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# Design and Analysis of PID Controller for DC Servomotor Control System

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***Abstract*— The objective of the system is to design and analyse PID controller for DC servo control system. The aim of the system is to develop proportional, integral and derivative controllers for the DC servomotor of the second order system. At first, MATLAB simulation is used for system unit step response of PID controller. The step response is evaluated the performance of a tuning servo system. It is error-driven, in other words, there must be a difference between the input and output before the servo will begin moving to reduce the error. PID based servo loop also called a compensator that has the job of keeping the DC servomotor at the desired position. Moreover, the characteristics and operation of control system is also analysed by using Ziegler–Nichols Tuning algorithm. Simulation results of the PID controller by using MATLAB program are described in the project. Then, PID controller circuit can be designed and calculated from software simulation results of closed loop second order feedback control system. PID controller circuit for second order dc servo motor control system is analysed by Proteus software.**

***Keywords*— PID controller, step response, DC servomotor, Ziegler–Nichols Tuning algorithm**

## I. INTRODUCTION

Proportional-Integral-Derivative (PID) controllers have been used extensively in the process industries since they are simple and often effective and represent the basic building blocks available in many process control systems. It is interesting to note that more than half of the industrial controllers in use today utilize PID or modified PID control schemes. Analogue PID controllers are mostly hydraulic, electric and electronic types or their combinations. Currently, many of these are transformed into digital forms through the use of microprocessors.

It has a simple control structure which was understood by plant operators and which they found relatively easy to tune. According to a survey for process control systems conducted, more than 90 of the control loops were of the PID type. It is generally believed that PID controllers are the most popular controllers used in process control. Because of their remarkable effectiveness and simplicity of implementation, these controllers are overwhelmingly used in industrial applications.

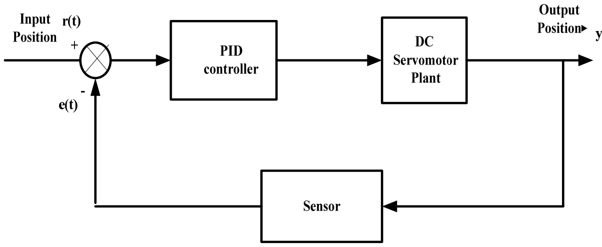

Fig. 1 Block diagram of DC servo control system

PID controller consists of Proportional Action, Integral Action and Derivative Action. It is commonly refer to Ziegler-Nichols PID tuning parameters. It is by far the most common control algorithm. PID controller algorithms are mostly used in feedback loops. This is a type of feedback controller whose output, a control variable (CV), is generally based on the error between some user-defined set point (SP) and some measured process variable (PV). Each element of the PID controller refers to a particular action taken on the error. Fig.1 shows the position control of DC servo mechanism. The servo operator consists of error amplifiers and PID filters. The PID controller is placed in the forward path, so that its output becomes the voltage applied to the motor's armature. The feedback signal is either an angular shaft position or velocity. In the block diagram, encoder is placed in the feedback path. The motor position is compared to commanded position, the motor is driven according to the position error, and the motor is moved and held to the commanded position. Finally, the error signal is the input to the PID controller. The control output of a PID controller is given by eqn. 1.

$$u(t) = K_P e(t) + K_I \int e(t)dt + K_D \frac{d}{dt} e(t) \tag{1}$$

$K_P$, $K_I$ and $K_D$ are the proportional, integral, and derivative gains, respectively, and e(t) is the error signal already defined. Consider the feedback system shown in Fig1 is a DC motor whose shaft position must be accurately regulated.

## II. P CONTROLLER OF CLOSED-LOOP STEP RESPONSE

Using only P control gives a stationary error in all cases except when the system control input is zero and the system process value equals the desired value. The stationary error in the system process value appears after a change in the desired value (ref). Using only P control gives a stationary error in all cases except when the system control input is zero and the system process value equals the desired value. The stationary error in the system process value appears after a change in the desired value (ref). Using a too large P term gives an unstable system. The control deviation signal has to be amplified, since it is too small and cannot be used directly as the manipulating variable. The gain ($K_P$) of a P controller must be adjustable, so that the controller can be matched to the process. The continuous output signal is directly proportional to control deviation, and follows the same course; it is merely amplified by a certain factor. The proportional action causes an instantaneous response on the control effort due to error change. The larger the proportional gain, $K_P$, the larger the control effort caused by a given error value. This usually improves the response speed of the system, i.e. smaller rise time, and reduces the steady-state error. However, a large proportional gain also increases the overshoot. In fact, making the gain too large might even cause instability in the system. This means that the step response grows unbounded or oscillates sustained. The closed-loop transfer function of the second-ordered system with a proportional controller is shown in eqn. 2 that is the design motor transfer function to control P controller.

$$G(s) = \frac{1.35}{(s+1)(s+2)} \tag{2}$$

Enter the commands into an m-file and run it in the MATLAB command window.

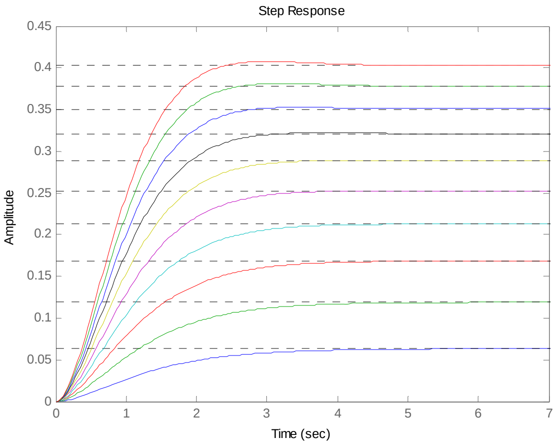

Fig. 2 Closed-Loop step response P controller

The closed-loop step response of P controller is as shown in Fig. 2. It can be seen that when $K_P$ increases, the response speed of the system increases and the rise time of the closed-loop system decreases. The setting time of the system is small changed and steady-state error is also decreases.

## III. PI CONTROLLER OF CLOSED-LOOP STEP RESPONSE

Proportional-integral (PI) control considers both the magnitude of the system error and the integral of this error. For the DC servomotor, by integrating the error of the shaft position over time, scaling the integral, and adding this term to the control voltage, steady-state errors in position can be eliminated that P control alone may not be able to cancel. This is the primary reason to add integral control action, to eliminate steady state error. The drawback of adding integral action is that it may have a destabilizing influence on the system response if $K_I$ is not properly selected. For the given system, the closed-loop second-ordered transfer function with a PI controller is shown in equ. 2. Create a new m-file and enter the MATLAB command window. The closed-loop step responses of PI controller are as shown in Fig. 3. The most important feature of a PI controller is that there is decreased steady-state error in the step response if the closed-loop system is stable. The delay time is decreased and overshoot is also increased. The rise time of the system is decreased but setting time is increased.

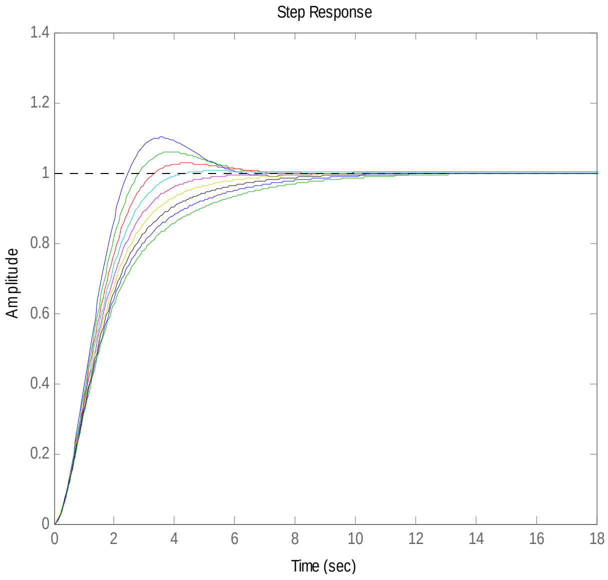

Fig. 3 Closed-loop step response of PI controller

## IV. PID CONTROLLER OF CLOSED-LOOP STEP RESPONSE

The combination of I component with a P controller offered certain advantages in each case. Now it seems logical to combine all three structures, resulting in the PID controller. The motor position may be controlled using a proportional-integral-derivative controller. This control should greatly reduce or eliminate any steady state error that may be present using a gain or proportional derivative controller. The downside to this method is that adding an integrator will degrade the transient performance of the system.

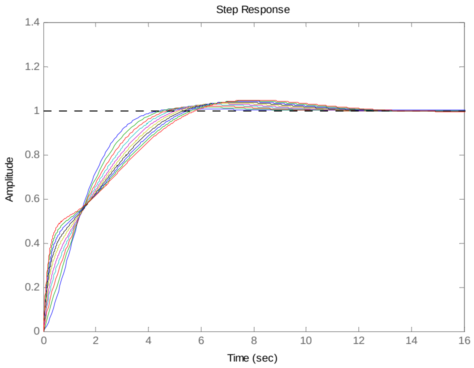

Fig. 4 Closed-loop step response of PID controller

The closed loop transfer function of the second order system with a PID controller is shown in eqn. 2. To confirm, enter the commands to an m-file and run it in the MATLAB command window. PID controller is decreased steady-state error in the step response if the closed-loop system is stable. And delay time is reduced but rise time, setting time and overshoot are increased. P controller would add damping to a system, but the steady-state response is not affected; the PI controller could add damping and improve the steady-state error at the same time, but the rise time and settling time are penalized. This leads to the motivation of using a PID controller so that the best properties of each of the P and PI controllers are utilized. So PID controller is used by tuning Ziegler-Nichols method.

## V. ZIEGLER-NICHOLS METHOD

Several methods for tuning the PID loop exist. The choice of method will depend largely on whether the process is taken off-line for tuning or not. Ziegler-Nichols method is a well-known online tuning strategy. In fact, the MATLAB function also embeds a design formula discussed. Enter the commands to an m-file and run it in the MATLAB command window.

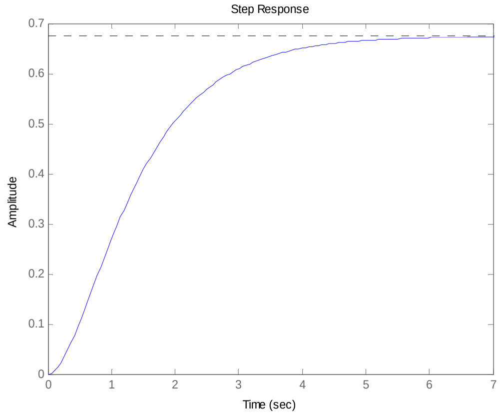

Fig. 5 Open-loop step response of Ziegler-Nichols

The open-loop step response is shown in Fig. 5, with a steady-state value of 0.675. From the step response, the parameters of the approximate FOPDT model are $L = 0.25$ and $T = 2.25 - 0.25 = 2$, based on which the PID controller is designed using the MATLAB statements. The closed-loop response for PID controller is also obtained using the MATLAB statements. The step responses of the closed-loop system are shown in Fig. 6. The PID controller designed from MATLAB simulation is shown in eqn. 3 which can be control the design motor transfer function.

$$G_{PID}(s) = 14.2222(1 + \frac{1}{0.5s} + 0.125s) \qquad (3)$$

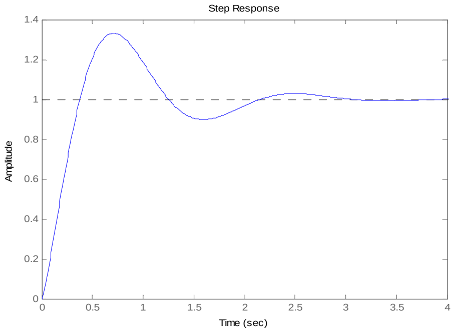

Fig. 6 Closed-loop step response of Ziegler-Nichols

## VI. DESIGN CALCULATION OF PID CONTROLLER

The transfer function of PID controller is shown in equation (4)

$$G_c(s) = 14.2222(1 + \frac{1}{0.5s} + 0.125s) \qquad (4)$$

$$= \frac{0.8889s^2 + 7.1111s + 14.2222}{0.5s}$$

The process of second order control system is

$$G_P(s) = \frac{1.35}{(s+1)(s+2)} \qquad (5)$$

The open-loop transfer function of the compensated system is

$$G(s) = G_c(s)G_p(s) \qquad (6)$$

$$G(s) = \frac{1.2s^2 + 9.6s + 19.2}{0.5s^3 + 1.5s^2 + s}$$

The characteristics equation of the system is

$$1 + GH = 0 \qquad (7)$$

$$1 + \frac{1.2s^2 + 9.6s + 19.2}{0.5s^3 + 1.5s^2 + s} = 0$$

$$0.5s^3 + 2.7s^2 + 10.6s + 19.2 = 0$$

$$\begin{array}{c|cc} s^3 & 0.5 & 10.6 \\ s^2 & 2.7 & 19.2 \\ s & 14.16 & \end{array}$$

The auxiliary equation of the system is $2.7s^2 + 19.2 = 0$

$$s = \pm j2.67$$

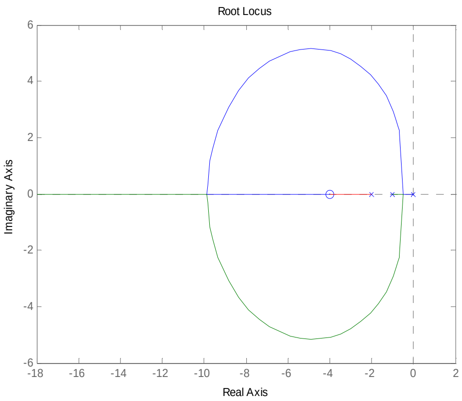

Fig. 7 shows that the system is stable because all the roots of the system are existed in the left of the imaginary axis.

## VII. DESIGN CALCULATION OF PID CONTROLLER CIRCUIT

The operational amplifier PID controller is as shown in Fig. 8. It has three simple operational amplifiers. They are proportional controller, integrator controller, differentiator controller.

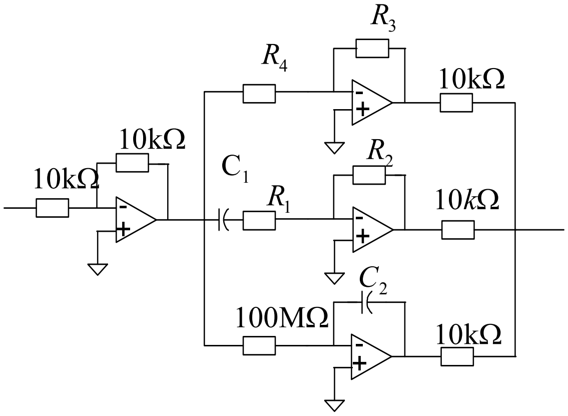

Fig. 8 Completed circuit of PID controller

### A. *Differentiator Controller (second order)*

The differentiator circuit is as shown in Fig. 9.

Choose $C_1$= 0.1 µF (coupling capacitor)

To stable $s = \pm j\omega$

$$s = \pm j2.67, \omega = 2.67 \text{ rad/s}$$

$$\omega = 2\pi f$$

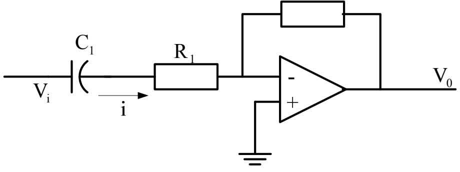

Fig. 9 Differentiator circuit of PID

$$f = \frac{\omega}{2\pi}$$

$$= \frac{2.67}{2\pi}$$

$$= 0.425 \text{ Hz}$$

$$f = \frac{1}{2\pi R_1 C_1}$$

$$R_1 = \frac{1}{2\pi f C_1} = \frac{1}{2\pi \times 0.425 \times 0.1 \times 10^{-6}} = 3.745\ \text{M}\Omega$$

$$T = \frac{1}{f} = 2.353 \text{ sec}$$

$$t = \frac{T}{2} = 1.1765 \text{ sec}$$

Pulse amplitude $V_i = 1\text{ V}$

dt = 1.1765 sec

For rated output $V_0 = 10\text{ V}$

$$V_0 = -R_2 C_1 \frac{dV_i}{dt}$$

$$\therefore R_2 = \frac{V_0}{C_1 \frac{dV_i}{dt}} = \frac{10}{0.1 \times 10^{-6} \times \frac{1}{1.1765}} = 117.65\ \text{M}\Omega$$

### B. *Proportional Controller (second order)*

The proportional circuit is as shown in Fig. 10.

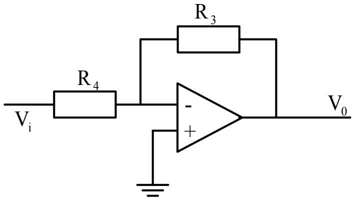

Fig. 10 Proportional circuit of PID

For rated output $V_o = 10\text{ V}$

$$R_4 = R_2 = 117.65\ \text{M}\Omega$$

Pulse amplitude $V_i = 1\text{ V}$

$$\frac{V_0}{V_i} = -\frac{R_3}{R_4}$$

$$R_3 = 117.65 \times 10^6 \times 10 = 1.1765\text{G}\Omega$$

### C. *Integrator Controller (second order)*

The integrator circuit is as shown in Fig. 11.

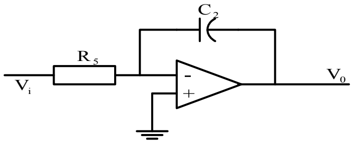

Fig. 11 Integrator circuit of PID

Choose $R_5 = 100\ \mathrm{M}\Omega$ (Ideal PID circuit)

For rated output $V_0 = 10\ \mathrm{V}$

Pulse amplitude $V_i = 1\ \mathrm{V}$

$$V_0 = -\frac{1}{R_4 C_2}\int V_i dt$$

$$V_0 = -\frac{1}{R_4 C_2}$$

$$C_2 = \frac{1}{100 \times 10^6 \times 10} = 1\,\mathrm{nF}$$

## VII. SIMULATION RESULT FOR PID CONTROLLER

From P, PI, PID simulations with MATLAB, the best optimal response is obtained by using PID controller.

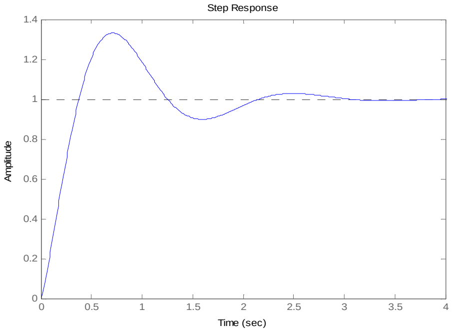

Fig.12 The time domain response of PID controller

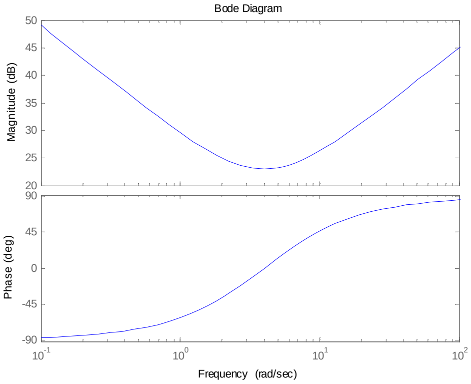

Fig. 13 The frequency response of PID controller

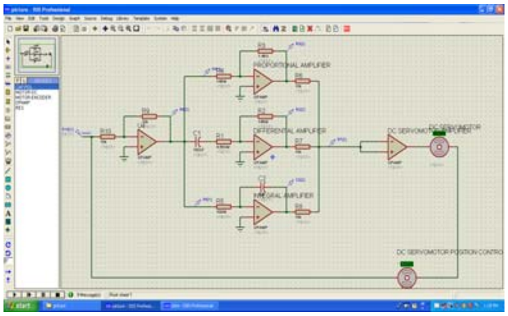

Fig. 12 Proportional integral differential controller circuit for second order servomotor control system

The time domain response of the PID controller and the frequency response of the PID controller are shown in Fig. 12 and Fig. 13 respectively. From design calculation, PID controller circuit is simulated by Proteus software. DC bias is used 1V in the PID controller circuit. It can be used to operate DC servomotor ($\pm 10V$) in normal operation. Complete PID controller circuit is shown in Fig. 12. So the PID circuit can be controlled the DC motor with 1000 rpm in optimal condition.

## IX. CONCLUSIONS

In this paper, design and construction of PID controller of the DC servo control system have already been implemented and analysed in detail. And then the parallel of PID controller structure is selected to construct the DC servomotor. The goal of PID controller design is to design and calculate the controller parameters ($K_P$, $K_I$, and $K_D$). These parameters depend on the whole process. If the actual process knows it can easily calculate the controller parameters. In this work, the PID controller parameters can be calculated from the step response by root loci method in a very simple way, using the areas.

## ACKNOWLEDGMENT

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