Automatic Vibration Mode Analysis with ESPI

Introduction

The determination of the modal parameters is one of the most difficult and time-consuming tasks in experimental component testing. Particularly components that require full-field information, about the modal behavior, require time consuming and complicated measuring procedures. In order to improve this situation, an automatic modal analysis system has been developed based on the full-field speckle interferometry measuring technique, ESPI.

Determination of amplitude and phase

A vibrating object is illuminated with the laser light at two different positions, e.g. at 0° and at 180° of the vibration excitation. The ESPI image will show the deformation amplitude between these two exposure times. Since, in the general case the phase between the excitation and the object vibration is not known, one cannot be sure to be seeing the maximum amplitude with this double exposure technique. Therefore, in case of sinusoidal excitation, a minimum of

2 different time settings are required to determine the absolute amplitude and phase at each point of the image. For practical reasons, typically more images at different time settings are taken in order to eliminate measuring errors, fig.2.

ESPI technique

Electronic speckle pattern interferometry (ESPI) can be used for non-contact, full-field and three-dimensional measurement of static or dynamic deformations of components. The component to be analyzed is illuminated with a laser and the image recorded with a camera, fig. 1. The comparison of two images, taken at two different times, provides a map of full field deformation between the two states of the object.

Reference point used

The complete set-up for automatic mode analysis is shown in fig. 3. The object is excited by a shaker. The vibration signal and the output of a force sensor is recorded with a signal analyzer.

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A point-measuring sensor (accelerometer or laser vibrometer) is used to provide the time signal of the vibration of the object at one point in the measuring field. ESPI techniques typically show relative deformations. Therefore, this point is used as reference point for the ESPI measurement. Complimentary it determines the absolute amplitude level of the precise ESPI measurement of relative displacement.

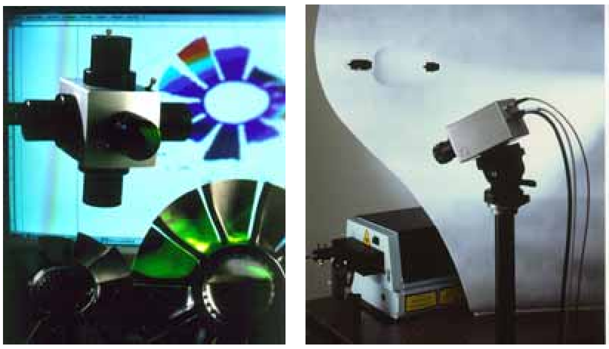

Fig. 1: VibroESPI and PulsESPI camera for automatic vibration modal measurement

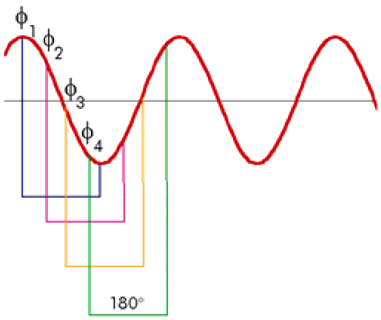

Fig. 2: Different measurement positions for automatic amplitude and phase determination

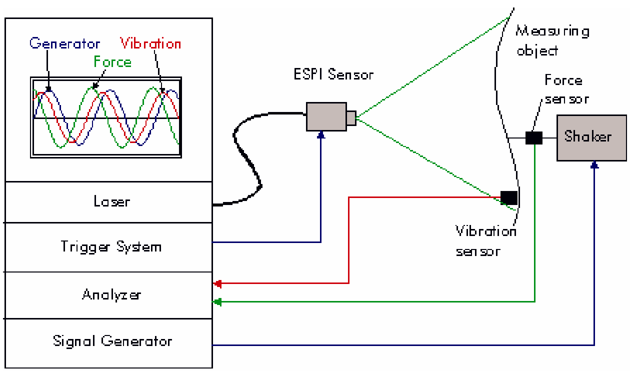

Fig. 3: Principal set-up for automatic vibration modal analysis

Amplitude and phase calculation

In the automatic inspection mode, the system records a minimum 3, but typically 6 to 8 images, at different phases between the recording times and the excitation signal, but at the same frequency. Each image gives an amplitude distribution as indicated in fig. 4, where the different colours represent different amplitude levels. When the phase between excitation and recording is shifted, the amplitude is reduced to zero and eventually changes sign. These images are used to calculate the imaginary and real amplitude of each pixel in the image, fig. 5. While theoretically, only two images are required to calculate real and imaginary amplitude of a sinusoidal function, multiple images are recommended to avoid noise, especially close to the nodal lines, which have small amplitudes. At the same time, the amplitude and phase can be calculated from the real and imaginary part of the vibration for every pixel in the image, fig. 6.

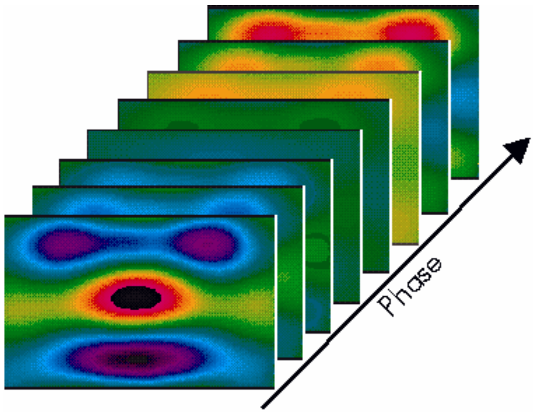

Fig. 4: Change of amplitude distribution at different phase positions

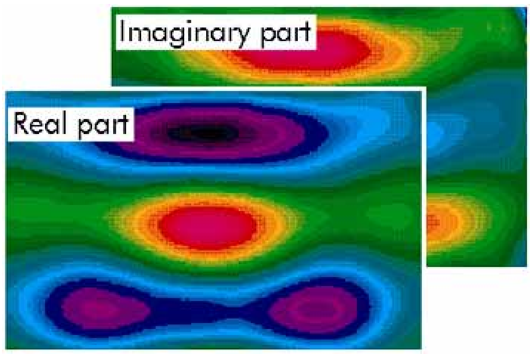

Fig. 5: Real and imaginary part of the amplitude, obtained by multiple measurement at constant frequency with different phase positions

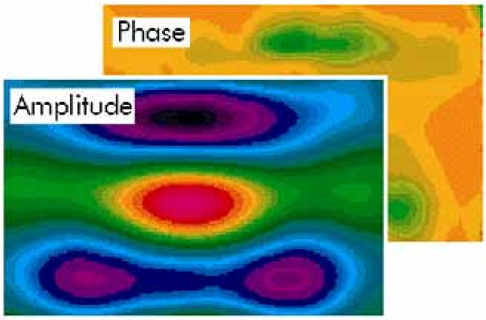

Fig. 6: Calculated absolute amplitude and phase at a certain frequency

Automatic frequency sweep

This procedure is automatically repeated at different frequencies around each resonant mode. The amplitude and phase of the force signal and of the reference point are recorded. If required, the software also can automatically adjust the force to constant level for each frequency step. With this new frequency, the automatic amplitude and phase measurement is repeated. The result is a set of images with amplitude and phase distributions at the different measured frequencies, fig. 7 and 8. In order to minimize the amount of data, typically a frequency range around a resonance is automatically analyzed in 10 to 20 frequency steps. The software allows the definition of several frequency blocks with different frequency steps and different force levels, which will automatically be analyzed.

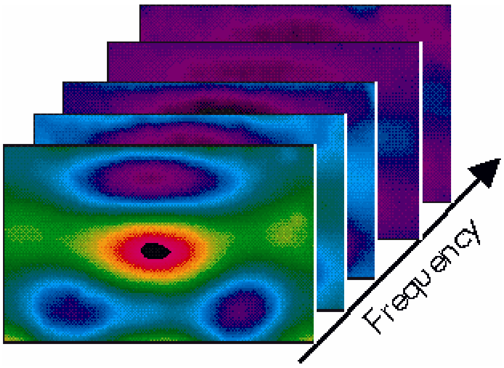

Fig. 7: Change of absolute amplitude distribution at different frequency positions

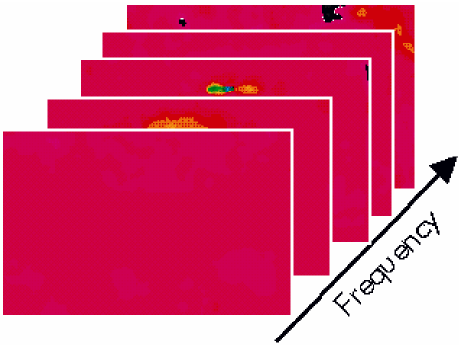

Fig. 8: Change of phase distribution at different frequency positions.

Data exportation

The system's format for the output of data to vibration analysis software packages is the Universal File Format (UFF). In the ESPI measuring area, a set of measuring nodes can be defined. At these nodes, the measuring data are automatically exported into a UFF file and can be read by the modal analysis software. Fig. 9 shows a measuring field on a plate. The blue rectangle shows the complete measuring field, the blue crosses indicate the data nodes for export. The number of nodes and their positions are variable. Also, the reference point and the point of excitation by the shaker are indicated.

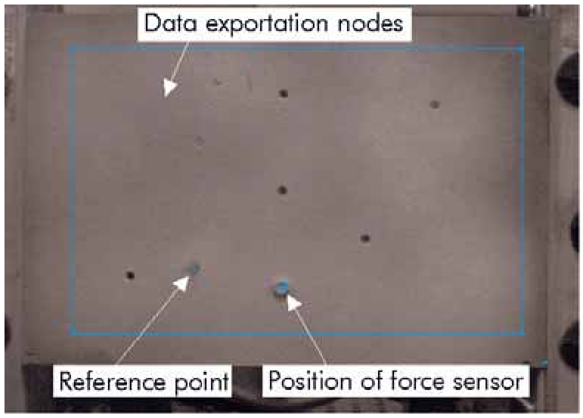

Fig. 9: Definition of data exportation and analysis points

Measurement example

The following figures show the results of an automatic measurement on the earlier mentioned plate in the frequency range between 1540 Hz and 1590 Hz. The plate was clamped at two sides and excited by an electrodynamic shaker. A laser vibrometer measured the absolute vibration at the reference point. In this frequency range the vibrometer has shown a peak amplitude. The force signal shows the resonance at 1565 Hz, fig. 10. In fig. 11 the measuring results (amplitude, phase, real part, imaginary part) of the laser vibrometer and the ESPI system are compared. All results are scaled to constant force. At the same time, the ESPI system delivers the vibration information at all points in the measuring field. Fig. 12 and 13 show amplitude and phase signals at some of the 80 selected measuring nodes. Since all the data can be exported in the UFF they can be post-processed without restrictions.

Summary

Automatic modal analysis with ESPI techniques shows the advantage of non-contact and fast generation of vibration information over the complete measuring area. The full-field simultaneous measuring technique allows for the analysis of complex vibration modes at the same speed as simple modes. In addition, non-steady events can be investigated.

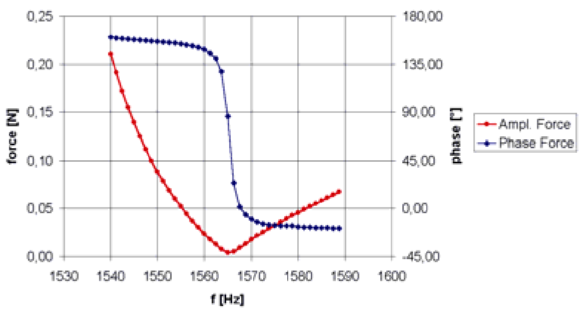

Fig. 10: Amplitude and phase of force signal at resonancy.

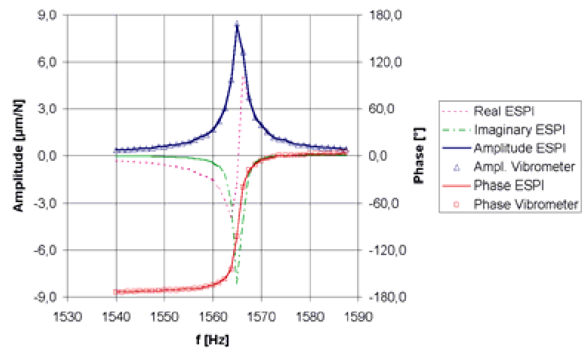

Fig. 11: Comparison of amplitude and phase measured with ESPI and with Vibrometer

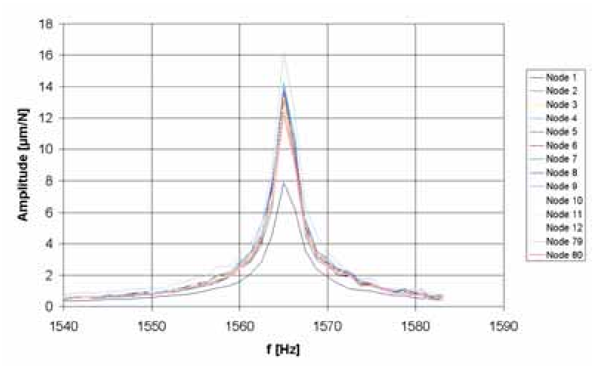

Fig. 12: Comparison of amplitude signals at different measuring points

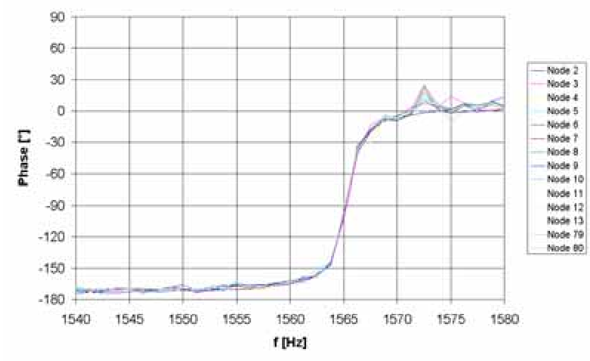

Fig. 13: Comparison of phase signals at different measuring points

References:

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For more information please contact:

Dantec Dynamics GmbH
Kaessbohrerstrasse 18
89077 Ulm
Germany

Tel.: +49-731-933-2200
Fax: +49-731-933-2299

E-mail: product.support@dantecdynamics.com
Internet: www.dantecdynamics.com