

Transfer Path Analysis of Brake Creep Noise

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ABSTRACT

Creep groan is a low frequency noise generated by the stick-slip phenomenon that occurs when moderate brake pressure is applied between the surfaces of the brake disc and brake pad in a low-speed vehicle. It generally occurs when a vehicle is starting to move from a complete static condition or as it slowly comes to a stop when driving. Transfer path analysis (TPA) is a technique than not only provides a methodical approach to trace the flow of vibro-acoustic energy but also allows users to analyze structure-borne noise contributions. Thus, TPA is extensively used to scrutinize creep groan. The primary purpose of this paper is to empirically identify and evaluate the influences of the environmental conditions, chassis system, and brake material on creep groan using the TPA technique. Once the route that contributes the most vibro-acoustic energy from the source to the receiver is identified through TPA, a mass is added on that specific path to observe the changes in creep groan. This test is iterated several times with different masses to determine the optimized mass for that path.

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INTRODUCTION

Creep groan is a low frequency noise generated by the stick-slip phenomenon that occurs when moderate brake pressure is applied between the surfaces of the brake disc and the brake pad in a low-speed vehicle. It generally occurs when a vehicle is starting to move from a complete static condition or as it slowly comes to a stop when driving. It has always been a challenge for NVH engineers to optimize the vehicle brake system and vehicle chassis to eliminate creep groan. They have endeavored to improve vehicle brake systems through various experiments. Kim [1] carried out an experiment to evaluate the correlation between the creep groan and its dependency on a material's friction. Brecht [2] showed that creep groan noise is produced by the twisting moment of the brake. Their works caused much of the researches on creep groan and the stick-slip phenomenon to veer in different directions. In the past, empirical approaches were frequently used to investigate such problems; nowadays,

structural design optimization approaches are being used. For example, Crowther [3, 4] carried out an experiment to investigate creep groan by coupling the brake to the driveline system and analytically investigating the system considering nonlinear dynamic behaviors. Bettella [5] showed that the creep groan phenomenon is structure-borne. Through a computer simulation, Donley [6] early on identified that the strut mount in a vehicle chassis significantly contributes to creep groan. However, no studies have successfully validated their data nor provided explicit solutions to reduce creep groan from either the vehicle chassis' or brake systems' perspective. This is because of the technical difficulties involved in the experimental setup. For valid empirical creep groan testing, both the internal and external environmental conditions have to be adjusted and maintained throughout the experiment, which obviously cannot be easily accomplished. The primary purpose of this paper is to empirically identify and evaluate the influences of the environmental conditions, chassis system, and brake material on creep groan using a

TPA technique. Once the route that contributes the most vibro-acoustic energy from the source to the receiver is identified using TPA, a mass is added to that specific path to observe the changes in creep groan. This test is iterated several times with different masses to determine the optimized mass for that path.

CREEP GROAN NOISE PHENOMENA

Experimental Setup for Generating Creep Groan

Creep groan noise generally occurs under the following three conditions: right at the moment when a vehicle is starting to move from a stopped condition (called the starting mode); right at the moment when a vehicle is slowly coming to a stop (called the stopping mode); and finally, the moment when a vehicle is rolling slowly as a result of constant moderate brake pressure being applied on the brake (called the just-slip mode). The creep groan generated during the starting and stopping modes is extremely difficult to measure because of its short duration. Thus, to persistently reproduce creep groan to achieve a reliable analysis, a test is conducted entirely using the just-slip mode, which could be artificially generated by providing moderate pressure on the brake. The creep groan is reproduced on a chassis dynamometer, as shown in [figure 1](#). The procedure for generating creep groan for the experiment is as follows. First, align the wheels on the chassis dynamometer roller and set the dynamometer in neutral mode. Make sure that the entire car is strapped down rigidly before firing up the engine. Second, switch the vehicle from the stop mode to drive mode while fully pushing down on the brake pedal. Third, gradually release the brake pedal to find the spots where creep groan is produced for several seconds. [Figure 2\(a\)](#) shows the actual laboratory setup where the experiment is conducted. In this experiment, creep groan is measured using a microphone located at the position of the driver's right ear, as shown in [figure 2\(b\)](#). The measurement was conducted 20 times to obtain an average to analyze the randomly occurring peak frequency between 180 Hz and 200 Hz, as shown in [figure 3](#). Because the magnitude of the creep groan is 20 dB higher than the operating engine sound in the frequency range of interest, data are recorded along with the operating engine.



Figure 1. Generating creep groan on chassis dynamometer.

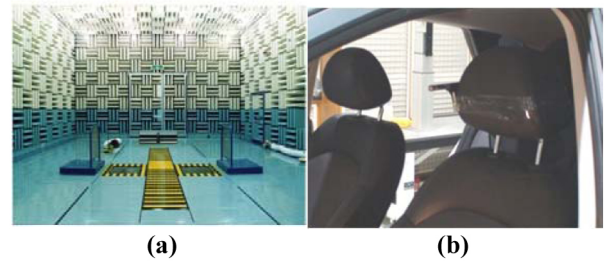


Figure 2. (a) Semi-anechoic chamber and (b) chassis dynamometer.

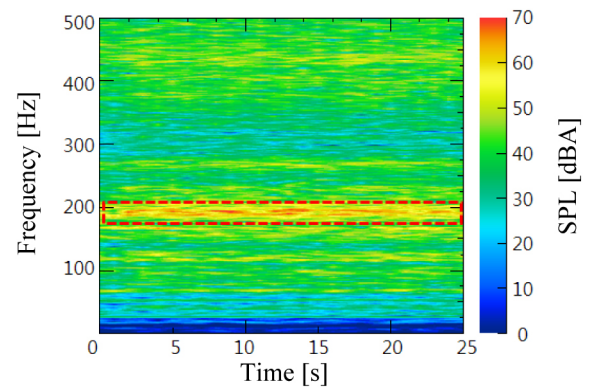


Figure 3. Colormap of creep groan.

Influence of Brake Pressure on Creep Groan

Two different brake pressure ranges that generate creep groan in different environments are shown in [figure 4](#). [Figure 5](#) shows the characteristics of the frequencies in the creep groan noise generated by two different brake pressures in the same environment. Notice that the magnitudes of these two datasets are almost the same even though they are measured in exactly the same environment but with different brake pressures. [Table 1](#) lists the average values of 20 repetitions of the tests for the noise characteristics of the creep groan, including the peak frequency, peak sound pressure level, and overall sound pressure level.

Table 1. Values of creep groan in two different brake pressure.

Brake Pressure [bar]	Peak Frequency [Hz]	Peak SPL [dBA]	Overall SPL [dBA]
8.4	180 ~ 200	67.11	73.89
6.1	96, 193	69.30	73.47

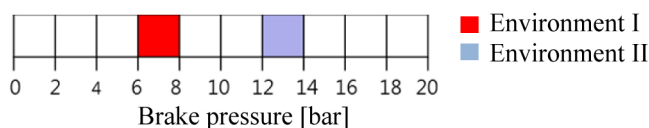


Figure 4. Brake pressures in different environments.

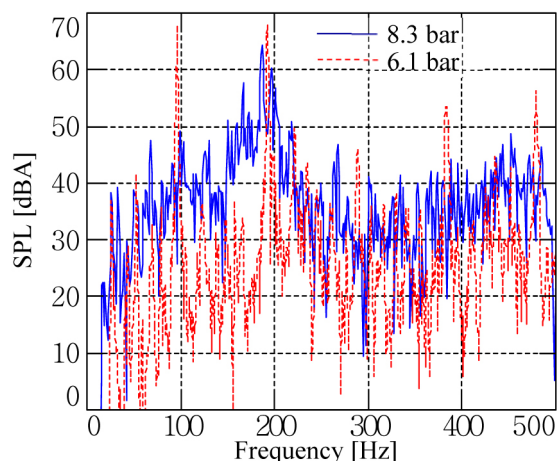


Figure 5. Spectra of creep groan generated by two different brake pressures.

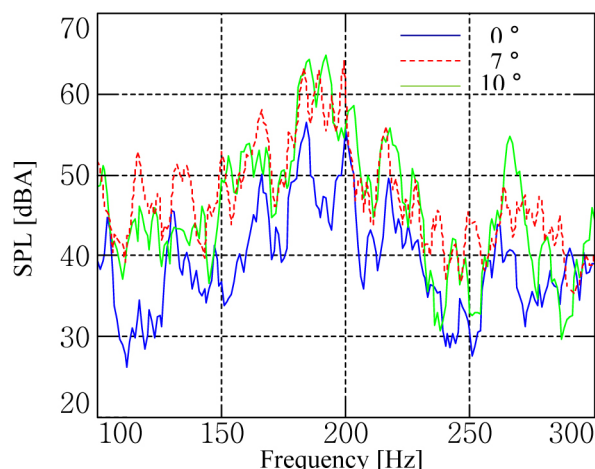


Figure 6. Spectra of creep groan for different slope angles.

Influence of Road Steepness on Creep Groan

When a vehicle is rolling down a steep hill, more brake pressure is required to stop than when it is moving on a flat road. Moreover, the steepness of the hill is directly proportional to the brake pressure required to stop the vehicle. From the results of the previous experiment, notice that the overall sound pressure level of the creep groan rises with the brake pressure level applied between the brake caliper and the disk at the range that generates creep groan. Thus, a louder overall sound pressure level is anticipated at a steeper slope for a road. However, this is only true until the slope of the road reaches a certain angle, as shown in [figure 6](#) and indicated in [Table 2](#). When the angle of the slope becomes greater than that particular angle, the overall sound pressure level seems to remain constant, without increasing. This result can be interpreted as indicating the existence of a specific threshold where the creep groan becomes maximum, which is influenced by the characteristics of both the brake pad and the disk material.

Table 2. Values of creep groan for different slope angles.

Steep Angle [°]	Brake Pressure [bar]	Peak SPL [dBA]	Overall SPL [dBA]
0	5.3	56.62	66.98
7	14.2	66.00	75.61
10	17.5	65.27	75.17

Influence of Absolute Humidity on Creep Groan

The creep groan is measured at various humidity levels after a vehicle is left for 10 hrs; the values are listed in [Table 3](#). For this experiment though, the first measured value is provided instead of the time-averaged data because the environmental condition changes each time the vehicle is runs for the test. [Figure 7](#) shows the result of the very first measured creep groan sound pressure level. This result shows that, as the absolute humidity increases, the brake pressure required to produce creep groan increases and hence, the overall sound pressure level also increases.

Table 3. Values of creep groan under different absolute humidities.

Absolute Humidity [g/m ³]	Brake Pressure [bar]	Peak SPL [dBA]	Overall SPL [dBA]
3.4	4.8	45.95	57.84
8.5	5.3	51.23	60.96
10.1	5.5	54.24	63.26
14.9	6.8	58.70	68.47