

Experimental Study of Plates by ESPI

S. Rusnáková, P. Košťal, D. Bakošová, J. Kučerova,
M. Mokryšová

University of Alexander Dubček in Trenčín, Slovak Republic
e-mail: rusnakova@fpt.tnuni.sk

Abstract

Fibre-reinforced components of various shapes and different boundary conditions (free, clamped, and hinged) commonly occur in practice. Designers need to be able to predict the stiffness parameters and damping values of such components for conditions such as aeroelasticity, acoustic fatigue, and so on. Electronic speckle pattern interferometry (ESPI) can be useful tool for easily determination of Poisson's ratio, Young's modulus E and shear modulus G from the measured resonant frequencies. In this study we investigate the vibration behaviour of square composite plates with different stacking sequences by ESPI and influence of various thicknesses to resonant frequencies of corresponding mode shapes. Both resonant frequencies and corresponding mode shapes can be compared by numerical calculations by the finite element method. Good agreement is obtained for both results of resonant frequencies and mode shapes. The mode shapes of laminate composite plates are influenced by material properties, boundary conditions, geometry, and the lamination arrangement.

Keywords: ESPI, vibration, laminate plate, FEM.

1. Introduction

Electronic speckle pattern interferometry (ESPI) is useful tool to carry out nondestructive tests in a variety of fields such as optical metrology, industrial process control, visual inspection line, etc. The technique is well suited to measure deformations in mechanical systems subjected to stress under several boundary conditions. Particularly, the visualization and measurement of the mechanical vibration of elastic objects is one of the most useful applications.

Experimental and computational methods can be combined so that the data obtained by one method can be used by the other one to verify the results. In this study we are interested in comparing the results obtained by means of a computational method with those obtained experimentally using ESPI method. As a test object we used a square laminate plate, with different stacking sequences, subjected to a periodic load and excited to different resonant vibrations by a sinusoidal acoustic source.

On the other hand we experimentally investigate influence of thickness of the pre - preg laminate plate to mode shapes with corresponding resonant frequencies.

Real-time displays of interference fringe patterns allow high precision tuning of normal modes of vibration, so that measurement of the corresponding

resonant frequencies can be done. Once the resonant mode is attained, images of the fringe pattern are recorded and stored for later analysis and comparison with the predicted computational solutions.

2. Experimental setup

The experimental layout of self-arranged ESPI optical system, as shown in Fig. 1, is employed to perform the out-of-plane vibration measurement of the resonant frequencies and mode shapes for square composite plate. A He-Ne laser with wavelength is used as the coherent light source. The laser beam is divided into two parts, the reference and object beams, by a beam splitter



Figure 1: Experimental set-up of ESPI

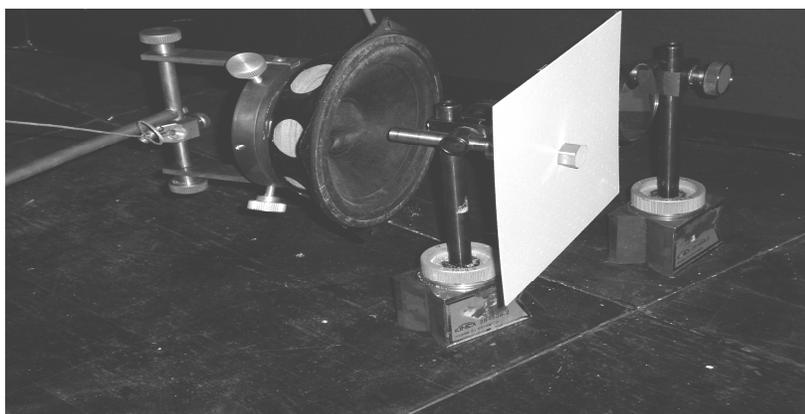


Figure 2: Fixation of the plate

The object's beam travels to the specimen and then reflects to the CCD camera. The reference beam is directed to the CCD camera via the mirror. Note that the optical path and the light intensity of those two beams should remain

identical in the experimental setup. The CCD camera converts the intensity distribution of the interference pattern of the object into a corresponding video signal at 30 frames per second. The signal is electronically processed and finally converted into an image on the video monitor. To increase the intensity of light reflection of the specimens and contrast of fringe patterns, the surfaces of the plates are coated with white paint. The plate was excited to resonant vibration by sinusoidal acoustical source, which provided a continuous range of audio frequencies. Fringe patterns produced during the time-average recording of the vibrating plate corresponding to several resonant frequencies were registered.

Thin plates have been extensively used as structural elements in many industrial applications. The study of the vibration behaviour of a plate is a problem of great practical interest and most of the published works are analytical and numerical results. There are very few experimental results available, especially for full-field measurement of mode shapes.

Transverse vibration of plates has extensive application in civil, mechanical, aerospace, and material engineering. Governing equation of a vibrating plate in the Cartesian coordinate system is first given by Sophie Germain. (Ref [1])

$$D\nabla^4 w + \rho w_{tt} = 0 \quad (1)$$

where $w = w(x, y, t)$ is the vertical displacement and

$$D = \frac{Eh^3}{12(1-\nu^2)} \quad (2)$$

with D - flexural rigidity, E - Young modulus, ν - Poisson ratio, h - half-thickness, ρ - density.

3. Influence of thickness of plate to resonant frequencies of mode shapes

The thickness of the square laminate plate is very important point by investigation of resonant frequencies of corresponding mode shapes. The resonant frequency of basic modes of composite materials strongly depends on thickness of investigated plates.

		Thickness h [mm]			
		0,8	1,05	1,35	1,65
Resonant frequency f [Hz]	1 	61	78	93	112
	2 	138	187	228	293
	3 	179	248	309	378
	4 	374	522	663	800

	5		432	620	758	919
	6		498	694	861	1 058
	7			795	983	1 200

Table 1: Dependence of resonant frequencies on thickness of plate.

The investigated plate was made from pre-preg, M 34 (epoxy/glass). Pre-preg is a term for "pre-impregnated" composite fibres. These usually take the form of a weave or are uni-directional. They already contain an amount of the matrix material used to bond them together and to other components during manufacture.

Material parameter of pre-preg is $\rho = 1665 \text{ kg/m}^3$, Young's modulus $E = 21 \text{ GPa}$ a Poisson ratio $\mu = 0,13$. Boundary conditions are in the centre fixed by special stand and the edges are free.

With increasing of thickness of plate is increasing resonant frequencies of corresponding mode shapes, too. It can be seen in Table 1. Experimentally obtained values resonant frequencies are corresponding with values obtained by FEM. In these two cases increasing resonant frequencies nearly linearly what is confirmed the principle: with increasing of stiffness of sample we need higher loaded frequency.

The results presented in Tables 1 and 2 shows generally good agreement between the numerically predicted and experimentally measured resonant frequencies. The error inn resonant frequency prediction is given by

$$\%Error = \frac{f_{theory} - f_{exp}}{f_{theory}} 100\% \quad (3)$$

		Thickness h [mm]			
		0,8	1,05	1,35	1,65
Resonant frequency f [Hz]	Mode				
		48	63	81	99
	2 	167	219	282	345
	3 	210	276	355	434
	4 	403	530	681	832
	5 	512	672	864	1055
	6 	515	676	869	1062
7 	626	821	1056	1290	

Table 2: Dependence of resonant frequencies on thickness of plate (FEM)

The worst error is 15% and the average error in the results is 6%. The errors are probably due to thickness variations across the plate, the material property measurement, the finite element approximation and boundary conditions of the plate.

4. Influence of various stacking sequence to resonant frequency of corresponding mode shapes

During our experimental investigation we observed four types of samples. Description of investigation samples are in the Table 3. The material properties - the samples was made from epoxy resin MGS L 285 with carbon reinforcement 200g/m²

Sample	Description of samples	Weave	Stacking sequency
1	Epoxy/Carbon	Plain Weave	(0°)6s
2	Epoxy/Carbon	Plain Weave	(0°,90°)3s
3	Epoxy/Carbon	Plain Weave	(0°, 0°, 0°, 90°, 60°, 90°)1s
4	Epoxy/Carbon	Plain Weave	6 x fabric

Table 3: Description of Samples –Influence of Stacking Sequences

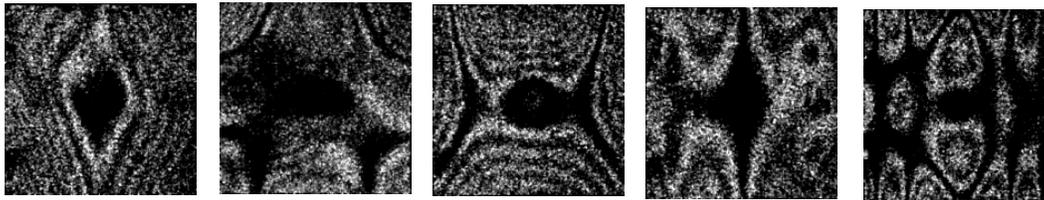


Figure 3: Mode shapes obtained by ESPI – sample 1

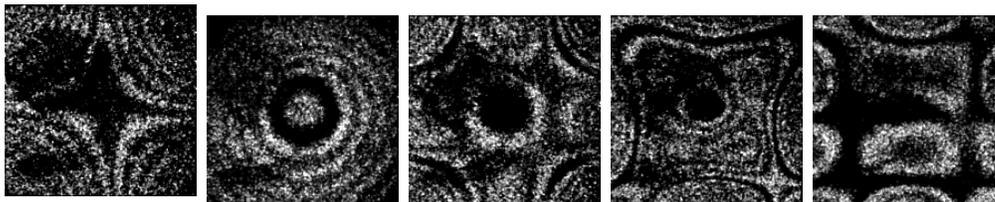


Figure 4: Mode shapes obtained by ESPI – samples 2,3,4

It can be seen from our experimental results, that samples 2, 3, 4 has the same mode shapes. We can consider the stacking sequence those samples like isotropic materials. On the other hand, samples 1, where the fibres are laying in the one way, we obtained asymmetrical mode shapes. It can be seen in the Figure 3. These mode shapes do not occur by samples 2, 3, 4. The mode shapes obtained by investigation of all four samples are by samples 1 deformed

and asymmetrical. Asymmetrical mode shapes by sample 1 is caused that Young's modulus and flexural stiffness are higher in the way of laying fibres like in the perpendicularly way to the way of laying fibres.

5. Computational simulations of natural mode shapes of plate

Analytical solution of equation for vibrations of thin plates is very complicated and is practicable only for some easy cases.

Works [2, 3] deal with approximate solutions of thin plates, which enumerate for resonant frequencies of thin square plates with free edges equation:

$$f = \frac{\alpha}{a^2} \sqrt{\frac{gD}{\rho h}} \quad (4)$$

where α is constant depend on mode shape, a is dimension of sample and D is flexural stiffness given by equation:

$$D = \frac{Eh^3}{12(1-\nu^2)} \quad (5)$$

Practicable solution of problem of vibrations is realized only by using of numerical method with using of finite element method (FEM). Because that various algorithms and software give results with different reliability degree and for some complicated shapes of investigated samples can break down, is experimentally verifying validity FEM results very valuable. Especially significant is comparison experimentally obtained natural vibrations with FEM results. Numerical calculations we made by using commercially available software COSMOS M 1.75.

6. Conclusions

We have presented a study of a vibrating plate, in which analytical solution and experimental measurements are compared. Several mode shapes of vibration have been visualized by ESPI technique. The experimental set-up is very simple to implement and shows great sensitivity for tuning resonant frequencies. 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. For this reason, ESPI (for its non-destructive characters) can be very useful tool for determination of vibration behaviour of composite structures, easily determination of basic materials properties (Young's modulus, Poisson's ratio, Shear modulus) [4].

Vibration behaviour of composite specimens is mainly influenced by the following factors: the type and kind of composite samples, volume fraction of the reinforcement (V_f), the orientation of the reinforcing material to the loading axis, the surface treatment of the reinforcement and the loading, dimension and

thickness of investigated composite samples, environmental factors, such as amplitude, frequency and temperature.

This method can be applied to many cases within a range of displacements between tens of nanometres and tens of micrometers. Because ESPI uses video recording and display, it works in real time to measure dynamic displacement, which enables implementation of this technique for vibration measurement.

7. References

- [1] L. Rayleigh, The Theory of Sound, Dover Publication, New York, 1995.
- [2] S. Timošenko, Kmitání ve strojnictví, SNTL Praha, 1996.
- [3] K. Julis, R. Brepta, Mechanika 2. díl – Dynamika. SNTL Praha, 1987.
- [4] S. Rusnáková, J. Slabeycius, V. Rusnák, The possibilities of holographic speckle interferometry by investigation of composite materials. In: Photonics Prague 2005. The 5th International Conference on Photonics, Devices and Systems, ISBN 80-86742-08-3, p.109, 2005