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A NEW AUTOMATIC INTERFEROMETRIC METHOD FOR MEASURING THE DEPENDENCE OF MAGNETOELASTIC PROPERTIES ON MAGNETIC FIELDS

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ABSTRACT
The aim of this work is to characterize the high dependence on applied magnetic field of both Young's modulus and damping, so-called ΔE-effect and Δδ-effect respectively, in some magnetic materials thanks to a new automatic and interferometric method.
The characterization of these properties is based on free longitudinal vibration theory in continuous systems. The studied samples are nickel slender rods, with 10 mm in diameter and 110 mm in length, longitudinally placed inside a coil. The excitation of the specimen is obtained thanks to a brief impact caused by a pellet shot with a compressed air system, and the measurement method consists of an interferometric vibrometer based on Doppler Effect.
This innovative method achieves a huge amount of advantages over other existing methods, especially precision, resolution and full automation. Attending to the developed studies in nickel, maximum variations relatives to Young's modulus and logarithmic decrement are 2.5% and 156% respectively.
Keywords: magnetoelasticity, young's modulus, damping, interferometry

1. INTRODUCTION
Magnetoelasticity is the phenomenon in which elastic and magnetic materials change their elastic properties depending on their magnetic state and vice versa. Sonic and ultrasonic emissions, electromechanical filters or several kinds of magnetoelastic sensors and MEMS are only some examples of scientific and engineering applications of magnetoelastic materials [1].
ΔE and Δδ effects are the particular magnetoelastic phenomena that are studied in this work. Several measurement techniques used to characterized these effects are been developed in several works [2, 3, 4] but most of them show some drawbacks that the proposed method try to solve or avoid.

2. EXPERIMENTAL SET-UP DESCRIPTION
Figure 1 shows a diagram of the experimental set-up used to carry out the tests, whose main components are described in detail next.
The solenoid is specially designed for generating a high and homogeneous magnetic field in order to saturate several ferromagnetic specimens. Both goals are achieved superimposing the effects of two different coils: a straight one which obtains the main component of the field and a couple of Helmholtz coils which contribute to reach the desired homogeneity. Ferromagnetic rods are longitudinally placed inside the coil thanks to a wooden ring: its external surface is fixed inside a cylindrical free space across the solenoid and its inner surface is used to fix the samples in their centre (the vibration node). Using a Delta SM400-AR-8 DC supply to feed the full solenoid a maximum value of 1970 Oe and a 95% homogeneity length along 110mm are reached.

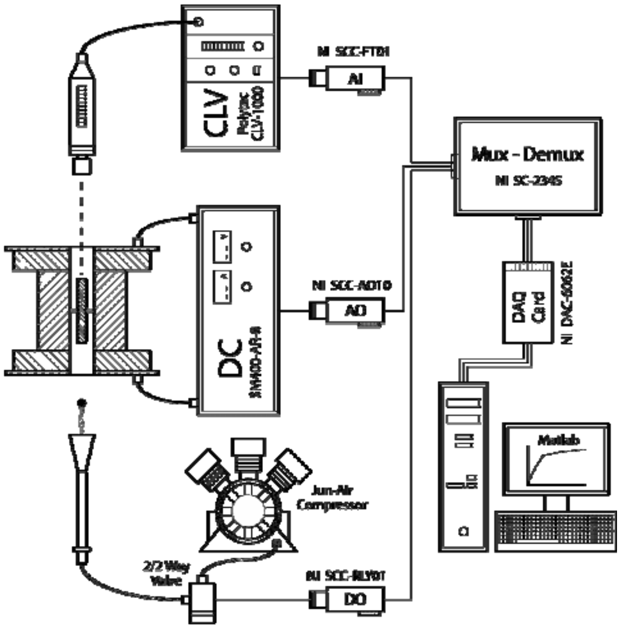

Figure 1. Diagram of the experimental set-up operation

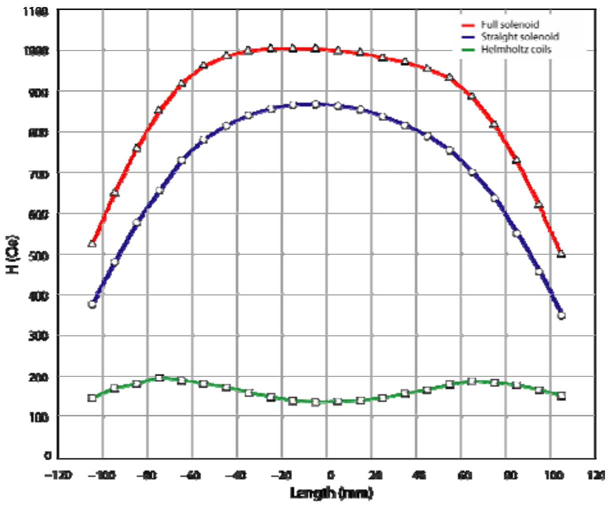

Figure 2. Experimental characterization of the solenoid with MG-4D Gaussmeter (Walker Scientific)

Free longitudinal vibration in the sample is induced by a brief impact perpendicular to one base of the cylinder in vertical position. A compressed air system which shoots a 4.5 mm pellet is used to apply it. The automation of the shoot is achieved with the aid of a 2/2 way electrovalve which controls the flux of compressed air and a special barrel which collects the pellets after its rebound. At the opposite base of the cylinder a Polytec CLV-1000 laser vibrometer based on Doppler Effect is pointed in order to measure the vibration velocity of the sample in a high bandwidth of 250 kHz.

The final step of the experimental set-up is to develop a data acquisition and signal conditioning system which allows the user to control all the measurement process. This goal can be divided into two necessary parts: hardware devices and software programming. The hardware requirements consist of National Instruments equipments, detailed in Figure 1, which are in charge of acquiring non-conditioned analog input from the laser, sending analog output towards the DC supply and acting as a digital relay to control the electrovalve. With regard to the software that manages the hardware devices, Matlab environment was chosen like programming language to take advantage of its calculation capacity and the existence of advanced toolbox in related subjects.

3. DATA POST-PROCESSING

For each magnetic field applied, a new acquisition of free vibration velocity is made. Then, a post-processing task, also automatic, is needed in order to obtain the desired ΔE and $\Delta\delta$ effects.

Figure 3 shows a temporal response belonging to an unmagnetized nickel rod in free longitudinal vibration and its corresponding Fast Fourier Transform.

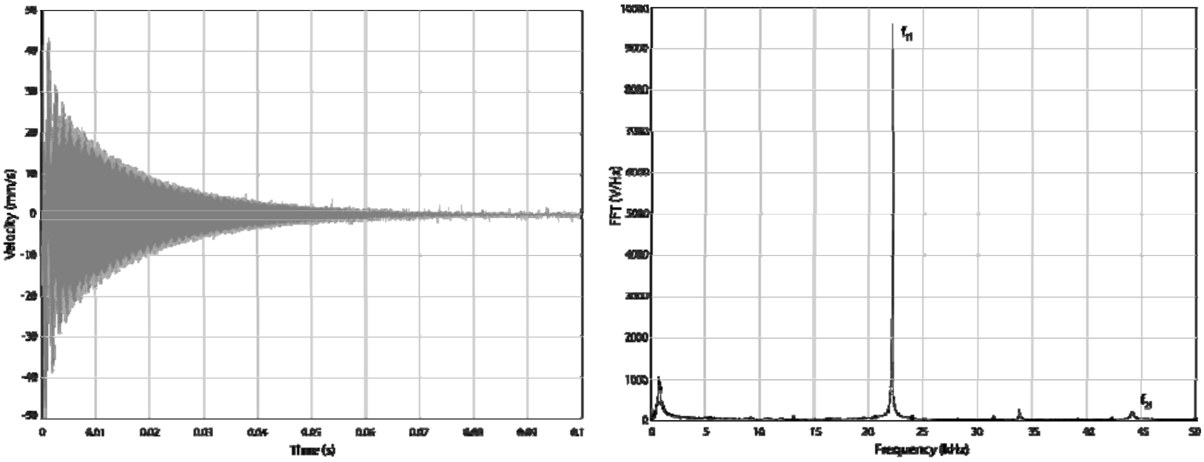

Figure 3. Temporal response (left) and FFT (right) of an unmagnetized nickel rod

The previous frequency spectrum can be used to detect the damped frequency corresponding to the longitudinal vibration mode and to recognize other possible undesired oscillation frequencies which appear as a consequence of an imperfect exciting impact. In order to isolate the appropriate compound, a 5th order Butterworth band-pass filter is applied around the desired frequency.

Attending to longitudinal vibration theory in continuous systems [5] and its application to ferromagnetic materials [1] the general expression for longitudinal displacement u_z is

$$u_z\left(z,t\right)=\left[C_1\cos\left(\frac{\omega_n}{c}z\right)+C_2\sin\left(\frac{\omega_n}{c}z\right)\right]\left[C_3\cos\left(\omega_\gamma t\right)+C_4\sin\left(\omega_\gamma t\right)\right]e^{-\frac{\gamma}{2}t} \quad (1)$$

where C_1, C_2, C_3 and C_4 are boundary and temporal constants, c the square root of the relation Young's modulus-density, ω_n and ω_γ are the undamped and damped longitudinal angular frequency respectively and γ is the attenuation constant. So, the damping of the oscillation can be estimated relating the theoretical exponential parameter with the mathematical one obtained thanks to a decreasing exponential function which fits the envelope of the wave.

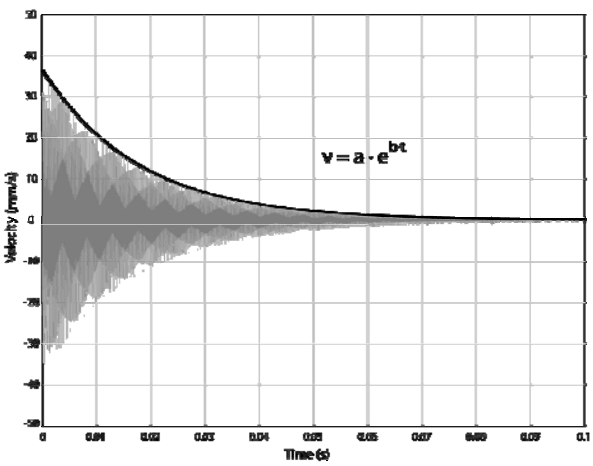

Figure 4. Exponential envelope for an acquired signal

Finally, once the damped vibration frequency and the attenuation constant have been calculated, it's easy to obtain the value of elastic modulus and logarithmic decrement which corresponds to each test thanks to the next relations [6, 7].

$$E=4\rho l^2 n^{-2} f_{nl}^2=4\rho l^2 n^{-2}\left(f_{dl}^2+\frac{\gamma^2}{16\pi^2}\right) \quad (2)$$

$$\delta = \frac{\gamma}{2 f_{nl}} \qquad (3)$$

4. EXPERIMENTAL RESULTS

The studied samples are nickel slender rods whose dimensions are 110 mm in length and 10 mm in diameter. A metallographic analysis gave purity higher than 99.9% and a density of 8912 kg/m^3. All the rods were cold worked and annealed at 900ºC in a continuous furnace.

Below, in Figure 5, the evolution of both parameters depending on the magnetic field applied is shown. With respect to ΔE-effect, a maximum increment of 4% is observed between the magnetized and unmagnetized state, but the higher variations are found at a range of low magnetic field. Finally, attending to the Δδ-effect, an initial increase of their values until 170% is shown, but for higher values of magnetic field a continuous and gradual decrease of logarithmic decrement is made clear until it stabilizes in –40% at the unmagnetized state.

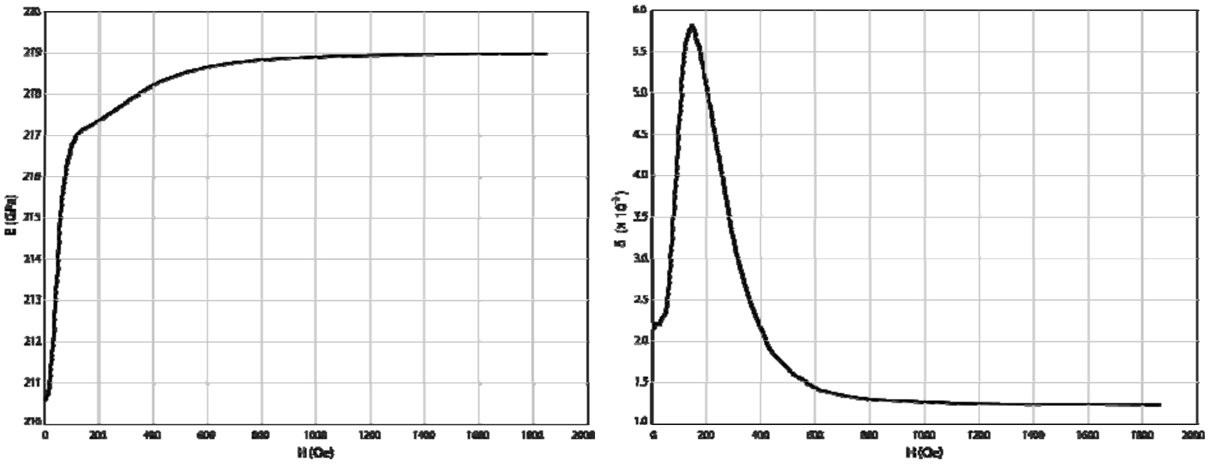

Figure 5. Young's modulus (left) and logarithmic decrement (right) dependence on magnetic field.

5. CONCLUSIONS

The main advantages of the method applied over others are: simultaneous measurement of both effects, lack of interaction with the sample, high accuracy and resolution, simple preparation of the sample and rapidity. As a consequence, unexpected results were found like the existence of a maximum in the Δδ-effect curve which was not detected in other similar researchs [4]. Furthermore, a full automation of the test process is achieved.

Finally, it is important to notice the giant magnetoelastic effect which nickel is able to undergo: up to 4% with respect to ΔE-effect, which is in accordance with the main consulted sources about this effect [6], and 170% regarding Δδ-effect. So this smart material may take a special significance in numerous technical and scientific applications.

6. REFERENCES

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