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Modeling of 6 DOF Shake Table and Its Control

Ranjith Pillai R. [1]*, *R. Mathiazhagan* [1], *P. Karthikeyan* [1], *Shiju Varghese* [2], *N. L. Soni* [2], *R. J. Patel* [2]

[1]Department of Production Technology, Madras Institute of Technology, Anna University, Chennai, India
[2]Bhabha Atomic Research Centre, Mumbai, India

Abstract

This paper focuses on the modeling of 6 DOF shake table and implementation of controller and inverse kinematics. Shake tables are widely used to validate the structural integrity and reliability of a specimen during earthquake. Hence shake tables are used to simulate the acceleration spectra of earthquake. Modeling helps to analyze the system and its parameters for better understanding. The inverse kinematics are developed using degree of freedom (DOF) control equation. The proportional-integral-derivative (PID) controller is used with the feedback of actuator leg displacement with desired trajectories as input. The controller is built in Simulink and the output forces of the controller are given as the input to the sim-mechanics prismatic joint of the actuator. The whole physical system is built in sim-mechanics. This paper is an initial work of modeling the physical system without considering the hydraulic parameters and is limited to the kinematics and control of the system.

Keywords: *Shake table, modeling, kinematics, PID controller*

**Author for Correspondence:* *Email ID: ranjithpillai_1988@rediffmail.com*

INTRODUCTION

Parallel manipulators have always been an area of research interest due to its stability and high load capacity. Shake tables are also a form of parallel manipulators with eight actuators unlike six legs of Stewart Gough platform. Stewart tables are also capable of providing six degree of freedom (DOF) motion but in earthquake simulation application, the rotational capability of the Stewart table is not fully exploited[1]. Many design of the vibration platform has been put forward by the researchers.

Yun *et al.*[2] has discussed a vibration platform especially used for the measurement of train bogie parameters with seven hydraulic actuators. Yin *et al.*[3] developed a servo system for a 6 DOF electrohydraulic shaking table and has also described the 6 DOF control and three-state variable controller implemented on the eight actuators. Ammanagi *et al.*[1] presented a three-axis shake table with eight actuators, horizontal X and Y axis actuator placed in opposing configuration. The digital controller and its various constraints have also been discussed in the paper.

Shake table modeled in the paper has eight actuators with four actuators in the horizontal plane and other four in vertical plane. The two actuators x_1 and x_2 as shown in Figure 1 are responsible for the X axis motion whereas the actuators namely y_1 and y_2 are responsible for the Y axis motion.

The action of X and Y actuators provide X, Y and yaw motion and the four actuators in the z axis provide the rest 3 DOF motion.

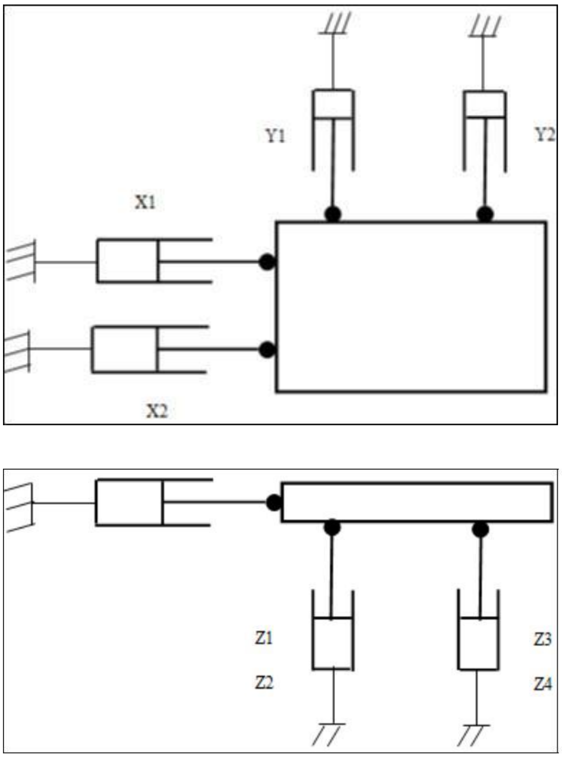

Fig. 1: *Schematic Representation of Eight Actuator Shake Table.*

SYSTEM MODELING

The physical modeling of the shake table is done using sim-mechanics. The 6 DOF shake table has a base and a top platform with total of eight electrohydraulic actuators. The electrohydraulic actuators have been used because of its high bandwidth and high force application. The model used has not considered any hydraulic parameters. The hydraulic actuators are represented as two bodies with a prismatic joint in between. Figure 2 shows the model of a single leg of the table. The top body represents the piston and the lower body represents the cylinder. Each body is defined by its mass and inertial tensor on each axis. The prismatic joint is actuated using the Simulink force signal from the controller.

The joints are also provided with the sensors for the feedback to the controller. The cylinder is grounded to the base using spherical joints and also the piston is hinged to the top platform using the spherical joint. In order to derive the motion of the platform, two coordinates system has to be built namely world coordinate system OXYZ and local coordinate system O'X'Y'Z'. The world coordinate system is fixed on the platform whereas the local coordinate system is fixed on the horizontal floor.

Initially both are assumed to be coinciding. All the coordinate points of the body and joints including the centre of gravity are measured using the above convention. The base actuators z_1, z_2, z_3, z_4 are located in XOZ plane, x_1, x_2 actuators in YOZ plane and y_1, y_2 actuator in XOY plane.

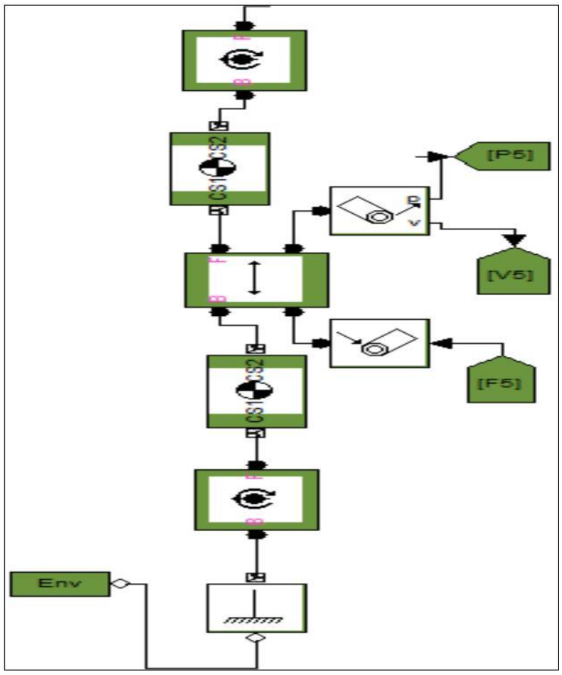

Fig. 2: *Sim Mechanics Model of a Single Actuator.*

KINEMATICS

Kinematics is the science of motion that treats subject without regard to the forces that cause it[4]. Kinematics includes the inverse and forward kinematics. In the inverse kinematics, the length of legs is computed from the pose of the top platform. The kinematic equations are derived using the DOF control matrix.

$$[\text{Trajectory space}]*[\text{kinematic matrix}]^T = [\text{Actuator space}] \quad \text{Eq. (1)}$$

Where, trajectory space is a nx6 matrix, kinematic matrix is a 8x6 matrix and the actuator space is a nx8 matrix.

Kinematic matrix or DOF control matrix can be written as:

$$\begin{pmatrix} 1 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & -1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & -1 \\ 0 & 0 & 0 & 1 & -1 & 1 \\ 0 & 0 & 0 & 1 & -1 & -1 \end{pmatrix} \quad \text{Eq. (2)}$$

The forward kinematics can be derived using the pseudoinverse of the kinematic matrix.

[Trajectory space] = [kinematic matrix]$^{-T}$ X [Actuator space] Eq. (3)

The trajectory space is the desired pose of the table platform in the form,

$$\begin{pmatrix} X \\ Y \\ R_Z \\ Z \\ X_R \\ Y_R \end{pmatrix}^T \quad \text{Eq. (4)}$$

The actuator space is the matrix containing the eight actuators

$$\begin{pmatrix} X_1 \\ X_2 \\ Y_1 \\ Y_2 \\ Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \end{pmatrix}^T \quad \text{Eq. (5)}$$

The actual length calculated using the inverse kinematics was compared with the feedback position and was manipulated in the controller to provide the necessary forces.

CONTROL DESIGN

A normal PID controller is applied to achieve tracking control of 6 DOF shake table. The input to the controller is the error signal which is the difference of the computed length of the actuator and the feedback length. The desired leg length of the actuator is calculated from the desired trajectory using the inverse kinematics. The control scheme for the table implemented in the model is shown in Figure 3. The PID controller outputs the force to be given to each individual actuator which makes the top platform to take the desired pose.

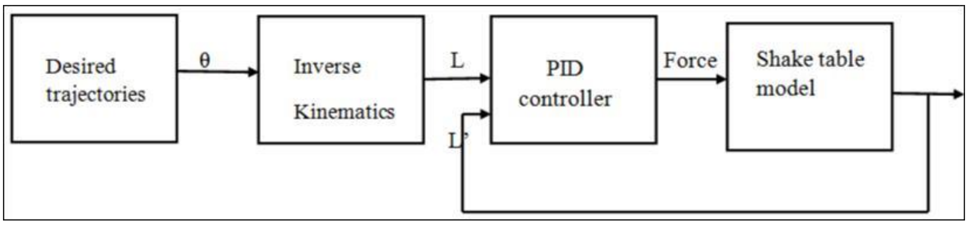

Fig. 3: *Control Scheme Implemented for Shake Table.*

SIMULATION

The 6 DOF shake table was established in sim-mechanics and the 3D animated model of the platform is shown in Figure 4. The simulation was carried out in forward dynamics mode with Adams solver. The simulation parameters are given in Table 1. The simulation results are shown for the desired trajectory (0.2, 0, 0, 0, 0, 0). Figure 5 shows the position of the x_1 and x_2 actuator with respect to time for the sinusoidal input of the mentioned trajectory. The top level diagram of the whole system is shown in Figure 6.

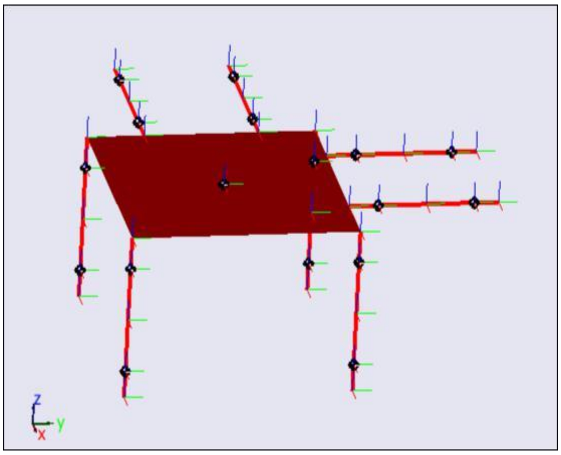

Fig. 4: *Animated Model of Shake Table in Sim-mechanics.*

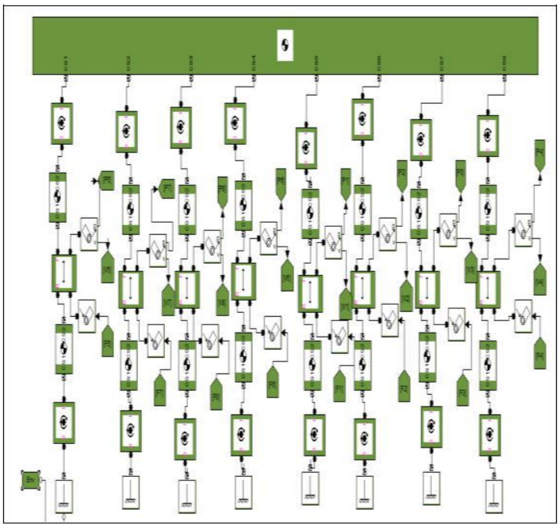

Fig. 5: *Top Level Sim-mechanics Model of the Shake Table.*

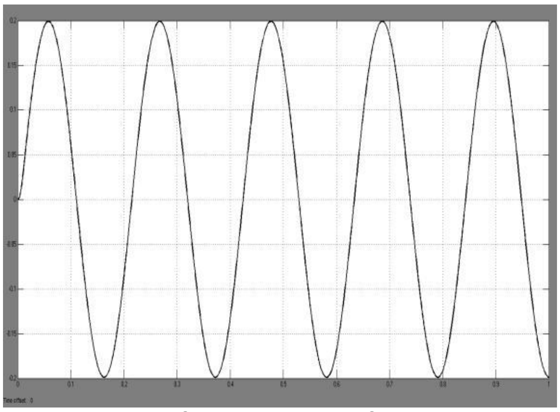

Fig. 6: *Plot of the Position of the x_1 and x_2 Actuator.*

Table 1: *Simulation Parameters.*

Parameters	**Values**
Mass of upper platform, m_p (Kg)	1000
Initial length of cylinder, (m)	1.845
Inertial tensor of upper platform, I_{xx} (Kg m^2)	534.167
Inertial tensor of upper platform, I_{yy} (Kg m^2)	534.167
Inertial tensor of upper platform, I_{zz} (Kg m^2)	1041.7
Mass of piston, (Kg)	25
Mass of hydraulic cylinder, (Kg)	50

CONCLUSION

The system model has been built as per the configuration in simmechanics. The kinematics of the system is verified with different trajectories. The controller and the desired trajectories are developed in Simulink which gives the actuation to the actuator. The work has not included any hydraulic parameters namely, servo valve dynamics, friction etc. This is the initial work to test the kinematics of the system. The work has to be extended to add the modeled servo valve and actuator to the simmechanics physical model so that all important parameters are taken into consideration and can have a better analysis of the system. The PID controller has limited gain [5]. Hence a different controller with high gain and better bandwidth has to be incorporated in the model as a part of future work.

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