Tuning PID Controllers for DC Motor by Using Microcomputer

Ali Mohammed Ali , Asst. Prof. Dr. Ali Hussein Mohammed and Asst. Prof. Dr Hassan M. Alwan

[1] *Ph.D student , Mechanical Engineering Department, College of Engineering- Alnahrain University,Baghdad-Iraq.*

[2]*Assistant Professor, Mechanical Engineering Department, College of Engineering - Alnahrain University,Bghdad-Iraq.*

[3]*Assistant Professor, Mechanical Engineering Department, University of Technology,Baghdad-Iraq.*

Abstract

This paper presented a review study of tuning of Proportional Integral Derivative (PID) Controller for speed control of DC motor, several methods for tuning of controller parameters in PID controllers, some of these methods the Ziegler-Nichols' methods are experimental and computing techniques such as MATLAB programs. The PID controller is the very commonly used compensating controller, which is used in nonlinear systems is important because these parameters have a great effect on the stability and performance of the control system. The microcomputer uses soft computing techniques such as MATLAB program in PC computer and transfer order direct to DC motor this mean to controller job too. Raspberry pi-3 one of microcomputer used Python as the main programming languages, it a technique used to implement both orders of DC motor control and better of the PID controller tuning.

Keywords: DC Motor, PID Controller, GUI/MATLAB, Ziegler-Nichols Method, Microcomputer

1. INTRODUCTION

DC motor is a continuous actuator that converts electrical energy into mechanical energy. DC motor is widely used in many industrial applications where wide speed ranges are required. DC motor is widely used in many industrial applications because wide with high resolution in speed ranges are required as well as get two directions [4]. The advantage of DC motors may be speed control, such as high start torque, high-speed response, portability, and conform with many types of control tuning methods; therefore, DC motors are used widely in many control applications, including robots, electrics vehicle application, disk drivers, machine tools, and servo-valve actuators.

The speed of DC motor relations is proportional with armature voltage and inversely with magnetic flux induced by the poles, adjusting the armature voltage or the field current will vary the rotor speed, therefore, it is important to make a controller to control the speed of DC motor at desired speed. PID controllers are probably the most commonly used controller structures in industry [2]. They do, however, present some challenges to control and instrumentation engineers in the aspect of tuning of the gains required for stability and good transient performance.

2. MATHEMATICAL MODEL OF DC MOTOR

There are two classes of DC motors: Filed-Current Controlled and Armature-Current Controlled.

In a Field-Current Controlled motor, the armature current i_a is kept constant while the field-current is controlled using field voltage V_f commands. On the other hand, in an Armature-Current Controlled motor, the armature voltage V_a is the command to control the armature current while keeping the field-current if constant as shown in figure (1).
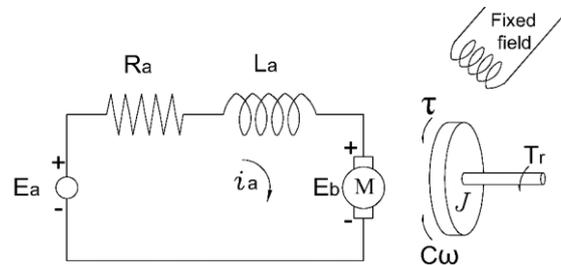

Figure 1: Circuit equivalent of a DC motor

In an Armature-Current Controlled structure, the motor torque is linearly dependent on the armature current by

$$\frac{T_m(s)}{I_a(s)} = K_m \ldots\ldots\ldots (1)$$

where, $T_m(s)$: the motor torque in S-domain.

K_m : the motor torque constant.

Using the Kirchhoff's law, the summation of the voltage in a circuit equal to zero, the following equation obtained

$$E_a = E_a + E_L + E_b = i_a R_a + L_a \frac{di_a}{dt} + K_b \dot{\theta}_m \ldots\ldots\ldots (2)$$

where, E_a : the apply voltage.

i_a : the current of the motor.

R_a: the resistance of the motor.

L_a: the inductance of the motor.

K_b: the velocity contant.

$\dot{\theta}_m$: the angular velocity of the motor.

taking Laplace transform of Equation (1) the following equation is achieved

$$E_a(s) - E_b(s) = E_a(s) - K_b\,\omega(s) = (R_a + L_as)I_a(s) \dots\dots (3)$$

For the free body connected to the motor rotational motion is formulated by

$$J\dot{\omega} + c\omega = T_m \dots\dots\dots (4)$$

where, ω: the angular velocity   c: motor friction constant

J: the moment of inertia of the rotor.

taking Laplace transform of Equation (1) the following equation is achieved

$$\frac{\omega(s)}{T_m(s)} = \frac{1}{JS+C} \dots\dots\dots (5)$$

$$G(s) = \frac{\omega(s)}{E_a(s)} = \frac{K_m}{(L_as + R_a)(Js + c) + K_bK_m}$$
$$= \frac{K_m}{L_aJs^2 + (R_aJ + L_ac)s + (R_ac + K_bK_m)} \quad \dots\dots (6)$$

Closed loop block diagram of DC motor model expressed in Equation (6) is shown in Figure (2).
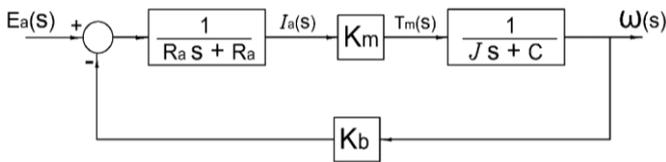

Figure 2: DC Motor Block Diagram

3. PID CONTROLLER

PID controller is a generic control loop feedback mechanism widely usedin industrial control systemresponse. The controller attempts to minimize the error by adjusting theprocess control input. The PID controller calculation (algorithm) involves threeconstant parameters called the proportional (P), integral (I) and derivative (D) values,these values can be interpreted in terms of time.P depends on the present error, I onthe accumulation of past error, and D is a prediction of future error, based on currentrate of change. The weighted sum of these three actions is used to adjust the processvia a control element such as the position of a control valve, or power supplied to aheating element.

$$U(t) = e(t)K_P + K_I \int_0^t e(t) + K_D \frac{de(t)}{dt} \quad \dots\dots (7)$$

The transfer function is expressed as follows,

$$C(s) = K_P + \frac{K_i}{s} + K_ds = \frac{U(s)}{E(s)} \quad \dots\dots\dots (8)$$

Where,K_P: proportional gain which used to increase the system response

speed and reducesteady-state error.

K_I: integral gain which used to eliminate the steady-stat error at all.

K_D:derivative gain used to reduce the system response overshoot.

The time constant formula of the PID controller is given asof Equation (8) get:

$$C(s) = K_P(1 + \frac{1}{T_is} + T_ds) \dots\dots\dots (9)$$
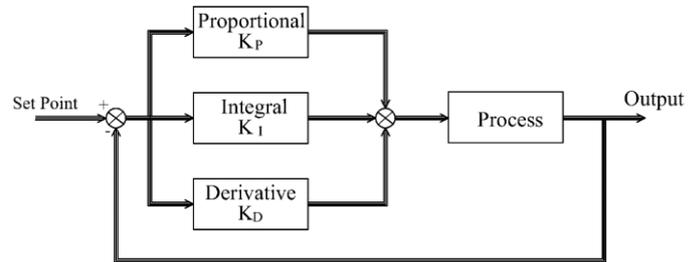

Figure 3: Block Diagram of PID Controller

The PID of DC motor speed control system can be represent when add equation 8 with equation (6) get:

$$R(s) = \frac{\omega(s)}{E(s)} = C(s) + G(s)$$

or

$$R(s) = \left(K_P + \frac{K_i}{s} + K_ds\right) + \left(\frac{K_m}{L_aJs^2 + (R_aJ + L_ac)s + (R_ac + K_bK_m)}\right)$$
$$\dots\dots (10)$$
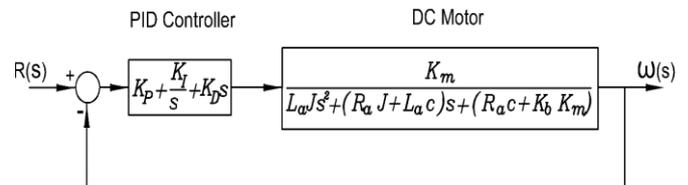
as blockdiagram is shown in Figure (4):

Figure 4: PID DC motor speed control system blockdiagram

4. PID TUNE CONTROLLER METHOD'S

This control tuning method used to get the PID controller parameters which ensure thatthe obtained control system would be meet given objectives. This method is based on a registration of the close-loop stepresponse of thesystem, which is characterized by many parameters (*L, T, K,* and *a*). Theseparameters are determined from a unit step response of the process, as shown in Figure 5.
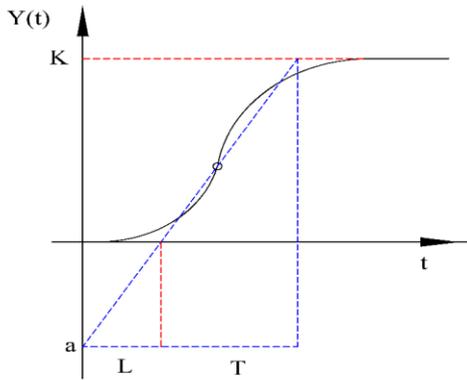
Figure 5: Ziegler-Nichols method Step Response

produces Ziegler-Nichols in 1942 methods of PID tune as the mother of all tuning methods [2].It was the first method used to represent the PID controller parameters using two sets of rules as explain in both Table (1),where:

$$a = \frac{KL}{T} \quad \ldots\ldots.. \text{ (11)}$$

Table 1: Ziegler-Nichols tuning

Controller	K_P	$T_i = \dfrac{K_P}{K_I}$	$T_d = \dfrac{K_d}{K_p}$
P	T/L	-	-
PI	0.9T/L	L/0.3	-
PID	1.2T/L	2L	L/2

MATLAB ("MATrix LABoratory") is a tool for numerical computation and visualization install on PC computer by using interface part to control Dc motor such as LabVIEW (Laboratory virtual Instrument Engineering Workbench) Technique and Arduino microcontroller connected with DC motor [3]. MATLAB program is used for calculation and simulation PID controllers the efficiency of the introduced controller is verified when using MATLAB simulation with the comparison of the conventional PID controller. The results of simulation of the use of MATLAB programs showed the effectiveness and more of robustness of the proposed approach. The Artificial Intelligence Techniques with MATLAB provides far better results compared to the conventional methods [9].

5. MICROCOMPUTER PID CONTROLLER

A Raspberry Pi 3B is a small single-board device, which supports Linux-based operating systems, USB connections for mouse, keyboard, Ethernet adapter, and other devices. The Raspberry pi 3B attach to monitor by using wifi with VNC programs or HDMI connector on the controller board for and general-purpose inputs and outputs [6]. A Micro SD card is used a storage device and Python is used for programming. General-purpose Input/output is generic pins on an integrated circuit of RaspberryGPIO. This module must beimported into the main control program.Python has been chosen as the programming language inthis work. Python is a higher

programming language, which does not need to have strictly defined variables,now we'll need to prepare things on the software side. We'll be using Python to implement our PID Controller. We made this choice since there's modules available to interact with the PWM (Pulse-width modulation) as well as modules that abstract the use of PID.Now, that code we writing with obvious delight are part of the program uploaded in the micro-controller. The micro-controller then gives orders to the motor control board, and this order is applied as a powerful signal into the motor.

6. SIMULATION RESULTS

The DC motor (12 V, 17 W, 3 A, 120 RPM) with the specifications listed in Table (2) has been selected because it is used in robotic applications, nanotechnology and scientific instruments. So there is always a need to improve the performance of this motor by using the controllers (PID).

Table 2: DC Motor Parameters

Terminal Resistance of motor (R_a)	1.9	Ω
Motor constant torque (K_m)	0.0134	Nm/A
Back-emf constant (K_b)	0.0134	V/rad/s
Inductance of motor (L_a)	65×10^{-6}	H
Motor Friction constant (C)	0.001	N.m.s/rad
Motor mass moment of Inertia (J_m)	57×10^{-7}	N.m s^2/rad

Give the transfer function according above parameters shown below:

$$\frac{\omega(s)}{V_a(s)} = \frac{K_m}{L_a J s^2 + (R_a J + L_a c)s + (R_a c + K_b K_m)}$$
$$= \frac{3.616 \times 10^8}{s^2 + 3.098 \times 10^4 \, s + 5.611 * 10^7}$$

The step response shown in Figure (3), give (L=0.3, T=0.8) $\times 10^{-4}$, which can be used fortuning Ziegler-Nichols method.

which set to calculate P, PI, and PID controller parameters for the DC motor transfer function ($\frac{\omega(s)}{V_a(s)}$) with applying Ziegler-Nichols step response method formula1 shown in Table (3) and equation 9 shown in Table (4).
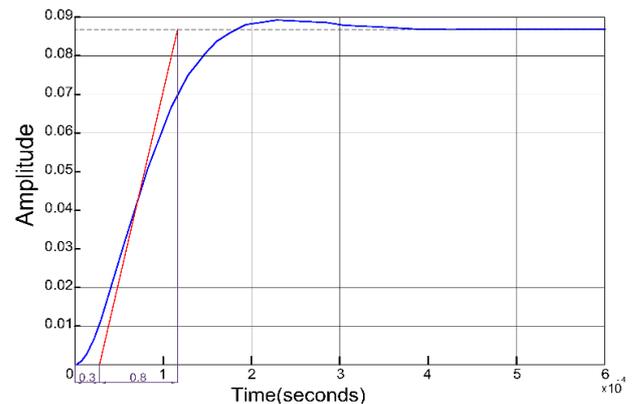

Figure 6: Step Response for DC motor

Table 3: Ziegler-Nichols tuning method controller's parameters-1-

Controller	K_P	T_i	T_d
P	2.66	-	-
PI	2.4	1×10^{-4}	-
PID	3.192	0.6×10^{-4}	0.15×10^{-4}

Table 4: Ziegler-Nichols tuning methodcontroller's parameters-2-

Controller	K_P	K_i	K_d
P	2.66	-	-
PI	2.4	24000	-
PID	3.192	53200	4.8×10^{-5}

we can represent the above transfer function into MATLAB bythe numerator and denominatormatrices and get The step response shown in Figure (7) and give gains in Table (5).

Table 5: MATLAB tuning controller's parameters-2-

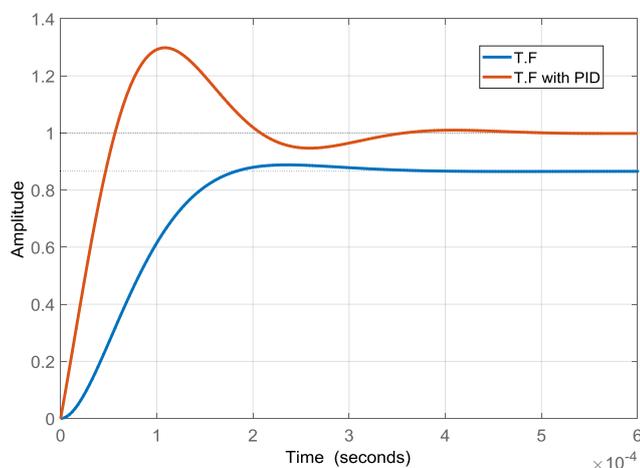| Controller	K_P	K_i	K_d
P	3.096	-	-
PI	3.096	1.695×10^3	-
PID	3.086	4.16×10^4	5.07×10^{-5}

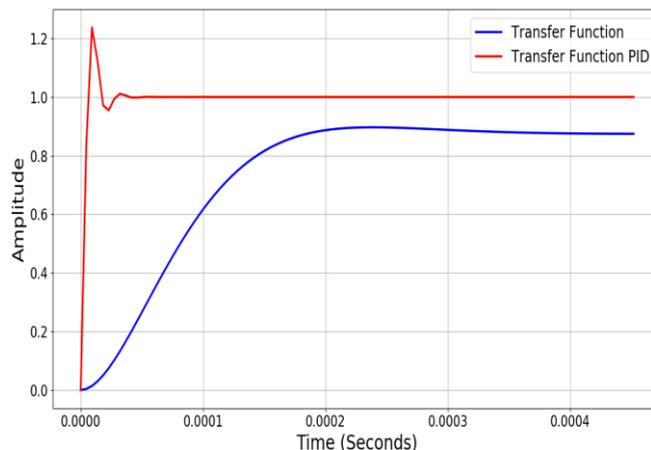**Figure 7:** MATLAB PID tuning controller's parameters

Figure 8: PYTHON PID tuning controller's parameters

Also can represent the transfer function into Python same as MATLAB by the numerator and denominator matrices and get The step response shown in Figure (8), by using gainsPID in Table (5).
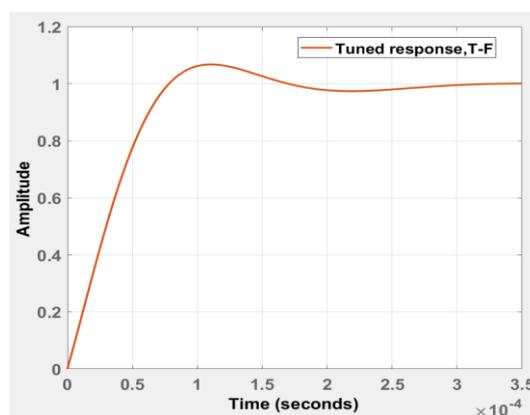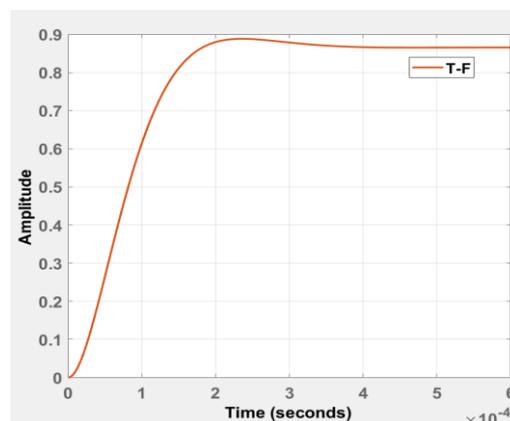

Figure 9: Intelligence MATLAB PID tuning controller's parameters

Also can represent the transfer function in MATLAB with the numerator and denominator matrices and get PID tuning by using a professional application with intelligence technics shown in Figure (9).

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7. CONCLUSION

In this paper, PID controller is tuned by using Python program's technique and compare results with two methods, Ziegler-Nichols method, and MATLAB programs. Comparison of the results with the use of the, a simplified program of Python with the Ziegler-Nichols method the result in figures (8) showsapproximate between themes therefore, it can be used this method to get results directly from the controller to any system connected with it.

The comparative results of, a simplified program of the MATLAB programs in figures (7), (8) shows approximate between themes. The applications of intelligence used in MATLAB shows in the figures (9) get high performance to obtain PID parameters, but the deference's with result gets by simple programs is near to accuracy for three methods and can be advancing for python programs to reaching to intelligence MATLAB program results.

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