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Reducing friction-induced vibration and noise by clearing wear debris from contact surface by blowing air and adding magnetic field

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ABSTRACT

The purpose of this laboratory-scale study was to compare two possible approaches to reduce friction-induced vibration and noise during the dry sliding contact of ferrous metals. These approaches were tested using a ball-on-disc sliding apparatus in which the ball was composed of Cr-bearing steel and the disc was made from forged steel. One approach was to blow air at the wear track using a hand-held rubber bulb with a nozzle, and the other was to use a magnetic field to remove loose wear debris. Results from tests run under a limited set of sliding conditions showed that although both approaches can remove wear debris, their effects on reducing unstable vibration and noise differed. Magnetic debris removal worked better in reducing unstable vibration and noise than did the alternate approach. In addition, wear debris particles accumulated in a different way for the two approaches, and the operative phenomena are explained by analyzing third-body behavior. While limited in scope to a laboratory situation, the current findings may help engineers to reduce unstable vibration and noise in related tribosystems.

1. Introduction

A wide range of friction systems exist in the mechanical industry, and some negative influences such as unstable vibration and noise are common in these friction systems [1–5]. Unstable vibration increase wear, greatly reduce the service time of a system, and eventually magnify the safety risks [6,7]. Noise can interfere with people's normal lives and reduce the quality of their life [8]. Considering that a friction system is indispensable in some mechanical designs, it is useful to take measures to reduce or suppress unstable vibration and noise from different aspects.

Researchers believe that the unstable vibration and noise caused by friction is a complicated process. The friction interface morphology (such as asperities, wear debris, and detachment) is considered to be one of the factors that affects the unstable vibration and noise [9–14]. It is suggested that the wear debris generated by a friction system in a friction interface can easily cause unstable vibration and noise, for the case in which the wear layer as the third-body leads to irregularity of the interface [14–19]. Therefore, the removal of wear debris can be considered as a method for reducing vibration and noise.

The methods for removing wear debris can be divided into two types—irreversible and reversible methods. The irreversible method changes the surface or structure of the friction pair, such as in the case of surface texturing, in order to allow the wear debris to be collected and discharged automatically to prevent or reduce unstable vibration and noise [11,20–24]. In our previous studies [20,21], it was found that a groove-textured surface can remove wear debris from the friction interface into grooves, and the grooves play the role of a storage cavity to trap wear debris. Similarly, Mosleh et al. [23] presented a radial grooved disc that can throw wear debris away when it is rotating. At the microscopic level, Varenberg et al. [24] machined a type of micro-pore with a diameter of 100–120 μm on the specimen surface to gather wear debris. Sheasby [25] used a brush to remove the wear debris in order for more basic interactions between a pin and countersurface can take place. These reports indicate that this type of irreversible method has a certain ability to remove wear debris. However, it is worth noting that, in this type of method, the surface or structure of the friction pair is required to be changed and cannot be recovered, which is usually unsuitable in industry because of certain limitations. By contrast, in the reversible method, external factors are changed, which does not change the structure of the friction pair or affect the system performance. This method can be used whenever friction systems generate unstable vibration and noise and stopped whenever necessary. Therefore, the reversible method seems more flexible than the irreversible method, especially when the surface or structure of a friction pair cannot be changed. It is worth studying and using the reversible method to reduce the unstable vibration and noise in a friction system.

Several researchers have already verified that magnetic field as an

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environmental factor can affect the wear and oxidation conditions of the friction interface [26–28]. Considering that a magnetic field can attract ferromagnetic wear debris, the use of a magnetic field may be a useful idea for removing wear debris and reducing unstable vibration and noise. Moreover, the blowing of air should be considered as a traditional wear debris removal method that can also be conveniently performed.

For the vibration and noise generated from a rolling guide apparatus and ball bearing system, which are typical friction-induced vibration and noise phenomena, can be simulated using a ball-on-disc (flat) configuration. Therefore, in this work, friction tests were performed using a ball-on-disc test setup, which can be a good response to practical problems. Moreover, although friction-induced vibration and noise can occur in various contact configurations (ball-on-disc, pad-on-disc, ball-on-flat, etc.) or real applications (brake system, lead screw system, bearing system, etc.), the generation mechanism is similar, and its generation is strongly related to the contact states, friction behavior, and wear debris accumulation. Therefore, an effective method for reducing friction-induced vibration and noise should be applied to a wide range of systems rather than a special test setup. This paper presents two possible approaches for clearing wear debris by air or magnetic attraction, which can be performed conveniently without changing the structure of the friction pair. The vibration and noise signals were recorded and analyzed to study the noise characteristics and to evaluate the ability of these two approaches in reducing unstable vibration and noise. The wear debris behaviors at the friction interface were analyzed to understand the mechanisms of the two approaches in reducing vibration and noise.

2. Experimental procedures

2.1. Experimental setup

The tribological test setup and the two types of approaches for clearing wear debris being proposed in this work are illustrated in Fig. 1. In the tribological test setup, a ball is fixed to the upper specimen holder, which connects to the suspension and can be moved on a 2D moving stage. A disc is mounted on the lower specimen holder, which can be driven by the rotational motion drive. A 2D force sensor (sensitivity: 0.025 N; measurement range: 5–500 N) is mounted on the suspension for the acquisition of force signals, a 3D acceleration sensor (measurement range: ± 150 g; frequency response: 0.5 Hz–7 kHz) is fixed to the upper holder for the acquisition of vibration signals, and a microphone (sensitivity: 50 mV/Pa; measurement range: 15–146 dB; frequency response: 3.5 Hz–20 kHz) is held by a tripod near the friction interface for the measurement of noise signals. As shown in Fig. 1, a hand-held rubber bulb with a nozzle is controlled near the friction surface to blow away wear debris while using approach 1. When approach 2 is used, two horizontal sliding boxes with magnets are mounted on the magnet base, which is fixed to the top platform of the frame. The boxes are bolted in order to secure their position such that they can support a stable static magnetic field and can be used to attract wear debris.

2.2. Materials and test parameters

In this study, the ball specimen is fabricated using GCr15 (GB/T18254-2016) bearing steel and has a diameter of 10 mm and a hardness of 1104.42 HV. The disc specimen has a diameter of 25 mm and thickness of 3 mm and is fabricated using forged steel with a hardness of 243.71 HV. Both the ball and disc are ferromagnetic materials, and the magnetic field can thus attract the generated wear debris irrespective of which component generates it. The discs are polished using silicon carbide abrasive paper and a polishing cloth under a water stream to a surface roughness R_a of approximately 0.2 µm. The ball and disc samples are cleaned using alcohol and acetone before the test. Furthermore, the samples were degaussed before every test. After a series of previous tests have been conducted with various loads and speeds, a large number of the results are found to exhibit a similar property and can be used to obtain a similar conclusion. Therefore, only one set of test parameters is selected to demonstrate the vibration and noise reduction and to explain its mechanism. The test parameters are listed in Table 1. Before the test, the 2D moving stage was moved down slowly to ensure that the ball made contact with the disc under a normal load of 30 N, which can be controlled by a computer. The disc then started to rotate at the configured speed of 6.28 rad/s and a friction radius of approximately 8 mm. That is, the linear velocity is approximately 50.24 mm/s. The acquisition system recorded signals at a sampling frequency of 20 kHz. The entire test was performed in an atmospheric environment at a temperature of 26 °C and relative humidity of 60 ± 10%.

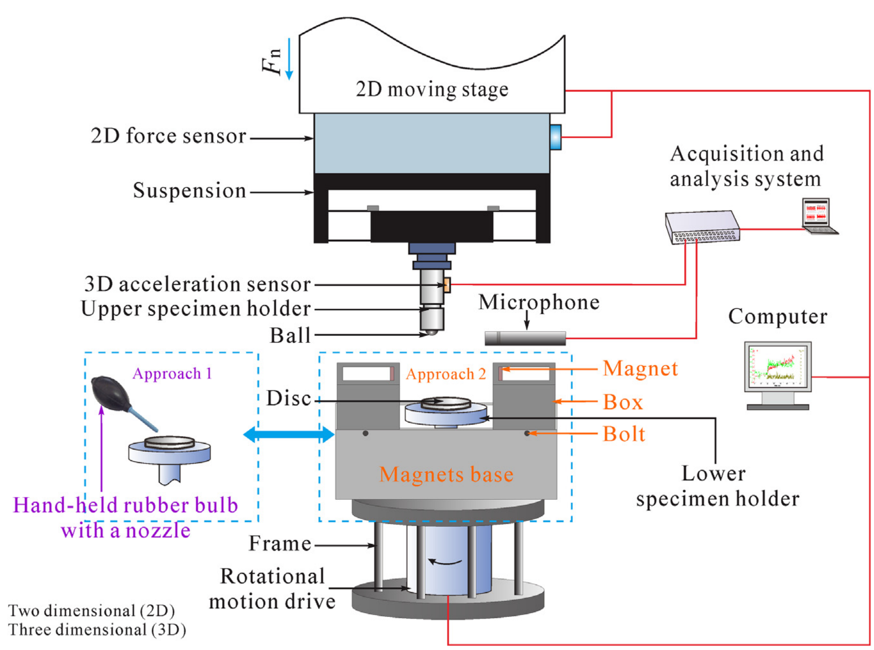

Fig. 1. Schematic of experiment setup for two approaches.