ME – PhD Thesis Colloquium

Dynamically isotropic Gough-Stewart platform for micro-vibration isolation in spacecraft

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ABSTRACT

Rotating components such as reaction wheels (RW) and momentum wheels (MW) on spacecraft generate micro-vibrations up to 250 Hz during on-orbit operations. While the use of Gough-Stewart Platforms (GSPs) for six degrees of freedom (DOF) vibration isolation has been proposed, conventional GSPs lack dynamic isotropy, hindering effective vibration attenuation. A dynamically isotropic mechanism, characterized by uniform first six natural frequencies is essential for effective vibration isolation, as it enables the attenuation of the first six modes of vibration effectively from a sensitive payload. Consequently, a dynamically isotropic Modified Gough-Stewart Platform (MGSP) has been investigated in this work to redress this limitation in conventional GSPs.

The design process encompasses the development of a geometry-based approach for deriving the design parameters in their explicit closed form, wherein all design variables for an MGSP exhibit intricate relationships resembling pairs of triangles endowed with specific geometric attributes facilitating straightforward design. The approach accommodates various payload configurations, including variable center of mass and mass/inertia properties. Validation through finite element software ANSYS® ensures similar natural frequencies across six modes, crucial for effective isolation. Practical viability is enhanced by incorporating flexural joints and structural damping in the design. A prototype of the MGSP featuring flexural joints was tested at ISRO test facility for a 10 kg dummy payload, and it yielded experimental outcomes in close agreement with the finite element analysis results -- the first six natural frequencies were close to the expected 29 Hz and vibration isolation of about 22 dB/octave in the region of isolation. The close agreement among analytical, finite element, and experimental outcomes underscores the efficacy of our design approach and the suitability of an MGSP for micro-vibration isolation applications in spacecraft.

Expanding upon the same principles, our investigation encompasses a broad spectrum of MGSPs incorporating more than six legs. In practical scenarios, the preference for a higher leg count (>6) stem from the need to distribute heavy loads across multiple actuators or to enhance fault tolerance capabilities. This can facilitate an economical approach to modifying previously developed dynamically isotropic 6-6 MGSPs into dynamically isotropic configurations with more than six legs with enhanced payload capacity.

Additionally, the simplifications of the micro-vibration isolation problem in MGSP were pursued by considering the first five modes, when the torsional mode can be ignored. The first design is based on a modification to the dynamically isotropic two radii GSP (MGSP), further simplifying our geometry-based approach and proving ideal for passive vibration isolation. The second design utilizes superposed geometrical parameters from two 3-legged manipulators and possesses a unique characteristic: only three legs require activation at any given time for specific motions, resulting in reduced power demands, particularly advantageous for active vibration control applications planned in the near future.

ABOUT THE SPEAKER

Yogesh Pratap Singh earned his bachelor's degree in mechanical engineering from the National Institute of Technology, Raipur, in 2018. He is currently pursuing a Ph.D. at the Indian Institute of Science, Bangalore, in the Robotics and Design Lab under the guidance of Prof. Ashitava Ghosal. He was awarded the prestigious Prime Minister Research Fellowship (PMRF) in July 2018. His research interests encompass dynamics, robotics, vibrations, and control systems