A Methodology for Modeling and Simulating Frictional Translational Joint with a Flexible Slider and Clearance in Multibody Systems

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The problem of modeling and simulating translational joints with clearances in mechanisms has attracted the attention of many authors over the last two decades[1-5]. Farahanchi *et al.* [1] investigated the influence of the clearance gap size, bearing friction, crank speed and impact parameters on the response of the system, and observed three types of responses: chaotic, transient chaos and periodic. Flores *et al.* [2,3] proposed a methodology for a dynamic modeling and analysis of rigid multibody systems with translational clearance joints using the non-smooth dynamics approach. In their study, when the clearance size is very small, some numerical difficulties can arise, which lead to drift problem. To overcome these difficulties, Zhuang *et al.* [4,5] presented a HCLP method for the rigid multibody systems possessing frictional translational joints with tiny clearances, combining with Baumgarte's stabilization method. All these studies mentioned above were based on rigid body models, which cannot consider the influence of the slider deformation. In view of this, Zhang *et al.* [6] analyzed the deformation of the slider and the clearance size using KED technique and penalty method. However, his study showed poor calculation efficiency. What's more, the KED method ignored the coupling between rigid body and flexible body motion [7].

This paper aims to present a simple and effective methodology for modeling and simulating multibody systems possessing a frictional translational joint with a flexible slider and clearance. The translational joint is illustrated in Fig. 1. By using the Finite Element Method (FEM), the slider is divided into a finite number of elements, and the distributed body forces and boundary stresses (contact forces) on the slider are equivalent to the nodal forces. The surfaces of the guide are modeled by appending plenty of virtual spring-dampers in the normal directions, and the spring-dampers work only if the nodes contact with or penetrate the surfaces of the guide. The tangential (fractional) contact forces acting on the nodes are described by Coulomb's dry friction law. The equations of motion of the slider can be expressed as

$$\boldsymbol{M}\ddot{\boldsymbol{u}} + \boldsymbol{C}\dot{\boldsymbol{u}} + \boldsymbol{K}\boldsymbol{u} = \tilde{\boldsymbol{Q}} + \boldsymbol{Q}_n + \boldsymbol{Q}_\tau \tag{1}$$

where $\boldsymbol{M}$, $\boldsymbol{C}$ and $\boldsymbol{K}$ are mass, damping and stiffness matrices, respectively. $\boldsymbol{u}$, $\dot{\boldsymbol{u}}$ and $\ddot{\boldsymbol{u}}$ are the columns of displacements, velocities and accelerations of the nodes, respectively. $\boldsymbol{Q}_n$ and $\boldsymbol{Q}_\tau$ are the columns of equivalent nodal forces of normal and tangential contact forces, respectively, while $\tilde{\boldsymbol{Q}}$ is the column of equivalent nodal forces of other forces. By lumping the mass matrix and presenting it in diagonal form [8], the equations of motion (1) are then inertial decoupled, and the fractional forces on the nodes can be solved independently of each other via trial and error algorithm. The connection between the slider and other components, the revolute joint, is treated as constraints, which can be solved by using the method of Lagrange multipliers. In the end, two numerical examples, a stick-slip oscillator and a slider-crank mechanism, are given, and the simulation results are compared with Refs. [4] and [6] to test the correctness and applicability of the methodology proposed by this paper.

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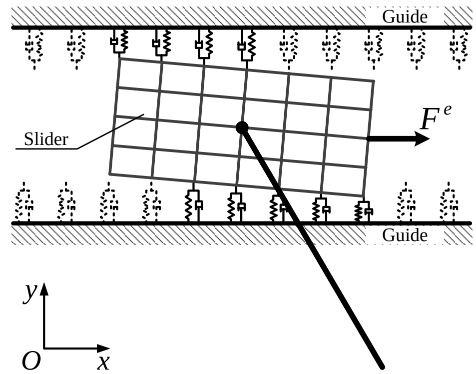

Fig. 1 The frictional translational joint with a flexible slider and clearance

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