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APPLICATION OF PID CONTROLLER TO STUDY THE PERFORMANCE OF A ROBOT MANIPULATOR USED FOR PAINTING WORK IN AN AUTOMOBILE INDUSTRY

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Abstract- A theoretical study has been carried out to find the application of a PID controller to study the performance of a Robot Manipulator that can be used for painting of vehicles in an automobile industry. For this, a Block Diagram model of the whole system has been obtained. From the Block diagram model, transfer function and hence the overall gain of the system have been derived. Using MATLAB, the frequency responses of Magnitude and Phase angle of the system have been plotted, and 'Gain Margin' and 'Phase Margin' have been determined. Study has also been carried out to find the steady state errors of the system with the application of unit Step, unit Ramp and unit Parabolic signal inputs. Results have been tabulated, shown graphically and discussed.

Keywords: PID Controller; Robot Manipulator; system function; Frequency response; Steady state error.

I. INTRODUCTION

Application of Robot, as a mechatronics device in various fields, particularly in manufacturing industries, has been given due importance for the last many years[1] due to the following fact i) It helps in reducing the time of operation .ii) saving manpower, and iii) conserving electrical energy, etc.
Again, the various types of electrical controllers, such as – proportion, derivative, Integral and combination of them :PID Controller, etc. are widely used to monitor and control the operations of the system[2,8,9]

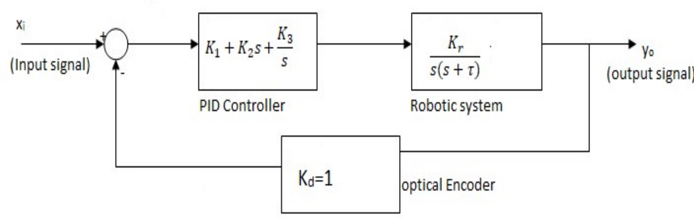

Fig1 : Block diagram model of Robotic system

In an automobile industry, various processes, like – assembling of the parts, welding, painting, washing, etc are done [3]. These are generally done manually or using some devices. But, Robot manipulators can be used to some of the jobs. Painting of the vehicles is an important operation in an automobile industry. It is done for beautification of the vehicle by covering its rough surface by paint. At present, many manufacturing industries are making use of Robots to perform this jobs[5].
In this paper, an attempt has been made to present the results of theoretical analysis done for the system consisting of Robot

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Manipulator and a PID Controller to regulate the painting operation in an automobile industry. Results have been tabulated to show the steady state errors and graphs have been shown for frequency response of magnitude and phase angle of the whole system. Results have also been discussed.

II. INSTRUMENTATION AND METHODS

A Robotic Control system

Figure 1 shows the Block diagram model of a Robotic system making use of a PID controller for painting work in an automobile industry[6]. Robotic system consist of robotic arm which can hold spraying device containing paint. It also consists of a servomotor to drive the robot. The amount of painting material is controlled by PID Controller and time of operation is controlled by servomotor. The optical encoder is used to check the smoothness of the painting surface. When the input signal i.e, the desired material to be deposited is equal to the output signal i.e, actual amount deposited on the surface, then the PID controller will automatically stop supplying of spraying material and operation is completed [7]

B. Analysis

Following assumptions have been made for analysis of the system

i) Single-arm robot manipulator has been considered

ii) Robot is driven by a servomotor.

iii) The optical encoder is sensitive to brightness.

The analysis of the system has been done to find-

a) the transfer function and hence the overall gain of the system,

b) the frequency response using MATLAB and,

c) the steady state error of the system.

C. *Determination of transfer function*

Let us consider the block diagram model as shown in fig.1. Using this model, the closed loop transfer function can be expressed as

$$A(s) = \frac{Y_o(s)}{X_i(s)} = \frac{K_r(K_2S^2+K_1S+K_3)}{S^3+(K_2K_rK_d+\tau)S^2+K_1K_rK_dS+K_3K_rK_d} \quad \text{------------(1)}$$

Where,

$X_i(s)$ = Input signal

$Y_o(s)$ = Output signal

K_1 = Proportional constant

K_2 = Derivative constant

K_3 = Integral constant

K_r = Robotic system constant

K_d= Optical encoder constant

τ = Time constant

At s = jω, the equation (1) can be written as

$$A(j\omega) = \frac{K_r(K_3-K_2\omega^2)+jK_1K_r\omega}{[K_3K_rK_d-(K_2K_rK_d+\tau)\omega^2]-j(K_1K_rK_d-\omega^3)} \quad \text{--------------(2)}$$

Now overall gain of the system in dB can be expressed as

$$|A(j\omega)|_{dB} = 20\log\frac{\sqrt{[K_T(K_3-K_2\omega^2)]^2+(K_1K_T\omega)^2}}{\sqrt{[K_3K_TK_d-(K_2K_TK_d+\tau)\omega^2]^2+[K_1K_TK_d-\omega^3]^2}} \text{------(3)}$$

Using equation (3), the frequency response at different values of ω can be obtained.

D.. MATLAB programme to find frequency response

```
num=[5 1 10];
den=[1 5.5 0 0];
sys=tf(num,den)

sys =

  5 s^2 + s + 10
  --------------
  s^3 + 5.5 s^2

Continuous-time transfer function.

bode(sys)


grid on
margin(sys)
[GAIN_MARGIN,PHASE_MARGIN,GAIN_CROSSOVER_FREQUENCY,PHASE_CROSSOVER_FREQU
ENCY]=margin(sys)

GAIN_MARGIN = 0.8998


PHASE_MARGIN = 0.4995


GAIN_CROSSOVER_FREQUENCY = 0.9486


PHASE_CROSSOVER_FREQUENCY = 0.9763


GAIN_MARGIN_IN_DECIBEL=20*log10(GAIN_MARGIN)


GAIN_MARGIN_IN_DECIBEL = -0.9168
```

2.2.3. Determination of steady state error

From the examination of Block diagram model as shown in fig.1 gives the open loop transfer function of the system as,

$$G(s) = \left(K_1 + K_2S + \frac{K_3}{s}\right)\frac{K_T}{S(S+\tau)} \text{---------------(4)}$$

Then, the error signal can be expressed as

$E_r(s) = \frac{X_i(s)}{1+G(s)} = \frac{s^2(s+\tau)X_i}{s^3+(\tau+K_2K_r)s^2+K_1K_rs+K_3K_r}$ ------------- (5)

The steady state error can be given as

$$e_{ss} = \lim_{s\to 0} sE_r = \lim_{s\to 0} \frac{s^3(s+\tau)X_i}{s^3+(\tau+K_2K_r)s^2+K_1K_rs+K_3K_r} \text{ -------- } (6)$$

The test signal can be used are

a. Unit step : $X_i(s) = \frac{1}{s}$ -----------------(7)

b. Unit ramp : $X_i(s) = \frac{1}{s^2}$ ----------------(8)

c. Unit parabolic : $X_i(s) = \frac{1}{s^3}$ -----------(9)

Using equations (6),(7),(8) and (9) we can determine steady stare errors of the system (Table-1)

III. RESULTS AND DISCUSSIONS

Bode diagram:

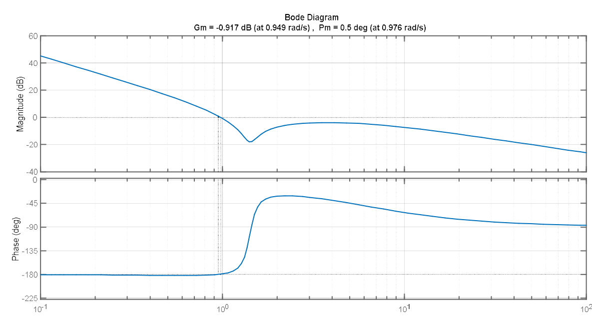

FIG.2 : Frequency response of Magnitude and Phase Angle

Table 1: Determination of steady state error

Type of controller	Type of signal	e_{ss}
PID	Unit step	0
	Unit ramp	0
	Unit parabolic	$\frac{K_3K_r}{\tau}$

The data obtained after the analysis of the Robotic system with PID controller can be used to study the performance of the same from the calculation of steady state errors and frequency response curves obtained. It can be seen from the Table-I that steady state error of the system is zero in both the cases of unit step and unit ramp inputs. It is possible only for an ideal system. But there will be always a small error, whatever precaution is taken. Again in the case of unit parabolic signal application the steady state error depends on the values of K_3,K_r and τ. This error can be adjusted by choosing the suitable values of K_3,K_r and τ. Figure 2 shows the frequency responses of magnitude and phase angle of the system over frequency range of 0.1rad/s to 100rad/s for some typical values of K_1=1,K_2=5, K_3=10,K_r=1,K_d=1 and τ =5.5s. From the above plots it is found that Gain margin=-0.917dB at ω=0.949rad/s and Phase margin=0.5^0 at ω=0.976rad/s.

IV. CONCLUSION

In this study, we have considered PID controller only. So, results will vary if we consider other types of controller, such as, derivative, integral, proportional and combination of them. If we take into account the other the other values of K_1,K_2,K_3,K_r and τ, steady state error will change only in case of unit parabolic signal input and the nature of the frequency curves will change. Hence, Gain margin and Phase margin will vary.

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