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*Editorial*

# Advances in Friction-Induced Vibration in Applied Engineering

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Friction plays a crucial role in various engineering fields, including advanced manufacturing, transportation, aerospace, and bioengineering. It is a fundamental factor that determines the efficiency, reliability, and lifespan of mechanical systems. Friction serves as a primary damping source in dynamic environments, typically stabilizing vibrating systems by consuming system energy. However, friction can also cause counterintuitive self-excited vibration known as friction-induced vibration (FIV). FIV is a significant and challenging vibration problem that exists in various fields. The manifestation of FIV can be flutter or unfavorable noise in most cases [1]. Typical examples are automotive or aircraft brake squeal [2], the unstable vibration of the drill string [3] or cutting machines [4], squeaking human or artificial joints [5], and rattling robot joints [6].

Over the past few decades, scholars have dedicated their efforts to gaining a better understanding of the mechanisms [7,8] and propensity of FIV [9]. It is accepted that the mechanisms basically fall into four categories: (1) the negative gradient in the relations of friction force and velocity (2); stick–slip instability [10,11], which is caused by the difference between static and kinetic friction forces; (3) mode-coupling instability [12] or mode lock-in instability caused by the geometric characteristics of the frictional structure; (4) and sprag-slip instability [13]. Stick–slip mechanisms have a broader range of applications compared with other mechanisms [11,14,15], which is demonstrated below. Investigating the mechanisms underlying FIV remains a highly active and ongoing topic [16,17]. For example, Fang et al. [17] pointed out that the high-frequency vibration of the frictional system could be aroused by the partial separation between the slider and the moving substrate even without mode-coupling instability.

The most well-known FIV issue is commonly referred to as brake squeal. In the automotive industry, over 50% of the research conducted by friction material suppliers is allocated towards understanding and addressing this challenging noise problem [18]. Research on brake noise has been underway for almost a century, preceding research in other fields. Therefore, a significant amount of important research on self-excited vibrations induced by friction has been carried out within the framework of investigating brake noise [19]. The advancements in high-speed transportation have led to increasing concerns regarding railway brakes [20] and wheel/rail noise [21], primarily due to the adverse effects of noise pollution on both the environment and human health [22].

Previous studies have investigated various phenomenological sources that contribute to FIV, including friction laws, geometry, operational conditions (the loading force and the velocity), and surface topography [23,24], leading to different research branches. In recent times, engineering advancements have led to a demand for the detailed modeling of frictional systems. Factors such as uncertainty [25], new materials [26,27], nonlinearities/nonsmoothness [28,29], computational accuracy [30], and efficiency [31] are all areas of concern. Lacerra et al. [32] developed a novel stochastic friction model that incorporates a perturbative term based on Coulomb friction. This modification enables the friction law to replicate the FIV of two rough surfaces without taking into consideration the surface



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topography. In Ref. [33], the irregular vibration of a disc model was compared using various friction laws, and it was discovered that the irregular friction formulation had a more significant effect on the amplitude of instability rather than on the unstable behavior itself. Lazzari et al. [27] investigated the friction behavior and dynamic instability of carbon/carbon composite materials, in which both mode-coupling instability and the negative slope of friction laws were observed. Do et al. [34] proposed a novel strategy for an instability analysis of FIV, which has been shown to maintain accuracy while significantly reducing computational time. Stender et al. [35] proposed a purely data-driven approach for detecting the occurrence of FIV and predicting the onset time of FIV.

Scholars have recently recognized that friction-induced vibration is not solely detrimental to engineering but could also have benefits. In contrast with other methods of converting vibration energy into electrical energy, friction-induced vibration does not depend on ambient vibration sources. New harvesting devices [15,36–39] that utilize FIV based on various energy harvesting technologies, such as electromagnetic, electrostatic, piezoelectric, and triboelectric, have been developed. Fu et al. [15] introduced a triboelectric energy harvester that utilizes a vibro-impact system, which effectively harvests energy from low-frequency ambient vibrations by using the chatter- and stick–slip-induced low-frequency vibrations in the vibro-impact system. Recently, the performance of the harvesters has been improved by combining different technologies. Zhao and Ouyang [39] developed a triboelectric energy harvester with grating-patterned films and magnetic biostability, showing notable improvements in harvesting efficiency.

In addition, FIV in robot finger or arm joints is a significant concern for precise control and positioning. Researchers [40] have utilized stick–slip transitions to drive the locomotion of soft robotics, and the tactile sensing function of robots or mechanical arms relies on vibration signals to identify and monitor object characteristics [41,42]. Investigations into the tactile sensation of texture have been conducted on various surfaces, including textiles [43], and textures with isotropic [42], periodic, or general topographies [44].

At the microscopic level, the emergence of atomic force microscopy and scanning tunnelling microscopy has brought new advances to studying the origin of frictional forces [45–47]. The Prandtl-Tomlinson (P-T) model is the most general model. Following that, extension models based on the P-T model were proposed that can fit the frictional behavior of various materials and incorporate more environmental factors. [48]. Atomic-scale stick–slip friction has been observed on a variety of materials, including metals such as copper and gold [49], sodium chloride [50], and mica [51]. Socoliuc et al. [52] suggested that ultra-low friction can be achieved when stick–slip diminishes. Various velocity-dependent relationships of frictional forces, such as logarithmic velocity dependence, 2/3-order velocity dependence, or square velocity dependence, have been discovered [53,54]. However, the mechanism of multi-atomic stick–slip vibration remains unclear [55,56].

In summary, the multidisciplinary and multiscale effects of friction present challenges in the analysis of friction-induced vibrations. Integrating multidisciplinary technologies can lead to a more comprehensive understanding of the characteristics of frictional forces, providing benefits to multiple engineering fields.

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