

SURFACE VEHICLE RECOMMENDED PRACTICE	J3130™	DEC2023
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Laboratory Measurement of Vibration Damping Properties Using Mechanical Impedance Method at the Center of a Bar		

RATIONALE

This recommended practice discusses a test methodology to measure composite loss factor of a bar (bare or damped) where the Oberst bar damping test method (SAE J1637) is not suitable. This could be for various reasons. Examples could be the bar is not made of steel or a steel bar that cannot be excited efficiently following the Oberst bar test method. In addition to the composite loss factor, this method can also provide bending stiffness properties of the damped test bar. The bar is excited at the center and therefore this methodology is also called the CenterPoint method. Currently there are no SAE standards for this type of test.

1. SCOPE

This SAE Recommended Practice describes a laboratory test procedure for measuring the composite loss factor and bending stiffness properties of a system consisting of a damping material bonded to a vibrating bar which is excited at the center. The bar could be a steel, aluminum, glass, or other metal or composite bar that would be used in ground vehicles, marine products, and aircraft. The damping materials could be homogeneous, nonhomogeneous, a combination of homogeneous and nonhomogeneous, used in conjunction without or with an inelastic material (such as aluminum foil) in an extensional layer or a constrained layer configuration. The damping material could be a heat bondable material, adhesive backed sheet material, sprayable coating material, or other kinds of viscoelastic materials.

The damping procedure discussed here provides means to measure damping over a range of frequencies and temperatures found applicable and useable for different transportation systems. The term composite refers to the combination of the vibrating bar and damping material. The composite loss factor is dependent upon the thickness, damping, and modulus of both the vibrating bar and the damping material layer. In many applications the vibrating bar is made of steel. However, in many other applications, the vibrating bar could be different than steel and the frequency range of vibration could also be different. This test methodology does recommend three specific bar sizes based on the vibrating bar material and the general frequency range of interest. However, it also explains and provides the equation that is to be used to size the bar and provides suggestions on the bar size depending on the type of bar material and thickness.

This document provides a means of rank ordering damping materials according to their composite loss factor values from test samples that represent typical applications for a given vibrating bar. However, the method can also be used to determine the damping performance of the bar by itself, such as steel, aluminum, glass, composites, etc.

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.

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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.

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

2.1.2 ANSI Accredited Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

2.1.2.1 ANSI S1.1, Acoustical Terminology

2.1.2.2 ANSI S2.9, Nomenclature for Specifying Damping Properties of Materials

2.1.3 ISO Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

2.1.3.1 ISO 16940:2008(E), Glass in building – Glazing and airborne sound insulation – Measurement of the mechanical impedance of laminated glass

2.1.4 JIS Publications

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

2.1.4.1 JIS G 0602:1993, Test methods for vibration-damping property in laminated damping steel sheets of constrained type

2.1.5 Other Publications

2.1.5.1 Wojtowicki, J.-L., Jaouen, L., and Panneton, R. (2004). New approach for the measurement of damping properties of materials using the Oberst beam. *Rev. Sci. Instrum.*, 75(8), 2569–2574. <https://doi.org/10.1063/1.1777382>.

2.1.5.2 Dowling, J. and Saha, P., “A Correlation between Oberst Bar and Center Point Damping Results,” SAE Technical Paper 2009-01-2134, 2009, <https://doi.org/10.4271/2009-01-2134>.

2.1.5.3 Malogi, D., Gupta, A., and Kathawate, G.R. (2009). Center Impedance Method for Damping Measurement, *Advances in Acoustics and Vibration*, Vol. 2009, Article ID 319538, 7 pages. <https://doi.org/10.1155/2009/319538>.

2.1.5.4 Stanley, D.R. (2014, September 8-10). *Alternative Method of Measuring System Loss Factor* [Conference presentation]. Noise-Con 2014, Fort Lauderdale, FL, United States.

2.1.5.5 Yoo, T., Gerdes, R., Lee, S., Stanley, D. et al., “Comparison of Long Bar Test Method to Oberst Bar Test Method for Damping Material Evaluation,” SAE Technical Paper 2017-01-1851, 2017, <https://doi.org/10.4271/2017-01-1851>.

2.1.5.6 Saha, P., “Mechanical Impedance Based Vibration Damping Test,” SAE Technical Paper 2017-01-1879, 2017, <https://doi.org/10.4271/2017-01-1879>.

2.1.5.7 Saha, P. and Anderson, C.F., “Rationale and Process for Developing an SAE Damping Test Method,” SAE Technical Paper 2023-01-1050, 2023, <https://doi.org/10.4271/2023-01-1050>.

3. TEST METHOD

This test method is based on measurements of a bare or damped test bar excited at its center by a shaker at a given temperature of interest. The shaker is driven by a broadband signal to excite the bar at its various modes of vibration. At the point of excitation, one measures the applied force (N) and the output velocity (m/s). The transfer function between the applied force and the velocity is the input impedance (Ns/m) at the point of excitation, i.e., at the center of the bar or at the half-length of the bar. The peak of the input impedance represents the resonance of the bar being excited at its center.

The transfer function corresponding to the input impedance, expressed in dB (ref 1N.s/m) is the vibration response of the test bar and is used for determining the resonant frequencies¹ and the response curves at each resonance. A typical plot of vibration response with frequency is shown in Figure 1.

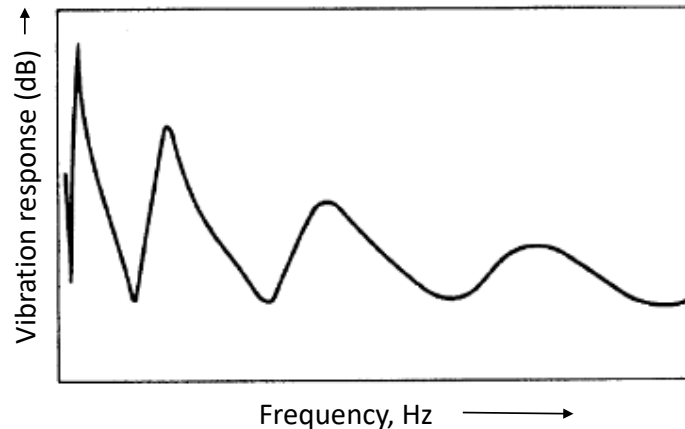


Figure 1 - Vibration response curve

The resonant frequency, f , at a given mode is measured from the vibration response (see Figure 2). 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 is the half-power bandwidth. The ratio of the half-power bandwidth and the resonant frequency is the damping performance of the test bar. Mathematically, this is expressed as:

$$\eta = \frac{\Delta f}{f} \quad (\text{Eq. 1})$$

where:

η = loss factor at resonant frequency, f , (dimensionless)

$$\Delta f = f_u - f_l$$

= half-power bandwidth, Hz

f = resonant frequency, Hz

If the test bar is a bare bar, the performance is called the loss factor of the bar. If the test bar includes a bar and a damping material, the damping performance is the combined performance of the bar and damping material and is expressed as composite loss factor (η_c).

¹ When a bar is excited at its base, its anti-resonant peaks in mobility are equivalent to the resonances of the same system in a fixed base boundary condition. Inverting mobility (velocity/force) into mechanical impedance (force/velocity) converts these anti-resonant valleys into peaks in mechanical impedance. A bar fixed at the center creates two identical cantilevered bars of one half the length of the original bar (see 2.1.5.1). The resonant frequencies of the half-length cantilever are equivalent to these peaks for the bare bar. However, the results of the composite material properties obtained from this test method shall not be compared with that of the Oberst methodology.

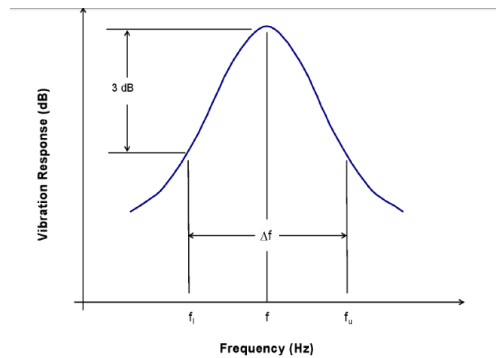


Figure 2 - Composite damping performance computation

4. TEST BAR

Three different bar sizes are shown in Table 1 and shall be used based on the application. For the automotive industry (e.g., passenger cars, pickup trucks), bars A and B shall be used. For the off-highway vehicles, bar C shall be used. The sizes are listed in Table 1.

Table 1 - Test bar dimensions

For 10 to 1000 Hz					
Bar	Material	Half-length L (m)	Thickness H (m)	Width W (m)	E (N/m ²)
A	Aluminum	0.24	0.002	0.04	6.7×10^{10}
B	Steel	0.15	0.0008	0.03	2×10^{11}
For 10 to 2500 Hz					
C	Steel	0.2	0.003	0.03	2×10^{11}

The modes of vibration for each bar size (uncoated) can be computed theoretically. Calculated values for modes 1 through 4 for the three bar types mentioned in Table 1 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.

Table 2 - Bare bar mode frequencies

**[using density of aluminum: 2613 kg/m³, modulus of aluminum: 6.7×10^{10} N/m² (Bar A) and
using density of steel: 7840 kg/m³, modulus of steel: 2.0×10^{11} N/m² (Bars B and C)]**

Bar		Estimated Resonant Frequency (Hz)				
		Mode	1	2	3	4
A	Aluminum		28	178	498	977
B	Steel		29	182	509	997
C	Steel		61	383	1074	2104

5. BAR SIZING

Proper size of the test bar is one of the critical factors in determining the damping performance of a viscoelastic material from the damped bar excitation. The test bars that are used for different applications in the ground vehicle industry and other applicable industries could be:

- Steel bars
- Aluminum bars
- Glass bars
- Polymeric material bars
- Different composite bars

The size of the bar depends on the frequency range of interest. Depending on the application, the frequency range of interest could be different. For example, in the automotive industry the general frequency range of interest could be between 100 and 1000 Hz, whereas in the commercial or off-highway vehicle industry, the frequency range of interest could be between 2000 and 4000 Hz. Therefore, the bar sizes for steel and aluminum bars are going to be different. Likewise, the bar size for a glass panel used to address issues around 3000 Hz is likely to be different from the steel and aluminum bars as mentioned above. However, a properly sized bar will allow to test different damping materials bonded to the bar for the same application.

The size of the bar establishes natural frequencies of the bar where the bar will vibrate at resonance due to random broadband excitation. Of these, the half-length is most critical and establishes the resonant frequencies of the vibrating bar. The longer the half-length, the lower the resonant frequency of a given mode. The thickness is generally selected the same as what would be used in the application. The width of the bar is generally selected between 0.020 and 0.030 m and does not impact the performance of the damping material. For CenterPoint testing, the natural frequency (or commonly also called resonant frequency) of the vibrating bar can be expressed as (see 2.1.3.1 and 2.1.5.2):

$$f_{res,i} = \frac{\lambda_i^2}{2\pi L^2} \sqrt{\frac{B}{\rho_s}} \quad (\text{Eq. 2})$$

This can be further rewritten as:

$$f_{res,i} = \frac{\lambda_i^2}{2\pi L^2} \sqrt{\frac{EH^2}{12\rho}} \quad (\text{Eq. 3})$$

where:

$f_{res,i}$ = resonant frequency for mode i , Hz

i = mode number: 1, 2, 3, . . .

λ_i = coefficient for mode i , of the bar excited at the center

$\lambda_1 = 1.875$

$\lambda_2 = 4.694$

$\lambda_3 = 7.845$

$\lambda_4 = 10.995$

L = half the length of the bar, m

B = bending stiffness of the bar, N.m

ρ_s = surface density of the bar, kg/m²

E = Young's modulus of the bar, Pa

H = thickness of the bar in the vibration direction, m

ρ = density of the bar, kg/m³

To fully understand the dynamics of the proper bar sizing, Table 3 lists the physical properties and size of the bars to get four resonances between 10 to 1000 Hz in one case and 100 to 4000 Hz in another case. The table also provides the estimated resonant frequencies for each mode.

Table 3 - Physical properties and bar sizes for specific frequency ranges²

For 10 to 1000 Hz				
<u>Material</u>	<u>L (m)</u>	<u>H (m)</u>	<u>ρ (kg/m³)</u>	<u>E (N/m²)</u>
Aluminum	0.24	0.002	2613	6.7x10 ¹⁰
Steel	0.15	0.0008	7840	2x10 ¹¹
Mode	1	2	3	4
Est res. freq. (Hz)	29	180	500	990
For 100 to 4000 Hz				
<u>Material</u>	<u>L (m)</u>	<u>H (m)</u>	<u>ρ (kg/m³)</u>	<u>E (N/m²)</u>
Glass ³	0.15	0.003	2500	6.9x10 ¹⁰
Steel	0.15	0.003	7840	2x10 ¹¹
Mode	1	2	3	4
Est res. freq. (Hz)	110	700	1950	3900

6. INSTRUMENTATION AND MEASUREMENTS

6.1 The instrumentation that is expected to be used for this measurement should be precision grade instrumentation and is as follows (see Figure 3 for a schematic of a typical set-up):

- Temperature chamber
- Shaker
- Broadband signal generator
- Power amplifier

² Table 3 is solely to understand the results of the selected half-length and thickness of a bar on the resonant frequencies of the bar.

³ It should be noted that ISO 16940 specifies the size (length, width, and thickness) of laminated glass used in buildings. In a vehicle, laminated glass studies, everyone in the industry follows the same width and half-length provided in the ISO 16940. The SAE Recommended Practice J3130 is not replacing the ISO standard but gives an example of how the length and thickness impact resonant frequencies of the glass as well as other possible materials.