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# A STUDY ON THE VIBRATION CHARACTERISTICS OF CFRP COMPOSITE MATERIALS USING TIME-AVERAGE ESPI

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# A Study on the Vibration Characteristics of CFRP Composite Materials by using Time-Average ESPI

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## Abstract

The ESPI (Electronic Speckle Pattern Interferometry) is a real-time, full-field, non-destructive optical measurement technique. In this study, ESPI was proposed for the purpose of vibration analysis for new and composite materials. Composite materials have various complicated characteristics according to the materials, orientations, and the stacking sequences of the ply and boundary conditions. Therefore, it is difficult to analyze composite materials. For efficient use of composite materials in engineering applications the dynamic behavior (i.e., natural frequencies and nodal patterns) should be known. With the use of Time-Average ESPI, one could easily analyze vibration characteristics of composite material by real time. We manufactured two kinds of laminated composites (i.e., symmetry and asymmetry) which were composed of CFRP(Carbon Fiber Reinforced Plastics) and the shape of the test piece was of rectangular form.

## Introduction

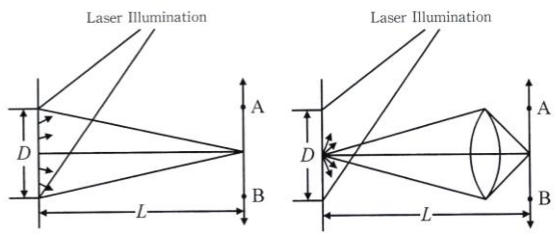
The Noise and vibration problems during the operation of vehicle engines and machine tools are one of the most important issues to machine designers (Suzuki, 1989; Sakada, 1979). To find the practical aspect of these problems, we have measured the vibration modes of rectangular plates clamped at two parallel edges by ESPI (Cloud, 1995; Ennos, 1975; Jones and Wykes, 1989). ESPI (Electronic Speckle Pattern Interferometry) (Kang and Moon, 1996; Kim and Yang, 1994; Kim et al., 1998), which was developed by adding the television image acquisition and the computer image processing to SPI, is a new method for the analysis of the vibration problems (Kang and Choi, 1996; Rastogi, 1997; Sirohi, 1993). In this paper, vibration modes are measured for laminated composite materials (Symmetry, Asymmetry). Frequencies obtained from the measurement are qualitatively compared with those of the theoretical analysis proposed by Warburton who considered the vibration of rectangular plates with all possible boundary conditions (Warburton, 1954). Shapes of vibration modes are quantitatively compared with those of numerical analysis using FEM (Finite Element Method, Nastran).

## Theory of ESPI

As shown in Fig. 1(a), when the laser light is illuminated to reflective plane , reglective pattern which is known as the objective speckle pattern is formed in the screen. If the wavelength of the laser light is λ, the diameter of circular region is D and the distance between the object surface and the screen is L, the average size of objective speckle is given by

$$S_{obj} \approx 1.2\lambda \frac{L}{D} \tag{1}$$

Speckle size is increased when the illuminated area is reduced. When alternatively, the laser light illuminated to the objective surface is focused with lens on the screen, speckle patterns are formed. As shown in the Fig. 1(b), this pattern(subjective speckle pattern) is formed when the reflective light is concentrated to the random direction from one point on the illuminated surface and the concentrated lights are interfered surface and the concentrated lights are interfered by each other.




(a) (b)
Fig. 1 Formation of (a) objective speckle, (b) subjective speckle

If M is magnification of the lens and F is the aperture ratio of the lens(F/Number), the size of subjective speckle on the scattering surface is given by

$$S_{suj} \approx 1.2(1+M)\lambda \frac{F}{M} \qquad (2)$$

Speckle phenomenon is occurred by coherency of the laser light. We have tried to eliminate the speckle that is background noise in holography. But, for a few years, we have used that phenomenon in the measurement such as SPI, which gives us easy measurement of in-plane deformation or vibration and does not require high level of stability of the instrument as compared with HI(holographic interferometry). SPI do not need the recording media with high resolution, whereas HI needs that. While the analysis of the speckle patterns is necessary, very fine fringes formed by the interference of object and holographic reference beam is not needed. The practical speckle size is within 5~50 $\mu m$. And this size may be changed to fit appropriately to the resolution limitation of the TV system. The major feature of SPI of ESPI is that they can create real-time correlation fringes to be displayed directly on a television monitor without recourse to any form of photographic processing, optical spatial filtering, or plate relocation. Because ESPI records the deformed image with a rate of 30 frames/sec, the effort to prevent the vibration is reduced in some extent. There is no need of the darkroom to process photo. Therefore, we found that ESPI could be easier than HI.

## Experimental Setup

Verified reliability of Time-Average ESPI system before experiment of this research. Specimen is aluminum metal of diameter 70mm, thickness 2mm. Laser used red color source diode laser of maximum output 20mW. Figure 2 shows a schematic of Time-Average ESPI used in this experiment.

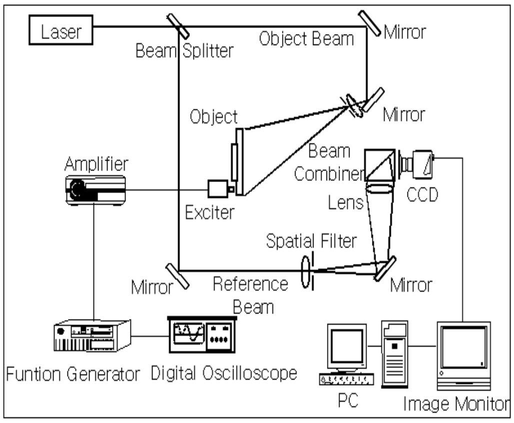
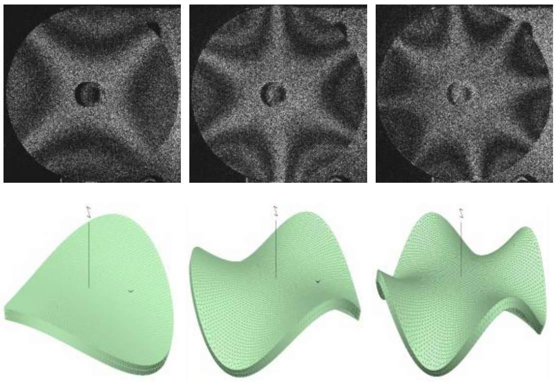



Fig. 2 schematic of Time-Average ESPI

Attach exciter behind specimen to shake specimen, connect amplifier and function generator. Can shake specimen by control function generator. The laser beam is divided into two parts by a beam splitter. One beam, called the object beam, travels to the specimen and to the CCD camera. The other beam, called the reference beam, goes directly to the CCD camera via mirrors. Beam combiner was set in front of the CCD camera. Correlation of two beams is occurred on the CCD array. A video system converts an image formed on the CCD array into an equivalent image on a PC monitor screen. The vibration frequencies of the specimen were approximately determined by using the Time-Average ESPI. Figure 3 is as result that compare Time-Average ESPI and FEM(Finite Element Method, Nastran) vibration mode. Experiment result of Time-Average ESPI has error rate ±5%. Study had performed an experiment by this system(error rate ±5%).



(a) 2180Hz (ESPI) 2130Hz (Nastran) (b) 4900Hz (ESPI) 4930Hz (Nastran) (c) 8610Hz (ESPI) 8610Hz (Nastran)

Fig. 3 Compare Time-Average ESPI with Nastran

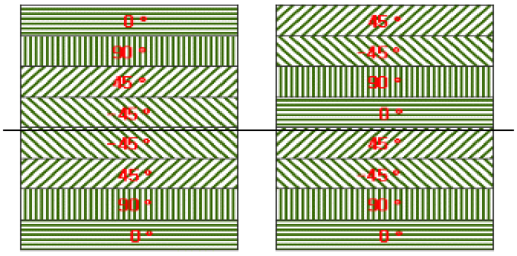



Fig. 4 (a) symmetry laminated plate, (b) asymmetry laminated plate

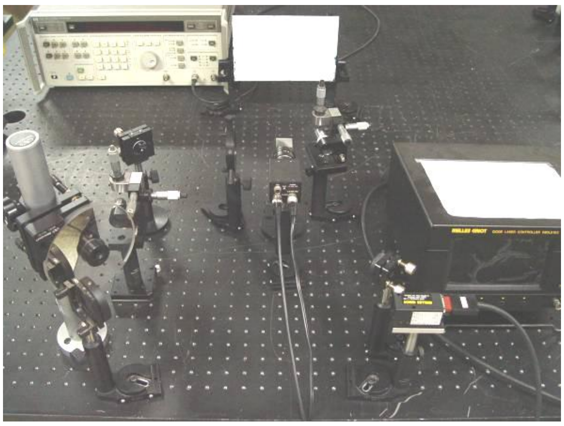


Fig. 5 Time-Average ESPI system setting

We manufactured laminated composite materials of symmetry and asymmetry configurations, which consisted of CFRP(Carbon Fiber Reinforced Plastics) and the shape of the specimen was of rectangular form. We used a laminated plate of fabric form that was not a laminated plate in uni-direction. The laminated composite material specimen had a thickness of 3mm and a size of 200mm by 150mm. Figure 4 shows the two kinds of CFRP : (a) symmetry laminated plate $[0°/90°/45°/-45°]2_S$ and (b) asymmetry laminated plate $[45°/-45°/90°/0°]2_T$. A photographic image of the Time-Average ESPI system to measure vibration mode is shown in Fig. 5. The system verification is shown in Fig. 3 with an error rate of ±5% and the experimental method was the same.

## Experimental Result

Each of the vibration fringe patterns of symmetry and asymmetry laminated composite materials are shown Fig. 6 and 7. The fringe patterns were of different form with uni-direction composite materials than those that were studied previously. The fringe patterns of symmetry laminated composite materials were clearer than the asymmetry laminated composite materials.

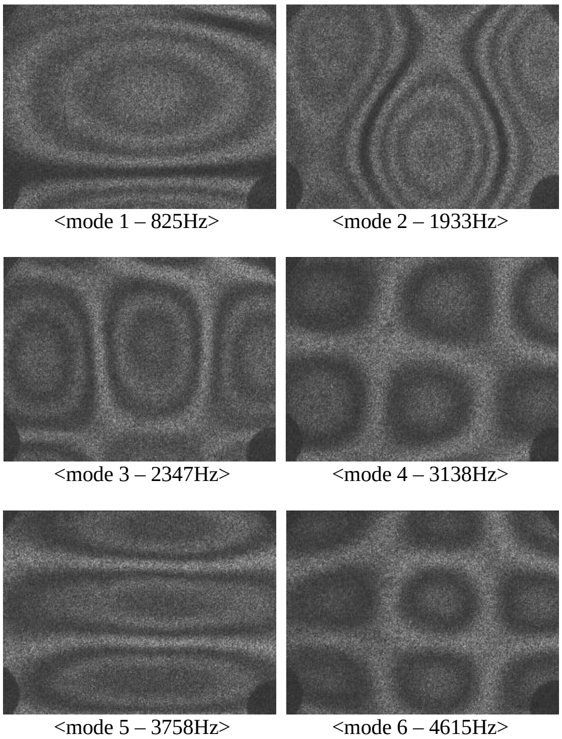



Fig. 6 Vibration fringe patterns of symmetry laminated composite materials

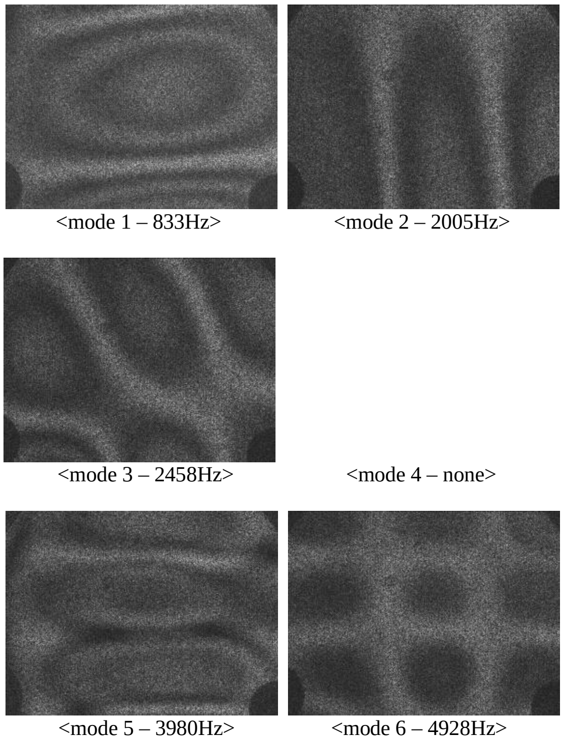



Fig. 7 Vibration fringe patterns of asymmetry laminated composite materials

## Conclusion

In this study, we composed Time-Average ESPI system by using laser with an error rate of ±5%. This system could measure vibration mode of laminated plate in fabric form. Also, could evaluate practical application of this Time-Average ESPI system as that manufacture symmetry and asymmetry laminated composite materials and measure vibration mode by this system. The fringe patterns of symmetry laminated composite materials were clearer than those of the asymmetry laminated composite materials. The shape of the vibration mode was more unstable in asymmetry laminated composite material, which was not able to detect vibration mode 4. This Time-Average ESPI system could measure vibration mode and natural frequency without being influenced with the state of interior as well as external forms and the quality of the material. When we observe the vibration mode using FEM(Finite Element Method), we must know first the properties, the state and the condition of composite materials. But, if we use Time-Average ESPI system in this study, we don't need to know the properties, the state and the condition of composite materials and we could observe the vibration mode by real time in an easier and faster way.

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