SAE INTERNATIONAL

SURFACE VEHICLE RECOMMENDED PRACTICE

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Brake Insulator Damping Measurement Procedure

RATIONALE

This document has been revised to include the table "Data Acquisition and Equipment Specifications" from the SAE J2933 technical report.

1. SCOPE

This procedure is applicable to modes from 500 Hz and 13000 Hz. The parameters measured with this procedure are defined as the damping factor, ξ, for the first nine vibration modes of the beam. The measurement will be done in free-free conditions and with temperature.

1.1 Purpose

This SAE Recommended Practice is intended to establish a standardized and repeatable method for performing damping measurements on a brake insulator. The insulator is bonded to a standardized steel plate. The procedure measures the Frequency Response Function (FRF) of the specimen with insulator, and the damping is calculated at the resonance frequencies. The measurements are performed at different temperatures, and the damping of the insulator is hence established as a function of temperature and frequency.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J437 Selection and Heat Treatment of Tool and Die Steels

SAE J438 Tool and Die Steels

SAE J2933 Verification of Brake Rotor and Drum Modal Frequencies

TO PLACE A DOCUMENT ORDER: Tel: 877-606-7323 (inside USA and Canada)
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For more information on this standard, visit
https://www.sae.org/standards/content/J3001_202408/

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM A681 Standard Specification for Tool Steels Alloy

2.2 Related Publications

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

Ewins, D.J. (2000). *Modal Testing - Theory, Practice and Application* (Second Edition). Research Studies Press LTD.

Gade, S. and Herlufsen, H. (1994). *Digital Filter Techniques vs. FFT Techniques for Damping Measurements*. Brüel & Kjaer Technical Review No. 1.

3. DEFINITIONS

3.1 RESONANCE (NATURAL) FREQUENCY (EIGENFREQUENCY)

One of the frequencies at which the beam 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

It is generally expressed as a percentage of critical damping. The damping ratio in % is given by: $\xi = 50 \times \eta$.

4. ORGANIZATION OF THIS DOCUMENT

The first step is to define the basic measurement configuration and the measurement requirements. We will then describe the test procedure, the damping calculation, and proposed data format.

5. MEASUREMENT CONFIGURATION

Excitation (two options):

- An electromagnetic exciter can be used. The exciter must be located at a suitable distance to the specimen, and the signal amplifier must be adjusted to properly excite the specimen in the frequency range of interest.
- An impact hammer with force transducer can also be used. The hammer must be equipped with a tip sufficiently hard to excite frequencies in the range of interest. An automated hammer is preferred to ensure repeatable impacts.

Response:

- An accelerometer will be used to measure the beam response. A single point laser can also be used.
- The recommended accelerometer will be lightweight, screwable, and with a top cable connector. The cable should be as thin as possible to ensure that its influence on damping is negligible. The accelerometer should be screwed with a given torque to ensure repeatable results.

- The weight of the accelerometer should be less than 2 g. It should have a ±3 dB frequency response function from 500 to 13000 Hz. Examples of recommended accelerometers are PCB353B18, PCB320C18, and Brüel & Kjaer 4518.

- A dual-channel FFT analyzer capable of calculating a frequency response function (FRF) and simple coherence is required.

The transducers specifications are given in Table 1.

Table 1 - Transducers specifications

DAQ setting	Specifications
Small impact hammer	Sensitivity: ≥20 mV/N to 25 mV/N Frequency range: 1 to 20 000 Hz (-10 dB) Maximum range: ±220 N
Uniaxial accelerometers	Mass: <2.0 gm Sensitivity: ≥1 mV/(m/s^2) Frequency range: 1 to 20000 Hz (±3 dB) Maximum range: 500 m/s^2 Resolution: > 0.0005 m/s^2 Transverse sensitivity and non-linearity: ≤ 5% and ≤ 1%
Laser Doppler Vibrometer	Sensitivity: 1 mm/s/V to 1000 mm/s/V Frequency range: 1 Hz to 20 000 Hz (@ > 5 mm/s/V) Resolution: 0.3 µm to 10 µm Non-Linearity: ≤ 2.5%

Temperature Conditioning:

- The specimen must be brought to the required temperature, using an environmental chamber or equivalent to heat up and cool down the sample. The minimum required range is -10 °C to +120 °C, with a delta of 10 °C. A sufficient soaking time is recommended. If the FRF measurements are done while the specimen is on a transient temperature slope, the actual specimen temperature must be measured with, preferably, a noncontact equipment. If a contact temperature sensor is used, it must be validated to show that it has no influence on the damping measurements.

Boundary Conditions:

- The specimen will be placed on a suitable support that allows its free-free vibration. These include rubber mounts or wires. It is not recommended to use foam due to the additional damping generated by the friction between the specimen and the foam.

Test Specimen:

- The plate must be 180 x 50 x 5 mm with a tolerance of ±0.1 mm and will be made out of a steel material according to ASTM A681, SAE J437/438, DIN 1.2510, or equivalent.

- The eigenfrequencies of the plate for the bending modes will be located around 821/2, 264/4, 424, and 7256 Hz and for the torsion modes around 1740/3, 619/5, 761/8, 275, and 11248 Hz.

- The insulator material (160 x 50 mm) should have a tolerance of ±0.3 mm and must be bonded to the steel plate with an accuracy of ±0.5 mm. Two 10-mm sections on each side will be free of insulator material to accommodate for the hammer excitation when used (see Figure 1).

- The insulator bonding will be performed according to the insulator material supplier specifications, and the damping measurement will be conducted at least 24 hours after the bonding.

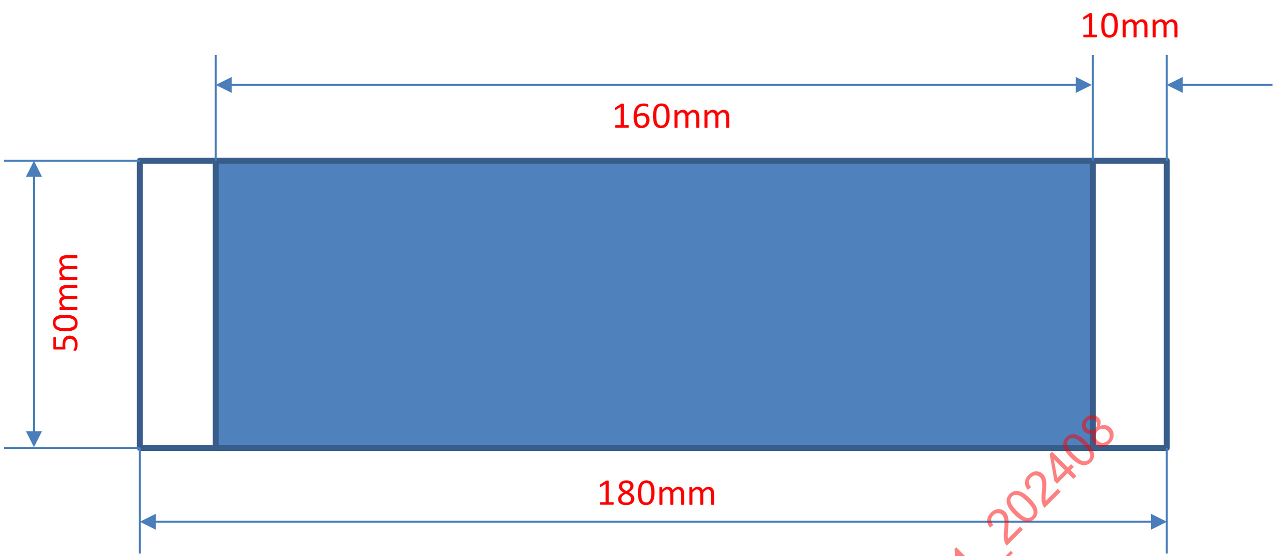


Figure 1 - Steel plate dimensions and insulator location

6. TEST PROCEDURE

6.1 General Setup

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

- Analyzer frequency range from 500 to 13000 Hz
- Excitation will be "Chirp" (500 to 13000 Hz) for the noncontact exciter. The duration of the chirp will be < 1/Δf, where Δf = Sampling Frequency/Number of Lines.
- The distance between the noncontact exciter and the beam should be around 1 mm. Deviation from this value will not change the damping results as long as the coherence function is above 0.98 at the resonances.
- For the hammer excitation, an automatic hammer is preferred.
- Trigger and Window for the Input Signal:
    - Noncontact exciter: Free run + Hanning Window
    - Hammer: Trigger on impact signal + Rectangular Window
- Window for the Output Signal: Rectangular is recommended.
- Minimum sampling frequency of 32 kHz.
- Minimum of 24 averages for chirp, 5 for the impact hammer.
- The maximum value for the frequency resolution Δf should be 4 Hz.
- Results will include FRF amplitude, real part, imaginary part, and coherence function.
- Coherence function between the excitation and measurement should be >0.98 for all the resonances.
- Record the analyzer setup for each measurement.

6.2 Procedure

Bond the insulator to the steel plate according to the manufacturer's specifications. Wait a minimum of 24 hours before conducting the measurement.

Connect the exciter to channel 1 and the accelerometer to channel 2 of the analyzer. Set up the FFT analyzer to the recommended parameters (see 6.1).

Place the beam on rubber mounts or wires (see Figure 2) to simulate free-free conditions. Wires will be connected to the edges of the beam.

Use a suitable temperature conditioning device to make sure that the beam is at the right temperature. The recommended temperature range is from -10 °C to 120 °C, with a delta of 10 °C.

The measurement will be performed with the excitation at points 1 and 2 and the measurement at points 3 and 4 (see Figure 2). Use points 2 and 3 to measure the bending modes (located around 821/2, 264/4, 424, and 7256 Hz) and points 1 and 4 for the torsion modes (located around 1740/3, 619/5, 761/8, 275, and 11248 Hz).

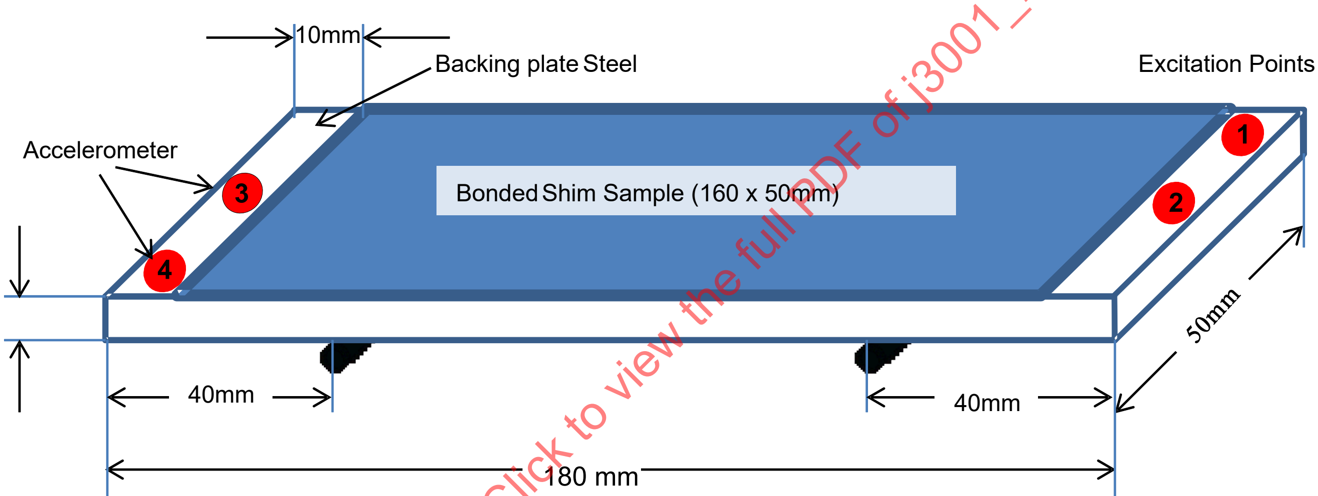


Figure 2 - Location of rubber mounts and excitation/measurement points

Screw the accelerometer to position 3, and locate the exciter to position 2.

Start the measurements.

It is important to adjust the analyzer so that the FRF between the accelerometer and the exciter and the coherence function are both displayed as shown in Figure 3.

Identify the resonance frequencies on the FRF, and calculate the damping (see Figure 3).

Repeat the measurement for the next temperature set point. When done, change the accelerometer and excitation locations to 4/1 to measure the torsion modes.

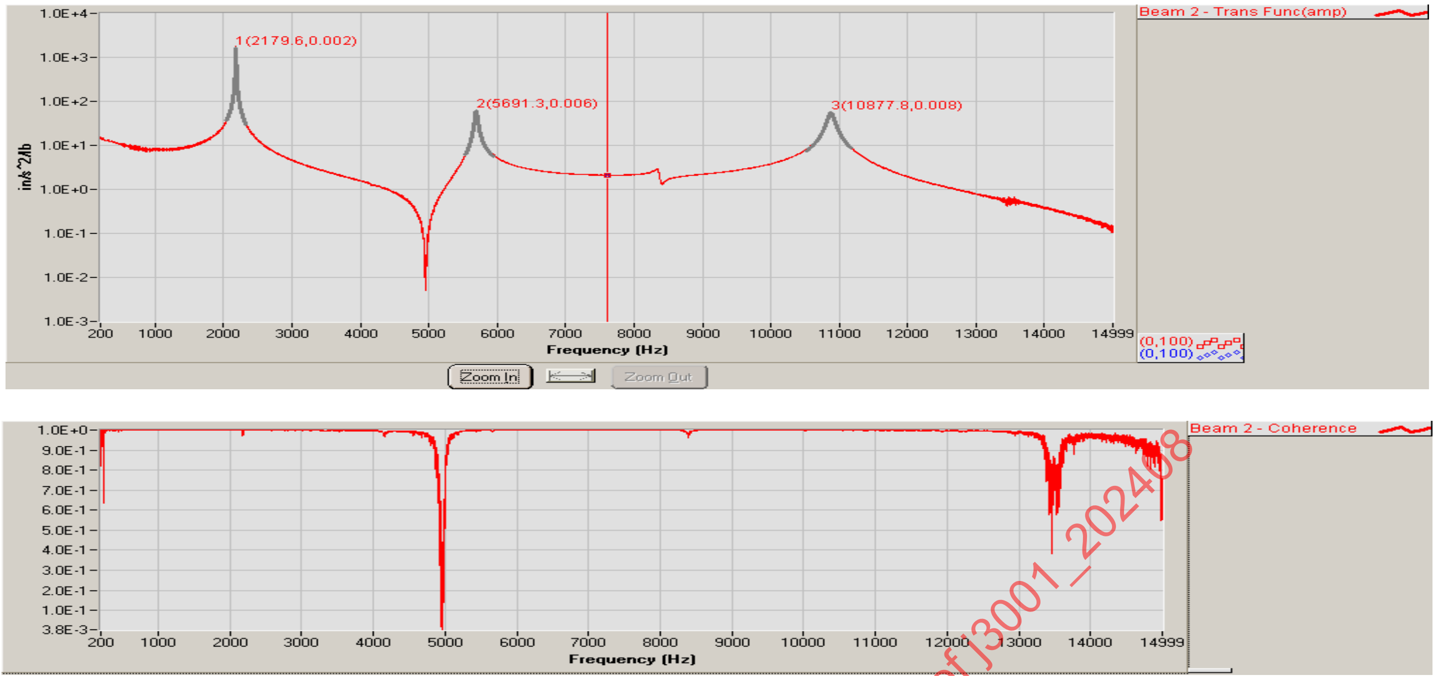


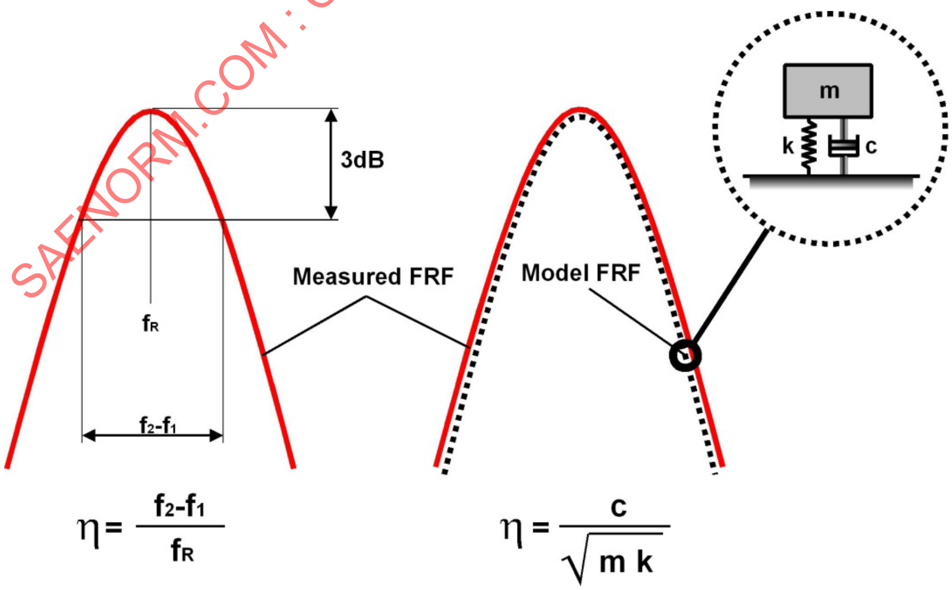
Figure 3 - Example of an FRF (top) and coherence function (bottom)

A minimum of three samples of the same insulator should be measured, and the average damping value should be used.

7. DAMPING CALCULATION

The loss factor and damping factor are evaluated using the “Curve Fitting Method.” It is more accurate than the 3 dB method, specifically when mode coupling is present.

This method tries to determine the parameters of the theoretical model to best fit the measured FRF. When the best fit curve is determined, the loss factor is calculated using the model parameters listed in Figure 4.



$$\eta = \frac{f_2 - f_1}{f_R} \qquad \eta = \frac{c}{\sqrt{m\,k}}$$

Figure 4 - 3 dB method and curve fitting method