Proceedings of the 2023 International Conference on Mechatronics and Smart Systems
DOI: 10.54254/2755-2721/28/20230231

Speed control of direct current motors using proportional integral controllers

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Abstract. Proportional integral(PI) controllers is widely used in direct current(DC) motor controlling in factories, requiring tuning of their parameters to achieve optimal performance. New tuning techniques may be developed with the aid of research, which can speed up and simplify the tuning process. This work examined the use of PI controllers to regulate the speed of DC motors. TinkerCad modelling and Falstad circuit simulation are used to simulate the circuit model. Two well-known methods, step response and root locus, were implemented and assessed using Octave Online. Results demonstrate that, provided the KP value is not excessively high, increasing KP can enhance the stability of the DC motor close-loop system. The goal of the research is to balance the system's oscillation and stability while determining the appropriate KP value for the PI controller in this closed-loop system. This research uses octave online to analysis the root locus and close loop positions in pole-zero maps and creates the step responses of the system with different parameters of the PI controller.

Keywords: proportional integral, direct current motor, optimal performance, tuning techniques.

1. Introduction

Electrical energy is transformed into rotating mechanical energy by a DC motor, an energy actuator. With a lengthy history, there are now a wide range of options for using DC motors as machines with variable speeds. The motor needs to be carefully controlled to provide the required performance in these applications. Industrial control systems frequently employ PD, PI, and PID controllers. Based on the output of a plant as monitored and as contrasted to a preset set-point, these controllers generate an error value. The controller modifies the input for plant control in an effort to reduce the error [1]. These traditional controllers have been successfully used to govern a range of industrial equipment and are extensively used in industry. To work at their best, PI controllers need their settings tuned. New tuning techniques may be developed with the aid of research, which can speed up and simplify the tuning process [2].

Rakesh Narvey and Umesh Kumar Bansal looked into the functioning and control of fuzzy PI controllers. The design of PI control of DC motors using GUI and MATLAB was the topic of a conversation amongst Marizan Sulaiman, MSM Aras, Dawood Saleem, and Ashwaq Abdulameer. Ahmed M. Ahmed, Mohamed S. Elksasy, Amr Ali-Eldin, and Faiz F. Areed examined the performance of the traditional PI controllers and fuzzy PI controllers. Hamid Saeed Khan and Hamid Saeed Khan presented the digital version of PI controller implementation on an 8-bit microcontroller in addition to exhibiting the hardware-in-loop simulation technique by testing the PI controller hardware on a DC

DOI: 10.54254/2755-2721/28/20230231

motor plant model. The technique for analyzing, simulating, and adjusting the PI controller while controlling the speed of a DC motor in a closed loop system is developed in this study [3-5].

In this research, the physical model of the DC motor with the PI controller is stablished by circuit simulation in the Falstad and realistic circuit model in the TinkerCad. The mathematical model is set by the analysis of close-loop transfer function and the math form of PI controllers. This research uses octave online to analysis the root locus and close loop positions in pole-zero maps and creates the step responses of the system with different parameters of the PI controller.

2. Method

This paper discusses the speed control of DC motor using PI controller. In this research, the first step is modelling or simulating the DC motor and PI controller, and analyse the system based on the modelling [6].

2.1. Physical model

Using a range of components, such as resistors, capacitors, inductors, diodes, transistors, and more, users may design and manipulate circuits using the user-friendly interface provided by the Falstad Circuit simulator. Users may change component values by double-clicking on them and connecting components together by dragging wires between them [7].

Tinkercad is a versatile tool that allows users to explore and create in the worlds of 3D printing, electronics, and robotics. Users of the Tinkercad platform may create and simulate electronic circuits using the Tinkercad Circuit feature. Users may add elements like resistors, capacitors, LEDs, switches, and more, as well as link them with wires, using this visual drag-and-drop tool. When the circuit is constructed, Tinkercad Circuit offers a simulation tool that enables users to test the behavior of their circuit. With the help of the simulator, users may apply various voltage or current inputs and watch the circuit's reaction in real time [8]. In order to gauge voltage and current at certain locations in the circuit, users can also utilize a multimeter. The title is set 17 point Times Bold, flush left, unjustified. The first letter of the title should be capitalized with the rest in lower case. It should not be indented. Leave 28 mm of space above the title and 10 mm after the title [9].

2.1.1. DC motor. In control systems, the DC motor is a common actuator. The free body diagram of the rotor and the electric circuit of the armature are shown in the following Figure 1:

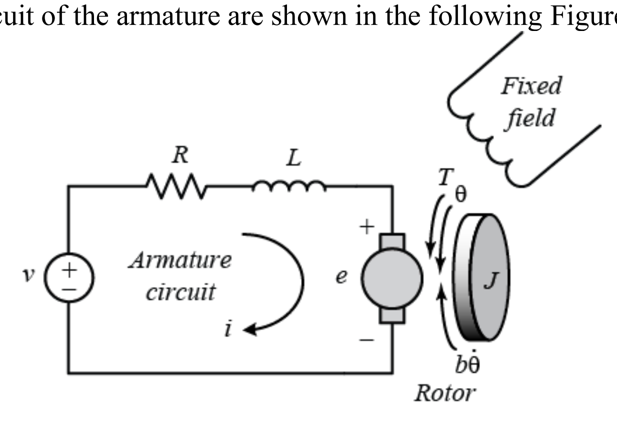

Figure 1. DC motor equivalent circuit.

Operational amplifiers (op amps), an analog circuit block that accepts a differential voltage input and generates a single-ended voltage output, are used in this study to construct the DC motor circuit. The motor is built up with an operational amplifier connect with a 60 kiloohms resistor and a 1.7 microfarad capacitor in parallel, and an inverse amplifier in series [10].

Figure 2 below shows the simulation of a DC motor in the Falstad.

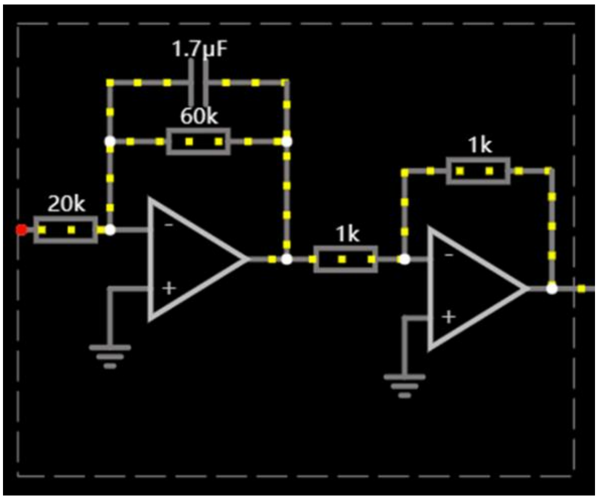

Figure 2. DC motor simulation in the Falstad.

2.1.2. PI controller simulation. The PI controller is component with two parts, Proportional controller and Integral controller. The Proportional controller is an operational amplifier connect with a resistor in parallel. The resistance of the resistor determines the proportionality coefficient the controller can give. The Integral controller is constitute with an operational amplifier and a capacitor (Figure 3). Figure 4 is the PI controller simulation in the Flastad.

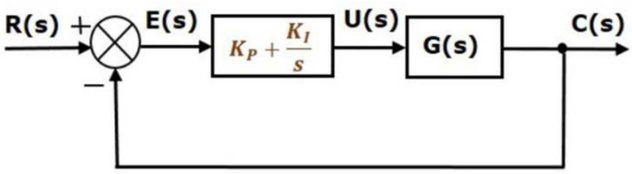

Figure 3. Block Diagram of PI Controller.

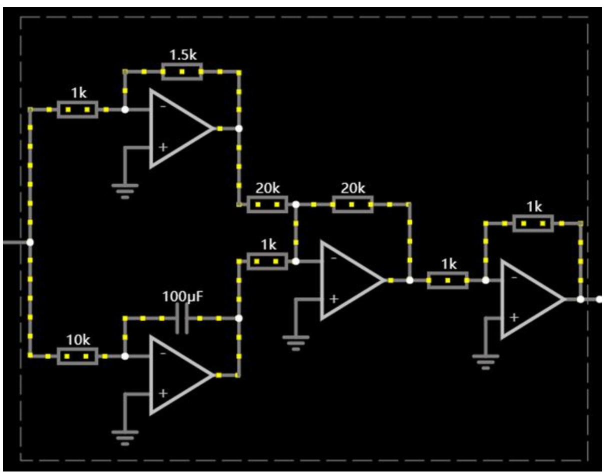

Figure 4. PI controller simulation in the Flastad.

2.1.3. Tinkercad model. The circuit of the system this paper discusses is a DC motor connect with a PI controller and a function generator, the circuit simulation of the system in the Falstad shows in Figure 5.

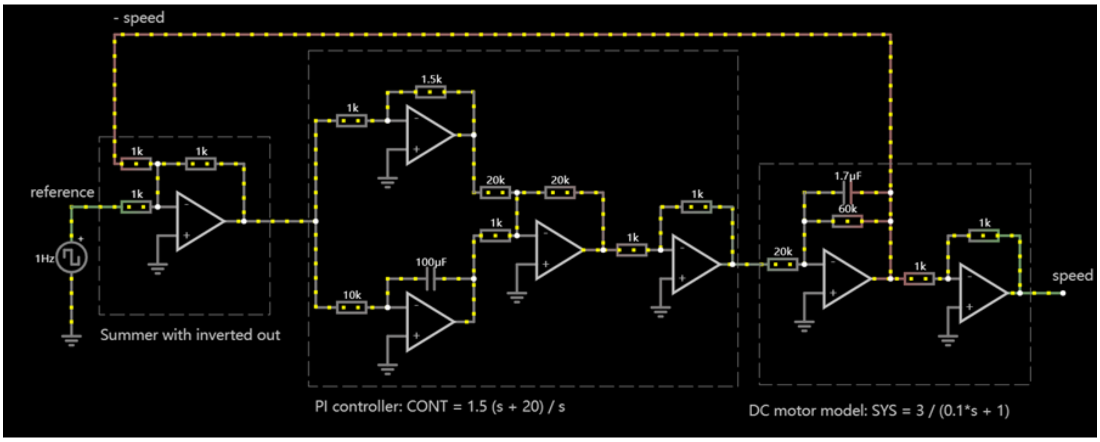

Figure 5. Falstad simulation of the close loop system.

In circuit modelling function of the Tinkercad, this paper uses 11 resistors, 5 operational amplifiers, 2 capacitors and power supply to build the whole circuit of the system. The Figure display below is the final Tinkercad circuit model of the close loop system this research focuses on. Figure 6 is Tinkercad circuit model of the system [11].

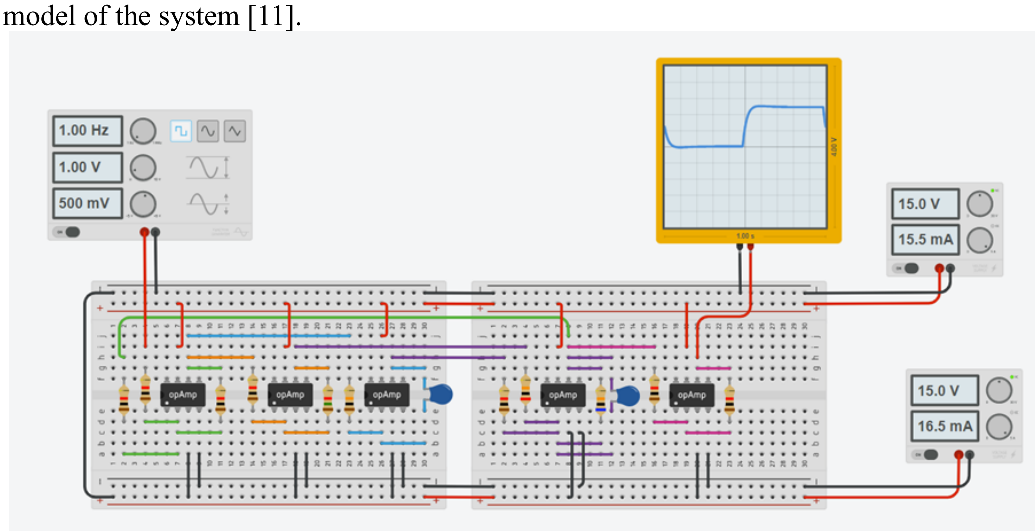

Figure 6. Tinkercad circuit model of the system.

2.2. *Mathematical model*

Figure 7 depicts the hardware-in-loop simulation control method.

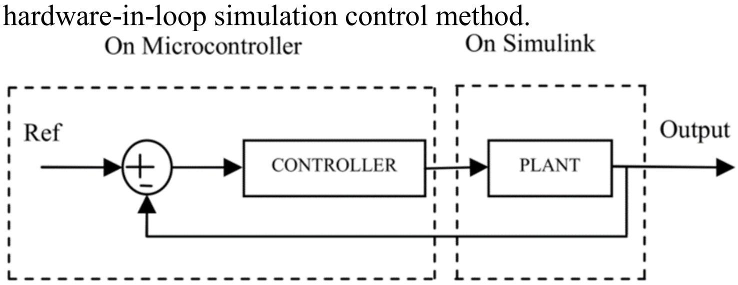

Figure 7. Block Diagram of close loop system.

2.2.1. Closed-loop transfer function. Consider Figure 8, a diagram of a generic closed loop in Laplace notation. Typical operations. The forward and feedback transfer functions are G(s) and H(s), respectively. The actuating error signal is E(s), and the feedback signal is B(s).

Numbers in Figure 8 are all identified as functions of the Laplace variable. To highlight the variations in the subsequent derivation of Out(s), the procedures follow naturally from Figure 8.

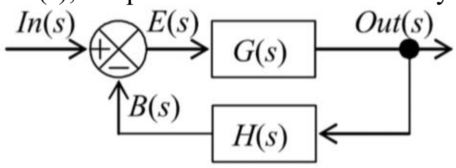

Figure 8. Diagram of a generic closed loop in Laplace notation.

In this research, G(s) = Plant*Controller, H(s) = 1. Based on the motor settings, the plant can be written as equation (1):

$$Plant = \frac{3}{0.1s+1} \tag{1}$$

In this research, the equation of controller can be written as equation (2), and the whole system can be written as equation (3) below.

$$Controller = K_P + \frac{K_I}{s} = \frac{K_P\left(s+\frac{K_I}{K_P}\right)}{s} \tag{2}$$

$$SYSCL = \frac{Plant*Controller}{1+Plant*Controller} \tag{3}$$

In this research KP was set to 0.15, 1.5 and 15 to compare and analysis the function of PI controller.

2.2.2. Math form of PI controllers. $U(t)=K_P*e(t)+K_I*\int e(t)dt$. Apply Laplace transform on both sides: $U(s)=(K_P+K_I\ s)*E(s)$; $U(s)E(s)=K_P+K_I\ s$. As the result, the transfer function of a PI controller is K_P+K_I/s. The following graphic displays the block diagram of the proportional integral controller with unity negative feedback closed loop control system (Figure 9).

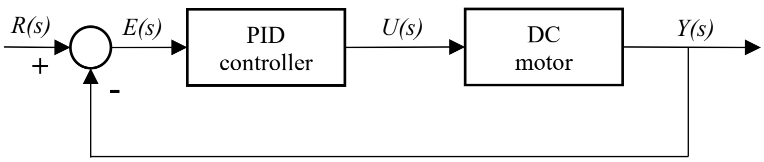

Figure 9. The block diagram of DC motor control system.

2.3. Octave analysis

This research uses Octave online to simulate and analyse the system. This paper uses Octave online to draw root locus diagram and analyze the system in Pole-Zero Map. The step response of the system with different KP values are also generated by Octave online in this analysis part. Figure 10 is the system analysis process.

Root locus analysis. In For a system whose close-loop transfer function is $T(s) = \frac{KG(s)}{1-KG(s)}$, using the following transfer function $G(s)H(s) = \frac{ansn+an-1sn-1+\cdots+a1s+a0}{bnsn+bn-1sn-1+\cdots+b1s+b0}$, equation (4) shows the close-loop transfer function:

$$T(s) = \frac{Kansn+Kan-1sn-1+\cdots+Ka1s+Ka0}{(bn-Kan)sn+(bn-1-Kan-1)sn-1+\cdots+(b1-Ka1)s+(b0-Ka0)} \tag{4}$$

When the system's gain K approaches the critical gain according to $Kc = \frac{bn}{an}$, the equation (4) changes to equation (5) below:

$$Tc(s) = \frac{anbnsn+an-1bnsn-1+\cdots+a1bns+a0}{bn(anbn-m-bnan-m)sn-m+\cdots+(anb1-bna1)s+(anb0-bna0)} \tag{5}$$

DOI: 10.54254/2755-2721/28/20230231

The output of the proportional integral controller is the total of the outputs of the proportional, and its closed-loop poles play a specific role in determining the stability of the control system. The essential characteristics of the transient response and steady-state response of the system are related to the positions of the closed-loop zeros and poles on the S-plane.

The roots of the system characteristic equation determine the essential characteristics of the system. If the relationship between the distribution of these roots on the S plane and the system parameters is transparent, the basic characteristics of the system will become clear.

Figure 10, 11 and 12 shows the root locus analyse when KP equals to 1.5, 0.15, and15.

Figure 10 below shows the location of the system when K_P equals to 1.5. The locations of zero points are presented with red dots.

```
octave:8> pzmap((plant*cont)/(1+plant*cont),'r.')
```

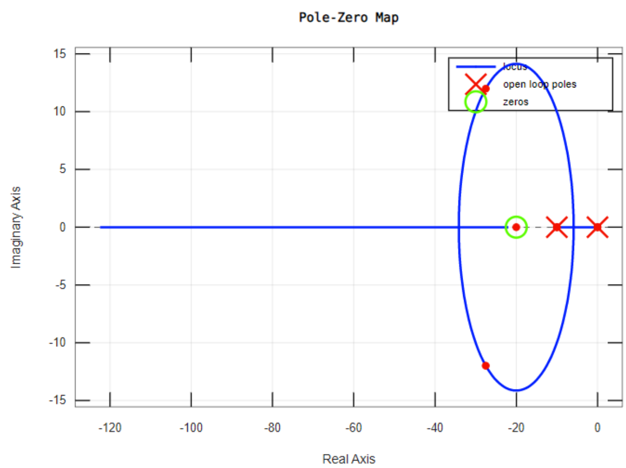

Figure 10. The position of the system when K_P equals 1.5.

This research changed the value of K_P from 1.5 to 0.15 and the change of controller and locations of zero points are shown in Figure 11. The locations are presented using cyan dots.

```
octave:9> cont = .15*(s+20)/s

Transfer function 'cont' from input 'u1' to output ...

      0.15 s + 3
 y1:  ----------
          s

Continuous-time model.
octave:10> hold on
octave:11> pzmap((plant*cont)/(1+plant*cont),'c.')
```

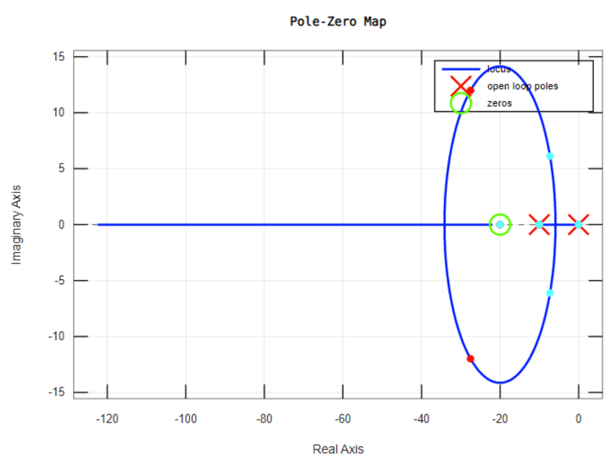

Figure 11. The position of the system when K_P equals 0.15.

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The controller and zero points locations with K_P value of 15 are shown in Figure 12 below. The locations are yellow dots. As the prediction of this research, there should be a yellow dot on the very left of the real axis.

```
octave:12> cont = 15*(s+20)/s

Transfer function 'cont' from input 'u1' to output ...

      15 s + 300
 y1:  ----------
          s

Continuous-time model.
octave:13> hold on
octave:14> pzmap((plant*cont)/(1+plant*cont),'y.')
```

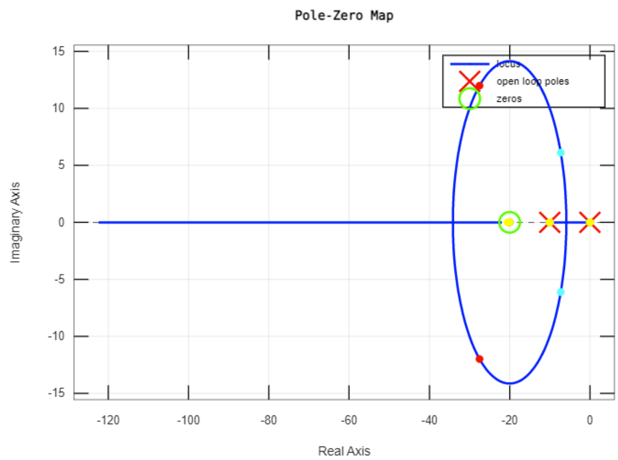

Figure 12. The position of the system when K_P equals 15.

All the locations of zero points are on the left side of S-Plane. Systems with the three values of K_P are stable. As the root locus of the system with K_P=15 is the farthest, the system with K_P=15 is the most stable system in this research. Theoretically, in a close-loop system with a PI controller, the value of K_P should not be too small. According to the root locus analysis, the range of K_P in this research relates to a linear response of stability of the system. However, the value of K_P should not be either too big or too small. Because of the velocity, the drone will have a bounce motion when arrives at the specific height. Therefore, it needs the differential control, which is the D is PID Controller. Moreover, it needs the Integral Controller to minimize the error of the result. In this case, all the value of K_P, K_I and K_D should not be too big or too small. This article needs to find the ultimate values to make the system the most stable and efficient.

3. Result and discussion

In this research the primary result is the step response of the close-loop system. As Figure 13 shows below, the middle one is when K_P equal to 0.15, the third line is when K_P equals to 1.5 and the first one is when K_P equals to 15. Analysis shows that in order to make the system more stable, it is necessary to increase the value of KP.

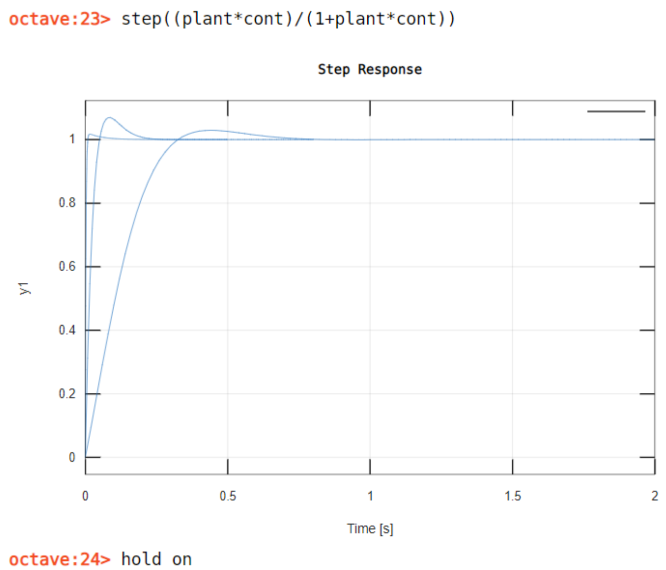

Figure 13. Step response of system with K_P values with 0.15, 1.5, and 15.

From the step response of 0.15 and 1.5 K_P value, the stability and oscillation of the system can be expected to be proportional to the magnitude of K_P. The result of the research shows the stability of a close-loop DC motor system with a PI controller is proportional to the magnitude of K_P. However, the oscillation of the close-loop system when K_P is 15 is the smallest. To improve the research, the range of K_P tested should be larger, to find the relationship between the magnitude of K_P and the oscillation. In this research, the best value of K_P for the close-loop DC motor system with the PI controller should be 15.

4. Conclusion

This paper discussed the speed control under different KP values of using PI controllers. The circuit models are simulated using Falstad circuit simulation and TinkerCad modelling. To analyze the step response, Octave Online was used to implement and evaluate two well-known ways: step response and root locus. Results demonstrate that, provided the KP value is not excessively high, increasing KP can enhance the stability of the DC motor close-loop system. For further research the range of KP value for testing should be larger to compare and regulate the KP value and oscillation of the system.

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