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Effects of Humidity and Silica Sand Particles on Vibration Generation by Friction Materials of Automotive Brake System

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***Abstract*—**This paper presents the experimental study of vibration generated by friction materials of an automotive disc brake system using brake test rig. Effects of silica sand particles which are available on the road surface as an environmental condition with a size varied from 150 μm to 600 μm are evaluated. Also, the vibration of the brake disc is examined against the friction material in humidity environment conditions under variable rotational speed. The experimental results showed that the silica sand particles have significant contribution on the value of vibration amplitude which enhances with increasing the size of silica sand particles at different speed conditions. Also, it is noticed that the friction material is sensitive to humidity and the vibration magnitude increases under wet testing conditions. Moreover, it can be reported that with increasing the applied pressure and rotational speed of the braking system, the vibration amplitudes decrease for all cases.

***Keywords*—**Friction material, silica sand particles, humidity environment, vibration of brake.

I. INTRODUCTION

THE friction material plays essential roles in various aspects of the brake performance such as a stopping distance, pedal feel, counter disk wear, and friction induced vibrations. The main requirements of friction materials are to supply unchanging friction coefficient and a small wear rate at several environmental and operation conditions. Moreover, the friction materials should be compatible with the rotor material to reduce its vibration, wear, and noise along braking action [1]-[3].

In the last few years, many researchers have investigated the brake vibration in vehicle to improve vehicle users' comfort [13]. Despite these efforts, the correlation between the physical properties of brake lining materials, the characteristic of friction layer, and their propensity to friction induced vibration generation have been poorly understood. Therefore, investigation of the relationship between the vibrations and properties of the brake lining materials are required [4].

The study of particle effect on brake performance has become a major subject between the investigators in the current researchers. Bergman et al. [5], and later Eriksson [6], are among the early researchers who relate the noise effect of brakes contact condition with the wear particles forming during the sliding process. While some researchers had found that third body formation of trapped material of the pad and disc during braking process influence the braking process and brake performance [7], Wahlstrom et al. [8] and Sanders et al. [9] had studied the effect of airborne wear particles on the wear mechanism of the automotive brake. They used various distribution particles which were obtained from different sources with several sizes. Hamid [10] studied the effect of different particle grit size on the accumulation and friction characteristic of brake system and found that the particle size affects the friction performance at certain sliding speed and pressure. The sand particles were examined at different brake pressures, disc temperatures and speeds. The experimental results found that both sand particles have a substantial effect on the brake noise occurrences [11].

This paper is focused on experimental work of disc brake vibration using brake test rig. Accelerometers are utilized to capture amplitude and vibration frequency. Conducting a series of tests under different conditions of disc speed and applied pressure are measured. Influence of silica sand particles with a different size which is available on the actual road surface is assessed. Also, water is sprayed on the friction material as an easy way to introduce the humidity condition and its effect on vibration generation is examined.

II. DEVELOPMENT OF BRAKE TEST RIG

Automotive disc brake test rig is designed to provide the necessary rotation speed and applied pressure to the different braking applications. Fig. 1 shows the brake test rig that has currently been developed. The driving unit consists of a 7.5 kW, 3 Phase AC motor with 413 Nm maximum torque. The desired speed is adjusted based on frequency mode to change rotating speeds. Brake assembly is fixed with the drive motor through a mild steel coupling and driving shaft, which is carried by two ball bearings. The required applied pressure is conducted by a hydraulic system, as shown in Fig. 2. All instruments are fastened to assess the operational and environmental parameters during braking event. An S-type load cell is used to measure coefficient of friction during the braking process by the measured braking force. Digital tachometer model DT2236B with range between 1 rpm to 1000 rpm is used to measure actual rotational speed with resolution of 0.1 rpm. Infrared thermometer with range between 20 and 250 ^{o}C is used to measure the temperature between the disc and friction brake. The main purpose of measured temperature is to ensure that the temperature of the

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braking is within the required range. A piezoelectric accelerometer type 4370 with voltage sensitivity 10 mV/ms^{-2} is used to acquire the acceleration signals. The accelerometer output signal is directly fed into five input channels analyzer Type 3560-B and is stored as vibration signatures. PULSE software is used to analyze the stored data, which are retrieved from the vibration analyzer through a charge amplifier and cable connected to the computer.

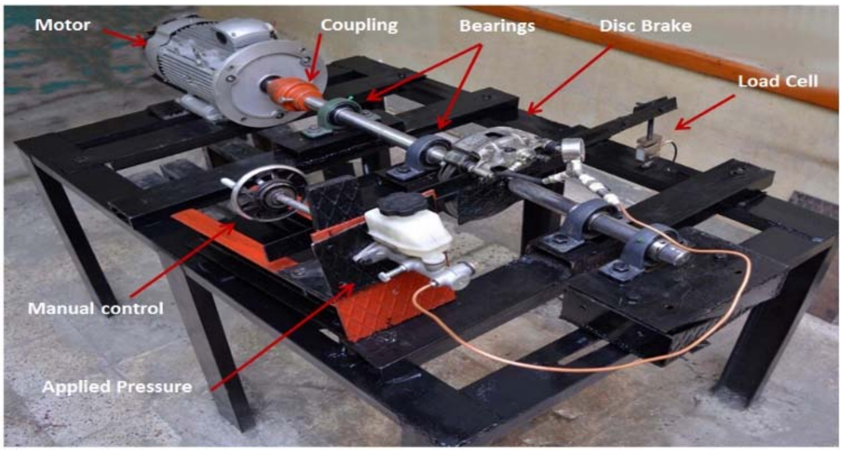

Fig. 1 Automotive brake vibration test rig

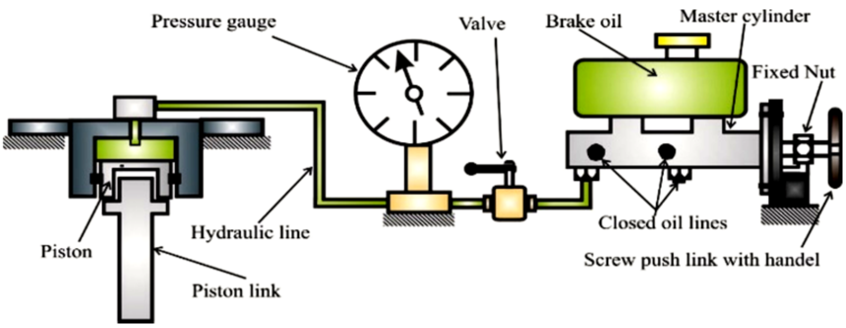

Fig. 2 Applied brake pressure measurement assembly

III. Experimental Results and Discussion

In this section, the vibration output results for various experimental tests at applied braking pressures varied from 3 bar to 12 bar and different rotational speeds ranged from 400 rpm to 1000 rpm are recorded. The baseline test is conducted at rotational speed of 400 rpm and applied pressure 3 bar at dry condition. The time domain is plotted and the maximum peak value is 0.013 m/s^2, as shown in Fig. 3. Also, the frequency domain is presented and the maximum amplitude is $6.33 *10^{-4}$ m/s^2, as shown in Fig. 4. There are many experimental tests conducted with changing the value of rotational speed as 400 rpm, 600 rpm, 800 rpm and 1000 rpm and applied pressure as 3 bar, 6 bar, 9 bar and 12 bar. It is observed that the comparison between different cases by using the time domain is difficult because of the similarity of results at several operation and environment conditions. In addition, the peak value of frequency domain can be obviously considered and used for further studies and comparisons. It is observed that changing the value of the rotational speed does not affect the maximum frequency amplitudes and at all conditions the magnitude of maximum frequency is approximately at 3.5 kHz, but only increasing the overall level of the vibration, as shown in Fig. 4.

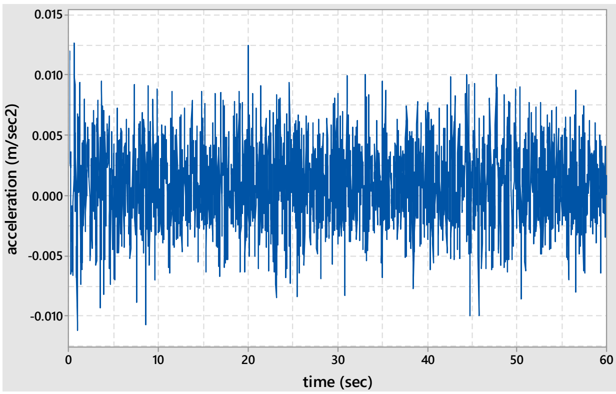

Fig. 3 Time domain baseline at 400 rpm, 3 bar and dry condition

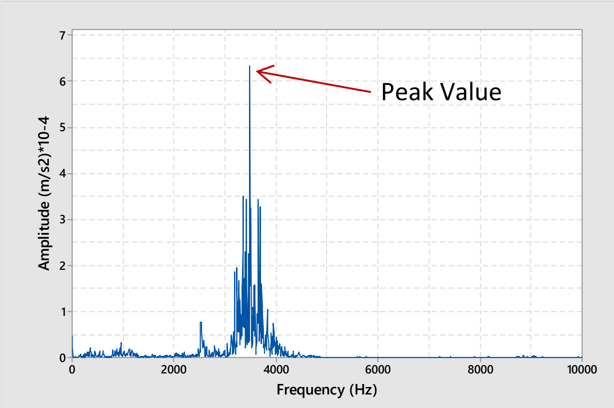

Fig. 4 Frequency domain baseline at 400 rpm, 3 bar and dry condition

A. Influence of Silica Sand Particles on Vibration Amplitude

During braking condition, all brake components are exposed to road environmental particles which may affect the surface condition of brake pads. In order to assess the influence of sand particles on the generation of disc brake vibration, a series of experimental tests are conducted in order to compare the alters in vibration amplitudes. Silica sand particles are used in this experiment as shown in Fig. 5. Silica sand particles' sizing process is carried through the sieve equipment which is sieved for 30 minutes to get the desired size. Three dissimilar size ranges of silica sand between 50-150 μm, 150-300 μm and 300-600 μm, are employed. The results show that the silica sand particles have significant influence on the vibration of the brake pad. Effect of particles of silica sand on vibration generation on the disc brake with different rotational speed is described in Fig. 6. It is found that with increasing the rotational speed from 400 rpm to 1000 rpm the vibration amplitudes decrease for all sand sizes. Moreover, the output vibration of the rougher surface area of the brake pads with silica sand particles presents more vibration than softer surface. It can be concluded that the vibration amplitude increases with increasing the size of silica sand particles. Effect of particles of silica sand on vibration generation on the disc brake with various applied pressure is depicted in Fig. 7. It is found that with increasing the applied pressure from 3 bar to 12 bar, the vibration amplitudes decrease for all silica sand particles.

Fig. 5 Adding small particles of silica sand between rotor and pad

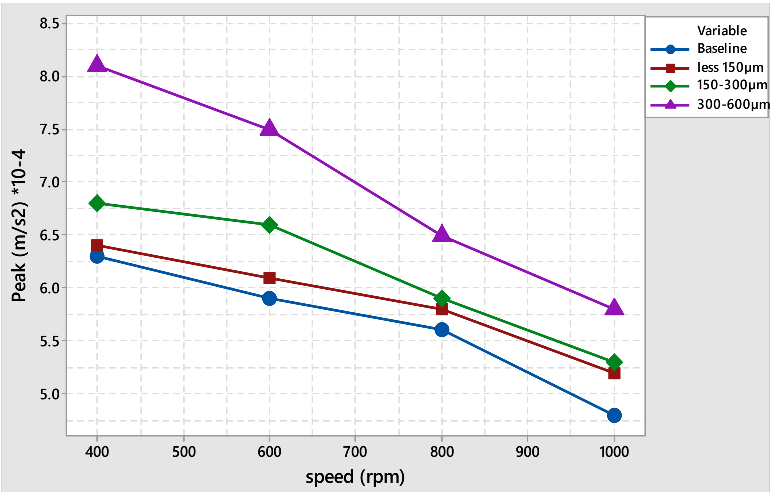

Fig. 6 Effect small particles of silica sand with different rotational speed

B. Influence of Humidity Condition on Brake Pad Vibration

In actual road conditions, a water film between the brake disc and pads is one of the factors effecting disc brake performance, which were investigated by [12]. In this study, the effect of humidity, represented by quantities of water, on friction induced vibration is examined. Water is sprayed in various quantities on the friction material as an easy way to introduce the humidity condition. Investigation of water spray is carried out at different quantities of water at 40 mm^3, 80 mm^3, and 120 mm^3 of water injection. The water injection mechanism is built to control the injected water, as shown in Fig. 8. It consists of a hose, mechanical valve, and two nozzles. A water timer unit consists of a solenoid valve, timer, and two-port electric switch, and wires are considered to control the time of water injection. The valve linked to the water hose to control the quantity of water and the solenoid valve connected to the timer via the two-port switch and wiring, controls the time injection. The timing of test is 60 seconds and the injecting spray commenced at the 30th second and ended at the 40th second. Experimental results showed that the friction material is sensitive to humidity and the vibration magnitude increases with increasing the quantities of water, as shown in Fig. 9 and Fig. 10. Effect of humidity condition on vibration generation on the disc brake with different rotational speed is described in Fig. 9. It was found that with increasing the rotational speed from 400 rpm to 1000 rpm, the vibration amplitudes decreasing for all quantities of water. Moreover, the effect of humidity condition on vibration generation on the disc brake with various applied pressure is depicted in Fig. 10. It was found that with increasing the applied pressure from 3 bar to 12 bar, the vibration amplitudes decrease for all humidity conditions.

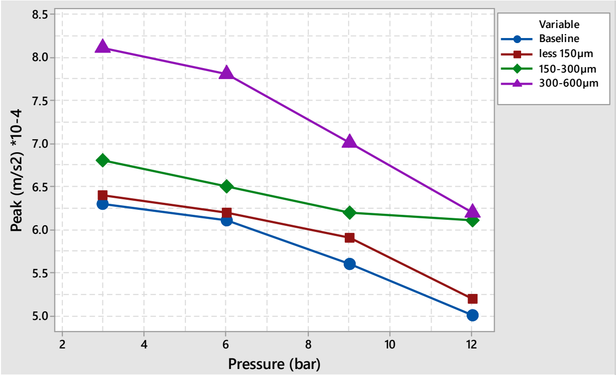

Fig. 7 Effect small particles of silica sand with different brake pressure

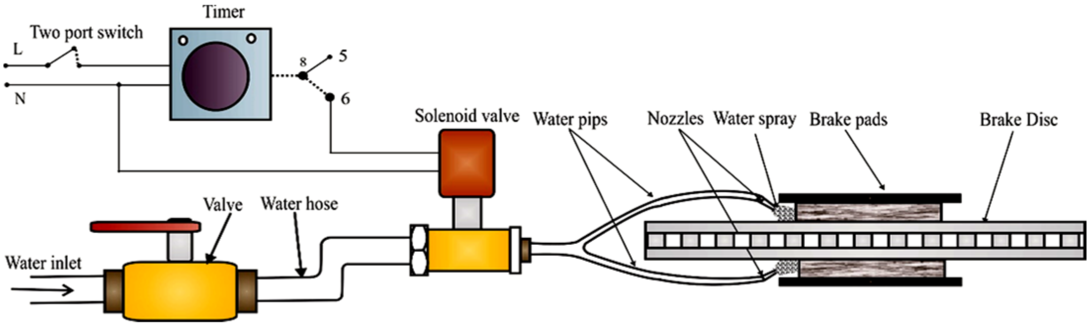

Fig. 8 Schematic of water injecting system

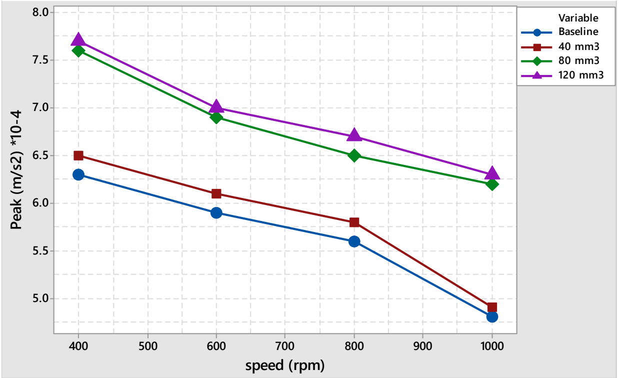

Fig. 9 Effect of humidity with different rotational speed

IV. Conclusion

In order to clarify the influence of silica sand particles and humidity on the brake vibration generation, a series of brake rig tests have been conducted. The influence of both operational and environmental conditions was assessed. The results show that, the increase of the applied force or rational speed decreases the vibration magnitude for all experimental tests. Furthermore, the results show that the silica sand particles have an influence on the surface behavior of the brake pad and vibration generation. It was found that with increasing the applied pressure, the vibration amplitudes decreasing for all silica sand particles size; this showed that the friction material is sensitive to humidity and the vibration magnitude increased dramatically by increasing the quantity of water under wet testing conditions. Moreover, it can be described that with increasing the applied pressure and rotational speed, the vibration amplitudes decrease for all conditions.

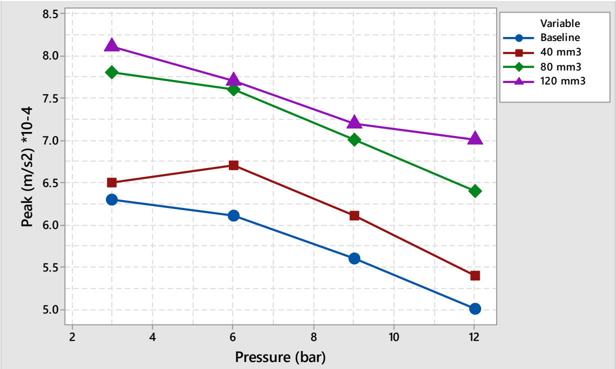

Fig. 10 Effect of humidity with different brake pressure

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