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Engineering

MODELING AND CONTROL OF NON-LINEAR BALL AND BEAM SYSTEM

Arya P Lal — PG student in Department of EEE, Mar Baselios College of Engineering and Technology, Kerala, India

Shalu George K* — Faculty in Department of EEE, Mar Baselios College of Engineering and Technology, Kerala, India *Corresponding Author

ABSTRACT Ball and Beam system is a non-linear and unstable under actuated system. It is generally linked to real control problems such as horizontally stabilizing an airplane during landing and in turbulent airflow. In this system a ball is placed on a linear beam which is allowed to roll in either direction of the beam without slipping. The beam is hinged with a lever arm at one end and with a DC servomotor at the other end. A linear transducer, similar to a potentiometer, fitted in the track is used to get the position of the ball on the beam. When the servomotor turns by an angle, the lever arm changes by another angle and hence due to gravity the ball rolls along the beam. The objective is to develop a suitable controller to enhance a better position control of the Ball and Beam system. The Ball and Beam system consists of inner motor control loop and outer ball position control loop. In order to regulate position of the ball on the beam, the design of a controller becomes necessary. A PD controller is used to control the inner loop and outer loop using root locus technique.

KEYWORDS : Ball and Beam, PD controller

1. INTRODUCTION

In recent age with evolution of science and technology many control problems have arisen in real physical world. Control problems can be solved by specific suitable controller. Controller design is an expression of control system imagination and creativity. The problem of designing a controller has always been a source of study for control system engineers. Some real physical problems can't be brought into laboratory to study. So to solve such problems an equivalent system is developed in laboratory. One of them is ball and beam control system. The ball and beam system is one of the most important models used in teaching control system engineering. This system is basically part of study of control system development and is widely used, because of its simplicity and safe mechanism to study dynamics of unstable system. The ball and beam system is also called 'balancing a ball on a beam'. It is generally linked to real control problems such as horizontally stabilizing an airplane during landing and in turbulent airflow. There are two degrees of freedom in this system. One is the ball rolling up and down the beam, and the other is beam rotating through its central axis. The aim of the system is to control the position of the ball to a desired reference point, and reject disturbances such as a push from a finger. The control signal can be derived by feeding back the position information of the ball. The control voltage signal goes to the DC motor via a power amplifier, then the torque generated from the motor drives the beam to rotate to the desired angle. Thus, the ball can be located at the desired position.

The ball and beam system is a typical example of a double integrator system with highly non- linear characteristics and unstable dynamics. The control problem is to regulate the position of the ball and beam system by changing the servo angle. The control scheme consists of two loops inner loop for controlling servo angle and outer loop for controlling ball position. For controlling the inner loop and outer loop PD controller is used.

2. THE BALL AND BEAM SYSTEM

Ball and Beam has two degrees of freedom. In this system a ball is placed at the beam as shown in Fig 1, and lever arm attached to one end point on the beam and other end of a lever arm also attached to a rotation system or motor. When lever arm changes the position of beam from its reference position with angle

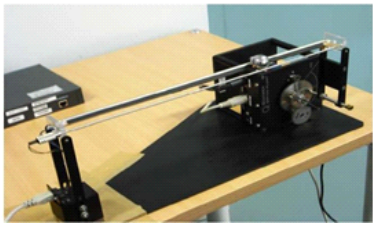


Fig 1: Quanser BBO1 system

The 'Quanser' ball and beam system uses this configuration for its product. The advantage of this system is that relatively small motor can be used due to the leverage effect.

This configuration consists of a steel rod in parallel with nickel-chromium wire wound resistor forming the track on which metal ball is free to roll. The track of the ball is fitted with a linear transducer to measure the position of ball ie, it outputs a voltage signal proportional to the position of the ball. One side of the beam is attached to the lever arm that is coupled to load gear of the Quanser SRV02 unit. By controlling the position of the servo, the beam angle can be adjusted to balance the ball to desired position. The beam is mounted on the output shaft of a DC servomotor. Position of ball is obtained by measuring the voltage at the steel rod. The control problem is to regulate the position of ball by changing the beam angle.

3. MODELING OF BALL AND BEAM SYSTEM

According to physics laws, mathematical equations are derived to model a system. Lagrangian method is used to derive the equation of motions of Ball and Beam system. The control objective is to control the torque

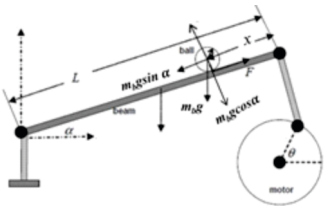


Figure.2. Forces acting during the motion of ball on beam

Deriving the expressions with respect to θ and x the equations of motions are obtained

$$(J_b + m_b x^2)\ddot{\alpha} + 2m_b x\dot{x}\dot{\alpha} + m_b g x \cos\alpha = \tau \quad (1)$$

$$\ddot{x} + \frac{5}{7}\left(g \sin\alpha - x\dot{\alpha}^2\right) = 0 \quad (2)$$

α be the beam angle and θ be the load gear angle required to change the height of the beam by h.

From these we can obtain the relationship between beam angle and motor gear angle as,

$$\sin\alpha(t) = \sin\theta_l(t)\frac{r_{arm}}{L_{arm}} \quad (3)$$

The non-linear equation of motion of the ball and beam system is given by equation. Around the operating point, we can take, $\dot{\alpha} = 0$. There fore the

$$\ddot{x} = -\frac{5}{7} g \sin\alpha \quad (4)$$

$\sin\alpha = \alpha$ is small. Hence this equation

becomes $\ddot{x} = -\frac{5}{7} g \alpha$ (5)

Substitute eqn (3) in eqn. (5)

$\ddot{x} = 0.4182\theta(t)$

Taking laplace Transform

$\frac{X(s)}{\theta(s)} = \frac{0.4182}{s^2}$

Table 1. Parameters of Ball and Beam System

Sl No.	Parameter	Value
1	Beam Length (L)	0.4255m
2	Radius of the ball	0.0127m
3	Acceleration due to gravity	-9.8m/s2

$\frac{\theta_l(s)}{V_m(s)} = \frac{1.53}{s(1 + 0.0248s)}$

Is the transfer function of DC servomotor

The ball position on the beam is controlled using a cascade control system. The control consists of an inner motor loop and outer ball position loop.

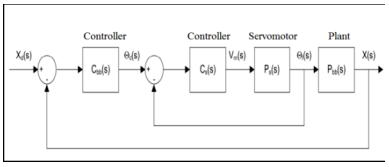


Fig 3. Cascade control block diagram

The ball position on the beam is controlled using a The outer loop computes the desired load shaft angle required to bring the ball to the required position. The inner loop is a servo position control system. The servo controller calculates the motor voltage required to provide the desired load shaft angle.

I. Design of inner controller

Design considerations for controlling the position of servomotor load shaft : e = 0 t = 0.15 s, and P.O = 5.0 %

ss p

The parameters of PD controller is obtained by root locus technique and obtained the values as K_p = 0.0341 and K_d = -0.625

II. Design of outer controller

Design considerations for controlling ball position $e_{ss} = 0.04$ and $w_n = 3$ rad/sec. The parameter of PD controller is obtained by root locus technique. The values are $K_p = 12$ and $K_d = 11$

4. SIMULATION AND RESULTS

The simulink model for open loop system

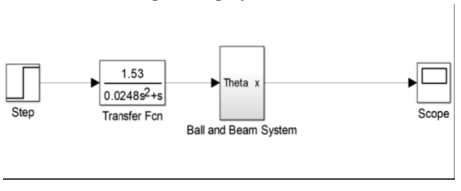


Figure.4 Simulink model for Ball and Beam

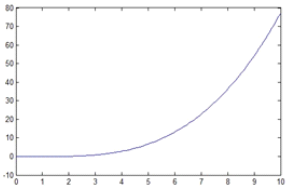


Figure.5.Open loop response

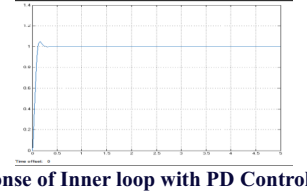


Figure.6. Response of Inner loop with PD Controller

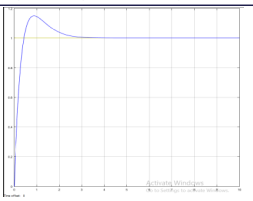


Figure.7. Response of Outer loop with PD Controller

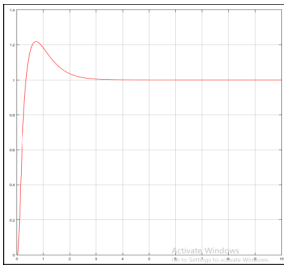


Figure.8. Response for Ball position

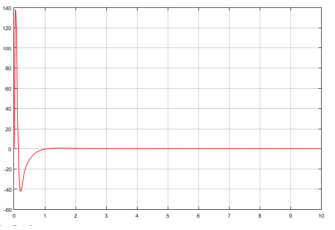


Figure. 9 .Response for load angle

5. CONCLUSION

In this paper, we study the design of PD controller using root locus technique for the implementation of Ball and Beam system. PD is designed and simulated in MATLAB/Simulink environment. The use of PD controller for inner loop and outer loop gives better performance for the overall system.

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