# Analysis and Modeling of a Platform with Cantilever Beam using SMA Actuator

## *Experimental Tests based on Computer Supported Education*

Leandro Maciel Rodrigues[1], Thamiles Rodrigues de Melo[1], Jaidilson Jó da Silva[2], Angelo Perkusich[2] and José Sérgio da Rocha Neto[2]

[1]*Post-Graduate in Electrical Engineering - PPgEE – COPELE, Campina Grande-PB, Brazil*

[2]*Electrical Engineering Department (DEE), Federal University of Campina Grande, Aprígio Veloso Street, 882, Campina Grande-PB, Brazil*

Keywords: Modeling, Platform with Cantilever Beam, Shape Memory Alloy, Computer Supported Education.

Abstract: This paper presents a test platform with cantilever beam that uses a SMA (Shape Memory Alloy) as actuator and strain gauges as sensors to study of the beam deformation. From the data acquired by means of heating and cooling processes, the engineering students can observe the hysteresis behavior of the SMA wire. Besides, the study of this platform provide to the students can put in practice their knowledge about data acquisition, system identification, modeling and programming based on computer supported education.

## 1 INTRODUCTION

Mechanical systems, such as industrial machinery, civil construction and transport vehicles are often subject to internal and external excitations, which result in undesirable vibrations, disturbing operators and in some cases, putting at risk the structural integrity of the system. This phenomenon has mobilized a significant number of researchers and there are numerous specialized publications in this area (Li *et al*, 2014).

The vibration control of flexible structures has been the subject of studies by many researchers. According to these studies, the integrated use of sensors, actuators and controllers would enable a system to respond in a controlled manner to external excitations, looking for the effects that would lead the response amplitude levels to deviate from acceptable levels (Schmidt, 2014).

Shape Memory Alloys (SMA) have been considered as one of the most interesting smart material systems, and they have great potential for applications in modern active structures, mainly as electrical or thermal actuators. Previously, strained SMA actuators recover their original shape when heated above a critical temperature. In the case of SMA actuators type wire under uniaxial tensile mechanical load, this shape recovery corresponds to a contraction, and the actuator provides useful external mechanical work (Nascimento *et al*, 2008).

Due to this phenomenon, the SMA can be used as sensors and/or actuators in aerospace, oil and automotive industries, in orthodontic, orthopedic and robotic applications, or vibration and shape control. When used as thermomechanical actuators, in which heating is performed by Joule effect resulting from the application of a certain intensity of current, SMA become an attractive alternative due to its large deformation and good recovery in systems where great strengths, large deformation and low frequencies are required (Lima *et al*, 2010), (Suzuki and Kagawa, 2010).

Modeling is the process of obtaining equations or graphs to represent, as closely as possible the characteristics or behavior of a real system. The importance of modeling real systems is evidence when the results can be used to provide a better understanding of the system (Ljung, 1999).

System identification is an alternative procedure that aims to build a model to explain, at least in part and approximately, the relationship of cause and effect present in a database without the need for prior knowledge of the physics of the process (Ljung, 1999).

In this context, this work presents an experimental methodology for engineering students perform the modeling of a test platform with



Rodrigues L., Rodrigues de Melo T., Jó da Silva J., Perkusich A. and da Rocha Neto J..
Analysis and Modeling of a Platform with Cantilever Beam using SMA Actuator - Experimental Tests based on Computer Supported Education.
DOI: 10.5220/0005443902380243
In *Proceedings of the 7th International Conference on Computer Supported Education* (CSEDU-2015), pages 238-243
ISBN: 978-989-758-108-3

cantilever beam dedicated to the deformation study. From the data acquired, the students can obtain a relationship between the voltage applied in the SMA actuator type wire (which provocate deformation on the beam) and the deformation measured by a strain gauge sensor on the platform. Besides, the students can observe the hysteresis behavior of the SMA wire.

Using the MATLAB tool for system identification, the students can generate mathematical models for the test platform and posteriorly, to implement a control strategy to control the beam deformation.

# 2 MATERIALS AND METHODS

## 2.1 Test Platform

The measuring system implemented for study of the platform with cantilever beam is constituted by: the physical structure of the test platform; two strain gauge sensors; a SMA wire; a set of connector blocks to make the connection between a PC and the platform; and an Human Machine Interface (HMI), developed in LabVIEW software, for monitoring of the beam deformation and sending commands to the SMA actuator.

The complete measuring system can be seen in Figure 1.

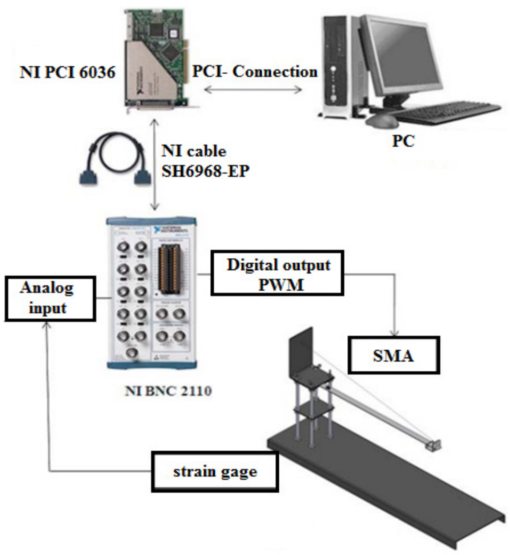
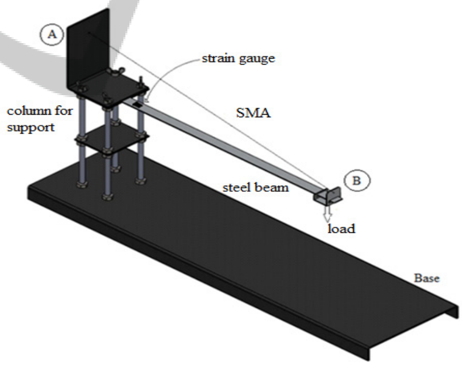



Figure 1: Scheme of the measuring system implemeted for data acquisition and acting of the SMA actuator.

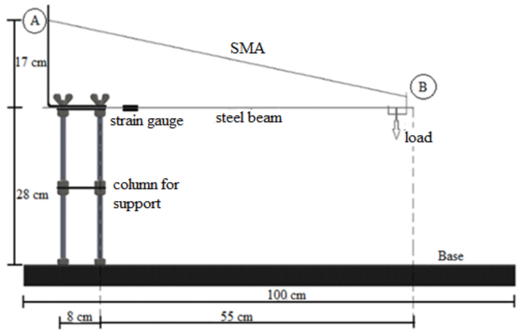
The physical structure of the test platform shown in Figure 2 is composed by three parts:

- Base: A flat rectangular base, made of iron, and with dimensions: 100 cm x 25.7 cm x 3.5 cm (L x W x H);
- Support Column: A column built on the base, consisting of four screws 28 cm long and 1 cm in diameter, arranged in a spaced manner to form a rectangle; two rectangular fastening plates measuring 10 cm x 12 cm; and a third plate of 22 cm, positioned vertically for attachment of the SMA wire (detail A of Figure 2);
- Beam: A steel beam 55 cm long, 2.6 cm wide and 2 mm thickness. One of the ends of the beam is clamped to the support column by means of two clamping plates and the other end is free, but connected to the actuator of SMA through a small metal piece (detail B of Figure 2).

The strain gauges sensors are glued on the top and bottom faces of the beam, in order to obtain data on the deformation of the beam. The SMA actuator type wire can pull the beam or release it. At the ends of the SMA wire, the electrical terminals are connected, which provide the electrical signal activation, making electric current pass through the wire and by Joule effect making it to contract more or less depending on the current intensity.




(a) Isometric view.




(b) Side view

Figure 2: The physical structure of the test platform: Isometric (a) and Side (b) view of the platform.

The sensors and the SMA actuator are connected to the PC via a BNC connector block manufactured by National Instruments, named as NI BNC 2110 model. This connector is linked to the PC via an internal PCI card model, named as NI PCI 6036-E (NATIONAL INSTRUMENTS, 2010).

From the PC, the informations about the test platform can be seen by means of the HMI implemented via LabVIEW software, as observed in Figure 3. On the HMI, the engineering students can view in the graphical boxes the deformation of the beam in $\mu m/mm$ (micrometer per milimeter) and a sample of the RMS voltage that is applied on the SMA. The signal that is sent to the SMA is a PWM (Pulse Width Modulation), in which the students can choose the frequency and the duty cycle of the PWM.

After being performed the test, the data collected during the experiment can be stored for later viewing. This is done using a LabVIEW tool that allows integration of this software with MATLAB. The block in LabVIEW that makes the interaction with the MATLAB is the "MATLAB Script". When the student stops the test pressing the STOP button in the software interface, then the data is sent to MATLAB and stored in variables.

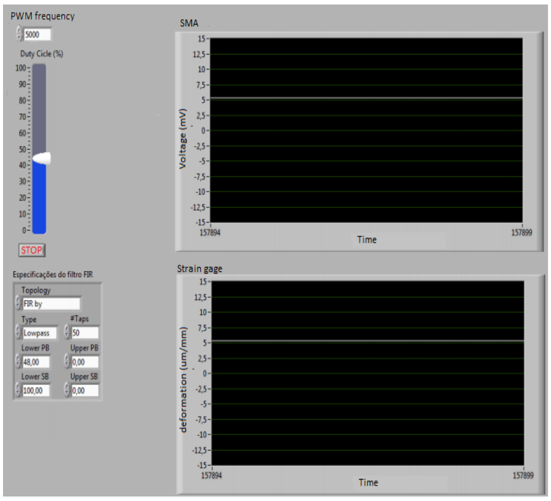



Figure 3: The screen of the HMI implemented in LabVIEW software for monitoring of the beam deformation.

## 2.2 Experimental Methodology

To observe the hysteresis behavior of the SMA wire in study, it is necessary to plot the heating and cooling curves of this actuator. These curves can be obtained by means of the relationship between the voltage applied on the SMA (a sample of the RMS voltage) and the deformation suffered by the beam when the SMA is heated or cooled.

Hence, a set of measurements are realized and a statistical treatment is made, in order to calculate the arithmetical average and the standard deviation and then to verify a confidence interval.

The heating curve is generated applying on the SMA a PWM signal with 1 kHz of frequency and 10% of duty cycle, and after 25 seconds, the duty cycle is increased in 10%. This action is repeated until it reaches a duty cycle of 100%. The same process is made to obtain the cooling curve, but with decreasing duty cycle of 10% until it reaches 10% of duty cycle.

## 2.3 Mathematical Models

Due to the actuator has different behaviors when occour the heating and cooling processes, then it is interesting that students obtained different models for each process.

To identify and generate a model for the test platform, the engineering students use a MATLAB tool called *ident*, as shown in Figure 4. From the data obtained in the tests, models of different orders are generated by clicking in "Estimate -> *Process models*" in the window.

Using the *ident*, the students can also to validate the models, to compare the output model generated and the output measured, and to qualify with an index how they fit.

Thus, the validation of the models are done by means of a set of measurements does not used for modeling. These measures are imported in the "Validation Data" box, also present in the window.

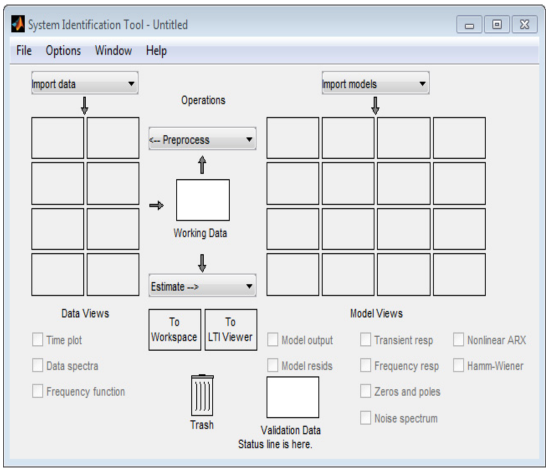



Figure 4: Interface of the System Identification toolbox (*ident*) of the MATLAB.

Two models are used for modeling of the platform with cantilever beam: First Order with Dead Time (FOPDT) model and Second Order with Dead Time (SOPDT) model, which are shown in Equation (1) and (2), respectively:

$$G(s) = \frac{K}{\tau_p s + 1} e^{-s\tau_d} \quad (1)$$

where: $G(s)$ is the transfer function of the system in study, $K$ the steady-state gain, $\tau_d$ the transport delay and $\tau_p$ the time constant.

$$G(s) = \frac{K}{(\tau_{p1} s + 1)(\tau_{p2} s + 1)} e^{-s\tau_d} \quad (2)$$

where: $\tau_{p1}$ is the first time constant and $\tau_{p2}$ is the second time constant of the system in study.

# 3 RESULTS

## 3.1 Hysteresis Behavior

After to acquire the measurements, the engineering students realized the statistical analysis, in which calculated the arithmetical average and the standard deviation of the data.

In Table 1 is shown the relationship between a set of the RMS voltage measured in the SMA and the deformation of the beam measured with the strain gauges sensors, when the SMA is heated.

Table 1: Average values and standard deviation when SMA is heated.

| Voltage (V) | Deformation ($\mu m/mm$) | Standard deviation |
|---|---|---|
| 0.38 | 2.87 | 0.21 |
| 0.62 | 5.60 | 0.59 |
| 0.88 | 8.50 | 0.27 |
| 1.12 | 11.65 | 0.31 |
| 1.36 | 18.27 | 0.18 |
| 1.60 | 45.43 | 0.31 |
| 1.84 | 68.14 | 0.54 |
| 2.08 | 87.18 | 0.90 |
| 2.32 | 97.02 | 0.36 |
| 2.44 | 101.78 | 0.68 |

In Table 2 is shown the relationship between a set of the RMS voltage measured in the SMA and the deformation of the beam measured with the strain gauges sensors, when the SMA is cooled.

From the data of Voltage and Deformation presented both the tables, the students can plotted the heating and cooling curves and consequently, can observed the hysteresis behavior of SMA actuator, as shown in Figure 5. The solid line represents the heating process and the dotted line represents the cooling process.

Table 2: Average values and standard deviation when SMA is cooled.

| Voltage | Deformation ($\mu m/mm$) | Standard deviation |
|---|---|---|
| 2.44 | 101.78 | 0.68 |
| 2.21 | 96.77 | 0.75 |
| 1.97 | 88.27 | 0.21 |
| 1.72 | 78.54 | 0.75 |
| 1.48 | 62.47 | 0.75 |
| 1.23 | 43.61 | 0.68 |
| 0.99 | 22.29 | 0.95 |
| 0.75 | 9.76 | 0.21 |
| 0.50 | 5.28 | 0.61 |
| 0.26 | 1.85 | 0.36 |

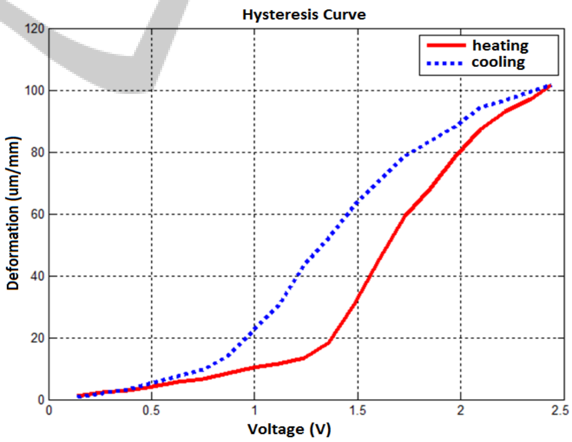



Figure 5: Graphic of hysteresis of the SMA actuator obtained by engineering students from the experimental methodology adopted.

## 3.2 Modeling and Validation

Using as input the data of a set of the RMS voltage measured in the SMA and as output the data of the deformation of the beam measured with the strain gauge, were generated FOPDT and SOPDT models in MATLAB tool for heating and cooling of the SMA wire.

In Equations (3) and (4) are presented the FOPDT and SOPDT models, respectively, obtained by students for heating process:

$$G(s) = \frac{41.68e^{-0.2s}}{2.63s + 1} \quad (3)$$

$$G(s) = \frac{36.85e^{-0.2s}}{(1.78s + 1)(1.49s + 1)} \quad (4)$$

The FOPDT model curve obtained for heating process can be seen in the Figure 6. The model fits the output measured 86.43%.

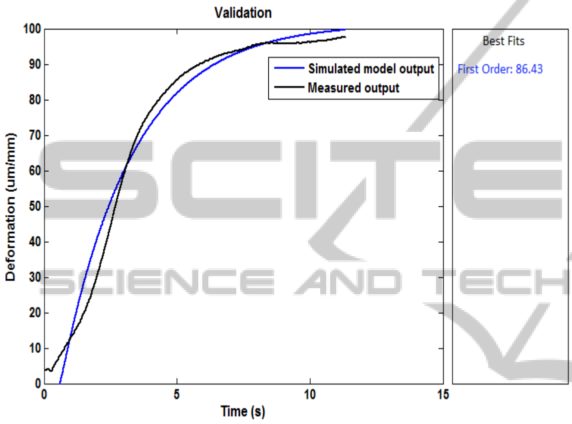



Figure 6: Validation FOPDT model curve obtained for heating process.

The SOPDT model curve obtained for heating process can be seen in the Figure 7. The model fits the output measured 74.42%

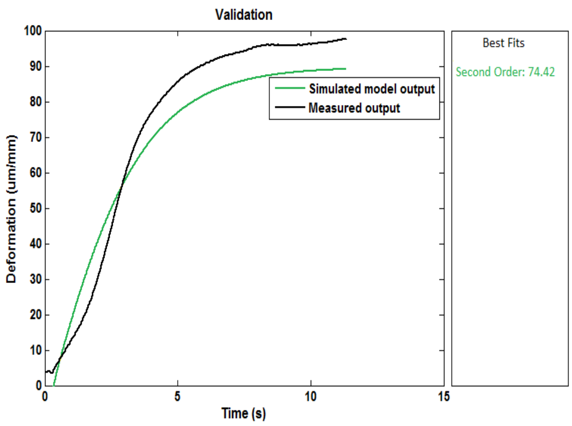



Figure 7: Validation SOPDT model curve obtained for heating process.

Similarly, in Equations (5) and (6) are presented the FOPDT and SOPDT models, respectively, obtained by students for cooling process:

$$G(s) = \frac{41.05e^{-0.1s}}{0.98s + 1} \quad (5)$$

$$G(s)\frac{38.22e^{-0.1s}}{(0.89s + 1)(0.13s + 1)} \quad (6)$$

The FOPDT model curve obtained for cooling can be seen in the Figure 8. The model fits the output measured 95.35%.

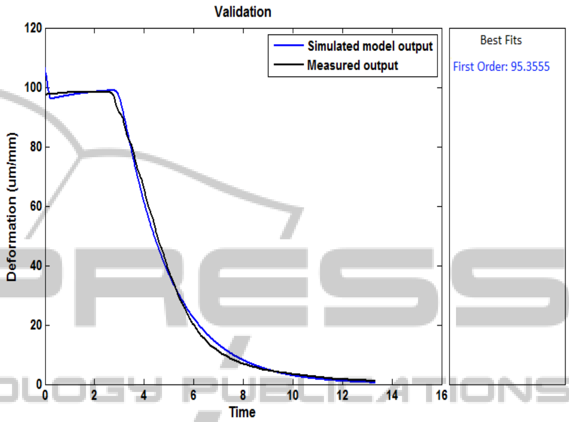



Figure 8: Validation FOPDT model curve obtained for cooling process.

The SOPDT model curve obtained for cooling process can be seen in the Figure 8. The model fits the output measured 96.45%.

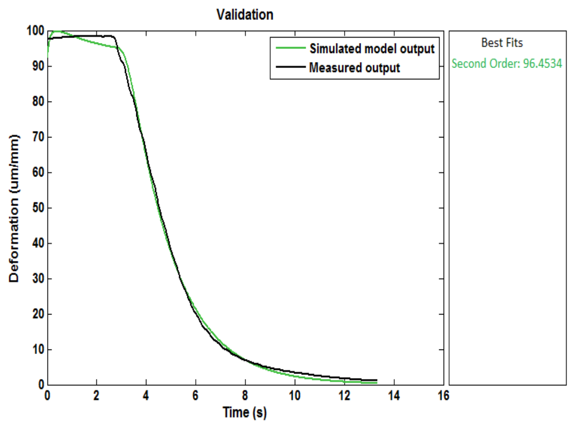



Figure 9: Validation SOPDT model curve obtained for cooling process.

The four models generated for the test platform fits with the output measured more than 74% based on *ident* index.

Comparing the two models obtained for heating process based on *ident* index, the students considered the FOPDT model a better model than a SOPDT model.

Likewise, comparing the two models obtained for cooling process, the students consider both types of models as good, because the FOPDT and SOPDT models have almost the same value of index.

# 4 CONCLUSIONS

In this work, it was presented an experimental methodology for engineering students performed the modeling of a test platform with cantilever beam that uses a SMA wire as actuator. By means of the MATLAB tool for system identification, the students could obtain the mathematical models and to make the validation of them.

Furthermore, the students observed that the hysteresis behavior of the SMA wire is associated to the beam deformation, verifing the importance of generating different models for heating process (by Joule effect, increasing the current in the SMA) and cooling process (decreasing the current in the SMA) of the actuator.

From the FOPDT and SOPDT models, the students can implement a control strategy, for example using a PID control, to control the beam deformation, in order to reduce or eliminate disturbances, such as vibrations, on the physical structure of the test platform.

Other possibility was the students used the data acquired and the models obtained for developing of a soft sensor, i.e., in case of fail of the real sensor, the measures can be estimated by means of data stored on the PC.

Therefore, the study of the platform with cantilever beam provide to the engineering students a way for putting in practice its knowledge about system identification and modeling, data acquisition and programming based on computer supported education.

# ACKNOWLEDGEMENTS

The authors would like to thank CAPES and PPgEE-COPELE for financial support.

# REFERENCES

Li, S., Li, J., Mo, Y., 2014. Piezoelectric Multimode Vibration Control for Stiffened Plate Using ADRC-Based Acceleration Compensation. *IEEE Transactions on Industrial Electronics*; 61(12):6892-6902.

Lima W. M., Araujo, C. J., Valenzuela, W. A. V, Rocha Neto, J. S., 2010. Deformation Control of a Flexible Beam under Low Frequency Loading using Ni-Ti-Cu SMA Wire Actuator. *ABCM Symposium Series in Mechatronics* - Vol. 4 - pp.110-119.

Ljung, L., 1999. *System Identification: Theory for the User*. Prentice Hall, 2nd Edition.

Nascimento, M. M. S. F., Araújo, C. J., Almeida L. A. L., Rocha Neto, J. S., Lima, A. M. N., 2008. A Mathematical Model for the Strain–Temperature Hysteresis of Shape Memory Alloy Actuators. *In Materials and Design, vol. 30, pp. 551-556*.

NATIONAL INSTRUMENTS, 2010. MultiFunction DAQ Accessories Datasheet.

Schmidt, R., 2014. Smart Structures - Modelling and Simulation. *11th World Congress on Computational Mechanics* (WCCM2014). July 20 - 25, Barcelona, Spain.

Suzuki, Y., Kagawa, Y., 2010. Active Vibration Control of a Flexible Cantilever Beam Using Shape Memory Alloy Actuators. *Smart Materials and Structures*.