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Testing Dynamic Properties of Elastomeric Isolators

1. ***Scope*****—**These methods cover testing procedures for defining and specifying the dynamic characteristics of simple elastomers and simple fabricated elastomeric isolators used in vehicle components. Simple, here, is defined as solid (non-hydraulic) components tested at frequencies less than or equal to 25 Hz.

2. *References*

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein.

2.1.1 ASTM PUBLICATIONS—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM D 1349—Recommended Practice for Rubber—Standard Temperatures and Atmospheres for Testing and Conditioning
ASTM D 2231—Recommended Practice for Rubber Properties in Forced Vibration
ASTM D 2234—Method for Collection of a Gross Sample of Coal
ASTM E 177—Practice for Use of the Terms Precision and Bias in ASTM Test Methods

2.1.2 RAPRA PUBLICATIONS—Available from RAPRA Technology Ltd., Shawberry, Shrewsberry, Shrapshire SY44NR, U.K.

D. Hands, "Simple Methods for Heat Flow Calculations," RAPRA Technical Review No. 60, Class No. 96, July 1971

Marion D. Thompson, "Cooling Rubber Slabs," RAPRA Bulletin, May 1972

2.1.3 OTHER PUBLICATIONS

S. D. Gehman, "Heat Transfer in Processing and Use of Rubber," Rubber Chem. & Tech., 1967, pp. 36–99

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2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

2.2.1 SAE PUBLICATION—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE SP-375, ASTM STP-535—The Measurement of the Dynamic Properties of Elastomers and Elastomeric Mounts, B. M. Hillberry and A. F. Hegerich, Proceedings of Symposium presented at SAE International Automotive Engineering Congress, Detroit, January 1973

2.2.2 ASTM PUBLICATIONS—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM D 832—Recommended Practice for Rubber Conditioning for Low Temperature Testing
ASTM D 1053—Test for Rubber Property—Stiffening at Low Temperature Testing
ASTM D 1229—Test for Rubber Property—Compression Set at low Temperature
ASTM D 1329—Test for Rubber Property—Retraction at Low Temperatures (TR Test)
ASTM D 1566—Definition of Terms Relating to Rubber
ASTM E 4—Verification of Testing Machines
ASTM E 74—Calibration of Force-Measuring Instruments for Verifying the Load Indication of Testing Machines

3. Summary—These methods describe procedures for measuring the dynamic characteristics of automotive elastomeric mountings using forced vibration testing machines. These characteristics are the elastic spring rate, damping coefficient, and loss tangent. Either fabricated mountings or elastomer specimens may be tested. Since measured dynamic properties are highly dependent upon test conditions, emphasis has been placed on the definition of suitable conditions.

4. Description of Terms—These terms are in common use throughout the North American automotive industry. Alternate Terminology has been added to assist in cross-referencing terminology from other areas of the world. Please use SAE terminology to avoid confusion and data inaccuracies.

4.1 Test Temperature

4.1.1 AMBIENT TEMPERATURE—The temperature of the environment surrounding the test specimen. Unless otherwise specified, it is assumed that the sample is at the ambient temperature before being subjected to dynamic flexing.

4.1.2 PART TEMPERATURE—The temperature obtained by locating a temperature-sensing device in or on the specimen. In most cases, temperature gradients that develop within flexing rubber specimens make it necessary to define the precise points and techniques used to measure temperature.

4.2 Frequency (f)—The number of complete cycles, whole periods, of forced vibrations per unit of time caused and maintained by a periodic excitation, usually sinusoidal.

4.3 Preload—An external static load producing a strain in a test specimen. Preload is imposed prior to forced vibration testing. Preload is usually expressed in Newtons (pounds) of force instead of meters (inches) of deflection.

4.4 Double Amplitude (DA)—The peak-to-peak amplitude as applied to the elastomer specimen measured in the direction of the applied vibration. Two times the single peak value in either the plus or minus direction may not be equivalent to the peak-to-peak value.

4.5 Complex Spring Rate (K^*)—The effective spring rate of a part under sinusoidal dynamic stress. It is the peak-to-peak force across the sample divided by the peak-to-peak displacement. The complex spring rate can be visualized as being the vector sum of an elastic component and a viscous damping component.

4.5.1 ALTERNATE TERMINOLOGY

a. Complex Stiffness
b. K-dynamic (K_d, K_{dyn})
c. Dynamic Stiffness (sometimes confused with 4.6)

4.6 Dynamic Spring Rate (K)—The proportionality factor between the component of the applied force vector that is in phase with the displacement and the displacement vector. The dynamic spring rate is equal to the elastic component of the complex spring rate.

4.6.1 ALTERNATE TERMINOLOGY

a. Elastic Spring Rate (K_{el})
b. Dynamic Stiffness (K')
c. Storage Stiffness (K")

4.7 Damping Coefficient (C)—The proportionality factor between the component of the applied force vector which is in phase with velocity and the velocity vector.

4.8 Loss Rate (Cw)—The proportionality factor between the magnitude of the component of the applied force vector that is in phase with the velocity and the magnitude of the displacement vector, where:

$$\omega = 2\pi f \quad \text{(Eq. 1)}$$

NOTE—The magnitudes of the complex spring rate, elastic spring rate, and loss rate are related by Equation 2:

$$K^* = \text{complex spring rate} \quad \text{(Eq. 2)}$$

$$K^* = \sqrt{((K)^2 + (C\omega)^2)} \quad \text{(Eq. 3)}$$

Equation 3 is sometimes written as shown in Equation 4:

$$(K^*)^2 = (K')^2 + (K'')^2 \quad \text{(Eq. 4)}$$

where

$K'' = C\,\omega$

4.8.1 ALTERNATE TERMINOLOGY

a. Loss Stiffness (K")
b. Viscous Stiffness (K")

4.9 Loss Tangent (tan δ)—The tangent of the phase angle between the applied force and the resulting displacement:

$$\tan\delta = \frac{C\omega}{k} \quad \text{(Eq. 5)}$$

4.9.1 ALTERNATE TERMINOLOGY

a. Loss factor

5. General Testing Methods

5.1 Preparation Prior To Testing

5.1.1 Virgin specimens must be allowed to age between manufacturing and testing. Typically, a minimum of 24 h is suggested. Elastomeric specimens that have undergone some permanent deformation (such as that due to an assembly operation) may require additional time to permit relaxation of any internal stresses that may exist.

5.1.2 Parts that have been kept at temperatures other than the test temperature (for example, during shipment, storage, or environmental testing) must be conditioned at the test temperature long enough to achieve uniform temperature stabilization throughout. Minimum conditioning time depends upon many factors, including temperature difference, specimen size and shape, and airflow around the specimen. Guidance for determining the required conditioning time is given in Appendix A.

5.1.3 All test equipment instrumentation should be fully stabilized per manufacturer's instructions. At least 1/2 h is required. Greater stability is obtained by leaving electronic equipment on permanently. It is recommended that at the start and conclusion of every test session or operator change, a quick check of calibration be performed with a control specimen.

5.2 Outline Of Test Procedure

5.2.1 Insert the specimen.

5.2.2 Apply the preload.

5.2.3 Apply and maintain the dynamic conditions of test.

5.2.4 Stabilize specimen properties.

5.2.5 Read data within 1 min.

5.2.6 Remove the specimen if no further measurements are to be made.

5.3 Preferred Test Conditions

5.3.1 Where a single measurement is to be made on a specimen, the following reference test conditions are suggested in the interests of standardization. They take into account: the precision of equipment, stabilization of specimen dynamic properties, minimization of heat buildup, avoidance of regions in which elastomers are most sensitive to changes in test conditions, and relevance to most practical applications.

5.3.1.1 *Preload*—Selected to correspond to that existing in the intended application. Sufficient preload should be applied to prevent any separation of sample-to-machine interfaces unless all interfaces are securely attached. The preload should be chosen so that any sharp changes in the slope of the load-deflection curve are avoided.

5.3.1.2 *Double Amplitude*—0.50 mm (0.020 in).

5.3.1.3 *Frequency*—15 Hz.

5.3.1.4 *Ambient Temperature*—23 °C ± 2 °C (73.4 °F ± 3.6 °F).

5.3.1.5 *Stabilization Period*—2 min minimum.

5.3.2 Additional or alternate test conditions should follow the guidelines in ASTM D 2231 and ASTM D 1349. The ambient temperatures in Table 1 are suggested for testing elastomers used in automotive applications:

TABLE 1—AMBIENT TEMPERATURES

°C	°F
–40	–40
–10	+14
+23	+73.4
+100	+212
+150	+302

5.3.3 ALTERNATIVE COLD TEST PROCEDURE

5.3.3.1 *Discussion*—When a specimen has been temperature stabilized at a test temperature such as –40 °C (–40 °F), any test data obtained in the first few thousand cycles will be transient data. Each unit of energy input will change the specimen's dynamic properties. The following procedure is suggested so data can be obtained in a repeatable manner when specimen response is changing.

5.3.3.2 *Pretest Preparation*

5.3.3.2.1 Prepare the test machine to record test data continuously during test so that information pertaining to any particular cycle can be determined. Include the following:

a. Test Cycles Count
b. Dynamic Spring Rate
c. Damping Coefficient
d. Test Chamber Ambient Temperature—Temperature sensor will be located to best sense the temperature of the test chamber ambient to which the sample is subjected.
e. Energy Input $\left(\int_o^t F(t)V(t)dt\right)$
f. Specimen Temperature—Is assumed the same as chamber ambient when correctly stabilized at start of test.

5.3.3.2.2 Prior to Test—Weigh the specimen (include all specimen elements that are molded together or fastened together).

5.3.3.2.3 Insert the specimen.

5.3.3.2.4 Condition the specimen at test temperature.

5.3.3.2.5 Preload—There are two ways to soak the specimen at ambient temperature with or without preload. Measured dynamic characteristics are influenced by preload history. The desired condition should be specified in test requests.

5.3.3.2.5.1 Soak Period with Preload—The preload will be maintained until the entire soak period and test is complete.

a. Start of Preload:

Load Control—No stabilization required.
Displacement Control—Preload stabilization period will be required.

5.3.3.2.5.2 Soak Period without Preload—The preload is added following the soak period and maintained until the test is complete.

5.3.3.2.6 Precondition to Maximum Load/Deformation—Often precondition cycling to maximum load/deformation conditions is included prior to measurement of dynamic data. Dynamic properties will be influenced by this preconditioning. If this preconditioning is desired, it should be specified in the test procedure.

5.3.3.3 Data Reduction—Should include the following information pertaining to the cycle of interest:

5.3.3.3.1 Number of Cycles

5.3.3.3.2 Spring Rate

5.3.3.3.3 Damping Coefficient

5.3.3.3.4 Total Energy Input

5.3.3.3.5 Total energy input per unit weight of specimen. When reading the dynamic spring rate or damping, use the average for the specified cycle such as: cycle 100 equals the end of 99 to the beginning of 101.

6. Specimens

6.1 Standard Compression Specimens—Specimens used for comparing elastomer properties or standardizing test machines in compression should be chosen based on the following considerations:

6.1.1 The size of the specimens shall be chosen to suit the load capacities of the test machine but should be no less than 12.7 mm (0.50 in) nor more than 50.8 mm (2.0 in) high; the recommended height is 25.4 mm (1.0 in).

6.1.2 The preferred shape factor for comparing elastomer properties is 0.5 where:

$$\text{Shape factor} = \frac{\text{area of one loaded face}}{\text{area free to bulge}} \qquad \text{(Eq. 6)}$$

6.1.3 The preferred shape is a right circular cylinder with faces parallel within 0.001 mm/mm or 0.001 in/in.

6.1.4 TEST INTERFACE—For best reproducibility, the sample mentioned in 6.1.2 should have metal plates bonded to both faces during vulcanization.

6.1.5 OPTIONAL-TEST INTERFACE—The test machine will be equipped with loading plates top and bottom of sufficient area to support the loaded specimen. The specimen will be held in place with 300 grit sandpaper, securely bonded to both loading plates. The sandpaper prevents specimen lateral movement and aids in bulge control. The two plates exciting the specimen shall be parallel within 0.001 mm/mm (0.001 in/in) of platen length in neutral position. Plate parallelism will be within tolerances on orthogonal lines.

6.2 Standard Shear Specimens—Shear specimens shall comply with ASTM D 2234 for general configuration. Dimensions may be adjusted to provide required spring rates. Supporting fixtures should be sufficiently rigid to maintain parallelism of all plates.

6.3 Fabricated Mountings or Bushings—The following considerations shall apply when fabricated mountings or bushings are tested:

6.3.1 Supporting fixtures shall be designed to restrain lateral movement of the top or bottom surfaces of the mounting as a result of forces applied in the test direction.

6.3.2 It shall be carefully determined that any lateral forces which may develop as a result of forces applied in the test direction do not influence the test readings.

6.4 Standard specimens to be tested must be clearly marked for identification.

6.5 Standard specimens used for standardizing test machines shall be aged no less than one month and shall be accepted only after repetitive testing indicates that dynamic properties have stabilized.

7. Preferred Test Apparatus—Forced Nonresonant System

7.1 General Description—A forced nonresonant system is comprised of a drive mechanism which forces the specimen through a desired sinusoidal load, displacement, or energy. The desired frequency and amplitude of the test are not affected by the specimen's dynamic response; therefore, test conditions may be quite easily changed.

7.1.1 THEORY—In a forced nonresonant system, the sample is excited with a sinusoidal oscillation which is either force or displacement controlled. The forcing medium causing this sinusoidal oscillation can be an electromechanical, electrohydraulic system, or a pure mechanical system.

This method assumes that the existing force or displacement and the response of the specimen can be considered to be sinusoidal. If this is not the case, special methods of analysis are required.

The transmitted force is measured by a load cell in contact with the sample, preferably on the stationary side to minimize errors due to acceleration of the mass of the fixture. The component of this force which is in phase with velocity and the component that is in phase with the displacement are usually determined electronically. From this information, the values of C and K are usually determined. The vector phase relationships are illustrated in Figure 1.

7.1.2 COMPONENTS—The basic elements of a forced nonresonant system are the drive system, the control system, a loading frame, transducers, and the instrumentation for readout.

7.1.2.1 *Drive System*—The system should be capable of providing sinusoidal dynamic operation, with minimum harmonic distortion, in the same direction as the applied force.

7.1.2.2 *Control*—A means of precise control over the input drive unit is required for repeatable test results. Controls for mean input, dynamic input, and frequency should be independently selectable for the desired test condition.

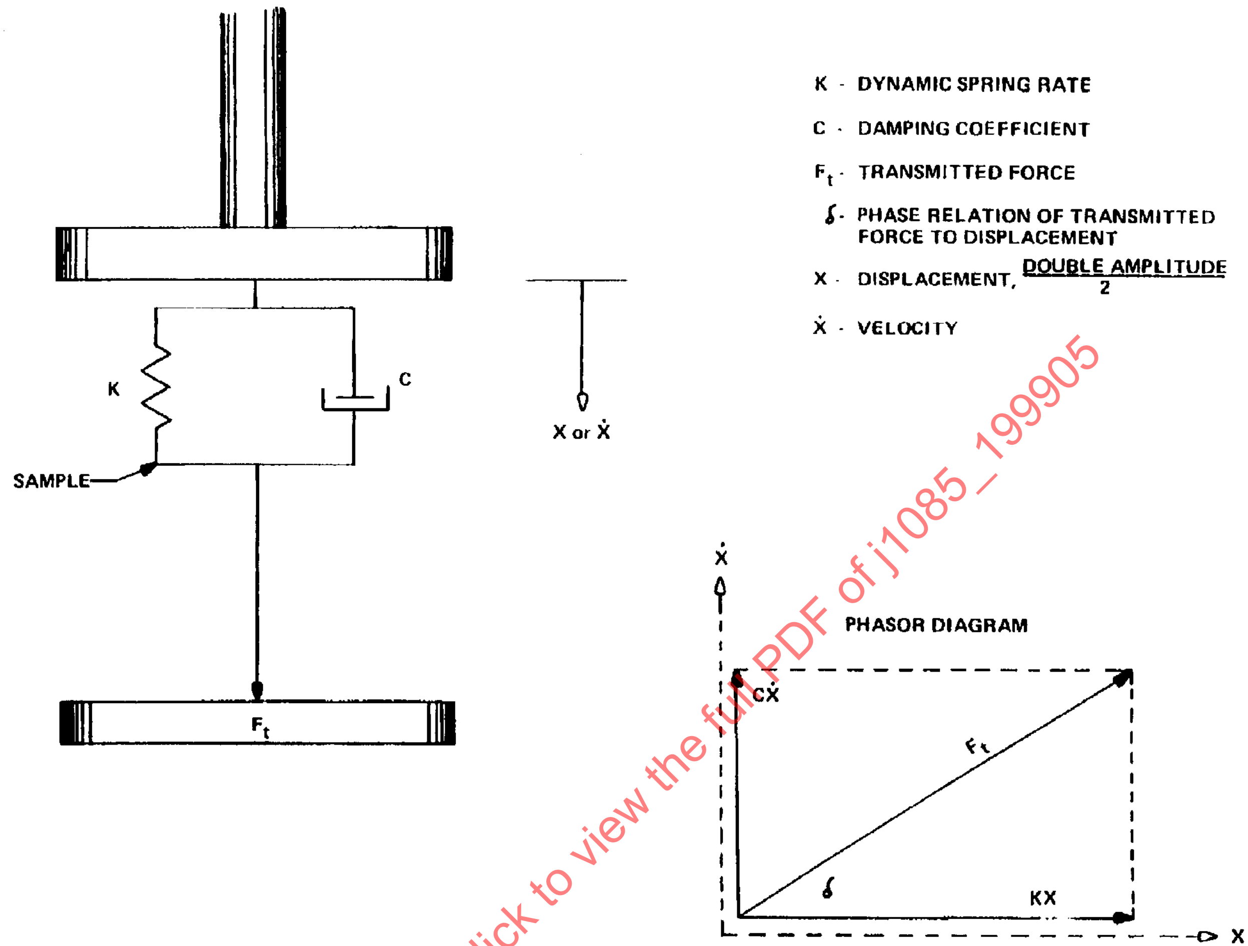

FIGURE 1—VECTOR PHASE RELATIONSHIPS

7.1.2.3 *Transducers and Instrumentation*—Common transducer signals used in forced nonresonant systems for obtaining data are load, displacement, and/or velocity. Each transducer should be calibrated to the following minimum accuracies:

a. Load—± 0.5% of full-scale for each calibrated range
b. Displacement—± 0.5% of full-scale for each calibrated range
c. Velocity—± 0.1% of full-scale for each calibrated range

Readout instrumentation for load, displacement, and velocity transducers should provide a sufficient number of ranges so that it will not be necessary to use less than 20% of range.

Precautions listed in ASTM D 2231, paragraph 4.2 should be observed in selecting transducers, electronics, and techniques of calibration.

7.1.2.4 *Preferred Location of Transducers*—The load cell shall be mounted on the stationary side of the sample being tested.

The displacement and/or velocity transducer should be located to accurately measure the motion of the dynamic surface of the sample. It should be located parallel to and as close as possible to the centerline of the existing force.

7.1.2.5 *Load Path Compliance*—A correction factor will be required unless the overall spring rate of the fixtures and the machine elements that are included in the measurement is sufficiently high. The machine and fixture spring rate should be at least 100 times greater than the nominal spring rate of the test specimen. If this degree of rigidity cannot be achieved, the correction factor shall be calculated and applied.

7.1.2.6 *Fixture Mass*—The mass of the fixture located on the stationary platen shall be minimized to reduce errors due to mass-inertia accelerations. The fixture located on the moving platen shall be rigid to eliminate any possibility of structural resonance near operating frequencies.

8. Report

8.1 Test Conditions—The report shall include the following:

8.1.1 Type of testing machine used.

8.1.2 Test specimen(s) identification.

8.1.3 Type of specimen loading, for example, compression or shear. For specimens of complex configuration, full description of fixtures used, with diagrams if necessary.

8.1.4 Date of test.

8.1.5 Preload[1].

8.1.6 Frequency[1] used at each test point in Hertz.

8.1.7 Double amplitude displacement[1] used at each test point.

8.1.8 Ambient temperature[1].

8.1.9 Specimen internal temperature (optional). If internal temperature is used, the following additional information is required:

8.1.9.1 Internal temperature before flexing.

8.1.9.2 Ambient temperature.

8.1.9.3 Exact location of the temperature measuring transducer.

8.1.9.4 Time from start of flexing until temperature and dynamic property readings are taken.

8.2 Calculated Values—The method for computing C and K from the measured variable shall be described.

8.2.1 Dynamic (elastic) spring rate, K.

8.2.2 Damping coefficient, C.

8.2.3 Loss tangent, $C\omega/K$

1. Include both actual and specified, if different.

8.2.4 For all test machines, as applicable:

8.2.4.1 Range scale settings.

8.2.4.2 Mode of test control, that is, stroke or load.

8.2.4.3 All observed and recorded data on which calculations are based.

9. Precision or Reproducibility—Precision as defined in ASTM E 177-71T is a function of the operator, compound, and maintenance of constant test conditions. The test conditions that can influence "level" are: preload, frequency, double amplitude displacement, temperature, and others not yet well defined.

10. Test for Dynamic Properties of Elastomeric Isolators with Multi-Axis Preloads

10.1 General—The purpose of this section is to review the procedures to determine the dynamic characteristics of automotive elastomeric mounts with multi-axis preloads. To test the dynamic characteristics in its three principle axes of the engine mount is a typical example. The following reference calculation and test setups are suggested in the interests of standardization.

10.2 Multi-Axis Preloads—Figure 2 shows two sandwich mountings in a vee with an included angle of 2 α between the compression axes.

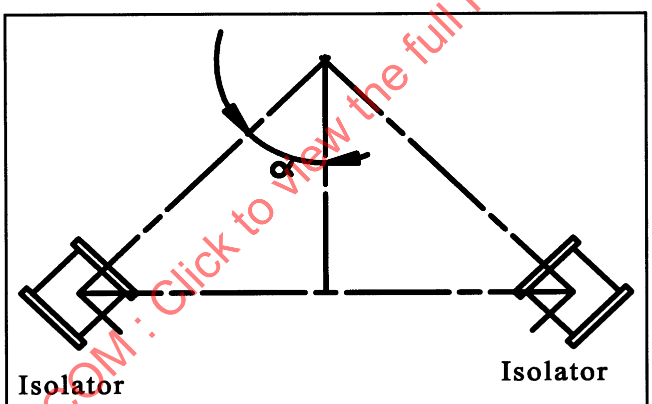

FIGURE 2—MOUNTING ARRANGEMENT

Assume a vertical static force F acts on the system. Figure 3 shows the static force diagram of one isolator.

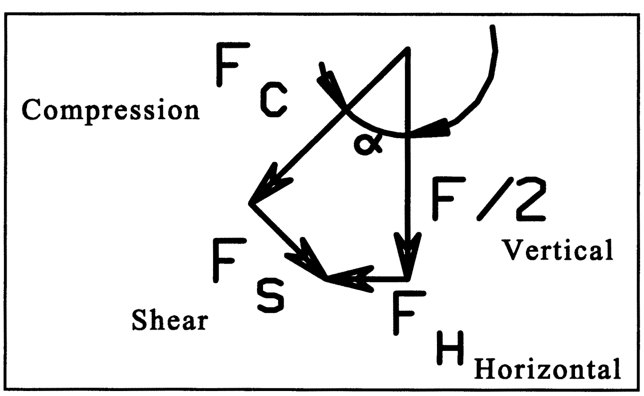

FIGURE 3—STATIC FORCE DIAGRAM

Notation

F - Static vertical force on the system
Fc - Static compression force on one isolator
Fs - Static shear force on one isolator
Fh - Static horizontal force on one isolator

The Fc and Fs can be calculated from the given F and α.

10.3 Preferred Test Conditions

10.3.1 The reference test conditions, suggested in 5.3, are applicable except the preload.

The following reference test preloads for the three principle axes are suggested in the interests of standardization. The preload should be chosen so that any sharp changes in the slope of the load-deflection curve are avoided.

10.3.2 DYNAMIC CHARACTERISTICS IN COMPRESSION AXIS—The applied excitation axis is in compression direction. The preload in this direction is Fc. There is an off-axis preload, Fs, should be applied on the test specimen.

10.3.3 DYNAMIC CHARACTERISTICS IN SHEAR AXIS—The excitation axis is in shear direction. The preload in this direction is Fs. There is an off-axis preload, Fc, should be applied on the test specimen.

10.3.4 DYNAMIC CHARACTERISTICS IN FORE AND AFT AXIS—The excitation axis is in Fore and Aft direction that is perpendicular to compression and shear axis. Sufficient preload in Fore and Aft direction should be applied to prevent any separation of sample-to-machine interfaces unless all interfaces are securely attached. There are two off-axis preloads, Fc and Fs, should be applied on the test specimen.

10.4 Test Setup—There are several methods to apply the off-axis preloads. This section outlines three methods:

10.4.1 MOVING LOAD CELL—Figure 4 shows a test setup for shear and Fore and Aft characterization of isolators. The load cell is mounted on the actuator and the isolator is mounted on the mounting base. The DC conditioner shall compensate the moving load cell. This setup reduces actuator side load, bending moments on the load cell and fixturing mass attached to the load cell, and applies a more easily controlled preload. This method works up to about 15 Hz. The spherical bearings and links lower the amplitude of bending moments and side loads introduced to the actuator and load cell. The attachment to the load cell should be configured so that the dead load can be connected first and then the actuator can be attached to minimize misalignment.

10.4.2 TEST TWO SPECIMENS IN PARALLEL—Use the arrangement shown in Figure 5. Two duplicate isolators are tested at the same time. A constant compression deflection is maintained on the mountings to simulate the results of a compression loading while the mountings are being tested in the shear direction. Special attention should be paid to the fixture design to minimize the fixture mass effect. This setup is not suitable for two off-axis preloads test.

10.4.3 MANUAL TRANSLATION PLATFORM—A manual translation platform is mounted on the load cell and the test isolator is mounted on the platform. Figure 6 shows the setup. By adjusting the translation platform, an off-axis preload is applied on the specimen against a hydrostatic bearing actuator. The test system design should minimize inertia effects.

10.5 Fixture—The resonant frequency of the fixture should be high enough so that these resonances do not affect the dynamic property measurements of the isolators.

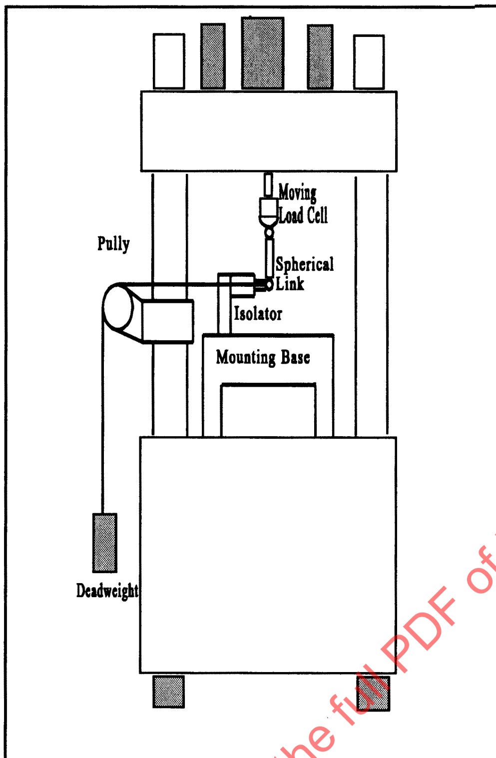

FIGURE 4—MOVING LOAD CELL

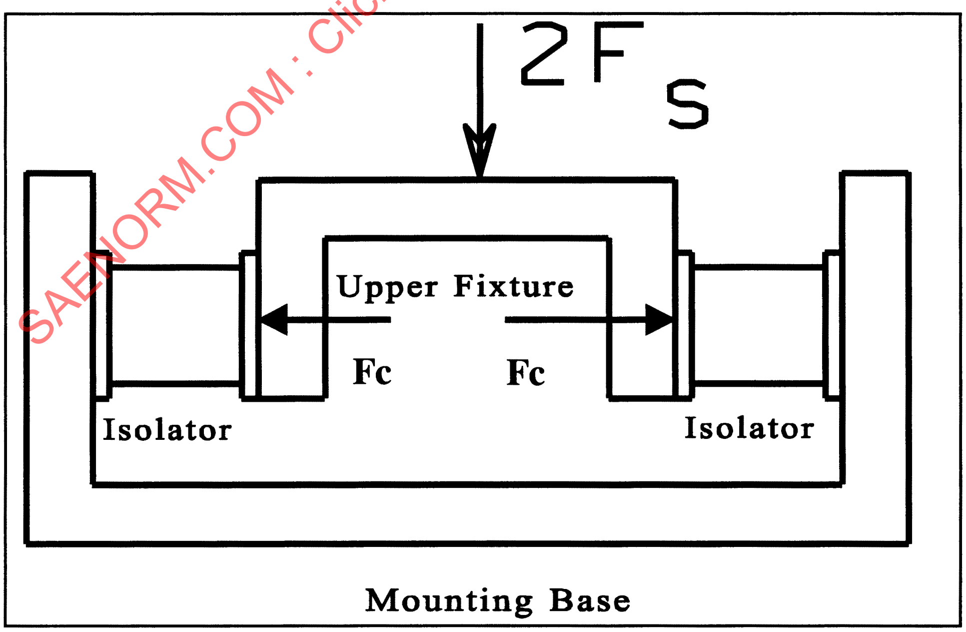

FIGURE 5—TWO ISOLATORS IN PARALLEL