SAE International	SURFACE VEHICLE RECOMMENDED PRACTICE	SAE J1637	REV. AUG2007
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Laboratory Measurement of the Composite Vibration Damping Properties of Materials on a Supporting Steel Bar

RATIONALE

Changes have been made to this standardized test procedure in order to incorporate various needs of the transportation industry. Some of these needs and assimilated changes are: (1) the ability to compute a damping material's complex modulus from this test standard; (2) a standardized procedure for interpolating test results to a common frequency; and (3) the ability to utilize this test standard in order to measure the composite loss factor for other commonly used beam sizes.

1. SCOPE

This SAE Recommended Practice describes a laboratory test procedure for measuring the vibration damping performance of a system consisting of a damping material bonded to a vibrating cantilevered steel bar. The bar is often called the Oberst bar (named after Dr. H. Oberst) and the test method is often called the Oberst Bar Test Method. Materials for damping treatments may include homogeneous materials, nonhomogeneous materials, or a combination of homogeneous, nonhomogeneous, and/or inelastic (such as aluminum foil) materials. These materials are commonly installed in transportation systems such as ground vehicles, marine products, and aircraft to reduce vibration at resonance, and thus reduce the noise radiation from the vibrating surface. The test method described herein was developed to rank order materials for application on panels using general automotive steel but also may be applicable to other situations or conditions.

Damping performance for most materials and systems varies as a function of both frequency and temperature. Accordingly, this test procedure includes provisions for measuring damping over a range of frequencies and temperatures found applicable to many transportation systems. The measured damping performance will be expressed in terms of composite loss factor, η_c, within the frequency range of approximately 100 to 1000 Hz, and over the useful temperature range for the given application. The term composite refers to the steel and damping material combination. The composite loss factor is, therefore, dependent upon the thickness, damping and modulus of both the steel and damping material layer.

The test procedure described here is based on the method described in ASTM E 756. However, this SAE document differs from the ASTM E 756 method in that the SAE practice specifies the bar material, three bar sizes, and the mounting conditions of the test samples. This document provides a means of rank ordering damping materials according to their composite loss factor values from test samples that represent typical sheet metal applications.

The material properties of the damping material alone, including Young's modulus E', and the material loss factor η, may be computed from the test samples specified in this document if additional conditions are met. ASTM E 756 defines these additional conditions as well as the equations to be used to compute the damping material properties for the single layer (Oberst beam) configuration.

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2. REFERENCES

2.1 Applicable Publications

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

2.1.1 SAE Publication

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

SAE TSB 003 Rules for SAE Use of SI (Metric) Units

2.1.2 ANSI Publications

Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ANSI S1.1 Acoustical Terminology

ANSI S2.9 Nomenclature for Specifying Damping Properties of Materials

2.1.3 ASTM Publications

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

ASTM E 691 Conducting an Interlaboratory Study to Determine the Precision of a Test Method

ASTM E 756 Measuring Vibration—Damping Properties of Materials

2.1.4 DIN Publications

Available from Deutsches Institut für Normung e.V., Burggrafenstrasse 6, 10787 Berlin, Germany, www.din.de.

DIN 53 440 Testing of Plastics and Damped Laminated Systems; Bending Vibration Test

Teil 1 General Rudiments of Dynamic Elastic Properties of Bars and Strips

Teil 2 Determination of Complex Modulus of Elasticity

Teil 3 Determination of Dynamic-Elastic Values of Damped Laminated Systems

2.1.5 JASO Publication

Available from Society of Automotive Engineers of Japan, 10-2, Gobancho, Chiyoda-ku, Tokyo 102-0076, Japan, Tel: +81-3-3262-8211, www.jsae.or.jp.

JASO M 329 Asphalt Sheet for Automobiles

3. TEST METHOD

The method is based on exciting the damped bar at various modes of vibration at a given temperature of interest, and obtaining the damping performance using the half-power bandwidth technique. In this technique, first the resonant frequency, f, at a given mode of the bar is measured. Next, the lower and upper frequencies (f_l and f_u, respectively) are measured on the response curve on either side of the resonant frequency where the levels are 3 dB lower than the level at resonance (3 dB down points or half-power points). The difference of f_u and f_l in this case, is called the half-power bandwidth. This procedure is repeated for other modes of vibration and temperatures. The composite damping performance is given by Equation 1 (see Figure 1):

$$\eta_c = \frac{\Delta f}{f} \qquad \text{(Eq. 1)}$$

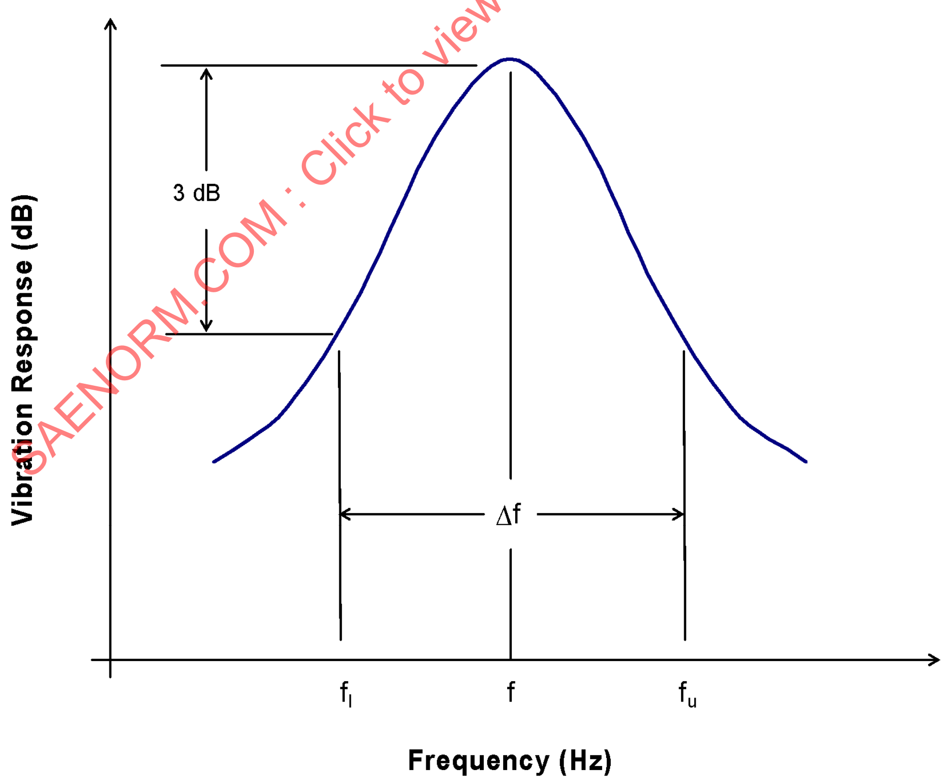
where:

$\Delta f = f_u - f_l$
= frequency bandwidth, Hz
f = resonant frequency, Hz
η_c = composite loss factor at resonant frequency, f, dimensionless

4. INSTRUMENTATION

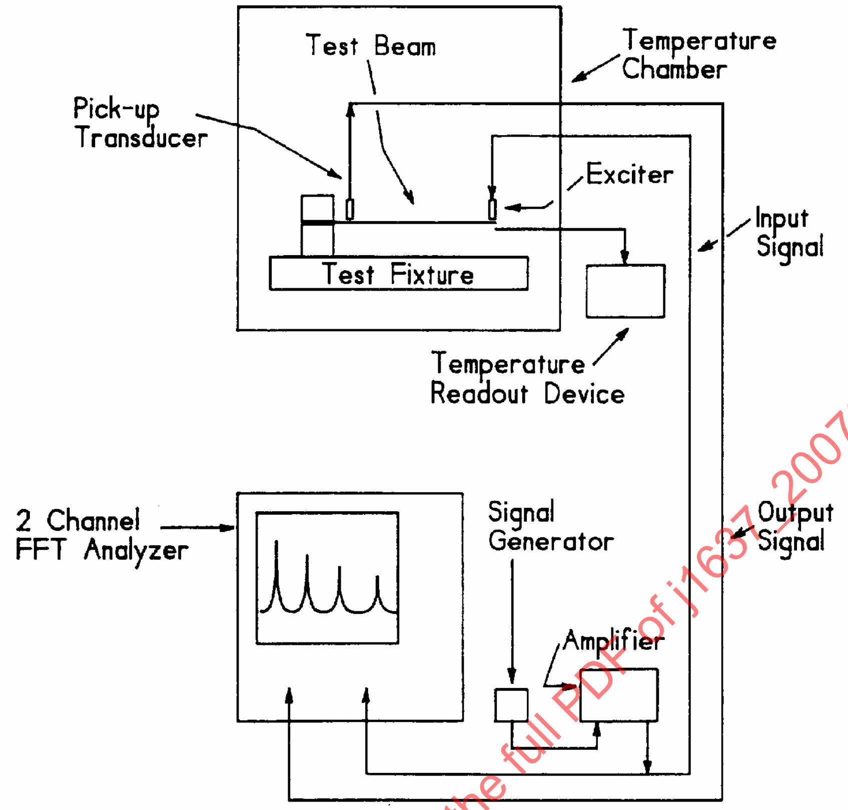
The instrumentation to be used is as follows (see Figure 2 for a schematic of a typical set-up):

4.1 A bar mounting fixture (test fixture) that is heavy, rigid, and can provide adequate force at the clamped end of the bar to simulate the cantilever boundary conditions (clamped-free).



$$\eta_c = \frac{\Delta f}{f}$$

FIGURE 1 - COMPOSITE DAMPING PERFORMANCE COMPUTATION



NOTE: Horizontal bar orientation is shown. A vertical bar orientation is also commonly employed. Also, the locations of the transducers may be reversed.

FIGURE 2 - SCHEMATIC OF A TYPICAL TEST SET-UP FOR DAMPING PERFORMANCE EVALUATION

4.2 A temperature chamber so that the sample can be maintained at the appropriate temperature.

4.3 Two transducers with associated power supplies and signal conditioners—one applies the excitation force (called the excitation transducer or the exciter) and the other measures the response of the bar (called the pick-up transducer). The purpose is to measure only the damping of the test sample, without any additional damping from any other effects. Therefore, the pick-up transducer used is often a non-contacting type transducer. If a contacting type transducer is used as a pick-up transducer, extreme care should be taken to ensure that the transducer does not contribute to the damping of the test sample (i.e., overdamp the test sample). The mass of the contacting type transducer shall not exceed 0.5 g. Refer to 7.2.2. The excitation transducer is generally a non-contacting type electromagnetic vibration exciter.

4.4 A signal generator that generates a sinusoidal or a random signal. The signal is applied to the excitation transducer by means of a power amplifier. The response of the bar will be measured using the pick-up transducer.

4.5 An analyzer or an analysis system capable of determining the transfer function between the excitation signal and the response signal. Examples include: a two-channel spectrum analyzer (e.g., based on Fast Fourier Transform algorithm) that is suitable for the signal, such as the random noise signal. Alternatively, a single channel system with separate excitation and response analysis systems can be used. However, efforts must be made to make the excitation force constant with frequency so that the response can be measured directly. The minimum amplitude precision of the measuring system should be 0.1 dB. The minimum frequency resolution of the measuring system should be 0.1 Hz.

5. TEST SAMPLE

5.1 Test Bar

The test bar to be used is as follows:

5.1.1 The metal for the bare bar should be steel. Precision Ground Gage Stock (or also called Precision Ground Flat Stock) bars should be used as the Oberst bar for damping tests. Precision Ground Gage Stock bars are commercially available (see Appendix A). Alternatively, the bare bar may be manufactured by machining a mild steel bar stock. A new bar should be used for each application. Selection of which of the three bar sizes to use should be based on the steel thickness of the intended application. Multiple Oberst beam sizes may be tested to determine the composite loss factor variation with steel thickness. For the purpose of rank ordering damping materials in extensional layer constructions, any one of the three bar sizes is sufficient.

Overdamping can occur when an excessively high damping material thickness is used on the bar. Overdamping can cause the response of the bar vibration to be reduced to a level, which cannot be used to measure the composite loss factor. The damping material thickness at which overdamping occurs is based on the given material's damping properties. If overdamping occurs, the transfer function of the bar will be very flat and the modes will be nearly eliminated. To prevent this from occurring, a thicker bar size may be used.

5.1.2 The dimensions of the bars shall be as shown in Table 1 (also refer to Figure 3).

The modes of vibration for each beam size (uncoated) can be computed theoretically. Calculated values for modes two through five for the three SAE J1637 bar types are provided in Table 2. Experience has been that measured values of mode-frequencies within 2% of the calculated values at 25 °C produce repeatable test results. Figure 4 shows the typical frequency response of a bare Oberst bar.

TABLE 1 - TEST BAR DIMENSIONS

Bar	Free Length, L_T (mm)	Minimum Clamping Length (mm)(1)	Minimum Total Length, L (mm)	Minimum Width, W (mm)(2)	Thickness, H_2 (mm)
A	200	25	225	12.7	0.8
B	216	25	241	12.7	1.0
C	254	25	279	12.7	1.6

1. The Free Length of the bar is a critical factor in determining the frequencies of the modes of vibration. The Clamping Length of the bar is important for ensuring that the prerequisite cantilever boundary condition is present for the test. The Total Length is the sum of the Free Length and the Clamping Length. The Clamping Length value given in the table is the minimum that can be used. It has been found that longer Clamping Lengths of the bar (with corresponding longer clamps on the fixture) tend to better match the desired cantilever condition. It is recommended that a Clamping Length longer than the minimum be used if possible. A Clamping Length of 50 mm has been found to perform especially well.
2. Since the width of the bar is not a critical factor in determining the frequencies of the modes of vibration, the width given in the table was chosen as a minimum practical width for preparing a sample bar and obtaining good clamping conditions. Wider bars may be used if they are more convenient to obtain. However, because the bar is intended to be excited in its bending modes only, there is a limit on the width of the bar. If the bar is too wide for a given thickness, torsional modes may be excited that will complicate the damping measurement. To avoid these torsional modes, the bar width should not exceed 50 mm.

Dimension Tolerances:
a. Mounted free length: ± 0.5 mm
b. Total length: ± 1.0 mm
c. Thickness: ± 0.03 mm

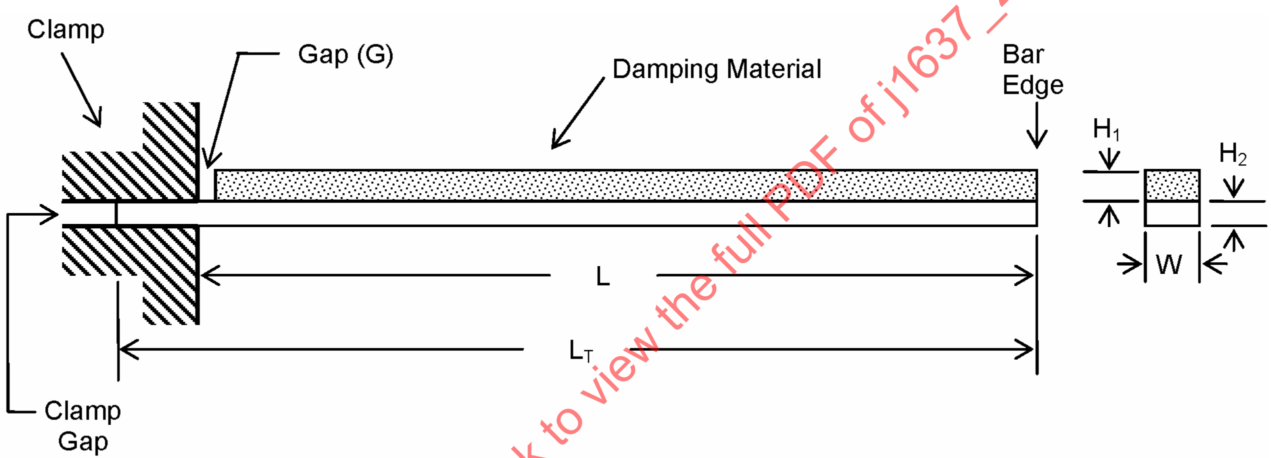
TABLE 2 - BARE BAR MODE FREQUENCIES
(USING DENSITY OF STEEL: 7840 kg/m^3, MODULUS OF STEEL: 2.0X10^{11} Pa)

Bar	f_2 (Hz)	f_3 (Hz)	f_4 (Hz)	f_5 (Hz)
A	102	286	561	927
B	110	307	601	994
C	127	355	696	1150

Mode 1 is usually not used for this measurement, primarily for the following reasons:

a. The bar and the fixture both tend to vibrate as a rigid body, thereby introducing error in measuring the composite loss factor.

b. The first mode is most sensitive to any error due to the static magnetic field of the transducers that may influence the vibration of the free end of the bar.



LEGEND:

L = Free Length of the bar (This is also the length of the damping material plus the gap (G)
L_T = Total Length of the bar
H_1 = Thickness of the damping material
H_2 = Thickness of the bar
W = Width of the bar

FIGURE 3 - TEST SAMPLE FOR OBERST BAR

NOTE 1: The damping material should not touch the clamping mechanism or the test fixture. The gap (G) between the clamping device and the material should be less than or equal to 1mm.

NOTE 2: If a gap is present in the test fixture clamp (Clamp Gap), it should be filled with a spacer made of the same steel thickness as used in the Oberst beam. This is done to ensure a rigid clamping force on the bar.

5.1.3 Some laboratories employ a stepped increase in bar thickness (also called roots) at the clamped end of the test bars to mount the bar in a fixture. These are not required, provided proper boundary conditions can be simulated at the clamped end of the bar to represent a fixed support cantilever condition. However, note that interlaboratory and intralaboratory studies suggest that the range of the results obtained from test bars without roots is likely to vary more than that of the test bars with roots, unless proper care is taken to ensure that the free length is precise, the clamped edge is perpendicular to the face of the bar, and that the bar mounting fixture is rigid and massive.

5.2 Sample Preparation

The damping material should be attached to one side of the bar simulating the damping treatment in its intended application (refer to Figure 3). The test sample should have material of uniform thickness and be flush with the edges and the free end of the bar, and of the same length as that of the free length of the bar. Other mounting conditions are explained in 6.1. The material should be applied using the manufacturer's recommended bonding method to simulate intended applications. Note that the bonding method (i.e., the adhesive layer or other bonding elements) will affect the damping performance in the laboratory tests as well as in the actual application. The preparation of the heat bondable test samples are especially critical, as some materials may shrink and some materials may expand during the heat bonding process.

6. PROCEDURE

6.1 Securely clamp the test sample in the test fixture to provide a sufficiently rigid mounting to simulate a cantilever bar condition. The test sample shall be mounted in the fixture with a free length of 200 mm and ensuring that the clamped edge is perpendicular to the face of the bar. The damping material should not touch the clamping mechanism or anything else associated with the test fixture. The gap between the clamping device and the edge of the damping material should be less than or equal to 1 mm, and yet maintain the tolerance of the mounted free length as mentioned in 5.1.2.

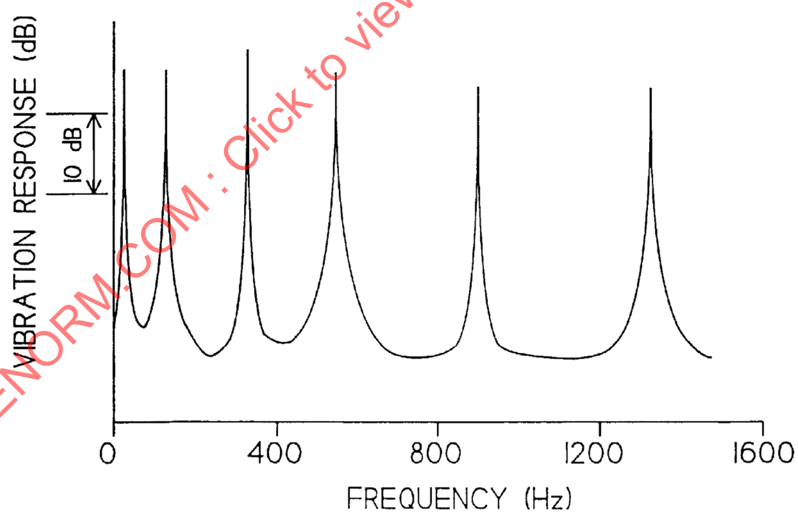


FIGURE 4 - TYPICAL FREQUENCY RESPONSE OF A BARE BAR

It is important to position the transducers at appropriate locations to obtain the best dynamic response and the optimal signal to noise ratio of the vibrating test sample. Generally, the transducers are located close to the clamped end of the bar and close to the free end of the bar. (The exciter and the pick-up transducers should be at least sufficient distance apart to reduce "cross-talk" effects between the two transducers. Cross-talk can be verified by removing the sample bar.) This will permit correct measurement of the damping performance. For non-contacting type transducers, the transducers may require positioning within 1 mm of the test sample.

6.2 Place the test fixture inside a temperature chamber so the damping performance can be evaluated at different temperatures. From experience it has been determined that the temperature in the chamber may vary considerably depending on where the temperature is measured. Therefore, the temperature shall be monitored close to the test sample. This requirement is best fulfilled by monitoring the temperature on a separate bare steel bar located very close to, but not touching the test sample. Once the separate bare bar has reached the test temperature, allow the sample to soak at that temperature for at least 30 min to ensure that the test sample temperature has stabilized and is uniform everywhere in the sample. This soak time varies depending upon equipment and the amount of mass inside the thermal chamber. A method for experimentally determining the minimum soak time is described in Appendix X2, Practical Aids for Testing, of ASTM E 756.

It is recommended that the damping performance be measured at –20 °C, –5 °C, 10 °C, 25 °C, 40 °C, and 55 °C for materials that are formulated to be used in this temperature range. Measurements shall be conducted at other temperature ranges should that be dictated by the usage. Measurements needed at a room temperature should be conducted at 25 °C. All measurements should be conducted within ±1 °C of the nominal test temperature.

6.3 Excite the test sample at each mode of vibration using the excitation transducer. Measure the response of the bar using the pick-up transducer. Measurements can be made using either random or sinusoidal signals. The input signal should be adjusted such that the peak at each resonance frequency is distinct, and that the output signal is at least 10 dB higher than the "background noise."

6.4 Measure the resonant frequency, the half-power bandwidth (3 dB down points) and then compute the composite loss factor as described in Section 3. Damping measurements should be made starting from the second mode of vibration for reasons explained in 5.1.2.

6.5 If the 3 dB down points on either side of the resonant frequency are not measurable for various reasons (such as high damping performance), an "n dB" down point technique can be implemented using Equation 2:

$$\eta_c = \left(\frac{1}{\sqrt{x^2 - 1}}\right)\frac{\Delta f_n}{f} \qquad \text{(Eq. 2)}$$

where:

x = $10^{n/20}$
n = "n dB" down point
Δf_n = frequency bandwidth for "n dB" down point, Hz

6.6 The "n dB down point" technique should not be used if n is less than or equal to 0.5 dB. In such cases, or if the composite loss factor could not be computed for other reasons (such as double peak or overdamped test bar), this should be noted in the test report.

7. ASSUMPTIONS AND PRECAUTIONS

7.1 Assumptions

The size of the steel bar is selected based on the following assumptions:

7.1.1 The frequency range (i.e., from 100 to 1000 Hz) where the damping performance is evaluated agrees with the frequency range of interest for the intended application.

7.1.2 The performance ranking of different materials (based on composite loss factor) tested in the laboratory will be similar to that of the same materials in the intended application.

7.2 Precautions

7.2.1 Extreme caution should be taken in mounting the test sample to ensure that the boundary condition at the clamped end simulates that of a cantilevered bar. For example, the faces of the clamp and that of the bar should be smooth and parallel to each other. Periodically, bare Oberst bars should be tested with and without well-defined roots to verify that the resonant frequencies for both bars are within 2% of each other.

7.2.2 If a contacting type transducer is used, precaution should be taken to ensure that the test sample is not influenced by the type of pick-up transducer. It is recommended that for laboratories where contacting type pick-up transducers are used on a regular basis, the same test sample be tested periodically using noncontacting type pick-up transducers also to ensure that the resonant frequency and the composite loss factor values are within the experimental variation of the test laboratory (refer to Section 9).

7.2.3 The spectrum analyzer should be maintained at high frequency resolution (i.e., the number of lines for FFT based analyzers) for measuring both the resonant frequency and the frequency bandwidth to determine the damping performance accurately. It is recommended that the analyzer be set-up such that the available frequency range is twice that of the bandwidth (Δf) necessary for computing the composite loss factor. This is especially important for measuring materials with low damping performance. Wherever possible, the zoom feature of the analyzer should be used for greater precision.

7.2.4 Damping measurements can be made using either manual or software-driven automated data acquisition systems. Extreme caution should be taken, especially for automated systems, to be able to identify "humps," double peaks, and/or other outlying data such as "spikes" in the response spectrum of each mode (refer to Figure 5). These occurrences should be noted in the test report, if they are used for damping calculations.

7.2.5 No single method of measuring damping performance may meet the needs of all users of damping materials. This document is a relatively simple approach for rank ordering materials. The potential user of this document must determine the level of sophistication required for the application. Those who require material properties such as loss factor η, Young's modulus E, may be able to calculate these properties using the results of this method and the appropriate equations defined in ASTM E 756 for an Oberst bar damped on one side. Also, note that ASTM E 756 includes expressions to avoid significant errors in the material properties based on the results and geometry of the tested bars.

8. REPORT

The report shall include the following:

8.1 A description of the test procedure used for conducting the measurements shall be provided. Any deviations or exceptions taken from this test method shall be explicitly noted. The report should explicitly state that the measurements made and data reported are that of a damping material bonded to a steel Oberst bar, and that the damping performance is expressed in terms of "composite loss factor" (η_c).

8.2 The report shall provide a description of the damping material including thickness, density or specific gravity, bake condition, and/or any other pertinent data. The report shall state the size of the steel bar and identify any chemical treatment (e.g., E-coat) to the steel bar prior to the preparation of the test sample.

8.3 The report shall identify how the test sample was prepared (i.e., how the material and the bar were bonded together, e.g., pressure-sensitive adhesive, self-adhesion type material, baked-on, etc.). If the material and the steel bar were baked to prepare the test sample, the bake conditions (i.e., temperature and time) shall be stated.

8.4 The test temperatures, the modes of vibration, the resonant frequencies, and the composite loss factor values shall be reported in the test results.

If the measured temperatures varied beyond ±1 °C of the nominal test temperature, this shall be noted, and the measured temperature shall be reported.

The value of the resonant frequencies shall be reported as an integer (e.g., report 101 Hz and not 101.2 Hz).

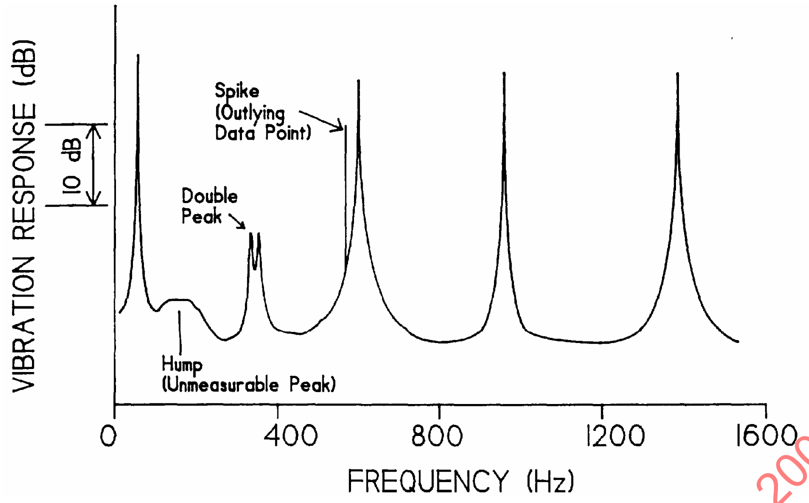


FIGURE 5 - POSSIBLE FREQUENCY RESPONSE OF A DAMPED BAR

The value of the composite loss factor shall be reported to the third decimal point (e.g., report 0.098, and not 0.0979).

If the vibration response of the test sample has double peaks that affect the measurements, or if the composite loss factor is computed based on "n dB down point" technique, this shall be stated in the report.

8.5 The test results shall be provided in tabular form, and wherever possible, in graphical form. Table 3 and Figure 6 illustrate recommended formats for presenting the test results in tabular and graphical forms, respectively. The graphical form of the data may also be presented as a function of temperature as illustrated in Figure 7.

8.6 An interpolation or, in certain special cases, extrapolation process shall be used when calculating a composite loss factor at a frequency that is different from the measured resonant frequency. Historically, users of SAE J1637 have used interpolation or extrapolation to estimate the damping performance at several desired frequencies, typically 200, 400, and 800 Hz. It is important to note that interpolated or extrapolated results are only a means of comparing materials at a single frequency which serves as an ad hoc reference point in comparing results from different bars, and that these results should not be confused with the measured results at the frequencies corresponding to the actual vibration modes of the bar. The calculation for the interpolation or extrapolation method uses Equation 3. This analytic method is equivalent to performing a graphic procedure on a log-log plot by plotting a straight line through two measured data points to find an interpolated value between the two points or an extrapolated value beyond the two points. The computed damping performance at a single frequency must be labeled as “interpolated” or “extrapolated” in the report (See Table 3 for example results table).

$$\eta_{ci} = 10^{\left[\log(\eta_1) + \log\left(\frac{\eta_2}{\eta_1}\right) \cdot \left\{\frac{\log\left(\frac{f_i}{f_1}\right)}{\log\left(\frac{f_2}{f_1}\right)}\right\}\right]} \qquad \text{(Eq. 3)}$$

where:

η_{ci} = composite loss factor at the interpolation or extrapolation frequency
η_2 = composite loss factor associated with the upper resonant mode at frequency (f_2)
η_1 = composite loss factor associated with the lower resonant mode at frequency (f_1)
f_2 = modal frequency of the higher of two consecutively measured modes
f_1 = modal frequency of the lower of two consecutively measured modes
f_i = interpolation or extrapolation frequency

To use Equation 3 for interpolation, the desired interpolation frequency must be higher than f_1 and lower than f_2 where f_1 and f_2 correspond to the lower and higher frequencies of consecutive modes. Interpolation is the preferred process but when interpolation is not possible because the measured results do not have consecutive modes whose corresponding frequency values are higher and lower than the desired interpolation frequency, it may be possible to use Equation 3 for extrapolation.

To use Equation 3 for extrapolation, the desired extrapolation frequency can be lower than f_1 or higher than f_2 where f_1 and f_2 correspond to the lower and higher frequencies of consecutive modes. Since the extrapolation process goes beyond the range of the measured results, it can only be used once in a given direction (i.e. either higher than or lower than the range of measured results). For example, if extrapolation must be used to calculate the loss factor at 400 Hz when f_2 is less than 400 Hz, the extrapolation process cannot be used again to calculate the loss factor at 800 Hz. Similarly, if extrapolation must be used to calculate the loss factor at 400 Hz when f_1 is greater than 400 Hz, then the extrapolation process cannot be used again to calculate the loss factor at 200 Hz.

TABLE 3 - EXAMPLE RESULTS TABLE OF SAE J1637 DAMPING TESTS

Test Material:

Bake Condition:

Data of the Test Material:

Specific Gravity or Surface Weight	
Nominal Thickness	
Measured Thickness	

Test Bar Dimension:

SAE J1637 Bar Type	A
Free Length	200 mm
Width	12.7 mm
Thickness	0.8 mm

Exception:

Test Temperature (°C)	**Mode**	**Resonance Frequency (Hz)**	**Composite Loss Factor**
10	2	105	0.076
	3	310	0.069
	4	620	0.067
	5	1100	0.071
	Interpolated	200	0.072
	Interpolated	400	0.068
	Interpolated	800	0.069
25	2	101	0.108
	3	294	0.132
	4	592	0.152
	5	1015	0.168
	Interpolated	200	0.123
	Interpolated	400	0.140
	Interpolated	800	0.161
40	2	96	0.097
	3	282	0.115
	4	563	0.120
	5	981	0.105
	Interpolated	200	0.109
	Interpolated	400	0.118
	Interpolated	800	0.110