EFFECT of PROPORTIONAL INTEGRAL CONTROLLER in the STABILITY of DIRECT CURRENT MOTOR

Mudathir A. O. Fagiri[*1] and Mohamed H. M. Nerma[*2]

[*]Assistant Professor at Sudan University of Science and Technology – College of Engineering – School of Electronic Engineering, Khartoum, SUDAN. Eastern Diems,

ABSTRACT

Direct Current (DC) motor has become an important drive for many applications across a wide area of powers and stability. The ease of control and excellent performance of the DC motors will ensure that the number of applications using them will continue grow for the future. The aim of this paper is to show the effect of proportional integral (PI) controller in stability of DC motor. The MATLAB code has been designed simply to show the effect of the PI controller in the DC motor. From the simulation, the result performance of the PI controller is compared in term of response and the assessment is presented.

Keywords: **PID, PI, DC, AC, Motor, Settling Time, Maximum Overshot, Steady State Error, Delay Time and Rise Time.**

1. Introduction

The modern motors require a form of energy conversion toward mechanical energy. There are well known types of energy converters such as electric motors, pneumatic motors, hydraulic motors etc. Perhaps the most widely used motors are the electric ones because of their high flexibility and reliability as well as of their cost. The common electric motors can be grouped in four major classes: direct current (DC) motors, stepper motors, asynchronous motors and synchronous motors. The mechatronic systems, robots and low to medium power machine-tools often use DC motors to drive their work loads. These motors have simple functional and constructive models. There are several methods to control DC motors such as: proportional integral (PI), proportional integral derivative (PID) or dispositional. These can quite easily be implemented using analog electronics. However, modern digital computers provide an easy way of implementing very complex control algorithms [1]. An electric motor is an electric machine that converts electrical energy into mechanical energy. In normal motoring mode, most electric motors operate through the interaction between an electric motor's magnetic field and winding currents to generate force within the motor. In certain applications, such as in the transportation industry with traction motors, electric motors can operate in both motoring and generating or braking modes to also produce electrical energy from mechanical energy [2].

Direct-current motors, as the name implies, use direct unidirectional current. DC motors are used in special applications where high torque starting or smooth acceleration over a broad speed range is required. The advantages of using these types of motors over conventionally used AC motors are stated below.

- DC motors have higher controller efficiency.
- DC motors have typical 98% efficiency.
- DC motors have better overload and peak voltage characteristics.

Speed control of dc motor could be achieved using mechanical or electrical techniques. In the past, speed controls of dc drives are mostly mechanical and requiring large size hardware to implement. The development has launched these drives back to a position of formidable relevance, which were hitherto predicted to give way to AC drives. Some important applications are: rolling mills, paper mills mine winders, hoists, machine tools, traction, printing presses, textile mills, excavators and cranes. Fractional horsepower dc drives are widely employed -as servo means for positioning and tracking [2]. Controlled rectifiers provide a variable dc voltage from a fixed dc voltage. Due to their ability to supply a continuously variable dc voltage, controlled rectifier and dc choppers made a revolution in modern industrial equipment and variable speed drives [3].

Adjustable speed drives may be operated over a wide range by controlling armature or field excitation.

Transistor and thyristor along with various analog digital chips used in firing or controlling circuits have made dc drives more accessible for control in innumerable areas of applications [4]. Recent developments in the area of semiconductor technology have made smaller, faster microprocessors and microcontrollers available at reduced cost [5]. The potential use of microprocessors to control some or all electronic functions justifies their use.

A reasonable number of works have found in the literature, regarding the employment of solid-state devices for the control of dc drives. The paper of Kurnera, Dayananda and Jayawikrama, elucidated the use of chopper in collaboration to PC for the control of dc motor speed. Software was developed, fed into a PC and consequently, commands were given to the chopper via the computer for control of motor speed [6]. The use of standalone micro controller for the speed control of DC motor is past gaining ground. Nicolai and Castgnct have shown in their paper how a microcontroller can be used for speed control. The operation of the system can be summarized as: the drive form rectified voltage; it consists of chopper driven by a PWM signal generated from a microcontroller unit (MCU). The motor voltage control is achieved by measuring the rectified mains voltage with the analog to-digital converter present other micro controller and adjusting the PWM signal duty cycle accordingly [7]. Another system that uses a microprocessor is reported in the work of khoel and Hadidi a brief description of the system is as follows: The microprocessors computes the actual speed of the motor by sensing the terminal voltage and the current, it then compares the actual speed of the motor with the reference speed and generates a suitable signal control signal which is fed into the triggering unit. This unit drives an Hbridge Power MOSFET amplifier, which in turn supplies a PWM voltage to the DC motor [8].

In this paper the effect of PI coefficients in DC motor to develop and design a PI control in controlling the DC at desire speed response with the input voltage and physical parameter given. In order to eliminate those problems, controller was introduced to the system. There's few type of controller but in this project, PI controller is chosen as the controller for the DC motor. This is because PI controller helps get the output, where we want it in a short time, with minimal overshoot and little error.

2. Characteristics of PI controllers:

A proportional controller (K_p) will have the effect of reducing the rise time and will reduce, but never eliminate, the steady-state error. An integral control (K_i) will have the effect of eliminating the steady-state error, but it may make the transient response worse [9].

Effects of each of controllers K_p and K_i on a closed-loop system are summarized in the table shown in Table 1.

Table 1: Effects of each of controllers Kp and K_i on a closed-loop system

Controller respond	Rise time	overshoot	Settling time	study-state error
K_p	Decrease	Increase	Small change	Decrease
K_i	Decrease	Increase	Increase	Eliminate

Doing analysis and research on the paper is the main things that had to be implemented first. On this purpose, all the information is collected from the sources from prevese studies (i.e. PI controller, cascade control structure, transfer function and DC motor) as shown in figure 1.

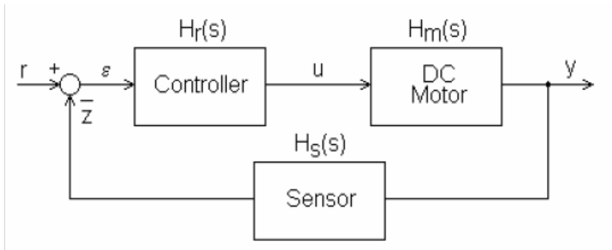

Figure 1: PI controller, cascade control structure

Where:

$H_r(s)$ – controller transfer function;

$H_m(s)$ – DC motor transfer function;

$H_s(s)$ – Sensor transfer function;

r – Reference signal;

u – Command signal;

y – Output signal (speed);

z – Sensor output signal;

E – Error signal (E = r – z);

The combination of proportional and integral terms is important to increase the speed of the response and also to eliminate the steady state error. The PID controller block is reduced to P and I blocks only as shown in figure 2.

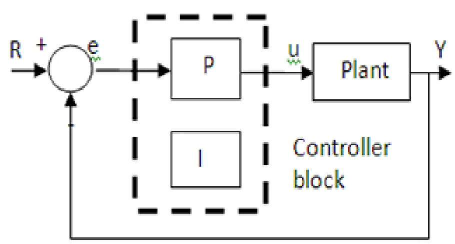

Figure 2: PI blocks only

The proportional and integral terms is given by:

$$u(t) = K_p e(t) + K_i \int e(t)dt \qquad 1$$

K_p and K_i are the tuning knobs, are adjusted to obtain the desired output. The following speed control example is used to demonstrate the effect of increase/decrease the gain K_p and K_i [10]. A DC motor dynamics equations are represented with second order transfer function:

$$G(s) = \frac{\theta}{V} = \frac{K_t}{(Js+b)(Ls+R) - K_e K_t} \qquad 2$$

Where:

K_t=K_e= electromotive force constant = 0.01Nm/Amp.

b = damping ratio of the mechanical system = 0.1Nms

J = moment of inertia of the rotor = 0.02Kgm^{2}s^{-2}

R = electric resistance = 1Ω

L = electric inductance = 0.5H

After we include the PI controller, the closed-loop transfers function become:

$$Gp(s) = \frac{Y}{R} = \frac{K_t K_p}{(Js+b)(Ls+R) - K_e K_t - K_t K_p} \qquad 3$$

The result obviously shows with PI controller, we are able to eliminate the steady state error. In summary with small value of K_i, we have smaller percentage of overshoot (about 13.5%) and larger steady state error (about 0.1). As we increase the gain of K_i, we have larger percentage of overshoot (about 38%) and manage to obtain zero steady error and faster response. With the response depicted in figure 2, PI controller can be introduced in order to reduce the overshoot and to ensure the response converge to the specified design objectives.

3. Results and Discussion

In order to eliminate this problem, (PI controller) is introducing to the system. So by integrating the PI controller to the DC motor were able to correct the error made by the DC motor and control the speed or the position of the motor to the desired point or speed.

The Matlab code has been designed simply to show the effect that the PI controller do to DC motor and doing that by showing the difference in the signals with and without the controller.

The PI controller calculation (algorithm) involves two separate Parameters; the Proportional and the Integral value so to make the comparison between the signals and the mount of stability that the PI gave to the Motor, the parameters had given a supposable values (30,70) the results were shown in figure 3 and figure 4.

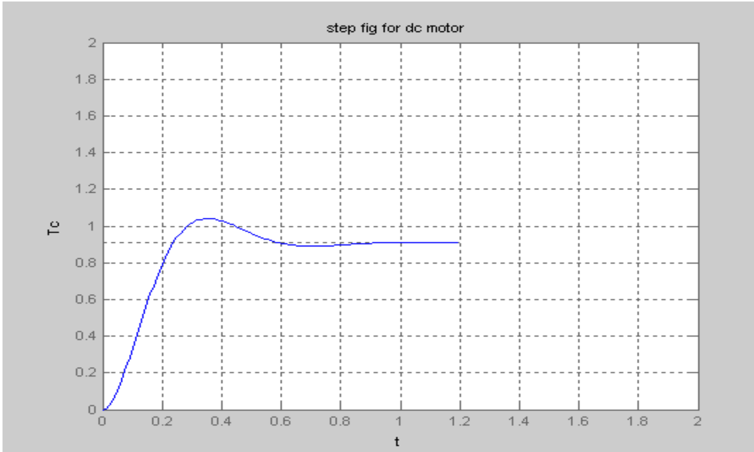

Figure 3: Step response for DC motor without PI controller

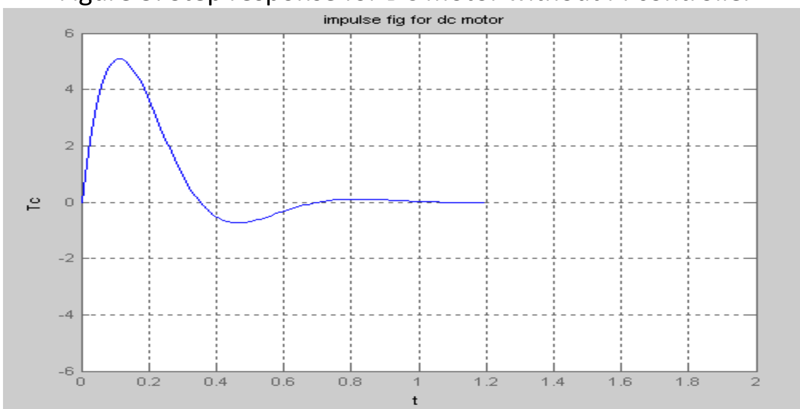

Figure 4: Impulse response for DC motor without PI controller

The major of the difference between the signals comes in five specifications: Settling time, Maximum overshot, Steady state error, Delay time and rise time.

Table 2: Specification of both figure 3 and figure 4

Specification	Step Response (Fig. 3)	Impulse Response (Fig. 4)
Settling time t_s	0.9	0.9
Maximum overshot	1.05	5
Steady state error	0.1	0
Delay time	0.1	0
Rise time	0.25	0.1

As it shown in the table 2 the output of the DC motor without PI controller has delay time and greater rise time. So to make it more stable PI controller's parameters K_p, K_i have been added to the DC motor transfer function and the results were as shown below:

3.1. Case one ($K_p < K_i$ (K_p=30, K_i=70)):

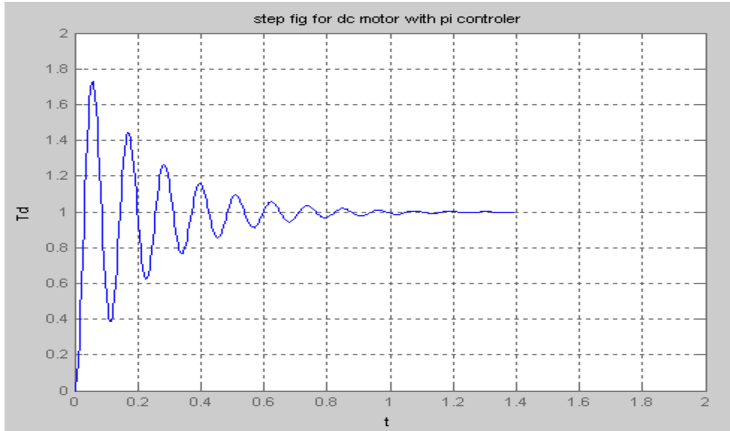

Figure 5: Step response of DC motor with PI controller (K_p<K_i)

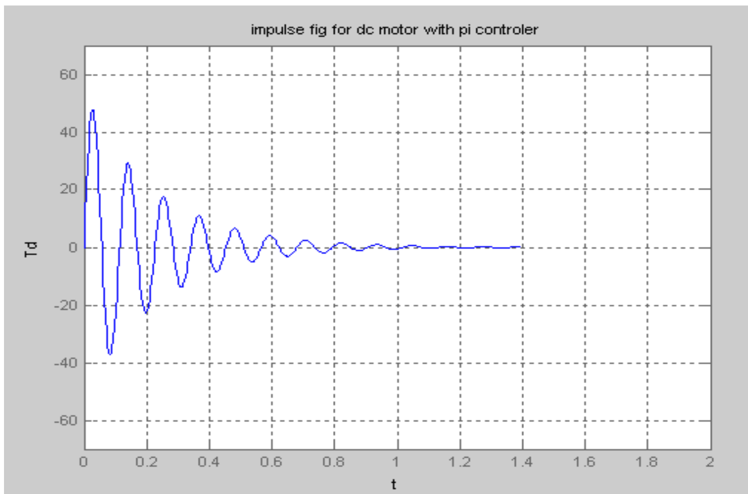

Figure 6: Impulse response of DC motor with PI controller (K_p<K_i)

As it shown in the figure 5 and figure 6 the PI controller made the signal more stable and less delay time and rise time. Specification of figure 5 and figure 6 are shown in Table 3.

Table 3: Specification of both figure 5 and figure 6

Specification	Step Response (Fig. 5)	Impulse Response (Fig. 6)
Settling time	1.2	1.1
Maximum overshot	1.75	48
Steady state error	0	0
Delay time	0	0
Rise time	0.02	0.01

3.2. Case two ($K_p > K_i(k_p=70, k_i=30)$):

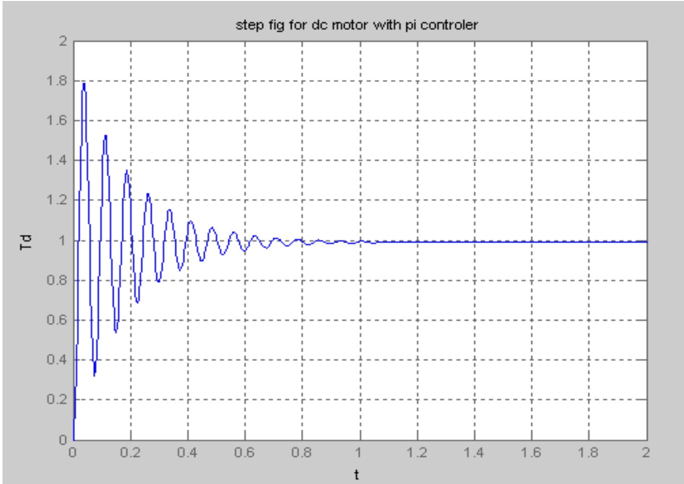

Figure 7: Step response of dc motor with PI controller(K_p>K_i)

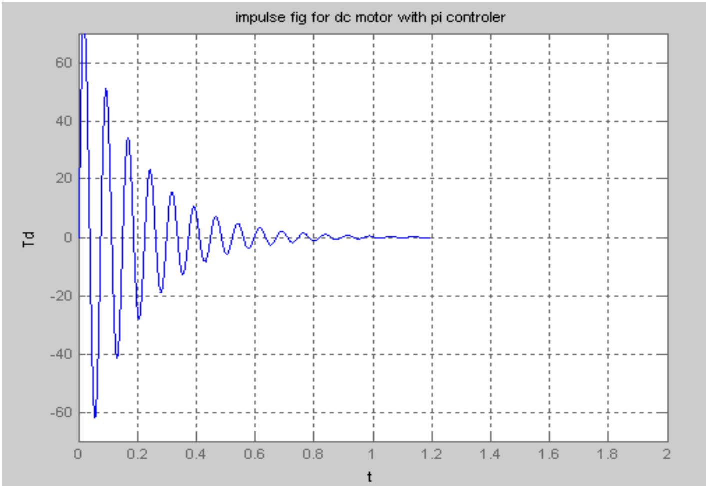

Figure 8: Impulse response of DC motor with PI controller (K_p>K_i)

As shown in the figure 7 and figure 8, the DC motor is even more stable than in the first case (k_p > k_i) and has zero steady state error. Specification of figure 7 and figure 8 are shown in Table 4.

Table 4: Specification of both figure 7 and figure 8

Specification	Step Response (Fig. 7)	Impulse Response (Fig. 8)
Settling time	1.2	1.18
Maximum overshot	1. 8	70
Steady state error	0	0
Delay time	0	0
Rise time	0.02	0.01

3.3. Case three ($K_p = K_i$ (k_p=30,k_i=30)):

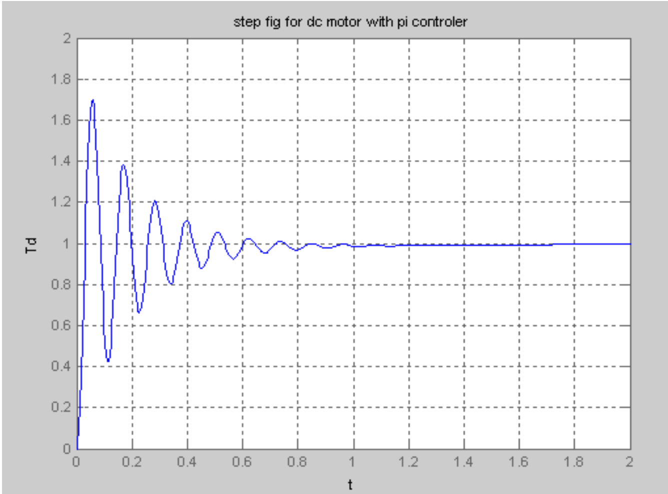

Figure 9: Step response of DC motor with PI controller (K_p=K_i)

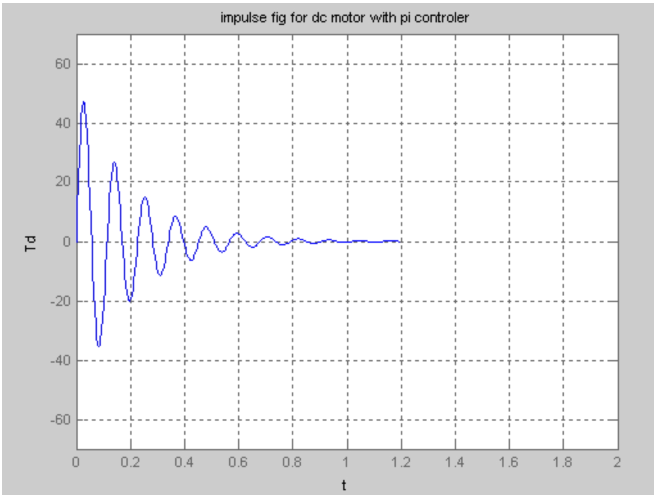

Figure 10: Impulse response of DC motor with PI controller (K_p=K_i)

As shown in the figure 9 and figure 10, the DC motor is even more stable than in the other two cases (k_p= k_i) and has zero steady state error. Specification of figure 9 and figure 10 are shown in Table 5.

Table 5: Specification of both fig (7) and fig (8):

Specification	Step Response (Fig. 9)	Impulse Response (Fig. 10)
Settling time	1.18	1.2
Maximum overshot	1.7	47
Steady state error	0	0
Delay time	0	0
Rise time	0.02	0.01

Finally, as shown in the figure 9 and figure 10, the DC motor is more stable than in the other two cases. Specification of figure 9 and figure 10 are shown in Table 5.

The algorithms of using the PI controller parameters to stable the dc motor are called PI tuning. It can be found by putting the controller in the proportional mode and increasing the gain until an oscillation takes place. The point is then obtained from measurement of the gain and the oscillation frequency. But in this project the algorithm had not been used as it has to be because the main purpose was not to show the real value of K_p and K_i that could tune the motor, it was to show the effect of any different values on the stability of it. This method provides higher efficiency, greater reliability, quick response and higher stability. All these results where agree with previous studies.

4. Conclusion

DC motors have speed control capabilities, which means that speed, torque and even direction of rotation can be changed at any time to meet new condition. It is simple, economic and easier to design and implement in normal speed control method.

From this work, following points can be concluded:

- The motor responds to the average value of the pulses and not to the individual pulses as the chopper works at high frequency.
- Changing the duty-cycle of the pulse by changing the no load area and increase the speed.
- It is possible to improve overall performance of the chopper drive.
- It fulfills all the requirements for its application.

Experimental results show that proposed system is suitable for different industrial applications such as trolley buses, subway cars, or battery-operated vehicles.

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