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Abstract #
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Title

Derivation and Verification of a Flexible Hexapod Model for Multi-Body Space Observatories

Authors

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Abstract (500 words)

Recent space telescopes are large complex multi-body and multi-actuator spacecraft, enabling to observe the same target successively with different on-board instruments by using a common and large movable focusing device (named primary mirror). Examples are the current James Webb Space Telescope and the future Advanced Telescope for High-Energy Astrophysics (ATHENA). They both use a hexapod (also named Gough-Stewart platform) as a high-accuracy pointing mechanism to orient their primary mirror in six degrees of freedom. With the movable mass amounting to up to 20% of the total spacecraft mass, multi-body/multi-actuator spacecraft pose new challenges for the attitude control system (ACS). In addition to the moving masses' effect on the global mass properties, their flexible modes could interact with other flexible modes (e.g. of solar arrays) and thus significantly impact the overall spacecraft attitude. To allow the consideration of these flexible modes in ACS design and analysis, this article presents the derivation and verification of an equivalent flexible model for a hexapod mechanism.

For common flexible appendages such as solar arrays or antennas, explicit state-space models are usually derived with direct access to modal parameters. In turn, these models can directly be fed with reliable modal analysis results. Unlike these serial appendages, hexapod mechanisms contain closed-loop kinematic chains and are ruled by differential-algebraic equations, making them highly non-linear. In this paper, we present an approach to derive a representative linear model of such a flexible hexapod. The starting point of our developments is the output of a modal analysis of a single hexapod actuator, obtained from a finite element model. Borrowing recent results from robotics, each actuator is modelled as a linear spring, whose stiffness is obtained from the most significant axial mode. The stiffness is mapped from the modal coordinates into Cartesian coordinates, leading to a 6-by-6 Cartesian stiffness matrix of the actuator. The advantage of such matrix is that it relates the forces and torques acting on the actuator to its translational and angular displacements. Using the hexapod's geometry, these individual matrices can be aggregated to form a Cartesian stiffness matrix of the entire hexapod. This matrix is again of dimension 6-by-6 and relates the forces and torques on the hexapod's platform to its linear and angular deflections. This equivalent linear model is verified using a commercially available non-linear multi-body simulation tool. Both the proposed linear model and a more detailed non-linear model of the hexapod have been implemented and their responses to identical forces and torques are compared. Preliminary results show that the natural frequencies of the linear model differ from the non-linear ones by less than 6%.

The main contribution of this article is thus a direct method to derive an equivalent Cartesian stiffness matrix for the flexible dynamics of a hexapod mechanism. The approach requires no iterative computations, and its result can be readily included in the control design model of a multi-body/multi-actuator spacecraft as it was derived in previous works.

The results presented in this article are part of a PhD project conducted by the University Carlos III of Madrid, Spain, and Airbus Defence and Space GmbH in Friedrichshafen, Germany.