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 consideration 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).

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

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

$$\mathrm{G_m} = \frac{\mathrm{K}}{(\mathrm{S}+\tau 1)(\mathrm{S}+\tau 2)}$$
(18)

$$\frac{y}{r} = \frac{\frac{K}{(S+\tau 1)(S+\tau 2)} \times K_p(1+Td_s+\frac{1}{T_{is}})}{1+\frac{K}{(S+\tau 1)(S+\tau 2)} \times K_p(1+Td_s+\frac{1}{Ti_s})}$$
(19)

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

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

Desire close loop system

$$K_p = \frac{3-\lambda^2 \tau 1 \tau 2}{\tau^2 K}$$
(22)

$$\mathrm{Ti} = \lambda(3-\lambda^2 \tau 1 \tau 2)$$
(23)

$$T_d = \frac{3\lambda-\tau 1-\tau 2}{3-\lambda^2 \tau 1 \tau 2}$$
(24)

3.3 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:

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

$$\frac{y}{d} = \frac{G_m}{1+G_mG_{c2}} \tag{26}$$

$$= \frac{K_{p2}(1+T_{ds}}{(1+T_{fs})}(s+\tau 1)(s+2)\left(1+T_{fs}\right)+KK_{p2}(1+T_{d2s})=0 \tag{27}$$

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

$$T_f = \frac{1}{3\tau-\tau 1-\tau 2}$$
(28)

$$K_p = \frac{1}{K}[\lambda^3 Tf - \tau 1 \tau 2]$$
(29)

$$T_{d2} = \frac{Tf}{KK_{p2}}\left[3\lambda^2 - \frac{\tau 1+\tau 2}{Tf} - \tau 1 \tau 2\right]$$
(30)

3.4 Simulation and Results

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

Process model		ISE	IAE
For full system	Smith Predictor	2.127	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

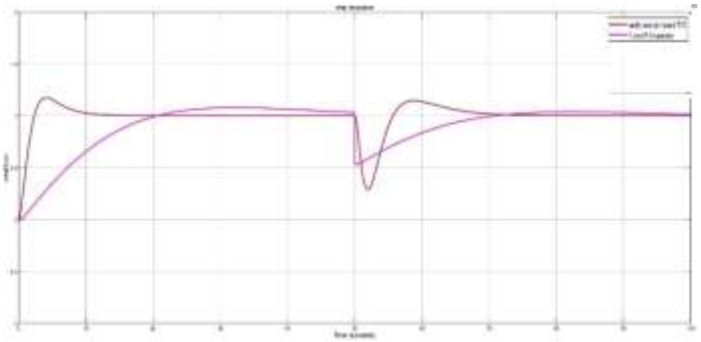

Fig 2 Step response of DC motor

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

Step response of PID controller for speed control of DC motor

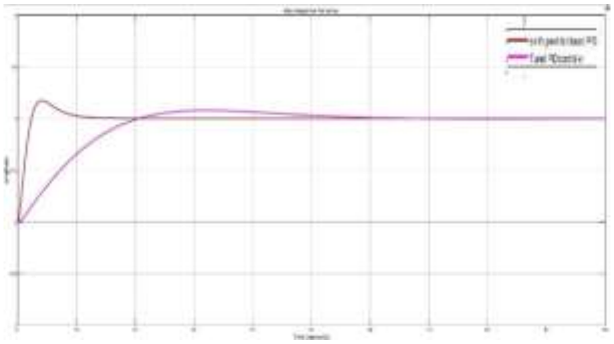

Fig 3 step response of DC motor for servo

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

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

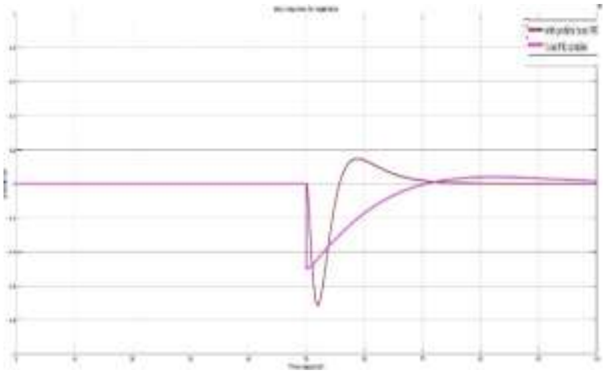

Fig 4 Step response of DC motor for regulatory

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

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

Process model		ISE	IAE
+30%change in K $T1\&T2$	Smith Predictor	2	5.195
	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

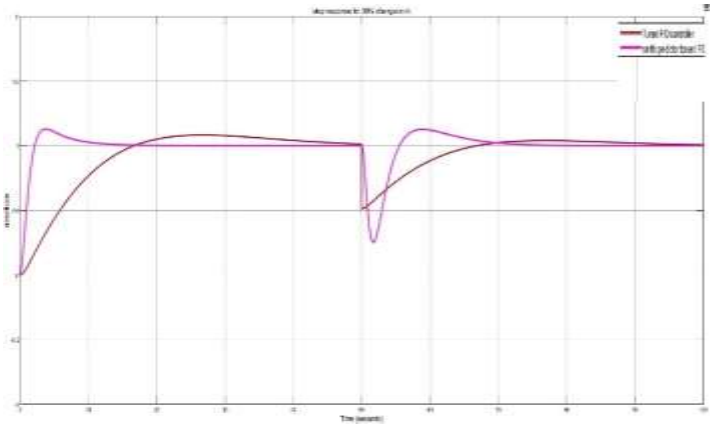

Fig 5 step response perturbation+30 of DC motor

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

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

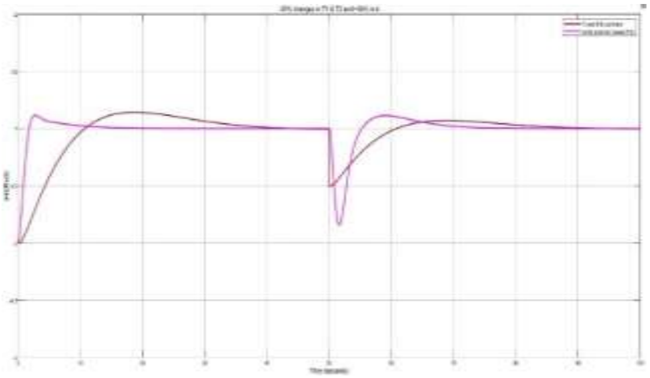

Fig 6 step response of perturbation -30 % of DC motor

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 PID controller for speed control of DC motor

4. Conclusion

This research presents an investigation into the development of a speed control system for DC motor. The set point tracking controller is tuned using a 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 Compared with the normal tuned PID we got smith predictor best PID/PD control gives a 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 improved. The simulation results show 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)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

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