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PID Control of a Single Degree of Freedom Flexible Robot Manipulator

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Abstract: The concept of control system is of utmost importance in the study of 'Automation and Robotics'. An attempt is made to study and analyze the response of a cylindrical robot manipulator which is undergoing some rotational movement. Here the shoulder joint of a cylindrical robot manipulator is considered and the movement of the robot arm is simulated using PID controller. First the mathematical model of the system is formulated. It is then simulated for its responses using BASIC language. Various responses of the system are obtained by varying one gain at a time and keeping other two gains fixed at some lower values. Responses for each gain are then analyzed to get the range of the gain and the best gain. Next all the three gains are varied around the best values and the system response is found for the best combination of gains.

Keywords - Gains, manipulator, PID, response, robot, simulation.

I. INTRODUCTION

Here in this problem a single degree of freedom cylindrical robot manipulator is considered which is modeled after the shoulder joint of a human being [5]. The manipulator is to be controlled so that it reaches its desired position very fast without any overshoot or jerk and settles down pretty quickly [8]. PID control is employed on the manipulator. The output of the system is controlled by modifying the proportional, integral & differential gains [3]. First the ranges of the proportional, integral & differential gains are found from their responses and the gains for the best responses are noted. Then the optimum combination of gains, which gives the best response of the system, is achieved by varying one gain at a time within its estimated range.

II. BLOCK DIAGRAM OF THE SYSTEM

Here PID controller [6] is employed to control the manipulator. The PID scheme with the block diagram of the system is given below. A step input R is applied to the system. Corresponding error from the comparator is fed to the PID controller and the resulting current is used to run the motor. The torque produced in the motor, in turn controls the manipulator.

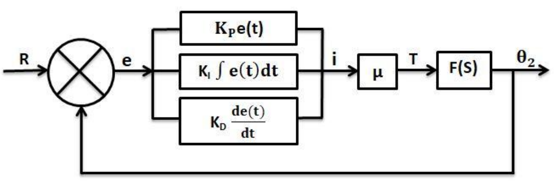

Fig. 1 Block diagram of the system using PID controller

Error $e = R - \theta_2$

Current in the motor $= i = (K_P + \frac{K_I}{s} + K_D.s).e$

Torque $T = \mu.i = \mu.(K_P + \frac{K_I}{s} + K_D.s).e$

III. MATHEMATICAL FORMULATION OF THE MODEL

The given system is a cylindrical robotic manipulator [2] which is driven by a motor and controlled by PID controller, the whole system is considered to be analogous with a mechanical belt-pulley system where spring and damper are considered as lumped parameters [4]. In this system the smaller pulley represents the driver motor excited by an input torque, and the larger pulley represents the driven manipulator, angular displacement of which results in the movement of the robot arm.

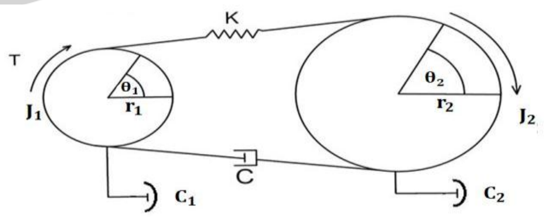

Fig. 2 Model of the system

Newton's law of summation of forces is applied to find the equations of the system. [7]

Equation for smaller inertia is given by:

$$J_1\ddot{\theta}_1 + C_1\dot{\theta}_1 + Cr_1(\dot{\theta}_1 r_1 - \dot{\theta}_2 r_2) + Kr_1(\theta_1 r_1 - \theta_2 r_2) = T$$

And equation for larger inertia is given by:

$$J_2\ddot{\theta}_2 + C_2\dot{\theta}_2 + Cr_2(\dot{\theta}_2 r_2 - \dot{\theta}_1 r_1) + Kr_2(\theta_2 r_2 - \theta_1 r_1) = 0$$

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Where,

J_1 = Moment of Inertia of the smaller pulley = 0.0018 kg-m^2
J_2 = Moment of Inertia of the larger pulley = 0.07 kg-m^2
r_1 is the radius of the smaller pulley = 0.01 m
r_2 is the radius of the larger pulley = 0.038 m

k = spring constant of the belt = 5×10^5 N/m

C = damping coefficient of the belt = 2100 N-s/m

C_1 = damping coefficient of damper attached to smaller pulley = 0.1 N-m-s/rad

C_2 = damping coefficient of damper attached to larger pulley = 0

R = step input = 1
μ = motor torque constant = 1.25 N-m/A
T = torque of the motor
θ_1 = angular displacement of smaller pulley
θ_2 = angular displacement of larger pulley

IV. COMPUTER SIMULATION

The system is simulated by solving its equations through 'Runge-Kutta method' using PC–BASIC software [1]. The system equations are solved as follows:

$$J_1\ddot{\theta}_1 + C_1\dot{\theta}_1 + Cr_1(\dot{\theta}_1 r_1 - \dot{\theta}_2 r_2) + Kr_1(\theta_1 r_1 - \theta_2 r_2) = T = \mu \times i$$

$$\ddot{\theta}_1 = \frac{1}{J_1}[\mu \times i - C_1\dot{\theta}_1 - Cr_1(\dot{\theta}_1 r_1 - \dot{\theta}_2 r_2) - Kr_1(\theta_1 r_1 - \theta_2 r_2)]$$

$$\dot{\theta}_1 = \ddot{\theta}_1 \times h + \dot{\theta}_1$$

$$\theta_1 = \dot{\theta}_1 \times h + \theta_1$$

$$J_2\ddot{\theta}_2 + C_2\dot{\theta}_2 + Cr_2(\dot{\theta}_2 r_2 - \dot{\theta}_1 r_1) + Kr_2(\theta_2 r_2 - \theta_1 r_1) = 0$$

$$\ddot{\theta}_2 = \frac{1}{J_2}[-C_2\dot{\theta}_2 - Cr_2(\dot{\theta}_2 r_2 - \dot{\theta}_1 r_1) - Kr_2(\theta_2 r_2 - \theta_1 r_1)]$$

$$\dot{\theta}_2 = \ddot{\theta}_2 \times h + \dot{\theta}_2$$

$$\theta_2 = \dot{\theta}_2 \times h + \theta_2$$

V. RESULTS & DISCUSSION

A desirable system response should have faster response, faster settling time and less or no overshoot at all. To achieve this all the three gains are varied one at a time keeping the other two constant at some lower values.

First, proportional gain, K_P is made to vary from 0.1 to 10 and K_D & K_I are kept constant at values 0.01 & 0.01 respectively. Corresponding responses are shown from figure Fig.3 to Fig.8. Figures clearly show that response is very slow when gain is too low and overshoot & vibrations are increasing when the gain values are higher. Hence range of K_P for better response of the system can be taken from 0.5 to 2.5

Next, derivative gain, K_D is varied from 0.005 to 0.75 when K_P & K_I are constant at values 1 & 0.01 respectively. Fig.9 to Fig.14 shows the responses for variations of K_D. Responses clearly show that initially there are very little overshoots which vanishes with increase of gains. But at higher values of gains the responses become very slow. Therefore range of K_D for better system responses is from 0.05 to 0.5

Finally, responses of the system for variations of integral gain, K_I from 0.01 to 5 are shown from Fig.15 to Fig.20 when K_P & K_D are kept constant at values 1 & 0.01 respectively. System responses show more overshoot and vibration at larger values of K_I. The range of K_I for better system responses is considered from 0.5 to 2.

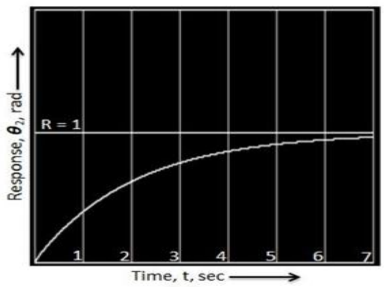

Fig. 3 System response for K_P = 0.1

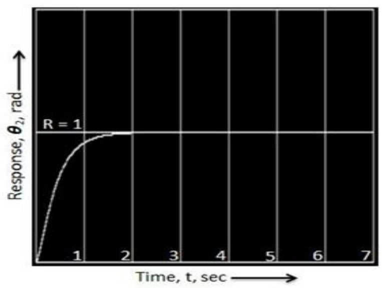

Fig. 4 System response for K_P = 0.5

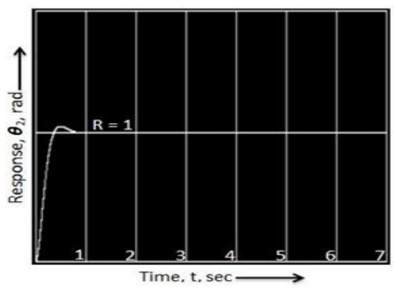

Fig. 5 System response for K_P = 1.5

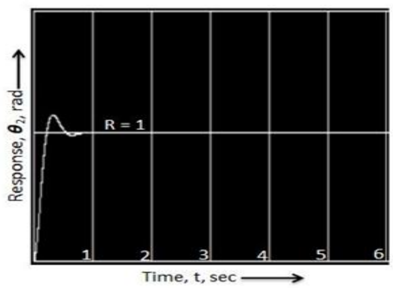

Fig. 6 System response for K_P = 2.5

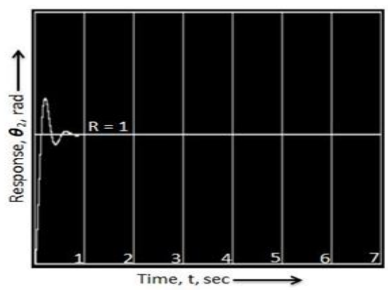

Fig. 7 System response for K_P = 5

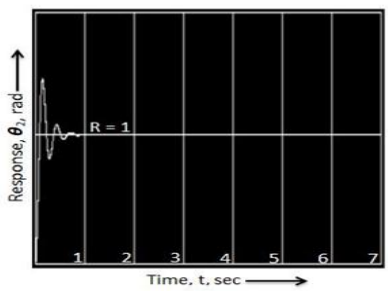

Fig. 8 System response for K_P = 10

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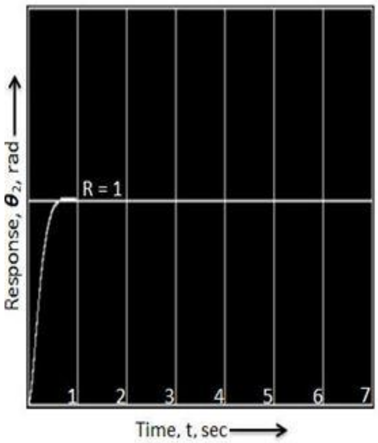

Fig. 9 System response for K_D = 0.005

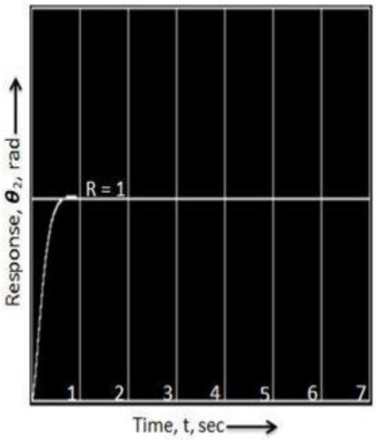

Fig. 10 System response for K_D = 0.01

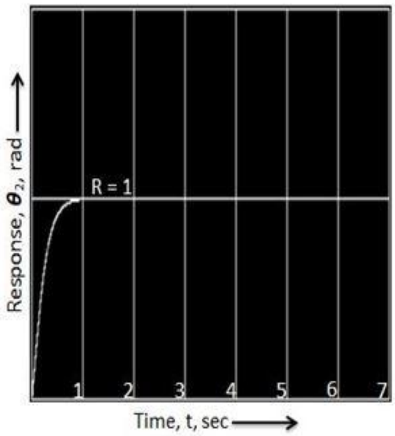

Fig. 11 System response for K_D = 0.05

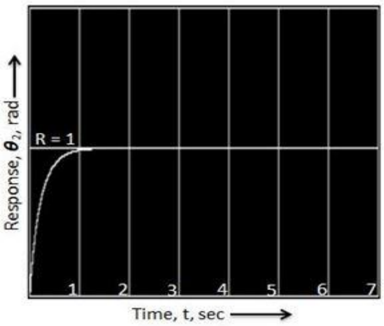

Fig. 12 System response for K_D = 0.1

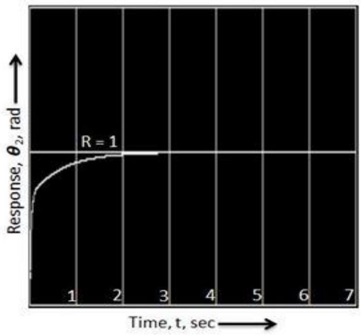

Fig. 13 System response for K_D = 0.5

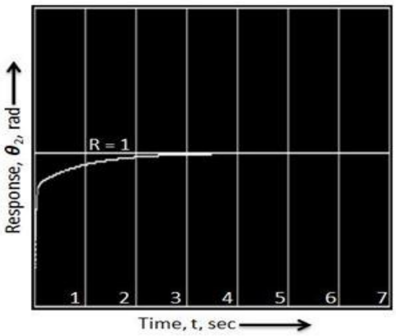

Fig. 5.14 System response for K_D =0.75

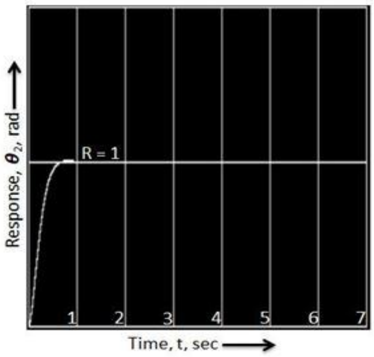

Fig. 15 System response for K_I = 0.01

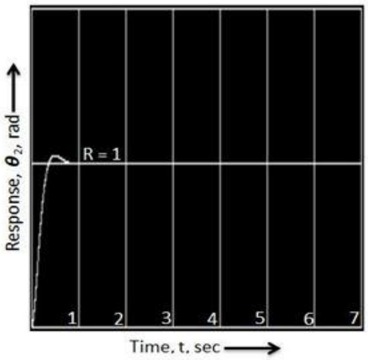

Fig. 16 System response for K_I = 0.5

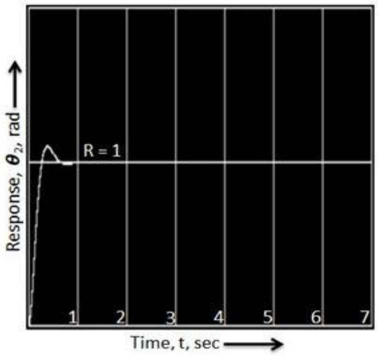

Fig. 17 System response for K_I = 1

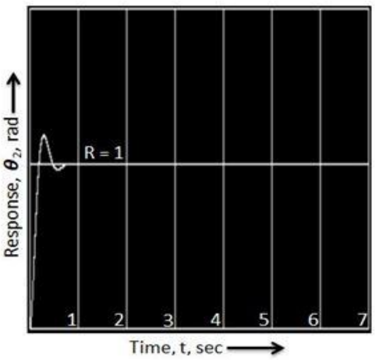

Fig. 18 System response for K_I = 2

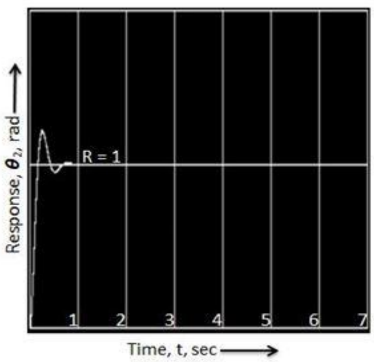

Fig. 19 System response for K_I = 2.5

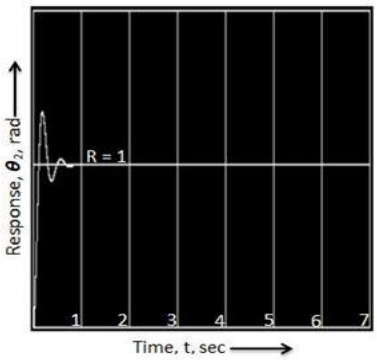

Fig. 20 System response for K_I = 5

After the ranges of all the three gains are found all the gains are made to vary within their ranges. First K_D & K_I are fixed at the arithmetic mean of their corresponding ranges and K_P is made to vary in its range. Then K_P is fixed at the value for which the response is best.

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K_D is varied its range and K_I is kept fixed at the arithmetic mean of its range. Next K_I is made to vary within its range and K_P & K_D are fixed at values for which the responses are best. Finally, the best response of the system is found at the gain combination of $K_P = 2.2$, $K_D = 0.4$ and $K_I = 2$

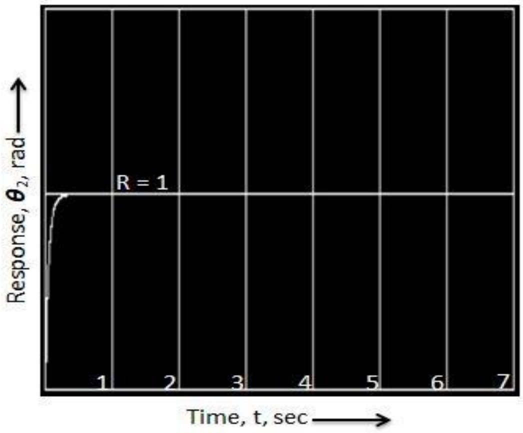

Fig. 21 System response when KP = 2.2, KD = 0.4, KI = 2

VI. CONCLUSION

PID control is a well-established method for controlling robot manipulators. It is also easy to implement. Here PID control is successfully used to control the cylindrical robot manipulator. Following salient points can be highlighted:

- System can be easily modeled for analysis.
- Ranges of the gains for better responses of the system are found precisely.
- By analyzing the variations of three gain factors in the system, range for each and every gain factor is evaluated and it is found that the best response can be achieved by arriving at the best combination of the gain factors. The system shows excellent response for the best combination of gains $K_P = 2.2$, $K_D = 0.4$, $K_I = 2$, even with the presence of flexibility in the system when there is no overshoot and the response is very fast.

VII. REFERENCES

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