Dynamic Analysis and Optimum Design of a Reconfigurable Planar Gough-Stewart Machining Platform

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EXTENDED ABSTRACT

1 Introduction

The Gough-Stewart platform has played a pivotal role in expanding the motion capabilities of conventional cascaded mechanical systems. Moreover, since its development in the early 1950's, hexapod applications have ranged from tyre testing utilities and flight mechanics simulators to satellite components and Computer Numerical Control (CNC) actuation.

These versatile applications substantiated the need for investigating the dynamics associated with this mechanism. Moreover, being able to develop a sophisticated computational model of this system will not only allow the user to investigate the fundamental dynamic principles in a cost-effective manner but can also advance the mechanism to ascertain optimum design characteristics for feasible operation, maximum life, and minimum cyclic fatigue during operation.

2 Problem Statement

The research study is more specifically focused on an inverse dynamic analysis of the Gough-Stewart platform; hence, the loading of the system is investigated based on the prescribed motion of the mechanism – i.e. a straight line prescribed path with no rotational motion of the mobile platform. Furthermore, since the planar motion of the 2D hexapod will be governed by three actuator legs, the forces associated with these members are of primary concern, as excessive loading could lead to premature failure.

To ensure feasible operation and to combat excessive wear, the mechanism dynamics are thus not only investigated, but also optimized and ensures actuator loading is kept to a minimum during operation.

3 Analysis Procedure

The current investigation thus regards itself with combining powerful computational tools to simulate the motion of a seven-body planar Gough-Stewart machining platform. The existing Dynamic Analysis Program (DAP) developed by Prof Parviz Nikravesh [1] forms the foundation for numerical application due to its general-purpose approach to multibody mechanical systems. Moreover, a body coordinate (BC) formulation is utilized extensively as it provides the necessary versatility to extend the existing functions for optimization incorporation.

Considering the optimum design characteristics, focus is placed on minimizing the actuator forces by adjusting the geometry and position of the components – such as the distance between the actuator legs, location of the joints and length of the mobile platform. Numerically, this can be achieved by combining a sophisticated optimization algorithm with the existing DAP_BC workbench. Additionally, to realistically capture the limitations of a physical system – such as mechanical interference that may arise when over-adjusting a variable – limitations are also imposed on these optimization parameters, meaning that a constrained optimum design is performed.

The Dynamic-Q optimizer proposed by Snyman and Hay [2, 3] proves most desirable for this application due to its extensive use for complex engineering problems and refined computational cost. Furthermore, it makes use of the Leap-Frog OPtimizer with Constraints (LFOPC) algorithm as a subroutine and is thus a testament to the integration of previous modelling approaches.

4 Results and Discussion

To parameterize the planar hexapod for optimum design investigations, the seven-body test model shown in Figure 1 is proposed and consists of five geometric design variables (denoted as X_1 to X_5). Since this model was based on a real-world physical asset, a large number of geometric constraints are imposed, adding to the model complexity.

Thus, a simplified hypothetical mechanism can first be developed – for which the results are given below – and then extended in future research, to incorporate the physical test model's constraints and geometric (and dynamic) conditions.

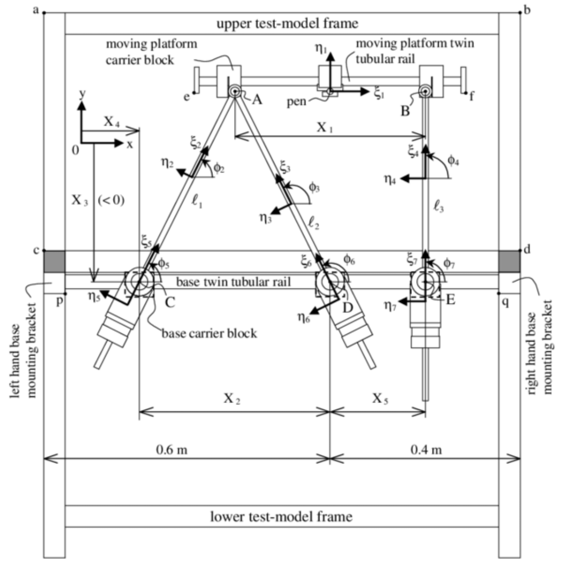

Figure 1: Schematic representation of the planar test-model hexapod with five design variables, as proposed by Du Plessis and Hay [5]

An initial design for the hypothetical model was first introduced as a starting point for the optimization, with design variables:

$$\boldsymbol{X^0} = \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \end{bmatrix} = \begin{bmatrix} 0.4 \\ 0.4 \\ -0.4 \\ -0.4 \\ 0.2 \end{bmatrix} m \tag{1}$$

This design yielded a maximum actuator force of 122.3 N.

After applying the Dynamic-Q optimization algorithm, it was noted that a converged minimum actuator force of 76.2 N was obtained, thereby reducing the load by 38 %. The algorithm was also considered extremely efficient since it was able to obtain an optimized solution after only 14 iterations and a computational runtime of 6 minutes. The resulting design variables were noted as:

$$\boldsymbol{X}^* = \begin{bmatrix} 0.4498 \\ 0.3415 \\ -0.1492 \\ -0.3801 \\ 0.1397 \end{bmatrix} m \tag{2}$$

5 Conclusion

The dynamic analysis of the Gough-Stewart platform therefore not only attempts to capture the variable motion of the mechanism but also concerns itself with finding the best possible solution to execute the motion, thereby ensuring optimal reconfigurability, minimized damage and maximum component lifespan.

References

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