Triglide Parallel Manipulator for Orientation and Positioning of Models for Wind Tunnel Testing

Dr. C. Dhandapani[1]
[1] Head, Dept of Mechanical Engg,
Rajagopal Polytechnic College,
Gudiyattam– 632 602, Tamil nadu, India.

Dr. R. Sivaramakrishnan[2]
[2] Professor and Head, Dept of Production Technology,
MIT Campus,
Anna University, Chennai – 600 044, India.

S. Yuvaraj[3], S. Yashwanth[4]
[3,4] Student, Dept of Mechanical Engg,
Rajagopal Polytechnic College,
Gudiyattam – 632 602, Tamil nadu, India.

***Abstract*:- An approach for accurate positioning of models for wind tunnel testing is presented in this research paper. Traditionally manual method is practiced for positioning and orienting models for which parallel manipulators provide a solution providing accuracy and quickness. For this purpose the modeling, simulation and Kinematic analysis of three degrees of freedom tri-glide type parallel manipulator actuated by screw pairs and spherical pairs are presented in this paper. The parallel manipulator is constructed with circular shaped top movable platform with a base fixed platform, which is linked through three rigid links of equal length spaced at equal angular distances from each other. One end of each link is provided with a spherical pair and is attached to the movable platform and the other end to a screw pair through a nut with ball joint. The three screw pairs are essentially actuated individually by separate stepper motors. A model has been fabricated and experimental analysis was carried out to find the angular tilt of moving platform. The rotations of screw and the position and orientation of the moving platform are used to perform the kinematic analysis of the manipulator. In order to further validate the model the software package ProE is used to simulate the linear displacement of the nut and the angle of tilt of the moving platform. The results obtained from experimental, analytical and simulation methods are verified and found to be closer in all the three cases.. This mechanism of parallel manipulator, no doubt shall also find its way for performing applications like machining inclined holes, contour milling and angular machining with accuracy for which, the paramount important requirements are load carrying capacity, good dynamic performance, stability and precise positioning of the manipulator.**

Keywords: Parallel Manipulator, Triglide Robot, Degrees of freedom, Simulation, ProE, Ansys.

1. INTRODUCTION

The modeling, simulation and kinematic analysis of three degrees of freedom (3-DOF) tri-glide type parallel manipulator, which can be used in applications like positioning and orientation, contour machining and angular drilling are presented in this paper. For application like drilling and material handling, the necessary requirements are better load carrying capacity and good dynamic performance and stability. It is expected that the platform of this parallel manipulator could be tilted up to ±60°, subjected to the imposed physical constraints. The three rigid links are individually actuated in parallel by motor actuators through screw pairs. The output angular tilts can be either about ‘x’ or ‘y’ axis or it can be a combination of ‘x’ and ‘y’ axes and translation along ‘z’ axis. A suitable 1-DOF strut for mounting models can be fixed over top movable platform so that the mechanism can find its application in wind tunnel testing of models. The positioning and orientation of an aero plane model inside the test section of wind tunnel can be automated using this tri-glide parallel manipulator [1]. This mechanism can also find its application in machining inclined holes when used in inverted fashion.

2. CONSTRUCTIONAL DETAILS OF TRI-GLIDE TYPE PARALLEL MANIPULATOR

The construction of 3-DOF tri-glide type parallel manipulator is shown in Fig.1 and part drawing showing the orthographic projection and exploded view are as in Fig.2 and 2(a). The manipulator consists of a fixed base plate, a movable platform, three rigid links of equal length, three ball screws each with a nut that translate along the screw and screw housings arranged over fixed base plate. Each of the three links (i.e., legs) is individually linked to spherical joints at one end while the other end of each link is connected to nut through a revolute pair. Prismatic pairs are formed by translating nuts along their respective ball screw. The top movable platform is provided with a strut or gripper for mounting models [2]. The manipulator has been designed to carry a maximum load of 3000 N under equilibrium condition after considering factor of safety. Therefore each link can sustain a maximum load of 1000 N. The base plate is made circular with 1000mm diameter from a 20mm thick frame and the top movable platform is also made circular with 550mm diameter from a 20mm thick frame. All the three screw box outer face edges are hinged to base plate at stepper motor end so that each of the screw boxes can be tilted about its hinge and fixed at any required angle. This angle measured from base plate to screw box rails is termed as actuator layout angle (LA). This improved architecture has been adopted in the literature Yangmin & Quingsong (2008).

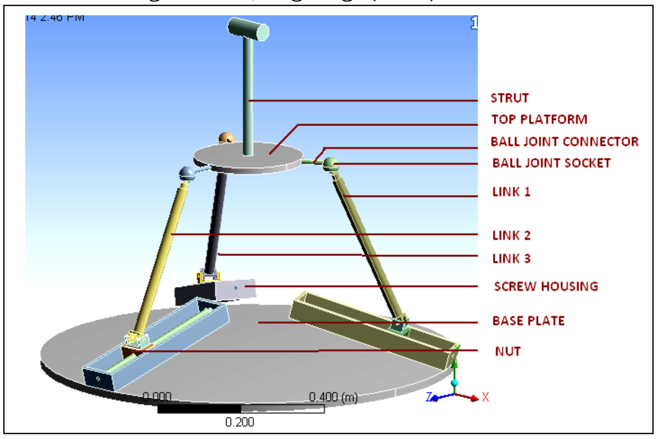

Fig.1 CAD model of tri-glide type 3-DOF parallel manipulator

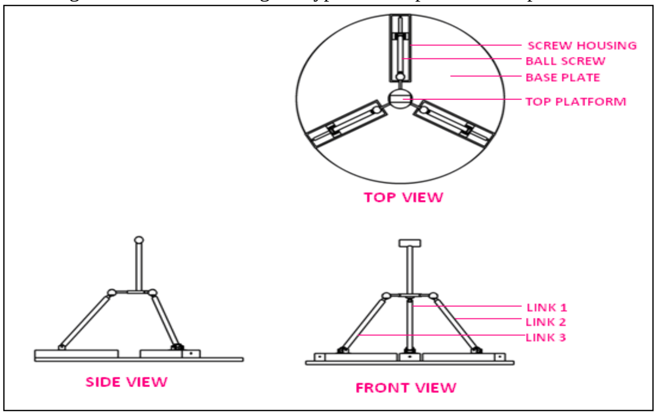

Fig.2 Orthographic Projection of tri-glide parallel manipulator

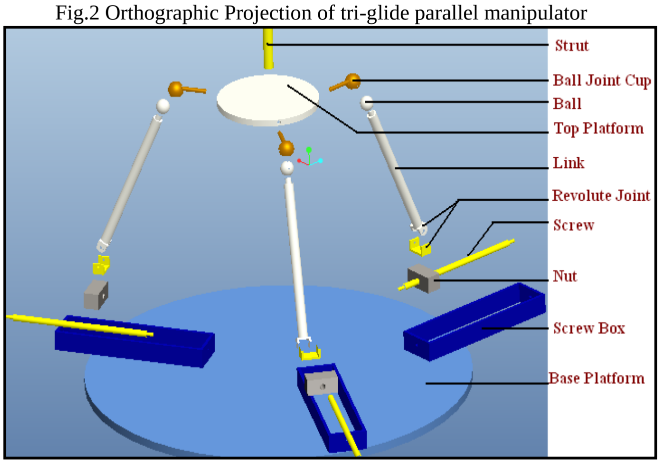

Fig.2(a) CAD Exploded view of tri-glide parallel manipulator

3. MOBILITY ANALYSIS

The general Grubler-Kutzbach criterion for mobility analysis holds good for many parallel mechanisms [7]. Since the mechanism considered is three degrees of freedom tri-glide type parallel manipulator having a moving platform connected to fixed base plate by three rigid links by means of ball joints and pin joints, the number of DOF of parallel manipulator as given by Hunt (1978) is

$$F = \lambda\left(n - g - 1\right) + \sum_{i=1}^{g} f_i \qquad (3.1)$$

$$F = 6 \text{ x } (8 - 9 - 1) + 15 = 3$$

Where λ = order of task space, n = number of links
g = number of joints f_i = degrees of freedom of joint 'i'

4. DESCRIPTION OF 3-DOF TRI-GLIDE PARALLEL MANIPULATOR

The three degrees of freedom parallel manipulator with three screw pairs, three revolute pairs and three spherical joints is composed of a moving platform, a fixed base and three links supporting moving platform with identical kinematic structure. The connection from fixed base to moving platform is by a 'P' joint (screw pair) 'R' joint (pin) and 'S' joint (ball and socket) in sequence. Screw pairs are essentially actuated by motor actuators controlled by PLC. The tri-glide parallel manipulator model has been fabricated to designed dimensions using structural steel channels, plates and rods and the photograph of actual model is shown in Fig.3. The three links that were made circular comprising of an inner solid rod enclosed by a hollow rod and fastened with through bolts [3]. This telescoping arrangement was aimed to provide different lengths for links as required for dimensional synthesis. Telescoping adjustments were provided to obtain link lengths of 400mm, 450mm, 500mm and 550mm. The photograph of top platform connected to links through spherical joints are shown in Fig.3(a). All the three screw housings were provided with adjuster rods so that each of the housing could be tilted around the hinge and fixed at required angles [4].

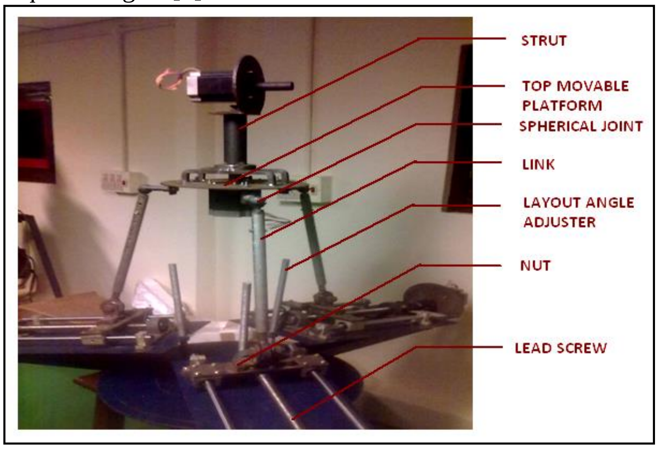

Fig.3 Photograph of fabricated tri-glide parallel manipulator

The Pro-E model showing the architecture is shown in Fig.3(b). This improved architecture had been adopted by Yangmin & Quingsong (2009) for translational mechanism in inverted fashion.

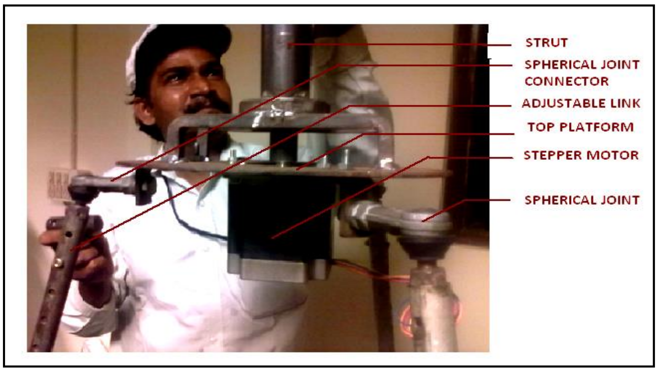

Fig.3(a) Photograph showing top movable platform

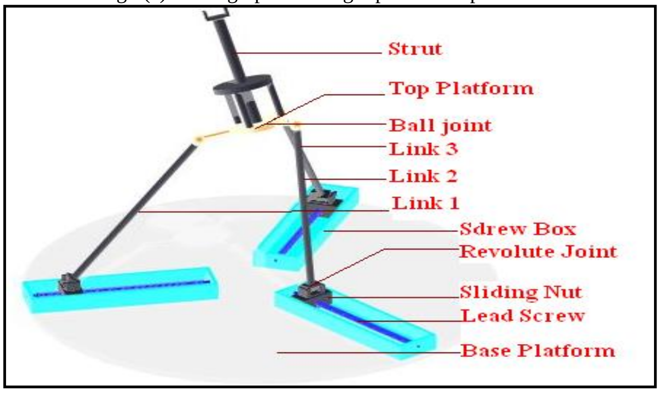

Fig. 3(b) Pro-E Model showing the architecture of tri-glide

5. PRINCIPLE OF WORKING

In order to obtain required angular inclination of top movable platform, the stepper motor coupled to one of the links should be actuated. This could be achieved by supplying suitable pulses to motor that rotate the ball screw, which in turn translates the corresponding nut. Taking input variable as the number of pulses supplied to actuator, the output variable in terms of angle of tilts of top platform was arrived [6]. A PLC module was used for the control of stepper motor actuators.

In order to implement the inverse kinematic solution, required angle of tilt of top platform was taken as input to calculate the number of pulses to be supplied to actuators as implemented by Sivaramakrishnan et al (2002a, 2002b). The working model is shown in Fig.3

6. RESULTS AND DISCUSSIONS

The kinematic study of three degrees of freedom Tri-Glide type parallel manipulator has been carried and dimensional synthesis to evaluate the influence of geometrical parameters of elements was performed. Dimensional parameters considered were LL, TPD, LA, LOA, and vertical distance A_Z. Simulations for constrained positions were conducted and the influences of these positions on angle of tilt of top platform were analyzed. In order to validate the structural stability of PM model finite element analysis were also carried out. Static structural analysis as well as harmonic analysis for combined vertical and horizontal loads were performed and analyzed for the selected dimensions of tri-glide PM.

6.1 POSITION KINEMATICS

Experiments conducted on fabricated tri-glide when LL=550mm and TPD=400mm by keeping LA as 0°, the angle of tilt (θ_Y) of top platform was observed to be 8.59° and vertical reachable distance (A_Z) was 533.96mm when nut-1 was displaced by 160mm away from OCP. Also by keeping LA as 15° and then 30˚ for the same LL and TPD the experimental observations for tilt angles (θ_Y) were found to be 16.14° & 22.84° respectively while the vertical reachable distances (A_Z) were measured to be 567.24mm & 604.20mm for the same 160mm DON connected to link-1. The results were approximately equal to the simulation results. Small variations of 0.08°(+0.001%), 0.16° (+0.01%) and 0.15°(+0.007%) observed between experimental and simulated tilt angles for LA=0˚, 15˚& 30˚ respectively were observed [5].

When nuts 2 and 3 were displaced by the same distance of 160mm, the angles of tilt and vertical distances were measured to be nearly equal to the results of nut-1. A set of results recorded for manipulator designations (550-1.38-435-9.48-00), (550-1.38-415-19.83-15) and (550-1.38-390-26.49-30) are shown in Tables 1 and 2 respectively.

Table: 1 Comparison of results when LA=0° &LL=550 mm

LA=0/LL=550/ TPD=400/ OCP=435	Designation: 550-1.38-435-9.48-00				
Actuated Link	DON (mm)	Tilt (θ_Y) of Top platform (degrees)		Vertical distance A_Z (mm)	
		Experiment (Expmt.)	Simulation (Simul.)	Experiment (Expmt.)	Simulation (Simul.)
Link 1	160	8.59	8.51	533.96	533.80
Link 2	160	8.54	8.51	533.88	533.80
Link 3	160	8.58	8.51	533.92	533.80

Position kinematic experiments were also conducted on fabricated tri-glide for reduced values of when LL=400mm and TPD=350mm by keeping LA as 0°, the angle of tilt (θ_Y) of top platform was observed to be 6.74° and vertical reachable distance (A_Z) was 391.66mm when nut-1 was displaced by 100mm away from OCP. Also by keeping LA as 15° and then 30° for the same LL and TPD the experimental observations for tilt angles (θ_Y) were found to be 11.90° & 16.42° respectively while the vertical reachable distances (A_Z) were measured to be 443.92mm & 507.44mm for the same 100mm DON connected to link-1. The results were approximately equal to the simulation results.

6.2 POSITION ANALYSIS EXPERIMENTAL METHOD

An experiment is conducted for position analysis by actuating one of the links at a time. A laser torch is mounted on the center ‘C’ of the movable platform and a laser light is projected on vertical screen at a point ‘A’, which is at a predetermined distance ‘CA’ from the point of laser source. When the platform is tilted by the actuation of link, the laser beam gets deflected to some other point ‘B’ on the vertical screen. The steady state positions of the laser beam on the vertical screen before and after actuation were tracked and the distance is considered to be K. Angle of tilt of the platform is measured from the orientation of the source, and is explained in the Figure 6. From the Figure, the movable platform rotates at an angle of γ which is measured as

$$\gamma = \tan^{-1}(AB / CA) = \tan^{-1}(K/CA)$$

where CA is fixed predetermined distance, AB is vertical height

6.3 POSITION ANALYSIS ANALYTICAL METHOD

A software program is written in C language for the algorithm as mentioned. The Flow chart for the algorithm formulated is shown in Fig.4 from the algorithm, the various results were found and were shown in Table 1. This is nothing but a reverse process of the experiment. In the experiment, the output was the angle of rotation of the platform and the input was in terms of displacement of nut or in other wards the number of rotation of screw. But, in analytical method in order to verify the displacement of the nut, angle of tilt of platform is given as the input.

6.4 POSITION ANALYSIS USING ADAMS

The manipulator model is constructed and simulated in ADAMS by building the physical attributes of the elements or parts in the mechanical systems that has rigid bodies, point masses, flexible bodies and constraints.

For the displacement of 35 mm of the nut, the angle of rotation of the moving platform about x axis and y axis are obtained from the simulation graphs.

Table: 2 Comparisons of Results by Experiment and ADAMS

Actuation Link	Displacement of nut (mm)	No. of rotations of screw	Angle of rotations of moving platform (degrees)	
			Experiment	ADAMS
Link 1	70.00	14	3.95	3.724
Link 2	70.00	14	3.89	3.724
Link 3	70.00	14	3.81	3.724

7. WORK SPACE ANALYSIS

The Workspace analysis was conducted using the MATLAB software to find the work volume of the manipulator. In order to find the workspace, the circumferential points while moving the links are taken from the simulation results of ADAMS. These points are given as inputs for creating program in MATLAB software. The movements of the platform along with their co-ordinate points are obtained by MATLAB. First, the legs of the manipulator are made to move towards the extreme positions and the work volume is obtained through the various points given as the input to MATLAB during simulation. Similarly, each one of the links is made to move to the minimum and maximum positions and the work envelope is found.

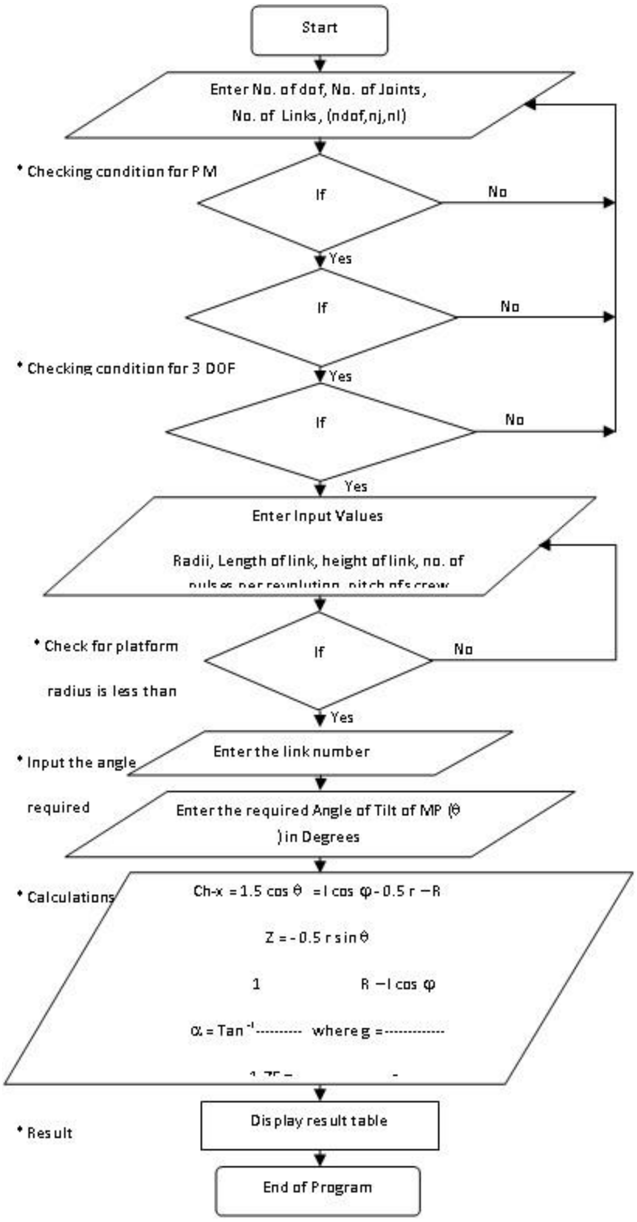

Fig.4 Flow chart for triglide

8. CONCLUSION

The results obtained from the Experiment, and the simulation results by ADAMS are shown in Tables 1 to 2. From the experimental work the angle of tilt of moving platform is found as 3.952° for 70 mm displacement of the nut connected to link one for 14 rotations of the screw having 5mm pitch. From the analytical results, by giving the angle of tilt of moving platform 3.952° as input, it is found that the nut displacement is 69.352mm and the number of rotations of the screw is 13.870. This is approximately equal to the input given in the experimental work (70mm). The error of 0.648 mm in the displacement of the nut is due to the mechanical inaccuracies and manufacturing errors at joints and at the links. For the same displacement of nut and same number of rotations of screws for all links, it is supposed to get equal angles of tilt of moving platform. The slight variation in the angle of tilt of moving platform is due to error in fabrication and alignment of parallel manipulator.

9. REFERENCE

[1] Kok-Meng Lee and Dharman Shah K. (1990), ‘ Kinematic Analysis of a 3 DOF Manipulator’, IEEE Transactions of Robotics and Automation, Vol.4, No.3, pp.354-360.

[2] R.Ben – horin, M.Shoham, Constructions of a six – degrees of freedom parallel manipulator with three planarly actuated links , proc, ASME design engineering conferene (1996), 18-22.

[3] K.H.Hunt. “Kinematic Geometry of Mechanisms”, Monash University of Victoria, Australia, June(1997), 17-25.

[4] Carretero J.A., Nahon M.A. and Podhorodeski R.P. (2000), ‘Workspace analysis and optimization of a novel 3-dof parallel manipulator’, Journal of Robotics and Automation, Vol.15, No.4, pp.178-188.Feng Gao, Xin-Liu and Xu Chan (2001), ‘The relationships between the link lengths of 3 DOF symmetrical planar parallel manipulators’, Mechanism and Machine Theory, Vol. 36, pp.205-220.

[5] Sivaramakrishnan R., Kalaichelvan K. and Dhanaraj R. (2000), ‘Kinematics and Construction of 3 DOF Parallel Manipulator’. 16th International conference on CAD/CAM, Robotics and Factories of the future CARS and FOF, Port of Spain, Trinidad and Tobago, Vol.1, 26th -28th June 2000, pp 63-71.

[6] Mr. Arockia selva Kumar A, 'Analytical study on Dimensional synthesis of Tripod Parallel manipulator', International journal on Advanced Mechatronics and Robotics, Vol 1, Pp 1-11., 2009

[7] Yangmin Li, Qingsong Xu, ‘ Kinematic analysis of a 3-PRS parallel manipulator’ , Elsevier – robotics and computer integrated manufacturing -23 (2007) 395-408.