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Full Length Research Paper

Stick-slip detection through measurement of near field noise

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The paper presents an experimental investigation to recognize the occurrence of the stick-slip phenomenon. As a trial to detect and evaluate this phenomenon, a pin on disk test rig is presented. The test rig consists of two separate blocks to ensure that the vibration of the elastic disk and emitted noise are completely adverted to friction between the moving pin and stationary steel disk. The occurrence of stick slip is clearly picked up using near field noise measurements. It can be distinguished from the vibration signal as high consecutive spikes, but the existence of such spikes is clearer and more definite in the noise signature.

Key words: Pin on disk, friction, induced vibration, noise, and stick-slip.

INTRODUCTION

Noise and vibration in the environment or in industry are caused by particular processes where dynamic forces excite structures. The vibration and noise induced by dry friction are overwhelmed by non linearity factors. One of the main origins of non linearity is the variation in the coefficient of friction. Such variation is attributed to many factors like change of pin velocity, occurrence of stick slip, and change of the acting normal force due to pin vibration in the normal (vertical) direction. The remarkable variation of contacting surface topology due to occurrence of abrasive and adhesive wear has a big contribution to the variation of the friction coefficient. Wave transmission and vibration modes of the disk and pin also have considerable effect on the measured vibration signature. The friction characteristics resulting from the motion of one surface over another can often strongly influence the behavior and operational efficiency of many physical systems. It is often cited that about 40% of the frictional problems in industries are due to vibrations induced by friction (Earles and Lee, 1976; Earles, and Badi, 1984; Earles and Chambers, 1985; Earles and Chambers, 1987; Ibrahim, 1992; Ibrahim et al., 2000; Akay, 2002; Chan et al., 1994).

Friction induced noise and vibration

Friction-induced vibration, chatter, and squeal are serious problems in many industrial applications. Many experimental and analytical studies have led to insight on the factors contributing to brake squeal or to the improvement of squeal in disk brakes of a specific type or in a particular make and model of automobile. Experi-mental studies have accumulated a wealth of information about the nature of squeal, the vibration modes therein, the wear of brake components, and frictional interactions in brakes. Analytical studies have provided useful insights into how friction, geometry and dynamics of brake components can lead to squeal or instability in simple models of disk brakes. Finite elements have been used to try to extend the insights to more accurate brake models. There are large numbers of models devoted to brake squeal.

Early work of Earles and Lee (1976) featured experiments in which a disk, contacted by a pin which is supported by a flexible cantilever, is spun at a constant speed. The system stability is dependent on the coefficient of friction. Earles and Badi, (1984) and Earles and Chambers (1985, 1987) used pin on disk systems in

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which two pins acted on the disk to investigate and quantify the sprag-slip mechanism for squeal. The investigations performed consisted of examining how the damping influenced squeal. Damping in the pin assembly (corresponding to damping of the brake pad assembly in a disk brake) could enlarge the unstable regions under certain circumstances, while disk damping always reduced such regions.

Ibrahim (1992) stated that the occurrence of stick-slip is unpredictable and is attributed to the fact that the slope of the friction-speed curve is not constant but varies randomly with contamination, surface finish, misalignment of sliding surfaces, and other factors. In the mechanical systems of vibrations there are three categories: stick-slip, vibrations induced by random surface irregularities and quasi-harmonic self-excited oscillations.

Ibrahim et al. (2000) measured the average normal and friction forces acting on a friction element, which was in the form of a pin placed in contact with a rotating disk. As the rotation speed and direction of the disk rotation were variable, the tests were performed at constant rotational speeds. Several interesting features were reported, most notably, neither the normal force nor the kinetic coefficient of friction was constant. In fact, the authors reported that the friction and normal forces acting on the friction element are random and non-Gaussian processes.

Considering the acoustics of friction-induced vibration, an illuminating discussion has been reported by Akay, (2002). By exposing many of the topics common to both fields, the modeling of friction induced vibrations and friction damping in mechanical systems requires an accurate description of friction for which only approximations exist.

Chan et al. (1994) presented a study on brake squeal which is based on the splitting of the frequency of the doublet modes in the symmetric disk when a friction force is applied; the splitting could lead to flutter which is associated with brake squeal. The study considered a clamped elastic annular disk which is loaded, at a discrete number of points, by a tangential follower force traction related to the normal pressure by the coefficient of friction.

Nakano (2006) addressed the tendency of a disk to generate noise when the natural frequencies of in-plane and bending vibrations are close to each other. In addition self-excited vibrations of a circular plate with friction forces acting on its edge are considered to model squeal in drum brakes.

Based on experimental investigation, Emira (2007) presented a three-degree-of-freedom model of a rotating pin-on-disk system to investigate the effect of varying both the normal force and the system stiffness parameters on the system response in three directions (namely normal, tangential and rotational) at different speeds. Research results stated that at any specific speed, increasing the normal force increases the calculated system response. Also, increasing the pin velocity increases the amplitude of system response in the three directions. The change in amplitude of system response is inversely related to changes in stiffness parameters of the system.

Stick slip and friction models

From a technological standpoint, one of the most important roles of tribology is to provide a smooth relative motion of contacting surfaces. An intermittent motion of surfaces (termed stick-slip) leading to the decreased functional status of a mechanical system is a nuisance, which should be predicted and prevented in its design stage. The fundamental framework to prevent stick-slip has recently been constructed through dimensionless analysis of its occurrence limit (Nakano, 2006; Nakano and Maegawa, 2009) it is an undeniable fact however, that the problems caused by stick-slip are diverse, which necessitates the studies of the individual problems.

JaeyoungKang et al., (2009) examined the dynamic response of a rotating squealing disc brake subject to distributed nonlinear contact stresses where two brake pads are assumed to be stationary and rigid. Their results showed that the wave pattern is associated with mode-coupling character. For a steady-squealing mode, the stick zone of the contact area is determined by a smooth friction–velocity curve having both negative and positive slopes. Maegawa and Nakano (2010) investigated the mechanism of stick-slip associated with surface waves. Surface waves are likely to occur for low contact load and high driving speed, which apparently contradicts the tendency of general stick-slip.

The experimental tests on a pin-on disk type sliding system by Dweib and D'Souza (1990) have indicated that, for a constant sliding speed, the friction force depends on the normal load. According to the value of the normal load, there are four different regimes; namely, steady-state, non-linear, transient friction, and self-excited vibration regions.

Kinkaid et al. (2003) presented a detailed revision of the pin on disk friction models. A revision of most of the models that have appeared in the literature is demonstrated. The inter-relationships between such models are highlighted. In the models, a linear stability analysis was performed in order to predict the onset of instability, which has been correlated to the occurrence of squeal.

For the typical test rigs usage, such as those used by Bin-Bin et al. (2007) and Hozumi and Yoshifumi (2003), the effect of the disk elasticity is not included since the disk is usually supported to a heavy rigid base. Figure 1 shows a typical pin on disk arrangement. In such test rigs, the frame used supports all parts: the pin arrangement (which is fixed), driven disk and driving motor. Thus, measured vibration (of the pin) would include traces due to vibration of the driving arrangement. The present paper is concerned with building a pin-on-disk test rig and evaluating its performance. Conducting a

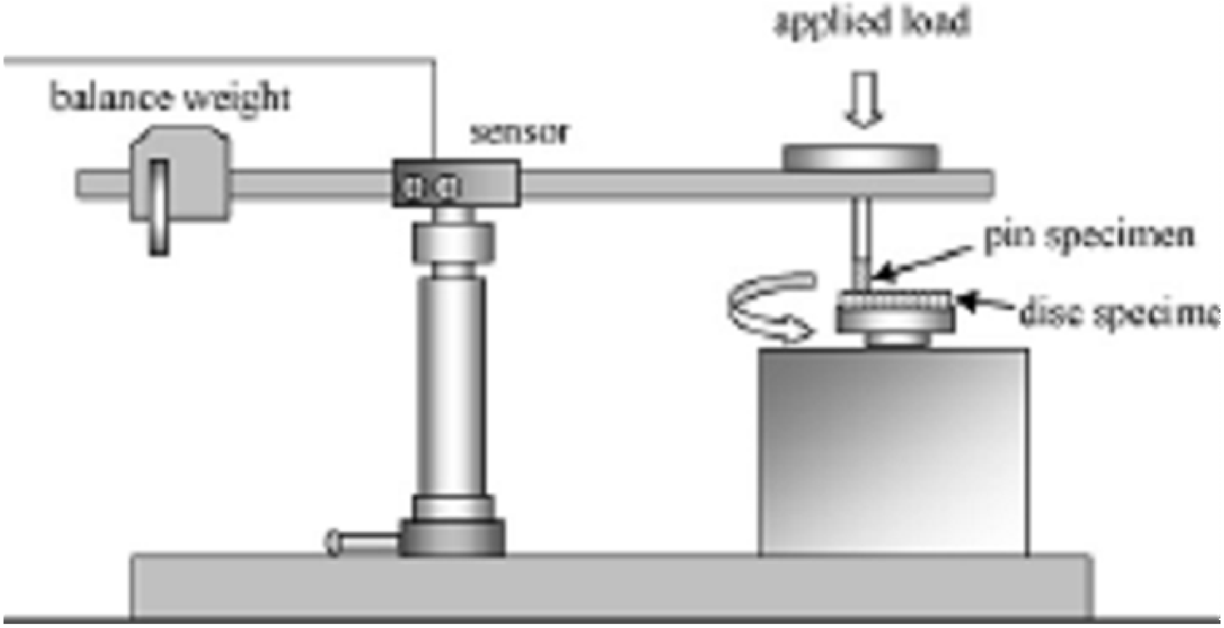

Figure 1. A typical pin on disk test rig.

series of tests under different conditions of pin speed, applied load, and pin material and recording the emitted noise is one of the research objectives. The experimental tests led to recognizing the occurrence of stick-slip phenomenon.

THE TEST RIG

The objective of the experimental set-up is to enable the measurement of both noise and vibration of the disk in three perpendicular axes induced by friction. The directions are: vertical/ normal (perpendicular to disk surface), horizontal (tangential to the locus of the pin), and radial (perpendicular to the tangential direction, in plane of the disk surface). Figure 2 shows the test rig arrangement.

The rig; shown in Figure 2, is installed in an anechoic chamber. It constitutes a sliding pin attached to a rotating pulley; whereas the friction disk (Φ300 x 15 mm) is fixed. A steel cube is attached to the fixed disk, on which accelerometers are attached in the required direction (three perpendicular axes). A ½ inch B and K microphone is fixed near to the accelerometer position (2 cm apart) and is 3 cm apart from the locus of rotation of the moving pin. It is directed radially towards center of rotation.

The testing apparatus is designed to study the friction-induced vibration of the disk at practical loads and speeds. Loads varying from 25 to 75 N applied on the pin in the vertical direction, can be tested. The present design also allows testing four pin linear velocities 2, 2.6, 4 and 5.2 m/s.

The pin, fixed to a pulley, is belt driven using a 1.1 kW electric motor. The pulley arrangement includes a greased sliding bearing to minimize vibration. Different from most of the reported pin on disk test rigs, in which the rotating plate is directly fixed on the motor shaft, the present test rig incorporates two separate heavy blocks supporting the test rig. On the first one, the disk and pin arrangement is fixed. The second block is used to hold the driving motor. The arrangement ensured negligible vibration transmitted to the disk from all other sources but the pin.

The measured vibration and noise signals, under no load operation, show no (negligible) trace due to the driving system. Therefore, the measured vibration and noise signals are due to the interaction between the moving pin and the fixed disk. The normal load is changed using steel plates bolted to the pulley driving the pin. Measuring the vibration of the disk in the three perpendicular axes is enabled through fixing a steel cube, of 15 mm side length, to the plate.

A 2.6 g B and K accelerometer type 4375 and 4.78 [mV/g sensitivity is used for picking up the disk vibration, and a B and K microphone type 4189 is used for recording the generated noise signal. An infra red diode with emitter and acceptor is used to pick up a timing signal. It should always be remembered that the measured vibration signal, picked up at a specific fixed location on the disk, is due to excitation induced by friction of the pin at a point somewhere on its locus.

The signal from the infra red diode, representing the timing and triggering signal, is fed directly to a four channel Tektronix digital oscilloscope type TDS200. The signals from the accelerometer and the microphone are fed to the oscilloscope through two B and K charge amplifiers. The acquired signals are transferred to a computer in both photographic and digital forms for storage and further analysis.

A sampling rate of 25000 sample/s is used. This ensures free of anti-aliasing amplitudes up to a frequency of 6 kHz. The three used pins are, steel (H.R = 99.67), copper (H.R = 98) and aluminum (H.R = 96.83).

RESULTS and DISCUSSION

The investigation into friction induced noise and vibration is based on using a fixed elastic steel disk in contact with a moving pin. The effects of changing the contact parameters such as: the pin material, pin speed, and normal load, on the disk vibration and emitted noise are

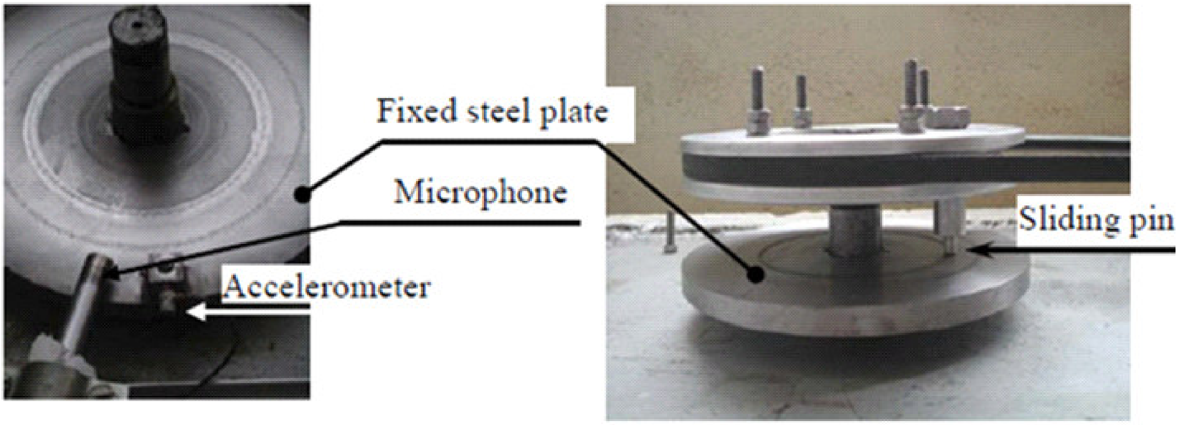

Figure 2. Test rig arrangement.

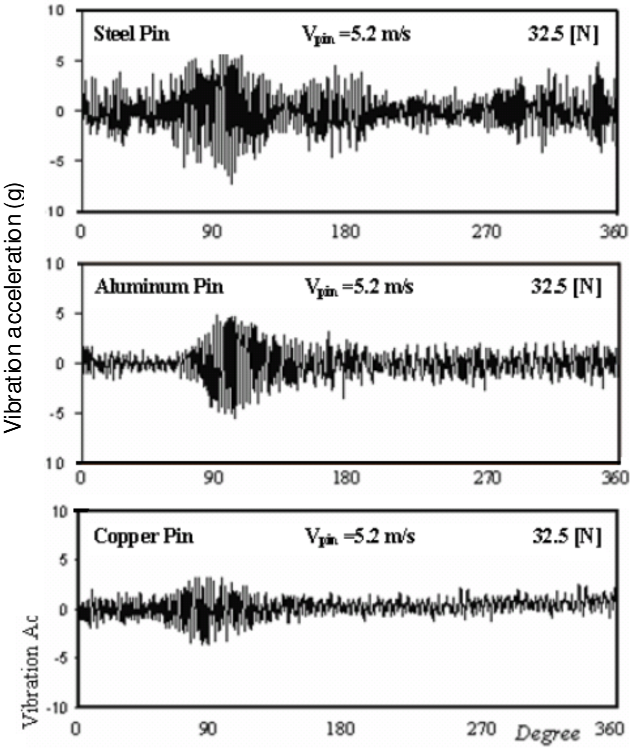

Figure 3. Effect of varying the contacting pin on the vertical vibration of the disk at pin velocity of 5.2 m/s and 32.5 N normal forces.

discussed.

Measurements are conducted three times for each test condition. Small variations; which were neglected, in the amplitude of vibration were noticed in cases stick-slip phenomenon was not detected. In such case, the first measurement is reported. In such cases where stick-slip phenomenon is detected, the variations in amplitudes of the spikes resulting from the slipping of the pin are appreciably varying; hence, the three measured vibration signals were averaged and reported.

In all figures, the vertical axes represent the vibration amplitude in gram around (10 m/s^2). The use of vibration spectrum would reveal the frequency contents of the signals, but would not show the start of the stick or the slip events. The only way to see the occurrence of these events is by means of using time signatures.

Effect of pin material on induced disk vibration

Three pins of the same geometric shape, but of different materials are used. The used pin's materials are steel, copper and aluminum. Figure 3 shows a comparison between the disk vibration, measured in the vertical direction, induced by friction between the fixed steel disk and the moving pins at pin's linear velocity of 5.2 m/s. The figure shows that, at a specific speed, the disk induced vibration because of friction is high for the steel pin and low for the copper pin.

Effect of pin speed on induced disk vibration

Figure 4 shows the disk vibration, measured in the vertical direction, due to the moving steel pin at two different pin's speeds, namely 4 and 5.2 m/s. The same comparison, when held between the copper and aluminum pins, shows the same attitude. In general, increasing the pin velocity increases the amplitude of vibration in the specific direction.

Effect of normal load on induced disk vibration

Figure 5 shows the vibration in the vertical direction for the aluminum pin, at a pin velocity of 5.2 m/s at different normal loads. The figure shows that the vibration usually increased with increasing the applied normal force. The same conclusion typically applies for all cases.

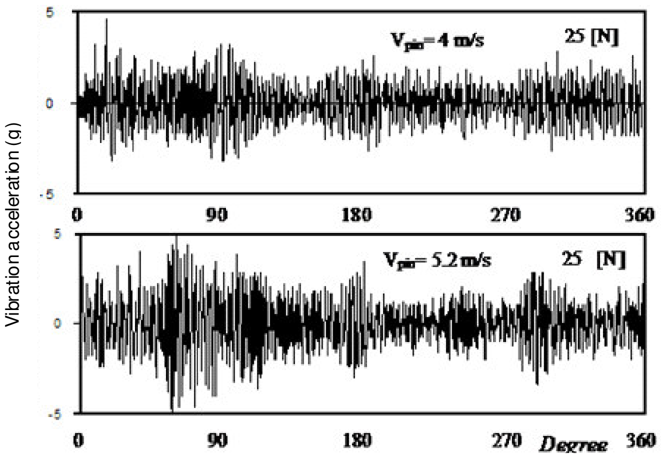

Figure 4. Effect of varying the steel pin velocity on the vertical vibration of the disk; at the same normal load (25 N).

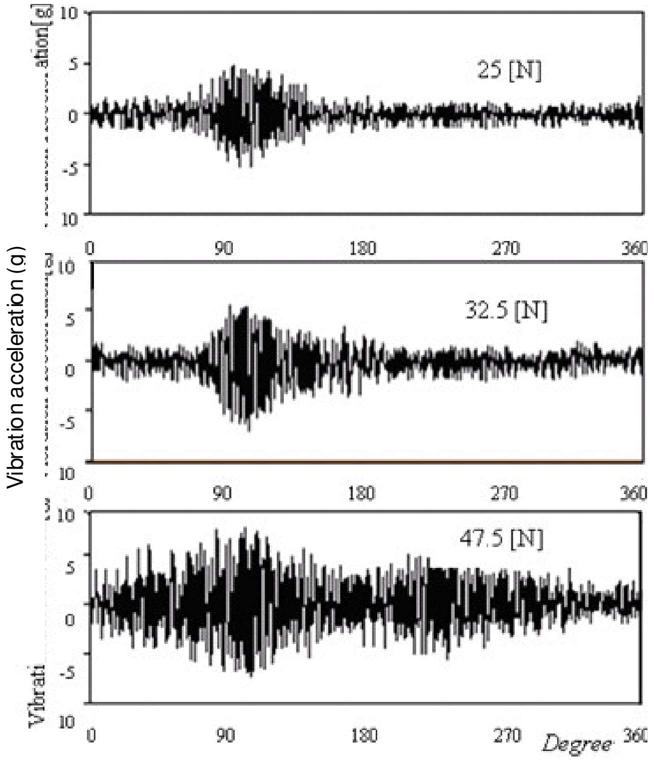

Figure 5. Measured vertical vibration of the disk using aluminum pin with linear velocity of 5.2 m/s (at different applied normal forces).

Comparison between induced disk vibrations in the three directions

Figure 6 shows a typical comparison between the induced vibration signals measured in the three perpendicular directions at a given speed and normal load. Normally, the vibration levels in the vertical direction are higher than that in the horizontal direction. However, the level of the horizontal vibration is higher than that in the radial direction.

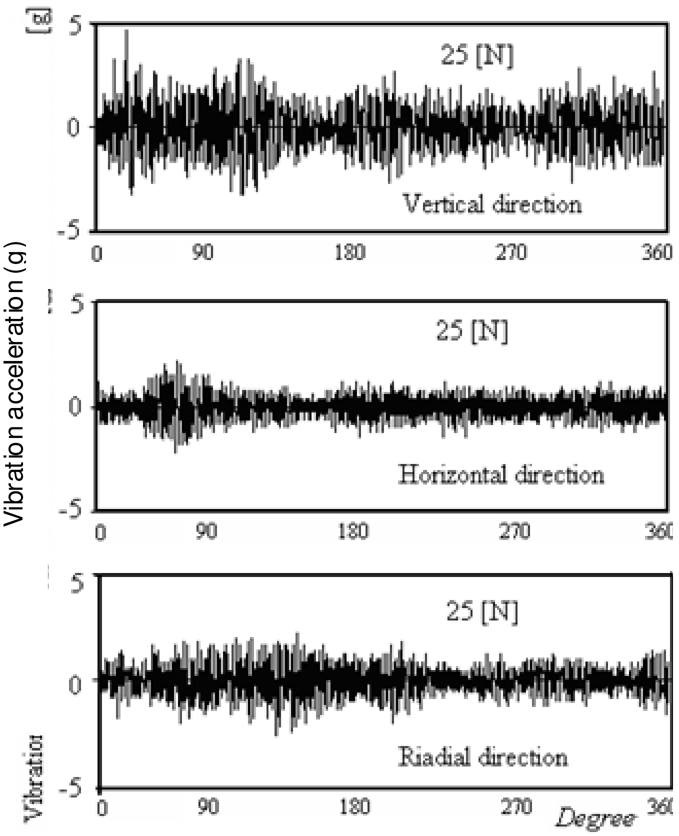

Figure 6. Comparison between disk vibration in the three directions, when the Steel pin is moving at a velocity of 4 m/s at 25 N normal forces.

Recognition of stick-slip

Simultaneous measurement of the disk vibration and the near field friction induced noise reveal the instant when the stick-slip phenomenon occurs. At that moment, the induced noise is zero. That moment is not clearly identified on the vibration signal. This is attributed to the fact that the disk will continue to vibrate even though the exciting friction force is momentarily zero. Occurrence of stick phase will momentarily induce no noise since there is no friction between the pin and the disk.

Figure 7 shows both the measured vibration amplitude in gram and noise signal (sound pressure level) in (dBA) on the same time basis for the steel pin at linear pin's velocity of 5.2 m/s and normal load of 40 N. Many stick-slip events can be identified. The arrows show some of these slipping events producing high spikes on the vibration signature and on the noise signature, too. Between any two successive slip events, there is a stick event, which is recognized by the substantially low radiated noise. This figure clearly identifies the occurrence

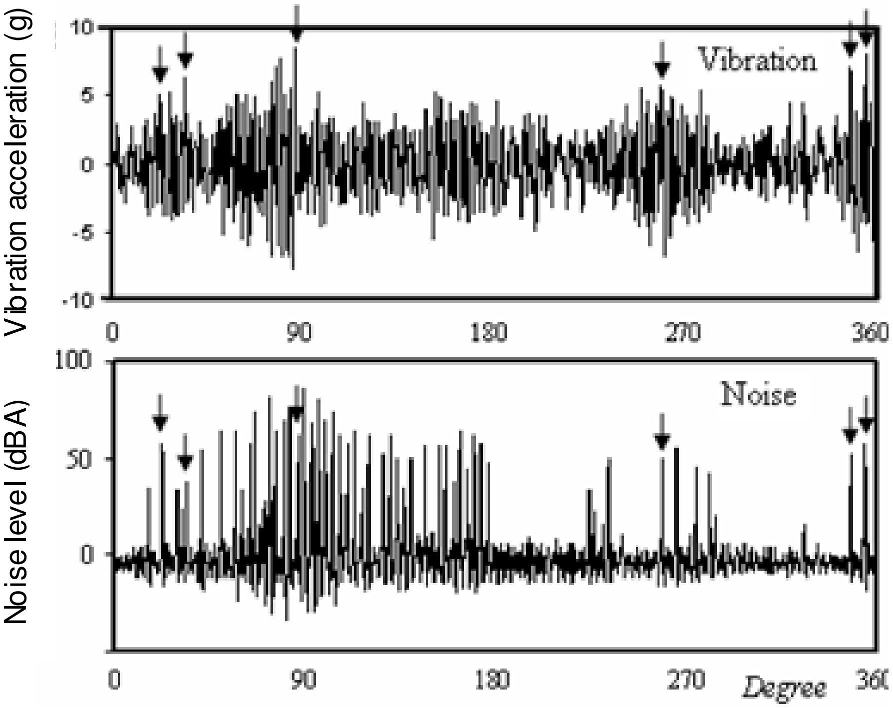

Figure 7. Measured vertical vibration of the disk and the induced noise (Steel pin, normal load 40 N, Vpin= 5.2 m/s).

of both stick and slip events. The start of the slip event is acknowledged by high spikes on both measured noise and vibration signals. On the other hand, the stick event is recognized by substantially low noise level. During the stick event, the elastic steel disk freely vibrates, therefore vibration level is not reduced greatly (during this period) like the noise level.

Conclusions

It is concluded that the vibration amplitude induced by friction is always high in the vicinity of the moving pin. In other words, the phenomenon is a transient one that, in general, has local effect on the disk.

Increasing the normal load and pin linear velocity generally increases the induced vibration amplitude. Vibration amplitude induced by friction between the steel disk and a steel pin is higher than aluminum and copper pins. Also, the amplitude of induced vibration in the vertical direction is the highest compared with that in the horizontal and radial directions.

At high loads or speeds, stick slip phenomenon is predominant. The occurrence of stick slip is clearly identified using the near field measurements of noise signals. It can be distinguished from the vibration signal as high consecutive spikes, but the existence of such spikes is clearer in the noise signature. This is attributed to the fact that noise due to friction momentarily vanishes as stick occurs.

REFERENCES

Akay A (2002). Acoustics of friction, J. Acoust. Soc. Am., 111: 1525–1548.

Bin-Bin J, Tong-Sheng L, Xu-Jun L (2007). Tribological behaviors of several polymer–polymer sliding combinations under dry friction and oil-lubricated conditions, Wear, 262: 1353-1359.

Chan SN, Mottershead JE, Cartmell MP (1994) Parametric resonances at subcritical speeds in disks with rotating frictional loads, Proc. Inst. Mech. Eng. Part C, 208(C6): 417–425.

Dweib AH, D'Souza LT (1990). Self-exited vibrations induced by dry Friction, Part I: Experimental study, J. Sound. Vib., 137: 163-190.

Earles SWE, Badi M (1984). Oscillatory instabilities generated in a double-pin and disk undamped system: a mechanism of disk-brake squeal, Proc. Inst. Mech. Eng. C, 198: 43–49.

Earles SWE, Chambers PW (1985). Predicting some effects of damping on the occurrence of disk-brake squeal noise, in: ASME Dynamic Systems and Control Division, 1, ASME, New York pp. 317–323.

Earles SWE, Chambers PW (1987). Disk brake squeal noise generation: predicting its dependency on system parameters including damping, Int. J. Vehicle Design., 8: 538–552.

Earles SWE, Lee C (1976). Instabilities arising from the frictional interaction of a pin-disk system resulting in noise generation, Transactions of the American Society of Mechanical Engineers J. Eng. Ind., 98(1): 81–86.

Emira, Nadim M (2007). Friction-induced oscillations of a slider: Parametric study of some system parameters, J. Sound. Vib., 300: 916–931

Hozumi G, Yoshifumi A (2003). Effect of varying load on wear resistance of carbon steel under unlubricated conditions, Wear, 254: 1256–1266.

Ibrahim RA (1992). Friction-induced vibration, chatter, squeal, and chao.; Part I: Mechanics of Friction; Part II: Dynamics and Modeling, ASME, J. Vib. Acoust., 49: 107-138.

Ibrahim RA, Madhavan S, Qiao SL, Chang WK (2000). Experimental investigation of friction-induced noise in disk brake systems, Int. J.

Vehicle. Design., 23; 218–240.

Jaeyoung K, Charles MK (2009), FarshidSadeghi, Wave pattern motion and stick–slip limit cycle oscillation of a disc brake, J. Sound. Vib., 325: 552–564.

Kinkaid NM, Reilly OMO, Papadopoulos P (2003). Automotive disk brake squeal, J. Sound. Vib., 267: 105–166.

Maegawa S, Nakano K (2010). Mechanism of stick-slip associated with schallamach waves, Wear, 268: 924-930.

Nakano K (2006). Two dimensionless parameters controlling the occurrence of stick-slip motion in a 1-DOF system with Coulomb friction, Tribol. Lett., 24: 91–98.

Nakano K, Maegawa S (2009). Safety-design criteria of sliding systems for preventing friction-induced vibration, J. Sound. Vib., 324: 539–555.