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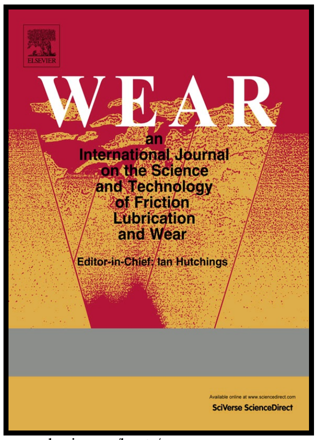

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Validation of a constitutive law for friction-induced vibration under different wear conditions

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Abstract

Recent work (A. Cabboi, T. Putelat, J. Woodhouse, The frequency response of dynamic friction: Enhanced rate-and-state models, Journal of the Mechanics and Physics of Solids 92 (2016) 210–236) has shown promising agreement between measurements and theoretical modelling of high-frequency dynamic sliding friction. This paper confirms and extends this agreement by presenting results for a wide selection of contacting materials. Additional measurement techniques are also introduced, to give independent confirmation of parameter identification and improve the robustness of the identification process. The results show that virtually every individual measurement can be fitted accurately by the proposed theoretical model, and that in all cases where rapid wear of the contacting materials was not an issue it was possible to achieve a good global fit to sets of tests at different normal loads and sliding speeds. The evidence suggests that this measurement procedure is able to characterise the dynamic behaviour at a frictional interface up to kiloHertz frequencies, and consequently provide the means to discriminate among, and calibrate, proposed dynamic friction models. Identifying a reliable model could significantly improve the prediction accuracy for friction-induced vibration such as vehicle brake squeal.

Keywords: Dynamic friction, contact stiffness, rate-and-state models, structural vibration, model validation.

1. Introduction

Friction is an essential ingredient of many engineering systems, as in devices like brakes or clutches where force transmission plays a key role. In others it is an unwanted phenomenon, for example resulting in loss of accuracy in positioning control or the appearance of self-excited vibration such as brake squeal. In either case it is important to be able to predict and control the dynamic friction force, but this has proved to be a very elusive goal: see for example [2, 3]. Friction-related phenomena have a reputation for “twitchiness”: in an experimental setting it is hard to obtain reliable and repeatable results. This suggests sensitivity to factors that are not well controlled or characterised [4], and it makes careful validation tests of theoretical models challenging.

The literature offers many attempts to decrypt the puzzling physics behind frictional interaction by proposing physics-based or phenomenological friction laws. The first type of constitutive law is typically based on integrating the mechanical principles applied at a microscopic scale (which might mean the molecular level or the asperity level) over the whole contact surface: see for example [5, 6, 7, 8, 9, 10, 11]. Such models require information concerning the geometry, such as the roughness distribution and the contact configuration (usually parameterised by the indentation depth), and the material properties including a characterisation of deliberate or accidental additional material near the sliding interface (be it an oxide layer, lubricant film or “leaves on the line”). On the other hand, phenomenological models are based on fitting to empirical observations: examples range from the familiar Amontons-Coulomb law or simple viscous friction, to more complicated effects such as time-evolving static friction and frictional memory. Different combinations of observed phenomena have led to more complex models such as the Stribeck-type model [12, 13], rate-and-state models [14, 15, 16, 17, 18], LuGre model [19, 20], or enhanced versions of the Maxwell-slip model [21, 22].

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