

Topology Based Rigidity and Modal Analysis of Six Link Single Degree of Freedom Kinematic Chains

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ABSTRACT: Kinematic chains are identified by researchers in the form of manipulators and hence stiffness and rigidity of kinematic chains are also important criteria. Topology of chain can vary their properties and hence in the present work an attempt has been made to compare the properties for different topologies i.e. for watt's and Stephenson chain and their inversions. Six links single degree of freedom Kinematic chains are considered for analysis for Deflection and the modal frequencies as flexible kinematic chains for different angular positions in software Creo (Mechanica).

KEYWORDS: Rigidity, Stiffness, Natural frequency.

I. INTRODUCTION

Significant aim for the design of most manipulators is overall stiffness of the structure. Stiff systems provide benefits as typical manipulators do not have sensors to measure the tool frame location directly; it is calculated by using the forward kinematics based on sensed joint positions. For an accurate calculation, the links cannot sag under gravity or other loads.

STIFFNESS

Parallel manipulators are more rigid in comparison to serial manipulators and provides better accuracy for the end-effectors to perform, similarly kinematic chains with more parallelism will result to more rigidity and can be a decision criteria to be selected. In the present work single degree of freedom kinematic chains and their inversions are analyzed for deflection by doing FEA using creo software. Kinematic chains are assumed to be single entity keeping the topology intact. Parallel link manipulators offer higher strength/weight, stiffness/weight ratios and accuracy than serial manipulators. Additionally, parallel manipulators allow the actuators to be fixed to the base or to be located close to the base of the mechanisms, which minimizes the inertia of the moving parts and which makes it feasible to use more dominant actuators. Planar closed kinematic chains can be considered hybrid manipulators.

II. RELATED WORK

Yang and Sadler [8] and Usoro [2] presented finite element models to reveal the deflection of a planar multi-link model. The effect of Rayleigh damping was incorporated in Yang and Sadler [8], whereas the model in Usoro [2] was developed as a complete nonlinear system in the generalized inertia matrix. The finite element models developed by Geradin et al. [1], Geradin and Cardona [6], and Naganathan and Soni [4–5] add in a fully three-dimensional element to simulate manipulator motions with possessions of gravity and strain energies from torsional, axial and lateral deformation. Beres and Sasiadek [10], and Beres et al. [10], used a Lagrangian finite element approach to create the dynamic model of a flexible manipulator system in three-dimensional space. Beam type finite elements with third order interpolating polynomials and six generalized coordinates per finite element nodal point were used for the explanation of the link small displacement field

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

NATURAL FREQUENCY

Natural frequencies of a structure are also noteworthy measure of its rigidity. Natural frequencies of a robot manipulator differ when the position of the robot varies. Vibrations which occur after starting and finishing the motion especially with high end point velocities influence the work of the robot. The acceleration and deceleration profiles can be regulated by the robot controller considering the natural frequencies according to position of the robot in the workspace to diminish the vibration levels. This subject becomes more significant for the Light Weight Robots (LWR).

Conventional industrial robots are made to be massive in order to enhance stiffness and therefore move at speeds much lower than the fundamental natural frequency of the system due to the limitations in the drive motor output torque. The realistic answer to this difficulty is to design and construct light weight manipulators, which are proficient of moving swiftly. Contrary to the rigid manipulators, lightweight manipulators tender advantages such as higher speed, better energy efficiency, improved mobility and higher payload-to-arm weight ratio. On the other hand, at high operational speeds, inertial forces of moving components become quite large, causes considerable deformation in the light links, generating redundant vibration phenomena. Such manipulators are called flexible manipulators [15].

RELATED WORK

Tokhi et al. [17-19] presented dynamic models for a single-link flexible manipulator using the finite element approach and compared the modal frequencies found experimentally to authenticate the FE modelling in some cases. They used bang-bang type of torque to study the dynamic response. Also they have applied a command shaping technique to control the vibration of single-link manipulator. Ahmad [9], Krishnamurthy and Yang [11], Matsuno and Hatayama [12], Yamano et al. [14, 16], Sun [20], and Zhang [21] described dynamic modelling and simulation of two cooperating structurally flexible robotic manipulators.

Stiffness and accuracy of a robotic architecture are robustly associated to each other since positioning and orientating errors are due to compliant displacements, and construction and assembling errors. The actual stiffness of a link or a member of a chain depends upon its dimensions, elasticity and support(s). Naturally, if all the links of a chain are stiffer, the chain can be estimated to have greater stiffness and this consecutively gives insight into the load-carrying capacities and natural frequencies. Larger structural stiffness will produce lighter chains or links. The knowledge of frequencies will assist in deciding the running speeds.

III. METHODOLOGY

MODELLING OF KINEMATIC CHAIN IN SOFTWARE

CAD software Creo is used to model different kinematic chains. All parameters, material and load condition are taken similar for all the chains and their inversions. At a particular instant it is assumed that each link is connected to other link and load is directly transferred. In six link single degree of freedom kinematic chains with the same link assortment, two distinct kinematic chains are available namely Watt's and Stephenson's chains Fig.(1)and (2) with 10 design (dimensions) parameters and seven joints. To obviate the influence of structure alone, all the links of the inversions of chains under comparisons are taken of same dimensions. Links are created in part mode and assembled as single entity, Watt's and Stephenson's kinematic chains are analysed in mechanism design extension mode of the Creo software.

In static frequency analysis, Kinematic chains are modeled. Software Creo (Mechanica) is used and load value is taken as 100 N in the downward direction. Material is assigned to the whole parts and stress distribution on the parts of the kinematic chain is investigated for different configurations. The static deflection is obtained as given in table (1) from the static analysis. Maximum deflection and minimum natural frequency of the models were analyzed for the different angular positions. As shown in table (1) the lowest natural frequency of the model, fig (3) is 64.96782 and maximum deflection is 5.46796.

It is a tough task to get high accuracy end-effector motion for flexible manipulators due to unnecessary structural vibrations. That is why, elastic vibrations of light weight links must be taken in to account the design and control of the manipulators with link flexibility.

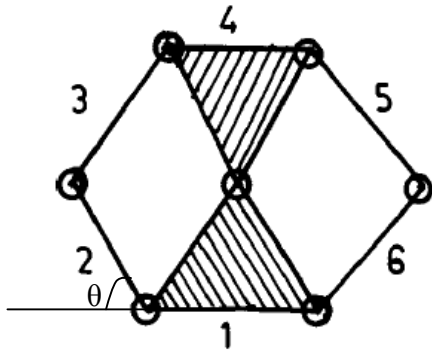


Figure (1)-Watts chain

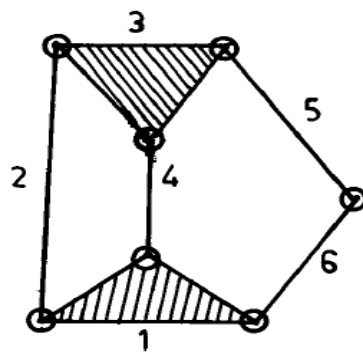


Figure (2)-Stephenson's chain

IV. SIMULATION RESULTS

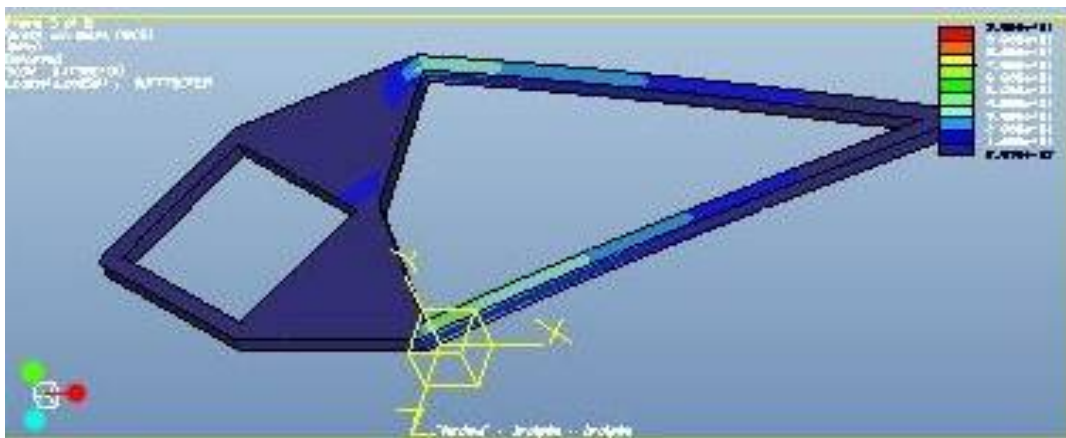


Figure (3) Watt's inversion 1 with 30 deg inclination of binary ($\theta=30$)

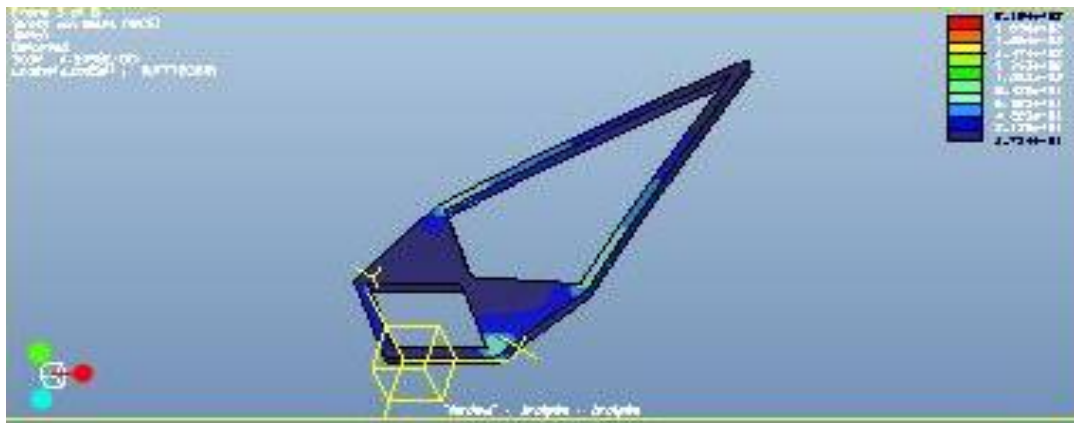


Figure (4) Watt's inversion 2 with 30 deg inclination of binary ($\theta=30$)

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

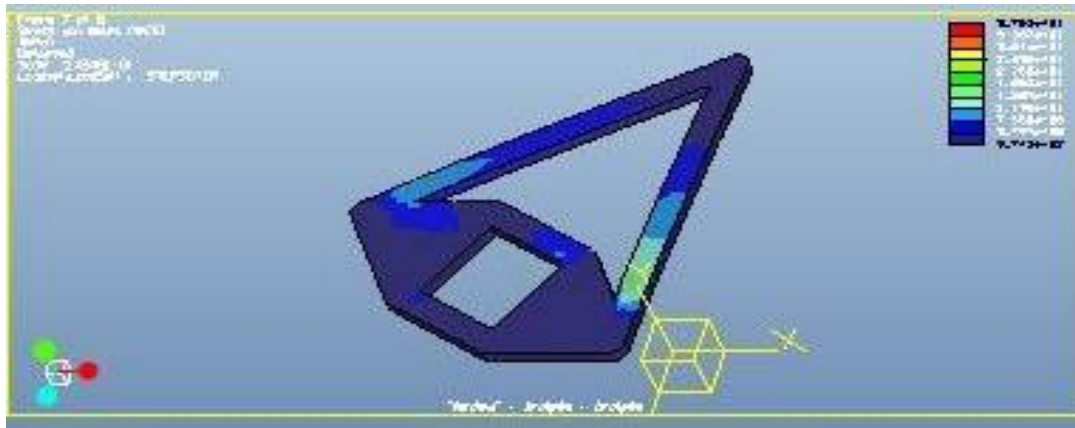


Figure (5) Stephenson's chain inversion 1 with 30 deg inclination of binary ($\theta=30$)

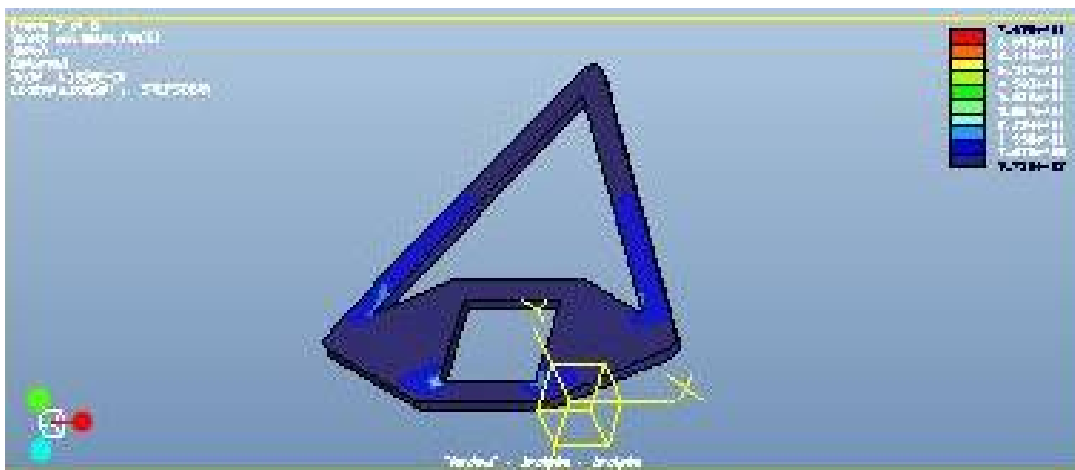


Figure (6) Stephenson's chain inversion 2 with 30 deg inclination of Ternary ($\theta=30$)

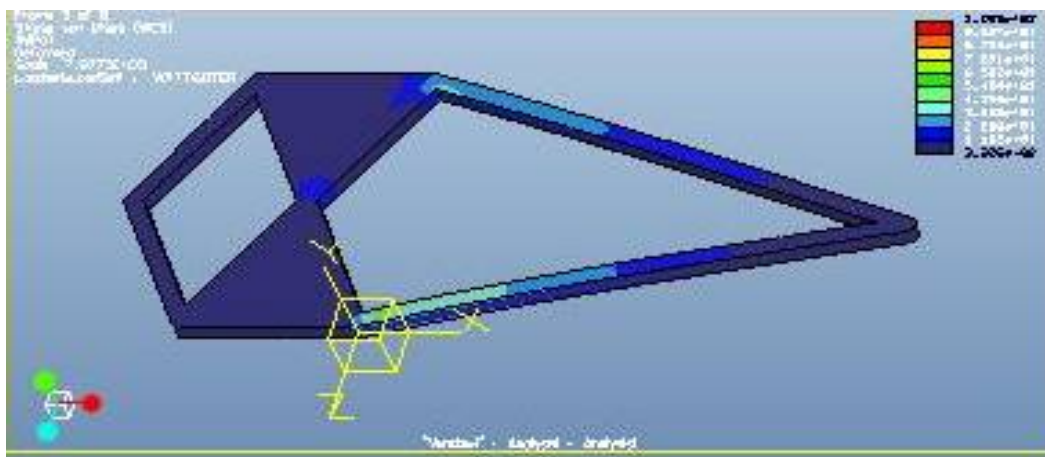


Figure (7) Watt's chain inversion 1 with 60 deg inclination of binary ($\theta=60$)

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 5, Issue 8, August 2016



Figure (8) Watt's chain inversion 2 with 60 deg inclination of binary ($\theta=60$)



Figure (9) Stephenson chain inversion 2 with 60 deg inclination of binary ($\theta=60$)

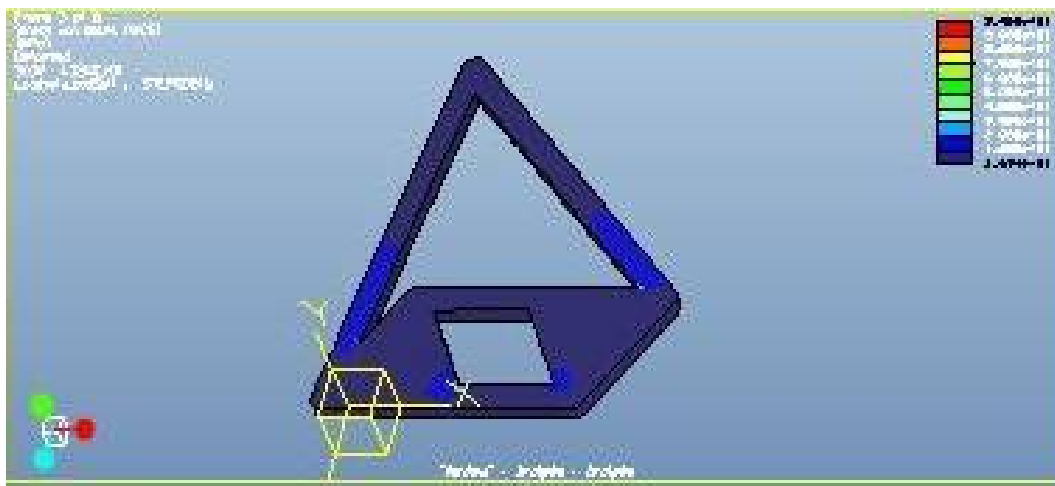


Figure (10) Stephenson's chain inversion 2 with 60 deg inclination of ternary ($\theta=60$)

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

V. RESULTS

KINEMATIC CHAIN	POSITION	STATIC MAXIMUM DEFLECTION	NATURAL FREQUENCY
WATT'S CHAIN	Binary fixed 30 deg inclined	8.343590	48.03762
	Ternary fixed 30 deg inclined	5.467968	64.96782
	Binary fixed 60 deg inclined	8.406940	47.89487
	Ternary fixed 60 deg inclined	5.619706	63.70918
STEPHENSON'S CHAIN	Binary fixed 30 deg inclined	2.527367	66.58412
	Ternary fixed 30 deg inclined	1.507757	82.50747
	Binary fixed 60 deg inclined	2.410915	67.90713
	Ternary fixed 60 deg inclined	4.879123	69.89678

Table (1):- Comparison of Maximum Deflection and Natural Frequency

VI. CONCLUSION

Based on simulated results it is observed that maximum deflection of Stephenson chain is less resulting high natural frequency in comparison to watt's chain for different configuration. Thus it can be concluded that Stephenson chain is more rigid due to its more parallelism. The results are validated from earlier reported work of Rao and Jagdish[15].

ACKNOWLEDGMENT

We are thankful to SSITM Bhilai and NIT Raipur for providing necessary facilities to carry out this research work

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