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Disc surface modifications for enhanced performance against friction noise

D.W. Wang[a], J.L. Mo[a,*], X.H. Ge[a], H. Ouyang[b], Z.R. Zhou[a]

[a] Tribology Research Institute, Southwest Jiaotong University, Chengdu 610031, China
[b] School of Engineering, University of Liverpool, Liverpool L69 3GH, UK

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ABSTRACT

Surface modifications of metal discs in the form of parallel and radial grooves are investigated for acquiring enhanced performance against friction-induced noise. Experimental and numerical studies indicate that grooved surfaces are capable of reducing squeal noise, and the groove width significantly affects the squeal noise level. Moreover, a disc sample with parallel grooves distributed on only half of surface well verifies the ability of grooves in reducing squeal noise generation. Numerical analysis is further performed to give an explanation on how the grooves can reduce squeal noise and why the disc samples with different groove widths exhibit different performance in reducing squeal noise.

1. Introduction

Brake noise can easily occur during the last stage of a braking action, which is usually undesirable and often associated with various friction problems such as excessive wear and surface damage of the brake components. Therefore, it has become one of the most important rating items in the vehicle initial quality standard test. Brake noise in different frequency ranges has been described by a number of terminologies, such as grunt, chatter, judder, moan, groan, squeak and squeal, etc. [1]. Among them, brake squeal having high frequency (usually above 1 kHz) and high sound pressure levels (usually above 78 dB) has been regarded as the most troublesome and annoying type of noise, because of its detrimental effect on the comfort of passengers and the brand image of vehicles [2–4]. Therefore, seeking an effective method to reduce and eliminate brake squeal is required, and has become a challenging subject for automotive engineers and researchers.

Over the past few decades, a large amount of effort has been made on identifying the main source of squeal generation. Mills [5] found that the negative friction coefficient with respect to the relative sliding speed played a key role in the friction instability. Spurr [6] indicated that self-excited vibration of a friction system depended on the contact area and friction coefficient. North [7] attributed friction-induced vibration to the coalescence of two adjacent eigenfrequencies of the system, and this theory was termed as ‘mode coupling’. In addition, Ouyang et al. [8] provided a detailed account of moving loads concept and illustrated that the brake squeal propensity was related to the rotational speed of brake disc. Graf and Ostermeyer [9] recently applied a new dynamic friction law to a simple model and found that squeal instability would occur in region with positive friction-velocity slopes. It is no doubt that those findings are significant for better understanding of friction noise. However, the underlying mechanisms of friction noise generation are still not fully understood and none of the above-mentioned theories can well explain all the phenomena related to friction noise, thus a thorough solution for elimination of squeal noise still seems to be an elusive goal [10].

In the case of brake squeal produced during braking, the surface topography is found to play a significant role in affecting the contact stiffness and wear performance of contact interface, which would consequently determine the dynamic instability and squeal generation of the friction system [11–17]. Researchers from Uppsala University conducted extensive research on identifying the relationship between microscopic surface topography of brake components and the occurrence of brake squeal [11–14]. In addition, AbuBakar et al. [15] introduced the real pad topography to a finite element model of a real disc brake system and verified that the squeal instability of brake system could vanish at particular surface topography. Shin et al. [16] found that the size of the zircon particles in the friction material would affect the

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[*] Corresponding author.
E-mail addresses: jlmo@swjtu.cn, mojiliang126@126.com (J.L. Mo).

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contact stiffness of interface and consequently the characteristics of friction instability. Hetzler and Willner [17] introduced tribological contact parameters into a brake model and found that the microscopic contact properties had a significant effect on the stability of the system. Yoon et al. [18] observed that the size of the surface contact plateaus significantly affected the propensity of dynamic instability and wear performance. Lee et al. [19] indicated that the surface roughness strongly affected the normal contact stiffness of interface, and accordingly determined the friction oscillation pattern. Lazim et al. [20] conducted brake squeal tests and found that the damage of pad surface was relevant to the squeal event. Magnier et al. [21] studied the influence of contact states on friction-induced vibration and found that the stiffness heterogeneities of the contact surface could significantly affect the lock-in modes. Duffour and Woodhouse [22] investigated the effect of uncertainty contact parameters on the squeal instability, and quantified the capability of this uncertainty on squeal predictions. Butlin and Woodhouse [23] performed a systematic experimental study of squeal initiation and explored the sensitivity of predictions to parameter variations.

These studies indicate that there is a strong relationship between microscopic surface topography and the generation of squeal noise. However, the microscopic topography possesses random characteristics, which results in the uncontrollability of contact states and relatively poor repeatability of experimental results. Therefore, more and more researchers try to create customised surfaces with good regularity to investigate their effect on the generation of squeal, and seek for an effective way to reduce squeal noise [24–26].

Nowadays, textured surfaces with their good geometric repeatability have been widely used in the field of tribology [27–30]. However, most of relevant studies focused on investigating the ability of textured surfaces in improving the friction and wear properties, and the effect of textured surface on squeal characteristics is rarely reported, and the knowledge about the influence of textured surface on squeal noise properties is very limited [26,31]. Therefore, studying the relation between the textured surface and squeal generation is extremely worthwhile, which may help provide a further understanding of the generation of squeal and also for optimal design of customised surfaces to reduce squeal noise of brake system.

In this work, two kinds of surface modifications of discs in the form of: grooves at parallel regular intervals (i.e. parallel grooves), and grooves at radial regular angular intervals (i.e. radial grooves) were manufactured on the disc surfaces, respectively. Experimental tests of friction noise were performed in a pad-on-disc configuration to study the capability of grooved surface in reducing squeal noise. Moreover, a numerical study was performed to provide a possible physical explanation for the experimental phenomenon.

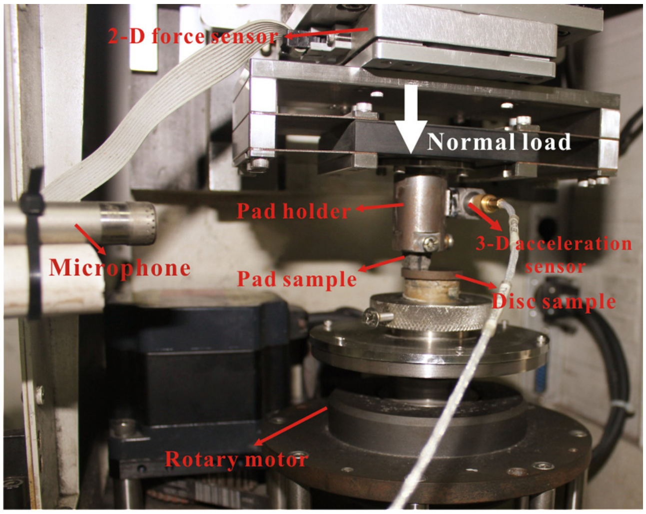

Fig. 1. Experimental pad-on-disc setup.

2. Experimental details

2.1. Description of experimental setup

For investigating brake squeal, a pad-on-disc setup is used. This simplified physical system is less complex than a real brake system but possesses the essential features of a real brake system, which permits the occurrence of modes lock-in between the components through a friction interface at a reduced scale. The image of the experimental setup is given in Fig. 1. The disc sample is driven at a certain speed by the rotary motor, and the pad sample is fixed in the upper pad holder, which is pressed down to rubbing against the lower disc sample and attached with a 2-D strain-gauge force sensor (CETR DFH-50: measurement range of 5–500 N and resolution of 0.025 N). A real-time recording of the vibration signals is performed by using a 3-D acceleration sensor (KISTLER 8688A50: measurement ranges of ±50 g, frequency ranges of 0.5Hz–5 kHz and sensitivity of 100 mV/g and mass of 6.5 g), which is mounted on the pad holder. A microphone (MTG MK250: dynamic range of 15–146 dB, frequency range of 3.5–20 kHz and sensitivity of 50 mV/Pa) is placed nearby the contact surface to detect the sound signal. All the signals measured from sensors are recorded and

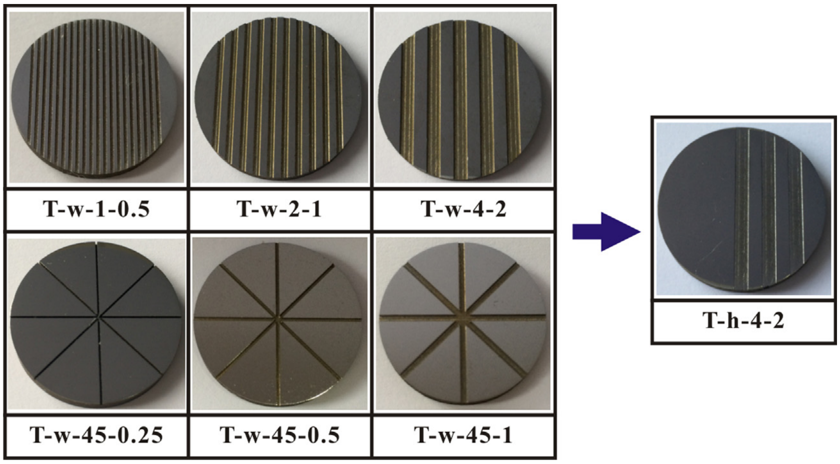

Fig. 2. Disc samples with different groove-textured surfaces.