INFLUENCE OF SURFACE ROUGHNESS ON THE FRICTIONAL SOUND GENERATED BY LIGHTLY LOADED PLANAR CONTACTS

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ABSTRACT

Practical engineering problems, which have motivated the past research on sound generation in sliding include brake noise, railway squeal noise, seal noise, screw-nut transmission noise, etc. While squeal noise can be explained with the occurrence of stick-slip under higher loads and lower speeds, the sound generation under light loading conditions is not well studied. In the present paper we have investigated the influence of surface roughness on frictional sound from a lightly loaded contact between steel disks. Frequency spectrum of sound revealed a shift of the peak frequency related to changes of surface roughness. Further analysis using the Greenwood-Williamson contact model suggests that this shift is due to the change of contact stiffness when surface roughness was changed. These findings provide suggestions for improving the design of noisy sliding contacts.

INTRODUCTION

Past studies on frictional sound have shown that the mechanism of sound generation is different under heavy and light loading, with surface roughness being the prime reason for the sound generation under light loading conditions [1]. It was shown by Othman et al. [2] that sound pressure level from a sharp stylus on a rough surface is strongly related to the roughness. In a previous study [3] we have found that for lightly loaded planar contacts peak frequency shifts by changing the roughness. Our findings were independently confirmed [4], and the possibility was raised that the peak shift mechanism is related to the change of contact stiffness. This mechanism is confirmed by the experimental results and modeling presented in this paper.

EXPERIMENT

Past experiments [3] were done with plates having free vibration modes inside the audible range and it was pointed out [3, 4] that the spectrum of sound is highly dependent on the modal behaviour of the specimens. The question was raised whether it is possible to investigate the effect of roughness independently of the shape or mechanical properties of the specimens. This led us to design new disk-shaped specimens with first mode well above the audible range – 147 kHz.

The disks were made of stainless steel SUS310. Two types of flat/flat contacts were prepared – first type is a contact between a rough and a mirror polished surface (Ra < 0.05 μm), the second is the contact between surfaces having similar roughness (in the range 0.006 ~ 1.2 μm). When the two specimens are rubbed together, the directional roughness is so aligned that surface asperities on both disks interlock during sliding. An accelerometer was mounted on the lower disk to measure acceleration in direction normal to the contact surface.

The tests were carried out at rubbing speed of about 2 cycles per second. Normal loading was by the weight of the specimen – about 0.37 N. Specimens were rubbed at a distance of about 10 cm away from the microphone. Sound pressure was sampled at a sampling rate of 50 kS/s and the frequency range of interest is up to 16 kHz. The length of the data record for each test was about 4 seconds.

RESULTS AND DISCUSSION

The power spectral density (PSD) of frictional sound generated by the rubbing of a rough and mirror disk is shown in Fig. 1. The frequency range containing the highest power in comparison to the background sound is the range between 2 and 8 kHz. In this region there is a single peak in the power spectral density (PSD). This observation can also be confirmed from the PSD of normal acceleration (Fig. 2). The peak frequency is gradually shifting to higher frequency as the surface roughness of the disk becomes smoother for both types of contact.

The shift of the peak frequency in the PSD spectrum of frictional sound when the average surface roughness Ra of the interacting surfaces is changed in the range of 0.05 – 1.2 mm is best described numerically by a power law of the form :

$$F_p = A_f (R_a)^{B_f} \tag{1}$$

where F_p is the peak frequency; R_a - the average surface roughness; A_f , B_f - experimental constants.

Further a model of the contact interface is considered from the viewpoint of contact stiffness change by the

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change of roughness. The model of Greenwood and Williamson (GW model) [5] describes the static contact of an ideally flat surface and a rough surface. It can be shown that such a simplified consideration is valid even in the case of two rough surfaces, because they can be represented by the contact of an equivalent rough surface and an ideally flat one.

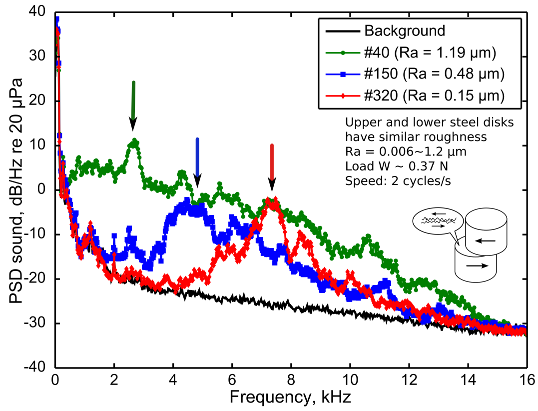

Fig. 1 Effect of roughness on the spectrum of frictional sound from disks having similar roughness. Arrows show the peak frequencies.

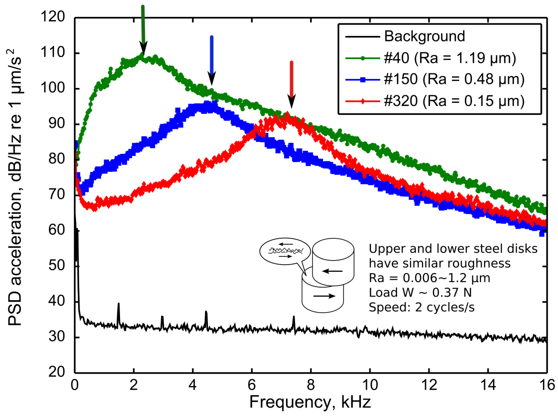

Fig. 2 Effect of roughness on the spectrum of normal disk acceleration when rubbing disks having similar roughness. Arrows show the peak frequencies.

The contact model takes three surface roughness parameters as inputs – standard deviation of asperity heights σ, average asperity curvature ρ and areal density of asperities η. In practice there are various methods for extracting these values from measured profiles, each based on a different set of assumptions. The method used here is the one originally used in [5], which assumes that an 'asperity' is any point on the measured profile, which is higher than its neighbours.

Contact load W – contact deformation Δx relationship obtained by the GW model is non-linear and contact stiffness obtained as the derivative:

$$k = dW(x, \rho, \sigma, \eta)/dx \qquad (2)$$

is not constant. The value of the stiffness was calculated for each roughness under the applied load of 0.37 N, which is the weight of the disk, under which the surfaces are rubbed. With the calculated stiffness value the natural frequency of the system shown in Fig. 3 is calculated by the formula:

$$F_p = \frac{C}{2\pi}\sqrt{\frac{k}{m}} \qquad (3)$$

and after adjusting by a factor of C=0.5, is plotted against the surface roughness together with the peak frequencies obtained in the experiments.

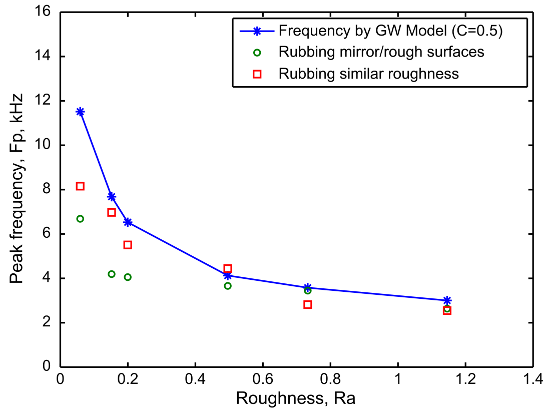

Fig. 3 Effect of roughness on the peak frequency of frictional sound from experiments and by modelling.

The calculated natural frequency increased as the roughness of the surface decreases. Qualitatively the change of natural frequency is very similar to the peak frequency shift observed in rubbing and in externally excited static contact.

CONCLUSION

Surface roughness influences the sound generated by lightly loaded planar contacts. When surface roughness is reduced from Ra=1.19 to Ra=0.006 μm the peak frequency of frictional sound shifts from 2.5 kHz to higher values in the range of 8 kHz. This observation is consistent with changing contact stiffness, as calculated from the Greenwood-Williamson contact model.

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