Study of the Performance of a Simple Robotic System using PID Controller

Sreyasree Mandal, and N. K. Mandal

***Abstract*—** Theoretical studies have been carried out to find the performance of a simple robotic system by calculating the steady state error due to applications of PID controller for different types of input signals, such as unit step, unit Ramp and unit Parabolic. A programming using 'C' language has also been developed to find overall gain of the system for different values of frequency and hence to plot the frequency response of the same. Some numerical calculations have been done. Results have been tabulated, shown graphically and discussed.

***Keyword*—** Robotic arm, PID Controller, input signal, steady state error, frequency response.

I. Introduction

APPLICATIONS of control systems in various fields have been given due importance for the last many years due to the following facts:

[i] They help in conserving materials, manpower and electrical energy etc.

[ii] They help in saving the time of operation.

[iii] They also help in increasing the reliability and stability of the systems.

Advances in servomechanism have led to the development of the new field of control and automation, the robot and robotology [1]. A robot is a 'force labour'. It is a mechanism device to perform in a hazardous environment. The science of robot is called robotic arm. It is also known as manipulator. Robotic arms are mechanically control devices designed to replicate the movement of the human arms.

This electromechanical device with multiplied degrees of freedom is programmable to accomplish a variety of tasks [2]. It is an arm-shaped device generally mounted on a platform or suspended from a track which reaches to various distances and locations. These are now widely used in road construction for removing and dumping materials and big workshop and factories for holding and shifting of machine tools, jobs and raw materials [3, 4].

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In this paper, an attempt has been made to study the performance of a simple robotic system with PID control actions with various types of applied input signals. A Programming has also been developed to find the overall gain of the system and hence the frequency response of the same for different values of frequency.

II. Instrumentation System And Methods

2.1 Robotic Control System

Fig.1 shows the schematic diagram of a single arm robotic system, making use of control system. Fig. 2 shows the physical model of a single arm robot with servo motors.

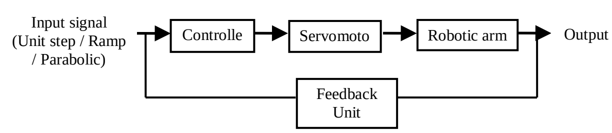

Fig. 1 Schematic diagram of a robotic control system

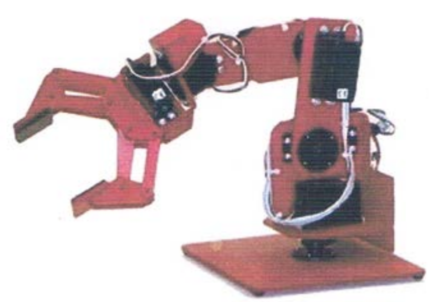

Fig. 2 Physical model of a single arm robot

A robotic arm is composed of a set of joints separated in space by the arm links and a gripper as shown in Fig. 2. The joints are where the motion in the arm occurs. In basic, a robot arm mainly consists three parts: base, links and a gripper. The base is the basic part over the arm and it may be fixed or active. The joints are flexible. They are used to separate two links. The gripper is used to hold and move the objects. Servo motors are used to control the angular positions of the joints and hence the position the arms. While these motors are driven by analog signals, the user often wants to use a micro controller or similar device to run a preset of commands. This is a controller which is used to translate the digital signals from the master system of appropriate analog motor signals.

2.2 Analysis

The analysis of the system has been done to find i) the overall transfer function the system ii) the steady state errors and iii) the frequency response.

For the analysis, following assumptions have been made:

a) The robot has a single arm
b) The coulomb frictions at the joints and base are ignored
c) Error due to disturbance of torque which appears at the output shaft has been neglected.

2.2.1 Determination of the transfer function of the system

To determine the transfer function of the system, let us consider the Block diagram model of the system as shown is Fig. 3.

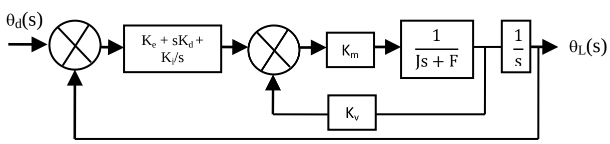

Fig. 3. Block diagram model of a robotic control system.

From the Block diagram model as shown in Fig. 3. We can get the closed loop transfer function of the system with PID Controller as –

$$A(s) = \frac{\theta_L(s)}{\theta_d(s)} = \frac{K_m(SK_e + K_i)}{JS^3 + (F + K_v K_m)S^2 + K_e K_m S + K_m K_i} \quad (1)$$

Where, θ_d = Desired position, rad/s

θ_e = Link position, rad/s

θ_e = Error signal, rad/s

K_e = Proportional control factor

K_d = Derivative Control Factor

K_i = Integral Control Factor

K_v = Velocity feedback constant, v/rad/s

J = Total inertia (link inertia + actuator inertia), kg/m^2.

F = Effective viscous friction, Nm/rad/s

2.2.2 Determinations of overall gain of the system:

At s = jω, (where ω = frequency in rad/s) the equation (1) can be expressed as

$$A(j\omega) = \frac{\theta_L(j\omega)}{\theta_d(j\omega)} = \frac{K_m(j\omega K_e + K_i)}{K_i K_m - (F + K_v K_m)\omega^2 + j(K_e\omega - J\omega^3)} \quad (2)$$

The overall gain of the system in dB can be written as

$$A(\text{in dB}) = 20\log\frac{K_m\sqrt{(K_i^2 + K_e^2\omega^2)}}{\sqrt{[K_i K_m - (F + K_v K_m\omega)]^2 + [K_e\omega - J\omega^3]^2}} \quad (3)$$

At different values of ω, the equation (3), can be used to find the frequency response of the robotic control system. A programme has been developed for the same as given in section 2.2.4.

2.2.3 Determination of steady state error of the system.

Examination of the block diagram model with a unity feedback system as shown in Fig. 3, gives the open loop transfer function of the system with PID Controller as

$$G(s) = \frac{K_m[K_e + K_d S + K_i/s]}{s[Js + (F + K_v K_m)]} \quad (4)$$

The error signal, $\theta_e = \theta_d - \theta_L$ (5)

Can be express as

$$\theta_e = \frac{\theta_d}{1 + G(s)} = \frac{\theta_d[Js^2 + (F + K_v K_m)s]}{Js^2 + (F + K_v K_m)s + K_m(K_e + K_d S + K_i/s)} \quad (6)$$

The steady state error of the system can be expressed as

$$e_{ss} = \lim_{s \to 0} \frac{s[Js^2 + (F + K_v K_m)s]\theta_d}{Js^2 + ((F + K_v K_m)s + (K_e + K_d s + K_i/s)K_m} \quad (7)$$

The various test signals that can be used for the system are

i) Unit step input, $\theta_d(s) = 1/s$ (8)
ii) Unit velocity or Ramp input, $\theta_d(s) = 1/s^2$ (9)
iii) Unit acceleration or parabolic input,

$$\theta_d = 1/s^3 \quad (10)$$

For the each signal, the steady state error can be determined using equations (7).

2.2.4 Computer programming using 'C' for determination of the gain the Robotic system

```
# include <stdio.h>
# include <math.h>
int main ( )
    {
    float A;
    char ch;
    int J, km, kv, ke, kd, ki, F, ω, x, y,z;
    printf (“Enter the values of J, km, kv, ke, kd, ki, F:”);
    scanf (“%d, %d, %d, %d, %d”,%d, %d, %d, & J, & Km, Kv, Kd, Ki & Ke, & f);
    getchar ( );
    printf (“Do you want to enter the value of ω (Y/N)?:”);
    ch = getchar ( );
    while (ch = = ‘Y’)
    {
    printf  (“Enter the value of ω:”);
    scanf (“%d”, & ω);
    x = pow (((ki ∗ km) – (F+Kv*Km∗ω∗ω)), 2);
    y = pow ((Ke*ω - (J*ω*ω*ω)), 2);
    z = sqrt (Ki * Ki + Ke * Ke * ω *ω)
    A = (km∗Z)/sqrt (x+y);
    getchar ( );
    printf (“The Gain of Robotic system is % f \ n”, A);
    printf (“Do you want to enter another value of ω (Y/N)?:”);
    ch = getchar ( );
    }
    return 0;
  }
```

III. Results And Discussion

The data obtained after the analysis of the Robotic system under study using standard values of the parameters, the performance the system, with respect to calculation of steady state errors and determination of gain at different values of frequency of the same, can be studied.

TABLE I
STEADY STATE ERROR FOR DIFFERENT TYPES OF SIGNALS

Types of Controller	Types of signal	Steady state error (e_{ss})
PID	a) Unit step b) Unit Ramp c) Unit Parabolic	a) o b) o c) ∞

Table-I shows the steady state errors for PID control action with various types of signal used. From this it can be seen that for this type of controller, the unit step input signal and ramp input signal these causes zero steady state error. So, this signal will make system to tend to operate in ideal condition. It can also be observed that for unit parabolic or acceleration signal the system shows infinite error for this type of control action. So, this type of signal cannot be used to operate the Robotic system.

The figure 4, depicts the frequency response of the system over a range of frequency of 0 to 1500 rad/sec. for some typical values of J = 10 kg/m^2, F = 20 Nm/rad/s, K_m – 2 Nm/v, K_v = 1V/rad/sec and K_e = 6.0, K_d = 1.0, K_i = 2.0

It can be observed from the Fig-4, that the gain of the system is increasing steadily with - 40 db/decade in negative direction.

IV. CONCLUSIONS

In this investigation, we have studied the performance of the Robotic system theoretically. The actual performance can be obtained by designing such system and conducting some experiments. Moreover, in this study, we have considered a single arm robot. The results will vary for multi-arm robot. In this study, we have also, neglected the Coulomb force and the errors due to disturbance torque that appears in output shaft. So, results will also vary if we take into account the some values of these parameters for the calculations.

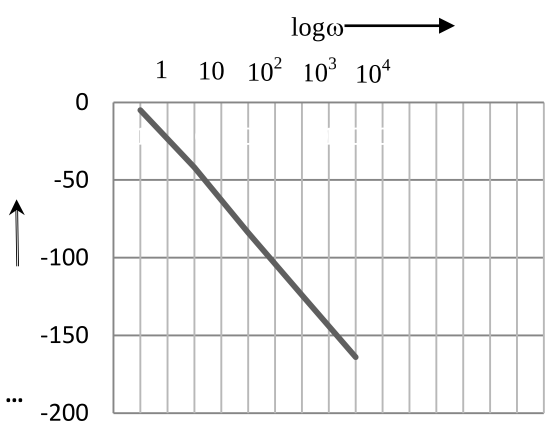

Fig. 4 Frequency Response of the Robotic System with PID Controller.

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