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A comparative algorithm for the detection of defects from holographic interferograms

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Introduction

Time averaging laser holographic interferometry is a classical technique used for the analysis of structural vibrations. It is especially effective when the vibration amplitudes are low (what is natural at high frequencies) and can be correlated with the wavelength of the laser beam. Time averaging holography is usually practised for examination of the response of structures to harmonic excitation, though it can be also applied for other kind of motions like transient vibrations, constant velocity vibrations [2, 7, 9, 10].

Nevertheless, small attention was devoted for the analysis of applicability of time averaging laser holographic interferometry for the structures performing stochastic or harmonic vibrations in the presence of background noise, or in case when the structures are non-linear. As the production of optical holographic interferogram is a complicated experimental procedure requiring skills and experience and it is important to differ the "wrong" measurement results caused by the malfunction of the optical system and the physical reasons producing specific effects, computer modelling is used for futher analysis.

Dedicated software applications were developed for the construction of patterns of interference lines from the dynamic finite element results. Such modelling enabled straightforward correlation between the physical formation of holographic interferograms and the precisely defined motion of analysed structures [1, 5, 6, 8].

The numerical method for the location of defects from holographic interferograms is proposed. It is illustrated for the problem of the analysis of the vibrations of the plate with the variation of the thickness.

Physical background

The intensity of illumination at the surface of the hologram formed by the time averaging laser interferometry is defined by the following relationship [3]:

$$I(x,y)=\lim_{T\to\infty}\left(\frac{1}{T}\left|\int_0^T \exp\big(ja(x,y)\xi(t)\big)dt\right|\right)^2, \qquad (1)$$

where j denotes the imaginary unit; t – time; T – the time of exposition; $a(x,y)$ – function not dependent on t; $\xi(t)$ – function describing the motion of the point (x, y) on the surface of the structure in the direction of the z axis; I – intensity of illumination.

When the projection plane is parallel to the structure in the status of equilibrium, and the coherent laser beam is perpendicular to the projection plane, then $a(x,y)$ defines the amplitudes of vibration at different locations on the surface of the structure.

The relation between the intensity of illumination I and the motion of the structure $w(t)$ can be characterised by a number of interesting features. One of the important features from the point of view of experimental analysis is that the intensity does not depend on the static deformations of the structure. In fact, the intensity characterises the magnitude of vibrations around the status of equilibrium. If $\varsigma(t)=q(t)+b$, where b is a constant, then

$$T\sqrt{I}=\left|\int_0^T \exp\big(ja(q(t)+b)\big)dt\right|=$$
$$=\sqrt{\cos^2 ab+\sin^2 ab}\left|\int_0^T \exp\big(jaq(t)\big)dt\right|= \qquad (2)$$
$$=\left|\int_0^T \exp\big(jaq(t)\big)dt\right|$$

If $q(t)$ is a harmonic function,

$$I=\left(\frac{1}{T}\left|\int_0^T \cos\big(aq(t)\big)dt\right|\right)^2 \qquad (3)$$

due to the fact that

$$\lim_{T\to\infty}\frac{1}{T}\int_0^T \sin\big(aq(t)\big)dt=0. \qquad (4)$$

By the way, when

$$\varsigma(t)=\sin(\omega t+\varphi), \qquad (5)$$

where ω and φ denote the frequency and phase of harmonic vibrations, the expression of the intensity takes the form [5]:

$$I=\left|J_0^2(a)\right|, \qquad (6)$$

where J_0 – the zero order Bessel function of the first kind. Another important feature of the time averaging holographic interferometry is that the pattern of interference bands does not hold any information about the frequency of vibrations.

Algorithm of comparative analysis

A novel method for location of defects is developed. It is based on the digital analysis of optical holograms of a structure without and with defects. The advantages of this method are in the fact that the locations of the defects can be performed by comparative methodology in the virtual

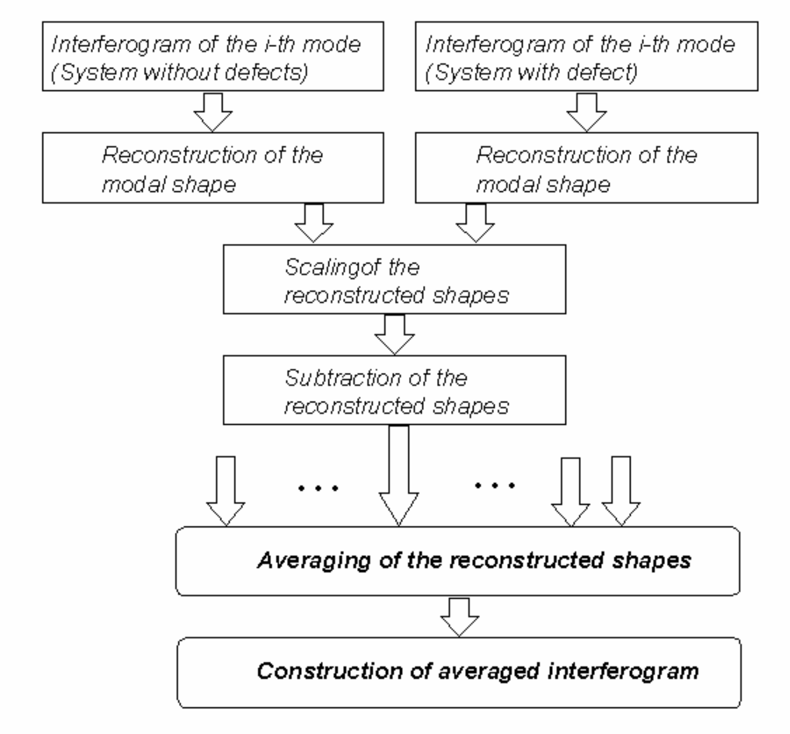

Fig. 1. **The schematic diagram of the algorithm for the detection of defects from holographic interferograms**

environment, while the holograms themselves can be registered using optical means (Fig. 4).

The algorithm for the location of defects consists from the following main steps:

- Registration of holograms for the structure without defects at different eigenfrequencies.
- Registration of holograms for the structure with defect at the same eigenfrequencies.
- Reconstruction of amplitude fields from the recorded holograms. This step requires the localisation of the centers of interference fringes, calculation of amplitudes from inverse Bessel functions and approximation of the surface through the pattern of izolines produced from the interferogram [7, 3].
- Construction of the difference of amplitude fields for every pair of holograms for appropriate excitation frequencies.
- Averaging of differences for the whole range of frequencies.
- Reconstruction of the interferogram from the averaged amplitude field.

The presented methodology is illustrated by Fig. 5 where the defect caused by the variation of the thickness of a cantilever plate was detected by the described method.

A special attention must be devoted for the scaling of the reconstructed shapes. The interference line patterns in the holographic interferogram do not carry information about the phase of vibration. It is not possible to identify the phase values of antinodes explicitly from interferogram. Therefore it is important to take care that the compared fields of reconstructed amplitudes are scaled in phase, otherwise small variations caused by the defect would be washed out due to large phase differences.

The procedure of the reconstrunction of amplitude fields from interferographic patterns is illustrated by Fig.3. It is clearly seen that the field of amplitudes does not hold the information about the phase of oscillation.

Further steps of the procedure are illustrated using numerical modelling tools whereas the thickness of the cantilever plate is varied as shown in figures Fig.4 and Fig.6. It must be noted that those figures are built out of scale, just providing the quantative information about relative thickness at appropriate elements.

Interesting result is that the reconstructed averaged interferograms do not provide information about the type of defect – in our instance if it is smaller or higher thickness at the zone of the defect. Anyway, the location of the defect is reconstructed with astonishing accuracy, keeping in mind that the numerical model involved really coarse grid, and the principle of detection is based only on the comparison of eigenshapes.

Naturally, this is a reference type method as it cannot be applied without having a data base characterising the dynamic features of a structure without defects. This drawback can be compensated if the methodology is used in trend-based analysis systems where the reference data on the analysed object is available apriori. Also, this method involves extensive computations, but modern computer technologies and effective algorithms make it attractive for analysis of complex structures like micro-cantilever plates or turbine blades. Besides, the methodology is scalable for parallel computations.

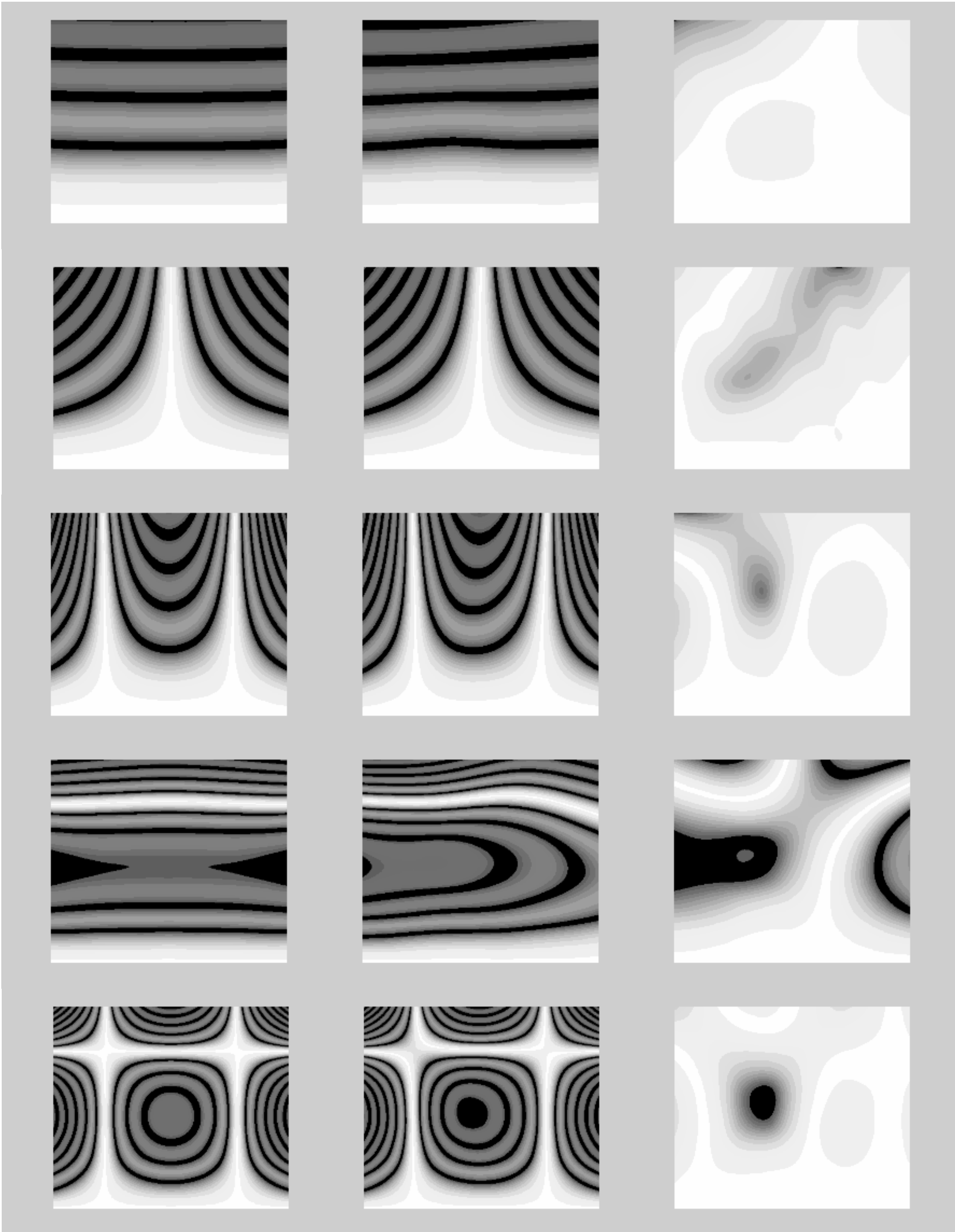

Fig. 2. **Interferograms of a cantilever plate with clamped bottom side: left column – construction without defects, right column – construction with a defect, third column - the relative difference of the fields of amplitudes; rows correspond to corresponding eigen-frequency of vibrations**

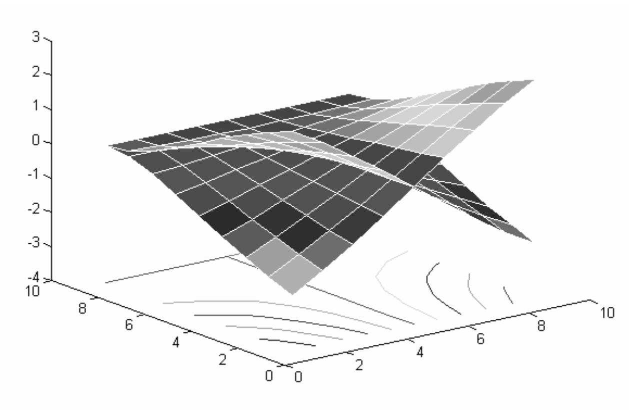

Fig. 3**. Reconstructed field of amplitudes for the second eigenshape of contilever plate without defects**

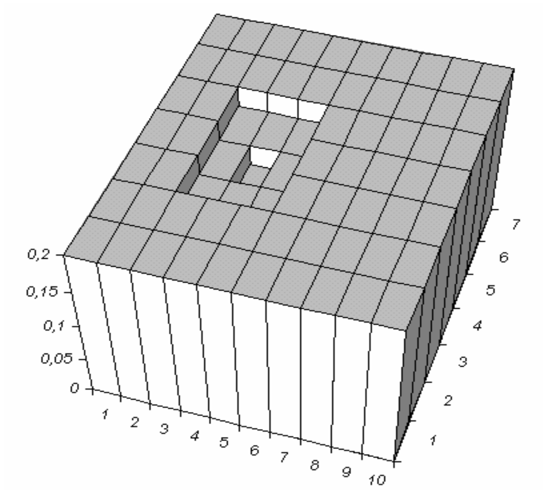

Fig.4. **Schematic drawing of the thickness of plate at appropriate finite elements**

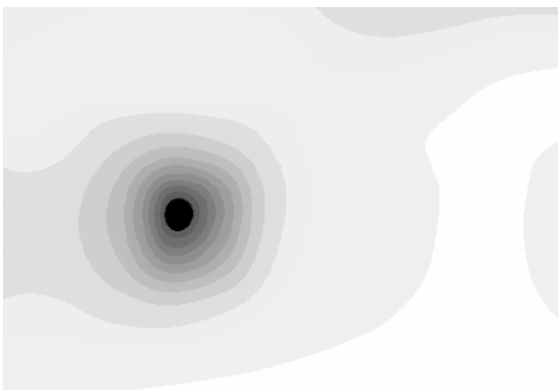

Fig.5**. Reconstructed intensity of the averaged interferogram**

Conclusions

The problem of visualisation of microvibrations is important in engineering of precise mechanical systems.

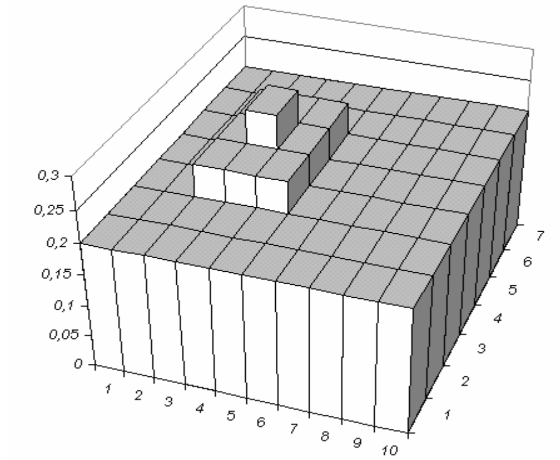

Fig.6. **Schematic drawing of the thickness of plate at appropriate finite elements**

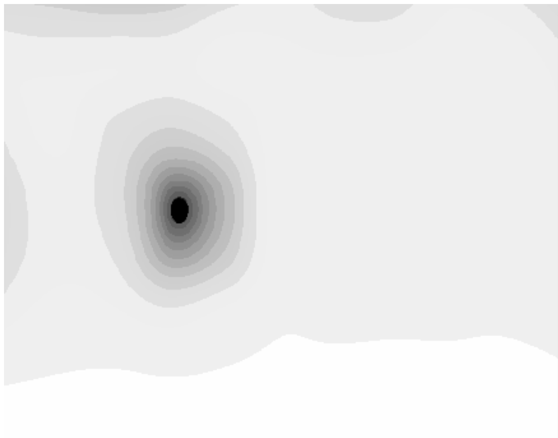

Fig.7**. Reconstructed intensity of the averaged interferogram**

The plotting of interference bands from the results of finite element analysis has clear physical background compared to other visualization techniques. Also that is important because of the ability of direct comparisons with the experimental results of holographic optical analysis. Presented methodology for the detection of defects is scalable in parallel computations and applicable to a wide variety of problems.

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Lyginamasis defektų detekcijos iš holografinių interferogramų algoritmas

Reziumė

Pasiūlytas naujas defektų lokalizavimo metodas, pagrįstas lazerinių laiko vidurkinimo interferogramų palyginimu rekonstruojant nagrinėjamos sistemos judesius esant skirtingiems rezonansiniams dažniams. Analizės procedūrose įvertinama tai, kad interferogramos neteikia informacijos apie judesio fazes. Ši metodika išplečiama paraleliniams skaičiavimams ir gali būti pritaikyta daugeliui problemų spręsti.

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