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STUDY OF VIBRATING KEVLAR/EPOXY PLATE: COMPARISON BETWEEN EXPERIMENTAL (ESPI) A NUMERICAL RESULTS (FEM)

Soňa Rusnáková, Juraj Slabeycius, Dana Bakošová, Ivan Letko,
Faculty of Industrial Technologies, University of Alexander Dubček in Trenčín
Department of Physical Engineering of Materials
I. Krasku 491/30, 020 01 Púchov
Slovak Republic
rusnakova@fpt.tnuni.sk

Ján Krmela
The Jan Perner Transport Faculty, University of Pardubice,
Department of Informatics in Transport
Studentská 95, 532 10 Pardubice
Czech Republic
jan2.krmela@post.cz

ABSTRACT

Most of the works on vibration analysis of plates published in the literature are analytical and numerical and very few experimental results are available. Existing modal analysis techniques such as accelerometers and laser Doppler vibrometers are pointwise measurement techniques and are used in conjunction with spectrum analyzers and modal analysis software to characterize the vibration behaviour. In this study, a technique called electronic speckle pattern interferometry (ESPI) optical system is employed to investigate the vibration behaviour of square laminate plate. This method is very convenient to investigated vibration objects because no contact is required compared to classical modal analysis using accelerometers. High-quality interferometric fringes for mode shapes are produced instantly by a video recording system. Based on the fact that clear fringe patterns will appear only at resonant frequencies, both resonant frequencies and corresponding mode shapes can be obtained experimentally using the present method. The square plate is most using structural element in industry. The square laminate plate we select for its shape simplicity and undemanding character for clamping. The square laminate plate is fixed by special metal frame on elastic rubber. So we reach all its degree of freedom. The tested object is vibrated by loudspeaker, which is situated behind the tested plate. The boundary conditions are investigated in this study, namely free–free–free–free (FFFF). The numerical calculations by finite element method are also performed and the results are compared with the experimental measurements. Excellent agreements are obtained for both results of resonant frequencies and mode shapes. ESPI has been recently developed and widely used because it has the advantage of being able to measure surface deformations of engineering components and materials in industrial areas without contact. ESPI was used for tuning and visualization of natural frequencies of Kevlar/epoxy square plate. Numerical calculations by finite element method are also performed and the results are compared with the experimental measurements. Good agreements are obtained for both results. Our experimental setup consists of tested object, laser, CCD-camera, PC, generator, loudspeaker, special optical head, lens, mirrors. Vibration of elastic plates has been widely studied; both from experimental and theoretical points of view [1–4], since plates are important components in many engineering applications. A vast literature exists for the flexural vibration of rectangular plates.

1. INTRODUCTION

Measurement/monitoring of vibration of machines, equipments and complex structures is necessary to diagnose various problems associated with them so that their breakdown is prevented and also the noise levels can be controlled.

Mathematical models for analytical solutions are only symbolic and useful for the idealized systems where all the assumptions are imposed on the physical problem. Analytical solutions for vibration of membranes and thin plates were considered for simplified cases [5]. In complex cases and in actual operating conditions, it is however, difficult to manage the vibration problem analytically. Measurement of vibration is needed to fulfill two main objectives: the first is to determine the vibration level of the structure or machine under actual operating conditions and the second is to validate theoretical predictions. Due to the pressing need to design lighter, more flexible and less damped structures and on-line monitoring of vibration in factory or shop floor environment, there is a need to develop an accurate and precise vibration measurement/monitoring system.

Optical techniques developed for measurement/monitoring of vibrations have wide dynamic range of frequencies [6–7]. ESPI technique is a full field, non-contact, non-evasive and almost real time method to measure the vibrations of structures subjected to various kinds of loading [6-7]. ESPI is faster in operation and less sensitive to environmental perturbations than holography. In ESPI, the speckle pattern is formed by illuminating the surface of the object by laser light. The object wave is imaged on the photosensitive part of the CCD camera where it is allowed to interfere with an in-line reference beam. The interferograms of two different states of the object are grabbed and subtracted. The speckle correlation fringes are thus displayed on computer monitor using digital techniques.

2. THEORY OF VIBRATION OF PLATE

Equation of motion for free vibration of a flat plate of uniform thickness made of homogeneous isotropic material is given by [8]

$$\boldsymbol{D}\nabla^4 \boldsymbol{w} + \rho \frac{\partial^2 \boldsymbol{w}}{\partial \boldsymbol{t}^2} = \boldsymbol{0} \tag{1}$$

where *w* is the transverse defection, $\boldsymbol{D} = \boldsymbol{E}\boldsymbol{h}^3 / 12(1-\nu^2)$ is the plate stiffness, *E* the modulus of elasticity, h the thickness of the plate, *ν* the Poisson's ratio of the material of the plate, *r* the mass density per unit area of plate surface, *t* the time, ∇^4 the biharmonic differential operator (i.e: $\Delta^4 = \Delta^2\Delta^2$), and $\Delta^2 = (\partial^2/\partial x^2) + (\partial^2/\partial y^2)$ in rectangular coordinate.

3. EXPERIMENTAL METHOD

The resonant frequency and correspondent mode shape for the vibrating laminate plate are determined experimentally using the non contacting optical method ESPI. Publications [9, 10] detailed describes a principle of this method. Plates are structural elements of great importance and are used extensively in all fields of engineering applications such as aerospace and electronic industry. The object of observation is Kevlar/epoxy composite plate. The material properties of the plate are: *E = 25,9 GPa, G = 10,4 GPa, ν=0,47,* the dimension of laminate plate *175 x 175* mm, the density $\rho = 1450\ kg/m^3$, thickness *h = 0,3 mm.* We compared experimental obtained the resonant frequencies by ESPI with the numerical frequencies (FEM). Isotropic materials have physical properties, which are the same in all directions. Orthotropic materials have properties, which are different when measured at right angles to one another. The view on corwesponding mode shapes is described on the Figure 1. Numerical results of resonant frequencies and mode shapes are calculated by using the commercially available software, Cosmos finite element package.

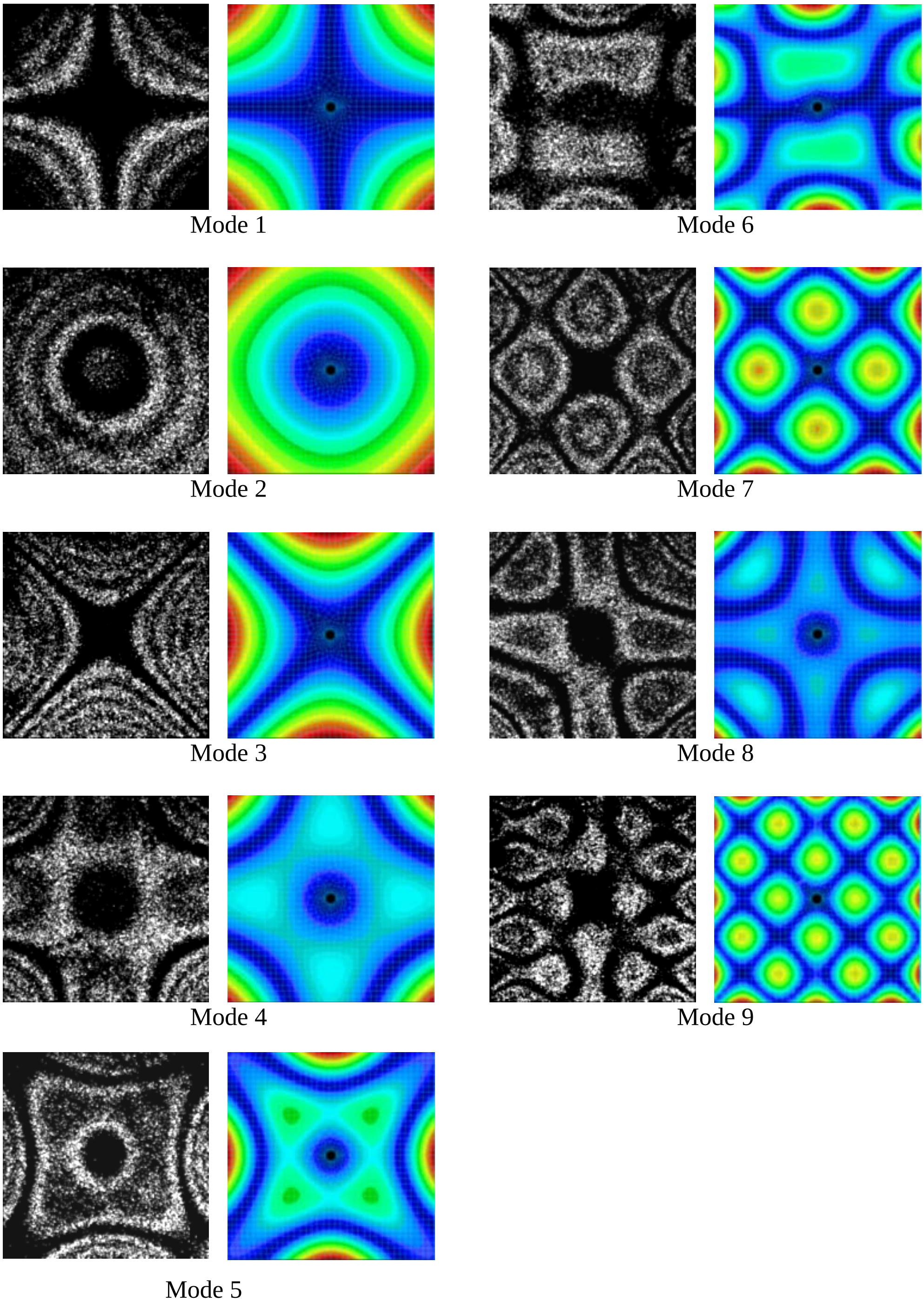
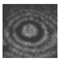
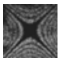
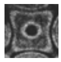
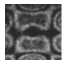
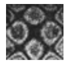
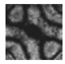
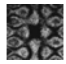


Figure 1. Mode shapes – experimental (ESPI) and analytical (FEM).

Table 1. Comparison of theoretical predicted resonant frequencies with experimental results for the FFFF plate.

Mode	1	2	3	4	5	6	7	8	9
									
ESPI (Hz)	69	79	156	264	560	640	742	837	1816
FEM (Hz)	91	69	132	303	580	736	740	899	1831
Error (%)	24	14	18	13	3	13	0	7	1

4. RESULTS AND DISCUSSION

This study investigates the resonant frequencies and mode shapes of laminate composite plate for out-of-plane vibrations by experimental technique ESPI and FEM. It has shown that the ESPI method has the advantages of non-contact, full-field, real-time and high-resolution measurement. Excellent quality of interferometric fringes for mode shapes is presented by a video recording system. For the laminate plate, the resonant frequencies and full-field mode shapes up to nine modes are measured by ESPI and are excellently correlated with FEM results. Excellent agreements between the theoretical predictions and experimental measurements of resonant frequencies and mode shapes are obtained. However, the difference between the experimental measurement and FEM results may result from the determination of the material properties and defects of the composite plate. Composite industry is very popular today, with big volume of different and unexplored materials. As well, we can say that each composite product is original. We determine the type of materials only in productions process. It is shown that this optical method has the advantages of non-contact, real-time and high-resolution measurement for the vibration behaviour of laminate materials.

5. ACKNOWLEDGMENT

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