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A distributed mechanical joint contact model with slip/slap coupling effects

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ABSTRACT

This paper introduces a zero thickness interface model that considers hysteresis effects in both normal and shear directions of a contact. The model is rate independent and represents coupling effects between normal and shear displacements. Contact effects are included through a segment-to-segment contact model which considers stick, micro-slip, slide and slap behaviors at every point within the contact interface. The model has six parameters and three memory variables without the need for integration during response computations. Behavior of the model is validated using the available mechanical joint records in the literature and it is successfully employed for model identification and dynamic response prediction of an internally resonating test structure with frictional support.

1. Introduction

Most engineering structures are composed of substructures attached together with mechanical joints such as bolts and rivets. These joints have decisive effect on the assembled system stiffness and often are the main reason for damping and nonlinear response. Consequently, much attention has been paid to modeling of the joints over the past decades [1]. The joint models are essential for studying and prediction of the dynamic response of structures and reduce the need for further experimentations in these studies. The success of these models depends on their ability to predict the relation between the field deformations and the transferred forces properly.

The contact behavior depends on interacting surface properties, loadings and contact region deformations. This behavior is studied from micro-scale [2,3] and macro-scale [1,4] observation points. In micro models, the contact is studied based on asperities shape, size, distribution, mechanical properties, molecular dynamics and statistical parameters. The macro models are not concerned with actual contact mechanics, but are parametric mathematical formulations that can be used for fitting experimentally obtained friction behavior. These investigations are performed in three fields; the first is studying the friction characteristics in contact interface considering variations of the tangential component while the normal force is assumed constant (e.g. Iwan, Valanis and Bouc–Wen models [1]). The application of these models is limited to contacts with simple geometry and negligible normal load fluctuation. In these models the coupling of normal motion and tangential vibration at the interfaces is ignored leading to the symmetry of hysteresis loops. However, in experimental observations asymmetric hysteresis loops are frequently seen [5]. The second field of study considers the behavior of interface in normal

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direction with no frictions in the contact (e.g. Hunt–Crossley and Lankarani–Nikravesh models [6]). The application of this approach is limited to collision of multi-body systems or contacts with perfectly frictionless surfaces. The third field of study focuses on developing a general contact model considering the interaction of normal and tangential vibration at the interface. Song and his colleagues [7] introduced an interface element that accounts for damping due to both vibro-impacts and friction. They used a gap element with linear stiffness and damping in normal direction and Jenkins elements with variable threshold force which is defined based on Coulomb's law in shear direction of contact. Menq and his co-workers [8] used a gap element with linear stiffness in normal direction and a complex slip model in tangential direction to model the contact. The shear stiffness of the model is independent of normal pressure and there is no damping considered in normal direction. Willner [9] presented a general simulation approach for the elasto-plastic contact behavior of rough surfaces based on a half-space model. In his model, normal and tangential stiffness of the contact as well as micro-slip effects depend on contact pressure. A linear relation between slip and tangential force is adopted and the slip threshold displacement is assumed constant; independent of contact normal force. Micro slip regime in the last three-mentioned studies is modeled linearly, therefore to reproduce real behavior of the contact mesh size should be very small.

Moerlooze and his colleagues [2] modeled the contact between two surfaces as the contact of a reduced set of asperities and an elastic non-dissipative counter profile. The local adhesion between the asperity tips and the counter profile, together with the elastic–plastic behavior of the asperities themselves, form the basis for their model. This contribution offers a mean to simulate verity of frictional behavior that is observed in experiments. To use this model, one must discretize the contact with meshes close to the aperies size.

Most of the contact models are deterministic with design variables identified via experiments. Number of the design variables and computational complexity beside the accuracy are other aspects of contact models. Recently, Ruderman and Bertram [10] introduced Modified Maxwell-slip model (MMS) for pre-sliding friction behavior that require two parameters to describe the smooth hysteresis of the pre-sliding friction. The present paper combines the solution of MMS model with empirical relation reported by Etsion and his colleagues [11,12] to relate slip threshold force to normal pressure, leading to a frictional contact model. The proposed contact model employs a Hertizian model with hysteresis properties in normal direction of the contact that is coupled with the suggested friction model. The number of model parameters are reduced by introducing a constant ratio between normal and tangential stiffness of the contact at the initiation of slip [13]. The proposed zero thickness contact model is rate independent with six design and three memory variables that model hysteresis effects and couplings effects between normal and tangential directions of the contact.

The organization of this paper is as follows. In section two the contact model is introduced and its predictions are validated in Section 3 against experimental observations reported in the literature. In section four, an experimental setup with a frictional contact is presented and its equations of motion are developed with special focus on the contact region. The contact region of the experimental setup is modeled using the proposed model of the current paper. The contact model parameters are identified using the experimental recorded response and the resultant model predictions are validated in section five. Finally, section six draws the conclusions.

2. Contact model

A conceptual reorientation of frictional contact is shown in Fig. 1. The current study ignores inertial effects of the asperities, and employs a simplified form of the Moerlooze and his colleagues [2] model to describe the contact behavior at the asperities level.

During quasi-static loading, the external normal and tangential loads, F_N and F_T respectively, are related to contact loads by

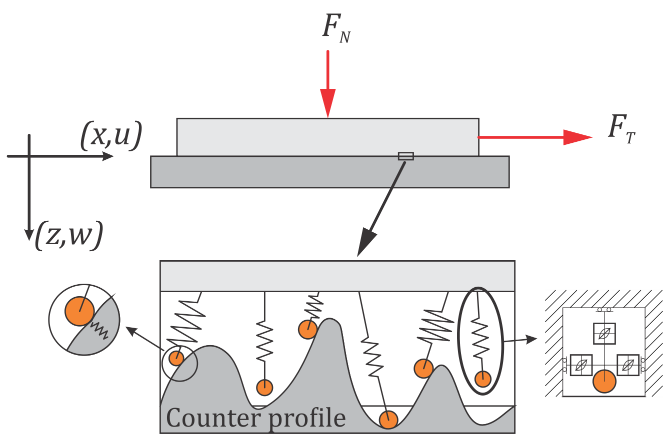

Fig. 1. The contact model introduced by Moerlooze et al. [2].