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Investigation of thermal stability of holographic plate

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1. Introduction

Holography is a unique method of recording and reconstruction of all the amplitude and phase information contained in the light that is scattered from an illuminated body [1-4]. This method is based on diffraction and interference of coherent light wave. Hologram contains all the information about surface deformation of the object [5-7].

A hologram is a record of the interaction of two beams of coherent light, in the form of microscopic pattern of interference fringes. It is a photographic registration of the interference pattern formed by two laser beams of coherent light. One beam goes straight from the light source and the other is scattered from the object. A holographic film or plate is exposed by two laser beams and is processed in such a way that when illuminated properly a three-dimensional image is produced [8-11].

Holography was invented in 1947 by Hungarian physicist Dennis Gabor. In our days holography is used for data storage [12], as a holographic memory, protection of documents [13], as well as for art, holographic interferometry [14-18], interferometric microscopes [19], electron holography, acoustic holography, and etc. [20-23]. Independent from application area it is important to ensure stability of the holographic system during recording process [24-25]. Interference image must be stable, i.e. interference lines shift must be less than one-tenth of the interference line. This means a very narrow tolerances area. Thermal conditions can affect the length of the optical way of object and reference beams at the time of exposure, and thus influence the phase difference. Since the thermal deformation can affect quality of the hologram it is important to test thermal deformation of holographic plate.

The aim of this paper was to determine the level of systems sensitivity to thermal conditions and analyse how fixing type of the holographic plate can reduce thermal deformations.

2. Experimental setup for recording of master hologram

The making of rainbow hologram can be divided into two processes: making of a master hologram and making of a rainbow hologram [26-28]. The scheme of master hologram recording is presented in Fig. 1. He-Ne laser (λ = 632.8 nm) was used for the recording of master hologram. Laser beam is divided by splitter into two beams: object and reference. Object beam goes through expanding lenses and illuminates the object of investigation, and finally, the reflected light from the object illuminates the holographic plate. The reflected by the splitter and mirror reference beam goes trough the expanding lenses and reflected by the mirror illuminates the same photoplate as the object beam. Interference pattern of both beams is recorded.

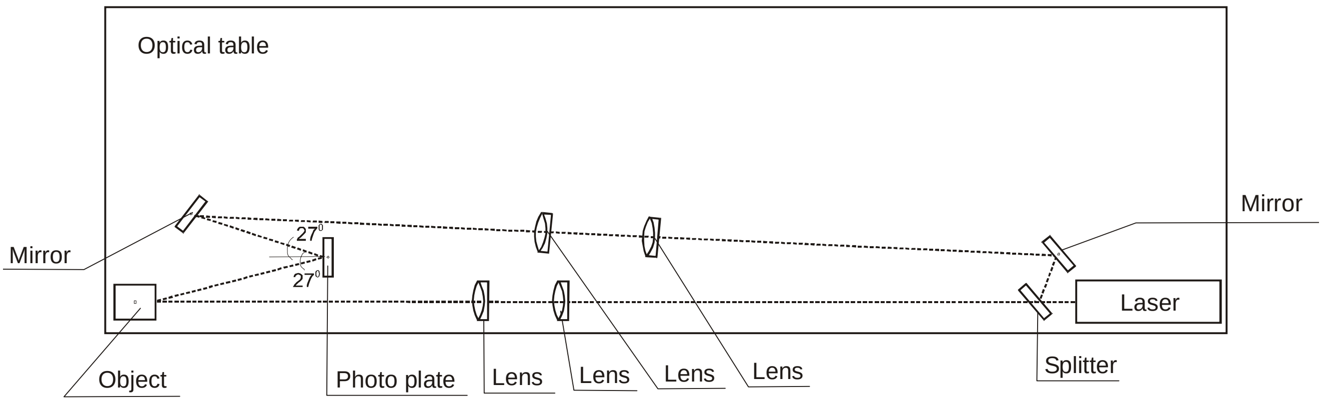


Fig. 1 Recording scheme of master hologram

Both processes of recording of master and rainbow holograms are very sensitive to external factors: temperature changes, vibrations, chemical developers and others [29]. Micro- or nanorelief is produced during recording of rainbow hologram, so it is important to assess the possible factors which may influence stability of the holographic system. If holographic recording scheme is fixed and there are no changes before the experiment, then the stresses, deformations and vibrations of optical elements and system are well established and do not affect the quality of the hologram. Then stability of holographic plate has the greatest impact on the quality of hologram. Generally, the holographic plates are stored in a cold place to increase the durability. Before recording process of a hologram the holographic plate must be placed in ambient temperature. When the holographic plate is heated, it expands. If this happens during exposure, the hologram may lose some information. So it is important to determine possible changes of temperature and deformations of holographic plate.

3. Calculations of thermal deformation of holographic plate

When the holographic plate expands during exposure, it impacts the length of the optical way. This could have an influence on quality of the hologram. Movement of the holographic plate in the range of more than 10 % of the wavelength (He-Ne laser, $\lambda = 632.8$ nm) will create a reduction of quality of the hologram image. This means that a movement of the holographic plate for more than $63.28 \cdot 10^{-9}$ m will disturb the hologram.

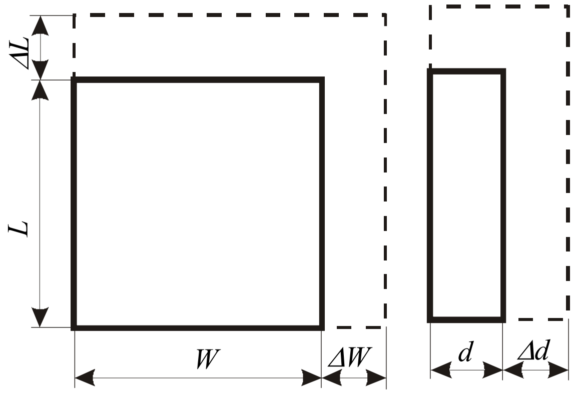


Fig. 2 Thermal expansion of the holographic plate

The main types of deformation of holographic plates are shown in Fig. 2. Variation of temperature of the holographic plate can change length L, width W or thickness d of the plate. Thermal expansions of the plate are marked as ΔL, ΔW and Δd according to temperature changes ΔT, when coefficient of thermal expansion of holographic plate is α, and laser wavelength - λ, then, thermal expansion of the plate can be written [30, 31]

$$\Delta L = \alpha\, L_0\, \Delta T \tag{1}$$

$$\Delta W = \alpha\, W_0\, \Delta T \tag{2}$$

$$\Delta d = \alpha\, d_0\, \Delta T \tag{3}$$

Maximum temperature changes during exposure of holographic plate could be calculated from formulas (1)-(3), when movement of the holographic plate (ΔL, ΔW and Δd) could not exceed 10 % ($63.28 \cdot 10^{-9}$ m) of the wavelength.

$$\Delta T = \frac{\Delta L}{\alpha L_0} = \frac{\Delta W}{\alpha W_0} = \\ = \frac{63.28 \cdot 10^{-9}}{7 \cdot 10^{-6} / 0.1} = 0.09^{\circ}\mathrm{C} \tag{4}$$

$$\Delta T = \frac{\Delta d}{\alpha\, d_0} = \frac{63.28 \cdot 10^{-9}}{7 \cdot 10^{-6} / 0.002} = 4.52^{\circ}\mathrm{C} \tag{5}$$

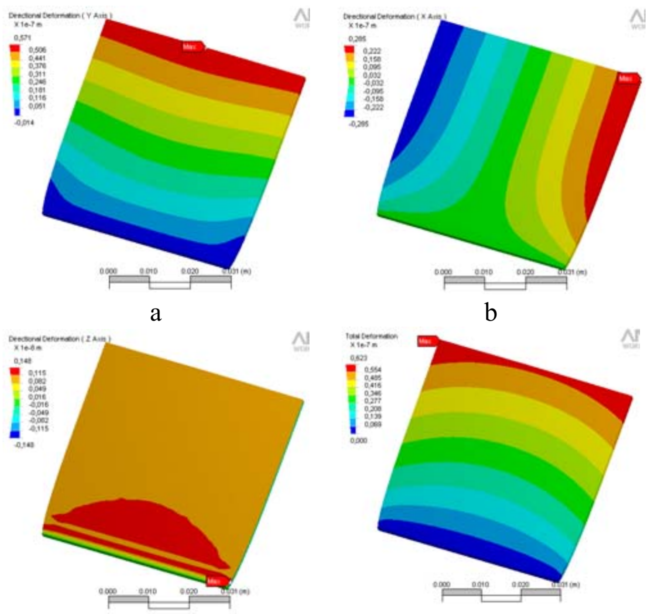
Holographic plate of $L = 10$ cm length, $W = 10$ cm width, $d = 0.2$ cm thickness, and $\alpha = 7 \cdot 10^{-6}$ coefficient of thermal expansion was used for recording of master hologram. Because the length and width in our case are the same 0.1 m., then maximum ΔT will be the same and the temperature variation could not exceed 0.09°C (Eq. 4). Thickness of holographic plate is 50 times smaller ($d = 0.002$ m) than its length or width and that means that the variation of temperature could bee much higher to 4.52°C (Eq. 5).

From the calculations we see that holographic system is very sensitive to thermal conditions, so it is important to make stable system for maximum brightness of the hologram.

4. Numerical modeling of thermally deformed holographic plate

Holographic plate is very sensitive to thermal conditions, so three fixation types of the plate were analyzed numerically using finite element method (FEM) by means of software Ansys. Thermal deformations of holographic plate fixed on one side using universal holder (Fig. 3) are presented in Fig. 4. In this case thermal changes of the length are the biggest (Fig. 5), but this type of fixation decreases thermal deformations 12 times. It means that temperature variation could not exceed 1.1°C.

Fig. 3 Photo of universal holder of holographic plate



a b

c d

Fig. 4 Thermal changes of length (a), width (b), thickness (c) and total deformation (d) of holographic plate fixed on one side using universal holder

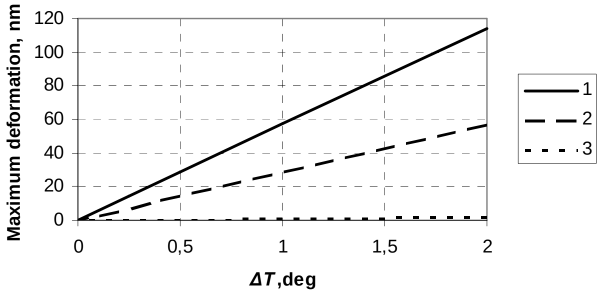


Fig. 5 Maximum changes of length (*1*), width (*2*) and thickness (*3*) according to the changes of temperature, when holographic plate is fixed on one side using universal holder

Thermal deformations of holographic plate fixed on two adjacent sides using multiple holder (Fig. 6) are presented in Fig. 7. In this case thermal changes of the length and width are the biggest and they are presented by curve 1 in the Fig. 8. The changes of length and width are the same, because holographic plate and fixation was symmetric. This type of fixation decreases thermal deformations 14.5 times. It means that temperature variation could not exceed 1.3°C.

Fig. 6 Photo of multiple holder of holographic plate

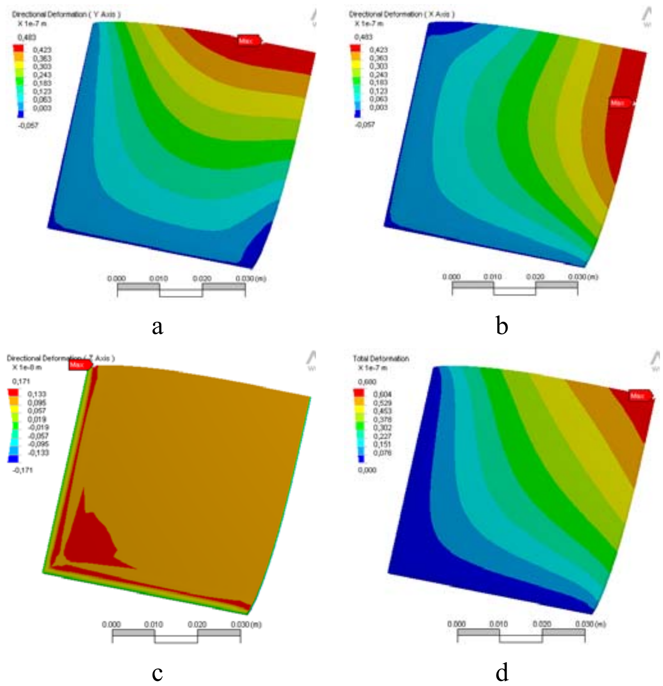


Fig. 7 Thermal changes of length (*a*), width (*b*), thickness (*c*) and total deformation (*d*) of holographic plate fixed on two adjacent sides using multiple holder

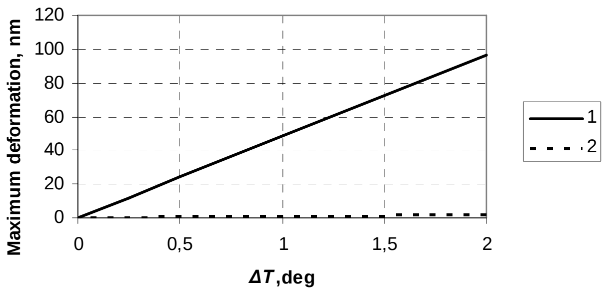


Fig. 8 Maximum changes of length and width (*1*) and thickness (*2*) according to the changes of temperature, when holographic plate is fixed on two adjacent sides using multiple holder

Thermal deformations of holographic plate fixed on two opposite sides using angular fine adjustment mount (Fig. 9) are presented in Fig. 10. In this case thermal changes of the width are the biggest (Fig. 11), but this type of fixation decreases thermal deformations 23 times. It means that temperature variation could not exceed 2°C.

Fig. 9 Photo of angular fine adjustment mount of holographic plate

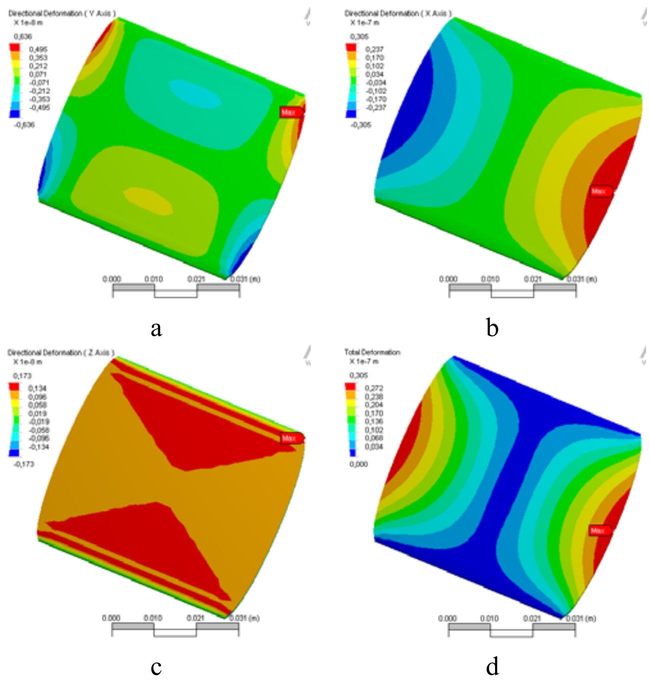


Fig. 10 Thermal changes of length (*a*), width (*b*), thickness (*c*) and total deformation (*d*) of holographic plate fixed on two opposite sides using angular fine adjustment mount

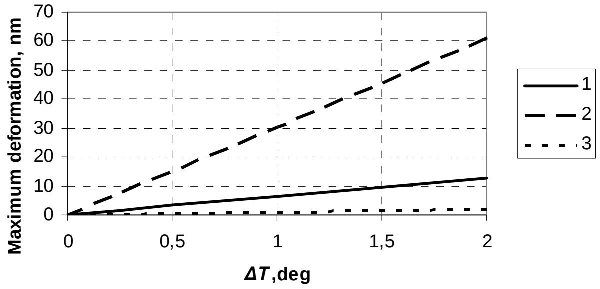


Fig. 11 Maximum changes of length *1*, width *2* and thickness *3* according to the changes of temperature, when holographic plate is fixed on two opposite sides using angular fine adjustment mount

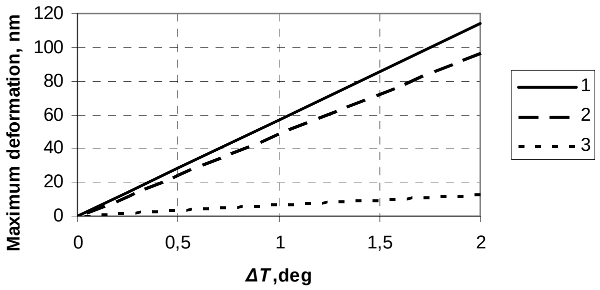


Fig. 12 Maximum changes of length of holographic plate according to the changes of temperature, when holographic plate is fixed using universal *1*, multiple *2* and angular fine adjustment *3* holders

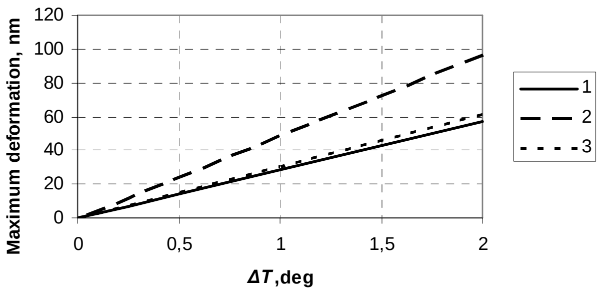


Fig. 13 Maximum changes of width of holographic plate according to the changes of temperature, when holographic plate is fixed using universal *1*, multiple *2* and angular fine adjustment *3* holders

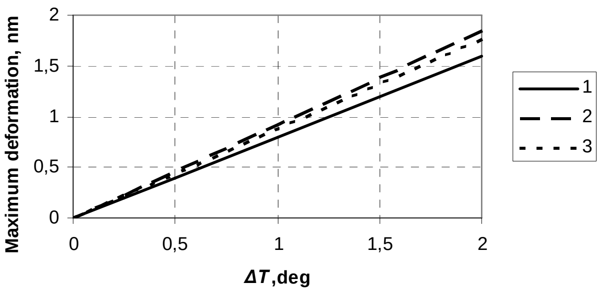


Fig. 14 Maximum changes of thickness of holographic plate according to the changes of temperature, when holographic plate is fixed using universal *1*, multiple *2* and angular fine adjustment *3* holders

If we compare all these three methods of fixation of holographic plate, we get the smallest changes of the length (Fig. 12) when the plate is fixed using angular fine adjustment mount (Fig. 9). We get the smallest changes of the width (Fig. 13) when the plate is fixed using universal holder (Fig. 3), and the smallest changes of the thickness (Fig. 14) appear when the plate is fixed using universal holder, too. Different holders reduce different deformations. From the calculation and modeling it is clear that length and width are most sensitive to temperature changes. So according to that for the fixation of holographic plates it is recommended to use angular fine adjustment mount, witch fixes the plate on two opposite sides.

5. Experimental investigation of thermal deformed holographic plate

A number of experimental studies are needed in order to ensure high stability of the optical system used for recording of rainbow holograms. In most cases the vibrations or deformations in optical scheme are measured in micrometers. Therefore, the holographic method was applied for the analysis of stability of optical scheme, and for visual comparison of modeling and experimental results. The tests used the PRISM system (Fig. 15). The PRISM system is a two beam speckle pattern interferometer. The laser beam from illumination head *3* directed at the object *4* is the object beam. Scattered laser light from the object is collected by the camera *1*. The reference beam goes directly to the camera, usually in an optical fiber. Shape changes that occur between a reference and a stressed state of the object produce fringes on top of the image of the object, which is displayed on the monitor.

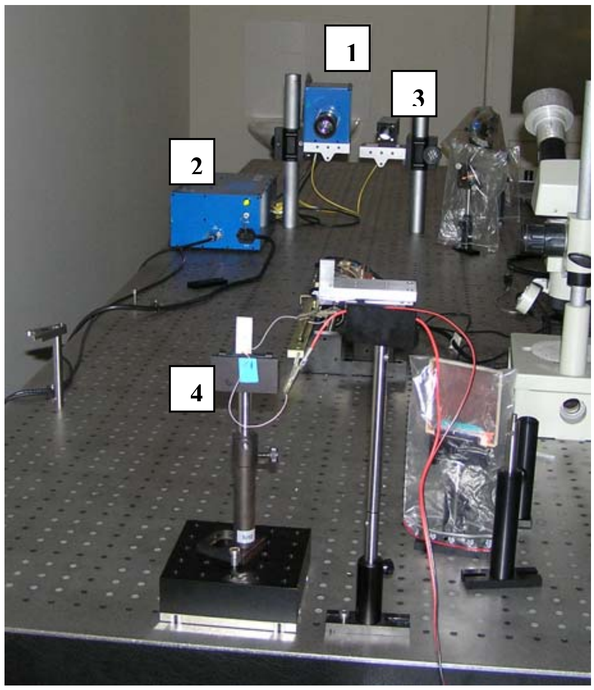
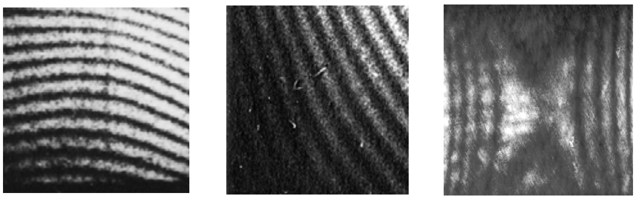


Fig. 15 PRISM system: *1* - camera; *2* - control block; *3* - illumination head of the object; *4* - object

Fig. 16 shows the pattern of holographic interference fringes on the surface of thermally ($T+2^{\circ}\mathrm{C}$) deformed holographic plate fixed using universal (Fig. 3), multiple (Fig. 6) and angular fine adjustment (Fig. 9) holders. White areas in the hologram and small number of interference lines correspond to very small field of deformation of the holographic plate. This means that the smallest ther-



a b c

Fig. 16 Holograms of thermally deformed holographic plate fixed using universal (*a*), multiple (*b*) and angular fine adjustment (*c*) holders

mal deformations appear when the plate is fixed on two opposite sides (Fig. 16, c).

6. Conclusions

Thermal deformation of the holographic plate, in the range of more than 10 % of the wavelength, could reduce the quality of a hologram. Because L and W in our case are equal to 0.1 m, then the maximum variation of temperature ΔT during recording process could not exceed 0.09°C.

Since any changes of thermal conditions during recording of a hologram could reduce brightness, we recommend to use the plate holder which fixes the plate on two opposite sides and prevents the hologram from thermal deformations. This type of holder increases thermal stability of holographic plate 23 times.

Numerical results were verified using holographic PRISM system. The minimum thermal deformations were determined when the plate is fixed on two opposite sides.

References

1. **Palevičius, A., Ragulskis, K., Vasiliauskas, R., Bubulis, A.** Historical aspects and future perspective of holography in Lithuania.-Proc. of the Int. Symposium to Commemorate the 60th Anniversary of the Invention of Holography, October 27-29, 2008, Sprigfield, Massachusetts, USA.-Bethel, 2008, p.368-377.
2. **Palevičius, A.** Multi-exposure digital holographic interferometry. -Informacinės technologijos ir valdymas. -Kaunas, 2001, Nr.1(18), p.22-29.
3. **Hayman, G., Steinzig, M., Palevicius, A.** Holographic PRISMA system for investigation of mechatronic systems.-Vibroengineering 2006: Pproceedings of the 6th International Conference, October 12-14, 2006, p.27-29.
4. **Denz, C., Pauliat, G., Roosen, G., Tschudi, T.** Volume hologram multiplexing using a deterministic phase encoding method.-Optics Communications, v.85, issue 2-3, p.171-176.
5. **Sosnowski, T. P., Kogelnik, H.** Ultraviolet hologram recording in dichromated gelatin.-Applied Optics, v.9, issue 9, p.2186-2187.
6. **Tandon, N., Yadava, G. S., Ramakrishna, K. M.** A comparison of some condition monitoring techniques for the detection of defect in induction motor ball bearings.-Mechanical Systems and Signal Processing, 2007, No.1, p.244-256.
7. **Mendlovic, D., Kiryuschev, I.** Two-channel computer-generated hologram and its application for optical correlation.-Optics Communications, v.116, issues 4-6, 1 May 1995, p.322-325.
8. **Tanner, L.H.** Some applications of holography in fluid mechanics.-J. Sci. Instrum., 1966, p.43 81-83.
9. **Tegze, M., Faigel, G., Bortel, G., Marchesini, S., Belakhovsky, M., Simionovici, A.** X-ray holography: atoms in 3D.-Journal of Alloys and Compounds, Issues 1-2, 29 September 2005, p.92-98.
10. **Valin, J.L., Gonçalves, E., Palacios, F., Pérez, J.R.** Methodology for analysis of displacement using digital holography.-Optics and Lasers in Engineering, v.43, issue 1, January 2005, p.99-111.
11. **Zhai, H. C., Mu, G.G., Wang, M.W., Liu, F.M., Pan, D., Hsu, K.Y.** 3D monochromatic image synthesized with vertical area-partitioned recording of master hologram in multiple-exposure holography.-Optics Communications, v.195, issues 1-4, August 2001, p.141-149.
12. **Chuang, E., Drolet, J.P., Liu, W., Psaltis, D.** Compact holographic memory module.-Photorefractive Optics, 2000, p.361-383.
13. **Kumar, R., Aggarwal, A. K.** Interferometric moiré pattern encoded security holograms with concealed phase object.-Optics Communications, v.279, issue 1, 1 November 2007, p.120-123.
14. **Palevičius, A., Busilas, A., Vasiliauskas, R.** Analysis holographic interferogram of links of vibrating systems.-Journal of Vibroengineering. -Vilnius: Vibromechanika. 2008, v.10, No.2, p.245-250.
15. **Palevičius, A., Janušas, G., Ostaševičius, V., Bansevičius, R., Busilas, A., Rubliauskas, D.** Analysis dynamics of piezoelectric optical scanner with periodical microstructure.-Active and Passive Smart Structures and Integrated Systems 2008, v.6928, art. no.69282H, p.1-8.
16. **Janušas, G., Palevičius, A., Bubulis, A.** Numerical analysis of holographic plate stability.-Vibroengineering 2008: Proceedings of the 7th International Conference, October 9-11, 2008. -Kaunas: Technologija, 2008, 1822-1262, p.83-86.
17. **Ostaševičius, V., Ragulskis, M. K., Palevičius, A., Kravčenkienė, V., Janušas, G.** Applicability of holographic technique for analysis of non-linear dynamics of MEMS switch.-Smart Structures and Materials 2005: Smart Electronics, MEMS, BioMEMS, and Nanotechnology, 2005, v.5763, p.405-413.
18. **Palevičius, A., Janušas, G., Busilas, A., Palevičius, R., Bubulis, A.** Digital holography for analysis of mechatronic systems.-Vibroengineering 2008: proceedings of the 7th International Conference, October 9-11, 2008. -Kaunas: Technologija, 2008, 1822-1262, p.78-82.
19. **Muller, J., Kebbel, V., Juptner, W.** Digital holography as a tool for testing high-aperture micro-optics.-Optics and Lasers in Engineering, v.43, issue 7, July 2005, p.739-751.
20. **Bansevičius, R.P., Dragašius, E., Palevičius, A., Ragulskis, M.K.** Development of smart sensors for solidification detection in composite materials. -Mechanika. -Kaunas: Technologija, 2004, Nr.5(49), p.50-54.
21. **Palevičius, A., Ragulskis, M. K., Ostaševičius, V., Palevičius, R.** Evaluation of the dynamic response of

the excited transmission system. -Mechanika. -Kaunas: Technologija, 2000, Nr.4(24), p.41-44.
22. **Palevičius, R., Ragulskis, M., Palevičius, A.** Analysis of dynamics of a straight section of an exhaust tube and its optimization. -Mechanika. -Kaunas: Technologija, 2000, Nr.1(21), p.59-62.
23. **Šukelis, A.Č., Ragulskis, M., Palevičius, A., Baužys, R.** Evaluation of dynamic deformations of acoustic generator's modulator. -Mechanika. -Kaunas: Technologija, 1999, Nr.1(16), p.24-28.
24. **Coleman, M.P.** Vibration eigenfrequency analysis of a single-link flexible manipulator.-Journal of Sound and Vibration, v.212, issue 1, 23 April 1998, p.109-120.
25. **Kopmaz, O., Telli, S.** Free vibrations of a rectangular plate carrying a distributed mass. -J. of Sound and Vibration, v.251, issue 1, 14 March 2002, p.39-57.
26. **Tamulevičius, T., Tamulevičius, S., Andrulevičius, M., Griškonis, E., Puodžiukynas, L., Janušas, G., Guobienė, A.** Formation of periodical microstructures using interference lithography.-Experimental Techniques. -Oxford: Blackwell Publishing, 2008, v.32, No.4, 0732-8818, p.23-28.
27. **Tamulevičius, T., Tamulevičius, S., Andrulevičius, M., Guobienė, A., Puodžiukynas, L., Janušas, G., Griškonis, E.** Formation of OVD using laser interference lithography.-Materials science, 2007, v.13, No.3, p.183-187.
28. **Jiang, C., Fan, C., Guo, L.** Two-step astigmatic rainbow holograms projecting real images in front of the hologram.-Optics & Laser Technology, v.25, issue 3, June 1993, p.171-174.
29. **Chomát, M., Gregora, I.** A method for testing the stability of the holographic system. -Optics Communications, v.5, issue 1, p.14-17.
30. **Bareišis, J., Daniškevičiūtė, A., Kleiza, V.** Stress distribution in multilayer structural element subjected to skew bending. -Mechanika. -Kaunas: Technologija, 2007, Nr.6(68), p.14-18.
31. **Partaukas, N., Bareišis, J.** The stress state in two-layer hollow cylindrical bars. -Mechanika. -Kaunas: Technologija, 2009, Nr.1(75), p.5-12.

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HOLOGRAMOS TERMINIO STABILUMO TYRIMAS

R e z i u m ė

Holografija yra naujas informacijos įrašymo, saugojimo ir atkūrimo metodas, kuris naudojamas dokumentams ir duomenims apsaugoti, makro- ir mikro mechaninėms sistemoms tirti, 3D vaizdams užrašyti ir atkurti ir t. t. Informacija apie bangos amplitudę ir fazę yra saugoma hologramoje. Tai labai jautrus metodas, todėl ypač svarbu užtikrinti sistemos stabilumą informacijos užrašymo metu. Šiame straipsnyje pateikti hologramos terminio stabilumo skaitmeninio tyrimo rezultatai.

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INVESTIGATION OF THERMAL STABILITY OF HOLOGRAPHIC PLATE

S u m m a r y

Holography is quite a new information recording, storage and recovery method that is used for documents and data protection, for the analysis of macro- and micromechanical systems, recording and reconstruction of 3D images, and etc. The information about the wave amplitude and phase is stored in holograms. It is very sensitive method, and for the stability of the system during recording process it is very important. Therefore, the aim of this paper was numerically to analyze the thermal stability of holographic plate during recording process.

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ИССЛЕДОВАНИЕ ТЕРМОСТАБИЛЬНОСТИ ГОЛОГРАММЫ

Р е з ю м е

Голография это новый метод записи, хранения и восстановления информации, используемый для защиты документов и данных, для анализа макро- и микро механических систем, регистрации и реконструкции 3D-изображений и т. д. Информация о амплитуде и фазе волны сохраняется в голограмме. Это очень чувствительный метод, и поэтому очень важно стабильность системы во время процесса записи информации. Таким образом, целью статьи является анализ термической стабильности голографической пластины во время процесса записи.

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