Testing Brief

Measuring Dynamic Properties of Elastomers between 400 Hz. and 10,000 Hz.

Introduction

Measuring the dynamic properties of elastomeric materials in the range of 400 Hz. to 10,000 Hz. is important because this is a significant range in human hearing. Elastomers are often used to control or reduce vibrational frequencies in this range.

The analysis of small amplitude vibrations in deformed viscoelastic solids (Morman and Nagtegaal (1983), Morman, Kao, Nagtegaal (1981) [3,4] is applicable to rubber support mounts, automotive door seals [2] and vibration isolation gaskets. Use of these capabilities in analysis software such as ABAQUS or MSC.MARC requires the equilibrium large strain material properties and the dynamic material properties. An outline for the experimental determination of the dynamic material properties at vibration frequencies between 400 Hz. and 10,000 Hz. using a wave propagation approach is provided herein.

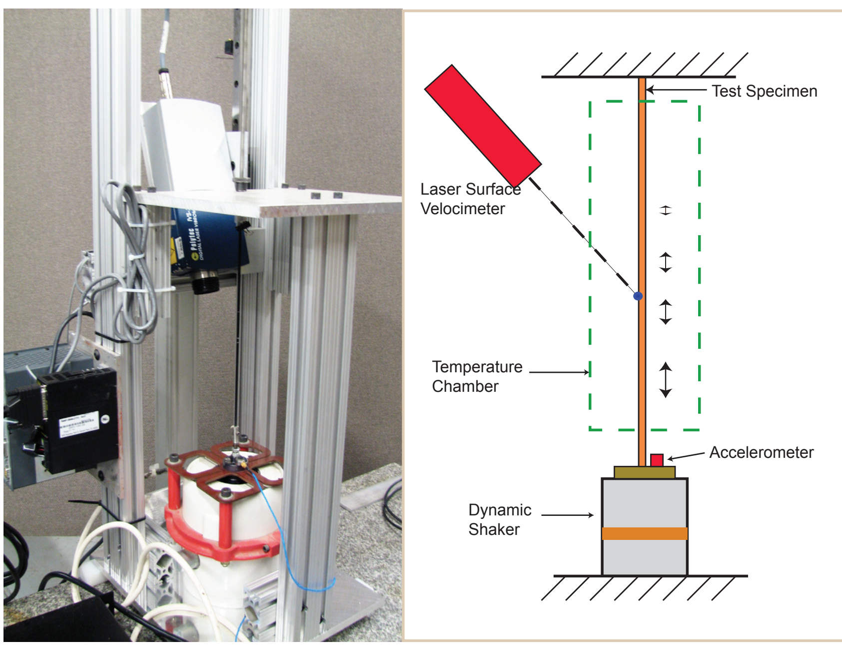

Figure 1, Storage Modulus Measurements for 1 Material using both Low Frequency and High Frequency techniques to generate data over a wide Frequency Range

Dynamic Properties

The dynamic material properties of interest are the storage modulus and loss modulus of the material when subjected to a sinusoidal vibration superimposed on a mean strain. The storage modulus and the loss modulus are the real and imaginary parts of the dynamic modulus [1]. In this case, for input into the analysis software, we are interested in the differential dynamic modulus described by Nolle [5] as follows:

"Differential dynamic modulus refers to dynamic modulus determined from a sample upon which a static deformation is imposed along the same coordinate as the dynamic deformation. Because the differential dynamic modulus is a complicated function of static strain for many rubbers, it is best to regard the sample at any particular static deformation as a distinct material from the standpoint of dynamic modulus measurements. … The differential dynamic modulus cannot be identified with the slope of the quasi-static stress-strain curve except at very low frequency."

In this discussion, dynamic modulus will be measured as differential dynamic modulus. The dynamic modulus measurements are not simply a function of frequency and therefore need to be made at mean strain levels appropriate to the application.

Measuring Dynamic Properties at Frequencies from 400 Hz. to 10,000 Hz.

As vibration frequencies exceed 400 Hz., the dynamic vibration wavelength becomes too small to be considered very large compared to the specimen length. As such, one needs to consider the effect of the wave traveling through the specimen. The mass of the specimen becomes significant (Figure 2). A method to measure the dynamic properties in the range of 400 Hz. to 20,000 Hz. is to perform wave propagation experiments [5]. In these experiments, the rate of travel and the attenuation of the wave amplitude of a traveling wave in a long thin strip of elastomer are measured.

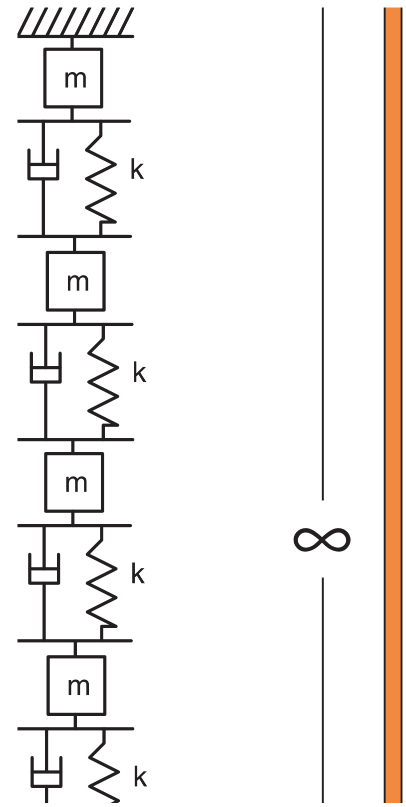

Figure 2, High Frequency Material Representation including Mass Effects

The experimental procedure is to stretch a long strip of elastomer to the mean strain level of interest and allow it to reach an equilibrium condition. The specimen needs to be very narrow such that the width and thickness are very small relative to the dynamic vibration wavelength yet very long such that a high frequency traveling wave doesn't reach the end and reflect back into the measurement. A small sinusoidal dynamic vibration of short duration is introduced at one end of the long specimen so as to produce a longitudinal traveling wave. An accelerometer is used to measure the vibration at the source and a velocity sensor is used to measure the amplitude of the wave as it travels past a point which is a known distance along the specimen. From this a phase relationship between the source and the point and an amplitude relationship between the source and the point is determined. The same dynamic vibration is again introduced and the phase relationship and amplitude relationship to a different point is determined. Given relative measurements at two known points along the specimen, the phase and amplitude relationship between the two points becomes known. From the phase of the wave between points a known distance apart, the wavelength λ can be calculated. The speed c of the longitudinal wave is given by:

$$c = f \lambda$$

where f is the vibration frequency. If the density (ρ) of the material is known, from basic wave equations the dynamic modulus can be calculated as follows:

Dynamic Modulus $E^* = \rho c 2$

The storage modulus and the loss modulus corresponding to the dynamic modulus may be determined using the amplitude attenuation measurements [5]. The advantage of the wave propagation experiment is that high frequency dynamic properties can be measured directly. The disadvantage is that the amplitudes for this type of experimental apparatus tend to be very small. Because the amplitudes are very small, they are relatively insensitive to the absolute value of dynamic strain. This may not be critical because high frequency vibrations in engineering application are often very small.

Experimental Methods

At Axel Products, a commercial laser surface velocimeter is used to measure the velocity on the specimen surface. This non-contacting method allows for the use of an environmental chamber such that the material properties can be determined between temperatures of approximately -40C to 150C. The test specimen is ideally very long (> 400 mm) but shorter specimens (>175 mm) have been used with modest success.

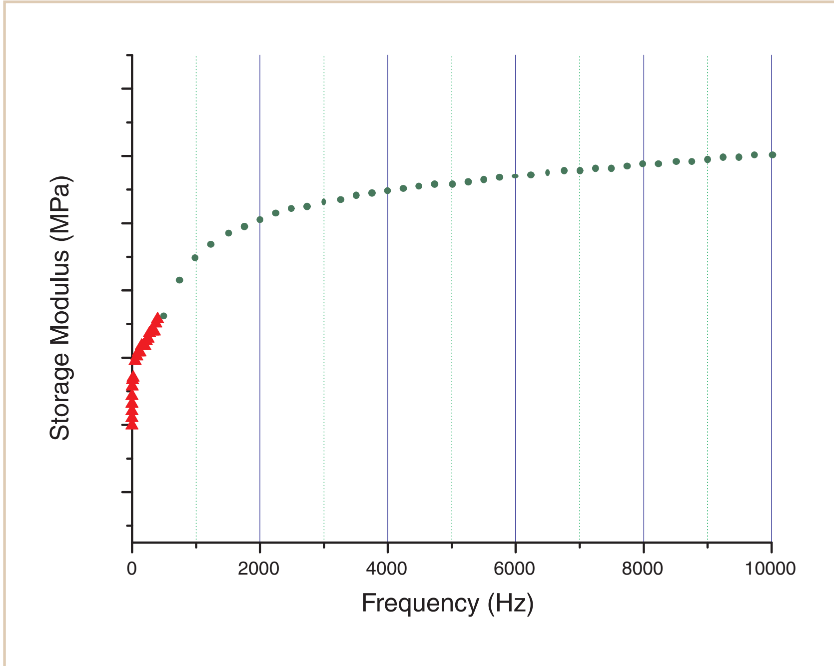

Figure 3, Storage Modulus Measurements for 1 Material using both Low Frequency and High Frequency techniques to generate data over a wide Frequency Range

References

1. J D. Ferry, Viscoelastic Properties of Polymers, 3rth ed. (Wiley, New York, 1980)

2. Y Gur and K N Morman, Jr., Analytical Prediction of Sound Transmission Through Automotive Door Seal Systems, Presented at The Third Joint Meeting of the Acoustical Society of America and the Acoustical Society of Japan, Honolulu, Hawaii, December 2-6, 1996

3. K N Morman, Jr., and J C Nagtegaal, Finite Element Analysis of Sinusoidal Small-Amplitude Vibrations in Deformed Viscoelastic Solids. Part I. Theoretical Development, International Journal for Numerical Methods in Engineering, Vol. 19, pp.1079-1103 (1983)

4. K N Morman, Jr., B.G. Kao and J C Nagtegaal, " Finite Element Analysis of Viscoelastic Elastomeric Structures Vibrating about Non-Linear Statically Stressed Configurations", SAE Paper 811309 (1981)

5. A W. Nolle, "Methods for Measuring Dynamic Mechanical Properties of Rubber-Like Materials," J. Appl. Phys. 19, 753 (1948)

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Axel Products provides physical testing services for engineers and analysts. The focus is on the characterization of nonlinear materials such as elastomers and plastics.

Data from the Axel laboratory is often used to develop material models in finite element analysis codes such as ABAQUS, MSC.Marc, ANSYS and LS-Dyna.

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