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Strain measurements of cylinder magnetostrictive samples by interferometer readings

R. Bellotti[1], P. Mei[2], G.B. Picotto[1], M. Santiano[1], M. Zucca[1]

[1] INRIM – Istituto Nazionale di Ricerca Metrologica
[1] Politecnico di Torino – Dipartimento Energia

m.zucca@inrim.it

Abstract

Magnetoelastic materials are utilized in applications under variable stress in presence of a magnetic field excitation. An accurate characterization of the material behaviour needs of magnetic and strain measurements on the material specimen, usually performed on a dynamic test machine equipped with a magnetic excitation core. Strain measurements are usually made by means of a strain gauge glued on the specimen. This method has some limitations: it requires a bonding of strain gauge for each specimen. Moreover, the strain gauge performs a local strain measurement, which is significant if the magnetization of the sample is uniform.

To overcome the above-mentioned limitations of strain gauges in this application, an interferometer with a differential optical set-up has been designed and tested onto a measuring machine. The design makes use of symmetric and differential paths by the reference and moving arms of the interferometer, thus compensating for drifts and dead-path of linear set-ups. The interferometer reading is zeroed or corrected afterwards by pre-registering strain of the loading cylinders at the same loading curve to be used for testing the sample. Preliminary results highlight a good repeatability of measured strain.

Some further steps are envisaged by suitable control of the strain test runs.

strain, interferometry, magnetoelastic materials

1. Introduction

Applications involving giant magnetostrictive devices must be designed having available an accurate magnetic and magneto-mechanical characterization of the material behaviour [1]. The latter is obtained through magnetic and strain measurements on a magnetostrictive specimen magnetically excited and, usually, mechanically preloaded [2]. This operation is typically done in a fitted dynamic test system, equipped with a magnetic excitation circuit and suitable magnetic field, magnetic induction, force and strain transducers [3].

Strain measurements are normally carried out by strain gauges, which provide suitable resolution (even one microstrain) and measurement uncertainties between ±0.2% and ±0.46% of the span in static and dynamic conditions [2]. However, strain gauges must be glued on each test specimen and provide a local measurement on a sample face, while in many cases it may be more interesting to get the total sample elongation. Moreover, when the specimen undergoes dynamic magnetic excitation, some electrical noise is harvested by the strain gauge.

It is worthwhile to mention early applications of optical Interferometry for strain measurement, either based on Michelson interferometers to measure longitudinal length changes by the moving mirror mounted on the loading side of the specimen, or based on interference by diffraction gratings engraved or mounted on the specimen under test [4]. Meanwhile, dynamic interferometric strain measurements make also use of a fiber-optic probe, which allows to operate in harsh/extreme environments [5].

To avoid the drawbacks of using strain gauges and to obtain the whole strain of the specimen an interferometric system based on a true-differential set-up has been designed and mounted on our strain tester to measure the longitudinal/axial length changes of the specimen under test.

In the following, the test machine, the magnetic excitation and the interferometric system are described in Section 2. Section 3 focuses on the magnetic system and provides preliminary measurement results. Finally, Section 4 draws conclusions.

2. Measurement setup

2.1. Test machine and magnetic excitation

The measurement setup is built on a 10 kN dynamic test machine (Instron, model E10000). A magnetostrictive cylindrical specimen under test was inserted as a central limb of a three-legged magnetizer with two identical exciting windings. The laminated yoke was realized with 0.20 mm thick non-oriented Fe-Si sheets. The rod ends were affixed to the compression plates of the test machine. The measurement setup includes a Lake-Shore magnetometer with Hall field-sensing plate placed in contact with the magnetostrictive rod surface at mid plane and the interferometric measurement system.

2.2. Strain measurement system

A two-frequency interferometer using a simple optical set-up for measuring the changes of the length by the loading head and the base is shown in Fig. 1.

Two mirrors facing to each other at 90° are fixtured on a holder, this last mounted on the head cylinder. Transversal holes have been made in the two cylinders joined to the head and to the base. This is to provide the optical paths of the measuring and reference beams of the interferometer.

The two frequency components representing the measuring and reference beams are separated by a polarizing beam splitters (PBS) and then recombined by a second PBS. The alignment of the two beams is provided by an X-stage moving the input PBS and by a mini prism table supporting the output PBS. The overall assembling of the two PBBs consists of an holder mounted on the base cylinder. The up/down optical paths by PBSs and mirrors are spaced symmetrically to the machine vertical axis, thus resulting in a compact arrangement. A half-waveplate is provided at the input beam to match the orientations of the two polarizations with the input PBS.

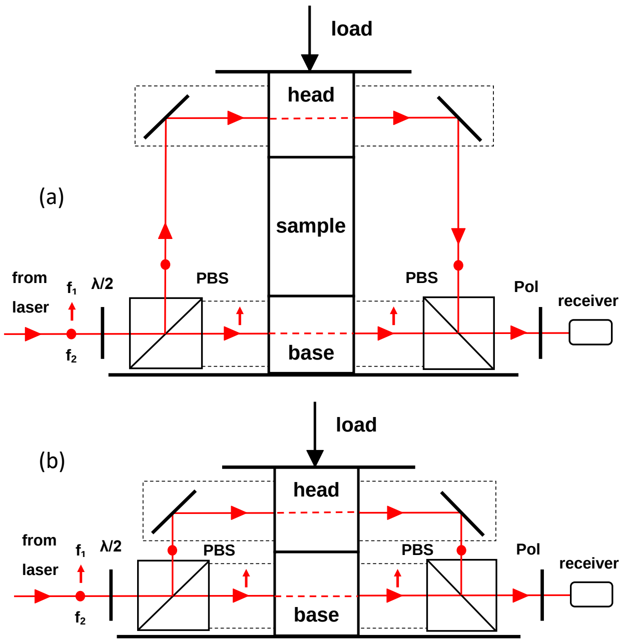

Figure 1. Sketch of the interferometer with (a) and without (b) specimen under test.

Being the moving and reference optics of the interferometer connected to base and head cylinders, the interferometer readings need to be zeroed or corrected afterwards by pre-registering strain of the head/base cylinders at the same loading curve used for testing the specimen, as is shown in Fig. 1(b).

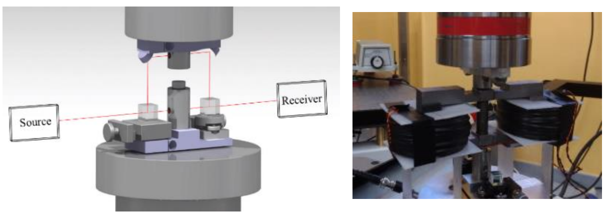

Figure 2. On the left: rendering of the strain measurement system. On the right: setup with the magnetic core and the specimen.

3. Results

The system described in the previous paragraph was utilized to calculate the Young modulus of a Galfenol ($Fe_{100-x}Ga_x$ being x~20) rod 60 mm long and having a 12 mm diameter. The rod has been previously demagnetized. Then, an increasing stress was applied up to 60 MPa and, subsequently, the applied stress was returned to zero. During the procedure, stress and strain values were simultaneously recorded and, as expected, the system showed mechanical hysteresis. The same procedure was repeated by applying a constant DC current to the excitation windings of the three-legged magnetizer where the specimen is the central limb.

The applied magnetic field was measured at specimen mid plane at zero pre-stress condition and three value have been set to 5 kA/m, 10 kA/m and 15kA/m. The first value keeps the material in the linear portion of the magnetic characteristics B-H independently from the stress magnitude (H is the applied magnetic field and B is the magnetic flux density in the material) .The third value definitely brings the material into magnetic saturation at 60 MPa applied stress, while the second is an intermediate value.

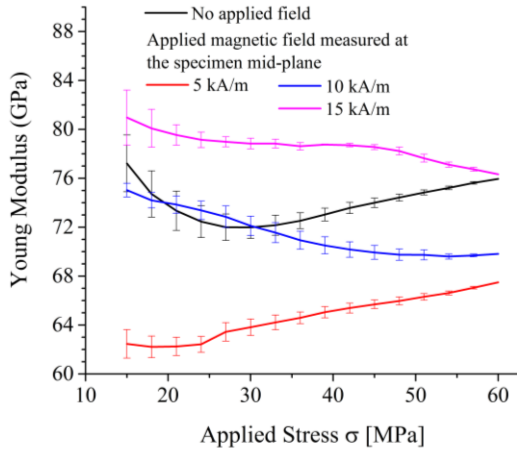

Figure 3. Variation of the Young modulus of Galfenol as a function of the applied stress under four magnetic conditions: without magnetic field applied, and with three values of magnetic bias field applied to Galfenol. The measured values at the specimen mid-plane under zero pre-stress condition was equal to 5 KA/m, 10 KA/m and 15 KA/m

The Young modulus (*E*) was calculated for each stress value by applying the zero correction (Fig. 1 b) to the strain. The *E* variation bands on the diagram show the effect mainly due to the material hysteresis. As shown in literature the *E* of Galfenol varies as a function of the applied stress and of the applied magnetic field and its value, measured with the here proposed setup (75.5±4.5 GPa at zero magnetic bias field), is perfectly coherent with the few data in literature [6].

4. Conclusions

An interferometric method has been successfully applied to the characterization of the Young modulus of a bulk magnetostrictive material rod. The same system can be used for the measurement of the magneto-mechanical characteristics, by imposing a harmonic variation of the magnetic field *H* and recording the corresponding values of strain. This non-contact method allows an overall measurement of the specimen deformation and avoids bonding operations.

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twenty10
33 Rothersthorpe Crescent Mews
Northampton
NN4 8JD
UK

Cranfield University Campus
Building 90, College Road
Bedford
MK43 0AL
UK
Tel: 0044 (0) 1234 754023
Website: www.euspen.eu