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Parametric damped vibrations of Gough–Stewart platforms for symmetric configurations

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ABSTRACT

Modal behavior of a Gough–Stewart Platform (GSP) is sensitive to several variables related to its inertia, damping and stiffness as well as its complex 3-D geometry. To optimize its dynamical performance, due to the complications of this system, it is crucial to have the equations parametrically at the neutral configuration. However, in the literature, no complete parametric solution to this problem is presented. In this paper, we establish a fully-parametric and closed-form model for the damped vibrations of GSPs. In particular, this analytical model can be used in order to design, optimize and control GSPs in high-precision/bandwidth applications. Parametric expressions of the damped eigenfrequencies and the corresponding eigenvectors as well as the Jacobian, stiffness and damping matrices are developed. Interestingly, despite the complexity of the system, it is shown how well-structured algebraic expressions are obtained using the Cartesian-space approach. Having analytically studied the eigenvectors, the conditions for decoupled vibrations are also analytically formulated. Finally, using a reference GSP, the sensitivity of the damped eigenfrequencies to stiffness and damping variations are investigated accompanied by a cross-check with an ABAQUS® simulation.

1. Introduction

Interestingly, the study of manipulators dates back to ancient times, see [1]. Generally, manipulators are categorized by their kinematic architecture, where parallel kinematic manipulators are those with a closed kinematic chain. *Gough–Stewart Platforms* (GSPs), which are also known as *hexapods* have, among the six Degrees Of Freedom (DOFs) parallel kinematic manipulators, attracted the most attention of researchers and engineers. This has been the case ever since the concept of GSPs was introduced by Gough and Stewart in 1947 and 1965, respectively [2–4]. GSPs have a wide range of applications, e.g. in vibration isolation, machining technology, astronomical telescopes and surgical robots, see [5,6]. From the mid-1990s, when the first parallel machine tools came into practice, there has been an increasing interest in studying stiffness and vibrational properties of GSPs, see [7,8].

The bandwidth and precision of a GSP is mechanically restricted by its eigenfrequencies, while the eigenfrequencies are sensitive to the geometrical variables. By definition there are six independent geometrical variables for a GSP at its initially symmetrical configuration (neutral configuration), see Figs. 1 and 2 in Section 2.1. If a GSP is in a gravity field (in z-direction), the neutral configuration is defined where the structure is in its static equilibrium. Considering this geometrical complexity, and in order to optimize the dynamical performance, it is crucial to have access to a parametric vibrational model of the system. To obtain such a model, firstly parametric kinematic and dynamic equations in terms of design variables are required. See the

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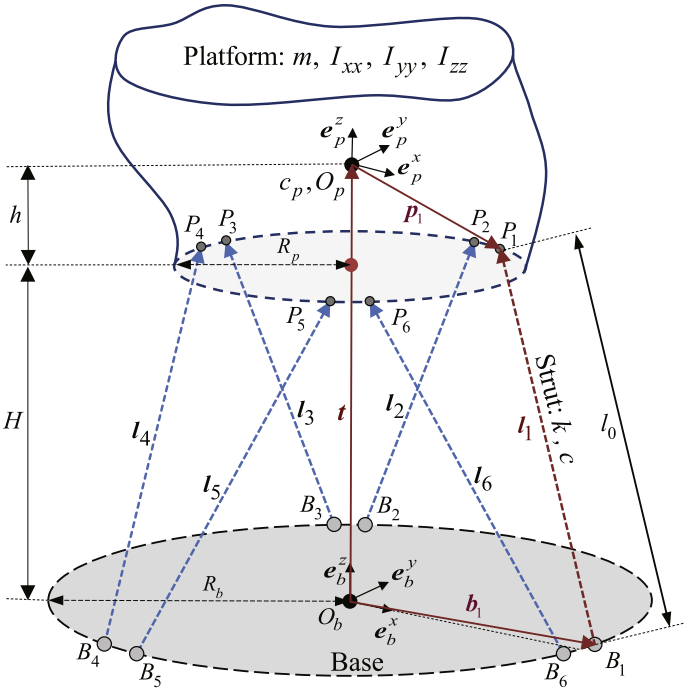

Fig. 1. Schematic drawings of a general GSP.

detailed definition of the design variables in Eqs. (2) and (23). Next, the eigenvalue problem based on inertia, stiffness and damping matrices has to be obtained in terms of the design variables. To obtain more realistic eigenfrequencies of GSPs, it is also essential to consider damping in the system. In particular, the axial damping of the struts should be added into the model. This is

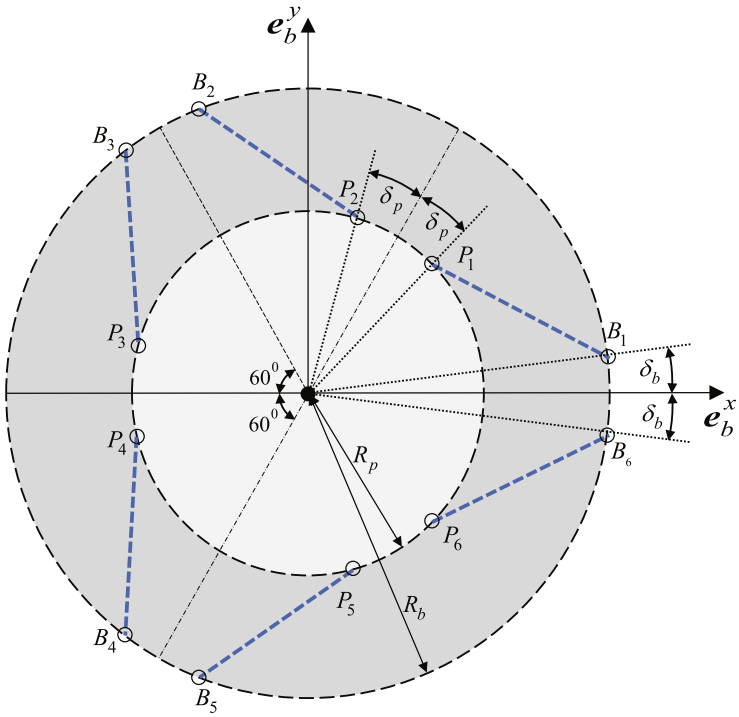

Fig. 2. Top view of a general GSP.