MEASUREMENT SYSTEM FOR THE CHARACTERIZATION OF PIEZOELECTRIC BIMORPHS

Bruno Andò, Pietro Giannone, Salvatore Graziani, Nicola Pitrone

Engineering Faculty, D.I.E.E.S., Viale A. Doria, 6, 95125, Catania, Italy nicola.pitrone@diees.unict.it

ABSTRACT

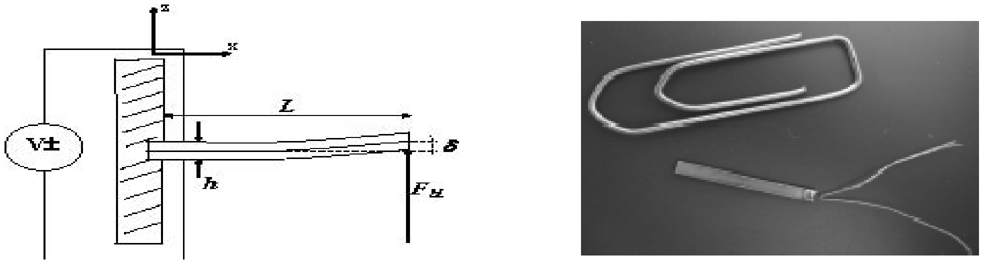
Hysteresis is a common phenomenon in various non linear systems including piezoceramic materials. Piezoelectric bimorph devices show hysteretic behaviour, when operating as actuators. In this paper an experimental set-up to investigate the hysteretic behaviour of a PZT is described. The strategy adopted uses a resistive readout scheme and a CCD tool for the system calibration. Moreover, software tools have been developed to manage the experimental and to process signals coming from the hardware developed.

1. INTRODUCTION

The word hysteresis originates from ancient Greek and means ‘to lag behind’. Some of the best known examples of hysteretic phenomena can be found in plasticity, friction, ferromagnetism, and piezoelectricity [1,2]. Piezoelectric bimorphs consist of two flat strip of piezoelectric elements joined one to each other, provided with electrodes in such a manner that when an electric field is applied, one strip elongates while the other contracts[3]. The motion of the tip can be considerable, making these devices useful tools for the conversion of electrical energy into mechanical energy and vice versa. Piezoelectric actuators are a standard option in positioning applications where the displacements must be small and highly accurate. In particular, ultra-precision manufacturing requires exceptionally fine and repeatable motions, making piezoelectric actuators a suitable choice. However, these actuators can be influenced by changes in the values of environmental quantities, among them the temperature, and their behaviour exhibits several nonlinearities [4]. There is an increasing interest in piezoelectric devices, on account of their versatile properties, therefore a deep investigation of the behaviour of such devices is required and the development of characterization tools allowing for the analysis under both static and dynamic conditions is needed. The device under consideration is the 285-784 M641 piezoelectric bimorph of the Sensor Technology®. To monitor the displacement of the piezoelectric bimorph a Strain Gauge (SG) based system has been adopted. Indeed, the displacement gives rise to a variation of the resistance, that can be easily measured. Actually, the proposed methodology could produce perturbation on the device under test. Anyway, the adoption of suitable banding techniques makes these effect negligible compared to undesirable drawbacks of conventional contact-less solutions [5]. The successive A/D conversion of the signal, needed for the elaboration of the experimental data, requires a suitable level of the voltage, therefore a differential amplifier has been adopted as a conditioning circuit, in particular the INA111 of Burr-Brown® has been used. A number of technological solutions have been tested to band the SG device to the bimorph under investigation.. The structure developed exhibits an acceptable dynamic range in both the voltage amplitude and the frequency interval, which fit the aims of the experimental. In order to calibrate the resistive readout system a CCD based architecture has been adopted as reference system. In the following sections the measurement system developed to characterize the piezoelectric bimorphs are described in some details along with preliminary result

2. THE PROPOSE READOUT STRATEGY TO MEASURE DEFORMATION OF THE PIEZOELECTRIC CANTILEVER BIMORPH

Let consider a bimorph consisting of two strips of piezoelectric materials of length L, width w, thickness h, with an electrode on the top of the upper element, and the other on the bottom face of the second strip as show in Figure 1a, the deflection of the piezoelectric bimorph device is obtained by applying an ac voltage across the electrodes [6].



(a)

(b)

Figure. 1:.(a) The deformation of a bimorph piezoelectric device. (b) A real view of the adopted device.

The x and z axes, have been chosen as reported in Figure 1a. The deflection of the bimorph, under the effect of a voltage signal, is measured along the z axis. Figure 1b shows the device adopted for the characterization procedure. The methodology adopted to detect the deformation of the piezoelectric cantilever bimorph is based on the use of strain gauges. The idea is to band a strain gauges on the surface of the piezoelectric cantilever bimorph, the flexibility and the lightness of the strain gauges is small respect the rigidity of the piezoelectric then it is possible to suppose that this sensor doesn't influence the behaviour movement of the device. The metallic strain gauge consists of a very fine wire or, more commonly, metallic foil arranged in a grid pattern. The grid pattern maximizes the amount of metallic wire or foil subject to strain in the parallel direction (Figure 1a). The cross sectional area of the grid is minimized to reduce the effect of shear strain and Poisson Strain. The grid is bonded to a thin backing, called the carrier, which is attached directly to the test specimen. Therefore, the strain experienced by the test specimen is transferred directly to the strain gauge, which responds with a linear change in electrical resistance.

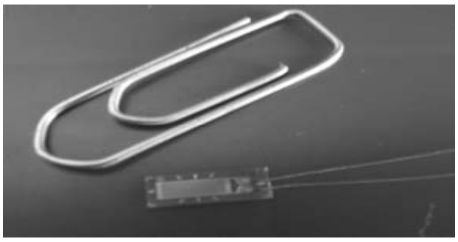


Figure. 2:. A real view of the adopted sensor.

A fundamental parameter of the strain gauge is its sensitivity to strain, expressed quantitatively as the gauge factor (G). Gauge factor is defined as the ratio of fractional change in electrical resistance to the fractional change in length (strain):

$$G = \frac{dR/R}{dL_0/L_0} = 1 + 2\nu + \frac{d\rho/\rho}{dL_0/L_0} = \frac{dR/R}{\varepsilon} \qquad (1)$$

where L0 is the length described in Figure 2a, R the grid resistance, ρ is the resistivity and ν the Poisson coefficient. In practice, the strain measurements rarely involve quantities larger than a few millistrain(ε x 10^{-3}). Therefore, to measure the strain requires accurate measurement of very small changes in resistance.

A real view of the bimorph under test with a banded SG is given in Figure 3. Figure 4 shows the bridge adopted to convert the deflection of the piezo bimorph into a voltage [7].

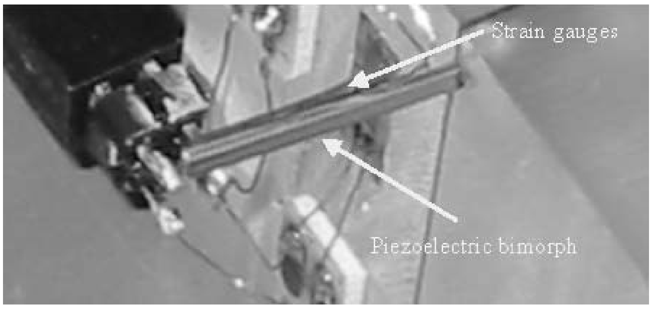


Figure.3: A real view of the bimorph under test with a banded SG

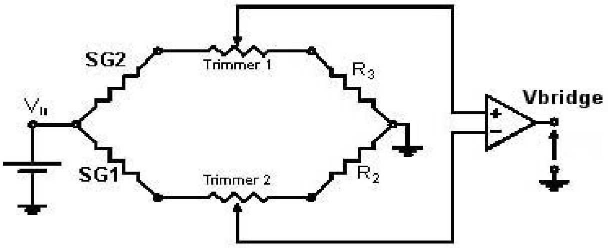


Figure. 4: The electronic conditioning based on Wheatstone bridge.

In the above schematization SG1 is the sensor banded on the bimorph plate which SG2 is the dummy gauge used to compensate the effect of temperature, infact any changes in temperature will affect both gauges in the same way. By using the electronic conditioning in Figure 4 is possible to obtain:

$V_{bridge}^{=f(\Delta R)}$ (1)

and also:

$\Delta R = g(\delta)$ (2)

by using equations (1) and (2) it can write:

$V_{bridge}^{=h(\delta)}$ (3)

Inverting relationship (3) it is possible define the relationship between the deformation of the piezoelectric bimorph and the voltage output of the conditioning circuit as show equation (4)

$\delta = h^{-}(V_{bridge})$ (4)

Identification of the function h^{-1} expose in section 5.

THE EXPERIMENTAL SET-UP

A schematic representation of the system developed is given in Fig. 5. A high voltage source, driven by an arbitrary waveform generator, stimulates the PZT actuator. Deflection of the PZT is captured by strain gauges sensors signals coming from the readout electronics and forcing waveform are acquired by a PCI 3036E DAQ card. To obtain information about piezo deflection and state diagram for the operating condition considered, a dedicated tool was developed in LabVIEW™.

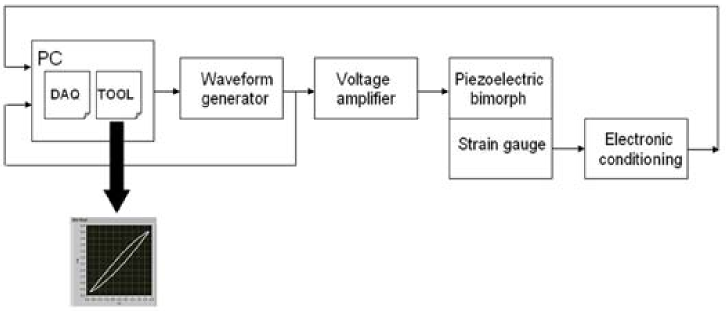
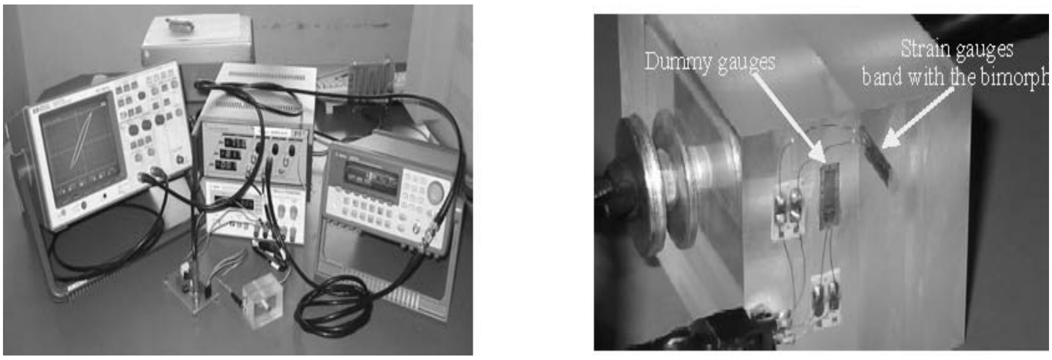


Figure. 5: An schematic of the set-up for the piezoelectric bimorph characterization.

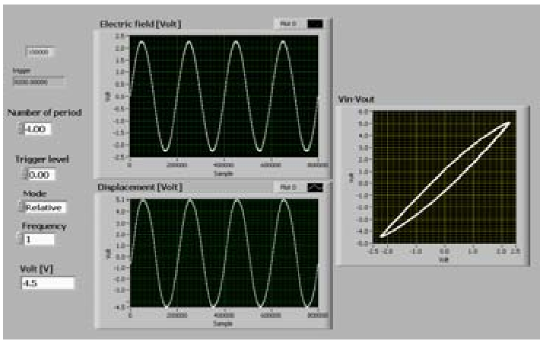
Figure 6a is a real view of the whole system developed , are possible to see the developed conditioning circuit, the structure developed to bind the piezo and the SG, the waveform generation to force the signal at the piezoelectric device and the scope to observe the signal involved in the process. Figure 6b a particular of the readout system, it is possible to observe the piezoelectric bimorph with the strain gauge band on the surface and the dummy gauge for the temperature compensation, the developed structure is made up by Plexiglass, this material is more indicated to use in fact is more easily to shape, non conductor and more stiff.



(a) (b)

Figure. 6: (a) The system developed. (b) A particular of the readout system adopted to detect the deformation of the piezoelectric bimorph.

Figure 7 is a typical view of front panel of the virtual instrument, developed in LabVIEW™ environment, during the signal acquisition phase.



Number of period 4.00
Trigger level 0.00
Mode Relative
Frequency 1
Volt [V] 4.5

Figure. 7: The front panel of the virtual instrument for signal acquisition and the data processing. The instrument drives the DAQ card PCI-6111E.

In the virtual instrument developed, is possible to manage the waveform generator via GPIB IEEE488.2 in fact are present two windows in which is possible to set the amplitude and the frequency of the forcing signal, and at the same time the instrument required the number of periods that the user want acquire, three graph represents the acquired forcing signal, the output of the readout elecvtronic (in this case the deformation of the piezoelectric bimorph), and the X-Y graph that represent the hysteresis of the piezo bimorph. To convert signals given by the readout electronic, in a deformation, a calibration system based on a CCD tool managed by PC was adopted.

5. RESULTS AND CONCLUSION

Equation 5 shows results obtained from the calibration procedure. The mean square root was used to characterize the developed system.

The characteristic curve are given by the following equation:

$$d = V m_{bridge} + b \qquad (5)$$

where

m=24.9130 μm/V ***b=-2.6137 μm***

Using the characterization procedure described in the previous section an investigation about the behaviour of a piezoelectric bimorph, has been performed.
Figure 8 shows various hysteresis loops obtained for forcing field with frequency equal to 0.5 Hz, and amplitude varying between 180 V/mm and 730 V/mm.

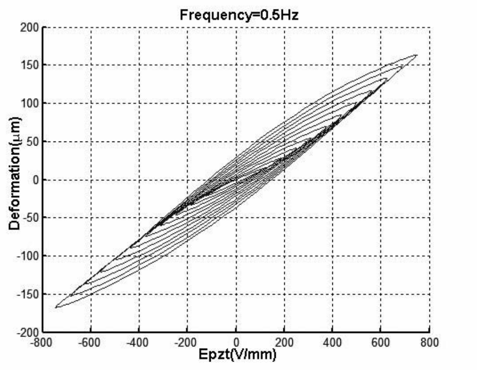


Figure. 8: The hysteresis loop for different amplitudes of the forcing signal when the system is forced by a stimulus at a frequency equal to 0.5Hz.

Figure 9 represent the output of the developed system and is possible to observe as the property of turning-point is respect and the property on minor loop of the hysteresis loop.

6. CONCLUSION

In the paper a low cost characterization system for a rough investigation of bimorph piezoelectric devices was suggested. The system uses strain gauges, dedicated readout electronics, and a virtual instrument to manage signals given by sensors. Results obtained with the developed equipment encourages the development of such low cost systems which allow for studying the non linear behaviour of PZT devices. Future works on the developed system will be dedicated to a rigorous formalization of the system uncertainty.

REFERENCES

[1] R. Banning, W. Koning, H. Adriaens, R. Koops, *Automatica* **37** (2001) pp:1883-1892.

[2] H. Richter, E.A. Misawa, D.A. Lucca, H. Lu, “Modeling nonlinear behavior in a piezoelectric actuator”, Precision Engineering, N. 25, 2001. pp. 128-137

[3] J. G. Smits, A. Ballato *Dynamic Admittance Matrix of Piezoelectric Cantilever Bimorphs* Journal of Microelectromechanical system, Vol**. 3**, No. 3, September 1994.

[4] A. Ballato, *Piezoelectricity: Old Effect, New Thrusts,* IEEE Trans. on Ultrasonics, Ferroelectrics, and Frequency Control. Vol**. 42**. No. 5 September 1995.

[5] B. Andò, P. Giannone, S. Graziani, “An opto-Mechanical System to characterize Piezoelectric Cantilever Bimorphs”, Proceedings of the Eurosensors 2004 – XVIII Edition, Roma/Italy, 2004.

[6] Q-M. Wang, X-H. Du, B. Xu, L. E. Cross *Electromechanical Coupling and Output Efficiency of Piezoelectric Bending Actuators,* IEEE Tans. on Ultrasonics, Ferroelectrics, and Frequency Control, Vol. **46**, No. 3, May 1999.

[7] John G. Webster The Measurement, Instrumentation and Sensors Handbook CRC PRESS 1999