Virtual Instrumentation for Study of Shape Memory Alloys Strip while Bending

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***Abstract* - In this paper, using LabVIEW graphical programming environment and the portable reconfigurable input/output (RIO) device from National Instruments (myRIO-1900), the concept of virtual instrumentation is implemented. Thus, it is created a hardware and software system that is used to study the nickel and titanium shape memory alloy (NiTi SMA) strip during bending under the influence of electric current. The SMA strip is caught in cantilever mode (fixed at one end only). For this study, the following quantities are measured: the deformation of the strip (using a created electronic transducer around an operational amplifier and a piezoelectric effect sensor), the voltage applied to its ends and the current flowing through it (with LEM transducers). The evolution of the electrical resistance as well as the bending of the SMA band at different values of the electric current, during and due to the heating process is reported using this system. The values of the measured quantities are presented in graphical and numerical form. Thus, the evolution on time intervals of the order of seconds can be followed with precision with the help of horizontal and vertical cursors, respectively. Amplitude values can also be accurately determined. The results obtained with the proposed system are useful in practical applications of cantilever SMA strip for development of simple, more compact and reliable actuators or sensors.**

Cuvinte cheie: *aliaje cu memoria formei, bandă fixată la un singur cap, instrumentaţie virtuală, senzor piezoelectric, traductor de deformare cu înaltă sensibilitate.*

Keywords: *shape memory alloy, cantilever strip, virtual instrumentation, piezoelectric sensor, highly-sensitive deflection transducer.*

I. INTRODUCTION

Shape Memory Alloys (SMA) or NiTi SMA (Nickel and Titanium or named Nitinol after the name of the components) are materials capable of remembering a previously memorized shape and exert a useful force or support very high deformations, thanks to their super elasticity properties [1-2].

Today, the use of shape memory alloys for the actuator is a technological opportunity for the development of these electromechanical components: the typical feature of the shape memory alloy strip to provide mechanical action, if stimulated by electricity (and heat) allows the development of more compact devices with light weight and small size [3-5], [8].

These devices will replace alternative technologies based on electric motors, solenoids and relays in automotive industry, healthcare, security and defense, consumer electronics, home appliance, damping systems, robotics.

A full range of SMA actuators advantages are: reduced cost, direct linear or angular movement, noiseless operation, compatibility with harsh environments, no electromagnetic emission.

In the last three decades, the community of researchers and engineers in the field of materials study has shown a significant interest in discovering, understanding and applying the characteristics of SMA.

The result of this intense interest and effort has materialized in numerous publications in the form of books, journal articles and volumes of international scientific events [7], [10-11].

To study the characteristics of the SMA (for example, to investigate by differential scanning calorimetry method during the heating-cooling process) and to extract its most important thermal parameters to correlate them with the evolution over time of other mechanical or electrical parameters, high-performance equipment is used [12-14].

Virtual Instrumentation (VI) can be a good solution in this field too due to its flexibility, performance and costs. In VI, with the help of a suitable hardware platform (built around a data acquisition module) we can easily create our own workspace with all the necessary tools for study of SMA characteristics. We can use VI to bring the facility of flexible software (LabVIEW) and personal computer technology to design applications making accurate measurements. The measurement system is controlled from a computer and data collected and analyzed are presented on a display screen [6], [21].

In the recent paper [9], it is shown how to evaluate the thermal characteristics of the SMA strip by using the differential scanning calorimetry (DSC) experiments. The results of this thermal analysis were the basis for determining the force developed by the SMA strip during the phase transformation. Evolution of the electrical SMA resistance at various values of the activation current is also studied.

In that work there are hints about hardware component of experimental platform but no explicit diagram details are presented. Our goal is to describe them in detail in the present paper.

II. HARDWARE PLATFORM

An experimental platform which uses a flexible piezoelectric effect film sensor for estimate of SMA strip deforming and a portable reconfigurable input/output (RIO) device for the measurement and rapid analyzing of parameters has been developed.

Fig. 1 shows block diagram of the experimental platform designed for study of SMA strip characteristics.

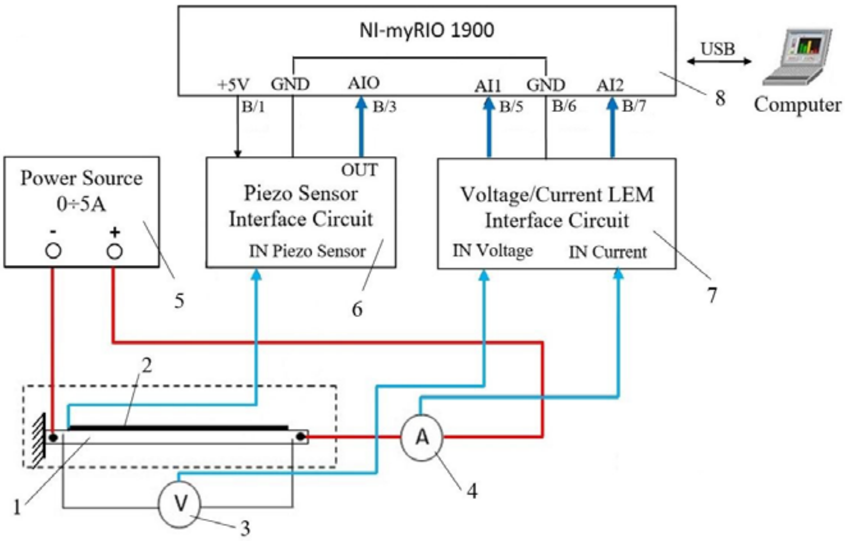


Fig. 1. Block diagram of the experimental platform for control and data acquisition during a displacement of the SMA strip.

The main components of proposed experimental platform are: SMA cantilever strip (1) under test, with piezoelectric sensor (2); voltage (3) and current (4) LEM transducers; power current source (5); piezoelectric sensor interface circuit (6); conditioner circuit for the voltage/current LEM transducers (7); data acquisition (DAQ) module (8) and computer (9). All these elements will be presented in detail.

A nickel-titanium shape memory strip with rectangular cross section (2.5 × 0.5 mm) was used in this study. The SMA strip was purchased under the name FLEXINOL® from DYNALLOY, Inc. [15]; Flexinol is a trade mark of Dynalloy, Inc., Irvine, California, USA, brand of NiTi shape memory alloy wire or strip [16].

The power supply (5) is a variable direct current source with stable output, available for testing requirements. Current and voltage wires are securely fastened to the SMA strip with small screws.

A flexible piezoelectric sensor (2) was used to control the deformation and movement of the SMA cantilever strip. The sensor is glued to the entire surface of the SMA strip.

Fig. 2 shows a close-up (in top and side view) of the tested SMA cantilever. The connection mode between SMA strip and current source, respectively the LEM current / voltage transducers is shown in the figure. It is also observed how to fix the piezo sensor foil on the SMA strip surface.

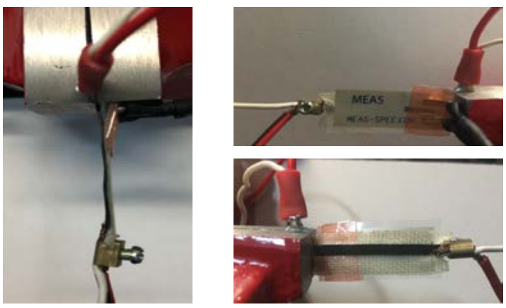


Fig. 2. Image of cantilever SMA strip (detail)

The acquisition of the data necessary for the proposed study is done with the help of NI myRIO - 1900 (8).

This device takes from the experimental platform signals in the form of voltage proportional to: SMA strip deformation (measured with the piezo transducer); the current flowing through the SMA strip and the voltage drop at its ends, respectively (measured with LEM transducers); the maximum length for signal wires is 30 cm.

The NI myRIO-1900 provides analog input (AI), analog output (AO), digital input and output (DIO), audio, and power output in a compact embedded device. The NI myRIO-1900 connects to a host computer over USB cables.

NI myRIO-1900 expansion port (MXP) connectors A and B carry identical sets of signals. The signals are distinguished in software by the connector name (i.e., as in Connector A/DIO1 and Connector B/AIO1).

The analog inputs are multiplexed to a single analog-to-digital converter (ADC) that samples all channels. The resolution of the ADC converter is 12 bits and the value in volts of the increment between data values is 1.221 mV if we use device to measure 0-5 V signals. Some other technical specifications: processor type Xilinx Z-7010 with 2 cores; speed 667 MHz; memory nonvolatile 512 MB and DDR3 256 MB; analog input sample rate 500 kS/s [22].

The image of all connections to NI myRIO MXP connector B, is shown in figure bellow.

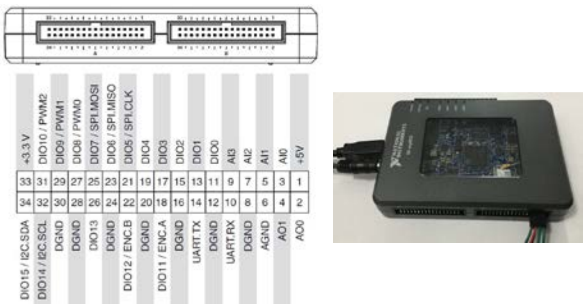
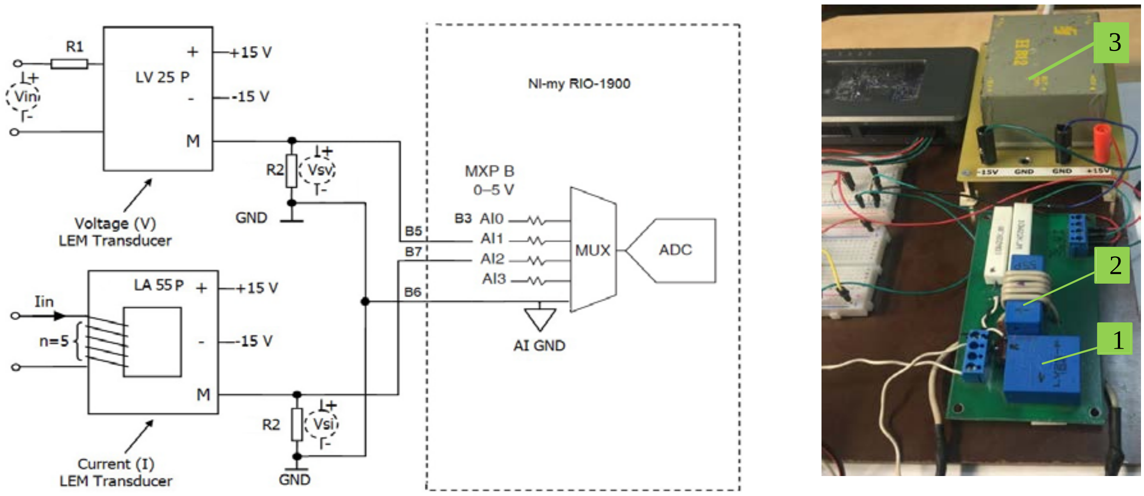


Fig. 3. Image of connections to NImyRIO MXP connector B, power input cable and USB cable



a) b)

Fig. 4. Voltage/current LEM interface: a) schematic diagram and b) top view image

Fig. 4 shows how to connect and power of LEM transducers and their interface circuit with NI myRIO device connectors (see also Fig. 1 and Fig. 3).

The V_{SV} and V_{Si} voltage signals (with values dependent on the SMA strip voltage *Vin* and the current through it *Iin*) connect to two analog inputs of the MXP Connector B (B5/AI1, B7/AI2).

Primary resistor *R1* of the voltage LEM transducer (position 1) should be calculated so that the nominal voltage had to be measured corresponds to a primary current of 10 mA. Measuring resistances *R2* of transducer is dependent on the values of primary nominal current.

Current LEM transducer dynamic performance is the best with a single bar completely filling the primary hole; to increase the sensitivity of the sensor to low values of the measured current, several winding turns are given, n = 5 (position 2 in Fig. 4, b).

LEM transducers are powered by a dual source voltage ± 15 V relative to GND (position 3 in Fig. 4, b).

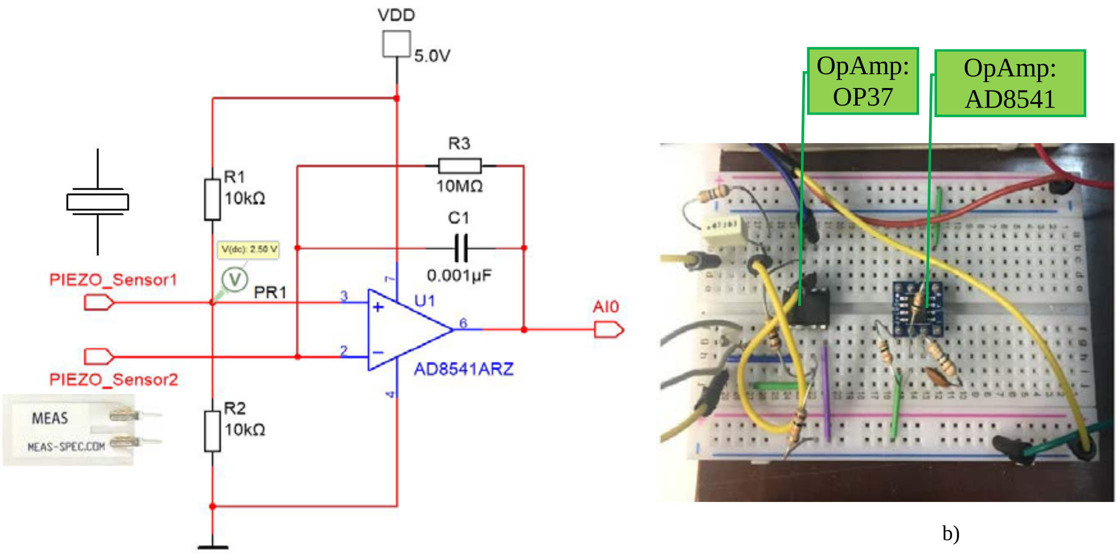
The voltage transducer used is LV-25P and the current transducer type is LA-55P; both are LEM [17].

Piezoelectric effect is the ability of certain materials to generate an electric charge in response to applied mechanical stress. When piezoelectric material is placed under mechanical stress, a shifting of the positive and negative charge centers in the material takes place, which then results in an external electrical field.

A piezoelectric sensor in combination with an electric charge to voltage converter make up the transducer that is used to estimate the deformation and displacement of the SMA strip under the influence of the current flowing through it.

The DT series of piezo film sensor elements are rectangular elements of piezo film with silver ink screen printed electrodes from TE Connectivity (TE); sensor capacitance is C_S = 1.38 nF [18].

Schematic diagram and breadboard layout of piezo transducer is shown on Figure 5.



b)

Fig. 5. Piezo transducer: a) schematic diagram and b) breadboard layout

The DT film element produces more than 10 millivolts per micro strain, about 60 dB higher than the voltage output of a foil strain gauge. The sensor can be readily adhered to SMA strip surface with double-sided tape or epoxy. Lead attachment can be achieved by low temperature solder. The piezo sensor can be seen as a capacitor with a piezoelectric crystal between two plates; it is an active sensor because any small deformation causes a variation of the charge which appears as a measurable voltage between the plates.

Piezoelectric sensor is followed by a charge-to-voltage converter that produces a voltage output proportional to the integrated value of the input current, or the charge injected. The converter uses an operational amplifier (U_1) which produces an output voltage inversely proportional to the value of the feedback reference capacitor (C_1) but proportional to the total input charge flowing during the specified time period. The gain of the circuit depends on the values of the feedback capacitor that plays the role of low pass filtering to the charge amplifier for noise mitigation.

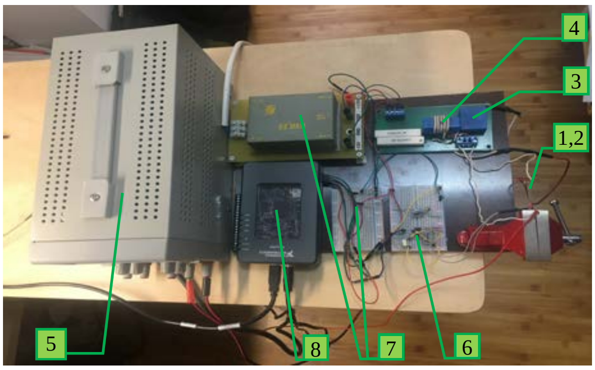
Decreasing the capacity *C1* has the effect of obtaining a piezoelectric transducer more sensitive to small changes.

Resistors *R1, R2* form a divider that sets the voltage on the sensor to $V_{DD}/2$ (i.e., 2.5 V) and *R3* is a feed back resistor to provide DC gain path.

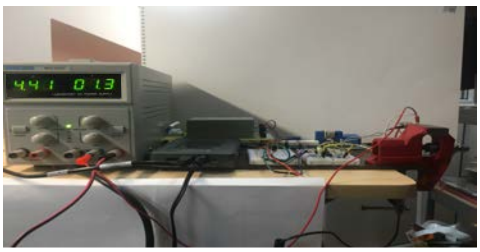
Two types of operational amplifiers were tested to converter design. High-quality operational amplifier with low noise, precision and high speed produced by Analog Devices – OP37 are used first [19].

Better sensitivity results were obtained with AD8541 operational amplifier. It is characterized by very low input bias current (4 pA), low levels of private noise, wide frequency band and rail to rail capability of input/output [20].

Fig. 6 pictures the experimental platform in a top view photo image a) and front view b). Items are noted according to the Fig. 1 (Block diagram of the experimental platform).



a)



b)

Fig. 6. Photo image of the experimental platform: a) top view and b) front view.

The real-time measurements and display acquired waveforms are displayed on a PC screen and the data associated with these waveforms are stored for a later use.

III. Software Interface

The demanding of the current research application requires a hardware and software integration. The LabVIEW graphical programming environment is best suited for this integration.

LabVIEW 2018 - myRIO Toolkit [21] was used to communicate with the hardware platform for data acquisition, processing and display of results with designed virtual instrument (VI).

It is known that software minimizes development costs of any complex systems. Graphic programming is highly interactive because it is based on wires and icons, and the data flow is visible in block diagram; the design of the user interface or frontal panel is part of the programming.

Front Panel (*FP*) is the virtual instrument interface with the user, containing setting and control elements, or elements for displaying the values of different quantities to be studied (buttons, displays etc.).

The *Block Diagram* (*BD*) contains the graphical source code (known as G code) for how the VI runs. Every Frontal Panel object appear as terminals on the Block Diagram.

A. *The Front Panels of virtual instrument*

The front panel window is our graphical user interface (GUI) of a virtual instrument. The front panel has two controls, push-buttons (*Write* and *Stop*) and indicators (*Waveform Chart* and *Data Table*). The indicators simulate the instrument's output devices and display the data that the block diagram acquires and processes.

Fig. 7 shows front panel of virtual instrument. The user can see the values acquired by the hardware component of the measurement system (transducers and my RIO device) and processed using the virtual instrument. The visualization of the data is done with the help of four *Waveform Chart* type indicators.

For ease of future development, a tab control consisting of Page 1 (position 1 in the figure) is used.

The voltage generated by the piezoelectric transducer is illustrated in the diagram on the top left of the front panel (*Piezo Sensor Voltage\V*, in volts). The significance of the times on the X axis (*Time index\s*, in seconds) is the following: $\mathbf{t_0}$ is the time at which the electric current is applied; $\mathbf{t_1}$ is the time at which the deformation begins, $\mathbf{t_2}$ is the time at which the deformation is maximum and $\mathbf{t_3}$ is the time at which the electric current is interrupted.

Below this diagram, the user can observe the evolution of the activation electric current (*LEM SMA Strip Current\A*, in amperes; position 4 in Fig. 7).

It is also possible to observe the evolution of the voltage at the terminals of the SMA strip (*LEM SMA Strip Voltage\V*, in volts; position 3).

Knowing the current through and the voltage at strip terminals, our virtual instrument calculates the SMA strip resistance. The evolution of resistance over time is shown in *SMA Strip Resistance\ Ohm* diagram (position 5).

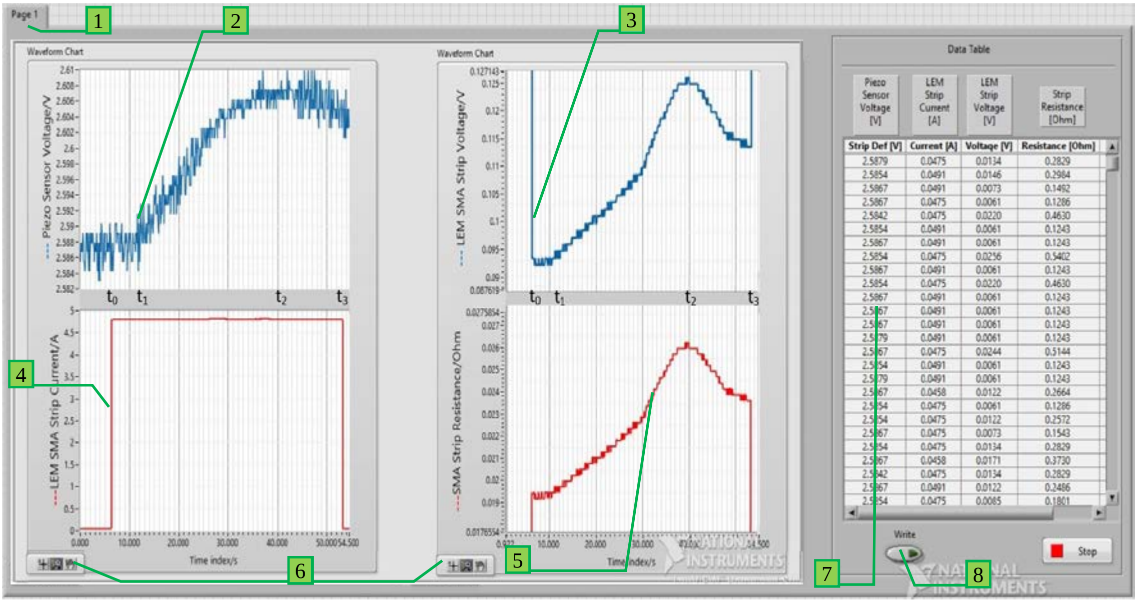


Fig. 7. Front Panel of virtual instrument (VI)

We can customize the appearance of a chart with the shortcut menu options. This allows a cursor to be displayed at a defined point coordinate. The *Graph Palette* (position 6) allows to move the cursor, zoom and pan the chart while VI runs.

The table with four visible columns (position 7 in Fig. 7) contains all the numerical values for the acquired and processed data. The number of rows might change with the vertical scroll bar. All data can be saved for further processing (*Write* control, position 8).

B. *The Block Diagram of virtual instrument*

*Block Diagra*m is the source code of the virtual instrument. Presentation of the Block Diagram is useful for understanding the operation of the virtual instrument because LabVIEW uses data flow programming and the data flow determines the order of execution.

As shown in Fig. 8, this is a *Flat Sequence Structure* with three sub diagrams that execute sequentially: initialize; acquire and process data; close. The last sub diagram reset all the I/O channels of NI myRIO device.

All the objects include terminals of indicator and control, subVIs, functions, constants, structures and wires are included in a *Timed Structures* (type *Timed Loop*); it executes a sub diagram sequentially, each iteration (**i**) of the loop at the specified period.

Using the 1 MHz clock, timed structure can execute an iteration once every 1 microsecond. *Period* (**dt**) is 100 microseconds and specifies the amount of time that elapses between two subsequent iterations of the *Timed Loop*.

Analog Input Express VI are used for reads values from one or more analog input channels. These *Express VIs* allow the configuration of analog input ports and read a sample each time with the default FPGA personality.

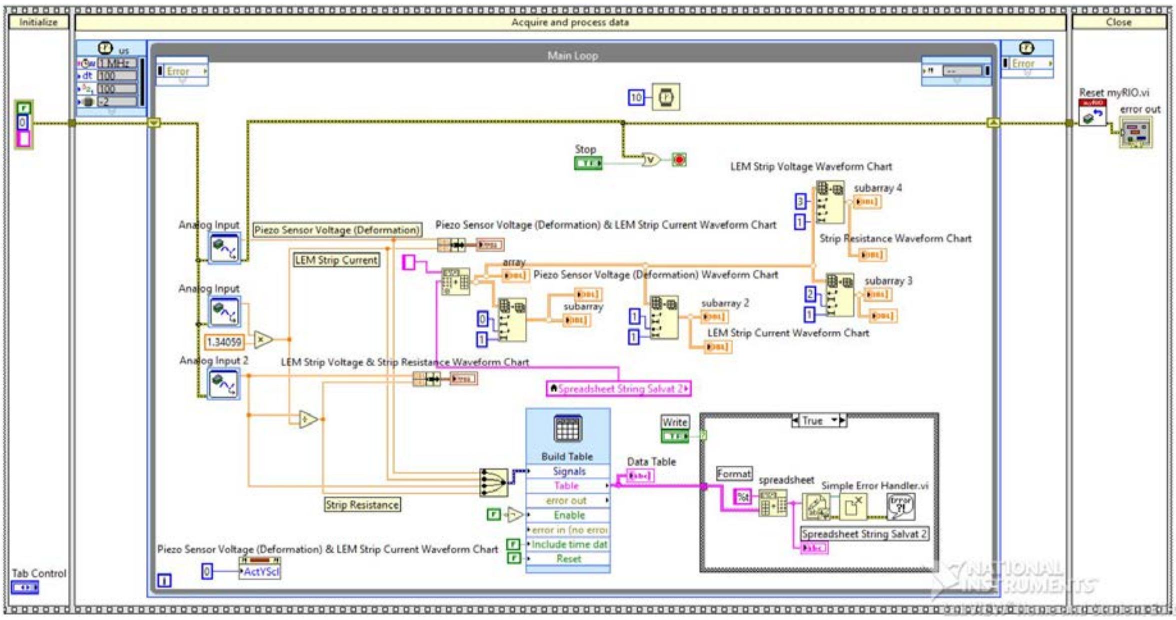
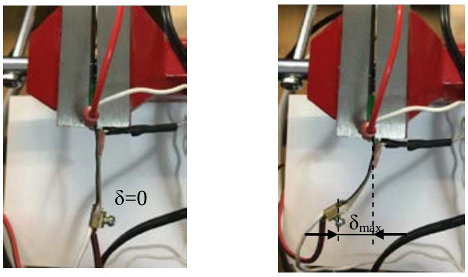


Fig. 8. Block Diagram of virtual instrument (VI)

IV. Experimental Results and Perspectives

Fig. 9 shows the tested cantilever SMA strip during the experiments; on the left - undeformed position (δ=0, when the activation current is zero) and on the right – maximal deformation position δ_{max}.



a) b)

Fig. 9. Close-up image of the tested SMA cantilever: a) in the position without deformation; b) in the maximal deformation position

The following table show the experimental values for tested SMA strip, at different values of activation electrical current (3.6 A to 4.8 A).

TABLE I.
The Experimental Values for Study of SMA Strip

Current [A]	t_0 [s]	t_1 [s]	t_2 [s]	t_3 [s]	V_1[V]	V_2[V]	R_1[Ω]	R_2[Ω]
4.8	6.16	8.35	40	53.11	2.58	2.6	0.0194	0.026
4.4	5.12	7.61	39.43	43.64	2.6	2.62	0.0246	0.0316
4.0	3.87	6.98	40.45	57.73	2.61	2.62	0.0255	0.0311
3.6	5.50	8.98	44.21	62.36	2.6	2.62	0.0289	0.0315

Data obtained and the connection with the phenomena that occur during the heating of the SMA band to the maximum deformation were analyzed in detail in [9]; the present paper focusing on the practical realization and use of the virtual measurement system.

The tested NiTi SMA strip can be used as an actuator to develop protection applications where very short activation times are required (i.e., vibration control, shape control, position control in automotive industries and fire protection).

In the future, using the advantages of virtual instrumentation (flexibility and minimizing set-up time costs) we will increase the analysis capability and the functionality of present system for testing and controlling of a cantilever SMA strip. Thus, sensors can be added to measure the temperature or elements to trigger an action when a certain threshold is reached.

V. Conclusions

The evolution of the electrical resistance and bending performance corresponding to the cantilever SMA strip was determined using virtual instrumentation.

The results of real-time measurements and acquired waveforms are displayed on a PC screen, and the data associated with these waveforms are stored on memory for later use.

Thus, the advantages offered by the virtual instrumentation were highlighted.

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First author – 60%
Co-author – 40%

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