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Relationship Between Sound and Vibration Generated in Sliding Contact

DRAFT

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Introduction

Frictional sound and vibration problems occur in many mechanical systems, e.g. brakes, clutches, etc. At the present time the occurrence and severity of these problems are unpredictable. Thus when designing new products, engineers can deal with these issues only at the prototype testing stage. Understanding the mechanisms involved in frictional sound and vibration generation would help expect and solve problems before the prototypes are built. This would result in shortened new product development time and reduced costs.

In the past interesting results about frictional sound were obtained by Yokoi and Nakai [1]. In their studies they concluded that frictional sounds may be generated due to tangential vibrations of the pin. Soom and Kim [2] studied the effects of dynamic friction. They found large high frequency fluctuations of frictional and normal forces during smooth unlubricated sliding. Yet, until now, according to the authors' knowledge, a concept summarising the general understanding of sound generated by dynamic friction has not been proposed. Such a concept is the starting point of the present study.

When dealing with dynamic phenomena such as sound and vibration, the traditional concept of kinetic (time independent) friction is not applicable. When dynamic friction is considered, changes in contact conditions result in changes of contact forces. These changes generate vibrations, which in turn change the contact conditions. This interdependence of contact forces and vibrations is represented by a closed loop on the diagram (Fig. 1). The implication of this is that changes of contact forces

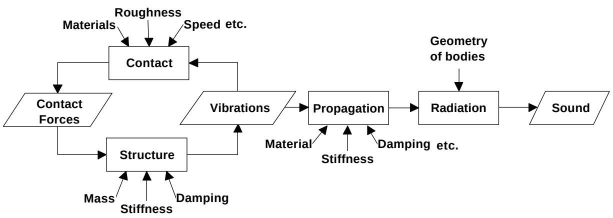

Fig. 1 Concept of frictional sound generation

can be evaluated by measuring the vibrations close to the contact. The diagram also shows some variables traditionally thought to affect kinetic friction, and others, thought to affect vibrations. The vibrations generated at the contact, are further propagated to other elements of the system. Propagation is also dependent on materials, mass, stiffness, damping. Finally mechanical vibrations are radiated as sound, for which process the geometry of the vibrating bodies is crucial.

With this concept in mind, the purpose of this study is to investigate the effect sliding speed (affects the contact), and of lower specimen fixing (affects the structure), on the frictional vibrations and their relation to sound.

Experimental Apparatus and Procedure

The experimental apparatus is a reciprocating tester. The stage is moved by the magnetic screws, rotated by a stepping motor. The motor is located in a separate compartment with heavy walls, which are covered with sound absorbing material, same as the test chamber. The load is applied by the elastic deformation of a leaf spring when the XZ-stage is lowered down. The lower specimen is mounted onto the stage. Vibration is measured in tangential and normal direction by two accelerometers mounted onto the upper specimen holder. The sound is measured by a microphone. It is placed at about 10 cm from the contact point. Tests were carried out for sliding speeds from 20 to 100 mm/s for three different methods of lower specimen attachment to the stage (Fig. 3). Disk and lower specimen material is steel. Disk RMS roughness is R_q = 1.05 μm, lower specimen RMS roughness R_q = 0.68 μm. All tests were carried out at load setting of 1 N.

The acquired data was filtered in 1/3-octave bands in the restricted audio range from 100 Hz to 5000 Hz. For the comparison of overall levels A-weighting was performed on the 1/3-octave band data. A-weighting is most commonly used in noise control, because the weighting curve closely approximates the human ear response to different frequencies. Because relations between sound and vibration are under investigation, the acceleration overall levels were also obtained by A-weighting.

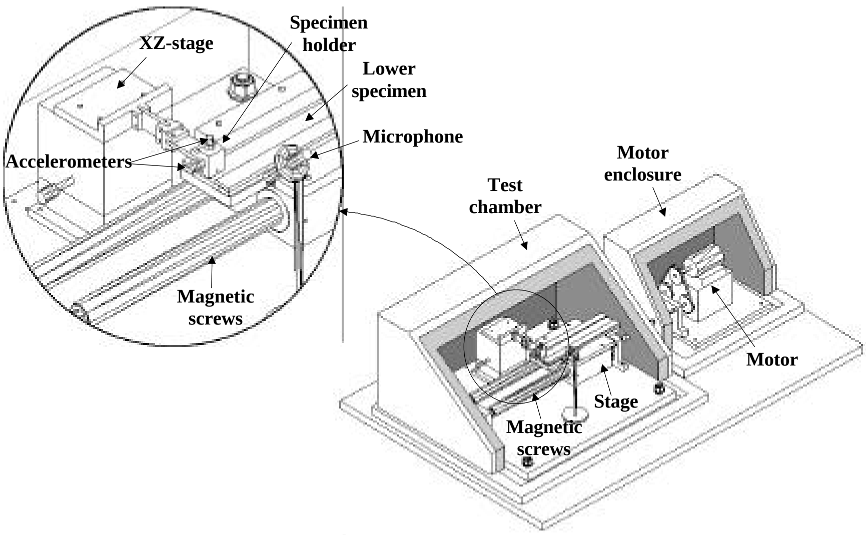

Fig. 2 Experimental Apparatus

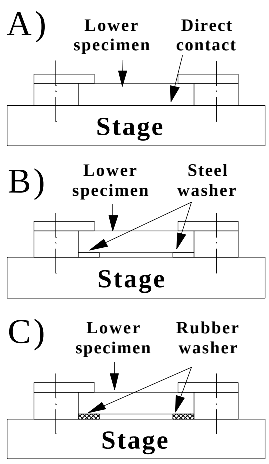

Fig. 3 Types of lower specimen fixation

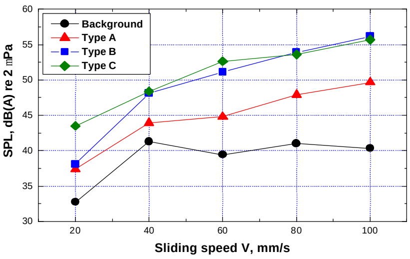

Fig.4 Effect of sliding speed on sound pressure level (SPL)

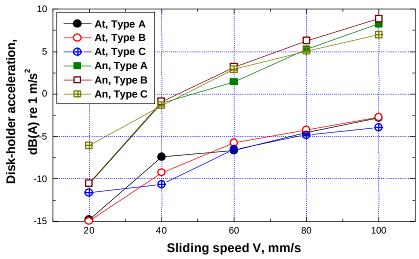

Fig. 5 Effect of sliding speed on tangential and normal acceleration levels of disk-holder.

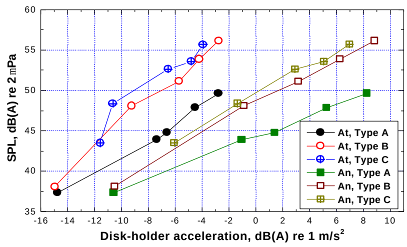

Fig. 6 Relation between tangential and normal acceleration levels and sound pressure level (SPL)

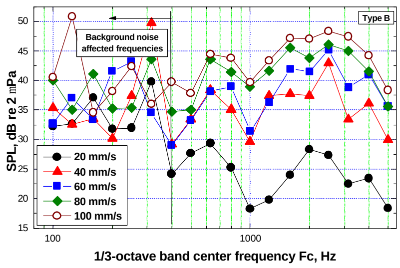

Fig. 7 1/3-octave spectrum of sound. Type B fixing

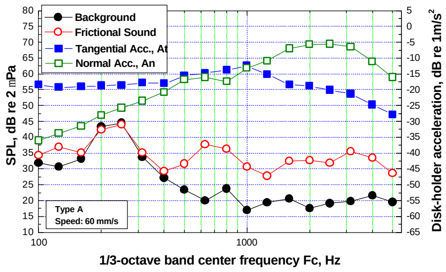

Fig. 8 1/3-octave spectrum of sound and acceleration. Type A fixing

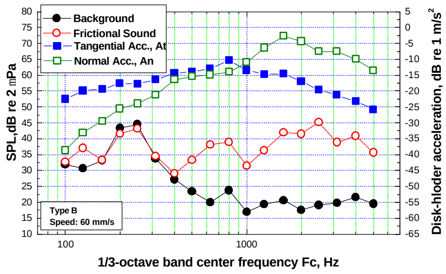

Fig. 9 1/3-octave spectrum of sound and acceleration. Type B fixing

Table 1 1/3-octave band frequency peaks

Fixing Method	Sound			Normal accel.	Tangential accel.
	1 peak	2 peak	3 peak		
A	630 -800	1600 - 2000	3150	2500	1000
B	630 -800	2500	-	1600	800
C	630 -800	2500	-	1600	800

Experimental Results

The results for the sound pressure level (SPL) dependence on sliding speed are shown in Fig. 4. The increase of sliding speed caused sound pressure level also to increase. Type C produces SPL about 7 dB lower than the other two types. It is worth mentioning that 10 dB difference in SPL is perceived twice as loud. If noise reduction were the objective, the change of fixing from type B or C to type A would have the same effect as reducing the sliding speed from 100 mm/s to 40 mm/s.

When sliding speed increases, disk-holder acceleration linearly increases (Fig. 5). The fixing method, however, does not seem to have very strong influence. Change of sliding speed of about 20 mm/s causes higher change in acceleration levels than the change of fixing from type C or B to type A. The normal acceleration levels are significantly higher than those for the tangential acceleration.

Fig. 6 summarizes the relation between acceleration levels of disk-holder and SPL. It is seen that for the same level of vibrations, B and C fixing, produced higher SPL. Therefore the position of the lines defines how effectively are vibrations propagated and radiated by different systems.

By comparison of 1/3-octave band spectra of sound for the same sliding speed with friction contact and without, it was found that in the frequency bands below 400 Hz the dominant effect is that of the background noise. These frequency bands were ignored in the following analysis.

For all three types of lower specimen fixing, speed was found to increase the levels in all frequency bands for sound (Fig. 7) and acceleration, but does not change significantly the shape of the spectra . This increase may be attributed to the increased energy input in the vibrating system.

Most complicated 3-peak shape of sound spectrum was displayed by type A fixing (Fig. 8). The sound spectra for types B (Fig. 9) and C fixing have two peaks, although for the type B pattern is more complicated .

Tangential acceleration spectrum is broadband and shows a maximum about 800 - 1000 Hz, rather than a peak.

Normal acceleration exhibits a characteristic peak for each of the holding methods.

The peak locations are summarized in Table 1. For B and C fixing types the respective peak frequencies for sound and acceleration are the same. The peak at 1600 Hz in the normal acceleration is lower than 2500 Hz for type A, because when supported on the whole surface the lower specimen stiffness is increased.

Surprisingly we note that the peak frequencies in accelerations do not correspond to any of the peak frequencies in the sound spectrum. In the case of B and C fixing this may be due to the acoustic effect of the cavity formed between the lower specimen and the stage. This is not the case for type A, however. In type A fixing, the reason for this discrepancy should be that during the vibration propagation some of the frequencies had been suppressed, while others had been amplified.

Conclusions

1. Vibration and sound overall levels increase linearly with the increase of sliding speed.
2. The peak frequencies of sound and vibration are not affected by sliding speed.
3. Sound overall level is linearly related to the levels of vibration. The position of the line defines how effectively are the vibrations propagated and radiated by different systems.
4. Peak frequencies in sound spectra are different from peak frequencies in vibration spectra.

References

1. Yokoi, M. and Nakai, M., (1979), *A Fundamental Study on Frictional Noise*, Bulletin of the JSME, (22)173, 1665 - 1671.
2. Soom, A. and Kim, C., (1983), *Interactions Between Dynamic Normal and Frictional Forces During Unlubricated Sliding*, J. Lub. Technology 105 (Apr), 221 - 229.