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Research Paper

Robot Manipulator making Use of PID controller for fighting Fire of a Building

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Abstract : *A theoretical study has been carried out to find the application of a PID controller to evaluate the performance of a Robot Manipulator that can be used for fighting fire that may caught in a building or house. 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 has been derived. Using MATLAB, the frequency response of the 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 applications of unit Step, unit Ramp and unit Parabolic input signals. Results have been tabulated, shown graphically and discussed.*

Keywords: *PID controller; Robot Manipulator; System function; Frequency response; Steady state error.*

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I. INTRODUCTION

For the last many years, human labors have been replaced by the robots [1,2]. Its application [3,4] has been given due importance because of the following fact : i) It helps in reducing the time of operation .ii) saving manpower and raw materials, 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 many systems [5,6,7]. In the Fire- Begrade unit, generally, many fire-fighters are engaged to extinguish the fire of the building or houses. They have to do this type of job manually and they have to wear protecting devices to save themselves from sock of fire and injury. This is a hazardous job and there is a risk of life. But, Robot manipulator can be used to perform this type of job [8]. In this paper, an attempt has been made to present the results of the theoretical analysis done for the system consisting of a Robot Manipulator and a PID controller to extinguish fire of building. Results have been tabulated to show the steady state error and Gain margin and Phase margin. The graphs have been shown for frequency responses of magnitude and phase angle of the whole system . The results have also been discussed.

II. INSTRUMENTATION SYSTEM AND METHOD

2.1 Robotic control system

Figure 1 shows the Block diagram model of a robotic system which makes use of a PID controller for extinguishing fire caught in building. The robotic system consists of a robot having two arms which can hold the pipes through which water or chemical reagent can flow to extinguish fire. It also consists of a servomotor that can drive robot. The amount of water flow or chemical reagent is controlled by PID controller and the time of operation is controlled by servomotor. The optical encoder is used to check the status of the fire, i.e. extinguished or not. When the input signal, i.e. desired water or chemical reagent to be sprayed is equal to the amount of actual material sprayed, then the PID controller will automatically stop supplying the fire-extinguishing material and the operation will be completed.

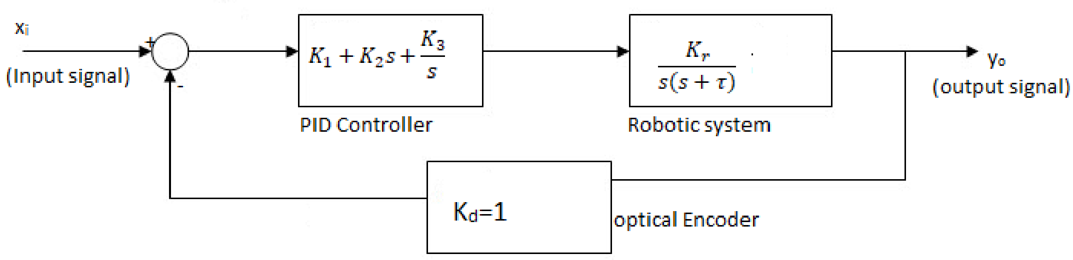

Fig1 : Block diagram model of Robotic system

2.2.Analysis:
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 errors of the system.
Following assumptions have been made for the analysis of system:
i) Two-arm robot manipulator has been considered.
ii) Robot is driven by a servomotor.
iii) The optical pyrometer is used as sensor to find the status of the fire.

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

$$|A(j\omega)|_{dB} = 20\log\frac{\sqrt{[K_r(K_3-K_2\omega^2)]^2+(K_1K_r\omega)^2}}{\sqrt{[K_3K_rK_d-(K_2K_rK_d+\tau)\omega^2]^2+[K_1K_rK_d-\omega^3]^2}} \quad \text{------(3)}$$

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

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_FREQUENCY]=  margin(sys)
```

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) = $(K_1 + K_2S + \frac{K_3}{S})\frac{K_r}{S(S+\tau)}$ ---------------(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

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

The test signal can be used are

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

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

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

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.

Bode diagram :

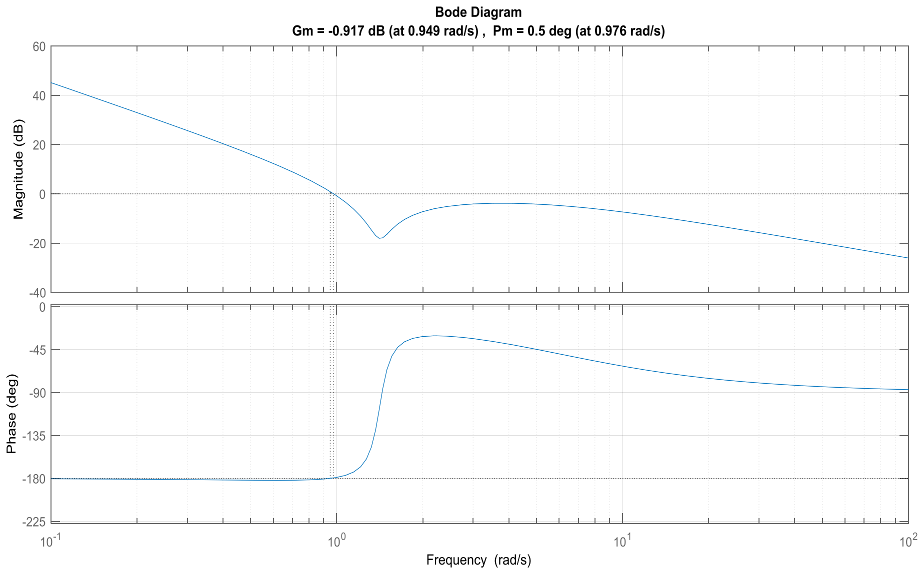

Fig. 2 : Frequency response of Magnitude and Phase Angle

Table 1: Determination of steady state error

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

Again in the case of unit parabolic signal application, the steady state error depends on the values of k_3, k_r and τ . Figure 2 shows the frequency responses of magnitude and phase angle of the system over the range of 0.1 rad/s to 100 rad/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. From the output of MATLAB programme as shown in Table 2, it can seen that the stability of the system can be maintained if we considered the typical values assumed for the system parameters.

Table 2 : Output data of MATLAB

Parameters	Value
Gain margin	0.8998
Gain margin in decibel	- 0.9168
Gain crossover frequency	0.9486
Phase cross over frequency	0.9763

III. 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 values of K_1,K_2,K_3,K_r and τ then, 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. The experimental setup will be designed using a robot manipulator to test and do practical work for welding job in our University workshop. Moreover, if this is successful, then, it will help in designing other systems, like-application robotic arm for washing, polishing and drilling jobs in automobile industries, and plucking flowers and fruits from trees, etc.

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