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Effects of a horizontal magnetic field on unstable vibration and noise of a friction interface with different magnetic properties

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ABSTRACT

An experimental investigation studying the effects of a magnetic field on vibration and noise that occur when using a ball-on-disc friction system is described. Three types of friction pairs are introduced. The results show that a magnetic field can significantly reduce the friction noise, the corresponding vibration acceleration, and friction coefficient, for a steel–forged steel pair. However, the effects of magnetic field on the vibration and noise for other two friction pairs are limited. Moreover, a physical explanation is provided to describe the phenomenon, where the magnetic field attracts ferromagnetic wear debris, and cleans the wear trace. The major finding is that the noise reduction mechanism elicited by using a magnetic field can have extensive applicability in different fields.

1. Introduction

Vibration and noise are two important attributes in tribological research [1]. Vibration caused by interface friction can lead to system instability, increase in the fatigue wear of the system, reduction in the service life of the system, and even security risks. Noise generation with high frequency and high intensity may negatively impact the auditory nerves. Therefore, it makes practical sense to investigate the impact of various factors on the vibration and noise induced by friction.

Researchers have conducted several studies on the impact of various factors on vibration and noise induced by friction. Some researchers have studied the impacts of friction upon interface modifications, including the friction materials and structure, system parameters, and others [1–10]. Other researchers have also studied the effects of environmental factors that can influence the vibration and noise [11–17]. Li et al. [11] discovered that the resonant amplitudes of vibration and sound pressure responses are reduced with increases in temperature. Eriksson et al. [15] determined that the correlation between air humidity and brake squeal generation was limited. Considering that the use of a magnetic field as an environmental factor may influence the tribological properties, it is also possible that it can influence vibration and noise, and is, therefore, worth studying.

Thus far, the tribological properties of different materials have been studied earlier in the presence of a magnetic field. Researchers have found that the use of a magnetic field can affect the friction pairs with a normal load [18], coefficient of friction [19–23], wear rate [24,25], oxidation rate [25,26], microhardness [27], and other parameters [28]. Jiang et al. [18] ascribed the role of an external magnetic field to an additional normal load. Furthermore, some other researchers have determined that a magnetic field can increase the coefficient of friction. For example, Zhang et al. [19] found that the coefficient of friction of magnetorheological fluids increases when a magnetic field was added, or when the intensity of an existing field was increased. Yetim et al. [20] found that the coefficient of friction differs between two different friction pairs, and as the magnetic field intensity increases, the friction values increase for both pin materials. Other researchers have found that a magnetic field can decrease the coefficient of friction. Abdel-Jaber et al. [21] found that a magnetic field can decrease the coefficient of both dry and oil sliding pairs. Lian et al. [22] also found that the coefficient of friction decreases with the application of a magnetic field. Zaidi et al. [23] found that the presence of a magnetic field decreases the coefficient in ambient air, and increases the coefficient in an increased vacuum state under a ferromagnetic-ferromagnetic coupling. Boubechou et al. [25] found that different current intensities have both different impacts on the wear response characteristics and the friction coefficients. In addition, Chin et al. [27] found that the microhardness of a magnetized sliding contact coupling increases after adding a magnetic field. Han et al. [28] analyzed the magnetic field distribution and electromagnetism induction phenomenon of 45 steel friction surfaces in DC magnetic field. Meanwhile, some tribological applications associated with the use of a magnet already exist [29–31].

The aforementioned studies indicate that a magnetic field

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environment plays an important role in affecting the tribological properties. However, none of these studies have focused on the effects of the applied magnetic field on unstable interfacial vibration or noise. Based on the correlations between friction, vibration, and noise, the characteristics of friction-induced vibration and noise change when the interface tribological behaviors change. Investigating on whether a magnetic field can affect the friction-induced vibration and noise has important implications.

For this study, a setup was designed that can provide a horizontal magnetic field for traditional friction and wear tests. Using this system, studies can be conducted to investigate the influence of a magnetic field on unstable vibration and noise. Three types of friction pairs, namely, steel–forged steel, steel–aluminum alloy, and SiC–forged steel, were used in this investigation. The comparison of the noise and vibration acceleration signals, friction coefficient, and wear debris—in the absence and presence of a magnetic field—focused on the determination on whether the magnetic field can affect the induced noise or vibration, and in the case it does, the extent at which it affects the relevant tribological properties.

2. Materials and methods

2.1. Experiment setup

The setup was designed to allow the addition of a magnetic field, as illustrated in Fig. 1. As shown in this figure, the experimental setup consists of a transmission device, a load mechanism, and the support of a building magnetic environment.

As shown in Fig. 1(a), the transmission device was designed with a disc installed on the lower specimen holder, which is mounted to a gear driven by a rotational motion drive. The load mechanism uses a ball fixed to the upper holder, which is connected to the suspension. On the suspension, a 2-D force sensor (sensitivity, 0.025 N, measurement range, 5–500 N) is installed. A 3-D acceleration sensor (sensitivity, 100 mV/g, measurement range, ±50 g, frequency response, 0.5–5 kHz) is mounted on the upper holder, and a microphone (sensitivity, 50 mV/Pa, measurement range, 15–146 dB, frequency response, 3.5–20,000 Hz) is held by a tripod near the friction interface to measure the vibration and noise signals. A magnet base for building the horizontal magnetic environment is mounted on the top platform of the frame with four connecting structures, as indicated in Fig. 1(b). On top of the magnet base there are two horizontal and sliding boxes destined for the magnets, which can be bolted to secure them in position. The magnets that are used to generate the magnetic field have sizes of 50 mm × 30 mm × 5 mm, and radial magnetic field intensity B_r of 1.22 T, and are oriented with their north and south poles perpendicular to the two largest faces of the rectangular magnet. The left view of the magnetic field part is illustrated in Fig. 1(c). It is worth mentioning that the holder will not be attracted by the magnetic field, and that the force sensor, acceleration sensor, and microphone, are all shielded.

The test processes include the following: first, the 2-D moving stage moves down slowly to ensure that the ball makes contact with the disc that operates under a normal load, which can be controlled by an operational tribological test computer. The disc then starts to rotate at the configured speed. The noise signals, vibration acceleration signals, and friction coefficient, can then be measured and analyzed during the test synchronously using the acquisition and analysis system at the sampling frequency of 51.2 kHz. During the test, the magnets will be put into boxes on both sides, with their north poles facing the same direction. Once the test is completed, the topographical characteristics of the discs are analyzed.

2.2. Materials and test parameters

The ball and disc specimens with different magnetic properties were selected to study the effect of the magnetic field on unstable vibration and noise of a friction interface. Table 1 lists the friction materials used for this investigation and their relevant properties.

As shown in Table 1, two types of ball specimens and two types of disc

Table 1
Parameters and properties of friction materials.

Material	Friction pair	Magnetic property	Size/ mm	Hardness/ HV
Steel	Ball	Ferromagnetism	Φ10	1104.42
SiC	Ball	Paramagnetism	Φ10	1804.52
Forged steel	Disc	Ferromagnetism	Φ25 × 3	243.71
Aluminum alloy	Disc	Paramagnetism	Φ25 × 3	136.26

Φ: diameter.

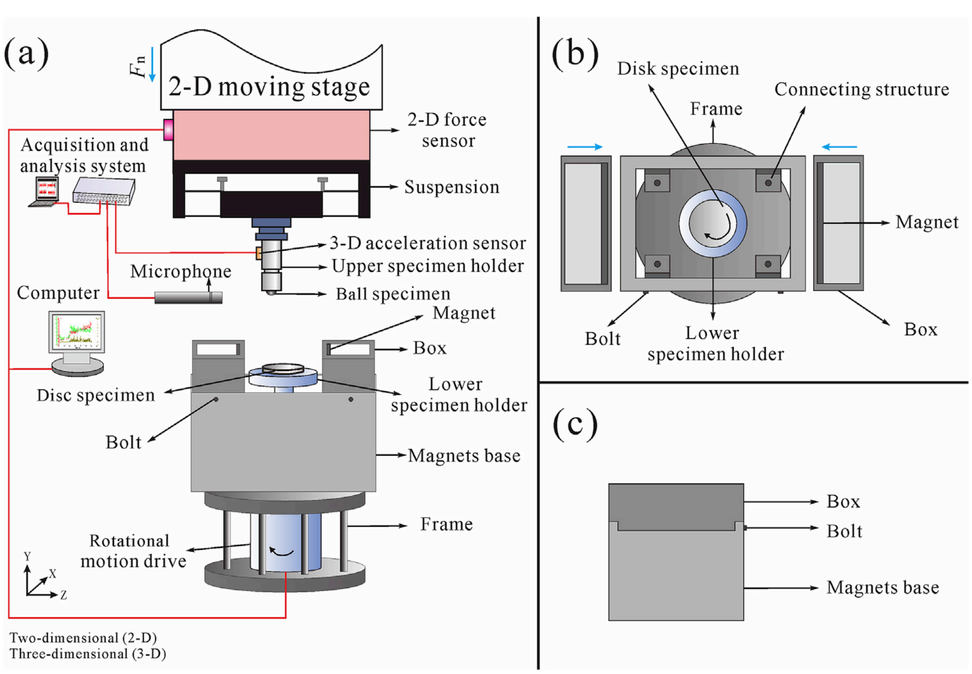

Fig. 1. Schematic of the experiment setup (a), top (b) and left (c) views of the part used to generate the magnetic field.