ESPI – OPTICAL METHOD FOR INSPECTION OF ENGINEERING STRUCTURES FOR AUTOMOTIVE INDUSTRY

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ABSTACT
This work provides non-contact optical technique to investigate the transverse vibration characteristics of laminate square plates in resonance. Most of the works on vibration analysis of plates published in the literature are analytical and numerical and very few experimental results are available.
This work collects some information about possibilities, advantages, and disadvantages of ESPI applications by nondestructive testing of composite materials and briefly introduces a damping feature of composites. Theory of plate vibrations allows us to determine Poisson's ratio ν, *Young's modulus E and shear modulus G from the measured resonant frequencies. We are able to analyze the damping behavior of various types of composite materials from measured shape modes. We also present ESPI like a very useful tool for determination of defects in composite components.*
ESPI can be used to perform nondestructive evaluation of glass-fiber reinforced plastic (GFRP) laminate plates containing various sizes and shapes of defects located at different depths.
Keywords: Electronic speckle pattern interferometry, vibration, defects in composites

1. INTRODUCTION

ESPI was proposed in the 1970s as the method of producing the interferogram without using traditional film-based techniques. The interferometric image is recorded and updated every 1/30 s; ESPI is faster and more insensitive to environment than holography, which uses slow and cumbersome process of film development. Because ESPI uses video recording and display, its real-time nature makes it practical for vibration measurements. ESPI can observe a vibration modes and corresponding resonant frequencies of various shapes and different dimension, also ESPI can employ to observe a dynamic characteristic of various kinds of laminate composites or oscillating tyres.
Modern engineering design requires the use of materials in a way that optimizes their inherent properties. The general class of materials that is most suitable for optimum design is composite materials. Composite materials are increasingly being used in many engineering transport applications for a variety of reasons, such as high specific stiffness and weight reduction.

Composite structural elements are now used in a variety of components for automotive, aerospace, marine, and architectural structures, in addition to consumer products. Fiber - reinforced laminated composites are the most popular because of their ability to offer outstanding strength, stiffness, low specific gravity, and unique flexibility, which satisfy the requirements of a large number of structural applications.

2. METHOD

The schematic layout of ESPI optical system, as shown in Fig.1, is employ to perform the out-of-plane vibration measurement of the resonant frequencies and mode shape of various objects.

The resonant frequencies and correspondent mode shape for the vibrating object are determined experimentally using the no contacting optical method ESPI. A He-Ne laser with wavelength $\lambda = 632,8$ nm is used as the coherent light source. The laser beam is divided into two parts, the reference and object beam, by a beamsplitter. The object beam travels to the specimen and then reflects to the CCD camera via the mirror and reference plate. The CCD camera converts the intensity distribution of the interference pattern of the object into a corresponding video signal. The signal is electronically processed and finally converted into an image on the video monitor. The experimental procedure of ESPI technique is performed as follows. First, a reference image is taken, after the specimen vibrates, then the second image is taken, and the reference image is subtracted by the image processing system. If the vibrating frequency is not the resonant frequency, only randomly distributed speckles are displayed and no fringe patterns will be shown. However, if the vibrating frequency is in the neighborhood of the resonant frequency, stationary distinct fringe patterns will be observed. Then the function generator is carefully and slowly turned, the number of fringes will increase and the fringe pattern will become clearer as the resonant frequency is approached. The resonant frequencies and corresponding mode shapes can be determined at the same time using the ESPI optical system

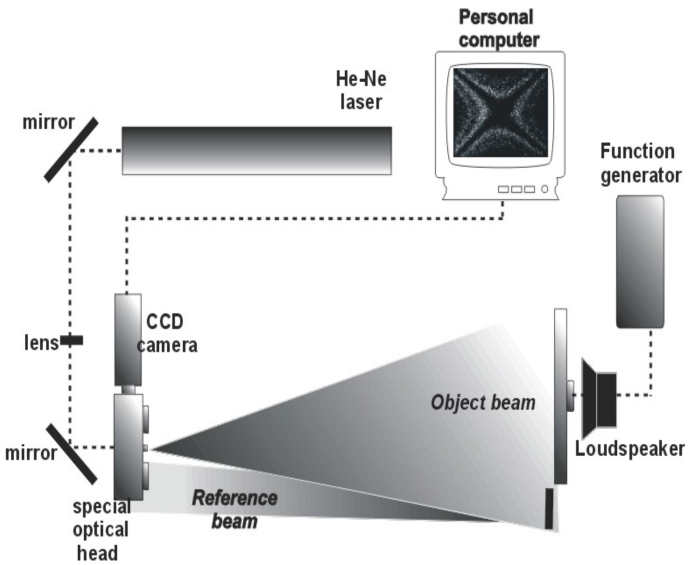

Figure 1. Schematic diagram of ESPI setup

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.

3. DETERMINATION OF DYNAMIC PROPERTIES

ESPI can observe a vibration modes and corresponding resonant frequencies of various shapes and different dimension investigated subjects.
The theory of plate vibrations allows us to determine Poisson’s ratio ν, Young's modulus E and shear modulus G in the case of isotropic composite materials and orthotropic materials from the measured resonant frequencies. We are able to analyse the damping behaviour and damping properties of various types of composite materials from measured mode shapes.
The results, which provide the relations between the measured resonant frequency and dynamic material parameters, are very well known in the literature, [1,2]
The specifically results of material characteristics of laminated composites are given in Rusnáková and all. (2005, 2006), [3,4].

4. THE POSSIBILITIES OF ESPI BY INVESTIGATIONS OF DEFECTS IN COMPOSITE MATERIALS

Instruments based on ESPI, double exposure holography or shearography are now available and can be used for tests and detection of various defects in composite materials in a transport industry.
In recent decades composite materials have found increasing use in structural applications because of their high specific tensile and compressive strength, and good fatigue and corrosion resistance properties. However, the response of composite structures can be greatly affected by presence of failure modes such as delaminations, matrix cracks and fiber fracture, which are typical of laminated composite materials. A fundamental problem in composite diagnostic is detection of material defects before and during the regular service of components. Fiber-reinforced materials, such as carbon/epoxy composites, have been successfully employed as structural materials in aerospace and aircraft industries. Severe damages to sandwich structures may occur as a consequence of microscopic disbands of the fiber-matrix interface, broken fiber, delamination or cracks. These defects may be due to fabrication errors, unwanted impacts, and excessive thermal or mechanical stress. In recent years, optical methods have been proposed for composite materials diagnostic. Optical testing of composites, through its different techniques, has two very general particularities: it has a full-field, non-contact character, and may detect a great number of defects. The most widely known of these techniques, electronic speckle pattern interferometry (ESPI), has already proved to be a technique of great potential in non-destructive testing of mechanical components and materials, especially composites. It is already a useful tool in detecting local anomalies such as flows, delaminations, voids, inclusions, imperfect gluing, broken glass or carbon fibres, and many others. Also is possible to detect rest of separates foils or another type of inhomogenities in laminate structure (prepreg technology). Success of detection of defects in composites strongly depends on size of defects and thickness of composite component. Non-destructive testing of composite products is very important, because many of these products are made by hand (hand-lay up) or by semi-automatic methods of production (vacuum molding, RTM). On the other hand, ESPI is very useful method also for investigation of vibration behavior of composite materials, especially laminate composites.

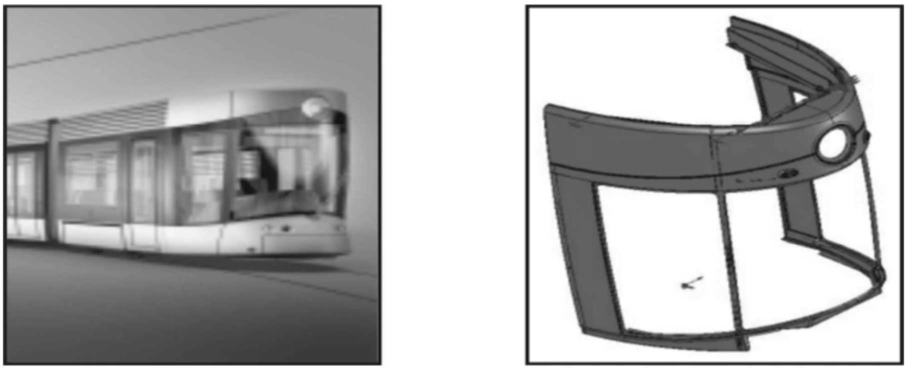

Figure 2. The face of the tram

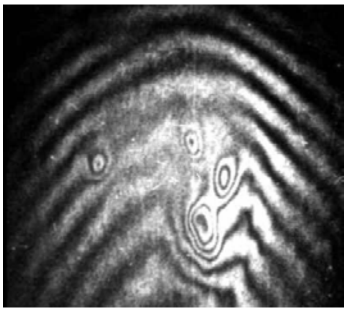

Figure 3. Honeycomb panel. [6]

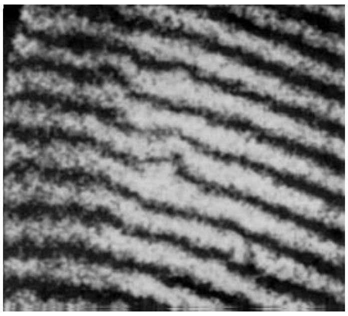

Figure 4. Delamination in aircraft component..[6]

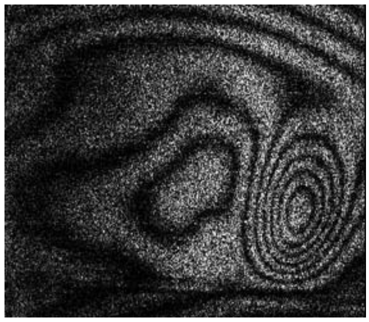

Figure 5. A large disband in aircraft component. [6]

Figure 3 shows a fringe pattern, with carrier fringes, on an aircraft component. Small irregularities in the fringes point out the effects of a delamination.
Figure 4 depicts an interferogram on an aircraft component (rotor blade). A large disbond is clearly present in correspondence of the oval fringe pattern in Figure 5. In this case the deformation fringes have an irregular appearance, which indicates the defect area, [6].

5. DETERMINATION OF FIRST RESONANCE MODES OF OSCILATING TIRES

Car tire is complexity construction with very wide range of dynamical modes under working loading – from static loading to high-frequency created vibration at amplitudes from micrometers to centimetres. Tyres are from viewpoint of mechanics very complicated dynamical system based on anisotropy composite structure with physical and geometrical non-linearities.
To basic dynamic properties of tires can be placed a spectrum of resonant frequency in which construction of tire oscillates preferentially.
ESPI – can sense only the change of deformation in the direction of observation. The ESPI can picture in the perpendicular sight to the wheel with tire only picture the dynamical displacements in the perpendicular direction to the surface of lateral side of the tire. Figure 6 describes the interference modes recorded during vibration tire in the one of the axial or radial vibration modes. The stiffness of the tyre is various on all directions. We can say on this fact that mode shapes – resonant modes are various, too.

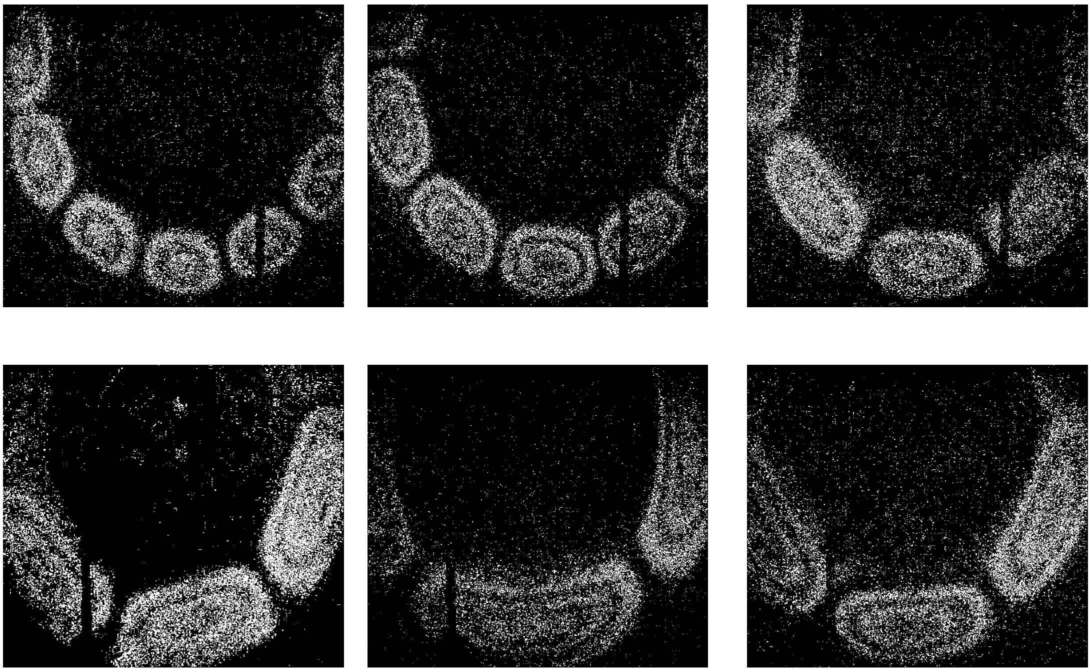

Figure 6. Resonant modes of oscillating tires.

6. THE POSSIBILITIES OF ESPI BY OBSERVATION OF VARIOUS ACTIONS IN CAR BODY

Laser measurement techniques are widely used in automotive development processes. Applications at Volkswagen are presented where laser metrology works as a diagnostic tool for analysing and optimising complex coupled processes inside and between automotive components and structures such as reduction of a vehicle's interior or outer acoustic noise, including brake noise, and combustion analysis for diesel and gasoline engines to further reduce fuel consumption and pollution.
Pulsed electronic speckle pattern interferometry (ESPI) and holographic interferometry are used for analysing knocking behaviour of modern engines and for correct positioning of knocking sensors. Holographic interferometry shows up vibrational behaviour of brake components and their interaction during braking, and allows optimisation for noise-free brake systems. Scanning laser vibrometry analyses structure-born noise of a whole car body for optimisation of its interior acoustical behaviour. Modern engine combustion concepts such as in direct-injection (DI) gasoline and diesel engines benefit from laser diagnostic tools which permit deeper insight into in-cylinder processes such as flow generation, fuel injection and spray formation, atomisation and mixing, ignition and combustion, and formation and reduction of pollutants. Necessary optical access inside a cylinder is realised by so-called 'transparent engines' allowing measurements nearly during whole engine cycle, [7].

7. CONCLUSION

Optical measuring methods have the advantage of being contact less, non-disturbing and whole field methods. They present "pictures" but they can be also being quantitative. Composite industry is today very popular, with big volume of different and unexplored materials. Also we can say that each composite product is original and we determine type of

material just in production process. For this reason can by ESPI (for its nondestructive character) very useful tool for identification basic material properties (ν, E, G) in composite industry.
Also we have eventuality to realize numerical calculations by finite element method, and the results compare with the experimental measurements. Subsequently we can use values obtained by ESPI method in computer simulation or we can compare this values with another measuring methods.
Another big possibility to use ESPI in composite industry is determination of inhomogenities in composite products – bubbles, delaminations and debonds.

8. REFERENCES

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