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ESPI and FEM – Analysis of oscillating membran

1. INTRODUCTION

In the field of engineering technology several methods to analyze the deformations of prefabricated parts regarding its mechanical characteristics are known and verified. Two technologies, the Electronic Speckle Pattern Interferometry (ESPI) and the Finite Element Method (FEM) are combined to create a tool for the analysis of oscillating membranes.

The Electronic Speckle Pattern Interferometry (ESPI) is a well known method of measuring deformations and (in correlation to suitable simulation programs) mechanical stresses within specimen or – even more important – technical structures [1]. Leendertz first showed it's applicability for the contactless determination of deformations [2]. Utilizing CCD cameras for fast data analysis finally opened the door to a number of specialized techniques that have been developed mainly used in car manufacturing industries, aeronautic industry and materials testing [1], to name just a few. The specimen normally are meso- or macroscopic in size with lateral dimensions typically ranging from centimeters to some meters, the topics of interest ranging from stress analysis in tensile test specimens unto the dynamic behaviour of complete structures like automobiles.

Meanwhile Speckle Interferometry is also used for (contactless) analysis of deformations even at high temperatures up to 1600℃, where a classical (contacting) determination of the strain is impossible [3]. The variety of materials investigated covers also composites [3], concrete [4] and even biological materials of botanical [5] or medical [6] origin. Meanwhile a novel surface preparation technique was introduced altering the surface of MEMS such that Speckle Interferometry now can be applied [7].

The aim of this work was to demonstrate the application of ESPI on FEM simutaneously on a membrane under dynamical conditions.

2. TECHNOLOGY

2.1 ESPI

The Electronic Speckle Pattern Interferometry (ESPI) is a laser based technique to visualize static and dynamic displacements. Usually located in the field of engineering technology this technology is able to measure displacements with a high precision. Basic principle of ESPI is the creation of a so called speckle pattern. If an optical rough surface is illuminated with coherent light each asperity is origin of a new elementary wave. These waves interfere with each other and result is a pattern of changing intensity maxima and minima, the speckle pattern (Fig. 1). A speckle pattern can be understood as some sort of “fingerprint” of the surface at a certain state. In general to measure a displacement two speckle pictures are taken (two pictures and two states) and the difference between both is mathematical calculated. Result is a visualization of the surface deformation between both states.

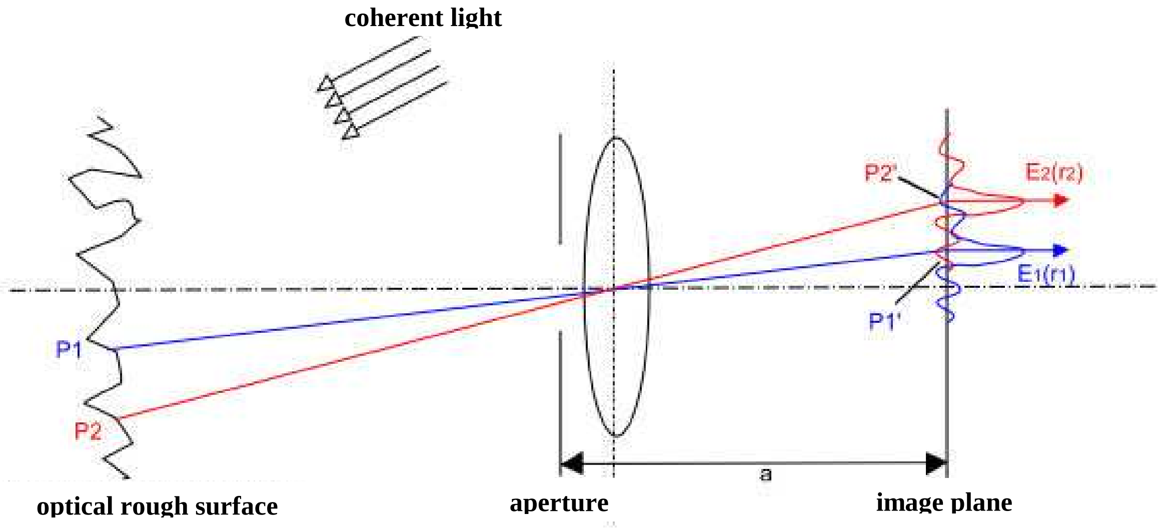


Fig. 1: origin of a speckle pattern, starting from the two points P_1 and P_2 elementary waves interfere at the image plane, result is the local distribution of amplitudes $E_i(r_i)$ or in other words a speckle pattern, modified from source: Bauer *et al.* 1991 S.153

2.2 FEM

The finite-element method [10] was developed from the need for solving complex elasticity and structural analysis. Its main idea is quite simple. One complex part is divided into big number of elements [11] by using a mesh discretization. Therefore a continuous domain is not examined as one system. Each sub-domain is examined by its own and then combined again to one complex. Commonly FEM is integrated in the design and development process regarding where structures bend or twist, and indicates the distribution of stresses and displacements.To solve that problem by the way of computer simulations one has to use FEM method. FEM methods became very popular with the growth of processors capacity. There is a number of FEM applications. The most popular for mechanical purposes are ABACUS and ANSYS, since they are able to calculate even for complex geometrical structures. For simple and basic computations there is a very simple software package available: NovaFlow&Solid. We will present our results from computations using this program.

2. SIMMULATION AND EXPERIMENT

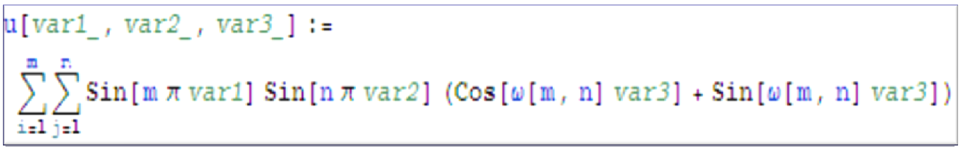
Of course the exact solution of a membrane equation (which in fact is a second order differential equation – a hyperbolic one)

$$\frac{1}{c}\frac{\partial^2}{\partial t^2}u(x,y,t)-\Delta u(x,y,t)=0$$

is possible since we can assume that,

$$u(x,y,t)=X(x)\cdot Y(y)\cdot T(t)$$

which method is known as a Bernoulli method separation of variables. Applying this to a rectangular membrane one finds



```
u[var1_, var2_, var3_] :=
 m  n
 ∑  ∑ Sin[m π var1] Sin[n π var2] (Cos[ω[m, n] var3] + Sin[ω[m, n] var3])
i=1 j=1
```

where the *ω function* is given by

```
ω[var1_, var2_] := (var1^2 + var2^2) π^2
```

Using the software program Mathematica Basic the modes of rectangular membrane vibration [m,n] are as follows from left to right for the cases [1,1], [3,1] and 2,2] in 3D (upper row) and 2D (lower row):

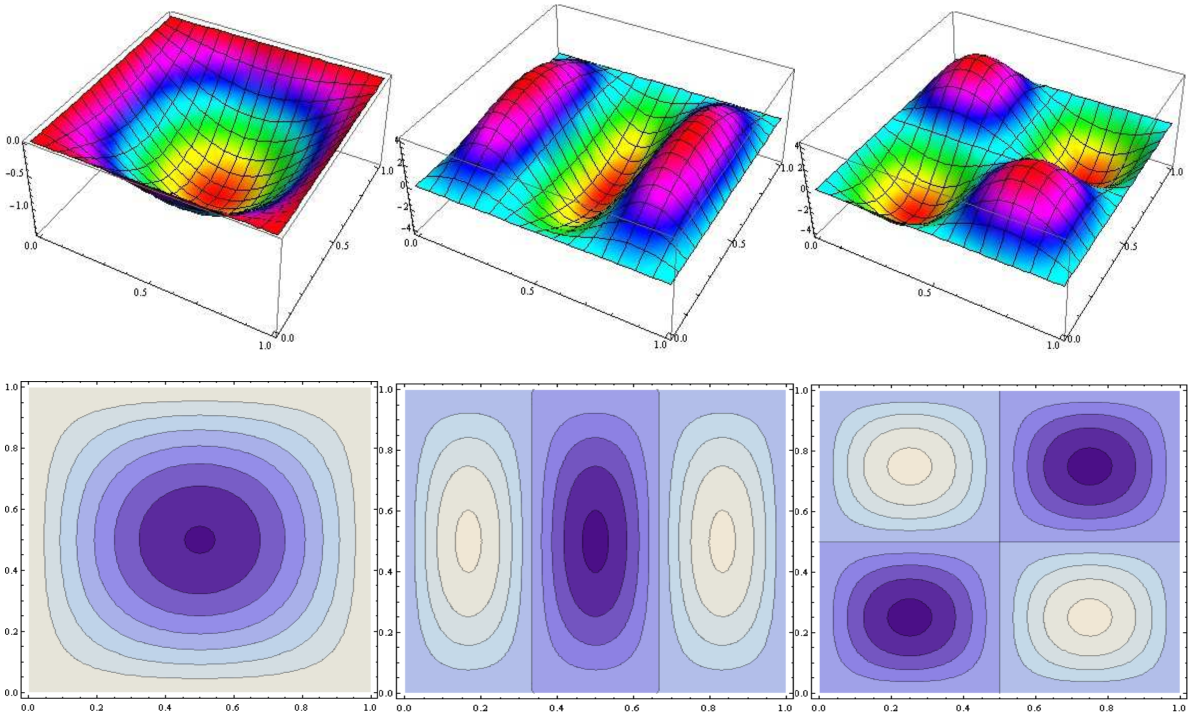


Fig. 2: Different „Eigenfrequencies” in a membrane.

Each one of the presented methods ESPI and FEM are well known and verified tools in the field of engineering technologies. In this work we used both methods to characterize different types of membranes on the basis of their dynamic vibration behaviour. In Fig. 3 an inorganic membrane in centimeter dimensions is dynamically exited at 2403 Hz (right picture) while the pattern of deformation is correctly visualized by the FEM simulation (left picture) utilising NovaFlow&Solid. In Fig. 4 the same inorganic membrane is dynamically exited at 3351 Hz (right picture) in goos accordance with the FEM simulations.

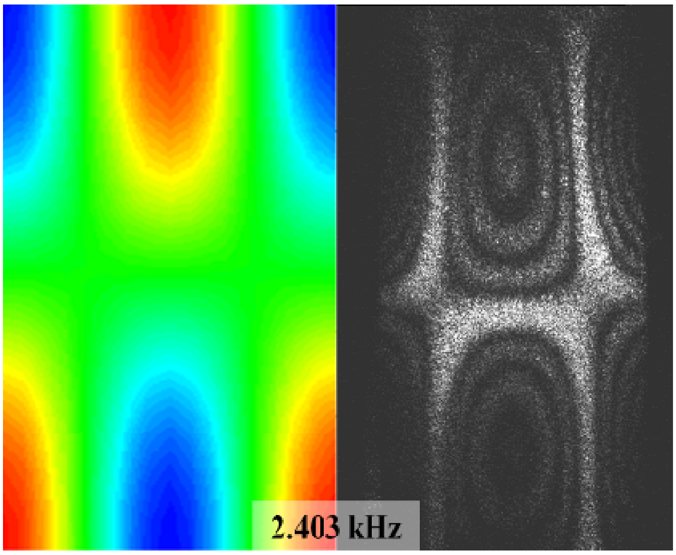


Fig. 3: Dynamic behavior of a Membrane at 2403 Hz. Left: FEM-Simulation using NovaFlow&Solid, right: experimental data utilising dynamic ESPI.

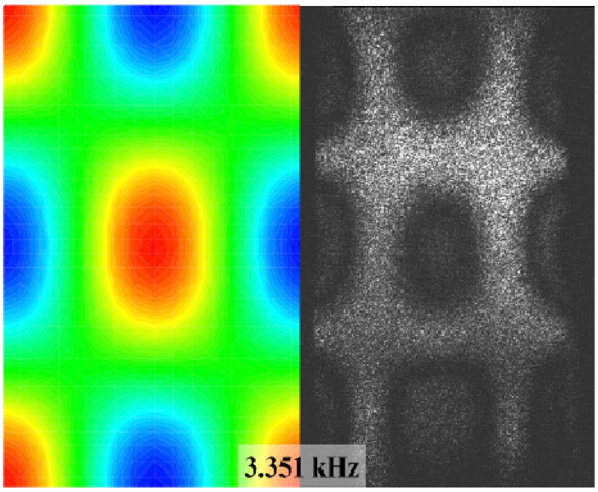


Fig. 4: Dynamic behavior of a Membrane at 3351 Hz. Left: FEM-Simulation using NovaFlow&Solid, right: experimental data utilising dynamic ESPI.

3. OUTLOOK

In this work we investigated macro anorganic membranes utilising ESPI and FEM simulations, resulting in a good accordance of the experimental and the simulated data. Based on the achieved results such inorganic membranes can be optimised for utilisation in pressure sensors for different applications. In the near future we also want to test and simulate membranes in biological specimen, even in microsised dimensions like living cells. Recent results show that such deformation analysis on microsized biological samples utilising ESPI is possible [12].

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