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RESONANCE APPARATUS OPERATING MANUAL

BY GILBERT F. LEE
RESEARCH AND TECHNOLOGY DEPARTMENT

15 SEPTEMBER 1991

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FOREWORD

The resonance apparatus, as described in this manual, has proven to be a valuable tool in obtaining dynamic mechanical properties of materials. The apparatus was originally developed as a research instrument but, more recently, the apparatus has been redesigned for use in the harsh environment of a factory. The apparatus was successfully demonstrated to be useful for quality control purposes. Because the instrument might only be used on an occasional basis at various locations during different stages of a program, it was desirable that the instrument be made easily portable and usable by personnel from different facilities with a minimum of training. This manual is intended to accompany the packaged instrument. It contains instructions for unpacking the instrument, setting it up, using it, and repacking it for shipment.

While the development of the resonance apparatus was carried out over the past several years, the preparation of this manual was done during Fiscal Year 1992 under support from the Naval Sea Systems Command.

Approved by:

Carl E. Mueller

CARL E. MUELLER, Head
Materials Division

ABSTRACT

This manual presents the following material: (1) a detailed description of the resonance apparatus, (2) a step-by-step electrical hookup of the equipment, and (3) the use of computer program QCP. The material is given in three tutorials. Operating diagnostics are also given.

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ILLUSTRATIONS

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INTRODUCTION

This document is the operating manual for a computer automated resonance apparatus for quality control (QC) of polymer materials mixed in a factory or shipyard. The apparatus determines dynamic mechanical properties: shear modulus and loss factor as functions of temperature and frequency in the kilohertz frequency range. Computer automation makes the apparatus easy to use by inexperienced operators. A computer program, named QCP, is designed to make the measurement, store the data on disc, plot the data, and compare the results to a pass/fail standard.

A pass/fail standard for a material relates the dynamic mechanical properties to the mix ratio and void content of the material. By measuring the resonance properties of a large number of laboratory-made test specimens for a given chemical mix ratio, the standard can be determined by taking an average of these properties.

The resonance apparatus[1] is based on producing resonances in a bar specimen. In brief, measurements are made over 1.5 decades of frequency in the kilohertz region at various temperatures. For many materials, only one temperature is required. The procedures for temperature equilibration are described in TEST TEMPERATURE. As shown in Figure 1, an electromagnetic shaker (Bruel & Kjaer Type 4810) is used to drive a test specimen at one end while the other end is allowed to move freely. Miniature accelerometers (Bruel & Kjaer Type 4374) are used to measure the driving point acceleration at the shaker end and the acceleration at the free end of the specimen. The procedures to prepare and mount the test specimen are described in TEST SPECIMEN PREPARATION AND MOUNTING.

The output signals from the accelerometers are amplified by charge amplifiers (Bruel & Kjaer Type 2651). A power supply (Bruel & Kjaer Type 2805) is used with these amplifiers. The amplified signals are then routed to a dual channel Fast Fourier Transform spectrum analyzer (Hewlett Packard Model 3582A). The analyzer digitizes and displays the measured signals as amplitude and phase of the acceleration ratio. The analyzer also supplies a random noise source to drive the shaker. The data is always sampled and root-mean-square averaged at least four times for low noise data and up to 32 times for noisy data. Details of electronically connecting the instruments are presented in ASSEMBLING THE ELECTRONIC EQUIPMENT.

At certain frequencies, the amplitude goes through local resonant peaks. The number of resonant peaks that can be measured is usually four to six. At resonance, Young's modulus and loss factor are determined. By assuming Poisson's ratio of 0.5, Young's modulus is converted to shear modulus. The loss factor for Young's modulus is assumed to equal the loss factor for shear. The equations that are solved for the modulus and loss factor are described in **Appendix A: Mathematical Equations.**

A computer program was specifically developed to automate the measurement for use by inexperienced operators. The program is written in Hewlett Packard BASIC 4.0 to run on any Hewlett Packard Series 9000 Model 200 or 300 computer. The purpose of the program is to automate the data collection from the spectrum analyzer, to store the data on disc for later use, and to compare the data to a pass/fail standard. The program is described in COMPUTER PROGRAM QCP. A detailed description of the data storage format on disc is discussed in **Appendix B: Data Storage Format.**

In OPERATING DIAGNOSTICS, instrument diagnostics are presented to aid the operator in checking the electronic setup. The operation of the resonance apparatus is usually done in automated mode. But as part of the operating diagnostics, manual operation of the apparatus is described in **Appendix C: Manual Setup.**

A list of equipment is given in **Appendix D: Parts List.** The computer and spectrum analyzer are mounted in transit cases, while the printer, charge amplifiers, power supply, shaker, and accelerometers are in two storage drawers. Please keep the foam blocks that are used to protect the equipment during shipping. Instructions for repacking the equipment are given in **Appendix E: Prepare for Shipping.**

TEST TEMPERATURE

For the purpose of QC, a simplified procedure is used to obtain data quickly but reliably. It was found for many polymer materials that measurements at 0°C gave the best results.

The procedure used is: first, cool the test specimen mounted in the test apparatus, which will be described later, to 0°C; second, allow the specimen to equilibrate at 0°C for at least 2 hours; and third, make the measurement using the QCP program.

TEST SPECIMEN PREPARATION AND MOUNTING

Test specimens should be molded in the shape of a bar. The mold should be at least 6-inches long and with square lateral dimensions of 0.25 inch. Once the specimen is made, it is trimmed of all flash and cut to 4-inch length using a razor blade and cutting block.

The following detailed procedure is used to cut the test specimen square:

1. Place the test specimen in the square channel of the cutting block, which is shown in Figure 2.

2. Position the razor blade across the specimen and in the slot provided in the cutting block. About one-quarter of the blade should be over the specimen and the rest in the slot.

3. Before cutting the specimen, place the cutting block on a solid surface to prevent the block from rocking.

4. Gently tap the razor blade once with a hammer to make a small cut in the specimen.

5. Place a drop of water between the razor blade and specimen to lubricate the razor blade.

6. Strike the razor blade with a hammer until the specimen is cut through.

7. The specimen should be able to stand upright on either end without support. If the specimen topples over, re-cut the ends until the specimen passes this simple squareness test. Square ends are necessary to obtain a good bond between the specimen and mounting blocks.

Three input properties--length, mass, and density of the specimen--are determined before bonding the specimen to the mounting blocks. The length is determined by a micrometer in centimeters and reported to four significant digits. The mass is determined by a balance in grams and reported to four significant digits. The density is determined by a water displacement technique, ASTM D 792, *Standard Test Method for Specific Gravity and Density of Plastic by Displacement.* This value is also reported to four significant digits.

At the mounting block attached to the shaker (Figure 1), the specimen and one accelerometer are adhesively bonded with a thin layer of contact cement (Loctite Black Max Item No. 38050) to this mounting block. The block is made of steel and has dimensions of 1 x 0.75 x 0.5 inch. It has been shown[2] that the adhesive thickness should be very thin and the modulus of the adhesive should be greater than that of the material to be measured. By following the above rules of thumb, the adhesive does not affect the measurements.

The second accelerometer is bonded to another but smaller mounting block using the same adhesive. Then this block is bonded to the free end of the specimen. The total mass that is hanging off the specimen is about 2.8 g, which consists of the body of the accelerometer, about 3 inches of the accelerometer electrical lead, and the mounting block. The purpose of this block is to protect the accelerometer lead from the abuse of repeated mounting and dismounting from the free end of the specimen. This block is also made of steel and has the following dimensions: 0.25 x 0.25 x 0.25 inch. In the determination of the modulus, the end mass is taken into account.[3] A large end mass will lower the resonant frequency, while a small end mass will raise the resonant frequency. However, the modulus of the material is the same using either size end mass.

The following procedure is used to mount the specimen to the mounting blocks:

1. Scrape both mounting blocks clean of adhesive with a razor blade.

2. Shake the adhesive (Loctite Black Max Item No. 38050) to suspend the black filler in the liquid adhesive.

3. Place a very small drop of the adhesive over the center of the larger mounting block.

4. Smear the adhesive with the end of the specimen to obtain a thin layer and then apply some pressure.

5. Place another very small drop of adhesive on the free end of the specimen. Smear the adhesive with a disposable stirrer to obtain a thin layer on the specimen, but do not bond the smaller mounting block on yet.

6. Allow the adhesive on both ends of specimen to dry for 30 minutes.

7. Apply a very small drop of adhesive to the end of the smaller mounting block.

9. Place the smaller mounting block on the free end of the specimen and allow to set for another 30 minutes.

10. Test the bonds by gently pulling on the specimen.

11. Screw the larger mounting block into the shaker using the supplied 10–32 threaded screw until snug. BE CAREFUL WITH THE ACCELEROMETER LEADS AS YOU TWIST THE BLOCK ON THE SHAKER.

ASSEMBLING THE ELECTRONIC EQUIPMENT

The computer (Hewlett Packard Model R/332), spectrum analyzer (Hewlett Packard Model 3582A), and printer (Hewlett Packard Model 2225B) communicate over the Hewlett Packard Interface Bus (HP-IB). The HP-IB connector of each instrument is located on the back and is marked "HP-IB."

1. Attach one HP-IB cable from computer to analyzer.
2. Attach the other HP-IB cable from computer to printer.
3. Plug power cords into the three instruments.
4. Feed the paper into the printer.

Two charge amplifiers (Bruel & Kjaer Type 2651) are used with a power supply (Bruel & Kjaer Type 2805). A specially made cable system is used to connect the amplifiers to the power supply. This system has three connectors: one 6-pin connector and two multipin connectors. The insulation on the wires in this system are black, white, and red.

5. Connect the multipin connectors to the back of the charge amplifiers.
6. Connect the 6-pin connector to the back of the power supply.

The following settings are made on the front panel of the charge amplifiers:

7. Turn "Sensitivity" knob to "1 mV/pC."
8. Set "Input" switch to "Grounded."
9. Set mode switch to "Acc. x 1."

Only one setting is made on the back of the charge amplifiers:

10. Set the switch to ± 14Vb.

The following settings are made on the power supply:

11. Set "Channel 1" and "Channel 2" to " ± 14V."
12. Plug power cord into power supply.

The following instructions are for connecting the accelerometers (Bruel & Kjaer Type 4374) to the charge amplifiers, charge amplifiers to spectrum analyzer, and shaker (Bruel & Kjaer Type 4810) to analyzer:

13. Connect the accelerometer lead on the shaker end of the specimen to "Input" of the charge amplifier (front) using a microdot cable.

14. Connect from "Output" of the charge amplifier (back) to "CHANNEL A" of the spectrum analyzer (front) using a BNC cable with a banana plug on one end. The ground (nib) on the banana plug should be connected to ground (black) on the spectrum analyzer.

15. Connect the accelerometer lead at the free end of the specimen to "Input" of the charge amplifier (front) using a microdot cable.

16. Connect from "Output" of the charge amplifier (back) to "CHANNEL B" of the spectrum analyzer (front) using a BNC cable with a banana plug on one end. The ground (nib) on the banana plug should be connected to ground (black) on the spectrum analyzer.

17. Connect the shaker to the "OUTPUT" of the "NOISE SOURCE" of the spectrum analyzer using a microdot cable with a microdot-BNC adapter.

18. Set "NOISE SOURCE" inner knob to "RANDOM" on the spectrum analyzer.

19. Set "NOISE SOURCE" outer knob to full clockwise until knob clicks on the analyzer.

20. Turn on the power for all the instruments.

21. Test the printer by pressing the "PWR" button (blue) on the printer.

COMPUTER PROGRAM QCP

Computer program QCP automatically searches for resonant frequencies, determines the modulus and loss factor results, stores data on either the floppy or hard disc, and compares the results to the pass/fail standards.

The program is menu driven using three sets of User menus. When the computer is on, the word "User" and a number appear in the lower right-hand corner of the cathode ray tube (CRT). In each set of User menus, there are eight function keys. Prompts, describing the function of the keys, are displayed on the CRT. The physical keys, which the user actually presses, are located on top of the keyboard and are labeled f1 through f8. The use of the function keys will be explained in the following three tutorials.

TUTORIAL I: DATA INPUT

In this tutorial, the method of entering and editing the specimen parameters is described. This tutorial assumes that a test specimen is mounted and all electrical connections made and the power for the instruments is on.

To start the QCP program, turn on the computer. Two disc drive identifiers are displayed on the CRT. The hard drive is called ":CS80, 700" and the floppy drive is ":CS80, 700, 1." Using the arrow keys on the keyboard, place the pointer on the hard drive identifier and then press All Done (f7). A list of all computer programs on the hard disc will be displayed. Move the pointer to QCP, then press All Done (f7). After the program is loaded, the following User 1 function keys will be displayed: PRINT FILE (f1), NEW SAMPLE (f2), EDIT PARAMeters (f5), STOP PROGram (f6), MEASURE MENU 2 (f7), and FILE MENU 3 (f8). A description of these keys is found in Table 1.

To enter the sample parameters, press NEW SAMPLE (f2). A dialogue box asking for input parameters appears as shown below:

```
Name of Test Specimen
Annotation/ Identifiers

Mass of Specimen in g
Length of Specimen in cm
Density of Specimen in g/cm³

End Mass in g                     2.8

Data File Name
Mass Storage Identifier
```

The end mass has already been entered as 2.8 g, which is the mass of the accelerometer and mounting block. DO NOT change this value. Three new function keys will appear: HELP (f1), Abort (f4), and All Done (f7). By pressing the HELP key (f1), an explanation for each data entry is given. The Abort key (f4) allows one to exit this dialogue box without making any changes. Type in an input; when you are done, press Return. After entering the input parameters for your test specimen, press the All Done key (f7). The User 1 function keys (Table 1) will appear.

Press PRINT FILE (f1). A new set of function keys will appear: SCREEN (f1), PRINTER (f3), and Abort (f5). To display the data on the CRT, press SCREEN (f1) key. To obtain a hard copy, press PRINTER (f3). To return to User 1 without printing, press Abort (f5).

The EDIT PARAMeters key (f4) is used to make changes to the input parameters. The changes are made in the same dialogue box as used in NEW SAMPLE (f2). DO NOT use NEW SAMPLE (f2) to make changes!

The function key STOP PROGram (f6) is used to terminate execution of the program. The program can be restarted from the operating system menu by pressing the RUN key (f3).

Function keys MEASURE MENU 2 (f7) and FILE MENU 3 (f8) will be discussed in TUTORIAL II and TUTORIAL III, respectively.

TUTORIAL II: MEASUREMENT

In this tutorial, the resonant measurements and the comparison of the measured data to the pass/fail standard are described. Press key labeled MEASURE MENU 2 (f7) in User 1. Three new keys appear in User 2: ACQUIRE DATA (f1), QC ANALYSIS (f4), and DATA MENU 1 (f8), which are described in Table 2.

Press ACQUIRE DATA (f1). A dialogue box is opened and one data input is needed. Enter the temperature of the measurement: "0". The computer will then take control of the spectrum analyzer.

The data on the screen of the spectrum analyzer will be changing as the measurements proceed. The first data displayed (during the first 30 seconds) is shown in Figure 3. If the display is different from Figure 3, then it is possible that the electronic hookup was done incorrectly. Refer to the OPERATING DIAGNOSTICS section to fix the problem.

The following are displayed, sequentially, on the computer CRT. First, the maximum frequency limit used in the search for resonances is displayed. Typically, this limit is between 5,000 and 16,000 Hz. Second, rough estimates of the resonant frequencies are listed. Usually four to six resonant frequencies are determined. Third, the final resonant frequencies and amplitude ratio are displayed. The measurement is completed in 5 to 8 minutes. At the conclusion of the search, the modulus and loss factor and associated measured data (temperature, resonant frequency, etc.) are printed on the printer.

To compare the measured data with one of the pass/fail standards, which is already part of the computer program, press QC ANALYSIS (f4). Pass/fail standard options are displayed. Select the standard that correspond to the material under test by using the arrow key to position the pointer at the desired standard, then press All Done (f7). Next the program displays the temperature of the measurement on the

CRT, 0°C. Press Return. The results of a linear least squares fit of the shear modulus (G) data will be displayed. Fitting constants to an equation of the form G (MPa) = P1 + P2 x $\log_{10}$ frequency (Hz) are printed. The program pauses so you can view these numbers. Press Continue (f2) when ready. Modulus data points versus frequency appear and the program pauses again. Press Continue (f2) when ready. The linear least-squares line is drawn through the data points and the program pauses once more. Press Continue (f2) when ready. The pass/fail standard window is superimposed on the experimental data. A visual comparison between the measured and standard data can be made. If the measured data is inside the window, then the data passes (Figure 4, example A). If the data is outside the window, then the data fails (Figure 4, example B). The program automatically makes a hard copy on the printer.

The program will automatically repeat the above analysis, done on the shear modulus, for the loss factor. Fitting constants will be displayed. Loss factor data points will be plotted. Linear squares line will be drawn through the data points. The pass/fail standard window (Figure 4, example A pass and example B fail) will be superimposed on the experimental data. A hard copy will be made.

Press DATA MENU 1 (f8) to return control back to User 1. Then press f8 again for FILE MENU to continue with TUTORIAL III.

TUTORIAL III: DATA FILE RETRIEVAL

In this tutorial, data file retrieval is discussed. The purpose of data retrieval is to be able to analyze previously measured data at a later date. Press FILE MENU 3 (f8) in User 1. Six new function keys appear in User 3: GET DRIVE (f1), LIST FILES (f2), RETRIEVE DATA (f3), DATA MENU 1 (f4), STOP PROGram (f6), and GET NEW PROGram (f7). A description of these keys is given in Table 3.

Press GET DRIVE (f1) to find all the disc drives which are in use by the computer. For this particular computer system, two disc drive identifiers will be displayed; one for the floppy drive ":CS80,700,1" and the other, the hard drive ":CS80,700." Move the pointer by using either the arrow keys and select the hard drive by pressing All Done (f7).

Press LIST FILES (f2). A dialogue box will appear that contains the identifier (":,CS80,700") for the hard drive that you selected in the previous step. Press All Done (f7). A display of all data files on the hard disc is shown, for example, 4G15 and MPT1. Place the pointer on 4G15 and press All Done (f7). The display changes to show you the data file name and sample name, comments and date of the measurement. For this tutorial, press ACCEPT (f1). If you reject this file, then the program gives you have another chance to select a different file.

Press RETRIEVE DATA (f3), which is another way of reading data off the disc. Enter the data file name 4G15 and enter ":,CS80,700" disc drive identifier. Press All

Done (f7). This method is faster than LIST FILES (f2), but you must know the two inputs.

Once the data file is retrieved, the analysis proceeds as outlined in TUTORIAL II.

The remaining three function keys in User 3 have the following use. DATA MENU 1 (f4) returns controls from User 3 to User 1. STOP PROGram (f6) terminates the execution of the program, but the program can be restarted by pressing the RUN key (f3) of the operating system. GET NEW PROGram (f7) returns the computer to the beginning of TUTORIAL I and displays all programs on hard disc. Further details concerning the format of the data stored on disk are given in Appendix B. A listing of all variable names is given in Table 4.

OPERATING DIAGNOSTICS

As a quick check of whether the electronic hookup is done correctly, a visual inspection of the spectrum analyzer display can be done. The spectrum analyzer can be run by using program QCP or manually setting up the front panel controls of the analyzer as described in ***Appendix C: Manual Setup***.

In the automated mode, the spectrum analyzer displays the amplitude and phase of the acceleration ratio during the search for the resonant peaks as shown in Figure 3 over a broad frequency range (0 to 25,000 Hz). The solid curve is the amplitude ratio. The amplitude ratio curve goes through several resonant peak maxima. The dashed curve is the phase. The values of the phase decrease to almost -200 degrees with increasing frequency between the first and second resonant peak maxima. There are several other points on the phase curve that change from approximately -200 degrees to +200 degrees.

As the measurement proceeds, the display shows just the first resonant peak (Figure 5). The solid curve is the amplitude ratio while the dashed curve is the phase. If these two figures are similar to the spectrum analyzer screen, then the electronic hookup is correct.

Results of common incorrect setups are shown in Figures 6, 7, and 8. In Figure 6, both amplitude ratio and phase appear as noise because the noise source to the shaker is not on. The remedy is to turn on the "NOISE SOURCE" at the spectrum analyzer.

In Figure 7, the curves are inverted in comparison to Figure 3. The reason is that the accelerometers are not connected to the right channels of the spectrum analyzer. The remedy is to connect the lead of the accelerometer nearest to the shaker to "CHANNEL A" and the lead of the accelerometer at the free end of the test specimen to "CHANNEL B."

In Figure 8, the amplitude ratio (solid) curve of the first resonant peak appears correct. But the phase (dashed) curve does a -200 degree to +200 degree jump before the peak maximum and then decreases from +150 degrees to 0 degrees with increasing frequency. In comparison to the phase curve in Figure 5, this phase curve is wrong. The problem is that the banana plug ground is not connected to the ground of the spectrum analyzer. The remedy is to match the ground of the banana plug (the side with the nib) with the ground (black) of the analyzer.

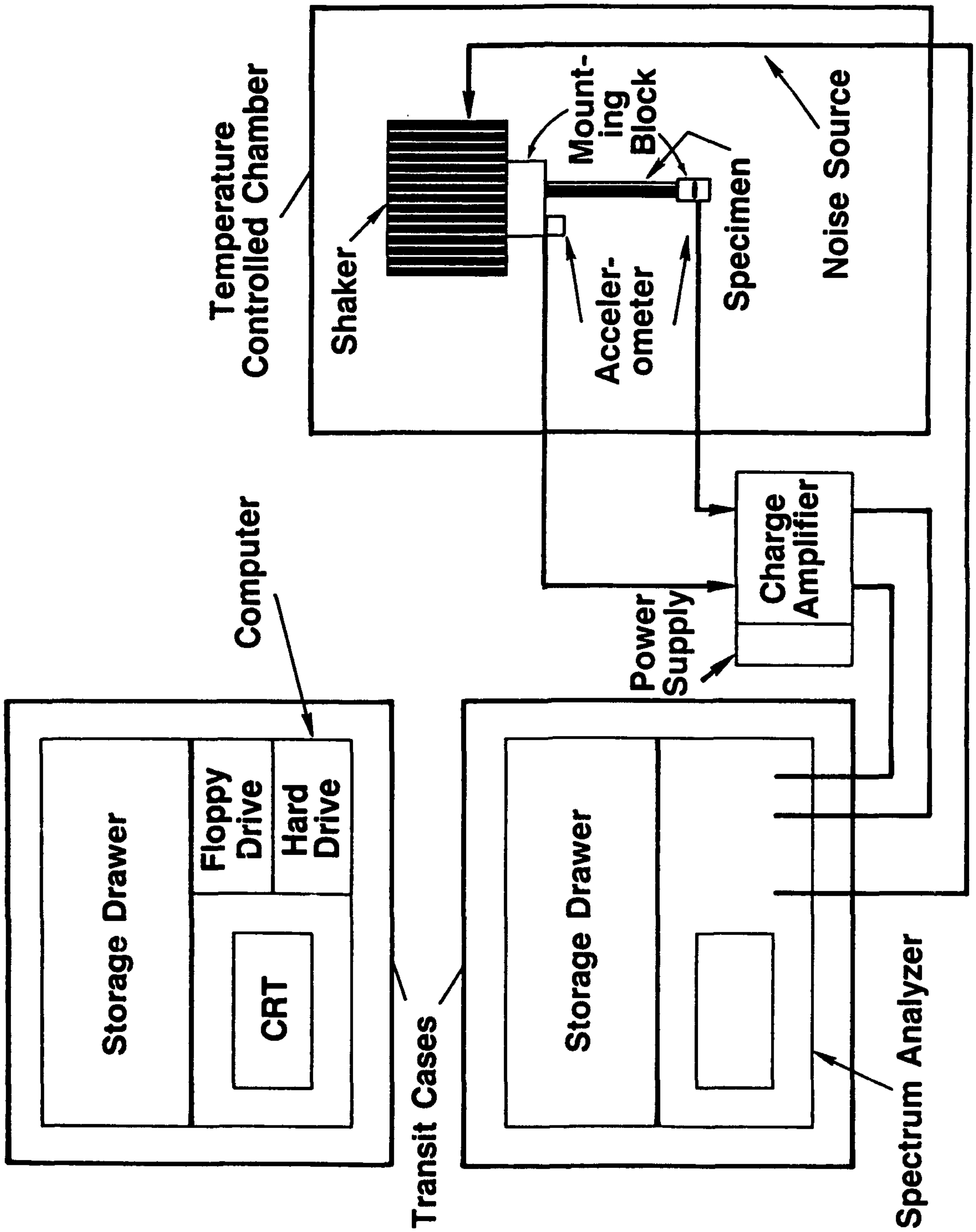

FIGURE 1. PORTABLE RESONANCE APPARATUS IN TRANSIT CASES

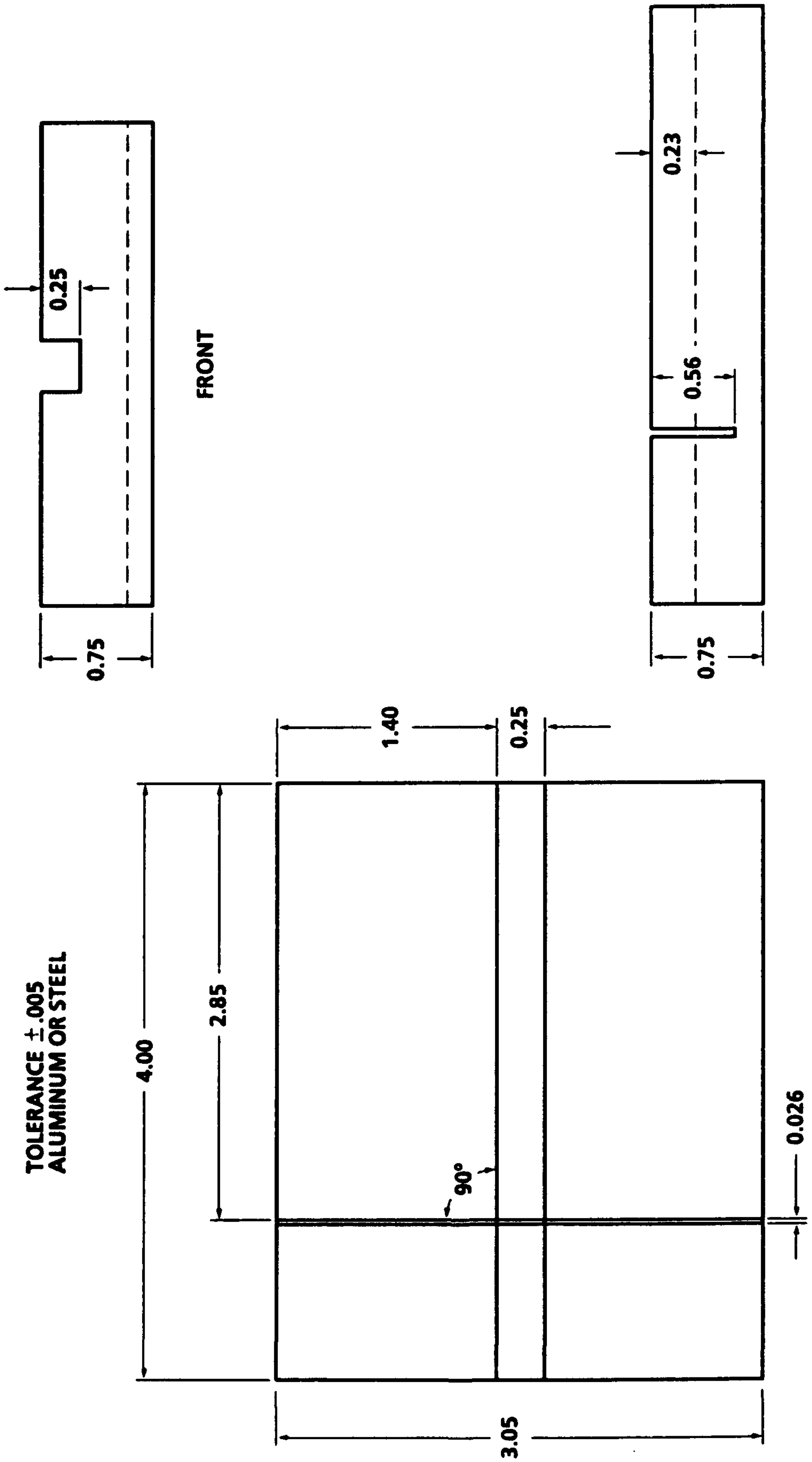

FIGURE 2. CUTTING BLOCK

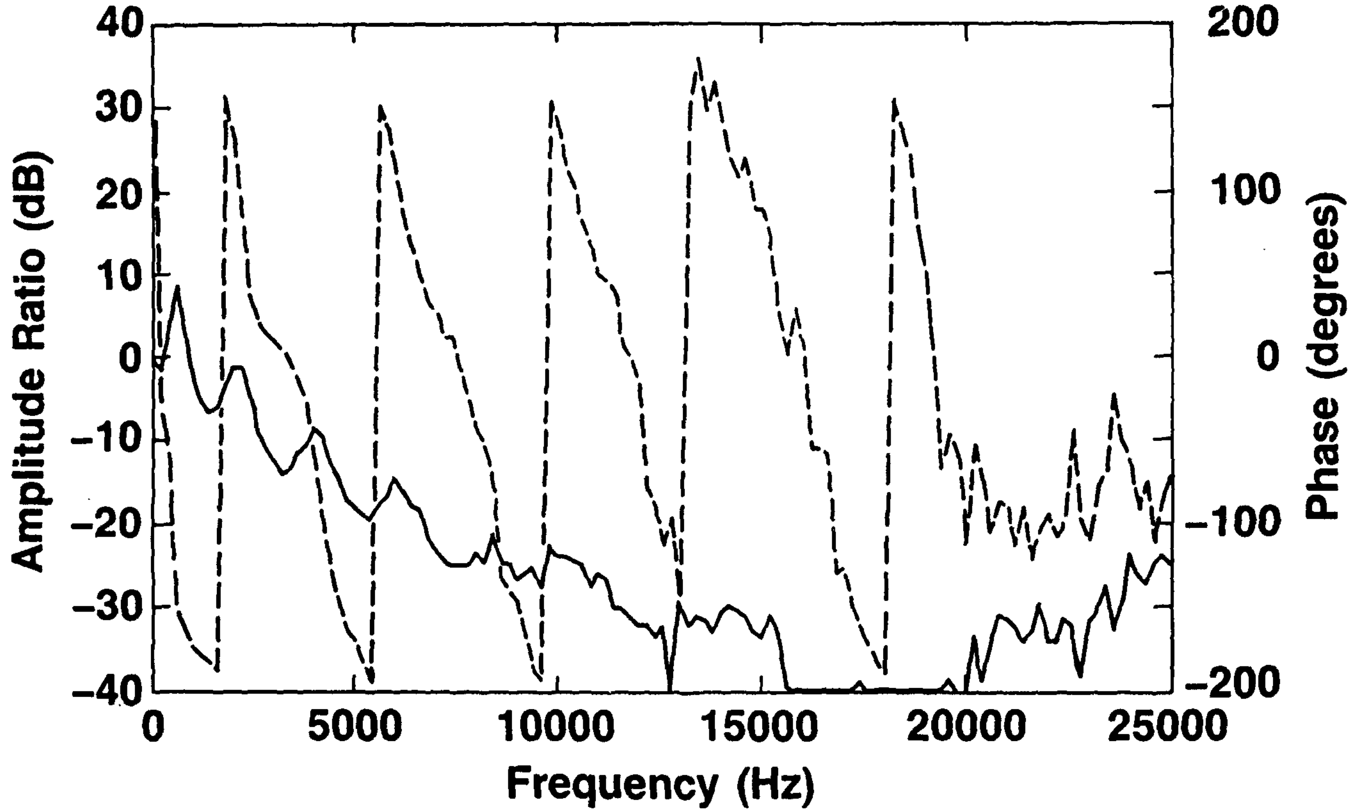

FIGURE 3. AMPLITUDE RATIO AND PHASE VERSUS FREQUENCY AS DISPLAYED ON THE SPECTRUM ANALYZER USING THE CORRECT SETUP

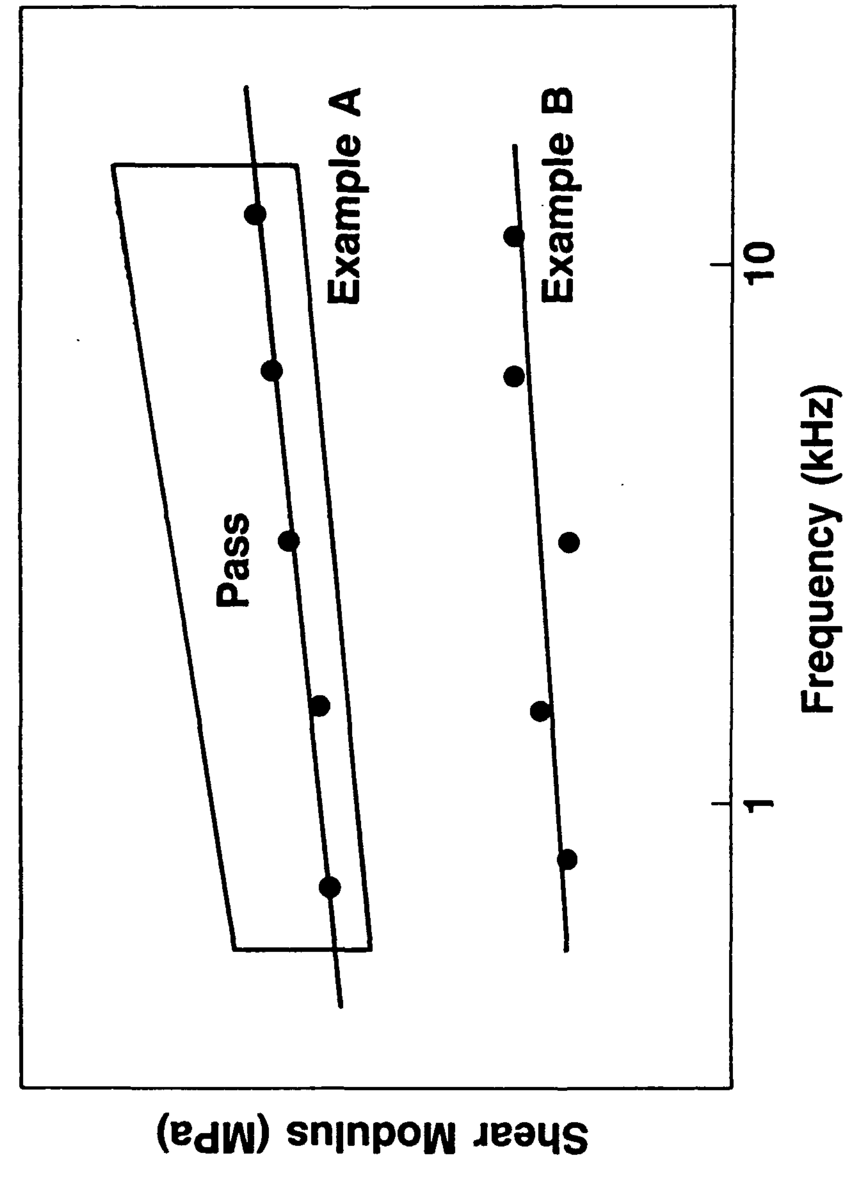

FIGURE 4. SHEAR MODULUS VERSUS FREQUENCY AND PASS/FAIL WINDOW

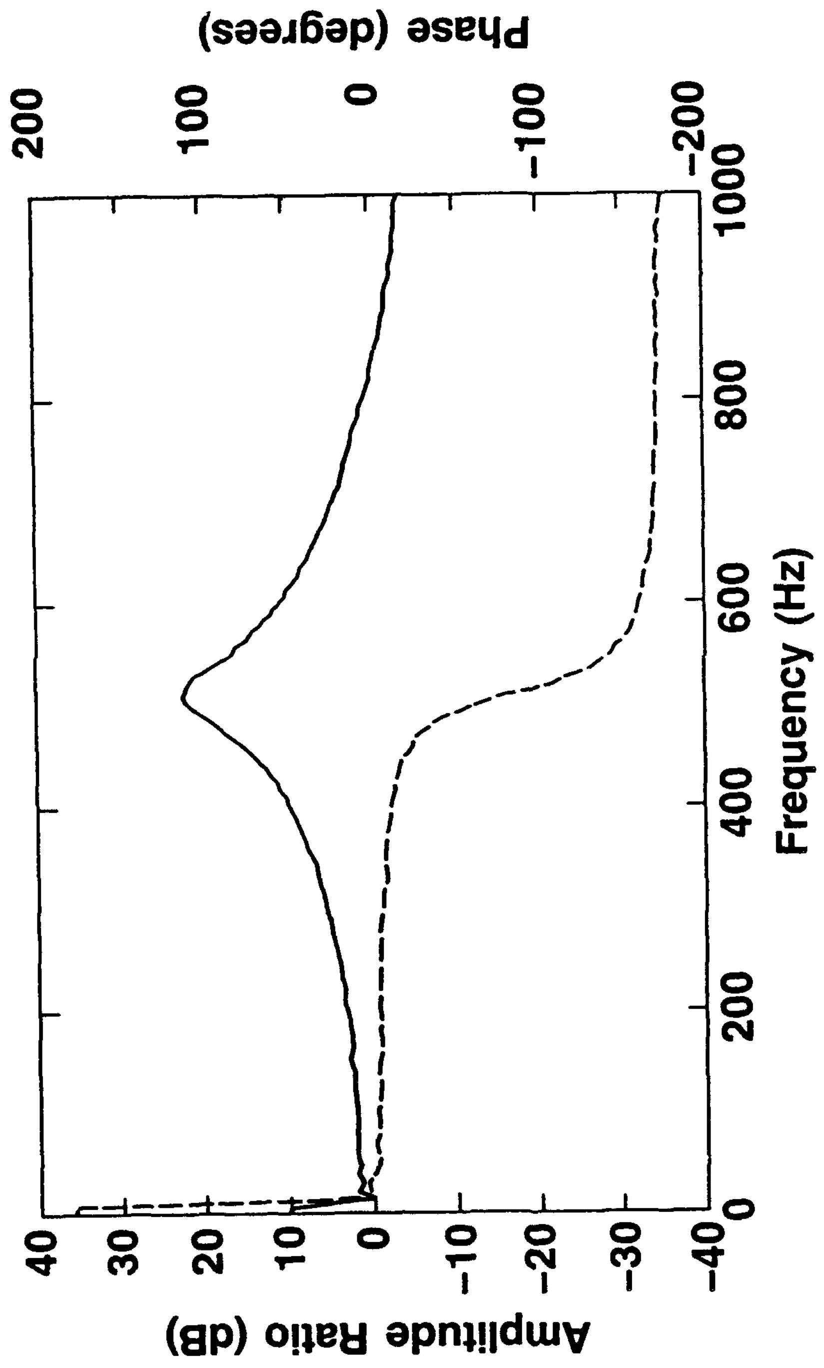

FIGURE 5. AMPLITUDE RATIO AND PHASE VERSUS FREQUENCY OF THE FIRST RESONANCE AS DISPLAYED ON THE SPECTRUM ANALYZER USING THE CORRECT SETUP

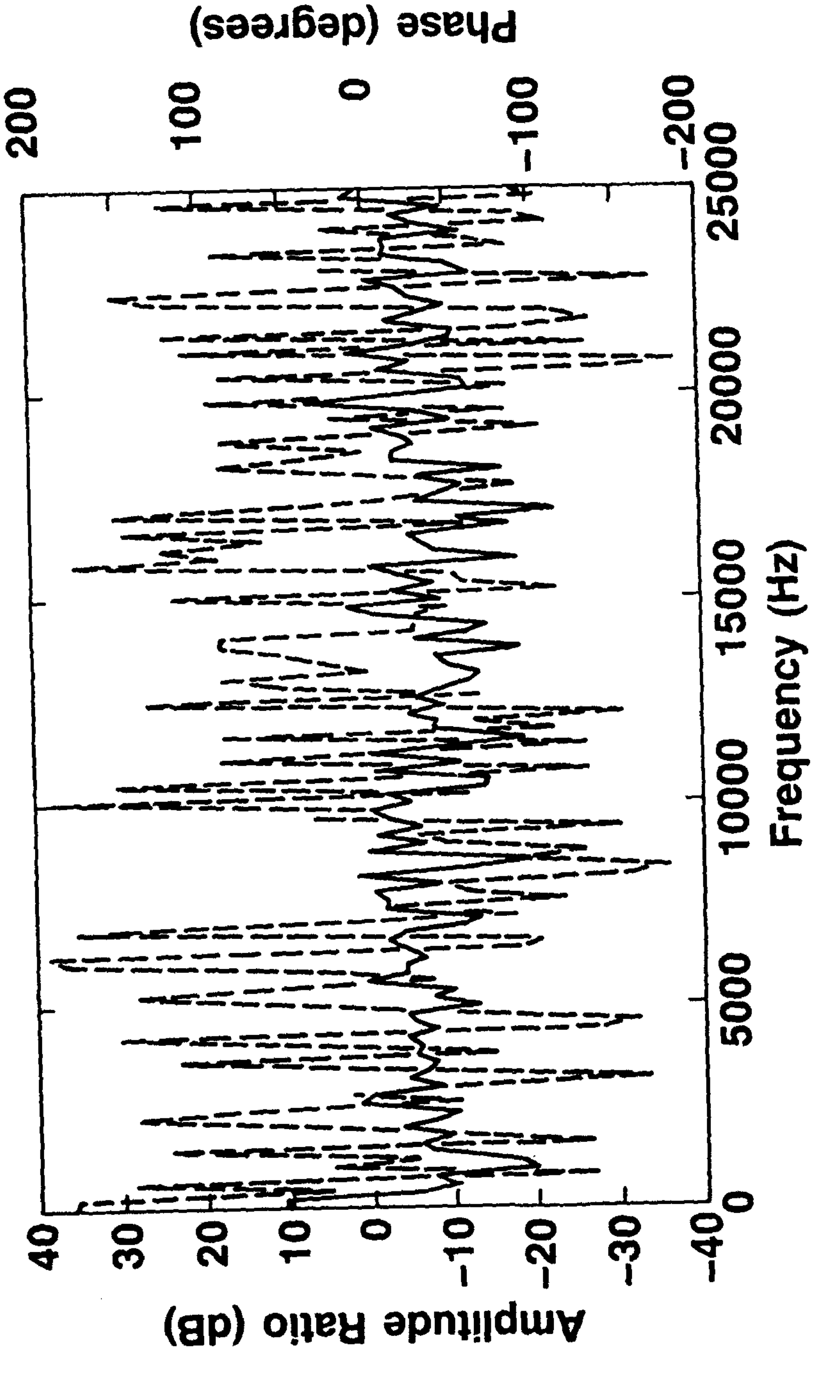

FIGURE 6. AMPLITUDE RATIO AND PHASE VERSUS FREQUENCY AS DISPLAYED ON THE SPECTRUM ANALYZER WITH THE NOISE SOURCE TURNED OFF

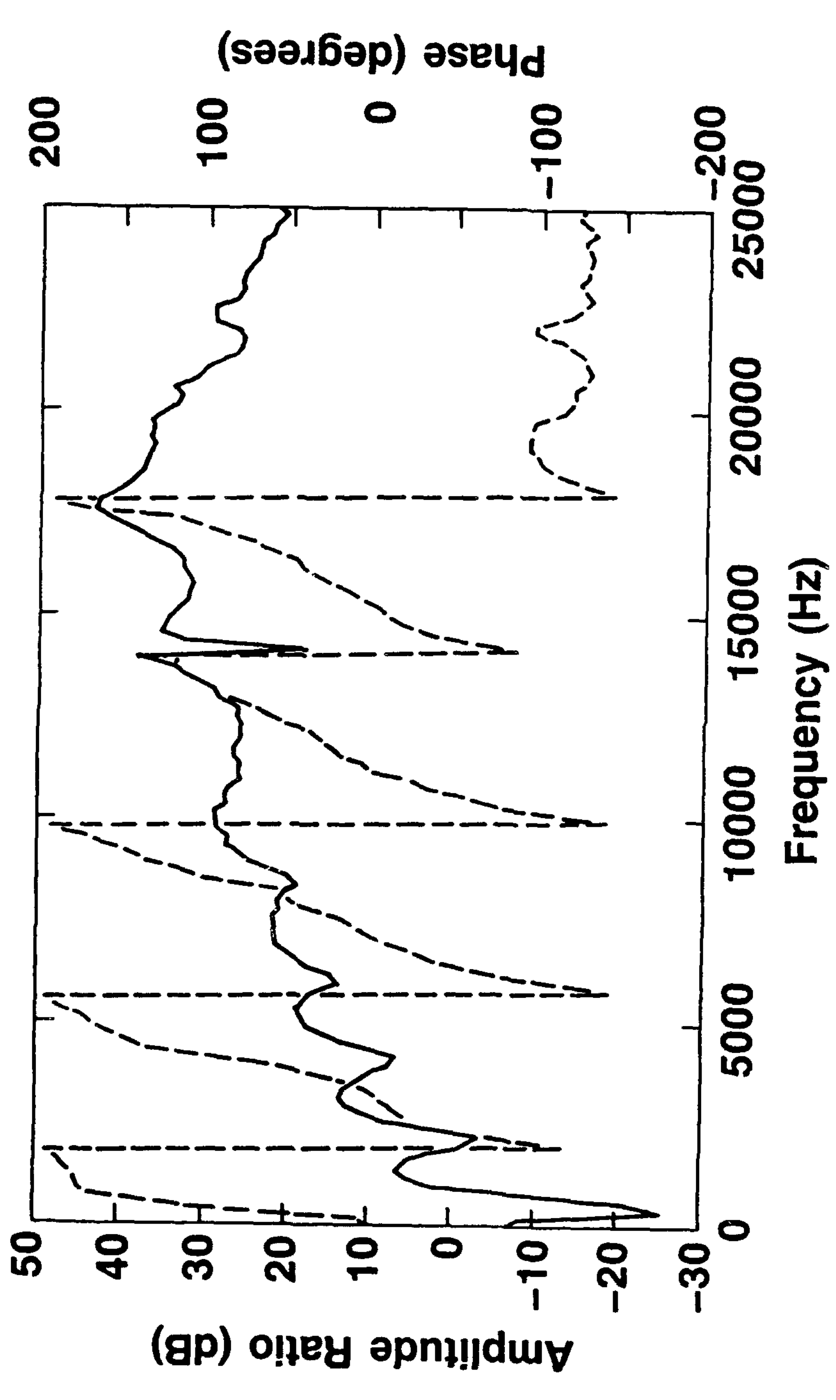

FIGURE 7. AMPLITUDE RATIO AND PHASE VERSUS FREQUENCY AS DISPLAYED ON THE SPECTRUM ANALYZER WITH THE ACCELEROMETERS CONNECTED TO THE WRONG CHANNELS

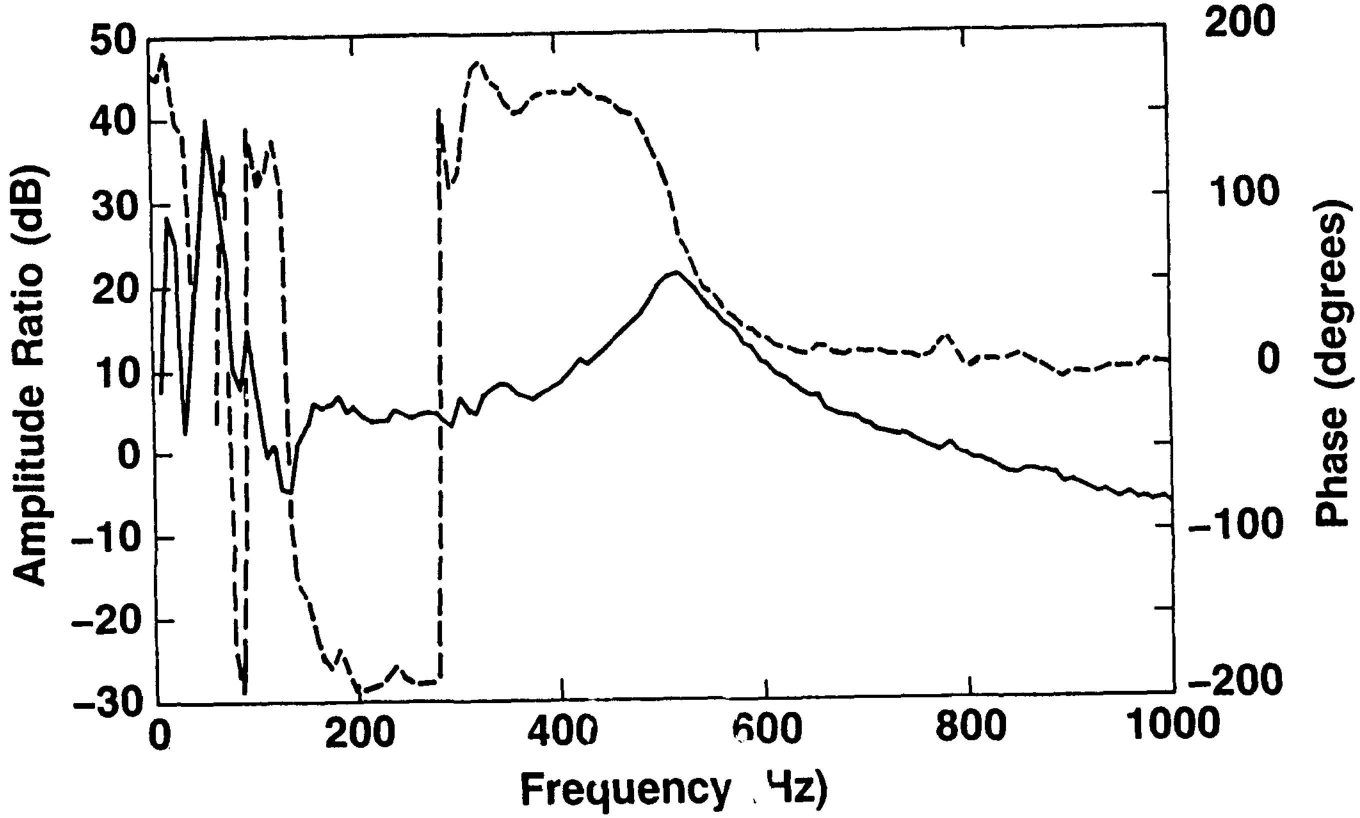

FIGURE 8. AMPLITUDE RATIO AND PHASE VERSUS FREQUENCY AS DISPLAYED ON THE SPECTRUM ANALYZER WITH THE GROUND OF BANANA PLUG NOT CONNECTED TO THE GROUND OF THE SPECTRUM ANALYZER

TABLE 1. DESCRIPTION OF THE USER 1 FUNCTION KEYS

PRINT FILE	print data on screen or printer
NEW SAMPLE	start a new sample, input the following data: mass, length, density, specimen and data file identifications
EDIT PARAM	to be used to correct the input data on the test specimen
STOP PROG.	terminate program execution, restart by pressing RUN key f3
MEASURE MENU 2	transfer control from User 1 to User 2 function keys
FILE MENU 3	transfer control from User 1 to User 3 function keys

TABLE 2. DESCRIPTION OF THE USER 2 FUNCTION KEYS

ACQUIRE DATA	start the resonance measurement of the test specimen
QC ANALYSIS	compare the measured data to the pass/fail criterions
DATA Menu 1	transfer control from User 2 to User 1 function keys

TABLE 3. DESCRIPTION OF THE USER 3 FUNCTION KEYS

GET DRIVE	list and select disc drives from menu
LIST FILES	list and select data files from menu
RETRIEVE DATA	get old data file
DATA MENU 1	transfer control from User 3 to User 1 function keys
STOP PROG.	terminate program execution, restart by pressing RUN f3
GET NEW PROG.	list and select new computer program to run

TABLE 4. VARIABLE NAMES, DATA TYPES, AND DESCRIPTION OF VARIABLES AS STORED ON DISC

Variable Name	Data Type	Description
Ndf$	String 10c	Data File Name
Sample_name$	String Array 1e 30c	Name of specimen
Comment$	String 30c	Comment or Annotation
Date_Done$	String 11c	Date of measurement
Ma	Real	End mass (g)
Ms	Real	Mass of specimen (g)
Length	Real	Length of specimen (cm)
Density	Real	Density of specimen (g/cm^3)
Temp	Real Array 200e	Temperature (°C)
Freq	Real Array 200e	Resonant frequencies (Hz)
E	Real Array 200e	Young's Modulus (dyn/cm^2)
Los	Real Array 200e	Loss factor
Mn	Real Array 200e	Mode number
Timed	Real Array 200e	Time and date (s)

c - characters, e - elements

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1. Madigosky, W. M. and Lee, G. F., "Improved Resonance Technique for Materials Characterization," *J. Acoust. Soc. Am.*, Vol. 73, 1983, p. 1374.

2. Pritz, T., "Transfer Function Method for Investigating the Complex Modulus of Acoustic Materials: Spring-Like Specimen," *J. Sound and Vibration*, Vol. 72, 1980, p. 317.

3. Norris, D. M. and Young, W. C., *Longitudinal Forced Vibration of Viscoelastic Bars With End Mass*, Cold Regions Research and Engineering Laboratory, Special Report 135, Hanover, NH, 1970.

APPENDIX A

MATHEMATICAL EQUATIONS

The equation that describes a bar subject to a longitudinal vibration is

$$\frac{d^2\overline{u}}{dx^2} + k^2\overline{u} = -k^2 U_o \qquad \text{(A-1)}$$

where u is time dependent displacement, U_o is the displacement at x=0, k is the complex propagation constant. The boundary conditions are:

$$u(o,t) = 0 \qquad \text{(A-2)}$$

$$A\sigma(L,t) = -m\frac{\partial^2}{\partial t^2}[u+u_o]_{x=L} \qquad \text{(A-3)}$$

The solution to Equation (A-1), without going into the details, is the following pair of coupled equations:

$$\cosh(XY)\,[\cos(X) - AX\sin(X)] + AXY\cos(X)\,\sinh(XY) = 0 \qquad \text{(A-4)}$$

$$\sinh(XY)\,[\sin(X) + AX\cos(X)] + AXY\sin(X)\cosh(XY) = 1/Q \qquad \text{(A-5)}$$

where A is the mass ratio (mass of the end mass to the mass of the test specimen), Q is the measured amplitude ratio at the 90 degree phase point (not peak value), X and Y are the two unknowns to be solved by Newton's iterative method. The variable X is known as the frequency ratio, which is related to the sound speed, and Y is related to the loss angle. Once X and Y are determined then the sound speed (c) and loss angle (D) can be determined from these equations:

$$c = \frac{2\pi f L}{X} \qquad \text{(A-6)}$$

where f is the resonant frequency and L is the length of the bar;

$$D = 2\tan^{-1}(Y) \qquad \text{(A-7)}$$

From the sound speed and loss angle, Young's modulus and loss factor are given by

$$E' = \rho c^2 \cos^2\left(\frac{D}{2}\right)\cos(D) \qquad \text{(A-8)}$$

where ρ is the density of the test specimen and

$$\textit{Loss Factor}\ (\tan\delta) = \tan(D) \qquad \text{(A-9)}$$

Finally by assuming a Poisson's ratio of 0.5, shear modulus is equal to 3 times the Young's modulus. The loss factor for Young's modulus is assumed equal to the loss factor for shear modulus.

APPENDIX B

DATA STORAGE FORMAT

In this section a description of the data storage format is presented, to facilitate transferring the measured data to another computer either by using communication software or by passing a floppy disc.

The data is stored in a BDAT format. The BDAT format allows either random or serial access of data and very fast transfer rates between the computer memory and floppy disc. However, in this format, the data files will not be compatible with communication software which requires ASCII format. If this is the case, a conversion of the BDAT to ASCII must be done. The conversion is quite easy if one knows the data structure on disc.

The data is stored in the following sequence: data file name, sample name, comment, date of measurement, end mass, mass of test specimen, length of test specimen, density of test specimen, number of data points, measurement temperature, amplitude ratio, resonant frequency, Young's modulus, loss factor, mode number, time, and date of measurement. The variable names and data types names are presented in Table 4 of the main report.

APPENDIX C

MANUAL SETUP

In the automated mode, all of the spectrum analyzer settings are done by the computer. If a manual setup is desired, make the following settings:

NOISE SOURCE SECTION:

1. Set "NOISE SOURCE" inner knob to "RANDOM."
2. Set "NOISE SOURCE" outer knob to full clockwise till knob clicks.

AVERAGE SECTION:

3. Push "RMS" button in.
4. Push "16" button in with "SHIFT" button out.

TRIGGER SECTION:

5. Set "LEVEL" to "FREE RUN" until click.
6. Push "REPETITIVE" button in.

INPUT SECTION:

7. Set "INPUT MODE" to "BOTH."
8. Set "A" and "B COUPLING" switches in the up position ("AC").
9. Set ground switch to "ISOL."

TRACE STORAGE SECTION:

10. "TRACE 1" and "2 RECALL" buttons out.

PASSBAND SHAPE SECTION:

11. Push "HANNING" button in.

DISPLAY SECTION:

12. Under "AMPLITUDE" push "XFR FCTN" button in.
13. Under "PHASE" push "XFR FCTN" button in.
14. Under "SCALE" push "10 dB/div" button in.

FREQUENCY SECTION:

15. Set "MODE" outer knob to "0-25 kHz SPAN."

To make a scan, do the following:

16. Press "LOCAL" button.
17. Press "RESET" button (orange button).
18. Press "RESTART" button (green button).

INPUT SECTION:

19. Select the appropriate input sensitivity for "CHANNEL A and B". The correct sensitivity can be obtained by down-ranging until the "OVERLOAD LED" light comes on and then backing off one position.

DISPLAY SECTION:

20. Select an "AMPLITUDE REFERENCE LEVEL" such that the amplitude displays in the middle of the CRT.

APPENDIX D

PARTS LIST

PARTS LIST

Description	Manufacturer	NSWC ID #	Quantity
Computer	Hewlett Packard Model R/332	60921067586	1
Spectrum Analyzer	Hewlett Packard Model 3582A	60921067560	1
Printer	Hewlett Packard Model 2225B	MINOR063903	1
Power Supply	Bruel & Kjaer Type 2805	MINOR067979	1
Charge Amplifier	Bruel & Kjaer Type 2651	MINOR104729	1
Charge Amplifier	Bruel & Kjaer Type 2651	MINOR104762	1
Shaker	Bruel & Kjaer Type 4810	MINOR096695	1
Accelerometer	Bruel & Kjaer Type 4374		4
Transit Case	ECS Composites		2
Electronic Surge Protector	Ruby Curtis		1
Microdot Cable			8
BNC Cable			2
Banana Plug			2
Microdot-BNC Adapter			1
HP-IB Cable			2
Power Cords			4
Cutting Block			1
Shaker Stand			1
Loctite Black Max Item No. 38050			1
Razor Blade			10
Packing Foam			
Manual			

APPENDIX E

PREPARATION FOR SHIPPING

The following instructions are used to prepare the resonance apparatus for shipping:

1. Park the computer hard disc heads by running the computer program named PARKHEAD.

2. Insert the yellow card into the 3.5-inch floppy drive.

3. Place the printer, charge amplifiers, power supply, shaker with stand, and accelerometers in the storage drawers.

4. Use the foam blocks to protect the equipment.

5. Lock the drawer by turning the lock knobs to the horizontal position.

6. Match the identification (ID) number on each of the transit case covers to the ID number on the case.

7. Secure each cover.

8. Ready for shipping.

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