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PD Control and Simulation Analysis of DC Motor for Intelligent Vehicle Applications

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Abstract:

This paper studies the proportional-derivative (PD) control method in the control field, which can be applied in industrial automation, robot control, aerospace, process control, and other fields. This paper discusses the PD control to adjust the motor angle and the fuzzy proportional-integral (PI)-PD control of the brushless direct current (DC) motor. How to apply PD control theory to practice is a part worth exploring. In the traditional control field, proportional-integral-derivative (PID) control parameters cannot adjust the changes of controlled parameters, and the traditional PID control must cooperate with three parameters at the same time to work. Therefore, in this paper, PD control is applied to the adjustment of motor angle, and PI-PD fuzzy control is used to adjust the controller parameters in real time. This method can improve the response speed of the controller, apply the control theory to the actual motor control, and improve the anti-interference ability. This research can improve the application scope of PD control and combine it with a variety of control theories, to achieve a better effect of the control system, optimize the response speed of the motor, and achieve the target speed faster.

Keywords: PD control; Brush-less DC motor; NFPI-PD design; Motor angle

1. Introduction

Most of the mechanical growth this paper observes around production is the result of electrical motors. A device that converts electrical energy into mechanical energy is an electrical motor. Motors can be divided into two categories: brushed DC motors, which run on direct current, and alternating current (AC) motors, which run on alternating current. Brushless DC motors are utilized in many different control systems, such as process control, automobiles, trains, and residential electrical systems, according to a study conducted by [1]. It is common knowledge that the mathematical model plays a crucial role in control system design. The permanent magnet motor, DC series motor, DC shunt motor, and compound motor are the four types of DC motors that have been stated by [2]. Next, there aren‘t many models. The permanent magnet motor, DC series motor, DC shunt motor, and compound motor are the four types of DC motors that have been stated by [2]. Then, only a small number of DC motor models precisely mirror the behavior of the system.

Brushless DC motors are frequently favored over AC motors for various reasons. Brushed DC motors feature many different speed control choices, including the ability to operate both below and above the rated speed, making them perfect for low-torque applications. In addition, it has a strong and substantial starting torque. The cost of brushed DC motors is considerably more reasonable, and one of their final benefits is that they require little to no maintenance. In addition, brushed DC motors are more reasonably priced, and one of their final benefits is that they require little to no maintenance, which leaves room for improvement [3]. It also has a huge and powerful starting torque. Brushed DC motors are used in a variety of systems, including turntables, conveyors, and other devices that need low-speed or continuous torque as well as positional accuracy [4].

Due to the electric actuators and computer technology‘s quick development, DC motor control is now widely utilized in many industrial applications, particularly in autos. A DC motor‘s quick response time, exceptional flexibility, and excellent adaptability allow it to operate over a wide speed range with precision and power. Whether it is used for position or speed control in many industrial applications, motor control is an essential and crucial function. The controller‘s efficacy can be exhibited through performance benchmarks like rapid movement or precise tracking [5].

PID controllers are typically used in the field of motor control to realize parameter control. However, because PID control parameters are fixed, their control stability is poor when it comes to the actual control of Brushless DC motors, necessitating the coordination of three parameters at the same time. Some academics proposed the fuzzy PID control system method as a solution to this issue. The correction values of K_p, K_i, and K_d fuzzy controllers can be produced by fuzzifying the deviation and deviation change rate; however, this method‘s control reaction speed and anti-interference capabilities are subpar.

As a result, this study proposes the NFPI-PD design. To find the final deviation E and the deviation change rate EC, the motor‘s actual speed and its specified speed are first compared and computed. The fuzzy controller fuzzifies the two deviations, then passes the fuzzified E and EC to the fuzzy controller for reasoning to produce the defuzzified K_p „and K_i“. The PI controller then receives the results, which are then input into the motor model through PD control. K_p ,and K_i‘ are the output variables of the fuzzy controller, whereas speed error E and error change rate EC are its input variables. To achieve motor rotation control in the PD control link, the transfer function of the loop converts the voltage signal into the motor rotation angle parameter. Simultaneously, this research addresses the motor angle parameter value regulated by PD and forms feedback through PD control to minimize error.

2. Methodology

2.1 Basic Principles Of The PD Controller

Proportional control and Derivative control are the two fundamental tenets of the PD controller concept. These two components work together to give the PD controller the capacity to efficiently lower control system error while enhancing system stability and reaction time. Accelerating the response can be achieved by increasing the proportional gain, however, a too high gain might lead to instability and oscillation in the system. Moreover, Derivative control can improve the response speed of the system and reduce overshoot, but excessive differential gain may cause the control system to be overly sensitive to noise.

2.1.1 Proportional control

The main component of a PD controller is proportional control, which produces an output signal that is proportionate to the present error. The discrepancy between the process variable’s (actual value) and the set value (target value) is called an error. One way to express the proportional control formula is:

$$u(t) = K_p * e(t) \tag{1}$$

where $u(t)$ is controller output, K_p is proportional gain, $e(t)$ is error (set value - actual value).

2.1.2 Derivative control

The Derivative control component modifies the control output according to the rate of change of the error. It has the capability to anticipate future changes in the error and implement measures proactively. The formula for Derivative control can be represented as:

$$u(t) = K_d * \frac{de(t)}{dt} \tag{2}$$

where Kd is derivative gain, $\frac{de(t)}{dt}$ is the rate of change of error.

2.1.3 Comprehensive representation of PD controller output

$$u(t) = K_p * e(t) + K_d * \frac{de(t)}{dt} \tag{3}$$

2.1.4 Simple circuit and formula derivation for PD controller

Since this circuit is a linear circuit, it can be analyzed based on the virtual short and virtual break characteristics of the operational amplifier

$$i_{f=}i_R + i_C = \frac{ui}{R_1} + C_1\frac{du_i}{dt} \tag{4}$$

$$u_o = -R_f i_f = -R_f\left(\frac{u_i}{R_1} + C_1\frac{du_i}{dt}\right) \tag{5}$$

$$u_o = -\left(\frac{R_f}{R_1}u_i + R_f C_1\frac{du_i}{dt}\right) \tag{6}$$

where i_f is the current passing through R_f, i_R is the current passing through R_1, i_C is the current passing through C_1, ui is the input voltage, R_1 is a resistor with a resistance value of 1k ohms, R_f is a resistor with a resistance value of 10k ohms, C_1 is a capacitor with a capacitance value of 200n Farads, uo is the output voltage. Typical circuit of PD control is shown in Fig. 1. Fig. 1 illustrates a general PD control circuit.

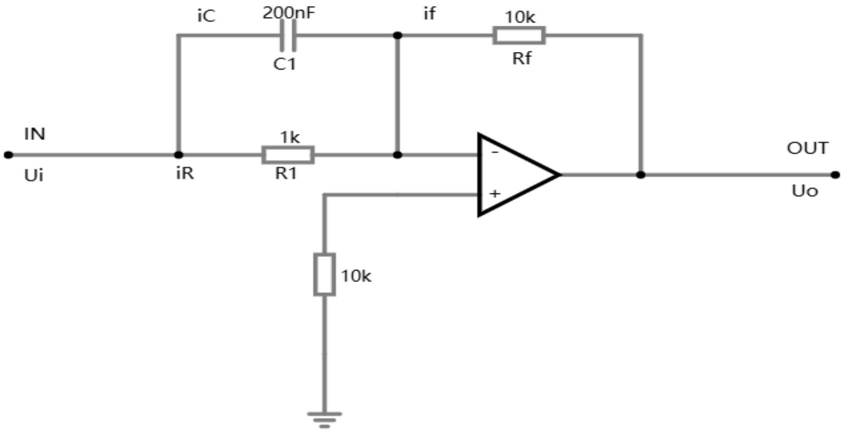

Fig. 1 Typical circuit of PD control. (Photo/Picture credit: Original)

2.2 Iteration PI-PD Brushless DC Motor Speed Control Algorithm

Fuzzy and PI-PD controllers make up the brushless DC motor speed modulation module. The performance of traditional PID control is not up to par when the control system changes since the parameters of the controlled object change and the classic PID control parameters cannot be changed in time. Thus, such issues can be successfully resolved if the fuzzy controller is used to regulate the speed of the Brushless DC motor speed control system and the PI controller‘s parameters are changed in real time via the fuzzy controller.

The specific method is as follows:

In order to calculate the deviation E and the deviation change rate EC, the specific method is as follows: first, the brushless DC motor‘s actual speed and set speed are compared. Then, the two deviations are fuzzified to obtain E and EC in the fuzzy control system. Finally, the fuzzy controller is used to reason in order to obtain the defuzzied KP ,and Ki‘. Ultimately, the PI controller receives the two values, and the motor model receives the PD control, which forms the adjustment.

The structure diagram of the fuzzy PD control system is shown in Fig. 2. Fig. 2 illustrates the process of PD Fuzzy control. It is necessary to obtain new KP and KD through the fuzzy controller.

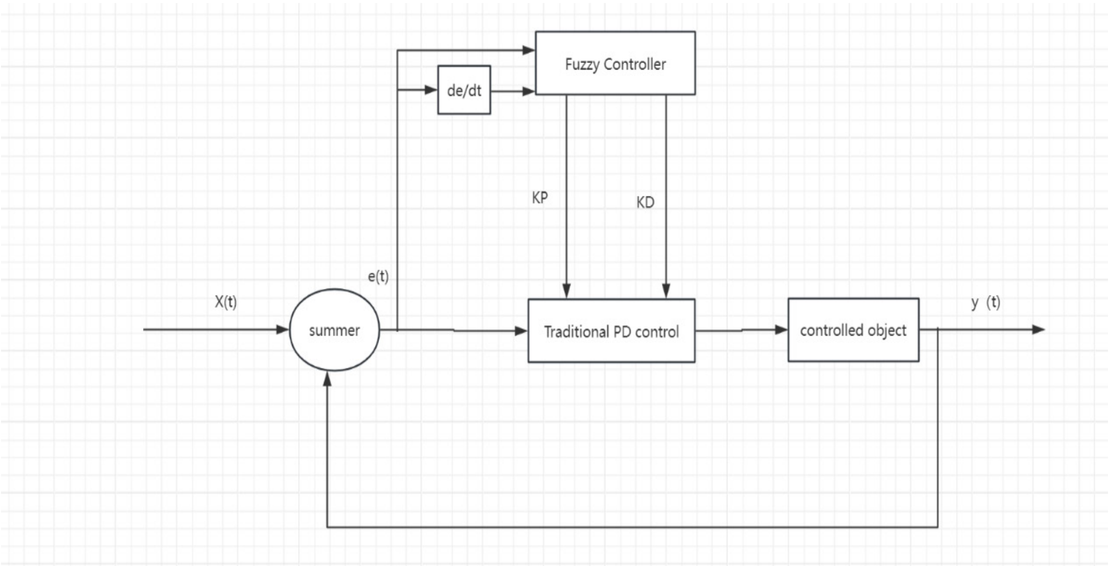

Fig. 2 Structure diagram of fuzzy PD control system. (Photo/Picture credit: Original)

PD Control Of Motor Angle

Firstly, it is necessary to establish a circuit that converts voltage values into angle values, and then combine it with feedback circuits and PD control circuits to complete PD control of motor angle.

2.2.1 Voltage to angle

The transfer function of the angular velocity to voltage is

$$\frac{\omega}{V}=\frac{K_m}{\tau s+1},\ \tau=\frac{JR}{K_tK_e} \tag{7}$$

where ω is angular velocity, V is voltage, K_m is K_e 's Countdown, J is moment of inertia, R is armature resistance, K_t is torque constant, K_e is back electromotive force constant.

And angle is the integral of angular velocity with respect to time:

$$\theta=\int\omega dt \tag{8}$$

Therefore, the transfer function of the angle to voltage is

$$\frac{\theta}{V}=\frac{K_m}{\tau s+1}*\frac{1}{s} \tag{9}$$

Voltage to angle flowchart is shown in Fig. 3. Fig. 3 illustrates the process of converting voltage value into angular velocity value and then into angular value through the transfer function.

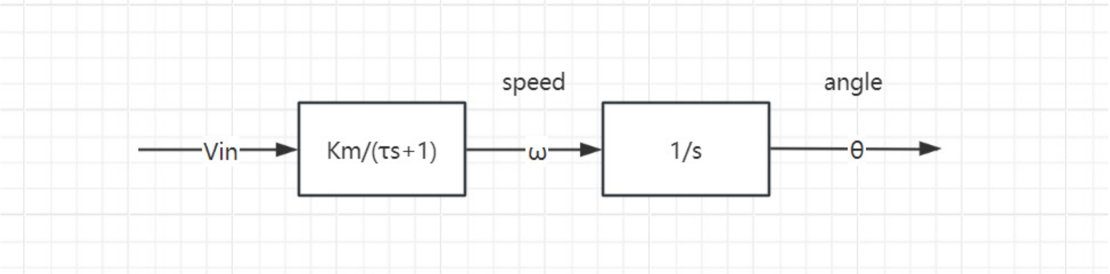

Fig. 3 Voltage to angle flowchart. (Photo/Picture credit: Original)

2.2.2 PD control part

In this part, this research needs to build a PD control circuit. The specific reasons for setting parameters will be mentioned in the result and discussion. Compared with the proportion control, PD control has a faster response speed and can reduce the output error.

Transfer function:

$$C(s)=K_p+K_ds \tag{10}$$

$$C(s)=K_p(1+\frac{K_d}{K_p}s) \tag{11}$$

where K_p is the numerical value of proportional control, K_d is the numerical value of derivative control.

The PD control flow chart is shown in Fig. 4. Fig. 4 illustrates the whole process of how to control the motor through PD control.

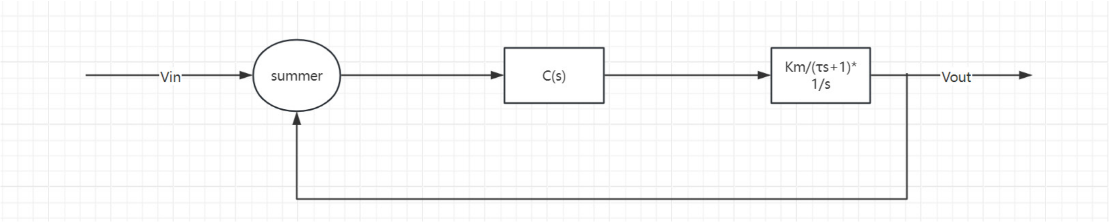

Fig. 4 PD control flow chart. (Photo/Picture credit: Original)

3. Results and Discussions

3.1 Discussion Of Speed Control Algorithm Of Brush-Less DC Motor NFPI-PD

It is clear from the fuzzy control of the brushless DC motor above that the fuzzy controller may modify the values of KI and KP in real time, after which it can modify the PD control to regulate the brushless DC motor. In the experiment, the motor's initial speed was set to 3000 rpm, and the load torque was initially recorded in the Matlab/Simulink environment at 0n · m. The speed stayed constant at 0.3s, while the torque mutation was recorded at 3N·m. At 0.4s, the torque stayed constant, and the speed abruptly changed to 1500 rpm [6].

The simulation results show that the brushless DC motor speed control method, nfpi-pd, first approaches the stable state when compared to the fuzzy PID control algorithm and the classic PID control strategy. When the tested system's torque varies, the nfpi-pd control algorithm's peak value varies less and it first returns to the steady state with strong robustness; when the tested system's target speed changes, the nfpi-pd control algorithm is the fastest to respond and reaches the target speed first.

3.2 Analysis of the Control Effect Based on the Improved PD Controller

3.2.1 Design the system

1) DC motor

Assuming K_m=3, R=1k, c=0.1mF, so Ri=333, the DC motor circuit diagram is shown in Fig. 5. Fig. 5 illustrates how to convert the voltage value into the motor angle value through a specific circuit.

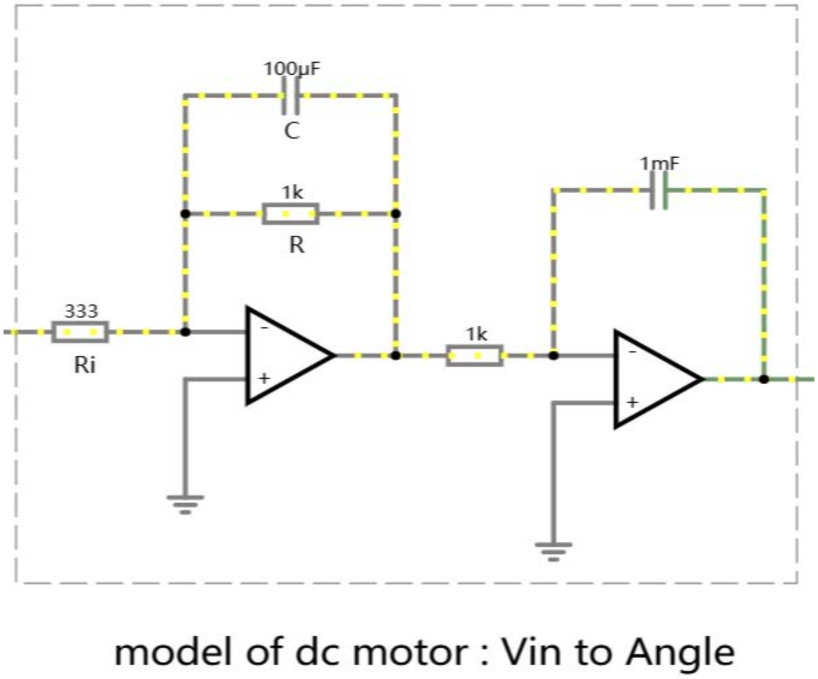

Fig. 5 DC motor circuit diagram. (Photo/Picture credit: Original)

This circuit can convert the angle value into the output voltage value through the transfer function.

2) PD control

Zero point is the value of S cause the numerator polyno-

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mial is zero. So the zero point of the formula is $-\frac{K_p}{K_d}$. Choosing the zero point at -11, circuit gain equals 6, according to the formula $\frac{\theta}{V}=\frac{K_m}{\tau s+1}*\frac{1}{s}$ and $C(s)=K_p\left(1+\frac{K_d}{K_p}s\right)$, the $\frac{K_d}{K_p}=\frac{1}{11}$, $K_p=6$, $K_d=\frac{6}{11}$.

Then according to the formula $V_{out}=-\frac{R_f+sL}{R_i}V_{in}$ designs the circuit parameters. PD control circuit is shown in Fig. 6. Fig. 6 illustrates how to complete PD control through specific circuit.

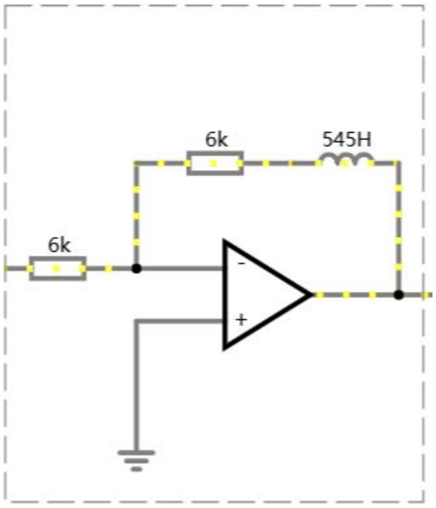

Fig. 6 PD control circuit. (Photo/Picture credit: Original)

3.2.2 The Control Effect of the Improved PD Controller on Motor Angle

3.2.2 .1 Disadvantages of proportional control on motor speed

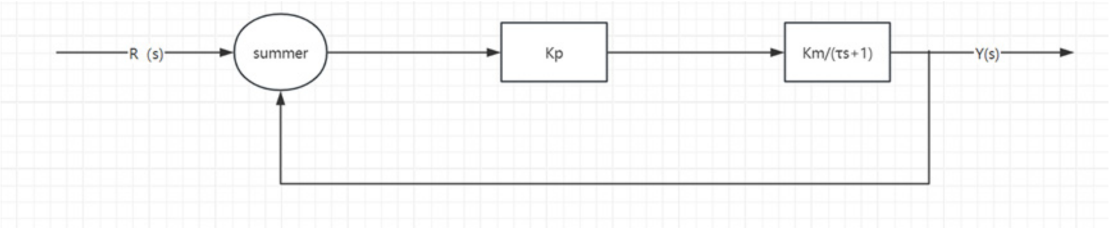

Fig. 7 Proportional control on motor speed flow Chart. (Photo/Picture credit: Original)

According closed loop control transfer function: $\frac{Y_s}{R_s}=\frac{P(s)*C(s)}{1+P(s)*C(s)}$, the transfer function of proportional control is

$$\frac{\frac{K_p*K_m}{\tau s+1}}{1+\frac{K_p*K_m}{\tau s+1}}=\frac{K_p*K_m}{(\tau s+1))+K_p*K_m}=\frac{\frac{K_p*K_m}{1+K_p*K_m}}{\frac{\tau s}{1+K_p*K_m}+1}$$, then

this research make $\overset{\text{¡ä}}{\tau}=\frac{\tau}{1+K_p*K_m}$, $\overset{\text{¡ä}}{K}_m=\frac{K_p*K_m}{1+K_p*K_m}$. Assuming $K_m=3$, $\tau=0.1$, $K_p=3$, so $\overset{\text{¡ä}}{\tau}=0,01$, $\overset{\text{¡ä}}{K}_m=0.1$. From this, this research can find that when s=0, the final output voltage is 0.9, which is far from the 1 this research set at the beginning. Proportional control on motor speed flow Chart is shown in Fig. 7. Fig. 7 illustrates the simple process of proportional control DC motor. Proportional Control of DC Motor Speed Circuit Diagram is shown in Fig. 8. Fig. 8 illustrates how to use proportional control to control the speed of DC motor through specific circuit. Input/output waveform diagram is shown in Fig. 9. Fig. 9 illustrates that there is a large stability error between the output voltage and the input voltage.

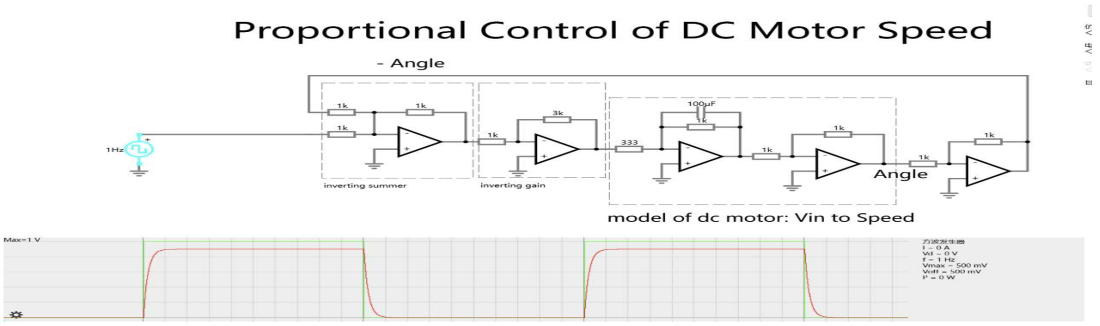

Fig. 8 Proportional Control of DC Motor Speed Circuit Diagram. (Photo/Picture credit: Original)

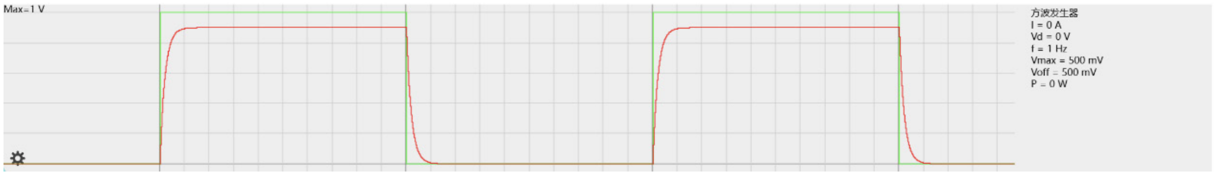

Fig. 9 Input/output waveform diagram. (Photo/Picture credit: Original)

Therefore, there will be some errors when the proportional control is used to control the motor speed, which cannot achieve the desired results. The reason for this error is that each motor has a different K_m, which will change, so the output voltage will also change in different cases. The DC gain is the value when s=0 in the transfer function $\frac{K_m}{\tau s+1}$, so the DC gain is K_m. It is found in the experiment that PD control can solve this problem And keep the value of DC gain at 1.

3.2.2 .2 Disadvantages of proportional control on motor angle and solution of frequency oscillation.

When using proportional control to control motor angle, in response to the step, it can get a little about overshoot. By changing the gain to ten, there is more overshoot. The proportional Control of the DC Motor Speed Circuit Diagram(gain=3) is shown in Fig. 10. Fig. 10 illustrates the proportional control of the DC Motor Speed circuit diagram when the gain is 3. The input/output waveform diagram is shown in Fig. 11. Fig. 11 illustrates the input voltage and output voltage waveforms of the proportional control circuit diagram when the gain is 3. The proportional control of dc motor speed circuit diagram (gain=10) is shown in Fig. 12. Fig. 12 illustrates the proportional control of the DC Motor Speed circuit diagram when the gain is 10. The input/output waveform diagram is shown in Fig. 13. Fig. 13 illustrates the input voltage and output voltage waveforms of the proportional control circuit diagram when the gain is 10.

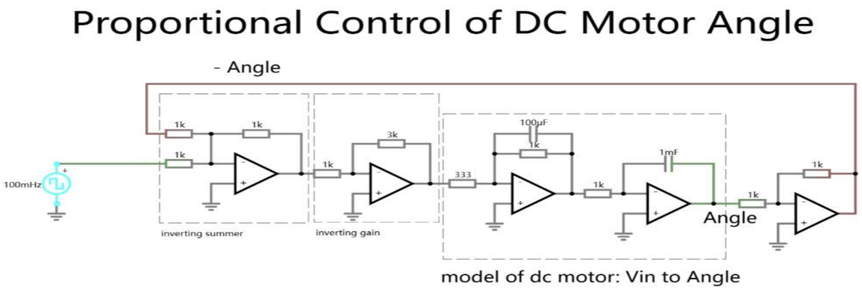

Fig. 10 Proportional Control of DC Motor Speed Circuit Diagram(gain=3) (Photo/Picture credit: Original)

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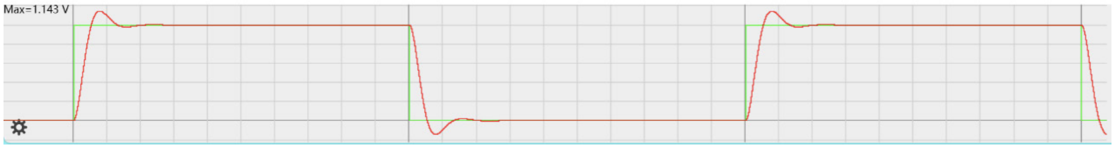

Fig. 11 Input/output waveform diagram

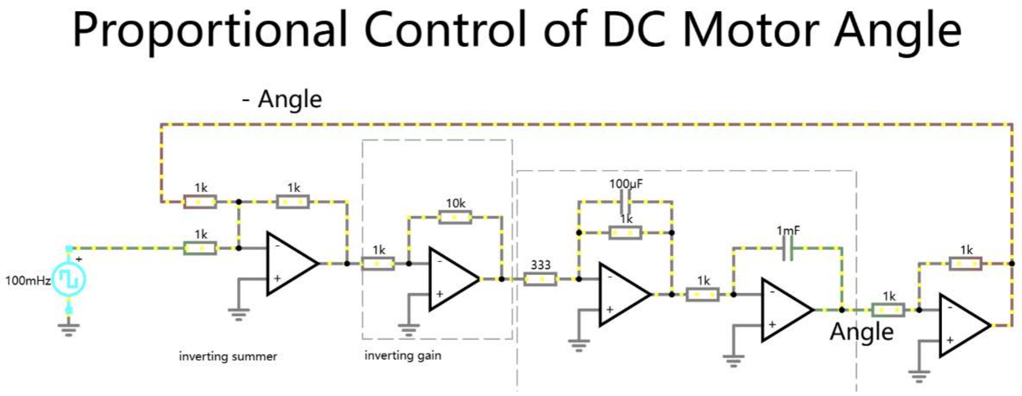

Fig. 12 Proportional Control of DC Motor Speed Circuit Diagram(gain=10) (Photo/Picture credit: Original)

Fig. 13 Input/output waveform diagram. (Photo/Picture credit: Original)

If the gain becomes 100, immediately there is a problem. Note that the oscillation frequency appears to have changed. In the beginning, it was a little slower, and then it accelerated. The oscillation frequency is not very constant because. In this particular case, the amplifier has been saturated. The proportional control of DC motor speed circuit diagram (gain=100) is shown in Fig. 14. Fig. 14 illustrates the proportional control of the DC Motor Speed circuit diagram when the gain is 100. The input/output waveform diagram is shown in Fig. 15. Fig. 15 illustrates the input voltage and output voltage waveforms of the proportional control circuit diagram when the gain is 100.

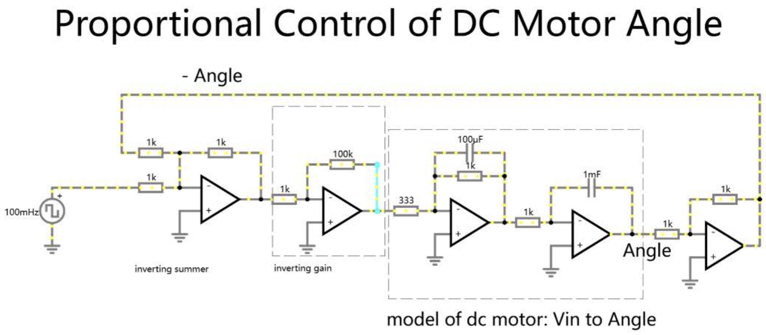

Fig. 14 Proportional Control of DC Motor Speed Circuit Diagram(gain=100). (Photo/Picture credit: Original)

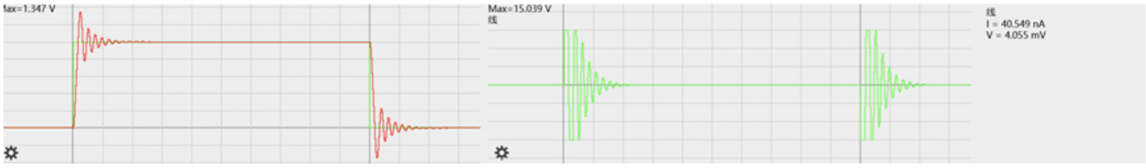

Fig. 15 Input/output waveform diagram

This is a very serious problem, which means that this research cannot carry out linear control in any case, because the amplifier will reach a saturation state. Like adding a first-order filter. Proportional control of the DC motor speed circuit diagram (with filter) is shown in Fig. 16. Fig. 16 illustrates the circuit diagram when eliminating frequency oscillation through a filter. The input/output waveform diagram is shown in Fig. 17. Fig. 17 illustrates the waveform of input voltage and output voltage when eliminating frequency oscillation through a filter.

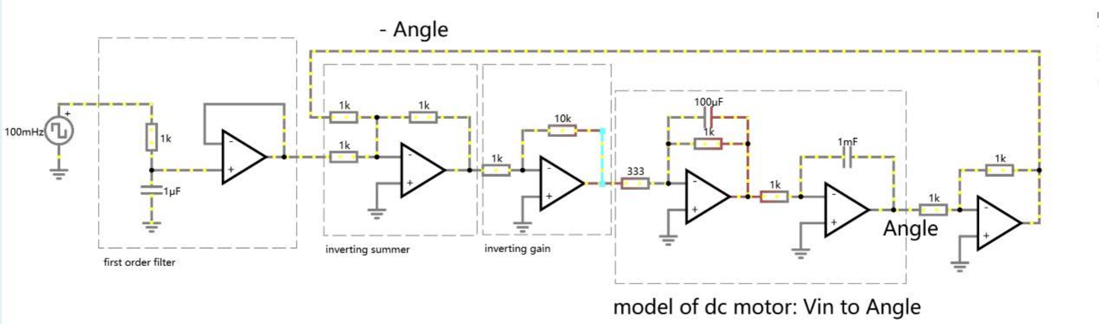

Fig. 16 Proportional control of DC motor speed circuit diagram (with filter). (Photo/Picture credit: Original)

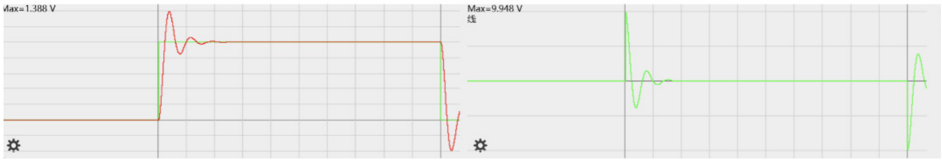

Fig. 17 Input/output waveform diagram. (Photo/Picture credit: Original)

So this research can get the response. Later in the experiment, it was found that the best approach is to prevent saturation or significant saturation. Reducing the amplitude of the request can be achieved by changing the resistance value in the inverting summer.

3.2.2 .3 Advantages of PD control.

According to the waveform diagram of the angle circuit diagram of the PD control motor in Figs. 18 and 19, the final output value can be stabilized at 1V. This circuit design effectively reduces the error and improves the response speed. In the whole circuit of PD controlling DC motor angle, through the adjustment of proportional gain and differential gain, the rapid response and accurate control of motor angle can be achieved. The proportional gain determines the response speed of the controller to the error, while the differential gain is used to predict the change trend of the error, so as to adjust the control quantity in advance and reduce the overshoot and oscillation.

PD control of the DC motor angle circuit diagram is shown in Fig. 18. Fig. 18 illustrates the overall circuit diagram of using PD control to control the angle of the DC motor.

The input/output waveform diagram is shown in Fig. 19. Fig. 19 illustrates the waveform diagram of the input voltage and output voltage of the DC motor angle controlled by PD control.

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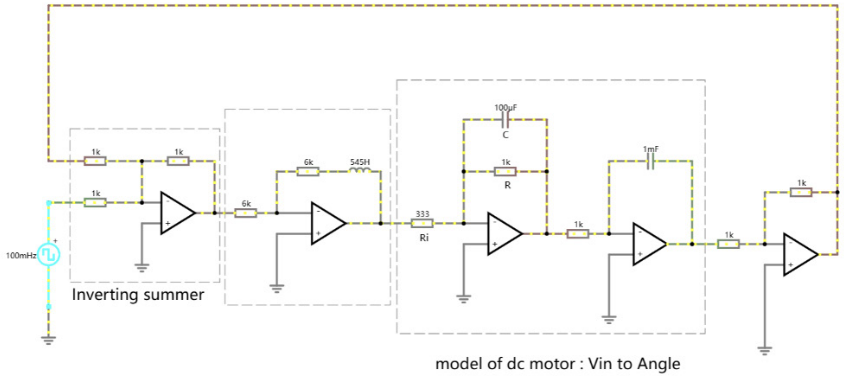

Fig. 18 PD control of DC motor angle circuit diagram. (Photo/Picture credit: Original)

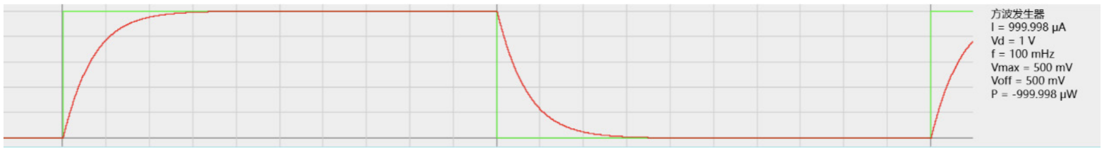

Fig. 19 Input/output waveform diagram. (Photo/Picture credit: Original)

3.2.2 .4 Root locus and PZ map of PD control

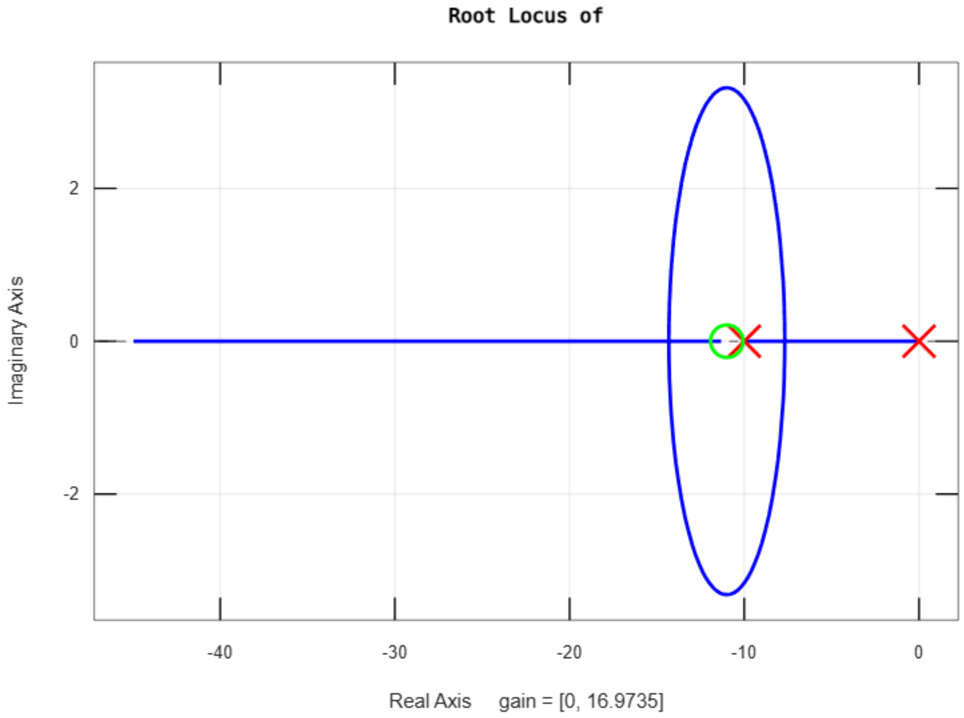

Fig. 20 Root Locus of PD control. (Photo/Picture credit: Original)

The Root Locus of PD control is shown in Fig. 20. Fig. 20 illustrates the root locus of PD control.

In Fig. 20, this research chooses Zero equal to minus 11.

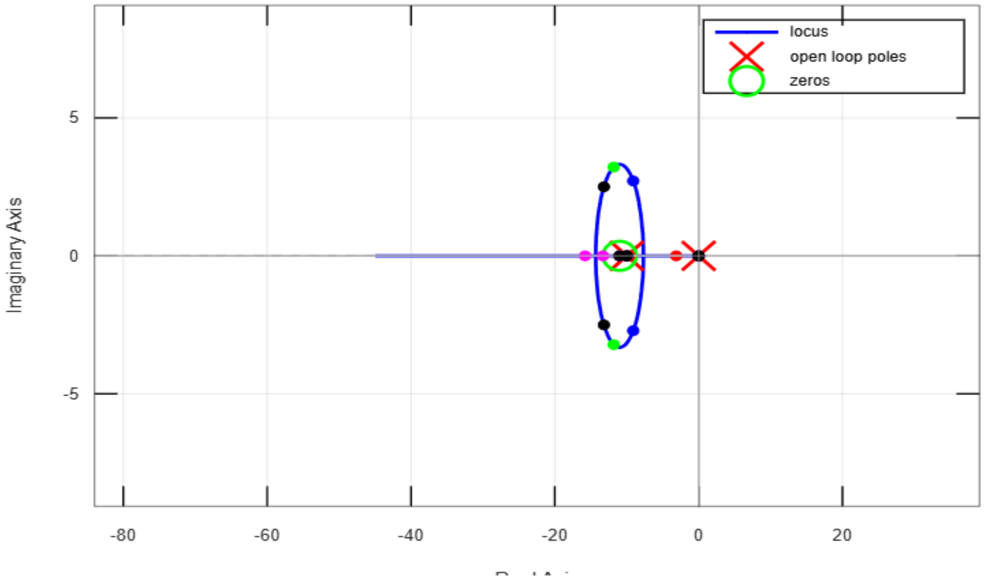

Fig. 21 Pole and Zero map. (Photo/Picture credit: Original)

The pole and Zero map are shown in Fig. 21. Fig. 21 illustrates the zero point and pole diagram of PD control when different gain values are selected. In the experiment, different gain values are selected, the red one is 1, the blue one is 3, the green one is 5, the black one is 6, and the pink one is 7. The first selected value is 1, but it was too close to the imagined entry, so it's not safe enough. Finally, when the gain value was 6, this was the most effective one.

3.2.2 Discussion of the Improved PD controller's anti-interference ability

The anti-interference ability analysis of the PD controller mainly involves how to ensure that the control system can operate stably according to the predetermined trajectory under the complex external environment and the disturbance of internal parameters of the system. In the nonlinear Jeffcott rotor system, by introducing time delay into the control loop, the efficiency of the PD controller can be enhanced, especially under the specific time delay value, the stability of the system can be significantly improved, and the oscillation can be reduced. Specific anti-interference technologies, such as digital notch filtering, direct wave trap filtering, and adaptive interference cancellation, can also effectively improve the anti-interference ability of the PD controller. These technologies can effectively identify and suppress specific types of interference through specific algorithms or hardware design, so as to ensure the stable operation of the system.

However, it should be noted that different anti-interference measures may be applicable to different interference types and application scenarios. For example, digital notch filtering is suitable for suppressing continuous periodic interference, while adaptive interference cancellation is suitable for a wider range of interference environments. Therefore, in practical application, it is necessary to select appropriate anti-interference technology and measures according to the specific interference situation and system requirements.

In the application of a voice coil motor direct drive micro motion table, a PD controller is used for position closed-loop control to enhance the anti-interference ability of the system. The experimental results show that this method can effectively meet the needs of inkjet printing and other applications [7].

In the heading control system of a remotely operated underwater vehicle (ROV), the fuzzy pd-pi method is used to verify the control effect. The results show that this method has a shorter transition time and stronger anti-interference ability than the conventional PID control, and it is an efficient ROV heading control method [8].

In the latest research results of fractional order PD controller in improving the anti-interference ability of the system. By combining fractional order PD controller with active disturbance rejection control (ADRC), the anti-interference ability of the system can be significantly improved. For example, it is mentioned in the literature that the position servo control system can achieve a good control effect by combining fractional order PD λ control with linear active disturbance rejection control [9]. In addition, the fractional order active disturbance rejection controller (fadrc) algorithm is proposed and applied to the motion control of a new 6-DOF parallel robot, which further enhances the robustness and anti-interference ability of the system [10].

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4. Conclusion

This paper mainly studies the use of PD control to control the angle of the motor and expands a fuzzy PI-PD control of Brushless DC motor. In the aspect of controlling the motor angle by PD control, the basic principle of PD control is explained through the derivation of proportional control and derivative control respectively. At the same time, the principle of PD control in the circuit and how to design the specific circuit are introduced through the typical circuit diagram. Then it is deduced how to use the transfer function to convert the voltage value into the motor angle value, and then this method is combined with PD control to control the motor angle through PD control. In terms of fuzzy PI-PD control of Brushless DC motor, the traditional fuzzy PID control is compared, and the shortcomings of traditional PID control in response speed and anti-interference ability are understood. Then the speed control algorithm NFPI-PD of the brushless DC motor is introduced.

In the PD control motor angle, the circuit design and principle derivation are carried out, and the error problem of a single proportional control is explored according to the waveform diagram, and then the derivative control is added for correction. After that, the problem of frequency oscillation was found in the research and then corrected. Then the PD control is simulated with different parameters through the root locus and pole-zero map of PD control. Finally, the improved PD controller's anti-interference ability is discussed.

In the fuzzy control algorithm of the Brushless DC motor, the simulation results of references are analyzed and discussed, and the advantages of nfpi-pd algorithm are obtained, such as faster response and more stable. Because in the speed simulation when the torque changes suddenly, the waveform of NFPI-PD reaches the stable state first and reaches the stable value first in the initial stage NFPI-PD algorithm has strong robustness to the torque changes of the tested system and faster response speed to the speed changes.

This research realizes PD control of motor angle, applies PD control to practical functions, converts the voltage value in the circuit into angle value, and combines with PI control to explore the fuzzy control algorithm of PI-PD, which can adjust KP and Ki parameters in real time, and improve the stability, accuracy, and accuracy of the control system. Then the improved NFPI-PD algorithm can optimize the response speed of fuzzy control, and improve the performance of the control system in practical applications.

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