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Holographic – nondestructive inspection of Litas banknotes

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Introduction

While holography is often used to obtain recreations of 3-dimensional objects, many industrial applications of holography make use of its ability to record two slightly different scenes and display the minute differences between them. This powerful technique, called interferometry, is an invaluble aid in design, testing, quality control, and analysis [1-4]. Holographic techniques are nondestructive, realtime, and definitive in allowing the identification of vibrational modes, displacements, and motion geometries.

If the object under study is changed or disturbed in some way during the hologram exposure or from one exposure to the next, then a pattern of "fringes" will appear on the image itself, making the object look striped. These fringes really represent maps of the surface displacement caused by the force or stress that disturbed the object.

Such a displacement map represents an extremely sensitive picture of the actual motion the object has experienced, with a single fringe contour representing lines of equal displacement. Holograms can record motions and displacements, deformations and bends, and expansions and contractions on virtually any object. The typical optical laser used in holographic interferometry gives an accuracy better than a half wavelength, and both qualitative and quantitative information can be derived from the fringe patterns. This allows us to look at the effects of vibration, temperature, stress and strain, and other physical forces in an entirely nondestructive way. A powerful feature of holographic interferometry is that information is obtained over the entire illuminated surface of the object being studied as a full and continuous field, which is important in understanding what is happening to the object as a whole [5-8].

The holographic interferometry is used in vibration and modal analysis, structural analysis, composite materials and adhesive testing, stress and strain evaluation, and flow, volume/shape, and thermal analysis. All these applications derive from one or more of the three basic methods of the applied holographic interferometry: real-time, multiexposure, and time-average holography.

Interferometric nondestructive testing can be accomplished with either continuous or pulsed lasers of almost all wavelengths. The continuous lasers are ideal for real-time studies of displacement and motion. The pulsed lasers can be synchronized with a motion and also can record holograms of extremely fast transient phenomena. The real-time holography allows one to observe instantaneously the effects of minute changes in displacement on, or in, an object as some stress affects it. This is done by superimposing a hologram of an object over the object itself while it is being subjected to some small force or stress. Multiexposure holography creates a hologram by using two or sometimes more exposures. The first exposure shows an object in an undisturbed state. Subsequent exposures, recorded on the same image, are made while the object is subjected to some stress. The resulting image depicts the difference between the two states.

The third technique, time – average holography, involves creating a hologram while the object is subjected to some periodic forcing function. This yields a dramatic visual image of the vibration pattern.

All these techniques reveal the shape, direction, and magnitude of the stress induced displacements in the structure under study. An important key to the holographic interferometry's success is that it allows the use of a very low-level, nondestructive stress to collect data that once required destruction of the material.

The aerospace industry, automotive manufacturers [9-11] and many other commercial and defense related industries rely on the holographic interferometry to investigate and test everything from microscopic computer chips and circuits [12] to automotive components and even large sections of entire aircraft and spacecraft.

These sophisticated tests have become useful in developing quieter machinery, lighter and stronger materials [13], and successful assembly of systems that will experience great stress. The holographic interferometry is a powerful ally in the field of nondestructive testing and inspection.

The holographic interferometry method for nondestructive testing and inspection of Litas banknotes is proposed in this paper.

Peculiarities of origin of holographic interference bands

In full field nondestructive testing using holographic interferometry methods it is necessary to describe the physical origin of the interference bands, the function describing the intensity of these bands and the methodology of their interpretation.

The applied method for development of the interference patterns on the surface of a vibrating body is based on the Time–Average methodology which presumes that the exposition of the vibrating surface to the laser beam is many times longer than the period of vibrations.

In the case when each point of the surface performs harmonic oscillations, the averaged lightening intensity distributed on the vibrating surface may be described by the following formula [5]:

$$I \approx \left| \frac{a}{T} \int_0^T \exp\left\{ -i \left[\psi_0 + \frac{2\pi}{\lambda} \int_0^t (\cos\theta_1 + \cos\theta_2) R dt \right] \right\} dt \right|^2, (1)$$

where I – intensity; T – time of exposition; λ – length of the laser beam light; R – the vector of vibration; t – time; θ_1 – angle between the lightening and the vibration vectors; θ_2 – angle between the observation and the vibration vectors; $\psi_0 = \frac{2\pi \sin\theta}{\lambda}$; θ – angle between the observation and the normal vector of the hologram plane; a – the coefficient of the light reflection of the surface (Fig.1).

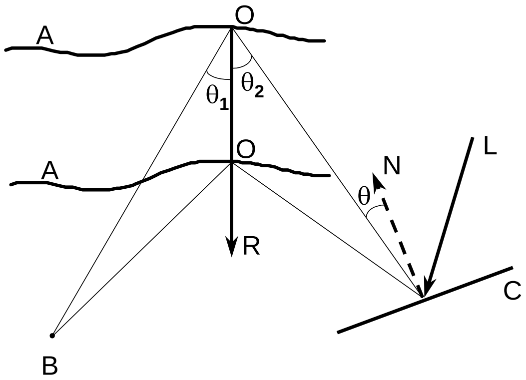

Fig. 1. **The scheme of holographic experiment: A – oscillating object; B – laser light source; C – hologram plate; O – point on the surface of the body; R – vector of displacement; L – reference laser beam; N – normal vector of the hologram plate**.

For a harmonic vibration Eq. 1 takes the form:

$$I \approx a^2 J_0^2 \left[\frac{2\pi A}{\lambda} (\cos\theta_1 + \cos\theta_2) \right]. \quad (2)$$

When $\theta_1 = \theta_2 = 0$, Eq. 2 takes the form:

$$I \approx a^2 J_0^2 \left(\frac{4\pi A}{\lambda} \right). \quad (3)$$

The function (3) modulates the intensity of the reconstructed object and forms the pattern of interference bands on its surface. Anyway, this method of band reconstruction has certain limitations in the case when the amplitudes of the reconstructed object are large. The brightness of the bands is rapidly declining as the amplitudes increase. E.g. the brightness of the tenth band is only 2% of the nodal band (the motionless area of the object). Thus, it is almost impossible to analyse an object the vibration amplitude of which exceeds 5λ.

The numerical modelling of the interference pattern using the time averaging method requires seeking for possibilities enabling clearer representation of the bands. At the same time, it is unconditionally important not to damage the physical relationships causing origin of the bands. The closest interference analysis method to the time averaging is the strobo–holographic method. Its idea lies in the property of the laser beam the exposition of which is synchronised with the appropriate phase of the vibration.

In that case the distribution of intensity is described by [5]:

$$I = a^2 \left| J_0\left(\frac{4\pi A}{\lambda}\right) + 2\sum_{p=1}^{\infty} J_{2p}\left(\frac{4\pi A}{\lambda}\right) \frac{\sin\left(2p\,\pi/k\right)}{2p\,\pi/k} (-1)^p \right|^2. \quad (4)$$

It is clear that in the case when the exposition is continuous (what corresponds to $k = 2$), $\sin(2p\pi/k) = 0$ for all p. Hence, Eq. 4 takes the form of Eq. 3. As the parameter k tends to infinity, double exposition method is obtained from Eq. 4, – when two views are projected on the same object (motionless and momentary view of the excited object). The interference pattern of these two positions may be described by the following relationship:

$$I = a^2 \left| J_0\left(\frac{4\pi A}{\lambda}\right) + 2\sum_{p=1}^{\infty} J_{2p}\left(\frac{4\pi A}{\pi}\right) \cos 2p \frac{\pi}{2} \right|^2. \quad (5)$$

Here $(-1)^p$ is substituted by $\cos p\pi$, and $\sin(2p\pi/k)/(2p\pi/k)$ is approximated by 1 in Eq. 5. Applying the facture of even Bessel functions, Eq. 5 is transformed to:

$$I \approx a^2 \cos^2\left(\frac{4\pi A}{\lambda}\right). \quad (6)$$

The intensity distribution described by Eq. 6 guarantees good quality of reconstructed interference bands and, therefore, is well pertinent for the analysis of holographic interferogram.

Experimental setup

Fig. 2 presents the structural diagram of a setup for experimental analysis of the Litas banknotes and the acoustical exciter. The stand contains a arrangement for fixing banknote 1, the acoustical exciter of which is harmonically excited by the high-frequency signal generator 2 and the amplifier 3.

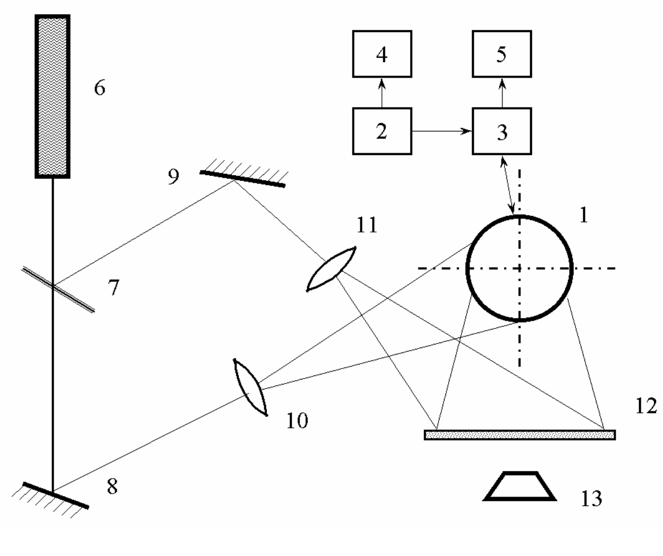

Fig. 2. **The schematic drawing of the laser holographic interferometry system.**

The signal frequency is monitored by the frequency meter 4, the voltage amplitude of the power supply is monitored by the voltmeter 5. The optical circuit of the stand includes a holographic installation with a helium-neon laser which serves as a source of coherent radiation. The beam from the laser 6 splits into two mutually coherent beams passing through the beam splitter 7. The object beam, reflected by the mirror 8, is split by the lens 10 and illuminates the surface of the investigated Litas banknote 1 and, after reflecting from it, impinges on the photographic plate 12. The reference beam, reflected by the mirror 9, and expanded by the lens 11, illuminates the holographic plate 12, where the interference structure is recorded.

Six different Litas banknotes samples were investigated using strobo-holographic method with acoustical excitation. The first column in Fig. 3 represents holograms of 100, 200 and 500 original Litas banknotes. Second column – the holograms of the faked of Litas banknotes. It can be noted that the falsifications are of very good quality and cannot be recognised without special test equipment. Nevertheless, the laser holography provides a powerful tool for the detection of falsifications. The same field of acoustic emission generates different response of the banknotes thus producing different patterns of interference fringes.

Naturally every experimental analysis method has its strengths and drawbacks. A certain drawback of the presented methodology is that the analyzed banknote samples must be new. If the banknotes are used, the mechanical properties of the banknotes are altered and the detection of falsifications is much more complicated. Nevertheless, this fact does not lessen the practical value of the method and can be successfully applied for identification of falsifications of different treasure papers.

Fig. 3. **Holographic interferograms of Litas banknotes**

Conclusions

Full field optical techniques have reached a level of maturity that makes it possible their application in a full range of areas of industrial interest and also for the nondestructive inspection of the Litas banknotes.

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Holografinė litų banknotų patikra

Reziumė

Aprašomas Lietuvos piniginio vieneto - lito - banknotų tyrimas holografinės interferometrijos suvidurkinimo laike metodu. Iš akustiškai sužadintų banknotų paviršiuose lokalizuotų interferencinių juostų galima spręsti apie banknotų kokybę.

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