Low-Frequency Stick-Slip of a Creep Groan on a Simple Caliper-Slider Experimental Model

Zahrul Fuadi
Department of Mechanical Engineering, Syiah Kuala University
Jl. Tgk. Syech Abdurrauf No. 7 Darussalam – Banda Aceh 23111, INDONESIA
Phone/Fax.: +62-651-7428069
E-mail: zahrul_fuadi2004@yahoo.com

Abstract

This paper discussed a preliminary study of low-frequency stick-slip of a creep groan using a simple caliper-slider model. The experiment model is constructed based on the real operating system behind a vehicle braking system. The model consists of a sliding bar, a caliper and an arm. The analysis shows that the main frequency of generated low-frequency stick slip of the creep groan is 100 Hz with sound pressure level of 70 dB. It is found that the low-frequency stick-slip motion the result of the vibration in tangential direction. The frequency of the generated stick-slip is close to the bending natural frequency of the system. Several parameters that are important in the generation of the low-frequency of stick –slip are the sliding velocity and the contact roughness. Therefore, further study of creep groan should take into account these important parameters as well as other operating parameters.

Keywords: low-frequency stick-slip, creep groan

1. Introduction

Brake NVH (noise, vibration and harshness) has been a problem that receives great concern from vehicle industries. Brake NHV can be classified into two general categories according to the frequency range of its occurrence. Low frequency noises are usually called by judder, groan, and moan which frequency is ranging from tens to several hundreds Hertz. High frequency noises, which is usually referred to as squeal, has frequency of more that 1 kHz. Although brake noise does not influence the safety of brakes, it may cause discomfort to the driver, especially of a luxurious car, usually to the impression that the brake is not working properly. This kind of problems have led to warranty claims and finally caused significant refinement cost to the industry. For example, low frequency brake noise has led to a cost to the industry of US$ 100 million a year in warranty claim alone [1].

From a great numbers of literatures about brake noise the majority of them discussed high frequency squeal noise. One of the reasons is because sound pressure level of noise in this frequency region is relatively high and found to be the most annoying [2].

On the other hands, discussion about low frequency brake noise is still limited in the literatures. One of the low frequency brake noise caused by stick-slip vibration is groan. Brake groan occurs at high brake pressure and slow speed and usually involves the vibration of suspension with the frequency ranging between 40 Hz to 400 Hz [5]. A sub-category of groan is creep groan, which occurs commonly on vehicle with automatic transmission when moving off from stopping position [6]. Either of the vibration is usually perceived by the passenger as an uncomfortable buzzing sound.

Previous researches suggested that the main cause of the problem is the difference between the static and kinetic coefficient of friction of the friction material [6-8] and suggested that the solution to this problem can be made by introducing the friction material that have this property improved [9]. Other researchers also found that the suspension, particularly strut in the case of McPherson suspension type, is the resonance part in the occurrence of creep groan [5]. This finding has led to suggestion to used damping in the form of “added mass” [5] or “dynamic damper” [11] to suppress the vibration.

Despite those recommendations, there is still no general guideline to avoid the occurrence of brake creep groan and the people in the industry are generally using the trial and error method to try solving this matter. One of the difficulties is that creep groan could not be reproduced using brake dynamometer, in what researches on vehicle brake are generally conducted with. Therefore, the main challenge of understanding the problem of creep groan is to find an experiment model that can imitate the phenomenon. If the model can be established, it can be used for a comprehensive study taking account as many involving parameters as possible.

This paper summarizes a preliminary study of low-frequency stick-slip of a creep groan using a simple caliper-slider model. The aim of this study is to identify important parameters behind the generation of low-frequency stick-slip motion of the creep groan phenomena.

2. Experiment model and Data Acquisition

Brake creep groan could occur when the brake pressure is released and at the same time the vehicle is moving from standing position. A low frequency vibration can be produced on the brake interface which excites the vibration of the brake and suspension causing structure-borne sound. Based on the principle operation of brake system, an experimental model is fabricated to imitate the above mentioned situation. The model consists of a caliper, two pins, a sliding bar, and an arm that connects the caliper to a supporting clamp (Figure 1).

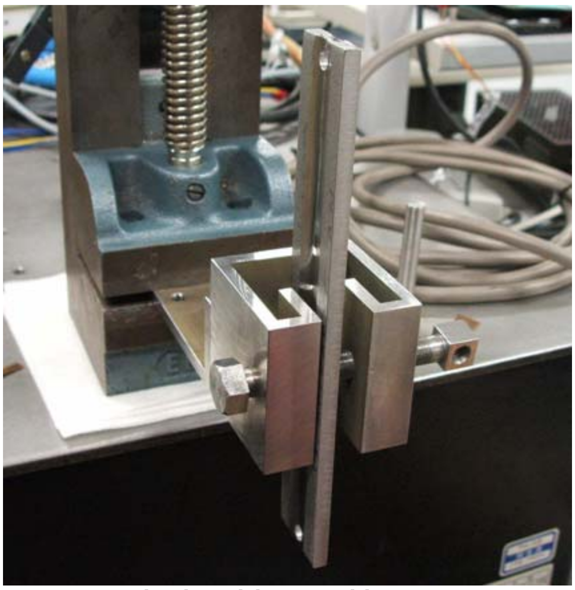
Figure 1. A simple caliper-slider test model

The caliper is made of stainless steel SUS410 (similar to AISI410) with the dimension of 45x45x45 mm. Two threaded pins of 8 mm in diameter are places on either side of the caliper and one of it is equipped by a lever for application of normal force. The pins are made of softer stainless steel of SUS403 with rounded end having a radius of 4 mm. The slider is made of stainless steel plate of SUS410 with dimension of 5 mm thick, 25 mm wide, and 150 mm long. The caliper is connected to a supporting clamp using an L-form arm of 5mm thick, 45 mm wide, and 45 mm long. A weight of 0.6 kg is hung on the slider to give a tangential force to the caliper, as well as for the slider balancing.

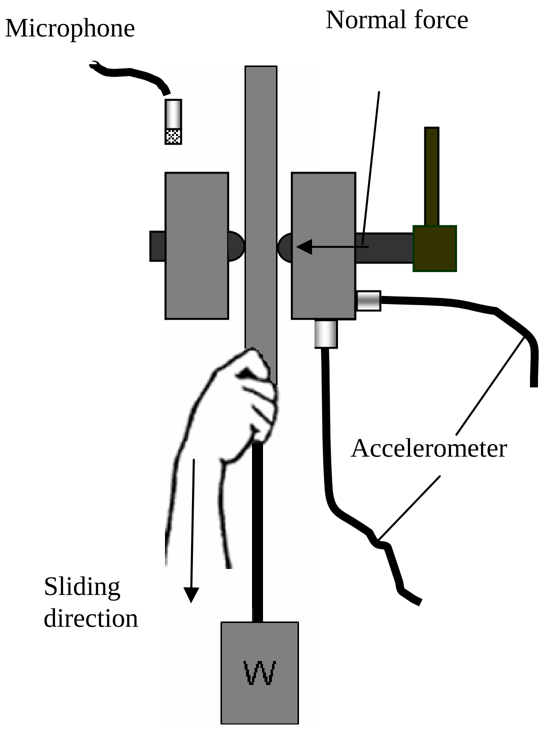

Figure 2. Experiment procedure

When the sliding bar with a hanging load is put between the caliper and the normal force is applied using the lever (Figure 2), the system acts like an operating brake of vehicle standing on a slope position. The contact between the pins and the slider represents that between pads and rotor, the normal force applied using the lever represents the brake pressure, the weight of the load represents the torque of the engine, and the arm represents the suspension that transfer the vibration to the body. If the normal force given to the caliper is just enough to keep the bar in place, the system will be in a condition where μs is about to change to μk so that even a slightest pulling force will drive the bar into sliding. If the condition is suitable, the sliding of the bar can cause a low frequency vibration at the system, resulting in a tonal sound. In this case, this phenomenon is similar to brake creep groan.

To record the vibration spectra, two accelerometers are placed on the caliper each in tangential direction (in sliding direction) and in normal direction (perpendicular to sliding direction). A microphone is also used to record the generate sound. The sensed sound and acceleration signal are recorded through a B&K Nexus conditioning amplifier. Recorded acceleration spectra and sound of a sliding test is given in Figure 3.

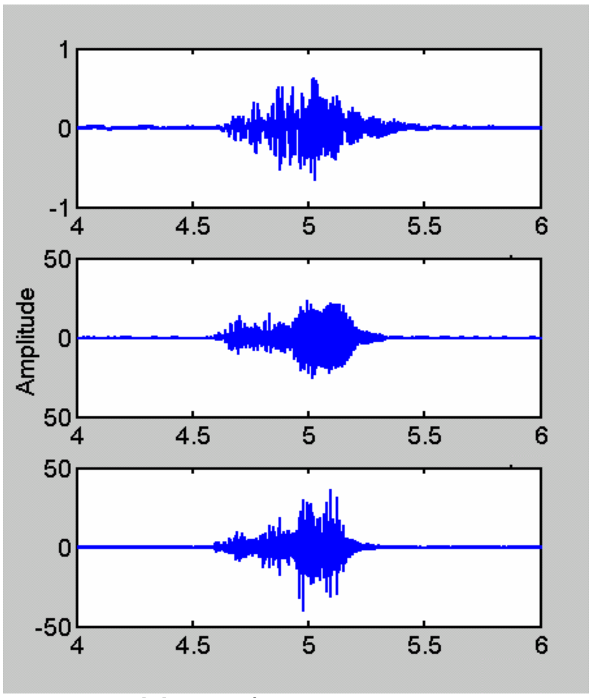

Figure 3. Recorded spectra of creep groan

3. Results and Discussion

Figure 4 shows recorded spectra of a sliding test in the frequency domain. The power spectral density (PSD) of sound has a dominant peak at the frequency around 100 Hz with a value of 62 dB/Hz (re 20 μPa). The second less dominant peak occurred at around 200 Hz with a value of 30 dB/Hz (re 20 μPa). As it can be observed from the figure, the PSD of tangential acceleration also shows a dominant peak at similar frequency region. On the other hands, acceleration in normal direction shows several dominant peaks in a wider frequency range and have lower value than that of tangential acceleration.

The first PSD peak at about 100 Hz gives a sound pressure level (SPL) of 70 dB and the second PSD peaks at near 200 Hz gives SPL of about 40 dB. Referring to groan frequency range, which is below 400 Hz, it is considered that groan in this analysis have the frequency of around 100 Hz which have SPL 70 dB, a well noticeable sound. The second peak of around 200 Hz is also potential for a creep groan but since the sound pressure level is quite low, 40 dB, it is not considered.

The sound at 100 Hz is contributed mainly by the acceleration in tangential direction because its PSD is dominant in this frequency. Although PSD of normal acceleration also has a peak in this particular frequency, this peak is not a dominant one. Therefore, normal acceleration is considered less important.

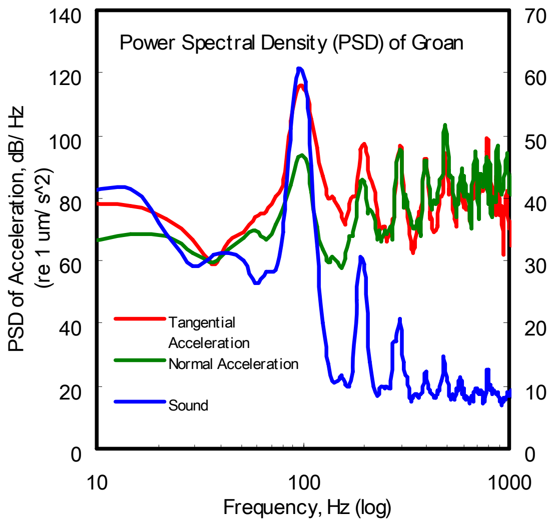

Figure 4. Recorded groan spectra in the frequency domain

Relationship to the system's dynamics

To find out what determines the frequency of the vibration, a modal analysis is conducted to the system. Figure 5 shows the frequency response function (FRF) curves obtained using impact response test. As it can be seen from the figure, the lowest bending mode of the slider has a frequency of about 1100 Hz. This frequency is well above the range of groan frequency so that it can be said that the recorded groan in this test is not coming from the vibration of the slider. On the other hands, the caliper system has several modes in the frequency region below 500 Hz. The first mode's frequency is 50 Hz, the second one is 96 Hz and the third one is about 500 Hz. When the slider with a load of 0.6 kg is put between the calipers with normal force applied, the two higher frequencies are decreased to 420 Hz and 85 Hz but the lowest mode stays at the same frequency.

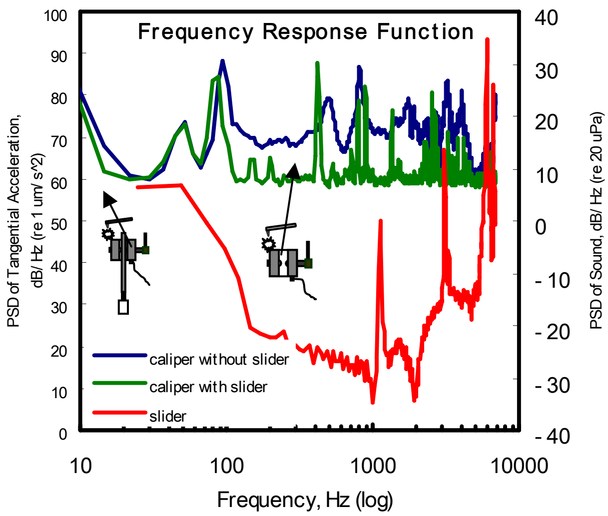

Figure 5. Frequency response function of the caliper-slider test model

From this result, the system's natural frequency that is closest to the occurred groan sound is 96 Hz. This is a lateral vibration of the caliper contributed by the stiffness of the arm. This is actually expectable because the arm is the part that has the lowest stiffness. It is further clarified that the frequency of groan increased when shorter arm is used.

If comparison is made with the real brake system, the role of the arm in this test model is almost similar to that of the strut of a McPherson suspension model. The strut is found to be the most vibrating part during brake creep groan of a McPherson suspension model and also the part that transmits the vibration to the body [5].

Effect of sliding speed

Because the system is driven into vibration as the sliding begins, it is interesting to examine whether the speed of sliding has any influence to the generated groan. Although the real velocity of the sliding is not available, the speed of sliding for this test is estimated to be 2 cm/s. To find out the effect of sliding speed, the tests are then conducted with sliding speed slower and faster than that value. The result (Figure 6) shows that the sound pressure level decrease when the speed of the sliding is higher or lower that about 2 cm/s. The SPL of the fast sliding, the 2 cm/s sliding, and the slow sliding of the PSD of sound in Figure 5 are 64 dB, 73 dB, and 48 dB, respectively.

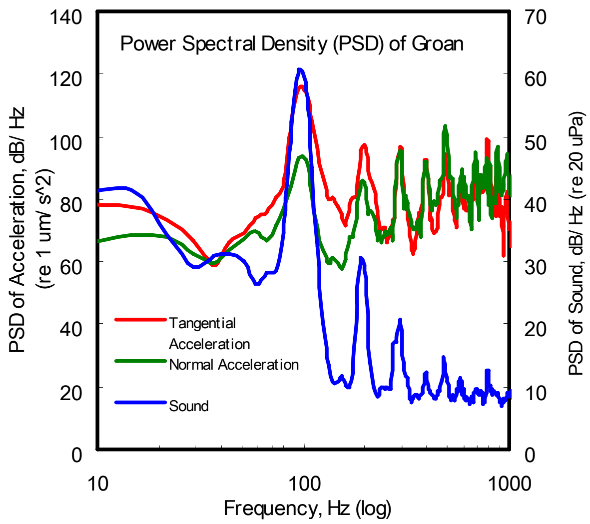

Figure 6. Effect of sliding speed

This result suggested that creep groan sound is not immediately occurred as the sliding starts but it requires a steady slow sliding before it is developed to its maximum intensity although the vibration does start on the immediate moment. It should be noted that although the speed of the sliding affects the groan sound intensity, it does not change the frequency of the sound or the vibration itself. However, in the real brake operation, sliding speed can not be taken into an input parameter because it is actually a result of combination among tangential force (engine torque), normal force release rate (brake pressure release rate), and the vehicle inertia. Therefore, tangential force and normal force release rate are likely more suitable for input parameter.

Effect of contact condition

Contact is one of the most important factors in the occurrence of stick slip vibration including creep groan. Among parameters that determine the contact condition is surface roughness. Figure 7 shows the effect of roughness to the generated power spectral density of tangential acceleration. When the roughness of the contact is Ra = 0.25 μm, the peak PSD has the value of 120 dB/Hz (re 1 μm/s^2) which is resulted in sound pressure level of about 70 dB. On the other hand, contact roughness of Ra = 0.14 μm only produce sound pressure level about 40 dB.

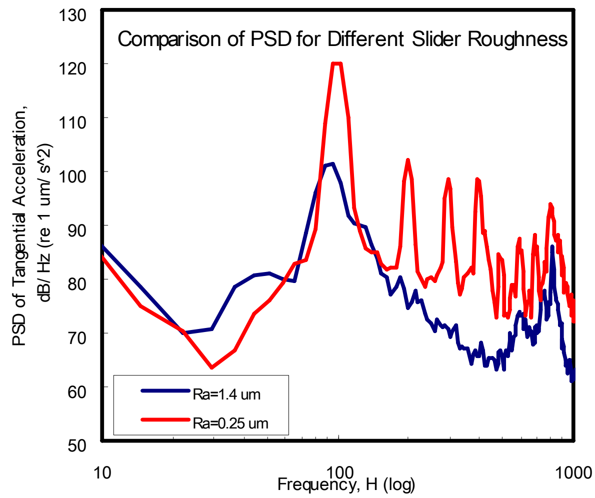

Figure 7. Effect of roughness

This result shows that roughness is a significant parameter that determines the quality of creep groan. However, other parameters such as material properties, humidity, and temperature are also important because they are altogether contributing to the complexity of a contact.

4. Conclusion

This paper has introduced a simple experiment model for studying the phenomenon of low-frequency stick-slip of a creep groan. The experiment model is based on the real operating system of vehicle brake consist of a sliding bar, a caliper and an arm to connect them to the base.

The analysis shows that the main frequency of generated creep groan is 100 Hz with sound pressure level of about 70 dB. Creep groan is found to be resulted from the vibration in tangential direction which is close to the bending natural frequency of the system. Several parameters that are important in the generation of creep groan are sliding velocity and contact roughness.

Further study of creep groan should take into account all of input parameters such as operating parameters and tribologycal parameters to obtain a comprehensive understanding about creep groan occurrence.

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