Project No. 981587

DAMPING TECHNOLOGIES, INC.
CHARACTERIZATION OF THE DYNAMIC MECHANICAL PROPERTIES OF MATERIALS USING THE VIBRATING BEAM TECHNIQUE

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Prepared for:
Quiet Solution, Inc.
3685 Enochs Street
Santa Clara, CA 95051

Prepared by:
Damping Technologies, Inc.
12970 McKinley Highway
Unit IX
Mishawaka, IN 46545-7518

Contacts:

Quiet Solutions, Inc.
Marc Porat
Matt Golden
(408) 523-4000
matthew@quietsolution.com

Damping Technologies, Inc.
Thomas M. Lewis
(513) 779-2237
(513) 779-2251 FAX
tomlewis@one.net

I. INTRODUCTION

The purpose of this program was to measure the dynamic mechanical properties of a viscoelastic material for Quiet Solutions, Inc. The viscoelastic material is being targeted by Quiet Solutions for use as a passive damping countermeasure in the marine industry.

The test procedure utilized to characterize the dynamic mechanical properties of the viscoelastic material is the ASTM E-756 Vibrating Beam Technique. The basic data acquisition technique associated with ASTM E-756 consists of evaluation of the resonance frequencies and modal loss factor of a cantilever beam consisting wholly of the test material, or of the test material combined with metal base beams. Using standard equations governing the particular test specimen configuration, this data is then combined with specimen geometry, specimen weight densities, and base beam flexural rigidity values to yield the dynamic mechanical properties of the test material itself.

In the case of the Quiet Solutions viscoelastic material that was submitted for test in this program, a sample of the material was applied to a steel base beam having a free length of (10”), a thickness of (0.0621”), and width of (0.5”). The Quiet Solutions viscoelastic material was applied to both sides of the steel base beam at an average thickness of (0.1264”).

Test Range

The viscoelastic materials were tested over a temperature range of about (-35 F) to (210 F). The data acquisition frequency range was approximately 100 Hz to 2700 Hz.

Use

These properties obtained are useful for material selection tasks, particularly when combined with suitable analytic models to predict damping and structural dynamics modification as a function of temperature and frequency. Such data can be used to assess structural integrity issues, damping, noise and vibration concerns, and high cycle fatigue issues.

II. TEST PROGRAM

Task 1 - Specimen Preparation

Dependent on the nature of the viscoelastic material to be evaluated and the properties required, one of four test specimens are typically constructed as shown in (Figure 1).

Modified Oberst Specimen

The modified Oberst speciment configuration was chosen for test of this material largely because the end-application is a free-layer damping system and the material is therefore able to be applied at fairly substantial thicknesses. The modified Oberst configuration has benefits compared to the Oberst configuration because material is applied to both sides of the base beam. This is advantageous with respect to coefficient of thermal expansion/contraction issues that can cause the test Oberst beam test article to bend, particularly as temperature decreases. The modified Oberst configuration balances these CTE stresses and the test article generally remains straight throughout the entire test temperature range. Also, application of material to both sides of the beam is helpful in terms of measurement resolution issues. In this test, the Young’s modulus and the material loss factor are deduced from the difference in measured properties between the modified Oberst or “composite” beam and the base beam. So, measurement resolutioin is improved as the viscoelastic material contributes more to the stiffness of the “composite” beam. Applying the viscoelastic material to both sides of the base beam results in a larger contribution to the stiffness of the “composite” beam.

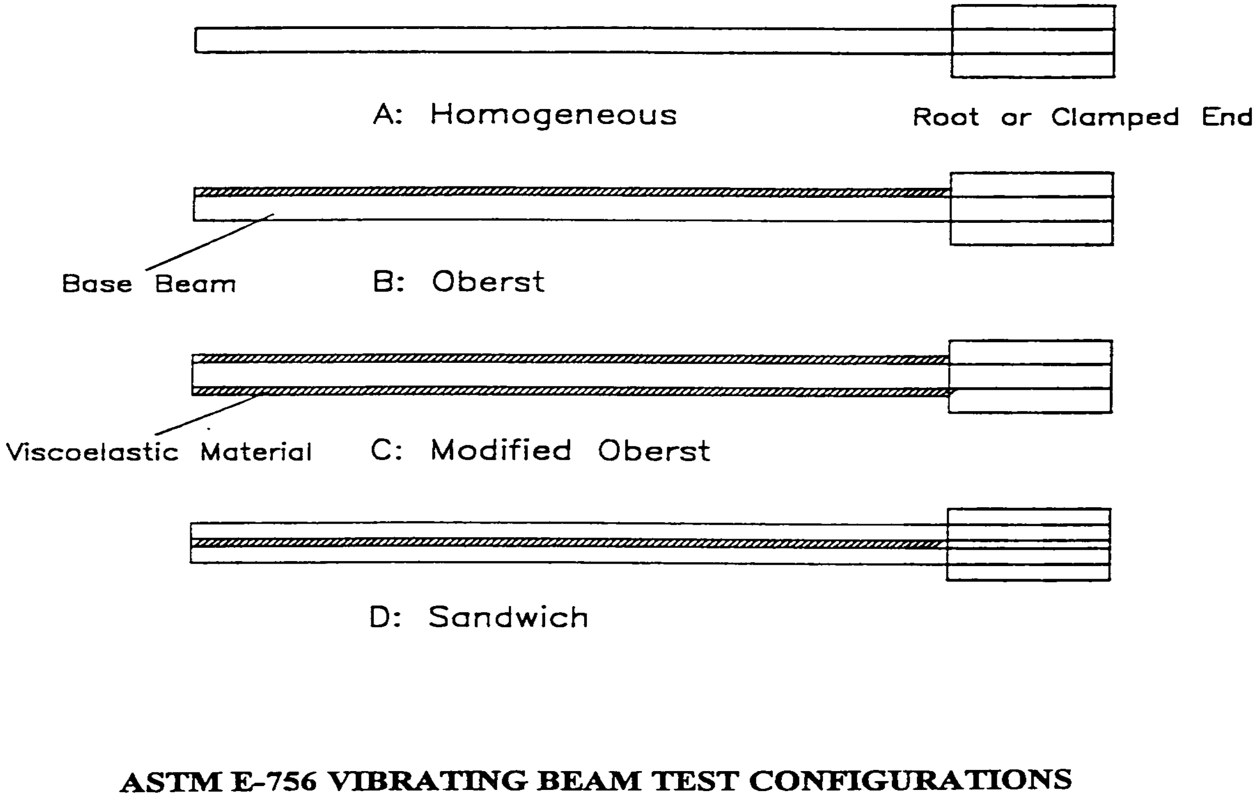


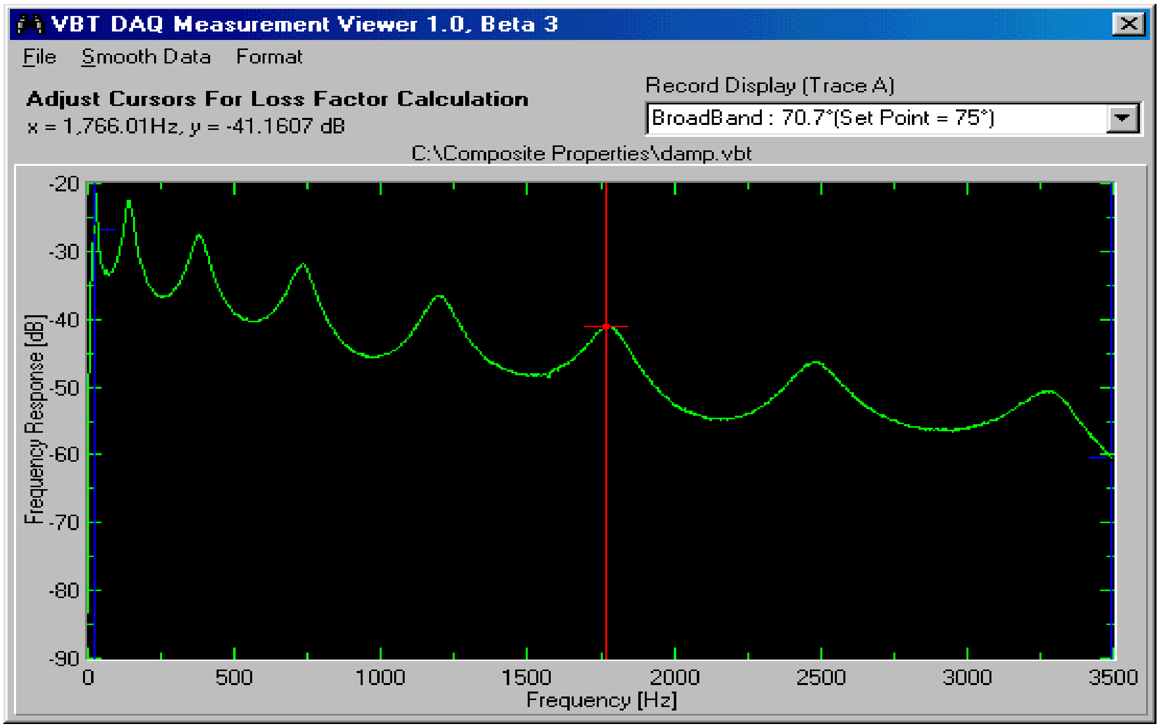
Figure 1: ASTM E-756 Vibrating Beam Test Article Configurations

<u>Task 2 - Data Acquisition</u>

A piezoelectric crystal was bonded to cantilever beam test article near the clamped end using a structural adhesive. The piezoelectric crystal was utilized to measure the response of the cantilever beam during data acquisition. The cantilever beam sample was mounted in a test apparatus which provides a firm boundary condition at the "root" or clamped end. Excitation was provided at the free end of the beam using a non-contacting magnetic exciter.

Basic Data Acquisition

Random noise was applied to the magnetic exciter via a power amplifier. The frequency response of the test article was monitored over a frequency range which includes a number of bending modes of the cantilever beam. (Figure 2) shows a typical base bend FRF measurement. For this work, modes 2 through 6 were monitored yielding a frequency range of about (100 Hz) to (2,700 Hz). Resonance frequency and modal loss factor were measured for each bending mode of interest. Modal loss factor was estimated using the half-power bandwidth technique. A typical zoom transform measurement is included as (Figure 3).



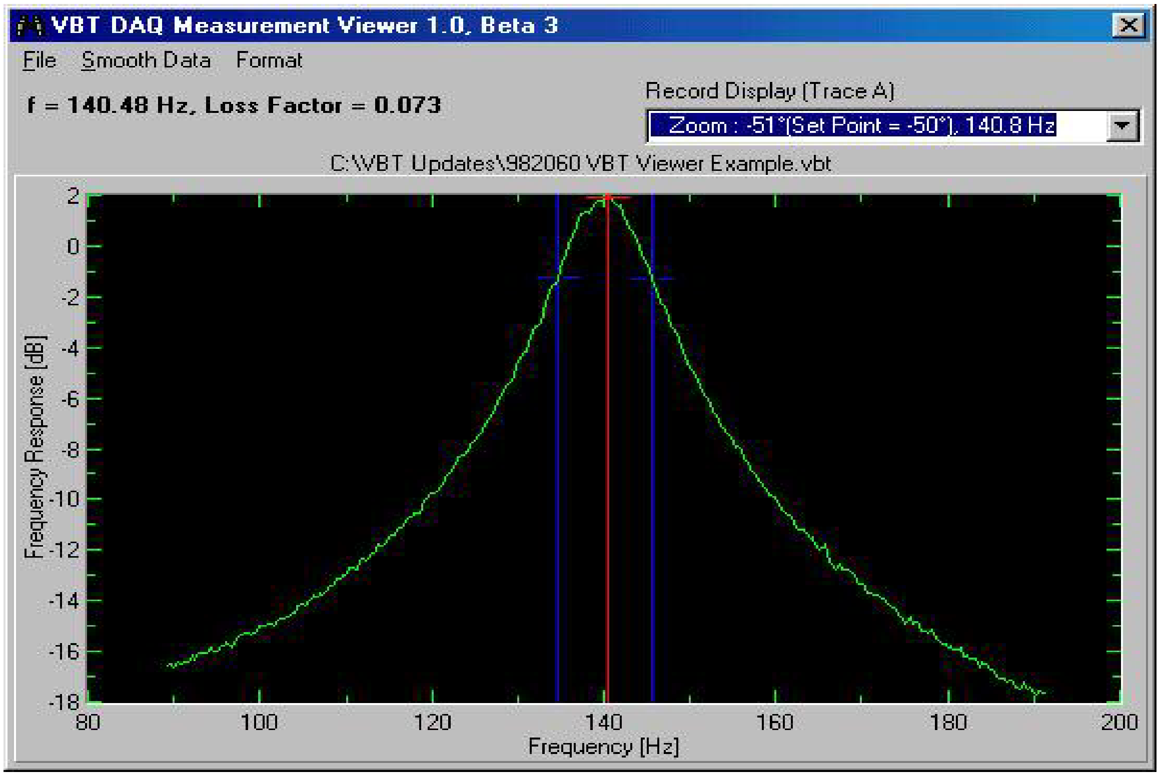
Adjust Cursors For Loss Factor Calculation

x = 1,766.01Hz, y = -41.1607 dB

Record Display (Trace A): BroadBand : 70.7°(Set Point = 75°)

C:\Composite Properties\damp.vbt

Figure 2: **Typical Base-Band FRF Measurement**



f = 140.48 Hz, Loss Factor = 0.073

Record Display (Trace A): Zoom : -51°(Set Point = -50°), 140.8 Hz

C:\VBT Updates\982060 VBT Viewer Example.vbt

Figure 3: **Typical Zoom Transform FRF Measurement – Extraction of Modal Loss Factor**

Data Acquisition Temperature

The test specimen and support fixture were placed inside an environmental chamber where the basic data acquisition is repeated at temperature increments of the full test temperature range. The data was gathered at approximately (15 F) increments where the modal loss factor was low. Where the modal loss factor exceeded (n = 0.10), the data was acquired in (5 F) increments. Measurements were conducted after a (45) minute dwell time to ensure full thermal equilibrium of the specimen after a change of temperature. Thus, data acquisition takes considerable amounts of time.

Data Acquisition Output

The data acquisition procedure yields data sets for:

- Modal Resonance Frequency
- Modal Loss Factor

for each bending mode of interest across the test temperature range.

(Figure 4) is a photograph of the vibrating beam technique test system data acquisition hardware. (Figure 5) shows the VBT System environmental chamber. (Figure 6) shows the vibrating beam technique mounting fixture in the environmental chamber. (Figure 7) describes details regarding the data acquisition system set-up. (Figure 8) shows a typical test article mounted in the vibrating beam mounting fixture.

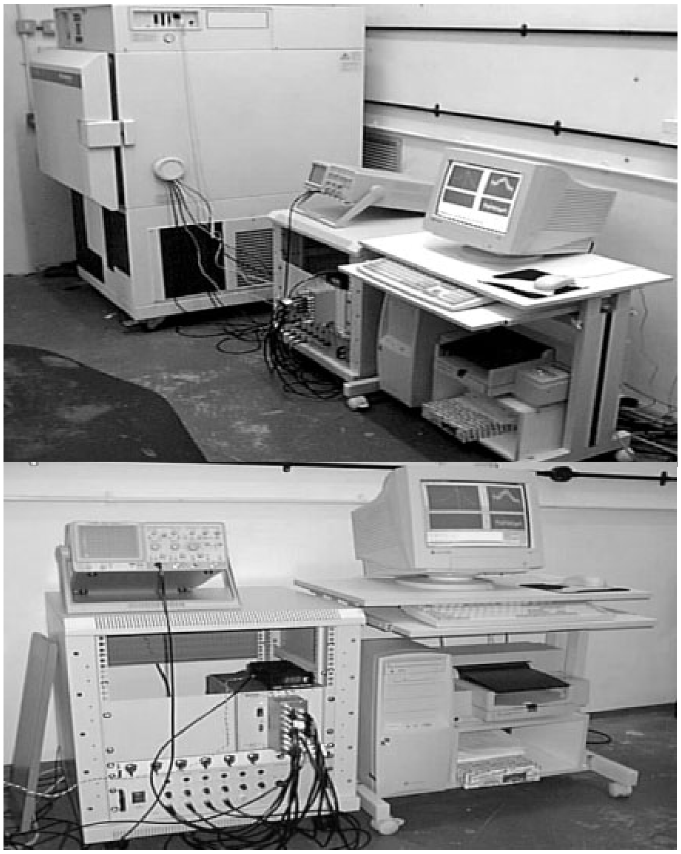


Figure 4: ***VBT System*** **– Vibrating Beam Technique Data Acquisition Hardware**

Figure 5: **Environmental Chamber Utilized for Vibrating Beam Technique Data Acquisition**

Figure 6: **Vibrating Beam Test Fixture in Environmental Chamber**

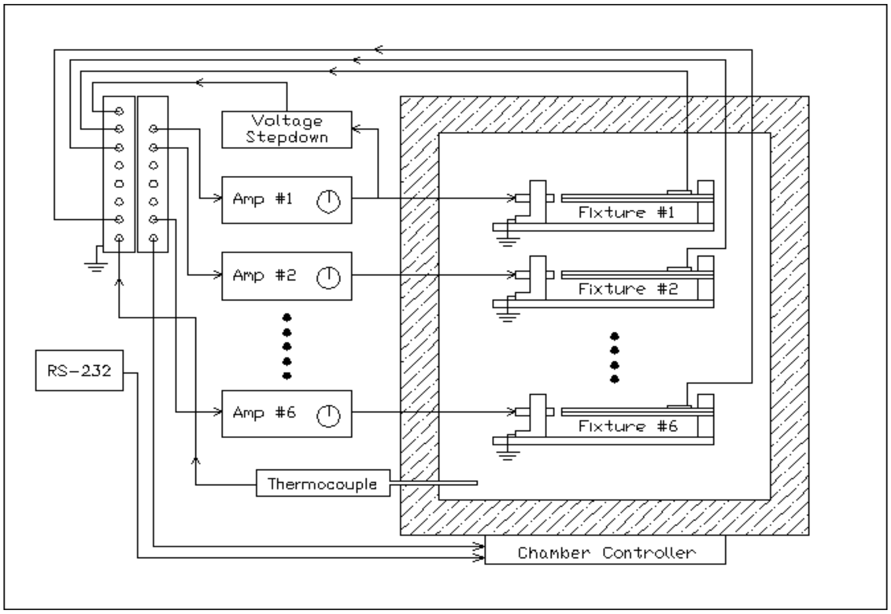


Figure 7: **Vibrating Beam Technique Test Setup**

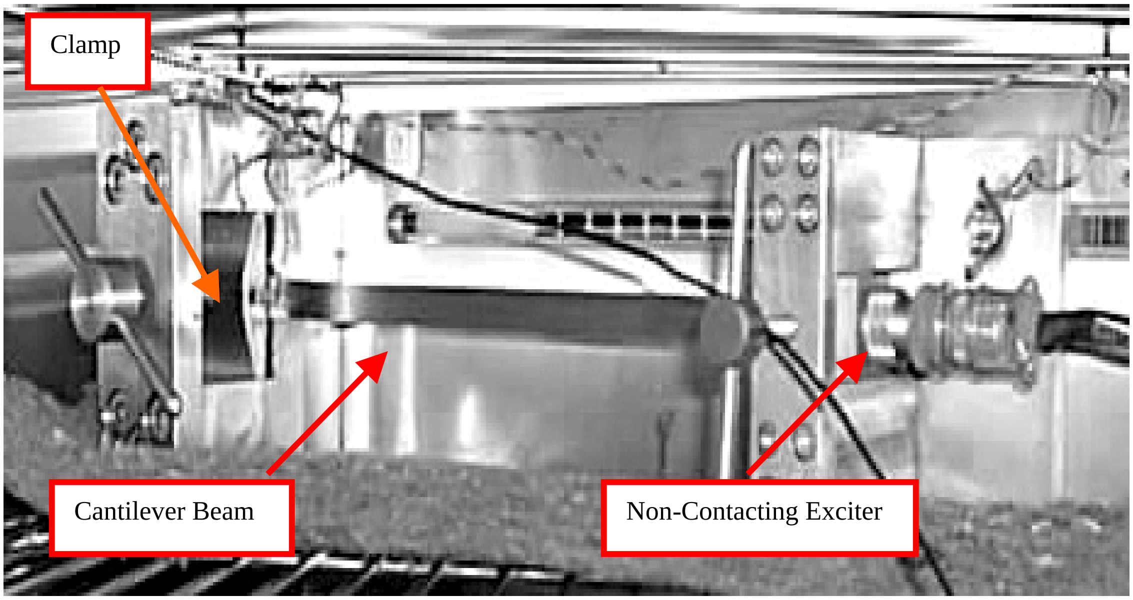
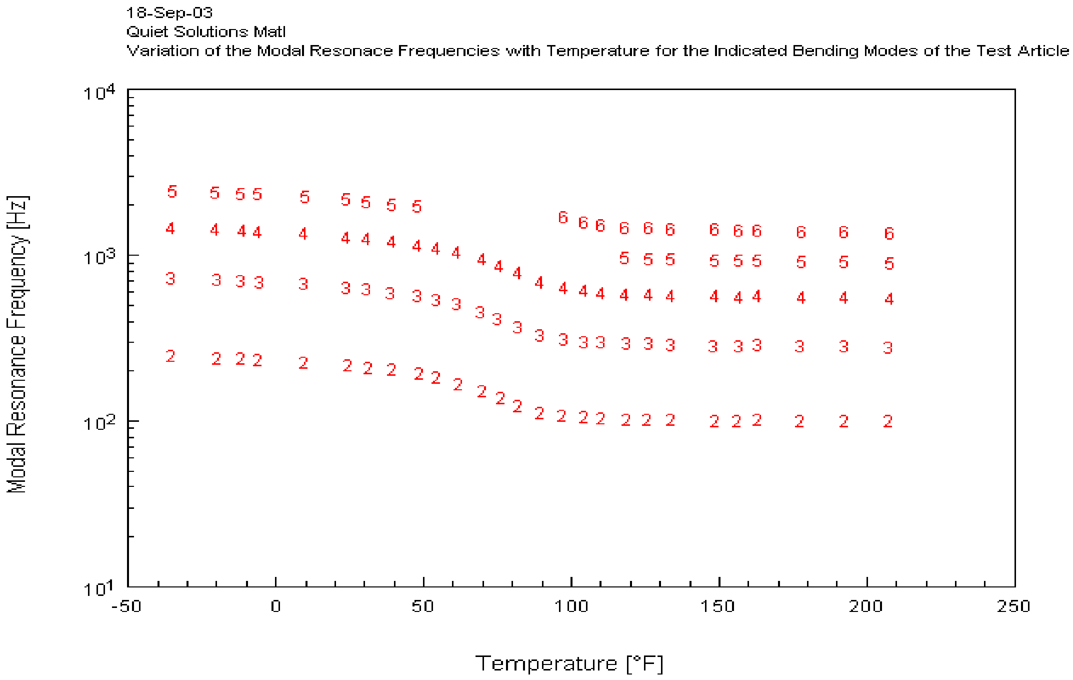


Figure 8: **Vibrating Beam Test Article and Mounting Fixture**

(Figure 9) describes the variation of the composite modal resonance frequency as a function of temperature associated with the basic data acquisition process. (Figure 10) describes variation of the modal loss factor as a function of temperature for the Quiet Solutions test article.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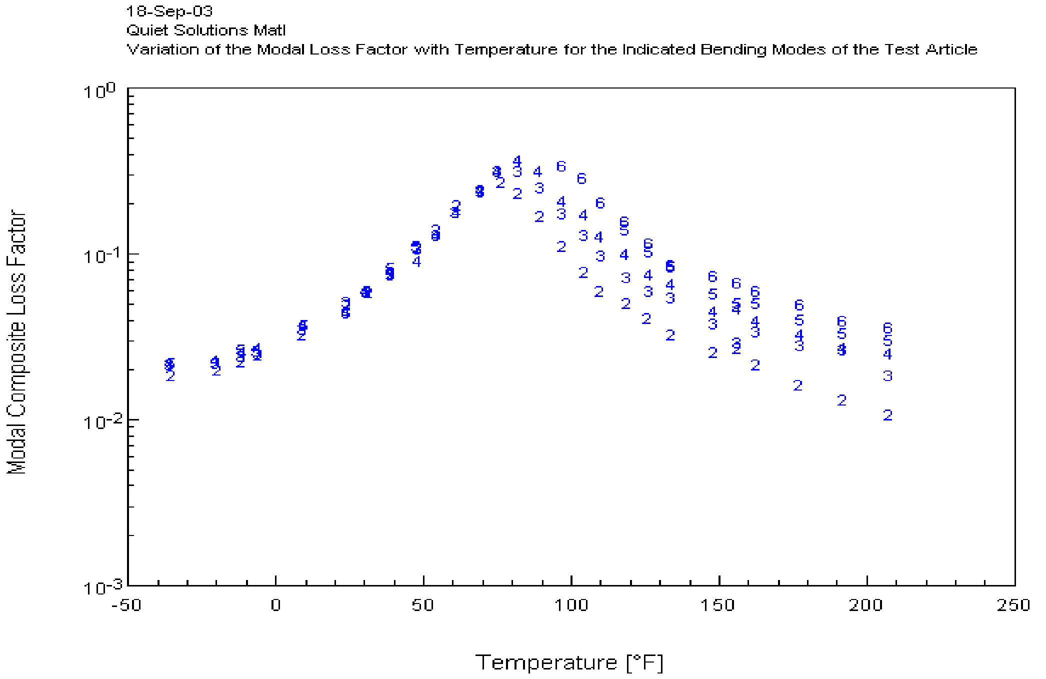
Variation of the Modal Resonace Frequencies with Temperature for the Indicated Bending Modes of the Test Article

Figure 9: **Variation of the Measured Composite Modal Resonance Frequency as a Function of Temperature Associated with the Data Acquisition Process**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Variation of the Modal Loss Factor with Temperature for the Indicated Bending Modes of the Test Article

Figure 10: **Variation of the Measured Composite Modal Loss Factor as a Function of Temperature Associated with the Data Acquisition Process**

Task 3 - Data Processing

The “composite property” data sets described in Task 2 were combined with data related to the specimen geometry, specimen densities, and base beam material properties. These were then utilized in characteristic standard equations which govern the particular test specimen configuration to yield the dynamic mechanical properties of the viscoelastic material itself, independent of the base beam or of geometry. This step yields discreet values of storage modulus, and loss factor for the data acquisition test frequencies and temperatures.

Temperature-Frequency Superposition

The data was then processed in the *reduced frequency* format by utilizing *temperature frequency superposition principles* which collapse data obtained at various temperatures, for specific test frequencies, to single master curves for Young’s modulus and material loss factor in terms of an arbitrary reference temperature. This graph is equivalent to the variation of the material properties that would be obtained had the material been tested over a very wide frequency range at a constant temperature (the reference temperature).

Curve Fit

The data was subsequently expressed in the *Jones temperature frequency nomogram* format where the effects of temperature and frequency can be viewed simultaneously. In this format, curve fit equations were used to describe the properties, such that the dynamic mechanical properties are characterized as a continuous function of temperature and frequency. Using these expressions, dynamic material properties at any temperature and any frequency can be quickly calculated. However, caution should be used when extrapolating the data far from the temperature and frequency ranges of the test.

Data Processing Output

Results of the data processing procedure consist of analytic expressions for:

- Shear Storage Modulus
- Material Loss Factor

These expressions describe the material properties for simultaneous effects of temperature and frequency. These expressions have been successfully utilized to extrapolate data far from the temperature and frequency ranges of the test.

(Figure 11) describes the *Jones* temperature–frequency nomogram for the Quiet Solutions material tested during the program. (Figure 12) describe the dynamic mechanical properties of the material as a function temperature for several constant frequencies.

The analytic curve fit parameters follow (Figures 11 and 12).

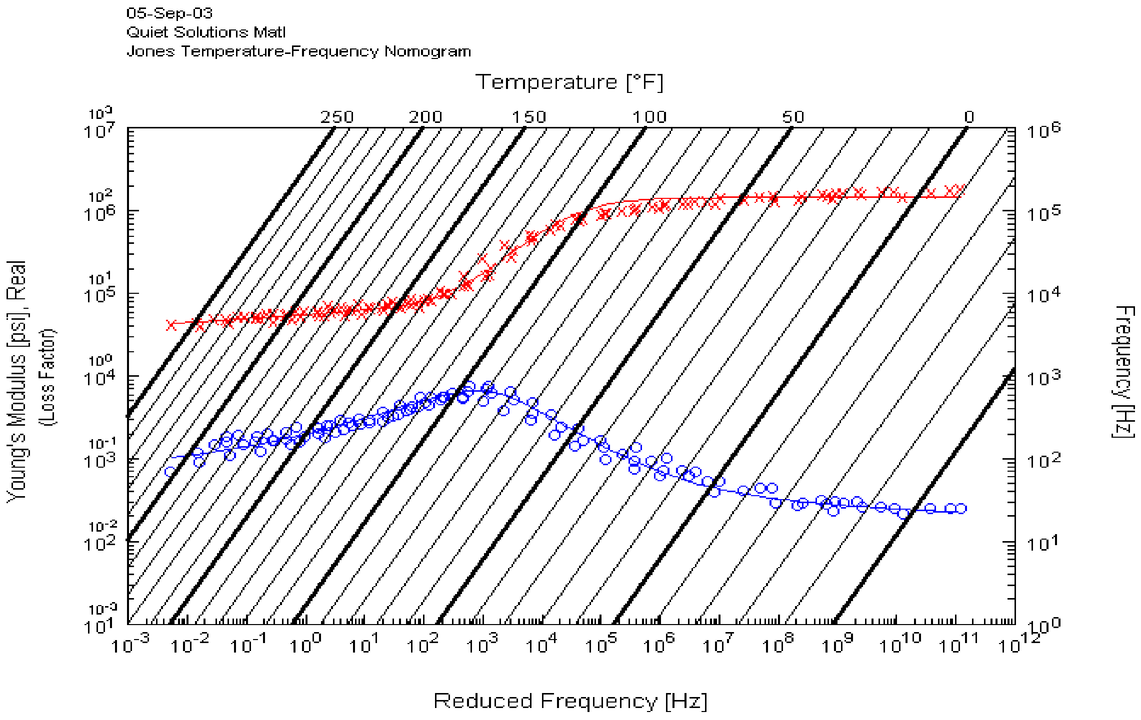


Figure 11: *Jones* **Temperature-Frequency Nomogram**

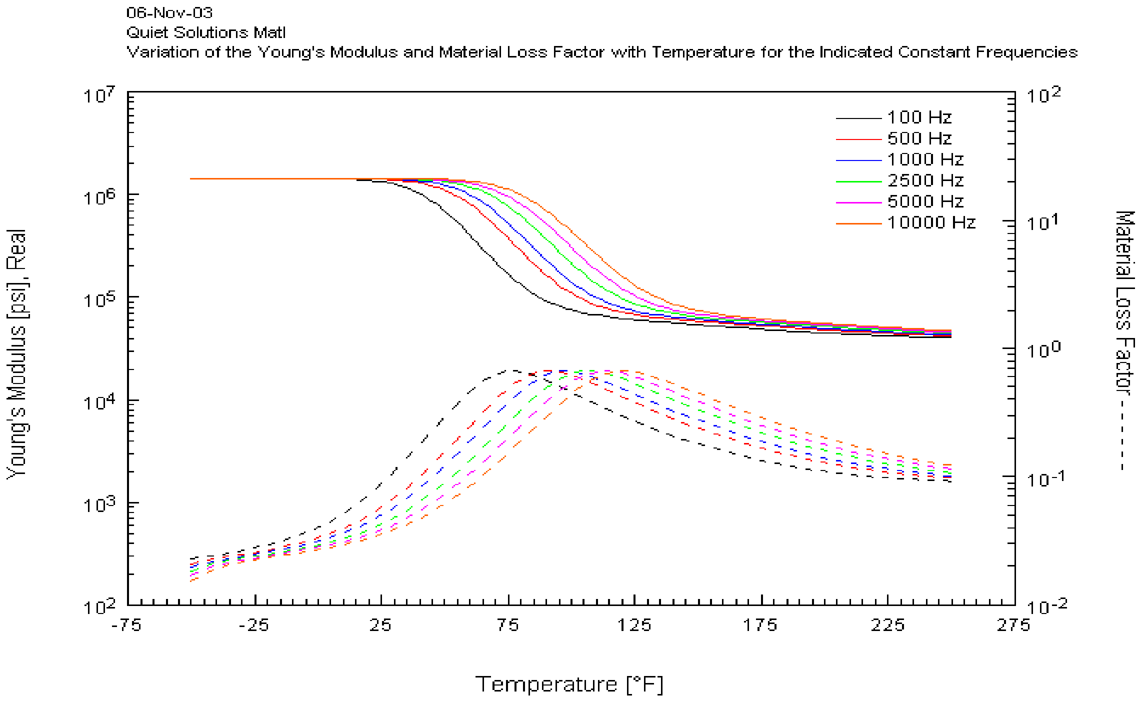


Figure 12: **Variation of the Dynamic Mechanical Properties as Function of Temperature for the Indicated Constant Frequencies**

CURVE FIT EQUATION SET #2 – (15 Parameter / Double Transition)

$$G' = G_{mid} - [(G_{mid}-G_{min}) / (1+K1_a*(f*alpha(T))^\wedge n_a)] + G_{max} - [(G_{max}-G_{min}) / (1+K1_b*(f*alpha(T))^\wedge n_b)]$$

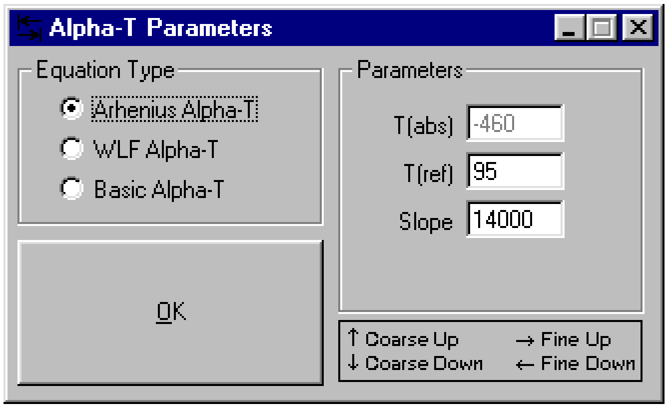
$$\text{Loss Factor} = K2_a*[(f*alpha(T))^\wedge(P_a-1)] / [(1+K_{3a}*(f*alpha(T))^\wedge P_a)^\wedge m_a] + K2_b*[(f*alpha(T))^\wedge(P_b-1)] / [(1+K_{3b}*(f*alpha(T))^\wedge P_b)^\wedge m_b]$$

Arrhenius Alpha T Equation:

In English Units

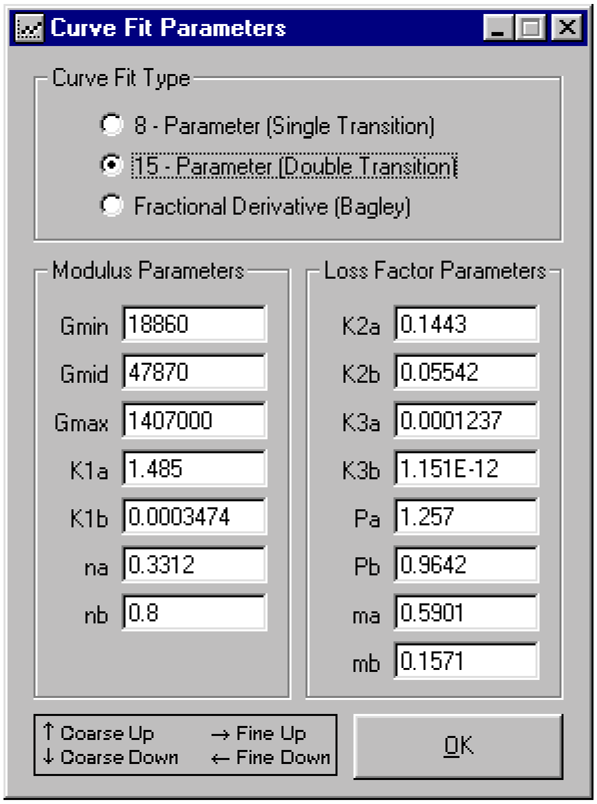
alpha(T) = 10^ [((Tref-T)q) / ((Tref+460)(T+460))]

q = “slope” or “activation temperature”
T = Temperature
f = Frequency



Equation Type
● Arhenius Alpha-T
○ WLF Alpha-T
○ Basic Alpha-T

Parameters
T(abs) -460
T(ref) 95
Slope 14000



Curve Fit Type
○ 8 - Parameter (Single Transition)
● 15 - Parameter (Double Transition)
○ Fractional Derivative (Bagley)

Modulus Parameters		Loss Factor Parameters	
Gmin	18860	K2a	0.1443
Gmid	47870	K2b	0.05542
Gmax	1407000	K3a	0.0001237
K1a	1.485	K3b	1.151E-12
K1b	0.0003474	Pa	1.257
na	0.3312	Pb	0.9642
nb	0.8	ma	0.5901
		mb	0.1571

III. BRIEF DISCUSSION AND SUMMARY

The data acquired on this Quiet Solutions material were typical of a good quality vibrating beam test in terms of the typical uncertainty and scatter. The data acquired on the test article should be considered reliable. Overall, the test and the results should probably be considered to be of above-average quality.