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MODELING AND SIMULATION OF 3-CRR TRANSLATIONAL PARALLEL MANIPULATOR

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Abstract

The kinematic motion pattern of the 3-CRR translational parallel manipulator is verified through the simulation of CAD model. The isotropic and non-isotropic layout configuration of the manipulators are deeply studied for displacement, velocity, acceleration behaviors of the actuation joints. The shape and size of workspace volume is investigated for both the isotropic and non-isotropic manipulator layouts, the possible occurrence of singular configurations and link interfaces are identified. The CAD simulation study of the mechanism revealed that isotropic configuration layout yields a more dexterous workspace.

Keywords: Isotropic layout, simulation, dexterous, motion patterns

Introduction

In recent years, the progress in the development of parallel manipulators (PMs) has been accelerated since PMs possess many advantages over their serial counterparts in terms of high accuracy, velocity, stiffness, and payload capacity, therefore allowing their wide range of applications as industrial robots, flight simulators, micromanipulators, and parallel machine tools, etc. Several types of architectures have been proposed in the literature [1], [2] to achieve pure translational motions with different theoretical approaches, like the (3-UPU) platform, (3-RUU), (3-PUU) mechanisms, (3-RPC) architecture, (3-PUC) manipulator, etc. Here the notation of R, P, U, C, and S denote the revolute, prismatic, universal, cylindrical, and spherical joint, respectively. Among these architectures, translational parallel manipulators (TPMs) have a potentially wide range of applications that need a pure translational motion in case of a motion simulator, a positioning tool of an assembly line, and others. However, the most notable drawback of parallel manipulators is their relatively limited workspace and singularities and collision and interface of links while motion transmission. Brogardh et al [3] discussed the kinematic simulation and computer aided design of the spherical parallel manipulators with revolute actuators for high performance robotic systems, in this paper, the rotation matrix from the base platform to the MP was derived from the Hartenberg - Denavit convention. The inverse kinematic problem was solved by the vector approach, and the direct kinematics solution was derived from the polynomial equations. Both the forward and inverse kinematics problems of a spherical parallel manipulator, lead equally to 8 solutions. SMAPS (Simulateur de MAnipulateurs paralleles Spheriques), a CAD package was used to simulate the parallel manipulator model, and the Euler angles, singularity, workspace and dexterity analysis were computed. Comin.F [4], Grace. W et al [5] presented the design of a reaction less 3-DOF and 6-DOF parallel manipulator. In that work, two types of the actuation schemes of the parallelepiped mechanisms were designed. The counter weight and rotations were used to balance the mechanism dynamically. The ADAMS simulation software was used to simulate the motion of the mechanisms. Finally, reaction less 6-DOF parallel manipulators was synthesized and analyzed by various authors in the literature [6],[7],[8],[9] using algebra and the screw theory, the 3-DOF parallelepiped mechanisms and the reaction less property was verified numerically. coupled a Brayden-Fletcher-Goldfarb's algorithm with the FEM system, using GNU Octave mathematical and numerical system, to achieve an efficient optimization on a tripod PM. The Clavell's tripod structure was taken into account to demonstrate the optimization algorithm the CAD model was created from simple pipe elements [10], [11].

The challenges of workspace determination of parallel manipulators are obtained principally from the lack of analytical solutions of the forward kinematics. The inverse-position kinematics-based approach for determining workspace tends to be inefficient, time consuming and unsophisticated and also in inverse kinematic analysis multiple solutions are obtained for the same end-effector configuration in this case need to implement elimination algorithms. In this paper, adopted a CAD enhanced geometry-based method for accurate and computationally effective calculation of the workspace size and shape of a constrained parallel manipulator. The Boolean geometric operations can simplify the process of finding the workspace and simulation can reveal the singular configurations. Comparative performance studies, in terms of workspace volume and motion patterns, are performed to two manipulator layout configurations.

Literature

The Most of the previously reported TPMs have the fully symmetrical topological architectures, leads to the highly nonlinear kinematic models due to the coupled input-output motion, introducing the difficulties in the motion control and trajectory planning. On the other hand, the asymmetric architecture can ensure advantages of motion decoupling for mechanisms. Moreover, the parallelogram (Pa, a.k.a, Π joint) structure is an important linkage to lay out TPMs [12,13], while, this introduces the structural complexity due to the presence of the closed sub-loop. Thus, the fewer use of parallelogram can ease the structural complexity in turn. Taking into consideration the two previous aspects, the design of TPMs with decoupled motion and lower complexity will be the focus of this paper. Using a topological design method of parallel mechanism (PM) based on position and orientation characteristic (POC) equations, this paper presents a novel three-degree-of-freedom (3-DOF) TPM. The TPM can for manufacturing large work pieces when the actuated joints move along a long-distance guide rail [14].

Architecture Description

The computer aided design (CAD) model fig no 3.1 and schematic diagram fig no 3.2 of a 3-CRR TPM is shown in Figs. 1 and 2, respectively. It consists of a mobile platform, a fixed base, and three limbs with identical kinematic structure. Each limb connects the fixed base to the mobile platform by a C joint, an R joint, and a R joint in sequence, where the C joint is driven by a linear actuator assembled on the fixed base. Thus, the mobile platform is attached to the base by three identical CRR linkages. The following mobility analysis shows that in order to keep the mobile platform from changing its orientation, it is sufficient for the three axes of joints within the same limb to satisfy some certain geometric conditions. That is, (i) the C joint axis and both R joint axes within the I'th limb. The general Grubler-Kutzbach criterion is useful in mobility analysis for many parallel manipulators, however it is difficult to apply this criterion directly to mobility analysis of over constrained limited-DOF parallel manipulators. However, can effectively analyses the mobility of a 3-CRR TPM by resorting to screw theory. For a limited-DOF parallel manipulator, the motion of each limb that can be treated as a twist system is guaranteed under some exerted structural constraints which are termed as a wrench system.

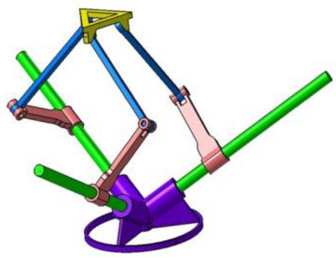

Figure 1: CAD model of CRR Parallel Manipulator

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CAD Modelling of CRR Manipulator

The computer Aided Design (CAD) model is developed in Catia V5 software for both the isotropic and non-isotropic layout configurations. The individual components of the manipulator like fixed base, moving platform, lead screws, hollow cylinders, link arms are modelled for the same geometric parameters. The geometric parameters considered for modelling and simulation of both isotropic and non-isotropic configurations are given Table.1. The modelled components of the manipulator are shown in Fig.2(a-e).

Table.1 Design Specifications

PART	LENGTH	DIAMETER	ANGLE
BASE PLATE		200mm	
LEAD SCREW	350mm	20mm	45^o - non isotropic 32.36^o - isotropic
LINK 1	175mm	20mm	
LINK 2	175mm	20mm	
MOVABLE PLATE		100mm	

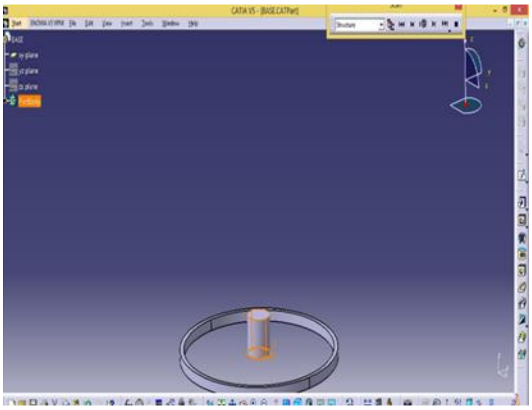

Figure 2a: Fixed plate

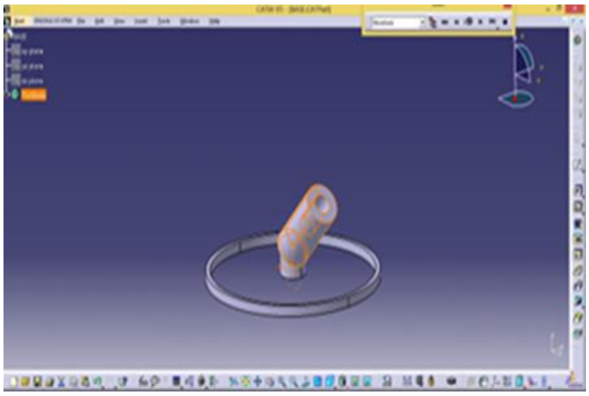

Figure 2b: Fixed plate with hollow cylinder

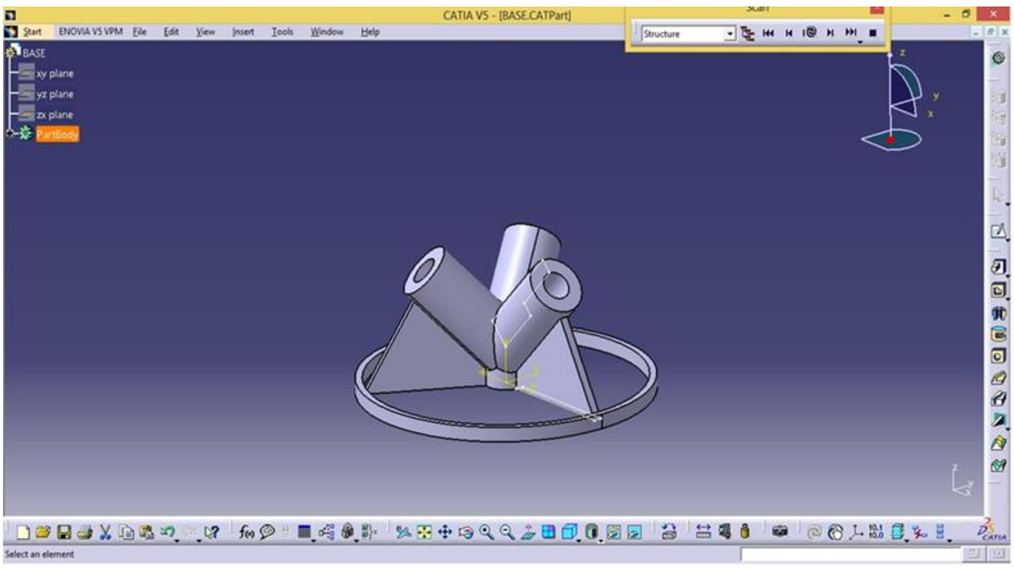

Figure 2c: Adding up supports to fixed plate

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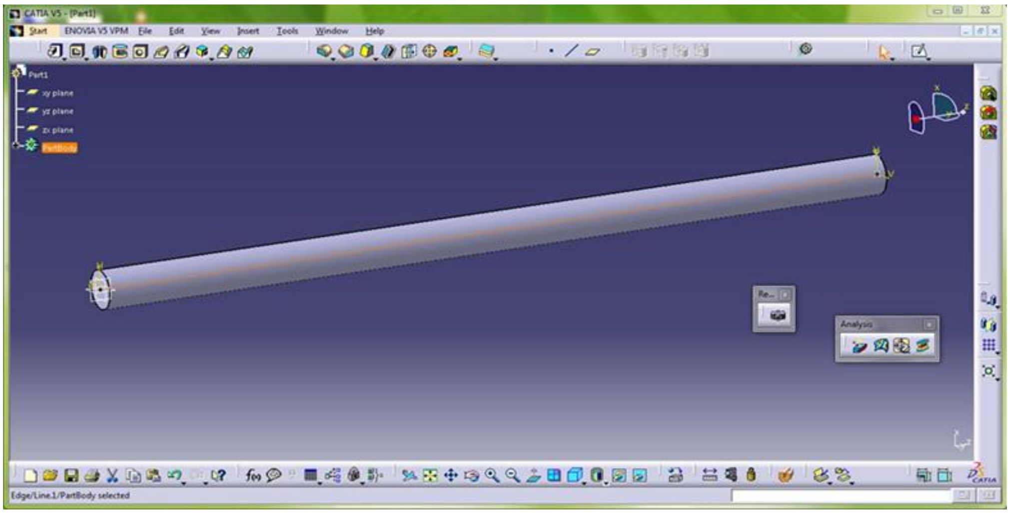

Figure 2d: Modelling Shaft

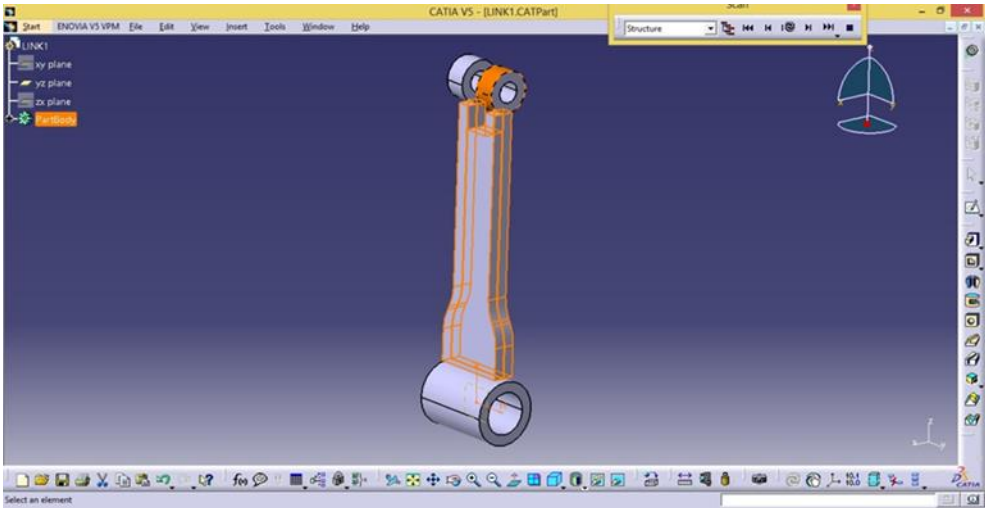

Figure 2d: Arm of Link

Assembly of CRR Manipulator

The mechanism is constructed by using bottom-up assembly method. This consists of creating individual parts and then calling them into the assembly workbench. Firstly, go to start icon and subtree options to Mechanical design and go to Assembly design. Next operate the insert icon and then click Existing component and then select the base part from the files, the base part will be inserted into the assembly design. This will be the first part. Repeat this process until to get all the other components into this workbench. Then again go to Start icon and click on DMU (digital mockup unit) for getting kinematics to create joints. Finally Insert the New joints and fix them for getting new mechanism for simulation. Insert the New joint as Revolute for this specify the two center lines and the two mating planes to create the joints between the base cylinder and the lead screw. The second joint is between the lead screw and the first link for implementing it click on Insert and on new joint select cylindrical joint, select the two center lines and give a pitch value of 1. Now Create a third joint between the link1 and link2 by inserting a revolute joint, select the two center lines and the two mating faces to form a revolute joint. Similarly create a revolute joint between the link and the tool holder and repeat this process for other two arms. The final assembly of the mechanisms for both isotropic non isotropic configuration are as shown in Fig.3 and Fig.4 respectively.

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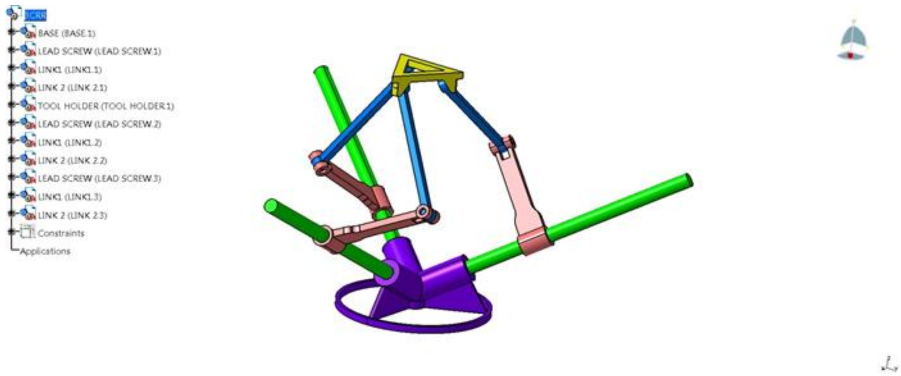

Figure 3: Assembly of the non-isotropic CRR Mechanism

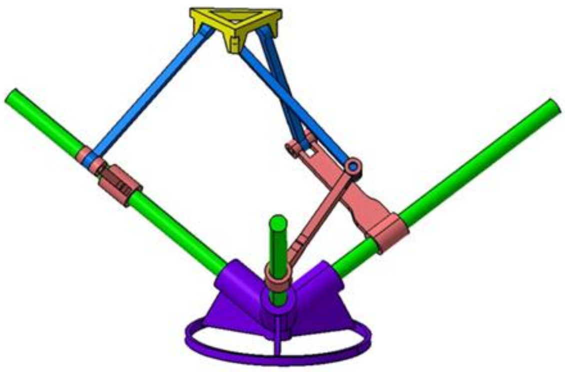

Figure 4: Assembly of the isotropic CRR Mechanism

Results and Discussion

The obtained results are discussed in two sections, section 4.1 briefs the workspace comparison of isotropic and non-isotropic configurations, section 4.2 describes the kinematic simulation motion patterns for line and circular tool path trajectories.

Workspace Analysis

The workspace of the manipulator is found practically by intersecting the surface areas developed by revolving a line which has a radius of sum of the two links in the legs about the axis of the cylindrical joint. Once all the three swept areas are found, their intersection area is found out. The workspace volume obtained is shown in the Fig.5.

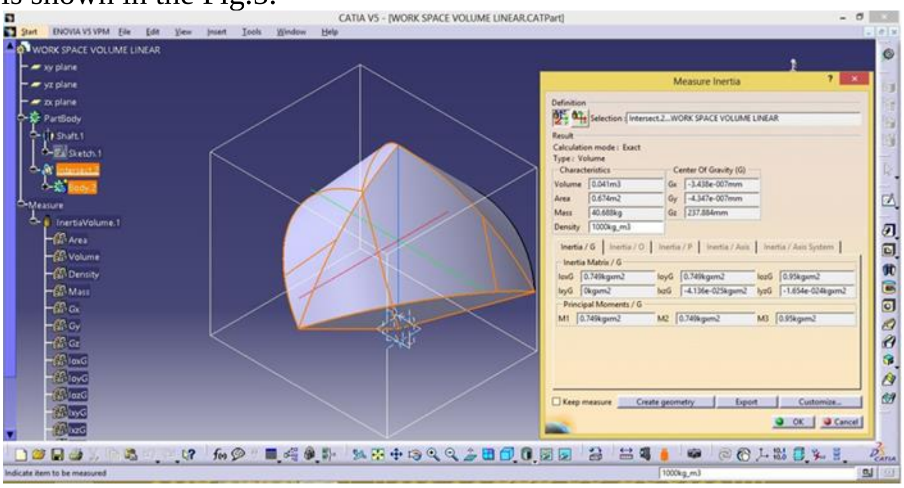

Figure 5: Assembly of the isotropic CRR Mechanism

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The workspace reachable workspace volume is approximately in the Shape of a triangular Pyramid but in actuation limits a regular workspace that is a cylindrical shape is obtained. The workspace volume of a non-isotropic model is found out to be 0.041 meter cube for the given geometric parameters and joint limits of the mechanism. The isotropic model is generated by initially considering the inclination angle to be 144.736^{0} and the radius of 350mm i.e, total lengths of the link 1 and link 2 of lengths 150mm and 200mm respectively. The workspace volume of an isotropic model is shown in Fig.6 and found out to be 0.025 meter cube in size. The total work space volume of an isotropic model is found out to be more than the workspace volume of a non-isotropic model.

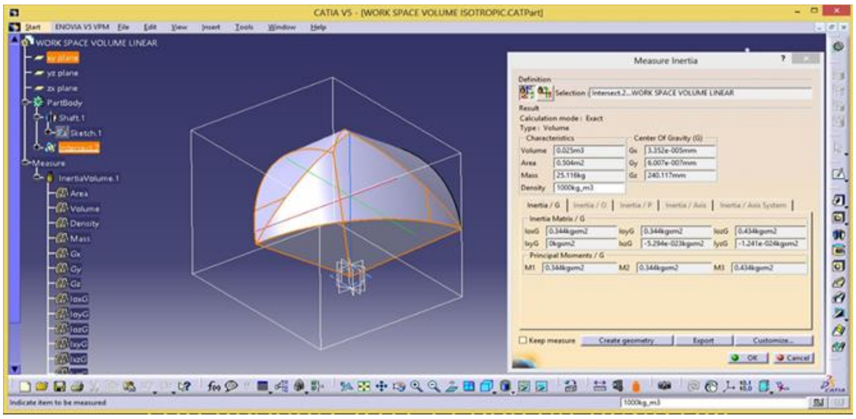

Figure 6: Workspace volume of a isotropic configuration

The cross-sectional workspace at various tool point heights is plotted using the MATLAB programming software by solving the inverse kinematic equations by considering the geometric constraints is shown in Fig.7. Some sectional workspaces are circular in shape and some are elliptical shape. Some irregular shaped geometrical workspaces are obtained at higher heights due to the occurrence of boundary singularities.

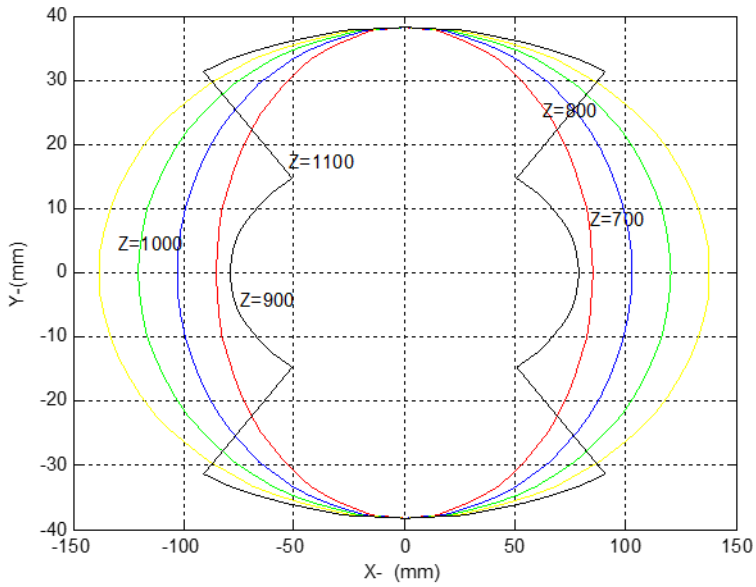

Figure 7: Workspace of a isotropic configuration at various Z positions

Simulation of Mechanism

The tool path simulation on straight line and circular path trajectories is carried out to predict the actuator joint displacements of the mechanism for both isotropic and non-isotropic configurations.

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A. Simulation of Mechanism for non-isotropic configuration: In a CRR configuration manipulator the displacement of a cylindrical joint such as centre of circle at z=0.5, x=0, y=0 meters in circular motion with a radius of 100mm are shown in Fig.8.

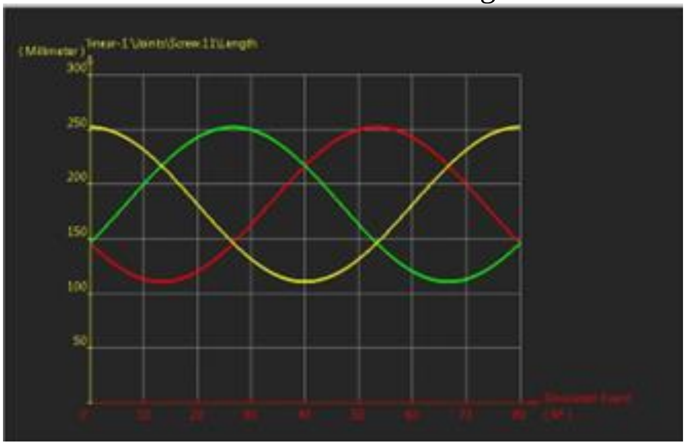

Figure 8: Actuator displacements for circular path in non-isotropic configuration

The velocity variations of three joints are shown Fig.9, Fig.10, Fig.11, the velocities for three joints are different from one another is observed a change in magnitude and velocity patterns.

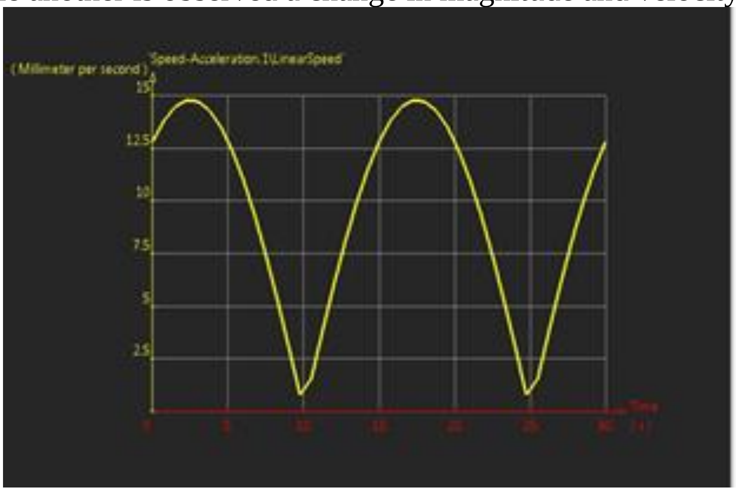

Figure 9: Velocity variation for actuator 1 in non-isotropic configuration

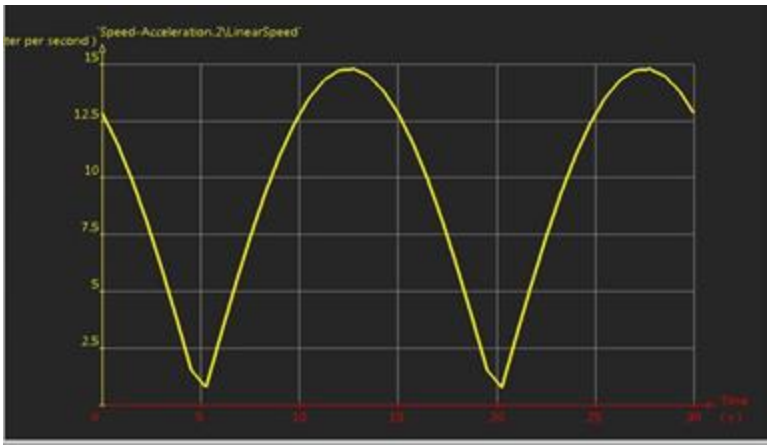

Figure 10: Velocity variation for actuator 2 in non-isotropic configuration

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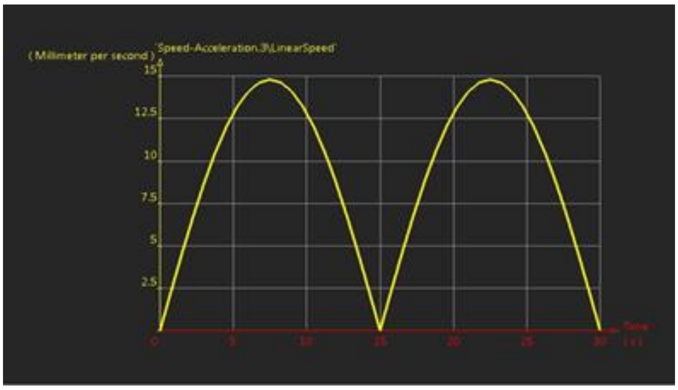

Figure 11: Velocity variation for actuator 3 in non-isotropic configuration

B. Simulation of Mechanism for isotropic configuration: th**e** isotropic mechanism is also simulated to the same circular geometric path as in non-isotropic configuration, the joint displacements for these configurations obtained is shown in Fig.12. A similar joint velocity is obtained for all three actuators which similar in shape and size as shown in Fig.13. The velocity path is started from zero and reaches a maximum and falls back to zero velocity which is for its half path travel; for the next half path the same velocity pattern is obtained. Whereas for the displacement of the actuator joints, the second and third joints are started their displacements at the same magnitudes and ends at the same displacement value. The displacement is in rising pattern and the actuator displacement 3 is in falling pattern, it means one is the mirror image of the other, the nature of joint pattern is same. The joint displacement for actuator 1 is symmetric from its mid-point on either side of the actuator.

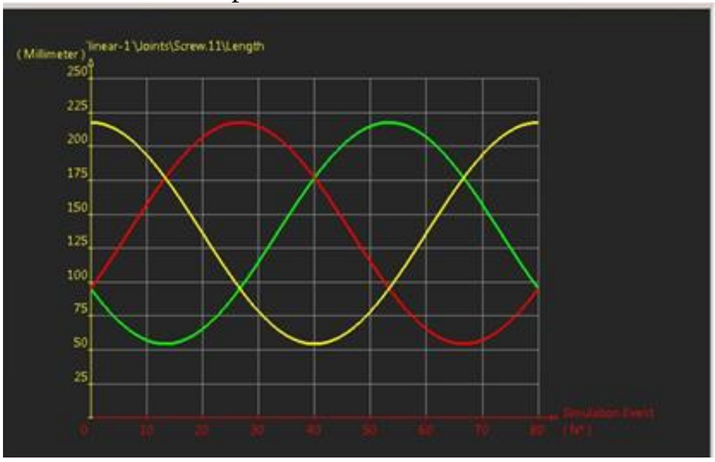

Figure 12: Displacement diagram for isotropic configuration

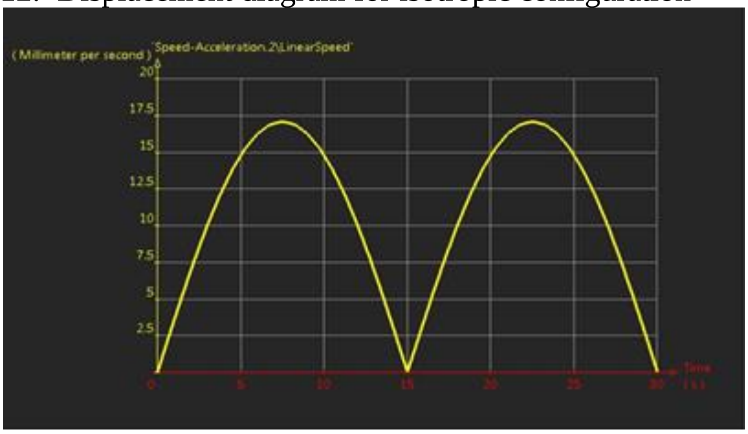

Figure 13: Velocity diagram for isotropic configuration

Conclusion

The modeling and design have been done in CATIA by considering geometric constraints, the design and modeling analysis of isotropic and non-isotropic 3CRR TPM has also been derived. From the obtained results conclude that displacement is less and work space volume is more in non-isotropic 3CRR TPM when compared to isotropic model. From DMU Kinematics, can conclude that non isotropic configuration is suggested for larger workspace volumes. The controllability of isotropic 3CRR can be easily achieved than non-isotropic configuration model. The obtained results are useful for developing a prototype and for real time control applications.

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