Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 11, No. 1, November : 2023

KINEMATIC SIMULATION AND STIFFNESS ANALYSIS OF 3PRC TRANALATIONAL PARALLEL MANIPULATOR

Dr. S. Ramana babu, Associate Professor Department of Mechanical Engineering, Gonna Institute of Information Technology and Sciences (Affiliated to Jawaharlal Nehru Technological University Gurajada Vizianagaram JNTUGV) Visakhapatnam, Andhra Pradesh, India -530053
Mr. Y. Suresh[1], Mrs. P. Ramanamma[1], Mr. K, V. Ganesh[1], Mrs. M, Nookeswari[1]
[1]Assistant Professor Department of Mechanical Engineering, Gonna Institute of Information Technology and Sciences (Affiliated to Jawaharlal Nehru Technological University Gurajada Vizianagaram JNTUGV) Visakhapatnam, Andhra Pradesh, India -530053

Abstract
A three degrees of freedom translational parallel manipulator (TPM) with Prismatic(P), Revolute(R) and Cylindrical (C) joints in each of the three legs is termed as 3-PRC TPM. The mechanism is modelled using CATIA V4 software, and kinematic analysis is performed. The stiffness analysis of the manipulator is being processed at different loads in ANSYS Software environment. The influences of design parameters on stiffness the of the manipulator is presented, which are helpful for the architecture design of TPM for better positioning accuracy and thereby developing the prototype of the manipulator.

Keywords:
simulation, constraint manipulator, stiffness analysis.

I. Introduction

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. Among the applications of parallel robots, the one that may have the largest economic impact is in machine tools. The first milling machine was presented by the Giddings and Levis Company (now part of Thyssen Krupp) at the IMTS machine tool exhibition in Chicago 1994; it was main attraction under the name Variax. It was designed based on the of the Gough platform. According to the manufacturer, despite the machine contains 6 degrees of freedom, it was 5 times stiffer than a classical machine and has superior advance speed. A new type of manipulator with 3-PRC topology actuated by fixed actuators is proposed to achieve three pure translational DOF. The fixed actuators make it possible that the moving components of the manipulator do not bear any loads of the actuators. This enables large powerful actuators to drive relatively small structures in order to facilitate the design of manipulators with faster, stiffer, and stronger characteristics. Additionally, being an over constrained mechanism, the 3-PRC TPM [1] is constructed using fewer links and joints than it is expected, and possesses a much simpler structure than most of the existed TPMs, that leads to an extensive reduction in cost and complexity of the device. a stiffness analysis of the robot is described. For this purpose, an CAD based methodology for stiffness matrix calculation of fully parallel manipulators is proposed. This methodology can make use of FEM or experimental results, and it is able to include the details of a specific design. The procedure developed can also be used to determine the influence of each component of the kinematic chain in the overall stiffness and detect which of them has the worst performance. The motion patterns of 3PRC manipulator is investigated using Catia DMU kinematic simulation. The stiffness analysis of this over-constrained manipulator is investigated in Ansys software environment for good approximation of results.

II. Literature

Kim et al [2] proposed the inverse kinematics, forward kinematics and workspace determination of a 3-DOF parallel manipulator with a SPR joint structure. An effective approach was developed for the solution of the inverse kinematics task in analytical form, for the given end effector positions. A method for workspace determination, which uses the numerical solution of forward kinematics task, is presented. Brogardh et al [3] proposed a 3-DOF Parallel Kinematic Machine of a large motion range in the Z axis for machine tool application. The direct and inverse kinematics problems were solved in order to implement the real time control of the machine tool. The kinematics results were validated numerically. The singularity analysis was carried out by the reciprocal screw theory. From their work, the authors concluded that the solution of direct kinematics will be affected when the structure is in a singular position, and a reasonable arrangement of geometric dimension is important to avoid singularity. Yangmin Li and Qingsong Xu [4] proposed the stiffness and static analysis of 3-PRC (Prismatic – Revolute – Cylindrical) translational parallel manipulator with fixed actuators. The manipulator mobility was analyzed with the screw theory. The closed form solutions for both forward and inverse kinematics problems had been derived and the velocity analysis was performed. Based on an isotropic configuration, three kinds of singularities had been identified. The reachable workspace was calculated, based on the actuator's lay out angles and different mobile platform sizes. The workspace of the manipulator was generated by the numerical approach. Finally, the obtained results were compared with the simulation results. The simulation results indicate that the different objectives should be taken in to consideration, and the actuator layout angle of the 3-PRC translational parallel manipulator was designed. Comin et al [5] presented an article to solve the forward kinematic problem of the 3-PRS parallel manipulator, using the homotopy continuation method. With the case study, they described the drawbacks of the traditional numerical techniques, and the advantages of the homotopy continuation method. 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],[12].

2.1 Architecture Description

The computer aided design (CAD) model and schematic diagram of a 3-PRC 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 P joint, a R joint, and a C joint in sequence, where the P joint is driven by a linear actuator assembled on the fixed base. Thus, the mobile platform is attached to the base by three identical PRC 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 R joint axis (r i) and C joint axis (c i) within the itch limb, for i =1, 2, and 3. The design specifications for the modelling and stiffness analysis are given in Table.1.

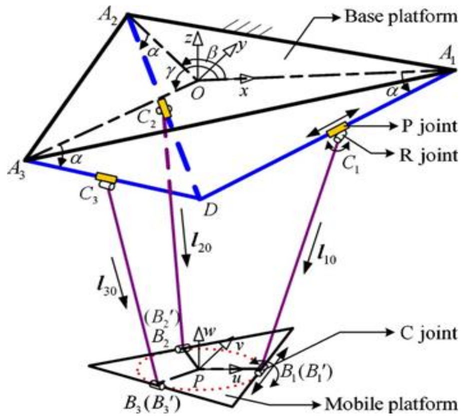

Fig 1: Architecture of 3PRC manipulator

Table.1 Design Parameters

Parameter	Value(m)	Parameter	Value(deg)
a	0.6	A	45
b	0.3	β	120
l	0.7	ϒ	240
d_{max}	0.4		
s_{max}	0.2		

2.2 Modelling and Assembly of Manipulator

The computer Aided Design (CAD) model is developed in Catia V5 software for 3PRC layout configurations. The individual components of the manipulator like fixed base, moving platform, lead screws, hollow cylinders, link arms are modelled for the geometric parameters given in Table.1. Select the product and click on existing component with positioning (calling of a component) in the assembly workbench as a top part. Fix this top part with the help of a fix constraint option. Click existing component with positioning and select shaft and import, using the constraint options assemble the shaft in the top part. Recall same shaft again and assemble it for remaining two arms. Click existing component with positioning and select coupling and import, using the constraints options, position the coupling in the shaft. Recall same coupling again and assemble it for remaining two arms. Click existing component with positioning and select links and import, using the constraint options, position the links in the coupling sides. Recall same links again and assemble it for remaining two arms. Import the mobile plate and using constraint option, assemble the mobile platform with the link.

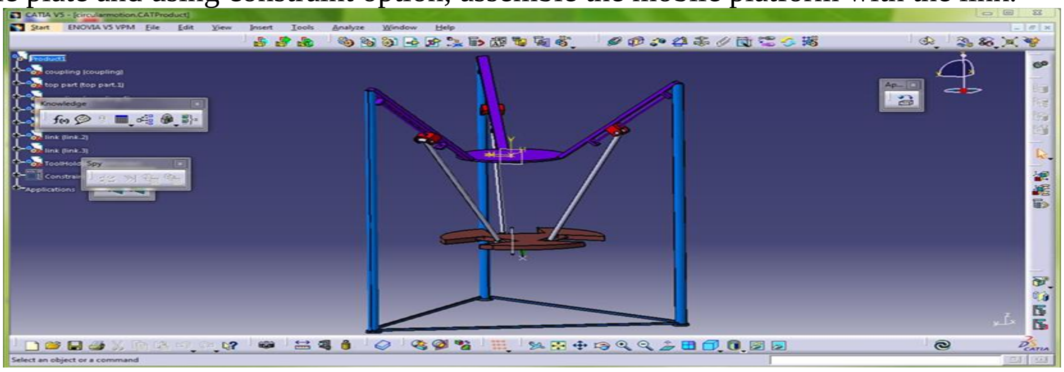

Fig 2: CAD Model of 3PRC manipulator

2.3 Kinematic simulation

In a PRC manipulator the displacement is shown in Fig.3, the prismatic joint 2 has the maximum displacements of 45 mm from its mean position. The joint 1 and joint 3 has minimum linear displacements for the simulation of circular path.

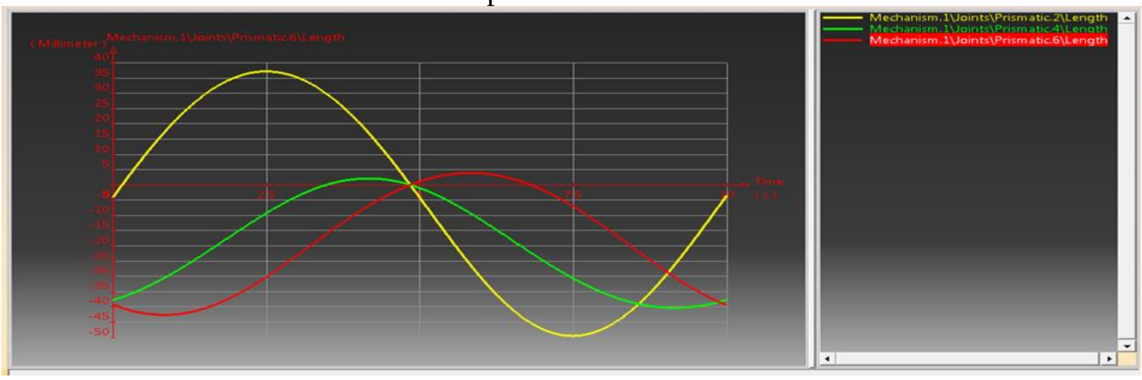

Fig 3: Displacement of the prismatic joints

2.4 Stiffness Analysis

First the Catia file is converted into the .stp file, then open the ANSYS work bench, import catia file into the ANSYS work bench. Then drag the Catia .stp file in a static structural and import new file as same name, and double click on model then mechanical work bench will be opened. It consists of Engineering Data, Geometry, Model, Setup, Solution, Result analysis. First the engineering data is opened and the properties of the components are defined here. Generally structural steel is the basic configuration and can be changed depending on the requirements. Here structural steel is taken as the material property because of its density and yield strength is high. The failure of joints is occurred at the cylindrical joint, more prone for registering maximum deformation.

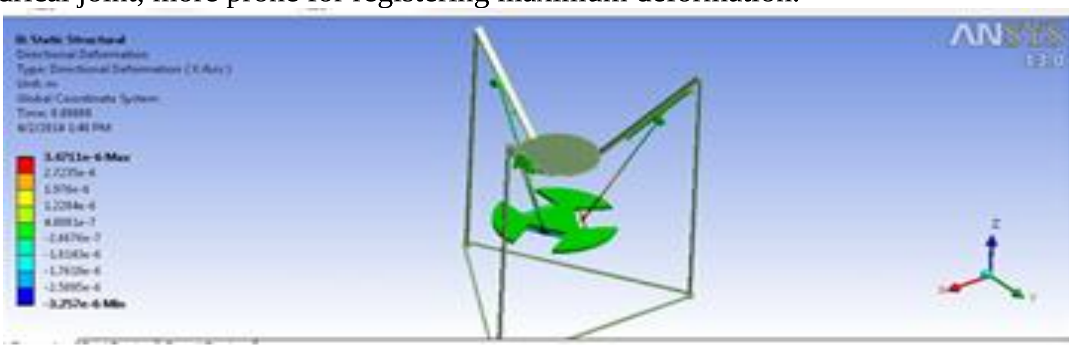

Fig 4: Static analysis in Ansys

The end-effector deformation for various configurations of the manipulator is given below in Table.2

Table.2 Deformation of the end-effector

Length from Base Plate (mts)	Co-ordinates Location (mts)			Minimum Deformation displacement (mts)		
	Px	Py	Pz	X min	Y min	Z min
0.200	0	0	0.4032	$-3.4711e^{-6}$	$-3.3660e^{-6}$	$-3.4722e^{-5}$
0.175	0	0	0.4302	$-3.2295e^{-6}$	$-3.0194e^{-6}$	$-3.4024e^{-5}$
0.150	0	0	0.4566	$-3.0220e^{-6}$	$-2.7074e^{-6}$	$-3.3358e^{-5}$
0.125	0	0	0.4825	$-2.7923e^{-6}$	$-2.4617e^{-6}$	$-3.2704e^{-5}$
0.100	0	0	0.5077	$-2.6050e^{-6}$	$-2.2478e^{-6}$	$-3.2094e^{-5}$
0.050	0	0	0.5325	$-2.4225e^{-6}$	$-2.0465\ e^{-6}$	$-3.1529e^{-5}$
0.025	0	0	0.5566	$-2.2407e^{-6}$	$-1.8265e^{-6}$	$-3.0998e^{-5}$

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 11, No. 1, November : 2023

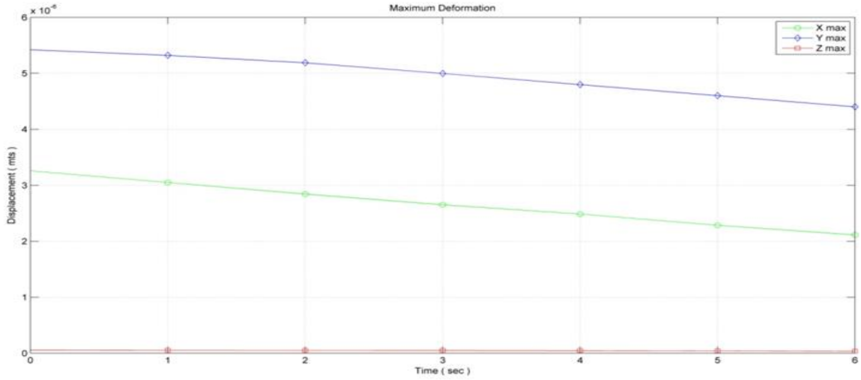

Fig 5 : Component deformations for various configurations

The magnitude of deformation is varying for one configuration to the other configuration due to the presence of singularities and reaction forces developed in the various links of the manipulator. From the Fig.5, can infer that the maximum deformation displacement decreases with increase in time i.e as the coupling in screw is near the fixed plate, the deformation is less because the force is absorbed by the fixed plate. This is same in all the 3 directions of the screw (x, y, and z) axis. The deformation in the Y direction is greater than the remaining two directions. The deformation displacement in the z axis is minimum which the required criterion of the manipulator. The maximum deformation plays an important role when this mechanism is used as machine for machining and positioning process because these values have to be reduced to get accuracy in the operation. For achieving higher positional accuracy the manipulator should be have high stiffness.

III. Conclusion

A novel 3-PRC manipulator with fixed actuators is modelled as per the design parameters. It is observed that such a mechanism can act as a constrained 3-DOF TPM with certain assembling conditions satisfied. The static analysis has been performed in the ANSYS Software and the deformation displacements have been presented. The manipulator is need to be operated with in the dexterous workspace and also operate at lower heights, at elevated heights stiffness is lower. At the singular regions also, lower stiffness is registered. The closed-form solution for the inverse problems has been derived, and the velocity analysis is performed.

References

[1]Yangmin,Li; Qingsong Xu. J. Stiffness analysis of a 3PRC parallel kinematic machine.Mechanism and Machine theory. 2008, 43, 186–200.

[2]Kim,D;Chung,W.K. Kinematic condition analysis of 3DOF pure 3dof translational parallel manipulators. ASME,J.Mech.Design.2003,125,323-331.

[3]Brogardh, T.; Hanssen, S.; Hovland, G. Application-oriented development of parallel kinematic manipulators with large workspace. In 2nd Int. Colloquium, Collaborative Research Centre 562, Braunschweig,10-11 May 2005; pp.153-170.

[4]Yangmin,Li; Qingsong Xu.Stiffness and static analysis of a compact 3PRC parallel manipulator for micro and nano scale applications. IEEE Conference on Robotics and Biomimetics,15-18,December 2007;pp.562-570.

[5]Comin, F. F Six degree-of-freedom scanning supports and manipulators based on parallel robots. Review of Scientific Instruments. 1995, 66,1665–1667.

[6]Shoham, M. Bone-mounted miniature robot for surgical procedures: concept and clinical applications. . IEEE Trans. On Robotics and Automation .2003,19,893-901.

[7]Wendlandt, J.M.; Sastry, S.S. Design and control of a simplified Stewart platform for endoscopy. In 33nd Conf. on Decision and Control, Lake Buena Vista, 14-16 December 1994, pp.357-362.
[8]Zlatanovo, D; Bonev, I.A;Gosselin,C.M. Constraint singularities of parallel mechanisms . Proceedings of the IEEE International Conference on Robotics and Automation, Washington, DC, USA, 11-15 May, 2002, pp.496-503.
[9]Frisoli,A; Checcacci, D ;Salsodo,F;Bergamasco, M. Synthesis by screw algebra of translating in-parallel actuated mechanisms . Advances in Robot Kinematics.2009,10, 433-440.
[10] Kong,X.W;Gosselin, C.M. Kinematic and singularity analysis of a novel type of 3-CRR 3DOF translational parallel manipulator. The International Journal of Robotics Research. 2002,21,791-798.
[11] Badreddin, A; Haeik,D; Bakkali,B. Optimization of Parallel Robot based on CAD approach. Procedia Manufacturing. 2019 , 32, 1085-1092.
[12] Sathia Narayanan,M; Venkat,K; Shah,S.L. CAD enhanced workspace optimization for parallel manipulators:A case study. 6th annual IEEE Conference on Automation Science and Engineering, Toronto, Ontario, Canada, 21-24 August, 2010, pp.816-821.