SAE International

SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J2598 JUL2012

Issued 2006-01
Revised 2012-07

Superseding J2598 JAN2006

Automotive Disc Brake Pad Natural Frequency and Damping Test

RATIONALE

The SAE Brake NVH Standards Committee reviewed the SAE J2598 standard and agreed that:

- No modification is required in the measurement requirements/test configuration sections.

- Additional methods to calculate the damping factor should be added to the standard (Chapter 9).

FORWARD

Natural frequencies and damping are important characteristics of a brake pad assembly. There are currently no recognized standards for measuring these quantities.

1. SCOPE

This procedure is applicable to brake pad modes between 500 Hz and 16 kHz. The parameters measured with this procedure are defined as the first three natural frequencies, f_n (n=1, 2, 3), and the corresponding loss factors, η.

1.1 Purpose

This recommended test practice is intended to establish a standardized and repeatable method for performing natural frequency and damping measurements on a disc brake pad.

2. REFERENCES

2.1 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

D. J. Ewins, Modal Testing Theory, Practice and Application, Second Edition, 2000, Research Studies Press LTD, England

B&K Technical Review n°1, 1994: "Digital Filter Techniques vs. FFT Techniques for Damping Measurements", Svend Gade & Henrik Herlufsen

3. GLOSSARY AND TERMINOLOGY

3.1 NATURAL FREQUENCY

One of the frequencies at which the pad naturally vibrates at when excited in a free-free condition.

3.2 LOSS FACTOR

The energy loss factor, η, which is the percent critical damping divided by 50.

3.3 DAMPING

This is generally expressed as the percentage of critical damping.

4. ORGANIZATION OF THIS DOCUMENT

This document separates the measurement procedures to obtain the brake pad natural frequency and that required to obtain the loss factor. The reason for this separation is that in the development of this procedure significant differences were found in the repeatability of the results for these two measurements between different testers. The result is that highly accurate and consistent natural frequency data can be obtained with less rigorous measurement system and procedure requirements. This measurement procedure is presented in Part A.

The more rigorous loss factor measurement procedure is presented in Part B. It is important to note that although the requirements for this measurement are more stringent there is still greater variability in the loss factor results. The magnitude of this variability will be discussed in some detail in Part B.

The first step is to define the basic measurement configuration and the requirements common to both parts A and B.

5. MEASUREMENT REQUIREMENTS

- Excitation:
  - A metal tipped impact hammer with force transducer is the preferred method of excitation. Other methods of excitation such as a shaker may be used with proper care and documentation of equivalent results.
- Response:
  - Typically a microphone or an accelerometer will be used to measure response. A single point laser vibrometer can also be used. If a transducer other than a microphone or accelerometer is used, a comparison test shall be run to show equivalence.
  - The recommended microphone is a 0.5 in free-field condenser type. The recommended accelerometer is one with an integrated amplifier or a charge type.
  - The recommended accelerometer is different for parts A and B. The specific requirements will be defined in these sections.
  - Frequency response from 500 to 16 000 Hz ±3 dB.
- Dual-channel FFT analyzer capable of calculating a frequency response function (FRF) and simple coherence.

6. TEST CONFIGURATION

The preferred measurement setup is shown in Figure 1. This configuration shows the use of a microphone for the response measurement and an impact hammer for excitation. The same setup can be used with an accelerometer. One may use equivalent non contacting measurements such as Laser Doppler Vibrometer, if the results can be shown to be equivalent.

To be sure that the lower three natural frequencies and their corresponding loss factor are measured, it is necessary to excite both torsional and bending modes. The lowest three natural frequencies may then be selected from these results with high confidence.

Figures 2 to 4 show three suggested measurement configurations. Using all three of these combinations of force input and response locations, one can be confident of that the lowest three natural frequencies will be measured.

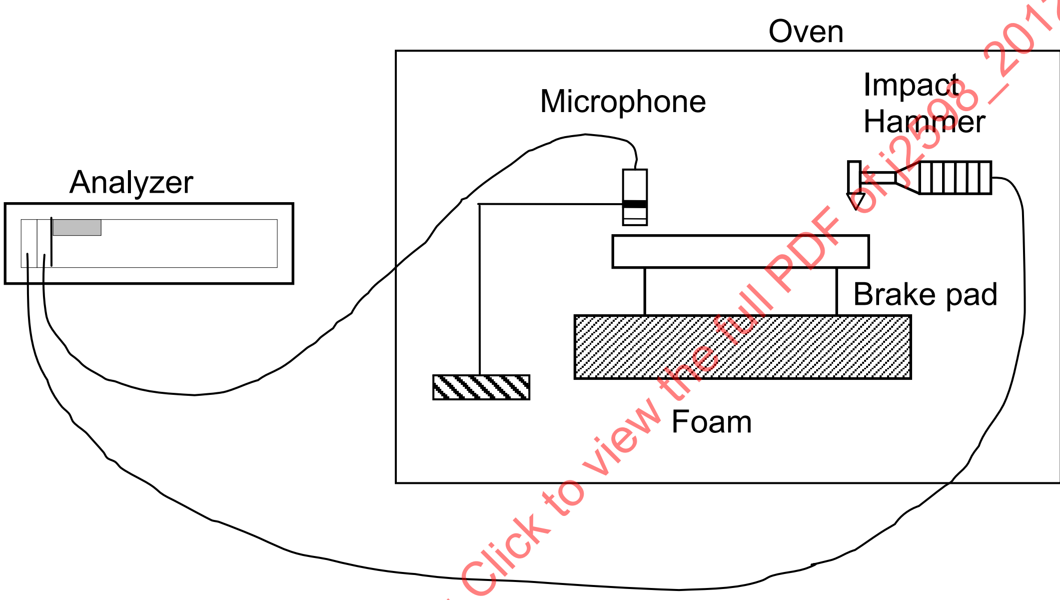

FIGURE 1 - BLOCK DIAGRAM OF A BRAKE PAD LOSS FACTOR MEASUREMENT SETUP

The Figure 2 setup will be prone to the excitation of the bending modes of the brake pad.

To assure that torsional modes are excited and measured, the configurations shown in Figures 3 and 4 can be used. In this arrangement, it is important to excite and measure at the farthest edges of the pad (even if it means exciting on chamfers).

FIGURE 2 - BRAKE PAD NATURAL FREQUENCY AND LOSS FACTOR MEASUREMENT CONFIGURATION NUMBER 1

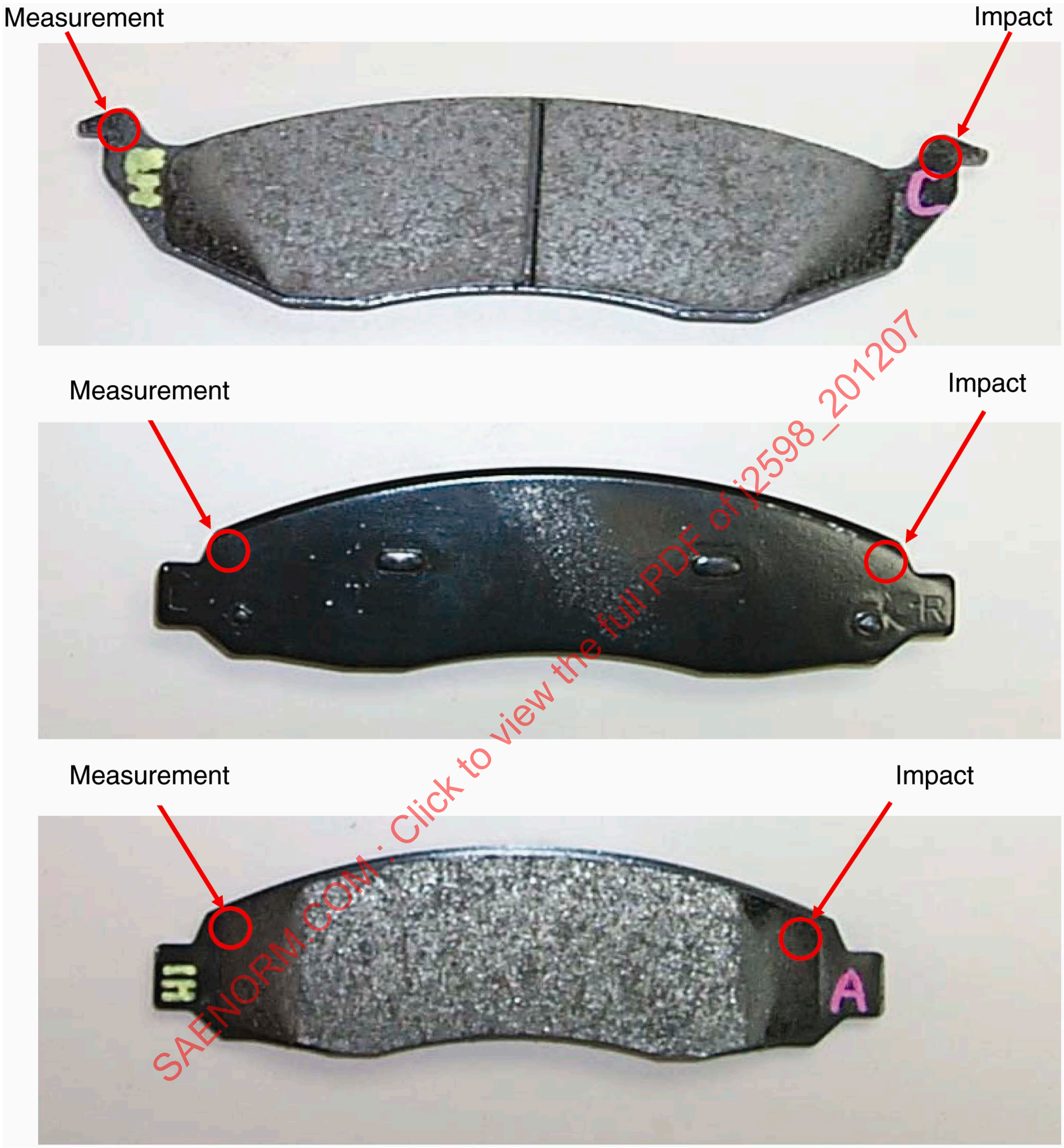

FIGURE 3 - BRAKE PAD NATURAL FREQUENCY AND LOSS FACTOR MEASUREMENT CONFIGURATION NUMBER 2

FIGURE 4 - BRAKE PAD NATURAL FREQUENCY AND LOSS FACTOR MEASUREMENT CONFIGURATION NUMBER 3

7. OPERATION

In an effort to minimize the effect of environmental conditions, the measurement should be conducted between 18 °C and 24 °C and 30 to 80% relative humidity. Record the ambient temperature and humidity.

Place the brake pad on a foam pad as indicated on Figure 1. For Part A any soft closed cell foam pad can be used. For Part B, a specific foam pad must be used. Other equivalent means of simulating free-free mounting conditions are also acceptable. Care should be taken to avoid restraining the motion of the pad at antinodes.

Locate the microphone or accelerometer on top of the pad, as indicated on Figure 1. The gap between the microphone and the pad should be around 5 mm. If an accelerometer is used, bond it to the pad using Loctite adhesive

The measurement can be done with or without a brake insulator. Record the microphone/accelerometer and hammer positions used for this test.

Connect the impact hammer to channel 1 and the microphone or accelerometer to channel 2 of the analyzer.

Prepare the analyzer for data acquisition and analysis according to the following:

- Analyzer frequency range from 500 to 16 000 Hz.
- Pre-trigger delay properly set to ensure that the entire force pulse is captured.
- Trigger level adjusted such that the data acquisition system properly captures the impact and acoustic response.
- The maximum value of frequency resolution should be 5 Hz.
- A force window shall be used for the excitation data acquisition.
- Absolutely no windowing should be required on the response channel. Should the response not decay completely in the sampling window, the analyzer parameters must be adjusted to allow the complete decay to be captured. This adjustment may be done by increasing the number of sample points, adjusting the period, or the frequency range.

Record the analyzer setup.

It is important to adjust the analyzer so that the FRF between the microphone/accelerometer and the impact hammer and the coherence function are both displayed as shown in Figure 5.

Hit the pad with the hammer a minimum of 5 times at the same location. These hits must occur preferably on the backing plate (hitting the friction material is an option). The analyzer should be configured to compute a linear average the results of these impacts to obtain a high quality signal. The quality of the signal will be judged by computed coherence. Reject the measurement if the coherence is below 0.9 for the resonant peaks. Avoid double hits. Data obtained with double hits shall be rejected. When using a microphone, reduce the gap between the microphone and the pad if the quality of the FRF needs to be improved.

8. PART A: MEASUREMENT OF PAD NATURAL FREQUENCIES

- Response:
    - Typically a microphone or an accelerometer will be used to measure response. A single point laser vibrometer can also be used. If a transducer other than a microphone or accelerometer is used, a comparison test shall be run to show equivalence.
    - The recommended microphone is a 0.5 in free-field condenser type.
    - The recommended accelerometer is one with an integrated amplifier or a charge type with a mass of less than 1 g.
- Operation:
    - Identify the resonance frequencies on the FRF (Figure 5).
    - Repeat the measurements for configuration 2 (Figure 3) and configuration 3 (Figure 4). The user must report the natural frequencies computed for each configuration. The reported natural frequencies are the average of the lowest three natural frequencies found (Table 1).
    - The variation expected from this measurement is natural frequency: ±5% from the average.

9. PART B: MEASUREMENT OF PAD LOSS FACTOR

It is extremely difficult to measure damping consistently. In order to achieve a reasonable level of consistency, the following steps have to be followed:

- Response:
    - Select an accelerometer with a weight less than 1 g. Examples of accelerometers that can be used are: PCB 357C10 (0.45 g), PCB 357A09 (0.6 g), PCB 357A08 (0.14 g), Endevco 2222C (0.5 g), Endevco 2250A/AM1-10 (0.4 g), Endevco 22 (0.14 g) or equivalent.
- Foam:
    - The foam rubber used to simulate the free-free conditions is GM251M (Type I or Type IA) from Plastomer Corporation, Livonia, MI 48150, Tel: 734-464-0700 or equivalent. The foam thickness is 50 mm.
- Operation:
    - Identify the resonance frequencies on the FRF (Figure 5).
    - Repeat the measurements for configuration 2 (Figure 3) and configuration 3 (Figure 4). The user must report the natural frequencies and loss factors computed for each configuration. The first three natural frequencies are the averages of the equivalent lowest natural frequencies detected. The loss factor for each natural frequency is the lowest computed value (Table 1).

The loss factor for each natural frequency shall be measured using the half-power or 3 dB method. The loss factor is defined by $\eta = \frac{\Delta f}{f}$ where Δf is the frequency bandwidth at 3 dB below the resonant peak and f is the resonant peak frequency (Figure 6).

If another bandwidth n is used, the following formula can be used:

$$\eta = \frac{1}{\sqrt{\left(10^{\frac{n}{20}}\right)^2 - 1}} \frac{\Delta f}{f}$$

Where:

n is the $n\ dB$ down point, and Δf_i is the frequency bandwidth for $n\ dB$ down point, Hz.

A single degree of freedom parameter identification method can also be employed.

The method used to calculate the loss factor (or damping factor) should be documented.

Many modern analyzers will have this calculation built in as an automated function. Whether this is done automatically by the analyzer or is done manually by the user, this calculation must be done using a linear interpolation between discrete points in the frequency response function. If only the discrete points of the FRF spectrum are used, significant errors in the loss factor estimate are possible.

Some analyzers have a function which gives you the damping ratio ξ in %, by placing the screen cursor on the peak. The loss factor is then defined by $\eta = \frac{\xi * 2}{100} = \frac{\xi}{50}$.

The measurement variation is estimated at ±10% or typically ±0.5% of critical damping.

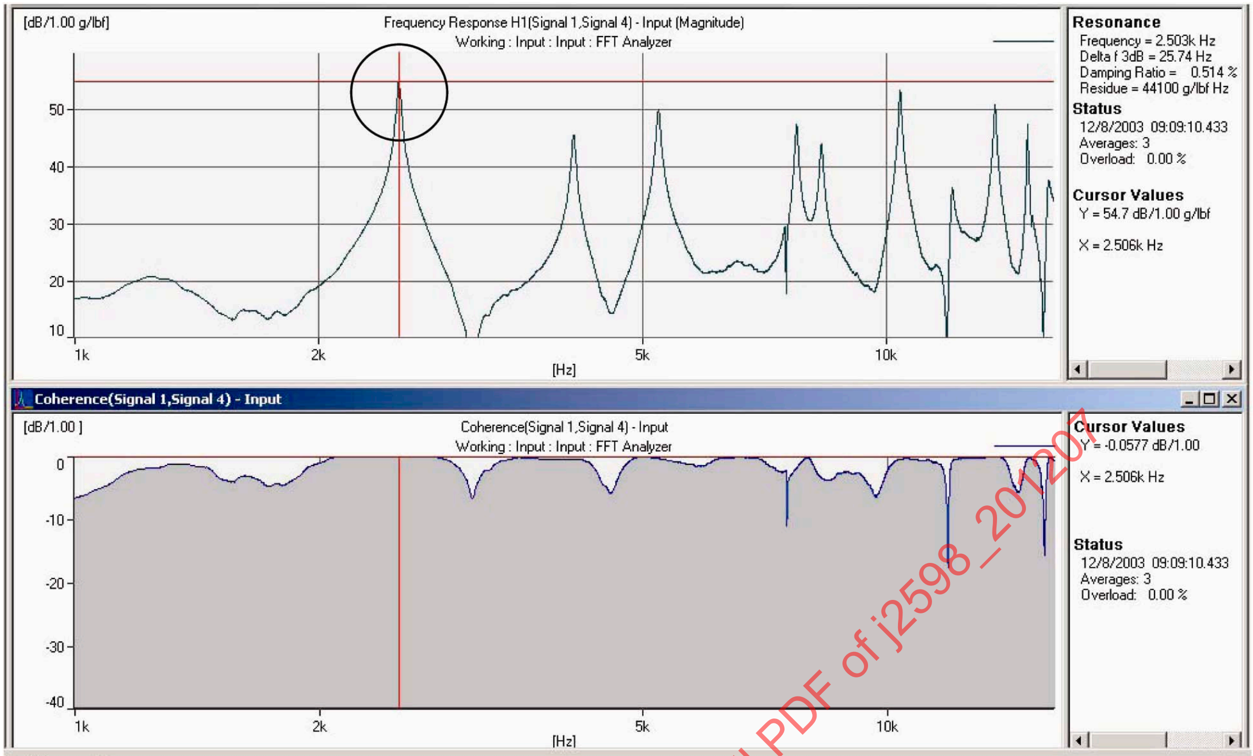

FIGURE 5 - EXAMPLE OF AN FRF (TOP) AND COHERENCE FUNCTION (BOTTOM) OF A DISC BRAKE PAD