556. Application of laser methods for identification of authenticity of documents fabricated from thermoplastic composite material

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Abstract. Processes of globalization and integration are pervasive all over the world, and rapid innovation of advanced transportation systems resulted in enormous increase in number of persons travelling cross-border. Normally, persons crossing the border are checked at the first control line. Therefore, application of innovative methods that allow identification of partial alterations in a document or a fully counterfeit document, for initial checking of documents remains a relevant issue. The holographic interferometry represents one of the non-destructive control methods applicable for document check that enables assessment of defects in the entire area of a document being checked. This paper presents validation of the real-time method of holographic interferometry used for document check as well as parameters of a holographic setup, description of document investigation and analysis of the obtained findings.

Keywords: holographic interferometry, mechanical vibration, acoustic excitation source, travel documents.

Introduction

Processes of globalization and integration are pervasive all over the world, and rapid innovation of advanced transportation systems resulted in enormous increase in number of persons travelling cross-border. Normally, persons crossing the border are checked at the first control line. According to the Schengen Borders Code [1], "all persons shall undergo a minimum check in order to establish their identities on the basis of the production or presentation of their travel documents. Such a minimum check shall consist of a rapid and straightforward verification, where appropriate by using technical devices and by consulting, in the relevant databases, information exclusively on stolen, misappropriated, lost and invalidated documents, of the validity of the document authorizing the legitimate holder to cross the border and of the presence of signs of falsification or counterfeiting". Such a procedure used for checking citizens crossing border from the third countries takes up to 3 minutes on the average [2], consequently both the human factor and appropriate technical devices play an increasingly important role here. Technologies used for production of travel documents are continuously improved in order to combat and prevent their falsification however officers working at the first control line use technical devices that facilitate decision-making regarding document authenticity without any destruction or disturbance of a document, though capabilities of such devices are limited, and authenticity of a document security can be checked with ultraviolet, transmitted, oblique and coaxial lights. Consequently, application of the innovative methods that allow identification of partial alterations in a document or a fully counterfeit document, for initial checking of documents remains a relevant issue.

Interferometry represents one of the non-destructive control methods applicable for document check that allows assessment of defects in the entire area of a document being checked. 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 bandd. These fringes really represent maps of the surface displacement caused by the force or stress that disturbed the object. This powerful technique is an invaluable aid in design, testing, quality control, and analysis. Holographic techniques are non-destructive, real-time and definitive in allowing the identification of vibrational modes, displacements, and motion geometries [3-7]. Such displacement map represents an extremely sensitive picture of the actual motion that the object has undergone, 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 holographic interferometry is used in vibration and modal analysis, structural analysis, composite thermoplastic materials (polycarbonate) and adhesive testing, stress and strain evaluation, and flow, volume/shape analysis. All these techniques reveal the shape, direction and magnitude of the stress induced displacements in the structure under study. An important key to the success of holographic interferometry is that it allows the use of a very low-level, non-destructive stress to collect data that once required destruction of the material.

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 [4]:

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

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; 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).

For a harmonic vibration Eq. 1 takes the form:

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

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

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

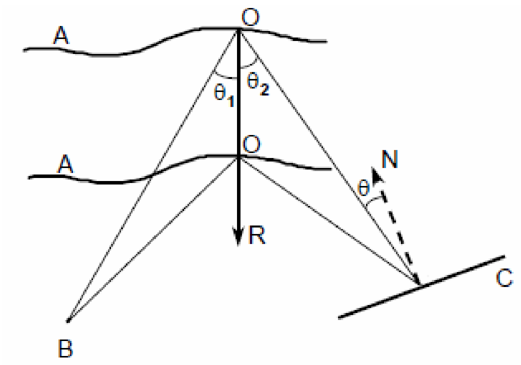


Fig. 1. The scheme of holographic experiment: A − oscillating object; B − laser light source; C − camera; O − point on the surface of the body; R − vector of displacement; N − normal vector of the hologram plate.

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 analyze an object the vibration amplitude of which exceeds 5λ.

The numerical modeling 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 [4]:

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

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:

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

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 into:

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

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

Investigation of personal documents using the method of real-time holographic interferometry

The method known as a real-time holographic interferometry was selected for the purpose of performing this investigation of travel documents (hereinafter referred to as "the object") made of thermoplastic composite material – polycarbonate, possessing features such as transparency, extremely high impact resistance (both under high as well as low temperatures), and mechanic strength, for such a method is considered to be highly informative. The polycarbonate plate with geometric dimensions of 85.7×54.1×0.8 mm was selected as the object of the investigation. Ways of fixing and ways of loading (bending, twisting, and compression), the selected magnitudes of which were supposed to ensure reversible surface deformations, as well as ways and parameters of surface excitation (in order to invoke their own vibration forms) of the object under study, were also taken into consideration in this investigation. Statistical findings of the object investigations using different methods suggest that objects are commonly disrupted in the area of personal photo image, consequently fixation of the object along the plate outer side opposite to the photo image was selected on purpose to minimize any impact potentially caused by mechanical means. The magnitude of compression force and area of the plate under study were the same for all the objects involved in the investigation. Given the selected way of plate fixing, the maximum probable information on existent defects would be obtained in case the plate surface is excited using an external acoustic source. This kind of fixing and acoustic excitation of the plate ensures generation of different vibration forms in its surface that will vary depending on the intensity and frequency of the external acoustic excitation source. Accordingly, quality of the object can be judged by distribution of the localized interferential bands on the surface of acoustically excited plate.

Fig. 2 presents a holographic system that uses method of real-time holographic interferometry, and Fig. 3 – its structural diagram.

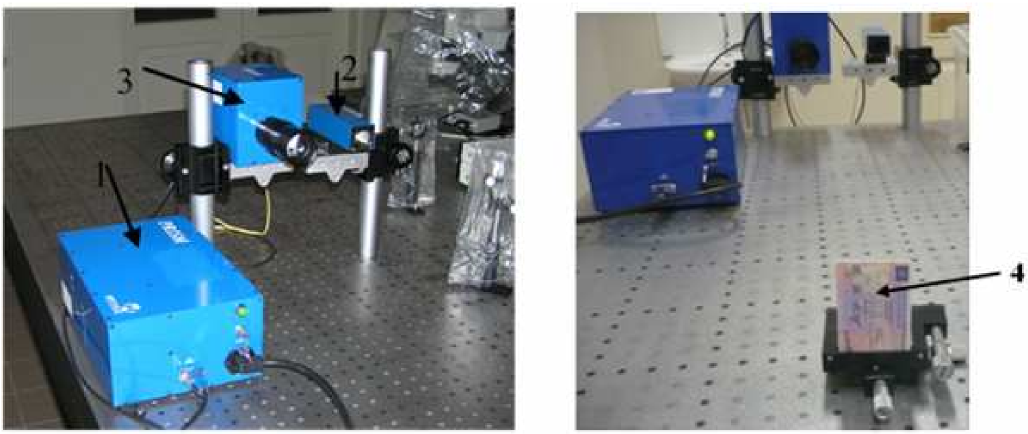


Fig. 2. Holographic system PRISM: 1 – control unit; 2 – source of the object-oriented beam; 3 – camera, 4 – the object to be investigated, namely a driving license (polycarbonate plate with dimensions of 85.7×54.1×0.8 mm)

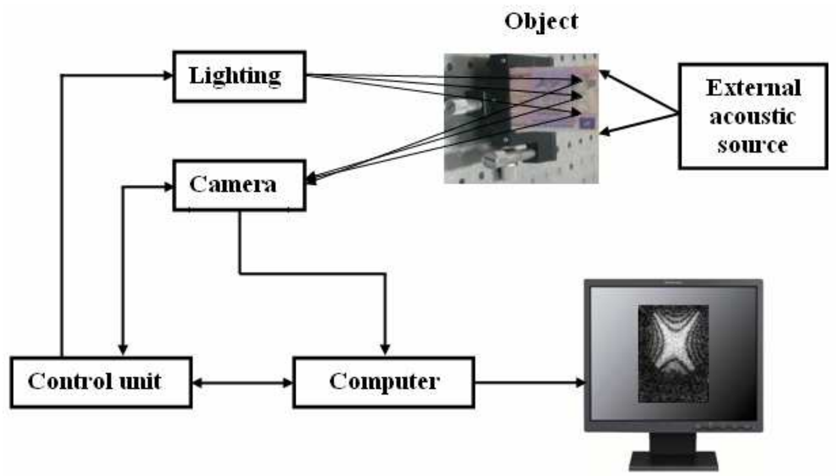


Fig. 3. A structural scheme of the holographic system PRISM

For the purpose of this investigation, a semiconductor green laser (λ = 532 nm) with the capacity of 20 mW was used. Object-oriented beam is guided from the control unit by the fiber waveguide to the system of lenses where it is expanded and directed to the object. The reference beam is passed via fiber waveguide to video camera where it interferes with the recordable object-oriented beam reflected from the object. Control unit and video camera serve to change the ratio between the intensities of object-oriented beam and reference beam (1:2.2) in order to obtain the maximum sharpness of interferential bands. The interferential image is transmitted from video camera to computer where it is further processed using a specific application software PRISMA-DAQ, which allows real-time tracking of dynamic processes that take place within the object under study as well as deformations caused by various external and internal factors.

PRISM system allows taking and processing measurements in less than 5 minutes, is capable of recording displacements under 20 nm, and enables to perform real-time measurements. It represents a non-contact technique requiring only for a direct visibility. Table 1 presents key parameters of the system.

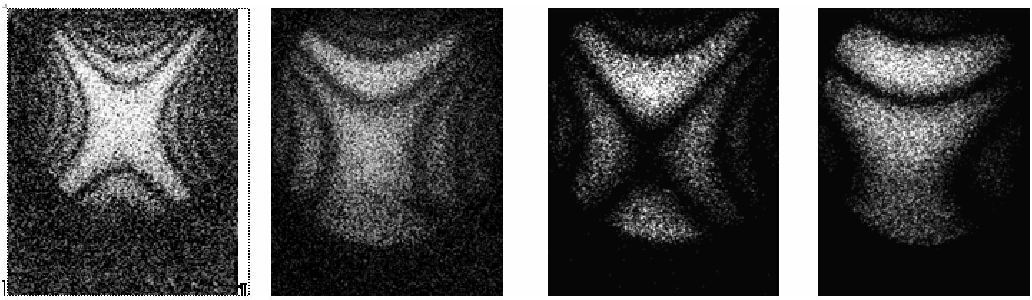
Table 1. Key parameters of the PRISM system

PRISM system's parameters	
Measurement sensitivity	<20 nm
Limit of dynamic measurements	10 μm
Limit of measurements	>100 μm
Maximum measurement area	with the diameter of 1 m
Distance to the sample	>¼ m (depending on the size of object under study)
Frequency of data reading	30 Hz

Test involved 4 objects; one of them was original without any external or internal defects. First of all, the original object was investigated. Using method of a real-time holographic interferometry, a distribution of interferential bands on the plate surface was observed in a wide range of frequencies and intensities of the external acoustic source used to excite plate vibrations. Plate vibration modes (localized on the plate source in the form of interferential bands) obtained under respective frequencies and intensities of the external acoustic source were selected to serve as reference ones due to their regular distribution, and afterwards were compared to the interferential images obtained from investigations of other objects.

Frequency range of the external acoustic excitation source that was used to induce plate vibrations was from 100 Hz to 2 kHz. Within this range, nature of vibrations excited in the plate, and their amplitude in a normal direction to vibration, were observed. Nature and amplitude of vibrations observed in a frequency range of 100 Hz to 400 Hz, did not make a pronounced distribution of interferential bands, consequently they proved to be inapplicable for document check. Within acoustic excitation range of 410 Hz to 850 Hz, nature and amplitude, in a form of interferential bands, evidence characteristic vibration modes on the plate surface. Nature of these plate vibration modes might be applicable for comparison with other objects under investigation. Within a frequency range of 850 Hz to 2 kHz, due to extremely low amplitude (approximately 20 nm), vibrations excited in a plate did not produce a distribution of interferential bands on the plate surface appropriate for any definitive interpretations or making conclusions about the object quality. Consequently, object investigation within this frequency range of acoustic excitation was not undertaken.

Fig. 4, 5, 6, and 7 present characteristic findings of this investigation that allow evaluating objects under study with respect to the distributions of interferential bands on their surfaces.

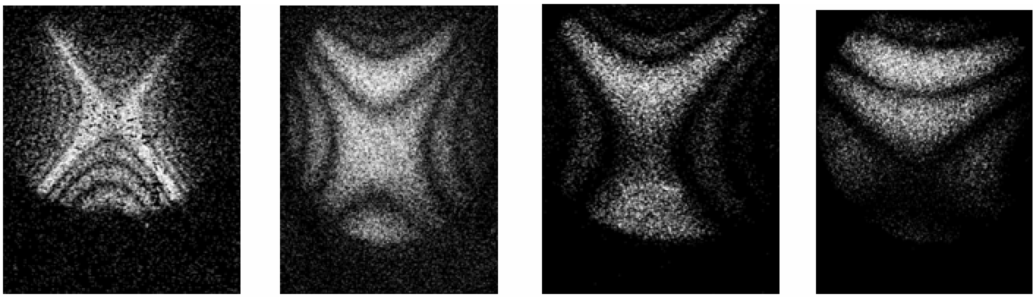


Object T Object L Object P Object F

Fig. 4. Interferograms of four objects that have been obtained under external acoustic excitation frequency of 417 Hz

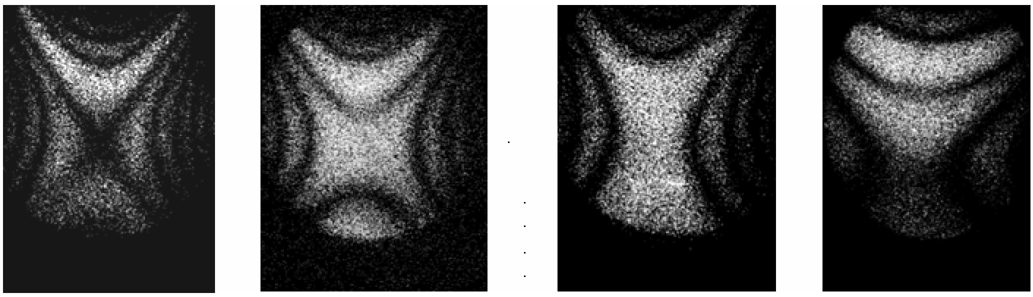
Each of these pictures show interferograms of all four objects that have been obtained under respective frequencies and intensities of the external acoustic excitation source, used to excite plate vibrations. Interferograms are presented in the following sequence: first of all, picture shows an interferogram of the original object that has no internal or external defects – it is labeled with index "T", whereas all the other objects, represents in a picture, have some defects (such as disrupted internal layer of the composite plate, defects of the repetitive joining, etc.)

Fig. 4 shows interferograms of vibrations on surfaces of the objects under external acoustic excitation source frequency of 417 Hz, and voltage of 20 V. Under such parameters of the excitation source, distribution of interferential bands of the tested object "T" surface vibrations, observed in interferograms, is symmetric with respect to the central section where person's photo is situated. Under the indicated acoustic excitation source frequency, vibrations on the object surface were generated only in outer regions; the central area with white color remained stable during the entire excitation and no vibrations were induced here. This indicates that internal structure of the object and its surface have not been disturbed or disrupted. The experiment under the same parameters of excitation is repeated many times in order to make sure the obtained result is reliable.



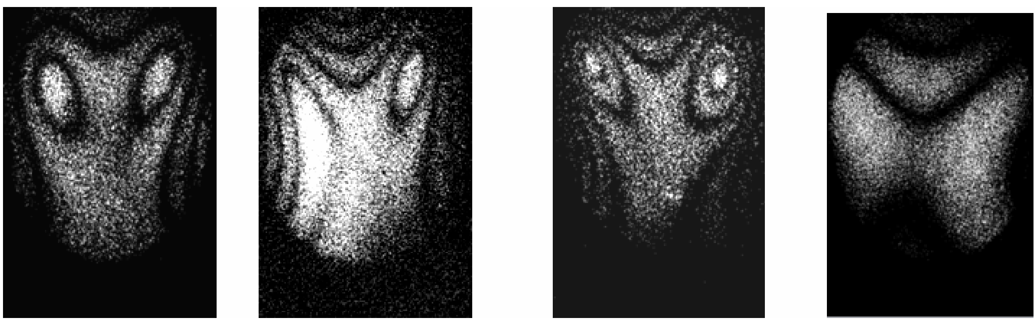
Object T Object L Object P Object F

Fig. 5. Interferograms of four objects that have been obtained under external acoustic excitation frequency of 427 Hz



Object T Object L Object P Object F

Fig. 6. Interferograms of four objects that have been obtained under external acoustic excitation frequency of 432 Hz



Object T Object L Object P Object F

Fig. 7. Interferograms of four objects that have been obtained under external acoustic excitation frequency of 460 Hz

Interferograms for the objects labeled "L", "P", and "F" are obviously different from that of the reference object. The interferogram of object "L" shows distribution of visible interferential bands to be very close to that of the referential, however it is obvious that amplitude of the vibration excited in the plate is significantly lower. This can be associated with changes in the very material, out of which the object is produced. The interferogram of object "P" shows distribution of visible interferential bands to be of the opposite nature than the referential one. Amplitude of vibrations excited in the plate reaches its peak with respect to the central section where person's photo is situated. This can be associated with the problem of integrating individual parts of the object when macro empty spaces (from 1 to 2 mm^2) occur in the central area of the document. The interferogram of object "F" shows distribution of visible interferential bands to be obviously different from that of the referential. Visualized form of the excited vibration and amplitude in a form of interferential bands leads to the conclusion that tested object "F" has significant defects caused in a course of its falsification or counterfeiting.

Findings and results obtained through object investigations under different frequencies of acoustic excitation source are analyzed in the analogous way. Interferograms obtained for tested objects under specific higher frequencies are close in their form to that of referential object, however low vibration amplitudes make it difficult to make a decision regarding authenticity of such objects.

Conclusions

The method known as a real-time holographic interferometry was selected for the purpose of performing the identification of the authenticity and counterfeiting of the plate-like documents.

Frequency range from 410 Hz to 850 Hz generated by the external acoustic excitation source was determined to excite plate resonant vibrations, within which test of the documents was performed.

The methodology based on the holographic interferometry may be used for vibration, modal and structural analyses of the plate-like information carriers that are produced from the composite thermoplastics.

Acknowledgement

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References

[1] Reguliation (Eu) No. 562/2006 Of The European Parliament And Of The Council of 15 March 2006 establishing a Community Code on the rules governing the movement of persons across borders (Schengen Borders Code).

[2] **Daniel Weber**. Optimization of human border control – requirements for supporting technology systems. // EU Symposium. The EU Aquis with regard to document security. 2008, Spindulys, p. 454.

[3] **A. Palevičius, K. Ragulskis, R.Vasiliauskas, A. Bubulis.** Historical aspects and future perspective of holography in Lithuania. The Society for Experimental Mechanics. Proceedings of the International Symposium to Commemorate the 60^{th} Anniversary of the Invention of Holography. Sheraton Springfield Monach Place Hotel, Springfield, Massachusetts USA, October 27 – 29, 2008. Numbers of p. 368 - 377. ISSN 1046-6762.

[4] **R.Vasiliauskas, A.Palevičius, A. Butavičius, V. Stupak**. Holographic - nondestructive inspection of Litas banknotes. / Ultragarsas./ Ultrasound. - ISSN 1392-2114. - Kaunas: Technologija. - 2004, No. 3(52), p. 38-41.

[5] **A. Palevičius, R. Vasiliauskas**. Application of laser interferometry and holographic methods for analysis and design of vibrational systems. Virpesių mechanika ir technika. Vibroengineering: monografija. Lietuvos Mokslų akademija. - Vilnius: Lietuvos mokslas. - ISBN 9986-795-02-8. - 1998, Kn. 19, p. 358-381.

[6] **Vasiliauskas R., Palevičius A. and Ragulskis K**. Analysis of holographic interferograms by ultrasonic piezoelectric transducers in the investigation of three-dimensional vibrations. Acoustical Physics.1988. Vol.34(6). P.573-575.

[7] **Ч. Вест**. Голографическая интерферометрия. Москва «Мир». 1982. с. 504.