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MEASUREMENT OF DEFORMATION AND SHAPE BY HOLOGRAPHIC INTERFEROMETRY

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Summary

A few ways of recording holographic interferograms are compared, their advantages and disadvantages in industrial applications of hologram interferometry is briefly analysed. A portable hologram interferometric system for measurement of displacement due to static/dynamic load is presented. Some aspects of shape measurement is discussed.

1. Hologram interferometry in industry

Holographic interferometry and speckle techniques are widely used; the major applications are not in optics but in measuring mechanical displacement, vibration, stress and deformation. Still although two decades have passed since its invention the technique is mainly confined to research laboratories. Nevertheless, there exist some examples of industrial applications mainly in aircraft, machine tool and motor industries.

Apart from the usual conservatism and sceptisism against strange, new methods some of this non-acceptans stems from the slow and cumbersome filmprocessing which prohibits for example on-line inspections. Another problem is associated with evaluation of interferograms. Interferograms recorded in factory environment does not contain te zero order fringe and so an unambigous interpretation meets with difficulties.

The thermoplastic recording have been promising but that process is too slow for many purposes and in addition to the thermoplastic film has a limited resolution, not enough for large industrial object holography.

For the last decade a modified version of holographic interferometric system has been developed based upon direct videorecording and reconstruction. The system which consequently works in real time is commonly called electronic speckle pattern interferometry.

The main building blocks of an ordinary ESPI system is illustrated in the symbolic flow chart on Fig. 1.

The optical part of ESPI is best described as an image holography set-up where the object — and reference waves interfere in-line by means of a beam-combining device. The recording step is performed by the photoelectric action of the TV-camera while the reconstruction is done by electronic processing on the videosignal. The videostore is necessary whenever a comparision of different videoframes is wanted. Finally the prossessed videosignal is converted into a „reconstructed" image by TV-monitor display. As in

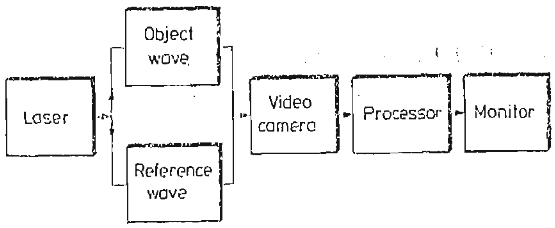

Fig. 1. The flow chart on an ESPI system

hologram interferometry the image of the test object will be covered by a fringe pattern representing the positional change of the object's surface during or between the exposure(*s*) for example, J_0^2-pattern for a vibrating object, while a double exposure provides a $\cos^2$-pattern.

The main advantage and strenghth of the ESPI-system are due to the videosystem. Another interesting property of ESPI is that the interferometric information at one stage is available as a videosignal. For one thing this simplifies the incorporation of computors into the system. In addition the videosignal may be relayed or transmitted over any distance to the analyzing station.

On the negative side the most notable drawback is the speckled appearence of the image which is caused by the low resolution of the videosystem. Commercial ESPI-systems tend to be somewhat costly but prices are coming down as competition increases.

ESPI-systems can not compete with hologram interferometry in the surveillance of a large area by one shot. The ESPI simply does not have the resolution capability for this.

Beside the moderate spreading the ESPI-systems in industry the application of hologram interferometry at leading factories has to be mentioned.

As an excellent example of the latest application the vibration analysis of automative structures at Ford Motor Company can be mentioned [1]. An Apollo model double pulse holographic system with thermoplastic film was used. Double exposure interferograms were recorded and gear-excited resonance on transaxle housing was studied. A local stiffening rib was added to the housing as close to the bullseve as was feasible. As the result resonant response was eliminated under original exitation conditions.

Hologram interferometry in automative industry has sucsessfully been applied at Central Laboratory of Optics by Dr. Pawluczyk investigating of engine walves, selected parts of car using a double pulse ruby laser system of time interval between the two pulses regulated in range of 0,15 - 0,25 ms and energy up to 1 J [2].

Industrial application of hologram interferometry is clearly demonstrated by Japanese. As an example of that work measurements at Mitsubishi Heavv Industries, Ltd should be presented [3]. Vibrational modes of compressor vanes were studied. As an example of the application of pw holography to large scale products the results of vibration mode analysis of a car body were presented.

These selected applications of hologram interferometry convince of its acceptance by industry. The application will be accelerated by solving the problem of automatic and unambigous evaluation of interferograms recorded in factory environment. The systems mentioned above recorded single interferograms which can mainly be used for qualitative evaluation.

2. The fundamental equation of evaluation

In the most common technique of hologram interferometry [4] an interference pattern contains only informations for determination of the component of the displacement vector lying along the bysector of the angle between illumination and observation directions.

Determination of all the three components of the displacement vector with approximately equal accuracy is possible when the interferometer is sensitive to the three orthogonal directions (bysectors, sensitivity vectors) in the same way. That optimum can be approached by a system, where the sensitivity vectors are realized by bysectors of angles between one illumination and more observation directions. Determination of a component of the displacement vector is founded upon measurements of fringe order numbers.

The fundamental equation for evaluation in case of a few interferograms recorded simultaneously with different sensitivity vectors is as follows:

$$S\mathbf{L} = \mathbf{N},$$

where S is the sensitivity matrix determined by the geometry of the object and measuring system, $\mathbf{L}$ is the displacement vector to by determined, $\mathbf{N}$ is the fringe order vector, λ is the wavelength of the light. Data stored in four interferograms are sufficient to determine the moduli and line of the influence of the vector. The main problem is the calibration of the fringes (interferograms do not contain the zero order fringe).

3. Hologram interferometric measuring system

In the following a hologram interferometric measuring system developed at the Institute of Physics, Technical University Budapest will be presented demonstrating our ambition to fulfill industrial conceptions. The portable interferometer can be used for inspection of virtually any industrial object, its behavior due to static/dynamic loading. Evaluation of the interferograms is computer aided.

3.1. **The interferometer.** The main building blocks of the interferometer of the system is illustrated in the symbolic flow chart in Fig. 2. The interferometer with the light sources (ruby and He-Ne laser) is mounted on a tripod. The interferometer can be lifted up hydraulically by foot or an electric motor. It can also be rotated along vertical and horizontal axis. Holographic plates in holocameras are illuminated by one object and four reference beams. The four interferograms provide data for determining the displacement vector.

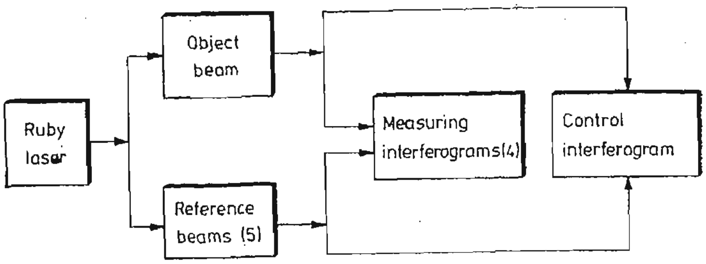

Fig. 2. The main building blocks of the interferometer

The control holocamera works with thermoplastic film, so recording is quick and the displacement field can be studied in some ten seconds after exposures. In case of any unsufficiencies the recording of interferograms can/must be repeated.

3.2. Interferogram evaluation. The main building blocks of the interferogram evaluation is demonstrated in Fig. 3. The reconstructed interferograms are photographed. Evaluating them two tasks must be solved: determination of elements of S and N in the fundamental equation.

The main steps determining the elements of S:

— sticking marking points to the object surface in order to be able to identify the given point on interferograms with different observation directions;

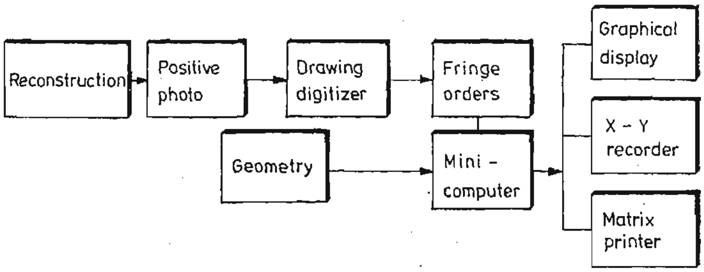

Fig. 3. The main blocks of evaluation procedure

— measurement of coordinates of the marking points as well as some points of the interferometer by theodolite;

— feeding coordinates of all that points measured on positive photos (4 ones) to the computer;

— to find an algorithm for identification of the points between the marking ones and points measured on photos and determination their position in coordinate system assigned to the object.

The main steps determining N:

— feeding coordinates of fringe maximum and minimum to the computer by drawing digitizer;

— fitting a function (fringe locus function) to the intensity distribution represented by the fringes on the interferogram, and fed into the computer, in the form of polynomials. The aim of this procedure is error correction and estimation of fringe fraction.

— determination of the fringe locus function in a coordinate system assigned to interferograms belonging to the four observation directions;

— coordination of picture points and object surface points knowing geometrical data.

Special properties of the evaluation system

— minicomputer with small memory;

— measured data are not stored in the memory. Using data aquisition methods functions are fitted to all data sets. The coefficients of the functions are only stored.

— at evaluation a person knowing the physics of interference is to be present.

Data processing

In data processing determining the components of **L** the equation is solved using computer programs; the actual fringe order even its fraction can be found as a value of the fitted function mentioned above at the object surface point considered.

The hologram interferometric system described above has been used in factories of Hungarian machine industry to inspect machine tools, engine vibrations at different clamping and speed of rotation, etc.

4. Measurement of shapes

There are no difficulties in contouring planar object such as rasor blade with a sensitivity of about 1 μm. In case of an object having normal size and complicated surface hologram interferometric contouring does not work in that sensitivity region.

During the last several years a new technique, the difference hologram interferometry [5] was developed providing determination of the difference between deformation of two objects subjected to the same load or difference in shape of two objects.

Holographic interferometric techniques for deformation measurement and contouring are quite analogous. The initial and final states of the object (before and after loading) and unaltered experimental set-up at deformation measurement can be compared to the initial and final states of the experimental arrangement (e.q. two-wavelength contouring) and unaltered object at shape measurement.

Because of the descriptivenes, the idea of difference hologram interferometry will be explained by Fig. 4. used at deformation measurements. The aim of the measurement was to determine the deformation difference between master and an another objects. On the figure beam expanding telescopes are not shown. The laser light coming from the right hand corner is devided into two beams. The beam passing through the beamsplitter BS_2 is the reference beam R_1. The reference beam R_2 is directed onto hologram plate by beamsplitter BS_3. The beam A surves for adjusting.

The two states of the master object are recorded on the same plate H_m with separate reference beams (R_1, R_2) coming from different directions. The developed plate is put back, the master object is taken away, the object to be compared is put in that place where the master one was before. The new object is illuminated holographically — that is the main feature of this technique — by projecting the real images of the master object back onto the surface of the new object. This is done by reconstruction of images with conjugate

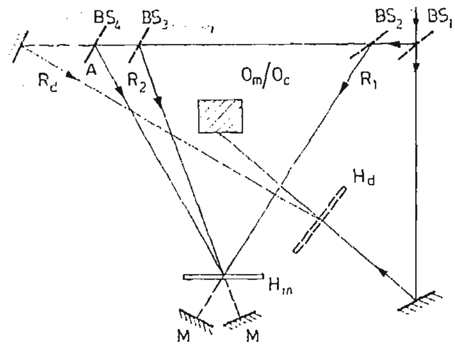

Fig. 4. Experimental setup for difference hologram interferometry

reference beams (Mirrors M). Then a new double exposure hologram H_d is taken. (The new object, reference beam R_d). This interferogram contains only the difference interference fringes.

Similar steps have to be taken at contouring. As the result the difference fringe pattern (a difference topographical map) corresponds to the shape difference between the two objects.

5. Conclusions

An industrial hologram interferometric system has to be portable, capable to work in factory environment, the evaluation of interferograms has to be fast and computer aided.

The technique of difference hologram interferometry can be used for measurement of differences in deformation/shapes of two objects. A hope may be expressed that this novel method will be the base of a measuring instrument in large scale product.

References

1. G. M. BROWN and R. R. WALES, *Vibration analysis of automative structures using holographic interferometry*, „Industrial Application of Laser Technology", W. F. Fagan, Editor, Proc. SPIE 398, 82 - 89, 1983.
2. J. SCHÖRNER, H. ROTTENKOLBER, *Industrial application of instant holography*, „Industrial Application of Laser Technology", W. F. Fagan, Editor, Proc. SPIE 398, 82 - 89, 1983.
3. M. MURATA and M. KURODA, *Application of holographic interferometry to practical vibration study*, „Industrial Application of Laser Technology", W. F. Fagan, Editor, Proc. SPIE 398, 74 - 81, 1983.
4. A. E. ENNOS, *Measurement of inplane surface strain by hologram interferometry*, J. Sci. Instrum (J. Phys. E.) Vol. 1, Ser. 2. pp. 731 - 734, 1968.
5. Z. FÜZESSY, F. GYIMESI, *Difference holographic interferometry: displacement measurement*, Opt. Eng. Nov./Dec. 1984 (to be published).

Р е з ю м е

ИССЛЕДОВАНИЕ ДЕФОРМАЦИИ ФОРМ ПРИ ПОМОЩИ ГОЛОГРАФИЧЕСКОЙ ИНТЕРФЕРОМЕТРИИ

В работе сравнено несколько методов записи голографических интерферограмм. Проанализировано их примущества и недостатки для применений в индустрии. Представлено также передвижной состав аппаратуры для голографических исследований, служащий до измерений перемещений в условиях статических и динамических нагрузок.

Обсуждено также исследования формы и сравнение форм похожих объектов.

S t r e s z c z e n i e

BADANIE ODKSZTAŁCEŃ I KSZTAŁTÓW Z POMOCĄ INTERFEROMETRII HOLOGRAFICZNEJ

W pracy porównano kilka metod zapisu interferogramów holograficznych. Przeanalizowano ich zalety i wady dla przypadku zastosowań przemysłowych. Zaprezentowano również przenośny zestaw aparatury do badań holograficznych służący do pomiarów przemieszczeń w warunkach obciążeń statycznych i dynamicznych. Omówiono też aspekty badania kształtu i porównywania kształtów obiektów podobnych

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