Research Article

Center Impedance Method for Damping Measurement

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Damping materials are used extensively for reduction of vibration and noise. These damping materials have viscoelastic characteristics and are used by automotive and other industries. Testing of these materials is important in order to predict their performance and traditionally the damping properties are measured by the Oberst method. This paper discusses an alternate method called the Center Impedance method where force and response are measured directly and the damping properties are obtained. The Center Impedance method is easy to use requiring only standard vibration equipment for excitation, namely, shaker, and is easy to control the experiment for repeatability. Results of beams tested by both Oberst and Center Impedance methods are presented in order to validate this test method.

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1. Introduction

Damping is of the utmost importance for noise and vibration harshness issues related to the automotive industry [1]. Traditionally the Oberst method is the method of choice recommended by both ASME [2] and SAE [3]. Other innovative methods, such as inverted shaker, have been proposed [4, 5] but did not gain acceptance due to its limitation of applicability in low frequency ranges. However, the Oberst method poses two problems: (1) only viscoelastic materials sprayed or coated onto beams made of magnetic materials can be tested, and (2) heavily damped beams cannot be tested since the force and response sensors are non contacting magnetic sensors. The Oberst method is suitable primarily for narrow samples and wider samples requiring shaker use. This has led to various industrial standards [6, 7]. The Center Impedance method [8], while based on the same theory as Oberst, overcomes both limitations associated with Oberst testing. The Center Impedance method does not require presence of a magnetic material and it provides direct measurement of force and response that permits the user to apply the necessary exciting force. It may be noted that the Center Impedance method is slowly gaining recognition [8–10] but a comprehensive study comparing

the Center Impedance method and the Oberst method is so far lacking. Dowling and Saha [11] have studied loss factors by the Oberst and the Center Impedance methods (only at room temperature). They did not study the Young's moduli and, consequently, could not compare the accuracy of these methods based on comparison of predicted and measured natural frequencies. It may be noted that a plate-based method called Giger Plate method [12] has existed in the industry. However, this method is not very useful [13] because it provides output only at one frequency (around 160 Hz) and the measurement is based on a 6 mm thick plate which is uncommon in many industries, including automotive industry.

2. Theory

The Oberst method uses a cantilever specimen and two magnetic sensors (one placed close to the fixed end and the other placed close to the free end) are used for excitation and response (Figure 1). The Center Impedance method (Figure 2) typically uses an impedance head (force and acceleration sensor combined) to measure applied force and response acceleration of the free-free beam driven at the

FIGURE 1: Oberst Setup.

FIGURE 2: Center Impedance Setup.

center. Since almost all laboratories involved with vibration testing have shakers and impedance heads (or separate force sensor and accelerometer), the Center Impedance method does not require any special apparatus whereas the Oberst method requires a specialized Oberst fixture. Since the properties of the damping material are highly temperature sensitive, tests at temperatures higher than room temperature are performed inside an oven as shown in Figure 3.

The equations for the Oberst method specified in ASTM E756-93 [2] are based on Ross-Kerwin-Ungar (RKU) equations [14]. For a two-layer beam this leads to the following equations:

$$E_1 = \left[(\alpha - \beta) + ((\alpha - \beta)^2 - 4T^2(1 - \alpha))^{1/2} \right] \frac{E}{2T^3}, \quad (1)$$

$$\eta_1 = (1 + MT)(1 + 4MT + 6MT^2 + 4MT^3 + M^2T^4) \times \frac{\eta_c}{MT(3 + 6T + 4T^2 + 2MT^3 + M^2T^4)}. \quad (2)$$

Since the above equations are applicable for a bar damped on one side, the same equations are applied for Oberst and Center Impedance methods (the effects of different boundary conditions are taken care of by natural frequencies of bare bars as well as damped bars).

FIGURE 3: Center Impedance test setup inside Oven.

TABLE 1: Frequencies of bare bar for odd numbered modes.

Theoretical frequency (Hz)	Frequency by Center Impedance method (Hz)	Error
42.5	43.5	2.4%
230.4	225.5	2.1%
571.0	569.0	0.4%
1084.0	1071.0	1.2%

TABLE 2: Specifications of thin bars used for Oberst and Center Impedance.

BATCH	R 690-64	R 690-64
Beam type	Oberst	Center impedance
Boundary condition	Cantilevered	Free-Free
Material density	1057 (kg/m ³)	1057 (kg/m ³)
Material thickness	0.00318 m	0.0030 m to 0.004 m
Beam length	0.2 m	0.305 m
Beam width	0.0127 m	0.0305 m

Theoretical calculations to determine the natural frequencies for bare or undamped beams are based on the following equations:

$$f_n = \left(\frac{1}{2\pi} \right) (\beta_n l)^2 \sqrt{\frac{EI}{\rho A l^4}}, \quad (3)$$

where β_n = the n th modal eigenvalue parameter and its magnitude depends on the boundary conditions of the beam [15].

The natural frequencies measured by the Center Impedance method are compared with the theoretical values in Table 1. The first mode shape obtained numerically (by Finite Element software Ansys displayed on left) and by Center Impedance method (displayed on right) is shown in Figure 4. Similarly third bending mode (theoretical and experimental) is shown in Figure 5.

FIGURE 4: First bending mode at 42.5 Hz (theoretical) and 43.5 Hz (experimental).

FIGURE 5: Third bending mode at 230.4 Hz (theoretical) and 225.5 Hz (experimental).

It may be noted that the Oberst setup involves fixed-free or cantilevered boundary conditions; whereas the Center Impedance method involves free-free boundary conditions. Since cantilevered boundary conditions are difficult to achieve, it is suggested to ignore the results involving the first mode [2]. The Center Impedance method, on the other hand, involves a boundary condition easier to simulate in experiment but only odd number modes are excited (due to placement of a stinger at the center). Natural frequencies by either method are obtained by the location of peaks of the transfer functions. Damping properties (loss factors) may be estimated by one of the three methods: Half power method, Schroeder integration (decay method), and power injection method [16]. In this study half-power method is

used because it works well for transfer functions with well-separated peaks and it is simpler than the Schroeder method. The power injection method has not been used because the previous studies [16, 17] have shown that the power injection method may produce erroneous results.

3. Results

Steel beams coated with liquid sprayable dampers with specifications, as shown in Table 2, were used for this study. Figures 6, 7 and 8 show the composite loss factors η_c of the beams measured at room temperature, 40°C and 60°C.

Next the material loss factor η_1 is computed based on (2), and the results are plotted in Figures 9, 10, and 11.

TABLE 3: Frequencies (in Hz) of thick bars at room temp.

Bar	Mode no.	Experimentally Observed frequencies	Frequencies based on Young's modulus from Center Impedance	Error for Center Impedance	Frequencies based on Young's modulus from Oberst	Error for Oberst
R690-64 S.no 4	1	110	115.4	5%	311.8	183%
R690-64 S.no 4	3	614.5	616.6	0.4%	1690	175%
R690-64 S.no 5	1	115	111.3	3%	311.3	179%
R690-64 S.no 5	3	633.5	615.3	3%	1687	166%
R690-64 S.no 6	1	115	113.5	1%	308	167%
R690-64 S.no 6	3	633.5	627.3	1%	1675	164%
3wk R690-64 40 Deg	1	129	128	0.8%	303.9	135%
3wk R690-64 40 Deg	3	680	708	4%	1649.7	142%
4wk R690-64 40 Deg	1	120.2	109.8	9%	303.9	153%
4wk R690-64 40 Deg	3	663.2	608	8%	1649.7	149%

FIGURE 6: Composite loss factors for thin-coated bars at room temperature.

It may be noted that at any given frequency such as 200 Hz, as expected thicker coating of damping material (bar R690-64 S.No2) will provide larger loss factor than that by bar with thinner coating (bar R690-64 S.No1) for a particular temperature as shown in Figure 12.

Since the loss factors as obtained by the Center Impedance method are consistently higher than those measured by the Oberst method, next Young's moduli of the materials were computed which would then be used to estimate the natural frequencies of thick coated bars and compare with the frequencies obtained by the experiment. Young's moduli of the material were computed using (1) and they are plotted in Figures 13, 14 and 15.

FIGURE 7: Composite loss factors for thin-coated bars at 40°C.

Next, these moduli were used to compute the natural frequencies of bars coated with the same material but of different thicknesses (0.0059 m to 0.0062 m nominal) and were compared with experimentally observed values as shown in Table 3.

4. Conclusion and Discussion

This paper shows the measurement of loss factor and Young's modulus of damping materials using the Center Impedance method. The Center Impedance method not only provided the loss factors which are higher, but more importantly provided Young's moduli which were in better

FIGURE 8: Composite loss factors for thin-coated bars at 60°C.

FIGURE 9: Material loss factor at room temperature.

agreement with experimentally observed values in terms of predicting the natural frequencies of the beams with thicker coating. It may again be noted that the Oberst method does not permit testing of damping material coated onto nonmagnetic materials or use thick coating whether attached to magnetic or nonmagnetic beams. The Center Impedance method does not have these limitations. One

FIGURE 10: Material loss factor at 40°C.

FIGURE 11: Material loss factor at 60°C.

limitation of Center Impedance method is that results are available at only odd numbered modes because this method involves excitation of a free-free beam at the center. Also care should be taken to place the shaker stinger at the center properly in order to avoid excitation of torsional modes. Considering the importance of accurately measuring the properties of damping materials, it is suggested that new

FIGURE 12: Variation of composite loss factor with thickness at various temperatures.

FIGURE 13: Material Young's modulus (in N/m²) at room temperature.

damping measurement standards be established based on the Center Impedance instead of the Oberst method. Future work is suggested to use this technique for several more types of damping materials and also utilize the properties obtained through this method to predict behavior of plates or more complicated structures.

FIGURE 14: Material Young's modulus (in N/m²) at 40°C.

FIGURE 15: Material Young's modulus (in N/m²) at 60°C.

Nomenclature

$$\alpha: (f_c/f_n)^2 (1 + DT)$$

$$\beta: 4 + 6T + 4T^2$$

$$D: \rho_1/\rho, \text{ density ratio}$$

$$A: \text{Area of the beam, m}^2$$

$$E: \text{Young's modulus of bare bar, N/m}^2$$

$$E_1: \text{Young's modulus of damping material, N/m}^2$$

H : Thickness of bare bar, m
 H_1 : Thickness of damping material, m
 I : Moment of inertia of the beam, m^4
 M : E_1/E , Young's modulus ratio
 T : H_1/H , thickness ratio
 η_1 : Loss factor of visco-elastic material, dimensionless
 η_c : $\Delta f_c/f_c$, loss factor of composite bar, dimensionless
 ρ : Density of Oberst bar, kg/m^3
 ρ_1 : Density of damping material, kg/m^3
 Δf_c : Half-power bandwidth for mode s of composite bar, Hz
 f_n : Resonance frequency for mode n of bare bar, Hz
 f_c : Resonance frequency for mode c of composite bar, Hz
 c : Index number: 1, 2, 3, etc.
 l : Length of bar, m.

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