Identification of nonlinear viscoelastic parameters based on an enhanced Oberst beam method

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Abstract

This work deals with payload vibration insulation in aeronautic applications. The main objective is to design stabilization devices for optical devices. To achieve this goal, polymer materials have been used because they provide damping and flexibility in order to isolate the optical devices from vibrations and shocks. This kind of material exhibit a mechanical behavior that strongly dependent on the temperature, the strain amplitude and the frequency. The purpose of this paper is to give a new identification method of the viscoelastic parameters based on the Oberst beam test. The aim is to carry out the dependence of the elastomer mechanical properties on the strain amplitude. By coupling this test with Dynamic Mechanical Analysis, it is possible to obtain the mechanical behavior of viscoelastic material according to the strain amplitude and the frequency. To achieve this goal, the experiment derived from the Oberst beam set-up and ASTM E756-05. The time response signal is post-processed using nonlinear unconstraint optimization method in order to identify the instantaneous frequency and damping ratio of the first eigenmode. Then, it is possible to recover the storage modulus and the loss factor of the polymer according to the strain amplitude using a finite element model of the setup. Finally, the identified frequency and amplitude dependent models are taken into account to carry out numerical simulations on the whole mechanical device.

Keywords : elastomer, damping, nonlinear, Oberst, characterization

1 Introduction

Viscoelastic materials are commonly recognized as efficient passive damping systems, and are widely used in many applications such as automotive, marine or aerospace. Viscoelasticity is studied since many years by many authors, for citing just a few of them: Ferry [4], Caputo and Mainradi [1], Lakes [8], Chevalier and Vinh [2]. The viscoelastic behavior can be described by the relaxation function or the creep function that express the delay between the applied force and the displacement. This behavior depends on several parameters such as the frequency, the temperature, the preload and the amplitude.

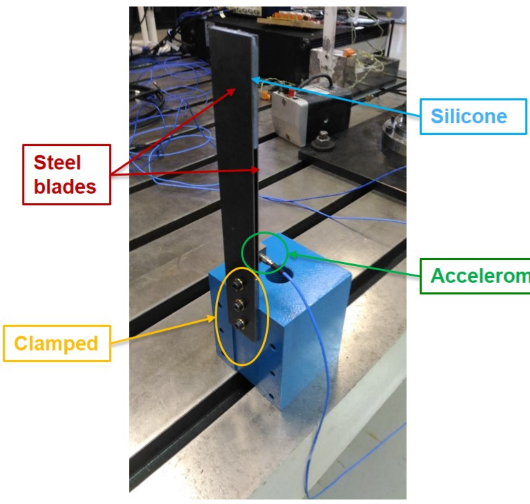
Our study focus on the amplitude dependency that is especially strong for the elastomer containing fillers such as carbon black. This characteristic is mainly led by two phenomenoms. The Mullins effect [11] represents a softening effect observed for the first excitation cycle on a sample of elastomer containing fillers such as carbon black. The second effect, named Fletcher-Gent or Payne effect [12], [5] express the dependency of the dynamics properties such as storage modulus on the amplitude of the applied strain. This effect is observed under cyclic loading conditions with small strain amplitudes. Origin of the Payne effect is not clearly defined but it is a reversible phenomenon due to a continuous breaking and reforming Van-der-Walls forces between carbon black particle [6].

Several experimental studies have been carried out to characterize this behavior such as tension-compression, bending and shearing tests. Theses experiments are usually realized thanks to viscoanalyzer using different sample holders in order to lead Dynamic Mechanical Analysis (DMA). The DMA is mainly used to characterize the mechanical behavior of a sample (here an elastomer) according to the frequency, the temperature and the strain amplitude. However, the range where the data are obtained is restricted by the experimental set-up (testing machine, sample holder and sample association). In fact, each set-up exhibit a confidence interval of measurements defined by a minimum and a maximum in frequency, temperature and

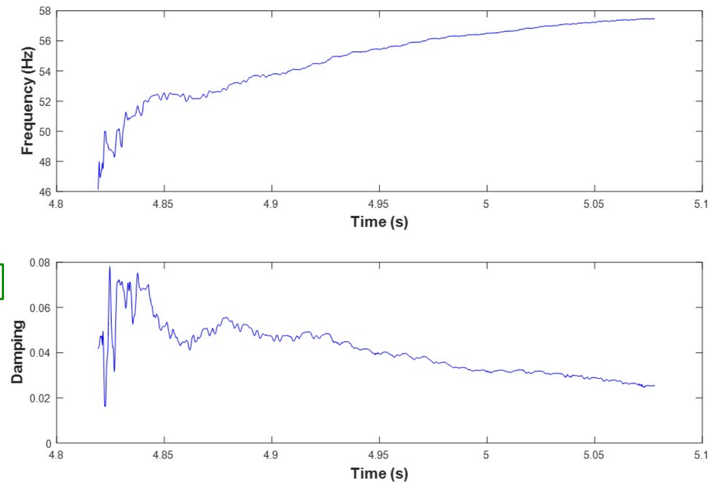
strain amplitude ranges.
There are other ways to characterize the dynamic behavior of elastomer. One of theses tests is the famous Oberst beam method [3] used to extract the storage modulus and the loss factor of the tested material. Practically, the sample is glued directly on a steel blade or sandwiched between two steel blades. This association form an "hybrid" beam which is clamped at one of its ends and free at the other. The Frequency Response Function (FRF) of this beam is carry out thanks to an accelerometer and an excitation signal realized by a hammer shock, a shaker or a magnetic exciter. Then, this response is compared with the FRF of an uniform steel beam to retrieve the storage modulus and the loss factor of the sample. This approach only allows the identification of theses mechanical parameters in the neighbourhood of the resonance frequencies. It is an important drawback of the Oberst method. However, several ways exists to expand the characterization range of the parameters. One can cite the work of Hillstrom & al. [7] and Liao and Wells [9] [10] for example.

2 Enhanced Oberst beam method

Despite the numerous studies based on the Oberst beam method to identify the storage modulus and the loss factor of viscoelasic material according to the frequency, it seems that no approach, using this method, has been developed to characterize theses mechanical parameters according to the strain amplitude. In order to investigate this possibility, a sandwich cantilever beam has been designed with a filled silicon containing black carbon sample (Fig. 1a).



(a) Experimental set-up of the sandwich cantilever beam



(b) Identified instantaneous frequency and damping ratio of the sandwich beam first mode

Figure 1: Experimental set-up of the cantilever beam and identification results

The geometry of the elastomer sample has been chosen to obtain a uniform shearing strain rate. A known displacement is applied to the cantilever beam to reach the desire strain rate. One can notice that the design of the beam bounds the range of measuring strain rate. The beam is released into its natural first mode of vibration. The measured acceleration coupled with an appropriate post-treatment and an identification method based on the Least-Squares method using a sliding window allow us to extract the instantaneous frequency and the damping ratio of the first eigenmode (Fig. 1b). Then, using a parametric study on the Finite Element Model (FEM) of the experimental set-up to determine the evolution of the first eigenfrequency according to the storage modulus of the sample, it is possible to retrieve the storage modulus and the loss factor of the silicon according to the strain amplitude. The dependency of the storage modulus according to the strain rate is the famous Payne effect. Finally, it is possible to take into account this behavior law in a finite element model of a damper composed of elastomer parts in order to drive non-linear simulations. From the industrial point of view, it could be interesting to observe and quantify the different non-linearity phenomena involved in the dynamic behavior of the passive damping systems to refine the defined dynamic modeling of this kind of devices and to improve their design cycle. For example, the RFS (Restoring Force Surface) method allows us to evaluate the non-linearities participation in the neighborhood of a chosen eigenmode as shown Figure 2.

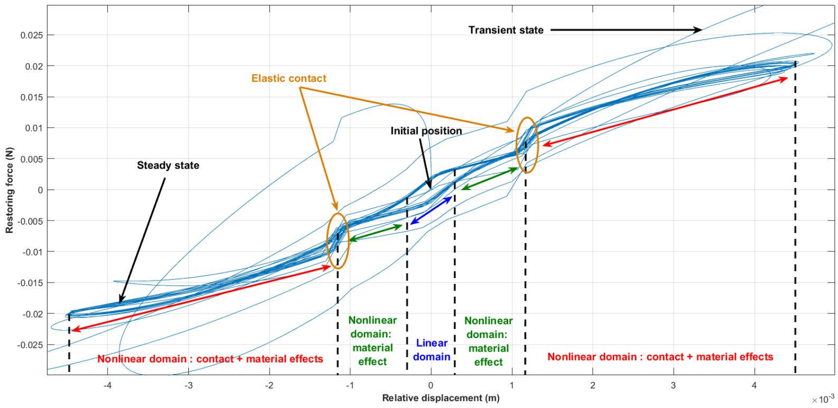


Fig. 2: Restoring force of a passive damper system made up of elastomer parts subject to Payne effect and an elastic stop

3 Conclusion

In this study, a framework is proposed to identify the storage modulus and the loss factor dependency of viscoelastic material according to the strain amplitude. This approach is based on the Oberst beam method. Instead of carry out the frequency response function of a sandwich cantilever beam, a chosen displacement is applied at the free end of this one and suddenly released in order to measure the free vibration response. Thanks to an identification method based on the Least-Squares method using a sliding window, the instantaneous frequency and the damping ratio of the first eigenmode are extracted. By coupling the modified Oberst beam method and a Finite Element Model of the experimental set-up, it is finally possible to retrieve the dependency of the storage modulus according to the strain rate and modeling the Payne effect. Thus, non-linear numerical simulations on passive damper systems using elastomer subject to the Payne effect can be carried out and correctly predict the dynamic behavior of the whole structure.

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