Experimental Equipment for Damping Capacity Analyze of High or Low Internal Friction Metallic Materials

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Abstract. An experimental equipment, type torsion pendulum was made in laboratory in order to analyze the damping capacity of metallic materials. The scheme of the equipment is presented, 2D and 3D visions at real scale. The equipment functioning (mechanical and electrical part) and principles are presented. In this article we present some preliminary experimental results obtained on different materials (aluminium, steel etc.) using two different methods for registration the outputs (one based on optoelectronic device with Arduino acquisition board and second on video analyze (cinematic review: video to jpeg) of the damped motion of the lead pendulum). Steel materials were with shoot penning surface modification with and without heat treatment in order to establish the heat treatment influence on the damping capacity property.

1. Introduction

Beside damping capacity materials (vibration amortization, earthquake etc.) in other industrial applications, specifically for electronic equipments used for guiding, materials (preferably metallic for very good mechanical properties) with a very low damping capacity value are required [1-4]. An example is the resonator element used in the gyroscope equipment. In this case, the metallic material vibrations are used to detect rotation and to be maintained as long time is possible without a new excitation (usually up to 30-60 minutes) [5,6]. For crystalline materials (metallic/alloys), damping capacity of mechanical external solicitation is mainly based on crystal defects (vacancies, interstitial atoms, dislocations, grain boundaries or plates presence) [7-10].

In case of amorphous materials (like metallic glasses, concrete [9]), the idea of defect is not so clear and, therefore, the damping level is not easy to predict [11]. In amorphous materials case the damping capacity behave differently based on the material. Amorphous polymers are often absorbing materials due to their high intrinsic molecular mobility, while amorphous oxides are often characterized by low damping. Silica (SiO₂) is a typical example: the damping coefficient can be lower than 10⁻⁶; i.e., the quality factor Q can exceed 10⁶ and represent a good option for low damping materials [12-14]. However, this amorphous material encounters two problems: it can be processed only at very high temperature, because its glass transition is higher than 1200 °C; and due its isolating nature, a conducting layer has to be deposited on its surface to enable electromagnetic excitation, limiting its damping performance [15,16]. Based on very good mechanical properties many industrial areas prefer metallic materials in crystalline state. A good compromise solution, taking in account the
working facilities of crystalline materials, will be a crystalline material with very low damping capacity and mechanical properties like cast-irons [17, 18].

This article presents an experimental laboratory pendulum to determine low or high damping capacity materials. It is present the main principle and two modalities to establish the damping capacity, both with electronic devices. Preliminary results are made on cast iron material after a mechanical operation of shot-penning.

2. Experimental details
In figure 1 a) is presented the full 2D and 3D schematic of the experimental laboratory pendulum and real scale dimensions. The equipment is formed from two parts: the mechanical part, figure 1 a), and the electrical part, figure 1 b). The electrical part is used to start the oscillation using an electromagnet. The mechanical part has a pre-strain possibility at the gripping system so it can be analyze pre-strain sample, a function that cannot be used on a usual damping analyzer (DMA).

![Figure 1](image)

**Figure 1.** a) Equipment schematic and b) electric scheme with Si: fuse, K: general switch, B: voltage signalling, At: autotransformer for adjustment, RD1: regulation cell, C: electro-condenser, I: magnet switch, EM: electromagnet, K1: measure switch, RD2: recovery cell, R1-R3: resistances, OC: optocoupler, EP: screen closure, V: voltmeter, P: potentiometer and OUT: signal output.

Cast iron material, plates with 5x20x1 mm were made using wire cutting procedure from experimental plates in order to fit the pendulum striping elements. The material surface, after shot-penning was analyzed using SEM equipment by 2D and 3D images. For the first type of results interpretation we use a video camera and a transition from video to image software, we register the main amplitudes and use the formula: \[ \delta = \frac{1}{t_f} \ln \left( \frac{A_0 - a_0}{A_n - a_n} \right) \] (1) to calculated the damping capacity of the material. In the second case we use an Arduino board to translate the signal from the pendulum in digital values for transfer and storage on a PC. The program that runs on Arduino board is:

```c
// the setup routine runs once when you press reset:
void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);
}

// the loop routine runs over and over again forever:
void loop() {
  // read the input on analog pin 0:
  int sensorValue = analogRead(A0);
  // Convert the analog reading (which goes from 0 - 1023) to a voltage (0 - 5V):
  float voltage = sensorValue * (5.0 / 1023.0);
```

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// print out the value you read:  
Serial.println(voltage);
}

After the experiment data acquisition all the value transmitted from the board it is saved on an excel document and the data processed in order to determine the parameters required for equation (1). The advantage of this type of processing data is given by the long time possibility to record data from the pendulum so low damping capacity materials can be analyzed from 30-60 minutes or more.

3. Experimental results
The experimental material surface, after shot-penning operation, is presented in figure 2 by SEM analyze. In figure 2 a) and b) are presented 2D insights for two different amplification scales and highlight the surface state, with modifications of the surface around 50 µm. In figure 2 c) by 3D SEM analyze the surface modification present different area, formed after shot-penning operation, with variations of height less than 10 µm.

Figure 2. Surface SEM analyze of shot-penning cast iron sample.

The experimental sample movement during the pendulum oscillation was filmed using a high performance camera and the movement film divided in 100 pictures. In figure 3 is presented the cinemetic movement snapshots of the experimental pendulum I (initial state) and HT (heat treated). Using a picture analyze software the movement can be registered with a very high precision and the displacement can be easily determined. These preliminary results analyze the movement of the pendulum for 60 seconds. In case of high damping materials this period is sufficient to determine the amplitude variation but for low damping capacity materials no variation was observed in this period.

Figure 3. Cinematic movement snapshots of the experimental pendulum I (initial state) and HT (heat treated)
We analyze the movement of pendulum and determine the values of \(A_0\) (first biggest amplitude above the zero line), \(A_n\) (last biggest amplitude used for calculus), \(a_0\) (first biggest amplitude under the zero line), \(a_n\) (last biggest amplitude under the zero line), register the analyze time, seconds, calculate the frequency and apply equation (1) we obtain a value of \(6.75 \times 10^{-6}\) for \(Q^{-1}\) and \(0.15 \times 10^6\) quality factor which represent a very good value for low damping materials. The reduced video registration time can influence the final calculation value of the \(Q^{-1}\) so further investigations with bigger registration periods is required.

In figure 4 is present the schematic of the acquisition board used to transform the analog signal of the pendulum in digital signal in order to be registered and after that transferred to a PC as digital results (tensions given by the optocoupler).

![Schematic of the acquisition part of the signal from the pendulum using an optocoupler sensor.](image)

**Figure 4.** Schematic of the acquisition part of the signal from the pendulum using and optocoupler sensor.

The results, after registration and interpretation, based on the diagrams presented in figure 5, show very small variation of the damping capacity in the first minute and few modifications appear after 5 minutes. Even the damping capacity can be evaluated after this period, taking care of the time analyze, frequency and oscillation amplitudes, at the beginning of the experiment and after a while, further analyze with time extended (30-60 minutes) are required to increase the quality of the analyze.

![Analog to digital signal analyze](image)

**Figure 5.** Analog to digital signal analyze a) first part of the experiment (first 60 seconds) and b) last registered part of the experiment (last 10 seconds after 300 seconds).

In the initial condition using a machined and shot-penning sample, the damping coefficient \(Q^{-1}\) is about \(3.75 \times 10^{-5}\); thus, the quality factor \((1/ Q^{-1})\) is about \(0.27 \times 10^5\). In comparison, for pure silica, this coefficient is similar [8]. Residual stresses are induced by the shot penning process itself, especially by the surface deformation and impact energy. A tempering heat treatment will induce a decrease of all the defects (residual stresses not previously eliminated or induced by shot penning operation and intrinsic material defects), and thus, an enhancement of the quality factor \(Q\) should be observed. At
room temperature, the quality factor of such an tempered sample was measured and found equal to $Q = 0.77 \times 10^6$; the result can be explain through the elimination of different defects from the material, surface and structure, that will decrease the damping capacity of the material.

As further work we propose to improve the equipment experimental conditions: a vacuum system will be applied and a heating system of the sample (using an electrical resistance) in order to establish the damping capacity at various temperatures for different application fields. Both registrations of movement systems will be re-analyzed and improved for a higher quality and larger time periods. Also the damping capacity of the material can be observed using a thermal camera to register thermal variation during oscillation, especially between the beginning and the end of the movement. High damping materials will present a high temperature variation in time that the low damping materials smaller temperature variations.

4. Conclusions

An experimental pendulum was obtained in laboratory conditions in order to analyze the damping capacity of metallic materials with possibility of a pre-stress apply. Preliminary results of $Q^1$ values determination for a cast-iron sample were obtained using two different acquisition systems. The results present a future of cast-irons in low damping capacity materials with different application possibility.

A tempering heat treatment applied will contribute to a decrease of the defects number and normally an enhancement of the quality factor $Q$ should be observed. At room temperature, the quality factor of such an tempered sample was measured and found equal to $Q = 0.77 \times 10^6$.

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