Journal of Sound and Vibration 423 (2018) 118–125

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Method for determining damping properties of materials using a suspended mechanical oscillator

S. Biscans [a,*], S. Gras [a], M. Evans [a], P. Fritschel [a], C. Pezerat [b], P. Picart [b]

[a] LIGO, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
[b] Le Mans Université, CNRS UMR 6613, 72085 Le Mans, France

ARTICLE INFO

Article history:
Received 9 October 2017
Revised 23 February 2018
Accepted 26 February 2018
Available online XXX

Keywords:
Damping
Loss
Materials
Epoxy

ABSTRACT

We present a new approach for characterizing the loss factor of materials, using a suspended mechanical oscillator. Compared to more standard techniques, this method offers freedom in terms of the size and shape of the tested samples. Using a finite element model and the vibration measurements, the loss factor is deduced from the oscillator's ring-down. In this way the loss factor can be estimated independently for shear and compression deformation of the sample over a range of frequencies. As a proof of concept, we present measurements for EPO-TEK 353ND epoxy samples.

1. Introduction

Material damping properties play a crucial role in the design of many modern experiments and devices. An appropriate material can be a solution to a variety of noise and vibrations problems. For example, high damping materials present an elegant method to reduce mechanical vibrations, and are extensively used in transportation and construction industries [1,2]. On the other hand, low damping materials are preferred in high-finesse cavity experiments and interferometric detectors to limit thermal noise [3].

The ASTM E756 standard [4] describes the standard method for measuring the damping properties of a material. This method involves using the response of a cantilevered laminated beam, composed of a base beam and one or two layers of the material to be tested. Beam theory is then applied to calculate the loss factor η. This method is widely used [5–7] but presents important limitations. First, it measures the sample in the shear deformation only, which is not adequate to characterize anisotropic materials. Second, the clamped boundary condition can introduce unwanted dissipation [8,9]. Finally, the sample geometry is very limited. The ASTM suggests a sample with a width of 10 mm, a free length of 180–250 mm, and a thickness of 1–3 mm (1:1 ratio with the base beam). These dimensions are not suitable for some materials, like sub-millimeter piezoelectric plates or thin adhesive bonds. Smaller cantilevers (called microbeams) have been used in the past, but these can introduce unwanted damping effects such as thermoelastic damping and air damping [10,11].

A common alternative approach is to directly measure the stiffness of the sample when it is deformed dynamically via a force gauge or an actuator. This method, known as the impedance method [12,13], presents the same limitations as the standard method in terms of boundary conditions and sample size.

* Corresponding author.
E-mail address: sbiscans@ligo.mit.edu (S. Biscans).

https://doi.org/10.1016/j.jsv.2018.02.061

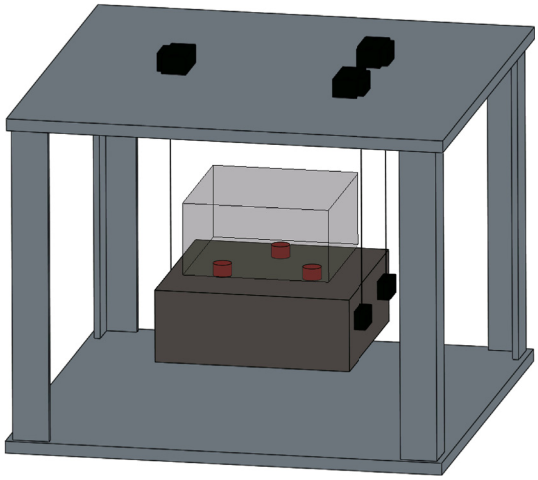

Fig. 1. Three samples, shown in red, are glued between a bottom aluminum mass (in dark grey) and a top aluminum mass (partially transparent for more visibility). The experiment is suspended from a cage by three steel wires to operate in a free configuration. The clamps and wires are shown in black. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

The method proposed in this paper addresses the problems listed above. The standard cantilever beam is replaced by a suspended mechanical oscillator, where three test samples are glued between two aluminum masses. The analysis is based on the transient response of the system at resonance. By exploiting several mechanical resonances, the samples are examined in both shear and compression. The oscillator is suspended to avoid unwanted damping from the boundary conditions. This method can be used for arbitrary types and sizes of samples, as there is no requirement on the sample geometry.

In Section 2, we present the general concept of this method in more detail. In Section 3 and 4, we explain how to tune the oscillator to the desired modal frequencies, and how to limit the coupling between the oscillator and the suspension. Finally, in Section 5 and 6, results for millimeter-sized samples of 353ND epoxy are shown.

2. Description of the method

A sketch of the mechanical oscillator and its suspension are shown in Fig. 1. The material under test consists of three identical samples, each sample being glued between two aluminum reaction masses. The samples are arranged in an equilateral triangle around the oscillator center of mass to make the experiment symmetric and balanced.

The experiment is suspended by three steel wires that are mechanically fastened to the bottom mass with clamps. The reaction masses act as rigid bodies, such that most of the strain energy of the oscillator modes is stored in the samples. The size and shape of the masses, as well as the position of the samples are calculated to tune the modal frequencies of the mechanical oscillator. The resonant frequencies of the suspension must be kept below the oscillator frequencies to avoid coupling between the suspension and oscillator modes.

The oscillator modes are excited by hitting the bottom mass with an impact hammer, and their time response is recorded with an accelerometer, as illustrated in Fig. 2. Both the excitation and sensing are performed on the bottom mass. The quality factor Q of each oscillator mode is computed from the recorded time series using the ring-down method. This method is based on the fitting of the time constant τ of the exponential decreasing signal envelope.

A general expression of the loss factor η [14] can be written as

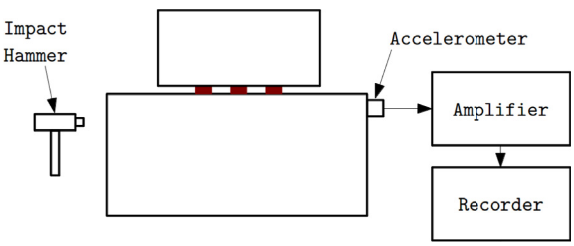

Fig. 2. Block diagram of the experimental set-up. The wires and clamps are not represented.