LASER SCANNING VIBROMETRY APPLIED TO NON-DESTRUCTIVE TESTING OF ELECTRO-ACTIVE POLYMERS

F. BREABAN[1] , V. CARLESCU[2], D. OLARU[3], Gh. PRISACARU[4], J. COUTTE[5]

Utilizările polimerilor de înaltă performanţă în industrie şi medicină în următorii ani aduc nevoia dezvoltării de noi metode de testare non-distructive. Obiectul este excitat electric pentru a induce o microdeformaţie măsurabilă. Am realizat un experiment pentru a evalua parametrii pentru Electro Active Polymer (PAM) cu eşantioane cu dimensiunile de suprafaţă între 30x30mm² şi 40x40mm² şi cu grosimea de la 28 până la 990µm. Am evaluat parametrii electrici - impedanţa electrică şi permitivitatea dielectrică - a eşantioanelor de EAP. Vibrometria realizată cu un scaner laser au arătat profilele dinamice ale microdeformaţiilor a eşantioanelor de EAP şi am evaluat sensibilitatea dinamică la diferite frecvenţe.

The applications of high performance polymers in the industry and medicine in the next years need to develop new non-destructive testing methods. The object is electrically excited to induce a measurable micro deformation. We have realised an experimental setup to evaluate the parameters of Electro Active Polymer (EAP) samples between surface dimensions of 30x30mm² and 40x40mm² and the thickness of 28 to 990µm. We have evaluated the electrical parameters – electrical impedance and dielectric permittivity - of the EAP samples. The laser scanning vibrometry measurements showed up the dynamic micro deformation profiles of the EAP samples and we have evaluated the dynamic sensitivity at different frequencies.

Keywords: Laser scanning vibrometry, Electro-active polymers, Non-destructive testing.

1. Introduction

The Laser Scanning Doppler Vibrometry - LSDV, like the holographic interferometry, are methods of non-destructive testing largely developed in the last years. ES2T team is a research unit dedicated to the Science and Technology for the Transport applications, in cooperation between CRITT-M2A and IUT Bethune of Artois University, integrated in CRITT-M2A. ES2T contains the Holography and Laser Vibrometry Laboratory, equipped with the Laser Scanning

[1] Prof., Univ Lille Nord de France, F-59000 Lille, France, UArtois, LGCgE, IUTB-CRITTM2A /S2T-EHVL F-62400 Béthune, France, florin.breaban@univ-artois.fr,
[2] Drd. UArtois, LGCgE - Univ "Gh. Asachi" Iasi
[3] Prof. Univ "Gh. Asachi" Iasi
[4] Prof. Ass. Univ "Gh. Asachi" Iasi
[5] Prof., Univ Lille Nord de France, F-59000 Lille, France, UArtois, LGCgE

Vibrometer PSV-200 from Polytec Company. The system applies non-destructive testing for detecting the micro deformation of the surface of the object when this one is excited [3], [4].

The energy applied to realize the light deformation of the surface of the object may be transferred by mechanical vibration, thermal, pneumatic, or electrical excitation.

The movement of a light-reflecting surface causes a Doppler shift in laser light, which can be detected and analysed using interferometry.

LSDV is one of the most flexible photomechanical instrumentation methods [3] and has many applications. The method is commonly used to analyse anything in fundamental and applied research: material science, biomedical, chemical, mechanical and civil engineering, and also from industry : car engines, plastic components, brakes and tyres [4], [8].

Laser Doppler Vibrometer uses laser light waves to make measurements.

A plane wave propagating in the positive x direction – figure 1 - can be written as

$$E(x,t) = E_0 \cos(\omega t - kx) \quad (1)$$

where: E_0 is the amplitude,

$\omega = 2\pi f$ - the angular frequency of the wave train,

$k = 2\pi/\lambda$ - the value of the propagation vector in x direction, and

λ is the wavelength.

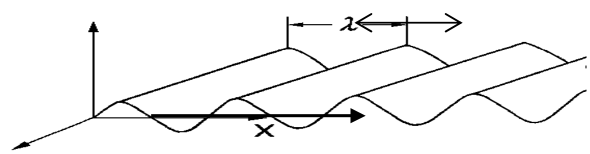

Fig. 1. A plane wave propagating in the positive x-direction.

Assume you have two waves E_1 and E_2 that travel in the same direction but that have travelled from the source to the point where they are superimposed via two different routs. The optical path difference ΔL produce a phase difference $\varphi = (2\pi/\lambda).\Delta L$:

$$E_1 = E_0 \cos(\omega t - kx), \quad (2)$$

$$E_2 = E_0 \cos(\omega t - kx - \varphi) \quad (3)$$

$$E_1 + E_2 = 2 E_0 \cos(\varphi/2) \cos(\omega t - kx - \varphi/2) \quad (4)$$

If $\varphi=0$ or an even multiple of π, $2n\pi$, n = 1, 2, ... there is a maximum constructive interference, and destructive interference if φ is an odd multiple of π : $2(n+1)\pi$.

LDV is based on a Mach-Zehnder Interferometer [3], figure 2.

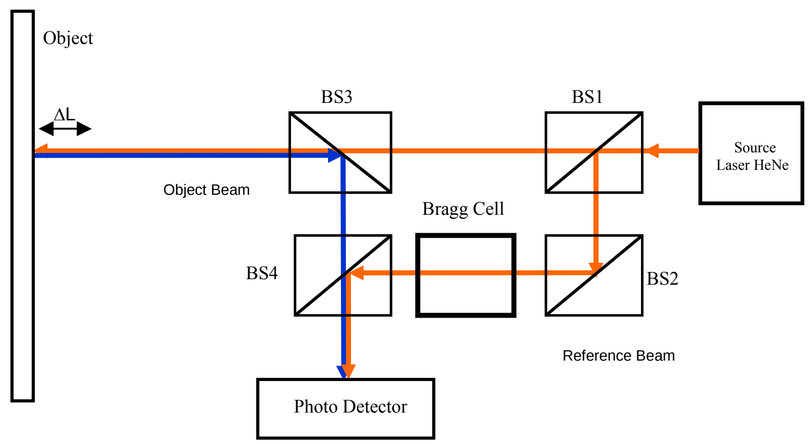

Fig. 2. The Mach Zehnder Heterodyne Interferometer.

If the distance x to the target changes continuously, then the light intensity I at the detector varies in a periodic manner. The periodicity is equivalent to a change in x of $\lambda/2$ or the phase ϕ of 2π.

It is important that the optical phase relationship is maintained. If this relation is lost, no interference will take place. The 1mW He-Ne laser has the coherence length of about 300m [3].

The photo detector is only sensitive to the intensity I of the light.

The signal at the detector has the form:

$$I = I_{max}/2. \{1 + \cos(2\pi(f_D + f_B)t\} \quad (5)$$

The phase difference $\Delta\varphi$ is a function of the optical path difference ΔL according to:

$$\Delta\varphi = 4\pi (\Delta L /\lambda) \quad (6)$$

When the object moves at a constant velocity v, the optical path difference becomes a function of the time $\Delta L(t)$.

The intensity at the detector changes periodically. The length of this period is $\lambda/2$. The frequency that is produced as a function of velocity is called Doppler frequency f_D.

$$f_D = \frac{2 * |v|}{\lambda} \quad (7)$$

Fig. 3 shows the synoptic of the PSV-200 Laser Scanning Doppler Vibrometer.

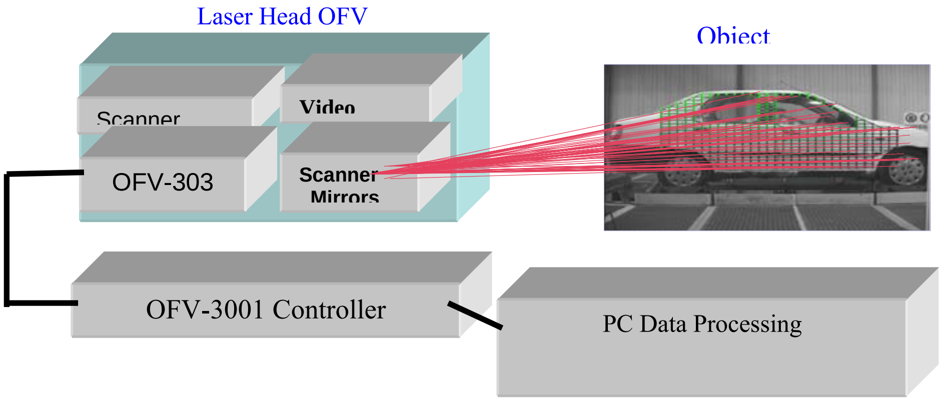

Fig. 3. PSV-200 Laser Scanning Doppler Vibrometer.

The measurement may be realised by the blank noise excitation and "FFT" analysis or by sinusoidal excitation and "Fast scan" analysis with the Laser Scanning Doppler Vibrometer. The PSV software guarantees the presentation of the results in the 3D modelling with animation.

2. The electro active polymers parameters

Electro active polymers (EAP) are materials for actuators capable to operate sometimes in special environmental conditions such as low temperatures and high humidity. There is a growing demand in robotics and bioengineering, regarding polymer elastomers with good flexibility, high efficiency, high actuation pressure, fast response time, durability and stability.

High driving electric fields are needed for silicone elastomer actuators, that may be reduced by preparing new compounds with improved electromechanical properties [1], [5], [7], [9].

We have tested some electro-active dielectric materials consisting of a series of new networks based on dimethyldiphenylsiloxane copolymer and tetraethylorthosilicats [2]. Electromechanical parameters like apparent electrostrictive coefficient, strain and response time, may be determined from the deformation of polymer films induced by dynamic driving electric field, from 0.1Hz to 200Hz.

The samples between surface dimensions of 30x30 and 40x40mm2 and the thickness of 28 to 990μm are excited by using the experimental setup presented in Fig. 4.

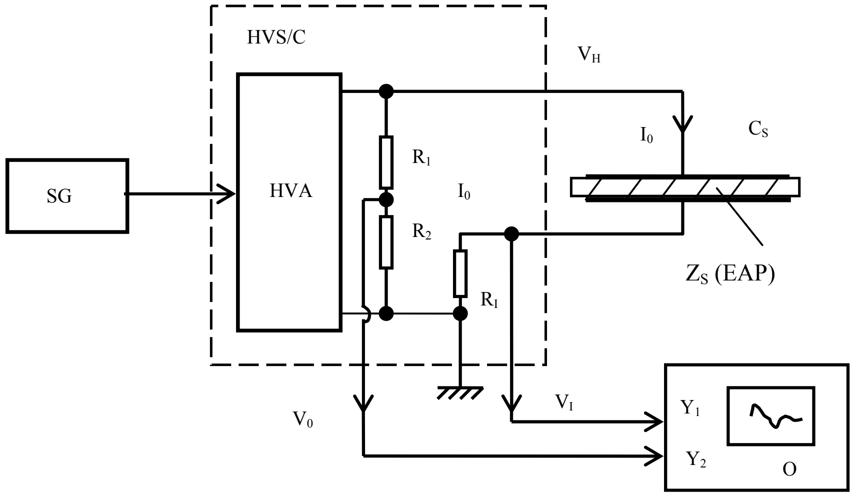

Fig. 4. Experimental setup for Electro Active Polymers excitation.

The sinusoidal voltage VH has peak to peak values between 0 and 10KV and frequencies from 0.1 to 10 kHz. The oscilloscope O allows the control of the parameters of the Electro Active Polymer sample:

$$V_0 = V_H \, . \, (R_1 / R_2) = 0.01 \, V_H \quad (8)$$

$$V_I = I_0 \, . \, R_I \, ; \, R_I = 5K\Omega \, ; \, V_I \, (I_0 = 200\mu A) = 1V \quad (9)$$

The signal generator SG is of HP33120A type. The High Voltage Supply/Controller is a TREK 610E model.
The impedance of the sample is modelled by the circuit presented in figure 5.

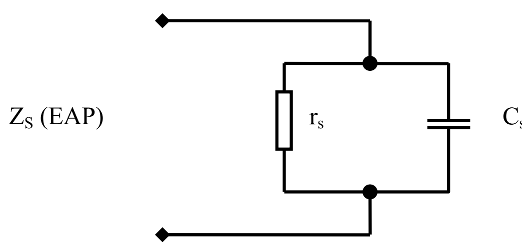

Fig. 5. Impedance of the sample.

For the dielectric electro active polymer (DEAP) films the value of the capacitance Cs is obtained by the following equation:

$$Cs = \varepsilon_0 \, . \, \varepsilon_r \, . \, (S/d) \quad (10)$$

with: $\varepsilon_0 = 1/(4\pi.9.10^9)$ F/m, the permittivity of the vacuum,

ε_r - the relative permittivity of the DEAP,
S – the area of the surface of the dielectric EAP film,
d – the thickness of the DEAP film.

For the dielectric electro active polymer films tested, the measured values of Cs for the different samples are between 20pF and 47pF, and □r ≈ 2.2.

The parallel loss resistance rs is greater than 50MΩ.

The relative thickness was expressed in %:

$$t\ (\%) = (\Delta d/d0).100$$

The dependence of the relative thickness by the static electric field for the sample of dielectric electro active polymer film [6] is shown in figure 6.

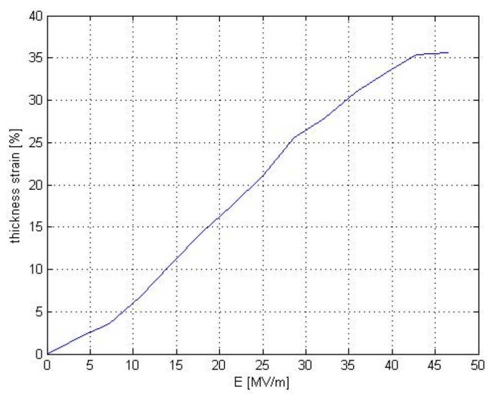

Fig. 6. The dependence of the relative thickness by the static electric field.

The dynamic micro deformation of the sample was measured by using a Laser Scanning Doppler Vibrometer.

3. Experimental setup and results

The experimental measurement system is presented in figure 7, summing the block diagrams from figures 3 – LSDV - and 4 - excitation EAP setup. The dynamic transverse micro displacement was measured by using the Polytec Co. PSV200 Laser Scanning Doppler Vibrometer (LSDV) at the ES2T laboratory in CRITT-M2A.

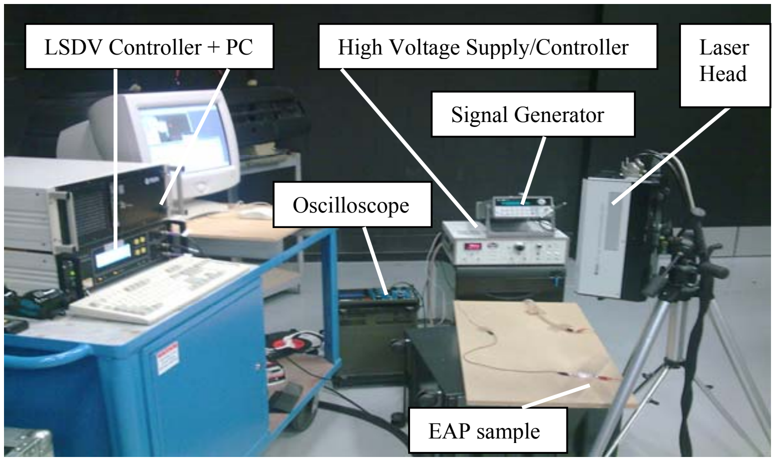

Fig. 7. View of the PSV200 in CRITT-M2A / ES2T.

The laser beam generated by the scanning head of the LSD Vibrometer falls perpendicular to the sample put in horizontal position on a plastic plate. A map of measurement points was defined and the laser beam measures the transverse displacement in each point. After that the LSDV software reconstructs the 3D model of the displacement profile of the sample.

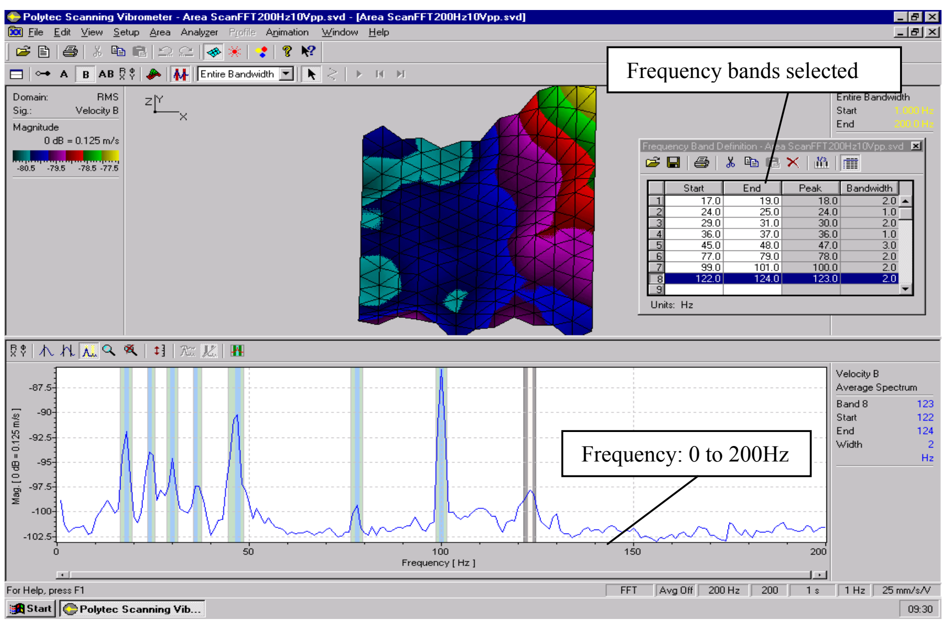

Fig. 8. Selection of resonance frequencies for a dielectric polymer film.

A white noise signal was first applied to the sample – the LSDV FFT mode - to find the resonance frequencies of the dielectric polymer film.

Figure 8 presents an example of resonance frequencies selection for a sample of dielectric electro active polymer film.

The dynamic micro deformation of the dielectric polymer film produced by a sinusoidal electric field has been investigated over a frequency range of 0.1 Hz to 200 Hz.

The peaks in figure 8 correspond to the resonance frequencies.

The surface dimensions of the samples of dielectric polymer films with aluminium electrodes were 30 x 30 mm2 to 40 x 40 mm2 respectively.

The thicknesses of the polymer films varied from 28 μm to 990 μm.

The vibrometer is synchronized with the signal generated by HP 33120A function generator. An oscilloscope was used to monitor applied voltage and current on the sample. The amplitude of sinusoidal voltage was in range of 0 to 6kV.

The signal voltage generated by a HP 33120A function generator is amplified by a TREK 610E power amplifier and then applied to the polymer films at each resonance frequency.

For these resonance frequencies the displacements measured are in order of micrometers as presented by the 3D models in figures 9 and 10.

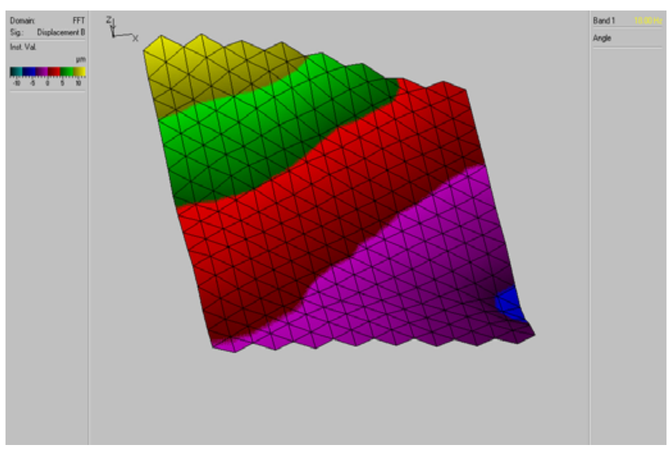

Fig. 9. 3D model of the dielectric electro active polymer film at the sinusoidal excitation voltage of 5kVpp and the frequency of 18Hz.

From Fig. 9, the peak-to-peak micro deformation of the dielectric electro active polymer film at the sinusoidal excitation voltage of 5kVpp and the frequency of 18Hz dpp1 = 12μm and the dynamic sensitivity s1 = 2.4μm/kV.

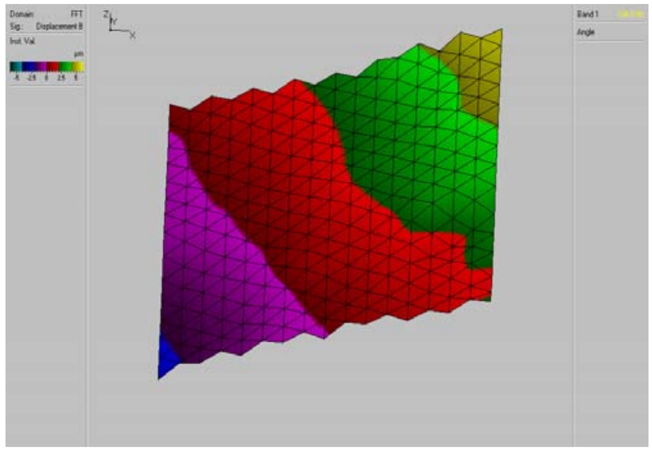

Fig. 10. 3D model of the dielectric electro active polymer film at the sinusoidal excitation voltage of 4kVpp and the frequency of 104Hz.

From Fig. 10, the peak-to-peak micro deformation of the dielectric electro active polymer film at the sinusoidal excitation voltage of 4kVpp and the frequency of 104Hz, dpp2 = 6µm and the dynamic sensitivity s2 = 1.5µm/kV < s1. The sensitivity of the EAP film diminishes with the frequency.

4. Conclusion

The Laser Scanning Doppler Vibrometry method was applied to measure the transverse micro displacement response of some dielectric electro active polymer actuators. This technique based on laser interferometry has a good accuracy and is easy to apply to thickness micro deformation measurements on thin electro sensitive polymer films.

The 3D models realized are important for electromechanical characterization of dielectric elastomer actuators. The results allow us to propose the application of these materials in some modern actuators in robotics, in bioengineering - to reduce the control energy and realise the artificial muscular fibres for the prosthesis – in intelligent civil engineering materials and structures, in deflectors for laser beams and in Micro Electro Mechanical Systems - MEMS.

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