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Investigation Internal Friction of High Elasticity Solids using Laser Shadowgraphy

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Abstract:

This paper discusses a non-contact method for measuring the internal friction of high elasticity solid materials using pulse excitation technique. The measured sample is prepared in form of 200mm long string, having a homogenous circular cross section of 3mm wide. A mechanical pulse is delivered to the fixed- fixed end sample by mean of a punch from a small solenoid motor plunger. A laser beam is used to generate a shadowgraph for the vibrating sample on an silicone photodiode. The obtained electric signal is fed to a storage oscilloscope to capture the natural resonance amplitude decay profile of the tested sample. The internal friction is obtained by mathematical analysis of the acquired data. This method is reliable, low cost, and accurate and suiting a wide variety of rubbery materials and elastomers. It is intended to alternate the torsion pendulum method that suites only low elasticity materials that resists creep under pendulum weights.

Keywords:

Dynamic elasticity, internal friction, pulse excitation technique, laser shadowgraphy, low cost, non-Doppler laser vibrometry.

Introduction

The investigation of internal friction of composite materials and elastomers, presents a crucial need in solid-state physics [1-4]. There is a number of experimental method in this context, mainly the torsion pendulum method [5], the continuous resonance method [6] and the pulse excitation method [7]. The first two methods may not be practical to test high elasticity materials that creep under pendulum weights and yield a very low self-sustained natural resonance frequency that requires sophisticated excitation measures. The third method is probably is the most suitable technique for these materials. Usually, pulse excitation technique requires contact measurements to detect vibrations, especially when using accelerometers as detector, when the use of non-contact microphones is impossible in such application due low resonance frequency [8]. It is necessary then to install a low mass accelerometer to the sample [9], and this could lead to an error in sample's mass calculation and distribution, even when using a negligible weight sensor. Therefore, we decided to use laser shadowgraph of the pulse excited sample to retrieve the optically modulated vibration signal, without changing the mass of the sample, to prevent such experimental complications, to increase measurement accuracy and to perform low cost non-Doppler laser vibrometry.

The theory

The internal friction represents the amount of resisting force toward the motion between the elements and molecules forming a solid subject to deformation. In the continuous resonance method, a solid sample undergoes periodic mechanical excitation by sinusoidal force and scanning the frequency range around the flexure resonance to obtain the quality factor of the oscillation Q around the resonance band, in order to obtain the internal friction [9].

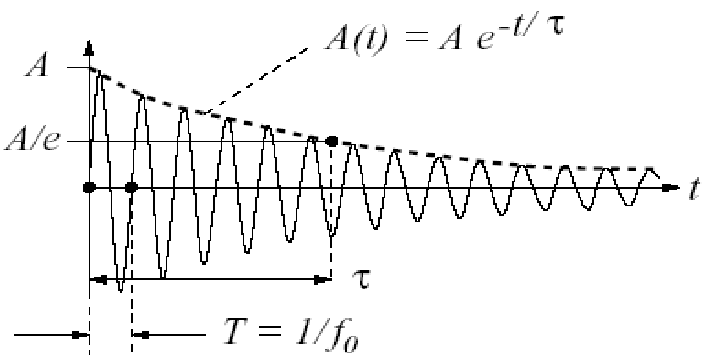


Figure 1. Free vibration pattern of elastic solids by pulse excitation technique

In the pulse excitation method (figure 1), only one mechanical pulse is required to excite the free natural resonance of the sample where the amplitude A of the oscillation at any time t after excitation, is given by the equation:

$$A(t) = Ae^{-t/\tau} \qquad (1)$$

τ is the time interval between A and A/e. the internal friction can be represented by the equation;

$$Q^{-1} = \frac{energy\ dissipated\ as\ heat\ per\ unit\ volume\ over\ one\ cyle}{energy\ stored\ per\ unit\ volume} \qquad (2)$$

$$Q^{-1} = \ln\frac{A(T)}{A(\tau)} = T/\pi\,\tau = 1/\pi\,\tau\,f_0 \qquad (3)$$

Where. *T* is the period of one oscillation of frequency f_0, hence, the quality factor of the oscillation can be obtained directly from the decay pattern of the oscillation of homogenous string sample of circular cross section. The natural fundamental frequency can be represented by the equation:

$$f_0 = \frac{1}{2\pi L}\sqrt{\frac{W}{m/L}} \tag{4}$$

Where L is the string sample length, W is the tension force and m is the string mass. If a small detector of mass μ, therefore, the new natural frequency of the system f_d is calculated from the expression:

$$f_d = \frac{1}{2\pi L}\sqrt{\frac{W}{(m+\mu)/L}} \tag{5}$$

The frequencies ratio percent can be calculated from the equation:

$$\left(\frac{f_0}{f_d}\right)_{\%} = 100 \times \sqrt{1 + \frac{\mu}{m}} \tag{6}$$

If the detector mass is one tenth of that of the sample, than the deviation in frequency ratio percent is about 5%, leading to one order of magnitude deviation in internal friction value. By excluding contacting detectors, the accuracy of the measurement is enhanced and any non-linearity in oscillation modes due to mass heterogeneous distribution is excluded. the idea behind this enhancement is to use the laser beam shadowgraphy of the string sample to retrieve its in-plan vibration by mean of a photodiode, and to display the signal on a storage oscilloscope. This technique is used before in many experimental measurements to exclude any physical contact with the sample [10].The string sample is hocked under constant tension. The plunger of a small solenoid motor is used to deliver mechanical strokes to the sample to induce free vibration as shown in figure 2

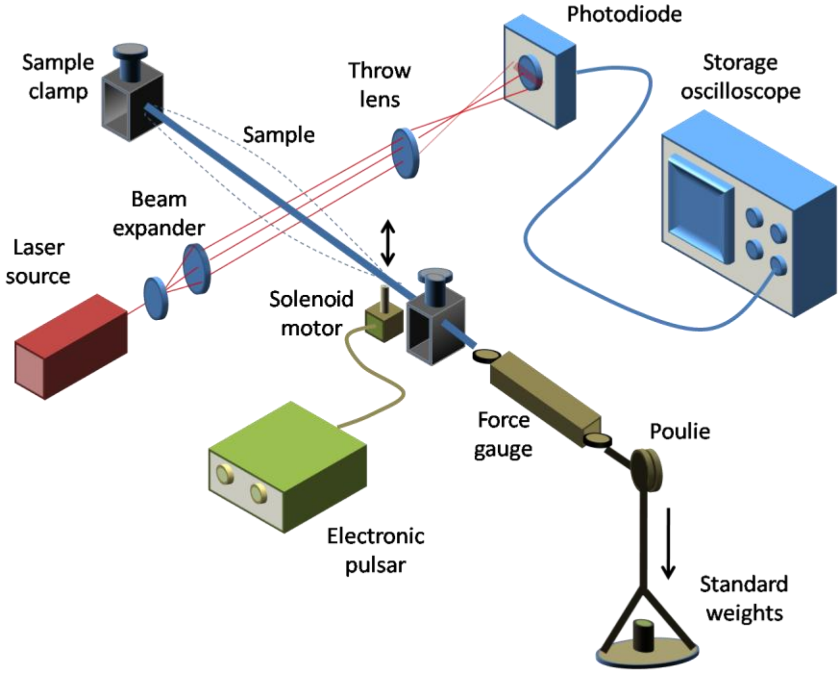


Figure 2. Illustration of laser shadowgraphy method for enhancing the measurement of internal friction of solid strings by Pulse Excitation Technique

Experimental setup

A natural rubber sample is prepared in form of 200 mm long string, having a homogenous circular cross section of 3mm wide. As shown in figure 3, the sample is fixed horizontally under constant tension of 2kg weight between a special clamp mounts on a rigid base. A focusable laser diode module of 635 nm wavelength and 15 mW power is used to backlight the sample. a large aria photodiode type BPW21 is used to receive optical signal. The photodiode is connected to Agilent DSO-X 3052A digital storage oscilloscope.

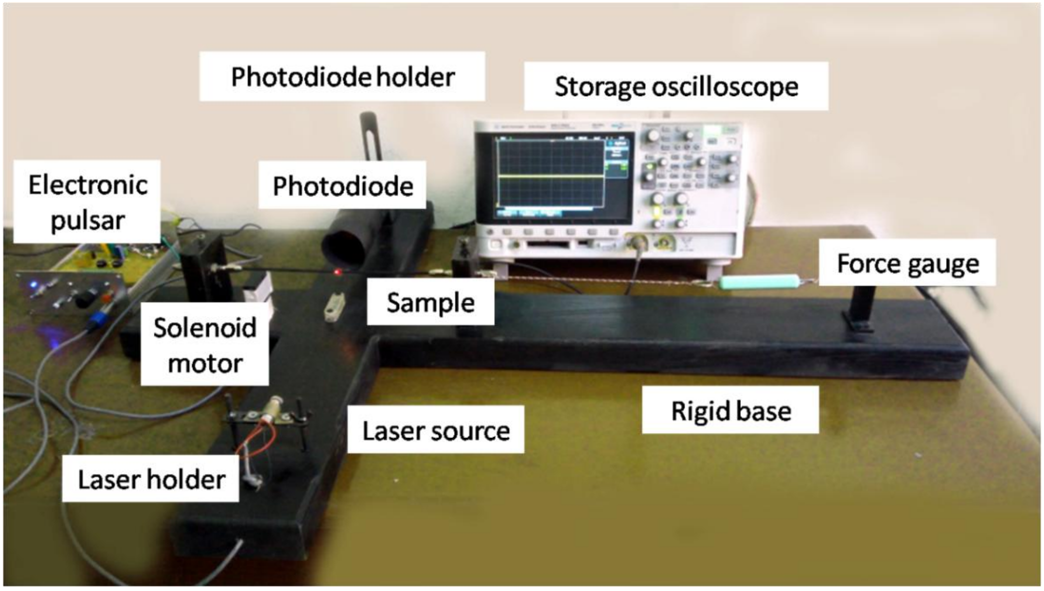


Figure 3. Experimental setup

As shown in figure 4, a close-up picture for the solenoid motor mount. Where the string sample receives a 5 ms stroke from the solenoid plunger, to start natural vibration. The solenoid motor is activated with 5ms electric pule. The gap between the solenoid plunger and the string sample is adjusted such that the maximum sample displacement does not exceed 1mm.

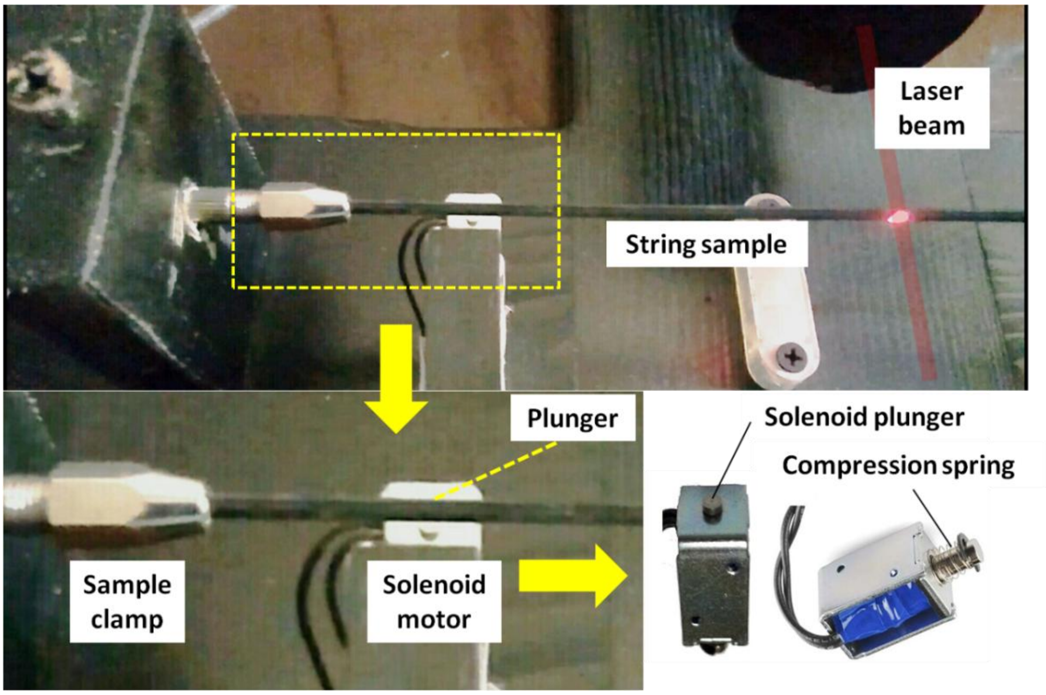
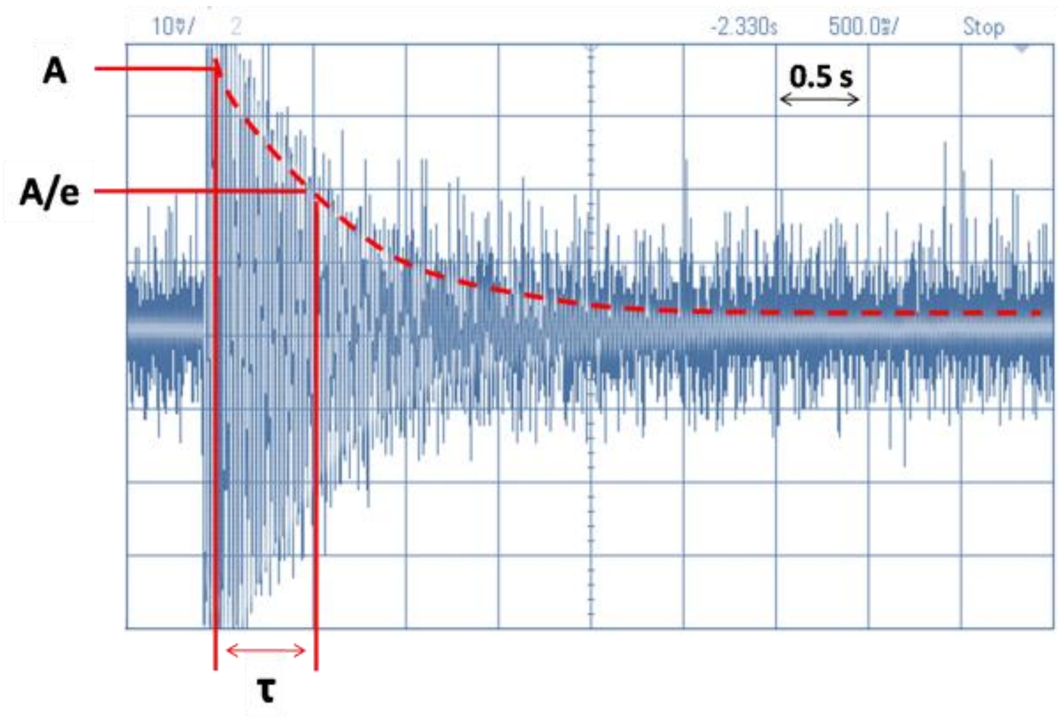
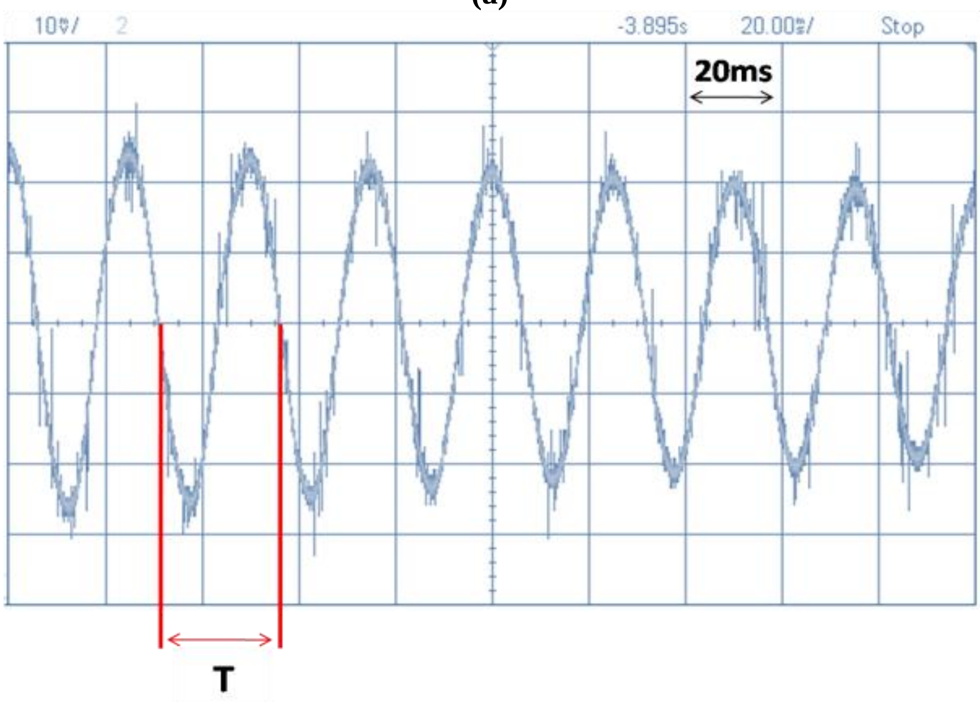


Figure 4. a close-up picture for the solenoid motor puncher

Result and discussion



(a)



(b)

Figure 5. Recorded digital oscilloscope vibration pattern of the sample (a) The envelope of the decay displayed on 10s wide screen (b) The sinusoidal wave pattern displayed on 0.2s wide screen.

The vibration pattern of the rubber sample (shown at figure 5), is analyzed, yielding the value of the parameters of equation 5 on two stages. The first stage is to obtain τ (as seen at figure 5a) by tracing the envelope of the decayed oscillation and the second stage is to obtain T by spreading the time scale of the pattern, Table 1 shows the calculated parameters.

Table 1 Summary of results

Parameter	value	unit
A	38	mv
A/e	20	mv
τ	500	ms
T	25	ms
f_0	40	Hz
Q^{-1}	0.159	-

The experiment showed that the free resonance vibration of the highly elastic rubber string sample was in the order of 40 Hz. This frequency range is not suitable for microphone detection. The shadowgraphy-based detection system detected successfully the flexure vibration of the sample. the value of internal friction of natural rubber was matching the published value [11]. We shall mention that the best results are obtained at small vibration amplitude displacement and by good adjustment of sample alignment across the clamping ends, such that no torsion acts on the string. Also it is must to adjust the punching point along the sample to prevent generation of multi-modal oscillations, only the fundamental mode is allowed. Finally, the measurement must be realized once the sample is clamped, to prevent the effect of creep on the process.

Conclusion

An experimental setup for measuring the internal friction of highly elastic materials using pulse excitation technique,was designed and tested in this work. It is intended to alternate the torsion pendulum method that suites only low elasticity materials that resists creep under pendulum weights Based on laser shadowgraphy, the free vibration of the sample, was detected by a photodiode. The signal is stored by a digital oscilloscope. The internal friction of the sample was measured successfully by this setup. This method is reliable, low cost, and accurate and suiting a wide variety of rubbery materials and elastomers.

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