Single Actuator Shaker Design to Generate Infinite Spatial Signatures

K D Lagoo, T A Dwarakanath and D N Badodkar

Abstract

The Prismatic-Spherical-Spherical (PSS) kinematic chain based parallel mechanism is discussed. Kinematic design of a 6-PSS based parallel mechanism is presented. The cam and the follower for a joint space prismatic displacement is proposed. The design of a single actuator based shaker to generate six axis motion is presented. The various combinations of cam and the follower options for the design are tabulated. The kinematic design analysis for generating an infinite signature set is given. A virtual simulator validates the design and six axis motion employing a single actuator. A six axis manipulator that follows a specific trajectory in 6 dimensions is described.

Keywords: 6-PSS Parallel Mechanism, Cam and follower, Shaker tables, Displacement signature, Single Actuator Manipulator.

1 Introduction

Universal-Prismatic-Spherical (UPS) joint configuration known as Gough-Stewart is a highly popular six DOF parallel mechanism based configuration [1,2]. The origin of the mechanism started with the prototype development for an application rather than theoretical designs translating into practice [3]. Prismatic-Spherical-Spherical (PSS) based mechanisms are very few, mainly because of further shrinking of the work space for the given size of the mechanism. The best part of the PSS configuration is that the actuators can remain stationary unlike in a UPS configuration. The invariance of the axis of actuation has a large influence on basing PSS type parallel mechanisms for many applications. This is a critical requirement for high speed and dynamic motion mechanisms like shakers. The elimination of the actuator inertia and the high mean time before fatigue failures are the main features of the PSS configuration. Fatigue failures in continuity at the cable-connector interfaces are also a serious concern. Shakers are a common device employed for varied purposes. They are used in biological and pharmaceutical laboratories to agitate the constituents in order to achieve a homogeneous mix in quick time. In

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agriculture, it is used to separate the chaff from the produce. In engineering, the shake tables are used in test rooms to impart vibrations on vehicles (of all modes of transport), building models and engineering devices to characterize the enduring capability. Often tests are to be conducted over a set of signatures varying in displacement amplitude, displacement space and rate of displacement. This paper will provide a new dimension in conceptualizing PSS (Prismatic-Spherical-Spherical) joint configuration based parallel mechanism for shake tables. A single actuator shaker design to generate Infinite Spatial signatures in six dimensional space is presented.

All the shake tables are designed on the basis of PSS (Prismatic-Spherical-Spherical) configurations. The shake table design illustrates the specific advantage of PSS over other configurations of parallel mechanism. The synthesis of the mechanism to generate a repeatable signature trajectory in six dimensions is presented. Settable analog options to vary the signatures within the same mechanism are presented to provide an infinite signature set. The mechanical design of the mechanism is illustrated. The sizing and proportion of the shake tables for various applications is organized in a tabulated form. The feasibility of the design for a range of sizes is discussed. Unique signatures to simulate very special conditions are analyzed. Grain free fall and push sequence operations in winnowing and sieving is simulated.

The single actuator shaker concept leading to the manipulators that follow a specific trajectory repeatedly is described. The design of the joint space and its constraints to serve the pre-determined station points for a pre-determined dwell period in the workspace is presented. A comprehensive design solution and simulation of a single actuator, parallel mechanism based shaker and manipulating devices for a wide variety of applications is envisaged.

2 6-PSS Joint Parallel Mechanism

Fig. (1) demonstrates construction of a highly sensitive 6 axis force-torque sensor based on 6-PSS joint parallel structure [4]. Unlike in UPS model, the axial leg forces are measured at the base formed by instrumented cantilever beams. In the absence of rigid body motion, the structural design of cantilever can be exploited to synthesize extremely high sensitive force torque sensor. In [5], the compliance of flexible legs is used for micro manipulation. The successful implementation of 6-PSS structure for sensing and manipulating applications is extended to a 6-PSS based manipulator in the paper.

The kinetic arrangement, design parameters and the variables are shown in Fig. (2). Two coordinate frames, $F_B = [x_b, y_b, z_b]^T$ and $F_P = [x_p, y_p, z_p]^T$ are defined at the circum centre of the base and the platform disc respectively. The six legs connecting the platform and the intermediary base is of constant length, l. The leg connection points $B_i(B_{ix}, B_{iy}, B_{iz})$ and $P_i(P_{ix}, P_{iy}, P_{iz})$, $i = 1, .., 6$ both at the base and the platform form the vertices of a semi-regular hexagon.

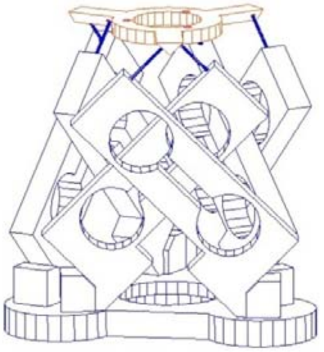


Figure 1: Stiff 6 axis Force-Torque sensor based on 6-PSS structure [4]

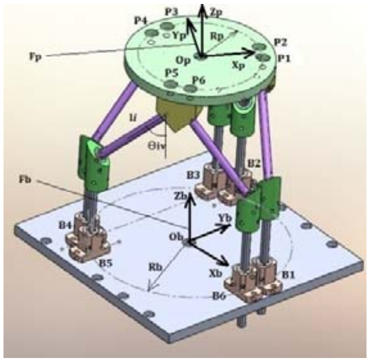


Figure 2: Kinematic sketch of 6-PSS manipulator

The points are represented with respect to F_B. R_b and R_p are the circum radius of the connection points at the base and the platform respectively. They are in cyclic symmetry about z_b and z_p axis respectively. The origin of the frame F_P with respect to F_B is given as Op = $[O_x, O_y, O_z]^T$ and the ${}^B_P R$ is the rotation of frame F_P with respect to F_B. The coordinates p_i of the leg connection points at the platform are expressed with respect to F_P, and can then with respect to F_B, given by:

$$P_i = O_P + {}^B_P R\, p_i \tag{1}$$

The projection of the leg i on the X_b-Y_b plane is given as

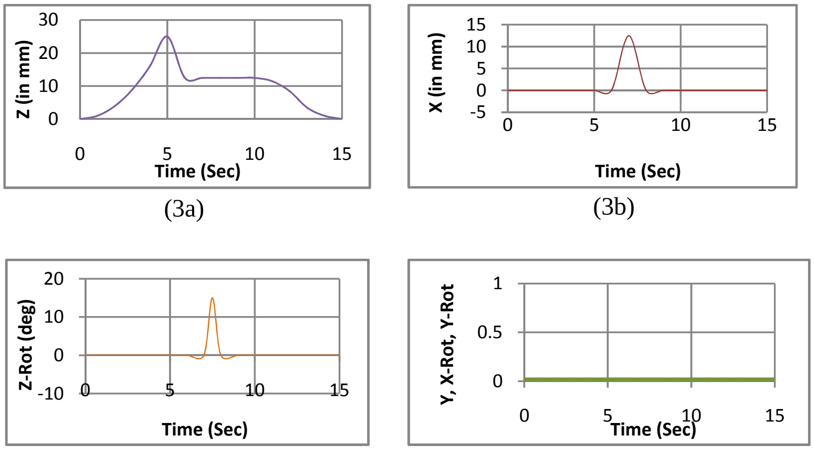
$$\bar{l}_{ixy} = (P_{ix} - B_{ix})\hat{\imath} + \left(P_{iy} - B_{iy}\right)\hat{\jmath} \quad ; \qquad l_{ixy} = \left\| l_{ixy} \right\| \; ;$$

$$\theta_{iv} = \sin^{-1}\left(\frac{l}{l_{ixy}}\right); \qquad \bar{l}_i = \bar{l}_{ixy} + (P_{iz} - S_i)\hat{k} \tag{2}$$

Then the prismatic actuating distance, S_i along $\hat{k}$ for the given position and the orientation of the platform is given as

$$S_i = P_{iz} - l\, \cos\theta_{iv} \tag{3}$$

The main feature of the 6-PSS configuration is that the actuator remains stationary. This feature is suitable for high speed and dynamic motion mechanisms like shakers as it eliminates actuator inertia. The consequence of low inertia forces is a high mean time before fatigue failures in case of manipulators based on PSS configuration. Fatigue failures in continuity at the cable-connector interfaces are also a serious concern. Such concerns are minimized due to stationary actuators. The cam and the follower displacement mechanisms for the joint space are proposed and the design is presented. The cam and the follower technology is one of the highly practiced motion transformation method. The design, accuracy and practicability of the design are given in [6]. The cam and the follower transmission mechanism are practicable and can be applied to wide ranging motion profiles. This feature is utilized to synthesize the PSS based parallel mechanism devises which have cyclic characteristics. Grain free drop and push sequence operations in winnowing and sieving, riding quality of the vehicle due to surface discontinuity are simulated. Grain free drop and push sequence has multi axis motions with discontinuity in the displacement and rate of displacement. The simple way to achieve this repeated multipart trajectory is through the combination of the six cam and the follower joint space displacement. To achieve the sequence of trajectories, the Distance-Time (S-T) graph of each component of the 6-component trajectory is obtained. Fig. (3) shows the typical winnowing S-T graphs of six components.

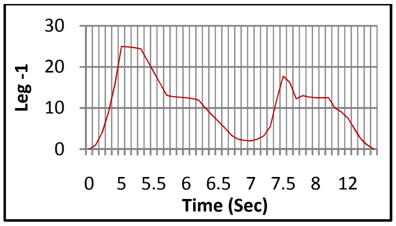


(3a) (3b)

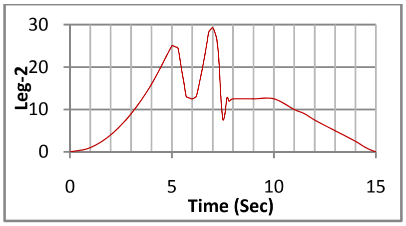
(3c) (3d)

Figure 3: Component S-T graphs of Platform

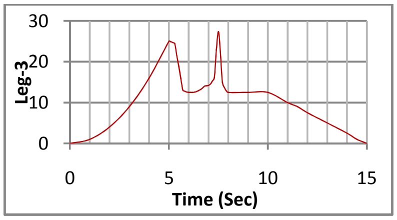
Fig. (3a) to (3d) are the 6 individual components of trajectories to be achieved in one time period (time for one cycle), the S-T graphs of three components, translation along Y, rotation about X and Y are shown in fig.(3d). The trajectory graphs show that during a time segment, the platform has to perform compound motions at varying rates. This is accomplished by using the cam and the prismatic leg follower transmissions for PSS based hexapod mechanism. From the task space S-T graphs of Fig. (3), the joints space trajectories are obtained using equations 1 to 3. The one cycle trajectory of each of the legs is shown in Fig. (4).



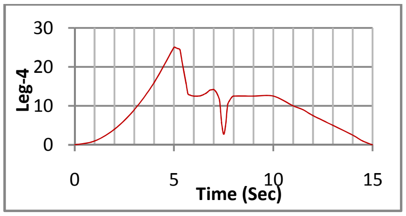
(4a)



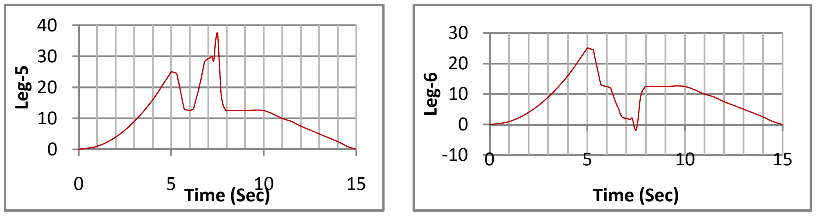
(4b)



(4c)



(4d)



(4e) (4f)

Figure 4: One cycle Time-Displacement diagram of the legs

The one cycle Time-Displacement graph is used to design the cam profile. It can be observed that the cycle time of all the six leg displacement profile is constant. Therefore all the cams are simultaneously rotated at constant angular velocity. Each of the cam connected to the prismatic leg follower is rotated at a constant speed of 4 rpm to provide the winnowing motion profile at the platform as described in Fig. (3). The point on position-time graphs in task space (Fig. (3)) maps to a point on the joint space given as displacement-time graphs (Fig. (4)). The reverse sequence of matching the leg displacements at the instant of time serves as the forward kinematic solution look up graphs of a 6-PSS system. The combinations of the cam and the leg displacement follower for PSS mechanism is described in the next section. The common cam, housing all the six leg profiles is shown in Fig. (5a). The kinematic design of the 6-PSS common cam manipulator to generate the platform profile of figure 3 is given in Fig. (5b).

Figure 5a: Common Cam Six Leg Profiles

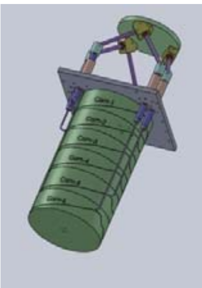
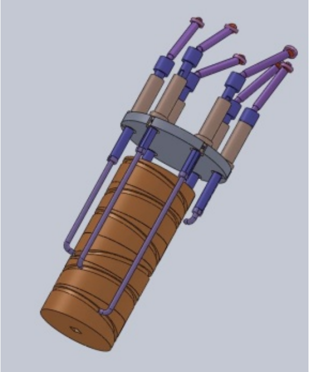


Figure 5b: 6-PSS based Common Cam Manipulator

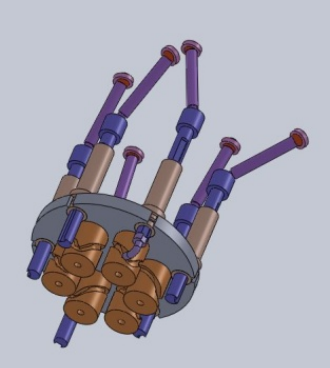
3 Single Actuator Shaker Design to Generate Infinite Spatial Signatures

It is shown that the base fixed actuation and the invariance of the cycle time of all the legs results in a spatial trajectory (shown in Fig. (3)). The synthesis of this feature can be utilized to build a single actuator based 6-PSS to generate the intended trajectory at the platform.

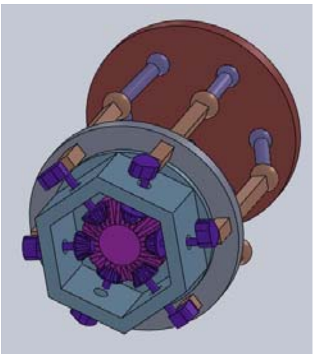
Table 1: Tunable connector displacement function generators for 6 dimensional displacement signature



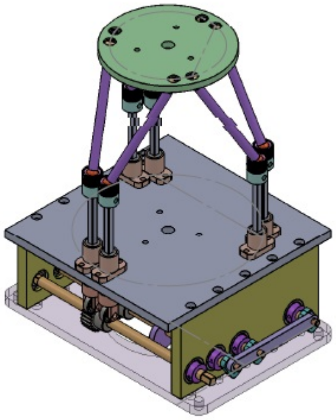
Fig(6a): Common Cam



Fig(6b): Individual Cams



Fig(6c): A gear driven Cams



Fig(6d): Link driven Cams

The task space Distance-Time graph for one time period is formulated. The corresponding joint space is computed using equations 1 to 3. The displacement-time trajectory profile is obtained as shown in Fig. (3). The functional relationship between the actuator motion and each of the leg displacement for actuation is to be established. The cam profile of each of the leg is proportional to the functional relationship with the motion of the actuator. There are six functions of Distance-Time profile, generating six cam profiles and transmitting it to corresponding leg followers from a single actuator is the task. The design space for this task is discrete, the primary and the technical objective is that the design should result in a positive transmission of the Distance-Time profile. The volume and the weight are the quality characteristics of the design, therefore the compact size and the light weight are considered as the secondary objectives. Many design solutions are generated based on the above objectives. Few of the design solutions, which are feasible, are simulated. The designs, which closely satisfy the objectives, are tabulated in table 1. The cam profile shown in Fig. (6a) is the common cam concept, housing all the 6 leg profiles on one surface. For a given time period, the path length of the profile can be very high; therefore the profile detailing can be achieved easily. A simple cylindrical surface as the common cam surface is shown in the Fig. (5a). The single cam concept can also make use of other geometrical surfaces like conical, spherical, stepped cylinder, combination of solids, etc. Fig. (6b) and (6c) use as many cams as legs to generate the individual cam profile. The design is more compact, the individual cams are driven by a common gear transmission. A central common spur gear or a bevel gear transmits the motion to the individual gear connected to the cam. The advantage of this arrangement is that the cycle period of each leg can be varied. Fig. (6d) is the gear and the link arrangement. The mechanics of each design is simple; a single actuator transmits motion to all the individual followers through a cam arrangement. Infinite signature sets can then be generated by various combinations. The cam profiles can be interchanged among legs and new cam profiles can be replaced with old ones.

Apart from above applications, large number of industrial manipulators are used to perform repeatable tasks. To extend the cam and the leg follower with single actuator to serve such manipulator actions, a simple toggle switch control can be used. The design of the joint space to serve the pre-determined station points for a pre-determined dwell period in the workspace is feasible. The stationary platform at the station point signifies simultaneous dwell for all the legs. The long dwell time at station points is mapped to the actuation switch off time. The motion profiles between the station points are resolved as component motion as described in section 2. The respective joint space S-T graph is obtained to design the individual cam profile for the manipulation task. Fig. (7) depicts such an application.

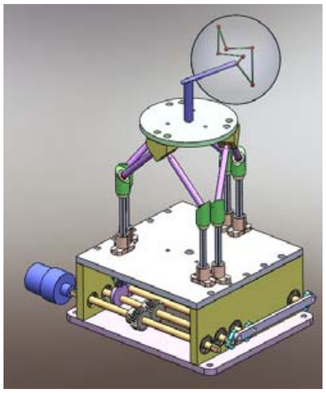


Figure 7: Single actuator, tunable, specific spatial path following manipulator

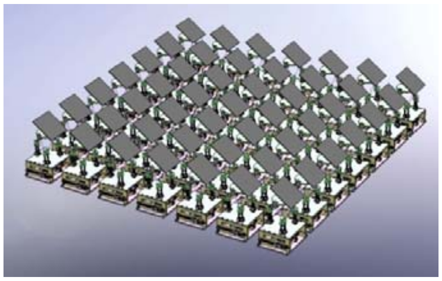


Figure 8: An array of 6-PSS manipulator based on the cam and the leg follower connected to a common drive shaft.

The feasibility of the widespread use of manipulators, which have to perform repetitive trajectory is simulated. An example of Heliostat trajectory is considered and the mechanism is synthesized with a single actuator to replicate the motion. An arrangement of array of mirror mounted 6-PSS based hexapod mechanism is illustrated in Fig. (8). Manipulators of each row in the array have a distinct platform profile influenced by its row position and the corresponding joint space displacement can be achieved easily by cam profiling. Also, it is important to note that all the manipulators in the array are actuated by one common drive shaft.

4 Conclusions

The cam and the follower prismatic leg displacement, PSS configuration based parallel mechanisms is introduced. The kinematic design of a PSS based parallel mechanism is presented. A multi-component repeatable cyclic trajectory at the platform is generated using the simple cam and the leg follower based hexapod. The design of a single actuator shaker to operate in six dimensional space based on PSS joint configuration is designed. The various combinations of cam and the follower options are discussed. An idea of using a single actuator driven manipulator to perform repeatable trajectories and serving stationary points is presented. The validation of the kinematic design and motion signatures in six dimensions employing a single actuator is carried out in simulation. The feasibility of array of manipulators driven through a common drive shaft is illustrated. A comprehensive design solution and simulation of the cam and the follower based parallel mechanism for a wide variety of applications is envisaged.

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