Vibration-induced friction force modulation

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Abstract. Exploiting oscillatory forces is one of the most efficient ways to alter friction forces. Several studies on the influence of external vibrations on friction have been conducted investigating the effect of in- and out-of-plane oscillations. These studies consider loads of high-frequency, while a clear statement as to what is considered high-frequency is still missing. The common method of analysis for high-frequency is the method of direct separation of motion (MDMS). However, when studying the effect of a general sinusoidal excitation on friction using the MDMS, the analytical solutions become cumbersome or impossible to obtain. Therefore, this study aims to show that, for both linear and nonlinear systems, a general relation of the effect of excitation on friction, regardless of the frequency range, can be obtained by utilizing the frequency response curve.

Introduction

The fact that friction forces can be significantly reduced by applying vibrations has been known since at least the 1950s. For the first 2-3 decades, the evidence collected was mostly experimental. Friedman and Levesque [1], and later on Tolstoi [2] showed experimentally that friction is altered under the effect of vibration. However, all the results seemed to be strongly dependent on the characteristics of each test rig. Thus, no general law explaining the observed behaviour was identified. Since then, several experimental and theoretical studies have been conducted. Some of these theoretical studies include the research conducted by Thomsen [3] and Hoffmann [4], where the Method of Direct Separation of Motion was used. In all the existing works, however, the effect of the external load on friction has been studied with an emphasis on high-frequency harmonic loads, while a clear statement as to what is considered high-frequency is still missing.

Results and discussion

This study aims to show that a general relation, regardless of the frequency range, accounting for the induced effect of excitation on friction, can be easily obtained by utilizing the frequency response function of the linear dynamic system. Besides the study of linear systems, this work also presents the effect of excitation on friction for some nonlinear systems. To solve the case of a nonlinear system, the harmonic balance method will be used. The proposed method will be applied to a classical mass-spring-dashpot system on a moving belt. First, the Amontons-Coulomb friction law will be studied, considering the sliding regime only, for which the system becomes linear. For this system, the frequency response function, used then to obtain the effect of excitation on friction, can be easily found, Figure 1. For the nonlinear case, two problems will be studied. In the first one, a harmonically excited Duffing oscillator will be investigated, where the nonlinearity is present in the stiffness term. In the second problem, the Stribeck law will be considered, where the nonlinearity is present in the damping term. Stribeck law is characterized by a force-velocity curve with a negative slope at low velocities which corresponds to negative damping. Thus, self-excited oscillations might occur which further complicate the process of obtaining the frequency response function. Lastly, a link between the obtained results and the stick-slip analysis of a mass on the belt system will be presented.

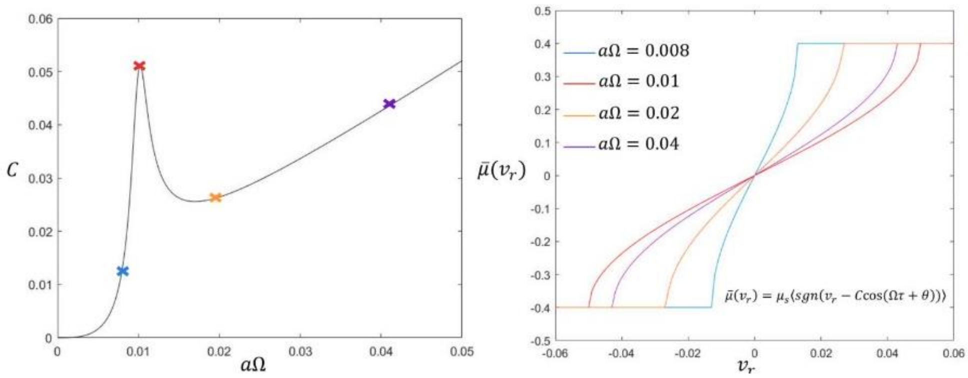

Figure 1: Frequency response function C vs excitation intensity $\alpha\Omega$ (left) and the corresponding effective friction $\bar{\mu}(v_r)$ vs relative velocity v_r (right) where α is the amplitude, Ω the frequency of excitation and θ a phase shift

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