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Stiffness Analysis of Parallel Mechanism with Prismatic–Revolute Joint

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For improving the performance of the mechanical equipment, it is very important to apply effectively the new types of mechanism with the high accuracy positioning and high speed machining to the machine manufacturing industry. Compared to the traditional serial–mechanism, the parallel mechanism is very attractive for innovative machine architectures, thanks to their advantages in terms of high accuracy, low inertia and high structural stiffness. Applications of the parallel mechanism require the development of efficient stiffness analysis techniques, which satisfy the computational speed and accuracy requirements of relevant design procedures. In this paper, Cartesian stiffness matrix is made and stiffness distribution is analyzed in the workspace for the postures and locations of the parallel mechanism with the prismatic–revolute joints, using the virtual joint method. Generally, the stiffness analysis evaluates the effect of the external torques and forces applied on the compliant displacements of the end–effector. This property is defined through the ‘‘stiffness matrix”, which gives the relation between the translational/rotational displacement and the static forces/torques causing this transition. For the computation of the stiffness matrix, several approaches such as the finite element analysis (FEA), the matrix structural analysis (MSA) and the virtual joint method (VJM) are used and these are differed in the modeling and computational techniques respectively.

The FEA method is proved to be the most accurate and reliable, since the links/joints are modeled with its true dimension and shape, which is usually applied at the final design stage for the verification and component dimensioning, because of high computational expenses required for the repeated re–meshing and calculating. The MSA method incorporates the main ideas of the FEA but operates with rather large flexible elements (beams, arcs, cables, etc.). For parallel mechanisms, the relevant stiffness model is a combination of flexible beams and nodes, where each beam is defined by two nodes and described by stiffness matrix derived from the Euler–Bernoulli presentation. Because it involves high–dimensional matrix operations, it is not attractive for the parametric stiffness analysis and analytical modeling. Finally, the VJM method, which is also referred to as the “lumped modeling”, is based on the expansion of the traditional rigid model by adding virtual joints (localized springs), which describe the elastic deformations of the mechanism components (links, joints and actuators). There are a number of variations and simplifications of the VJM method, which differ in modeling assumptions and numerical techniques. Generally, the lumped modeling provides acceptable accuracy in short computational time, so it is widely used at the pre–design stage, especially for the analytical parametric analysis.

However, it is very hypothetic and operates with simplified stiffness models that are composed of one–dimensional springs that do not take into account the coupling between the rotational and translational deflections. This paper presents a new stiffness modeling method, which replaces the link flexibility by localized 6 DOF virtual springs that describe both the linear/rotational deflections and the coupling between them. The distributions of the translational and rotational stiffness are respectively described in the whole workspace for the parallel mechanism with prismatic–revolute joint by decoupling of the Cartesian stiffness matrix.

The stiffness analysis corresponded to the position and poster of the parallel mechanism through the workspace can improve the stiffness performance in the stage of design and operation for the parallel kinematic machine tools. Moreover, the proposed method reduces the computational expenses explicitly to satisfy the accuracy requirements, compared to the FEM. This method can be extended to other parallel architectures; therefore, future work will focus on the stiffness modeling of more complicated parallel mechanisms and also the experimental verification of the stiffness models.