NUMERICAL ANALYSIS AND EXPERIMENTAL STUDY BY MICRO LASER DOPPLER VIBROMETER FOR THE DYNAMIC CHARACTERIZATION OF RF MEMS SWITCHES

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Abstract.

In this paper is demonstrated a coupled numerical and experimental approach to analyze the mechanical behaviour of series resistive RF M.E.M.Switches. The switch consists in a thin gold-chromium membrane suspended on both an interrupted RF line and a pad. In the narrow central part two wings realize the contact with the dimples placed at the end of the underpass line when a difference of potential is applied between the pad and the bridge, generating an electrostatic force that pulls down the structure. At present the reliability issues, represent the principal obstacle for a complete exploitation of these devices. Laser Doppler Vibrometry (LDV) is a non contact sensor that can be used to measure velocity and displacement of micro-devices to study their dynamic in order to understand and improve their behaviour. In this work the suitability of the vibrometer for measuring the velocity and the displacement in the microscale will be demonstrated by applying the developed system to RF MEMS switches designed and produced by the Microsystems division of the Istituto Trentino di Cultura (ITC-IRST Trento). Moreover it will be shown how to use the data acquired by the measurement system to validate numerical model of the same samples.

***Keywords**: MEMS, RF SWITCHES, VIBROMETRY, FINITE ELEMENT ANALYSIS*

1. Introduction

Micro-Electro-Mechanical Systems (MEMS) are miniaturized devices combining together electrical and mechanical functionalities. This aspect can be efficiently exploited in the area of microwave and millimetre wave systems in which MEMS technology promoted the development of new interesting devices. In fact, the increasing request of miniaturized efficient devices for the wireless communication market, is possible only by developing radio frequency MEMS, that for their small dimensions and weight, lower recurring cost, and high performances are of interest also for satellite configurations.

In this scenario the European Space Agency (ESA) and Alenia Spazio are following with high interest the development of the Micro-electromechanical technology for future on-board satellite applications. The leading idea would be to reach the development and realization of micro-satellites (µ-Sats) that would have considerable advantages compared to those currently used (Macro-Sats); in first place they would be smaller different orders of size, among the smallest currently in commerce; besides they could be produced with lower costs compared to a single conventional satellite, as well as the expenses of putting into orbit would be reduced.

On this matter the ESA, Alenia Spazio and ITC-irst Trento, are carrying out a project for the study, the development and the planning of RF Micro Electro Mechanical Switch (MEM Switch) for satellite application.

Nevertheless, the spread of this kind micro-electro mechanical systems is strictly related to the development of manufacturing technologies and to the implementation of numerical and experimental analysis and diagnostic technique that allow us to increase performance and reliability.

In this paper it will be demonstrated the application of a customized laser Doppler Vibrometer which has been designed and developed for measuring in the microscale[3], for studying the dynamic behaviour of RF MEMS switches and to validate the numerical analysis done by finite element methods[14,15]. The Laser Doppler Vibrometry[4,12] is a valuable technique for measurement in the microscale thanks to his non-contact nature and to the possibility to focus the laser beam into a micron size spot that can be positioned in every point on the object surface[1,2]. By using such a system it is possible to measure the vibration time response and the frequency content of micro systems.

2. RF MEMS switches

The RF MEMS switches are micro-electro-mechanical circuits that have a membrane or a thin cantilever suspended over an electrode. They represent an interesting field among MEMS devices thanks to their high switching capabilities in a large frequency band (DC-120GHz). The other main advantages of these devices are the high insulation, the low power consumption, and a very simple power supply circuit.

They are used mostly in the wireless communication industry (wireless handsets, wireless LANs, broadband wireless access and wireless data link) and global positioning systems.

The actuation force can be electrostatic, magnetostatic, piezoelectric or thermal. When a voltage is applied between the membrane or the cantilever and the electrode the electrostatic force push the membrane creating a contact with the electrode allowing the signal transmission.

The switches that have been studied in this work are electrostatic and have a very low switching time (2-30μs).

The RF switches can be classified depending on:

1. RF circuit configuration;
2. Mechanical structure;
3. Type of contact

The most common circuital configuration are the SPST (single pole-single throw) connected in series or in parallel.

Regarding the mechanical structures, the most used are the cantilever and the air bridge.

The type of contacts that usually are implemented are the capacitive one (metal-insulating material-metal) and the resistive (metal-metal).

In this work an array of three electrostatic resistive RF switches was examined (Figure 1). The difference with the capacitive type is that in this case the switch off condition is when the membrane is suspended over the electrode and the switch on (signal transmission) is when the membrane is in contact with the electrode.

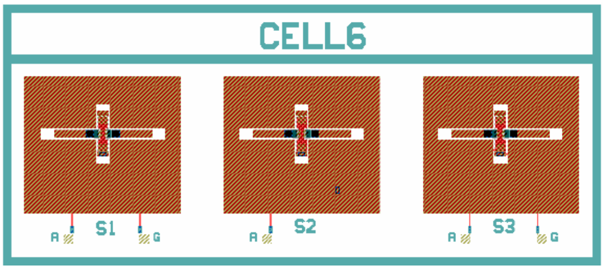

Figure 1: array of resistive RF switches

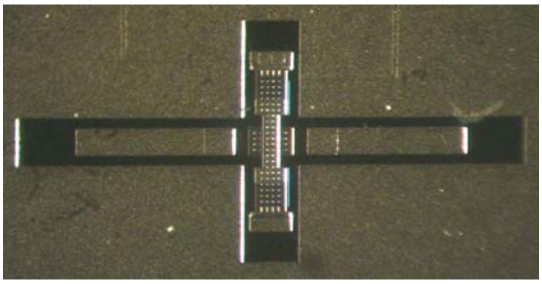

Figure 2: resistive RF switch

3. Measurement system

The system is based on a commercial Laser Doppler vibrometer, in which the optical setup, the mechanical arrangement and the processing software and hardware were modified and developed to measure vibrations with a resolution in the micro scale.

The main characteristics of the developed system is a very versatile platform, in which laser Doppler Vibrometry, two-axis stages micropositioner, digital signal processing and image acquisition and processing can work together (Figure 3)

An important element of our system is the post-processing software that was developed in LabVIEW environment and allows to automatically manage the Q factor calculation[10].

It integrates signal processing capability, such as the signal demodulation, giving an important contribution to the system performances.

The main characteristics required were the ability to integrate the control of each component (stages, cameras, laser etc) and to make easier and automatic the measurement procedure.

In particular it had to meet the following requirements:

- to manage the images acquisition
- to make possible to build the measurement grid
- to manage the excitation system
- to manage the acquisition parameters
- to manage the data post-processing
- to manage the measurement procedures:
    - vibrational analysis
    - automatic Q factor calculation

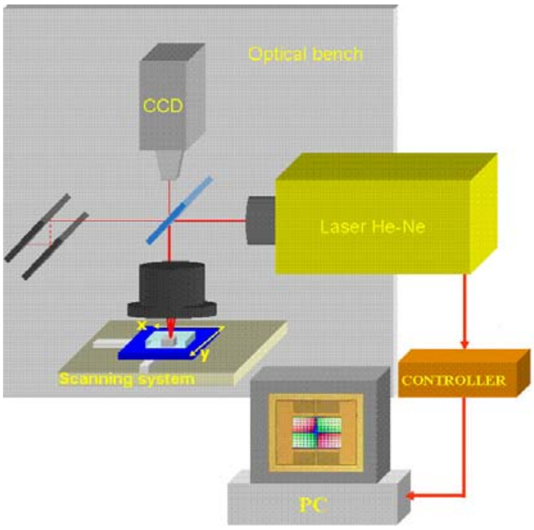

Figure 3: scheme of the measurement system

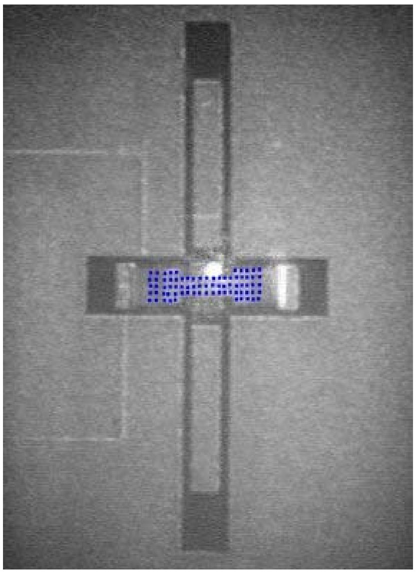

Figure 4: measurement grid

4. Vibrational analysis

In this work a resistive RF micro-switch designed and fabricated by the laboratories of IRST in Trento was measured by means of laser Doppler vibrometry based technique[9,13]. The aim of these measurements was to characterize from a mechanical point of view the dynamic of the device in terms of vibrational velocity and displacement.

The dynamic behaviour of the switch was monitored by varying the amplitude and the offset of the actuation signal. The sampling frequency used to acquire the time histories in all the test was 500 MHz.

The measurement point was in a central part of the bridge as shown in figure 5

Figure 5: measurement point

The measurement were performed by applying a square wave signal with a constant off-set of 20V and by varying the amplitude with a 5 V step increment until the signal reached the value of 87 V. As, is it possible to notice from figure 6 the bridge is lowered towards the electrode until the actuation voltage reaches the value of 40 V. As it possible to notice from figure 6, by further increasing the voltage the bridge shows a peculiar behaviour: the displacement goes in the opposite direction. In figure 7 the bridge displacement versus the applied voltage is shown.

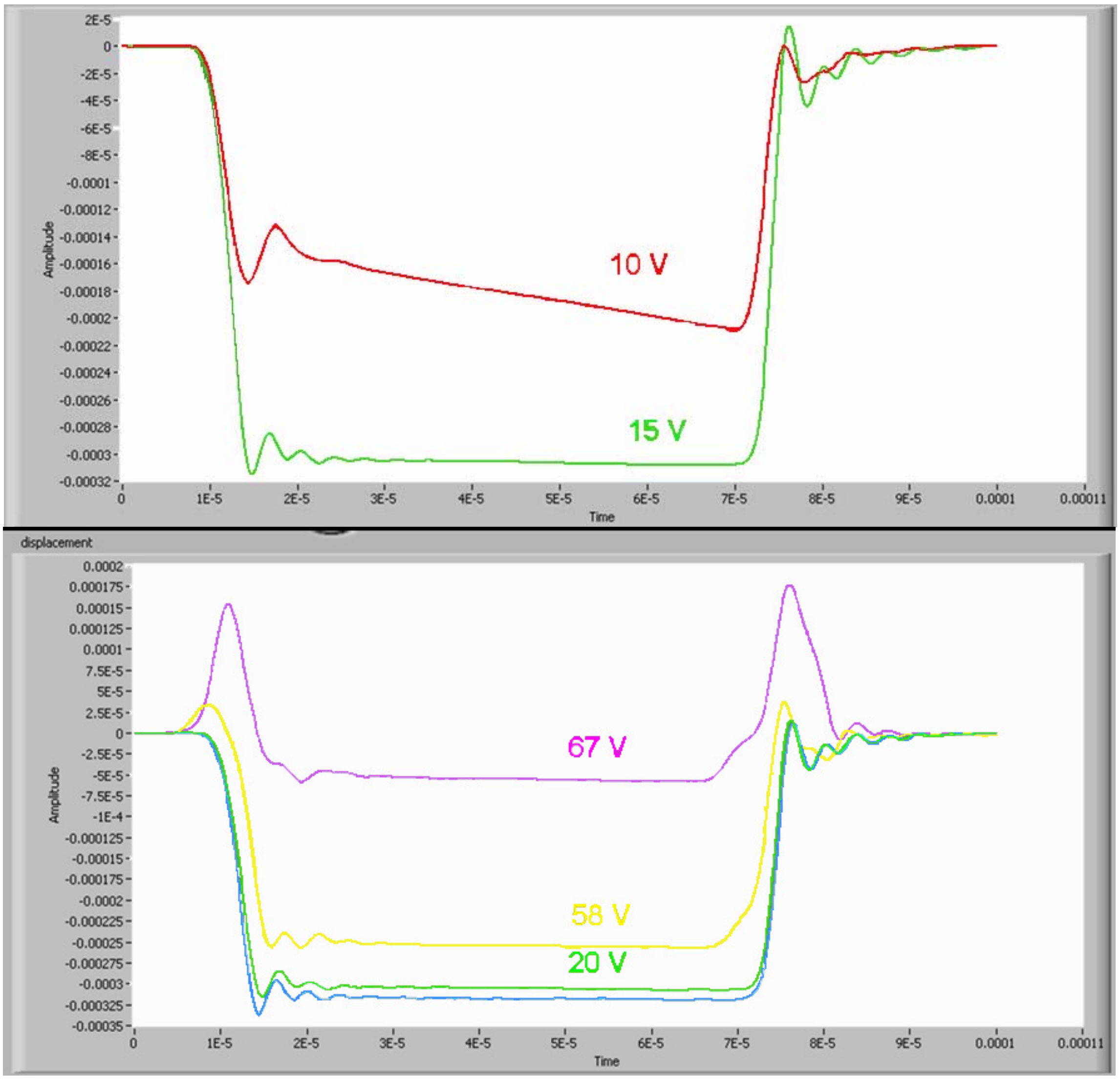

Figure 6: displacement of the centre of the bridge

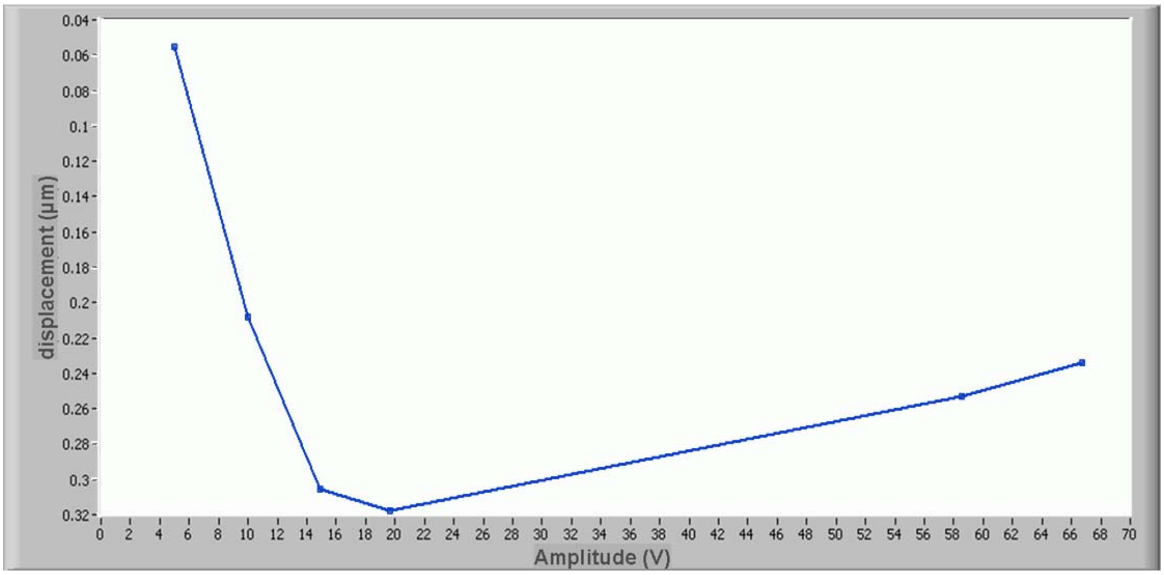

Figure 7: bridge displacement versus applied voltage (20 V off-set)

This behaviour is due to the design of this set of RF switches prototypes, as it is shown in the schemes of the following figures. In order to ensure the actuation of the bridge, the designer tried a configuration characterized by a higher actuation electrode (distance between the bridge and the electrode surface: d). In this way, by applying a voltage smaller than the usual value needed to actuate the bridge (around 60 V), was possible to realize the contact between the bridge and the electrode (figure 8b). By increasing the voltage beyond this value the bridge was subjected to the deformation schematized in figure 8c. Since the laser beam was measuring the centre of the bridge, this explains the course of the displacement as shown in figures 6 and 7.

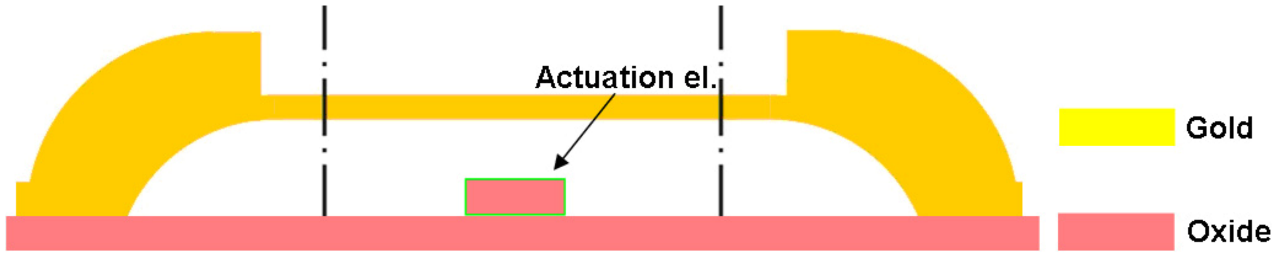

Figure 8a: bridge with no voltage application

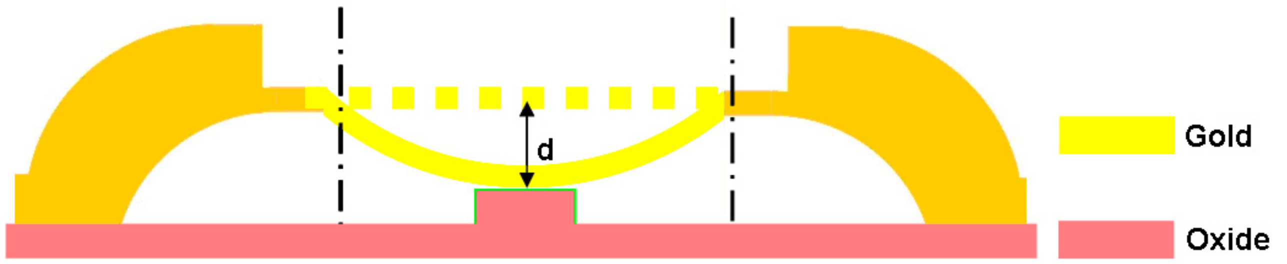

Figure 8b: bridge with an applied voltage smaller than 40 V

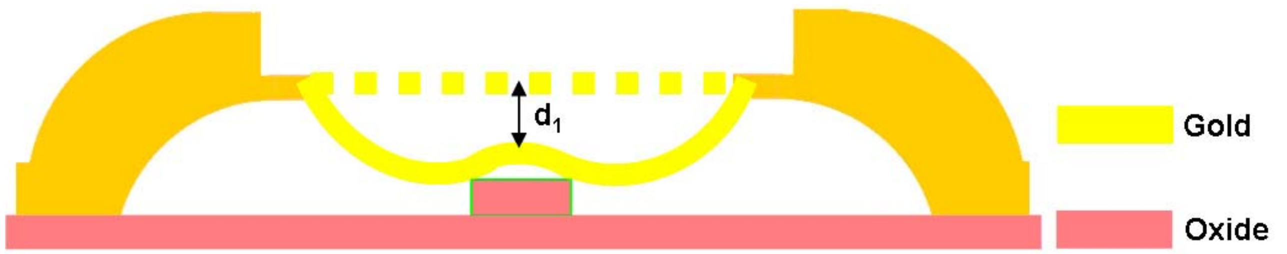

Figure 8c: bridge with an applied voltage greater than 40 V

Figure 9 shows the velocity measured in the centre of the bridge; it is possible to notice that the curve is not symmetrical, in fact, in the release phase the velocity reaches a higher value. This behaviour can be explained by the fact that the elastic force is greater than the electrostatic one so that when the voltage is removed the bridge is attracted to the initial position with a higher velocity.

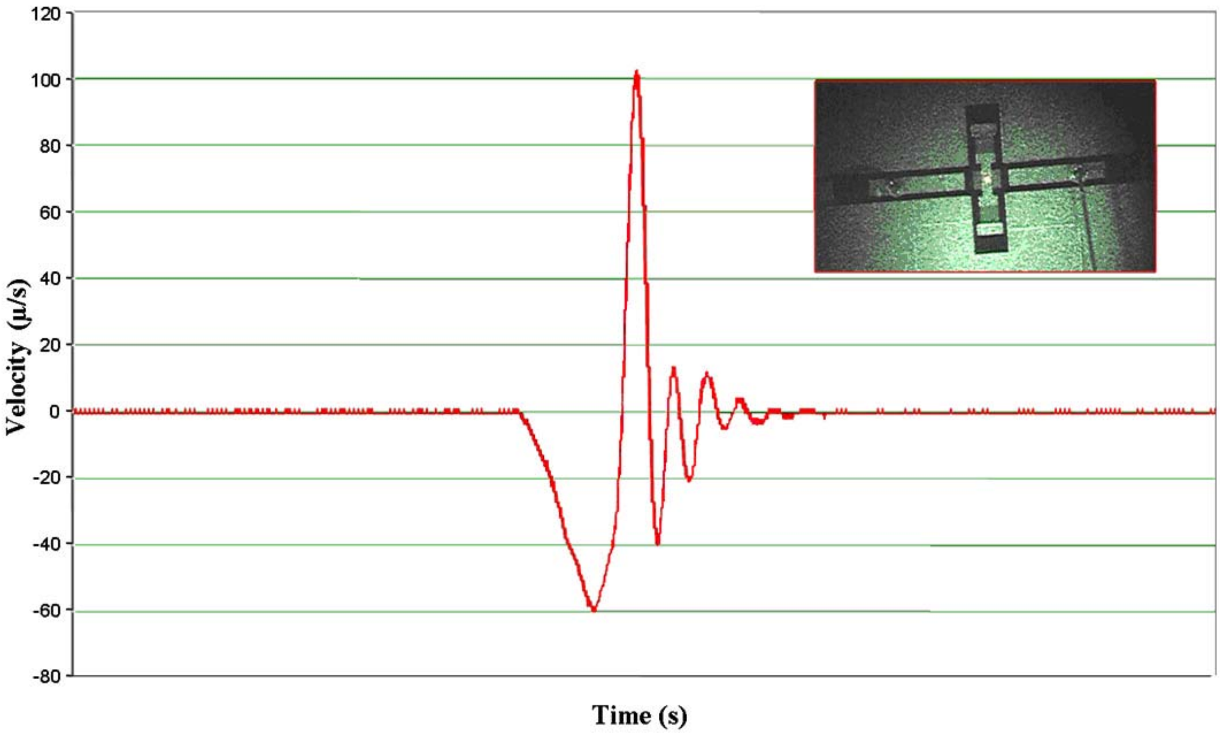

Figure 9: velocity measured by SLDV in the centre of the bridge

5. LDV to validate the results of the numerical analysis

A numerical model was realized in order to characterize the switches from an electromechanical point of view[6,7,8,11]. The dimensions of the device were measured by scanning electron microscopy and the material properties were given from the designer of the MEMS at IRST.

The displacement time histories were calculated in seven different point of the switch, as shown in figure 10.

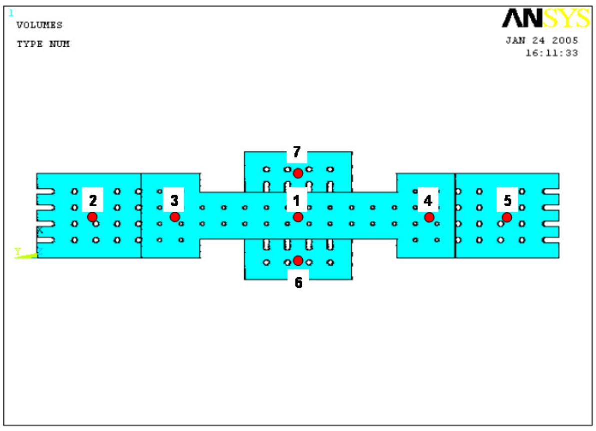

Figure 10: ANSYS model

Here is reported only the result related to the central point of the bridge that was used for the comparison with the experimental results.

In figure 11 the data obtained by the numerical and experimental analysis are showed; the difference between the two curve can be due to different reasons:

- during the electro-deposition phase of gold and chromium that will constitute the bridge, the gap is realized by using a photoresist. The problem is related to the fact that the planarity of this layer is dependent from the topography of the underlying surface. This induce the increasing of the thickness in the central part of the bridge that has been quantified from designer of ITC-IRST in 0.4±0.1μm;
- a time delay due to the time necessary to charge the capacitor;
- a residual deformation that was not taken into account in the numerical model;
- the difference of the real value of the material properties (Young modulus, Poisson coefficient) from the ones used in the model.

The average difference between the two curve is of about 9% and this result can be improved by taking into account the above mentioned reasons.

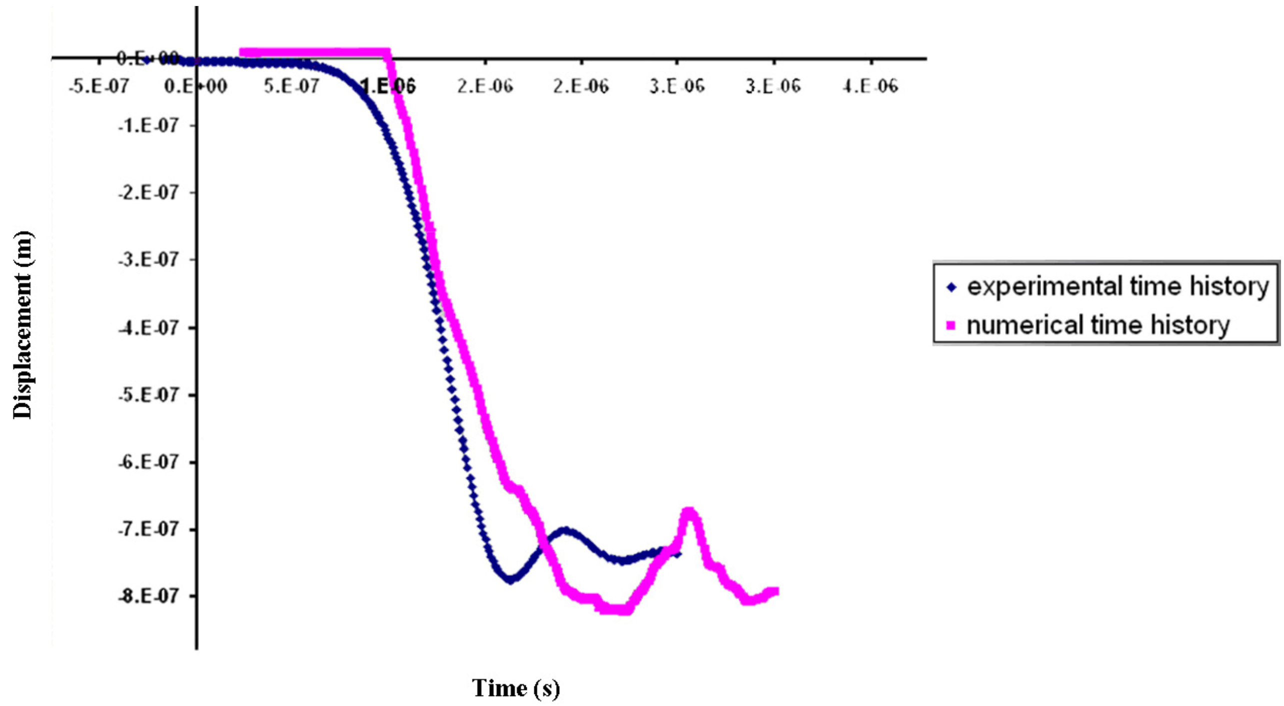

Figure 11: comparison between numerical and experimental curve

6. Conclusions

This paper demonstrated that the LDV is a suitable tool for characterizing electromechanical devices in the microscale. Thanks to his non-contact nature and to the fact that the measurement doesn't induce any electric or magnetic field that can interact with the operation of the device, it is possible to perform measurement in working conditions.

A set of measurements were performed in RF MEMS switches to measure bridge displacement and velocity. It has been shown that the displacement is a function of the applied voltage and of the height of the actuation electrode.

The experimental measurement were used to validate the results of the FEA analysis and it has been possible, with the help and indications of the designers to find the reasons of the discrepancy between the numerical and experimental results and this will allow the model improvement.

7. References

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