



MANAGING DENSE FRINGE SYSTEMS IN HOLOGRAPHIC INTERFEROMETRY

PhD thesis

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Research premises

It is a requirement at the development of the interferograms produced by holographic interferometric (HI) measurements that the full fringe system has to be recorded and observed in one piece. Nowadays, interferograms are mostly read out electronically by CCD or CMOS cameras into a computer and they are evaluated by computers, as well. Therefore the full image has to be imaged on the detector of a camera, which has limited size and resolution whereas proper optics is used (or not). The image processing program of the computer has to be able to identify the fringes for evaluation. From the point of view of the CCD detector, or rather the data processing software, it is sensible to define the maximum fringe density or fringe number which can be still resolved by the evaluation system. From here on, this fringe density will be regarded the practical upper limit of HI and according to the above, this is limited by the size and resolution of the CCD detector and by the capabilities of the evaluation program.

Therefore, according to the large sensitivity of HI, only those measuring regions can be investigated which are relatively small and which are especially not too great with respect to the practical application requirements. In addition to this, an otherwise manageable fringe system can become dense beyond measure locally, in some places because of a material fault causing rapidly changing deformation or because of some part of the object, which has significant surface gradient. This can be further aggravated the not wanted displacements occurring at loading simultaneously, the fringe system of which can make even denser the actual fringe system. Thus the management of the dense fringe systems and the rarifying of these fringe systems in any forms mean the same as the extension of the practical upper limit of the HI measuring technique. Therefore this has been a general goal since the beginnings of the applications of holographic interferometry, as well.

To achieve this, two different approaches have been evolved. The first one directly hinders the formation of dense fringe system by recording the changes of the object in small steps following the increase of load on series of intrferograms. However, this cannot always be performed at the actual type of loading and it may become very cumbersome in practice. The second approach, on the other hand, allows the formation of dense fringe systems which cannot be resolved and the modification of these fringe systems is set as a goal. It works by removing some parts of the fringe system to arrive at a fringe density which can be managed already and, naturally, the remaining fringe system still contains all essential information. These methods are called the fringe-compensation methods.

Nevertheless, in most cases, the fringe-compensation methods developed previously can subtract only very simple (straight line, concentric and equidistant) fringe systems from the full fringe system. The Holography Group at the Department of Physics developed two new fringe-compensation methods for the management of dense fringe systems, which can be used irrespective from the structure of the fringe system, quite generally, as well.

The first method is the so called “difference holographic interferometry” (DHI) in which the fringe-compensation is performed by the direct interferometric comparison of two objects. In DHI, the holographically recorded wave fronts of the master object are used for illumination of the test object (holographic illumination).

The phase differences of the wave fronts belonging to the two different states of the master object are subtracted from the phase difference of the test object. The result is the direct visualization of the difference of the two objects, even if the fringe systems are too dense in themselves for observation.

The second method is the so called interferogram-puzzle technique where the dense fringe system is recorded by scanning in parts and the sub-interferograms are put together in the memory of the computer to build up a large, complete hologram. This method does not require any accurate control of scanning because the correlation based fittings of the sub-holograms recorded with overlapping parts make this completely unnecessary.

The interferogram-puzzle technique was applied successfully in digital holography, as well, where it is similarly a basic point that interference fringes generated with high frequency by the overlapping of object and reference waves be managed properly.

Goals

During my PhD activity, I have latched on the above three research directions of the Holography Group at Department of Physics. Within this, I have chosen the following five goals to their further developments which I could reach, as well, with success:

1. extension of interferogram-puzzle technique to objects with larger sizes;
2. development of a compensation-friendly two-wavelength contouring method for making possible two-wavelength contouring in DHI;
3. optimization of the adjusting surface in the compensation-friendly two-wavelength contouring method;
4. maximization of the intensity of holographic illumination at the two-wavelength contouring in DHI
5. rendering the application possibility of detector matrix surfaces with larger sizes for scanning digital holograms with large magnification to decrease read-out time

Methods of investigation

The measurements of my PhD work has been done in the laboratories of the Holography Group at Department of Physics of BUTE where proper instruments were at my disposal: dark room, vibration isolated table, high power argon ion laser with long coherence length, optical quality mirrors, beam splitters, beam expanders, microscope objectives, photo objectives with small and large diameters, CCD cameras. These elements were used at building the measurement arrangements serving my goals. Computer work was done by the programs (ImPro2, DigHoloPro) developed by others earlier or partly during my PhD work. All in my measurements, naturally, I made continuous use of the measuring methods developed earlier or parallel at the Holography Group of the Department of Physics.

New scientific results

1. Extension of interferogram-puzzle technique onto objects with larger sizes

I have developed a new version of interferogram-puzzle technique to record the fringe systems, which makes it possible to apply it at the investigation of large objects, as well. It is an important evaluation requirement at the recording of sub-interferograms that the observation direction should not change significantly. In the case of objects with smaller sizes generally this can be provided. In the case of objects with larger sizes, however, this can be provided only by the method suggested by me where scanning is performed by Fourier-filtered optics moving together with the camera and a large hologram equal in size with the object itself is used^{1,2}. I have applied this method with success in a practical case, as well, where the hidden material fault of a large object could be revealed under large load only, which accordingly, resulted an extremely dense fringe system².

2.a. Development of compensation-friendly two-wavelength contouring method for difference holographic interferometry

The two-wavelength contouring version of DHI requires a special method where the characteristic parameters of the reconstructed images (image position, intensity etc.) can be modified separately even posteriorly. To achieve this, I have developed a new, so called compensation-friendly two-wavelength holographic contouring method where, in opposition to the previous customary methods, the posterior adjustment required by the wavelength change can be performed in a controlled and continuously monitored way. This version, which is based on two reference waves and on an adjusting surface, makes possible not only the posterior light intensity adjustments but it renders the possibility of moderating the effect of inaccurate object changes, as well, occurring in difference holography.

2.b. Optimization of the adjusting surface in the compensation-friendly two-wavelength contouring method

At the applications of the compensation-friendly two-wavelength contouring method, I have realized that the small sized adjusting mirror positioned beside the object, is not sufficient to observe the perfect coincidence of the reconstructed alignment wave fronts with interferometric precision. I have demonstrated that the annulment of the image shift can remain inaccurate even in the completely fringe-free state of the adjusting surface, too: the contouring fringes still contain the unwanted fringes caused by the inaccurate adjustment. I have shown that the best solution could be the application of an adjusting surface equal in size with the object, which could be put in a part of the object beam coupled out by a beamsplitter. However, this is very cumbersome to use and decreases the intensity of the object beam. Therefore, instead of this, I have suggested the application of a ring formed mirror surrounding the

object – which turned to be an equally perfect solution and did not even disturb the observation of the contouring fringes⁴.

3. Maximization of the intensity of holographic illumination at the two-wavelength difference holographic contouring method

The intensity of holographic illumination is always a crucial point in difference holographic interferometry because, quite naturally, they are always weaker than the direct illuminations. This is even more critical in the case of the two-wavelength contouring of DHI because there the illuminations have to be filtered, as well, to be separable. I have realized that the intensity of holographic illumination can be increased if the illuminations are separated by the use of a slit aperture and that the intensity of illumination can be maximized even more when a grating aperture is used which is put together from these slit apertures. In addition to this, I have determined the ideal directions for the reference beam and for the object beam within a compromise, where the shift of the central image point in the focal plane and with this the acceptable ring aperture diameter are maxima. In both cases, I could increase the intensity of the holographic illuminations, with respect to the basic situation, with one order of magnitude⁵.

4. Rendering the application possibility of detector matrix surfaces with larger sizes for reading holograms with large magnification to decrease read-out time

I have recognized that at reading holograms with magnification (that is with demagnified pixels), the use of the physically larger detector matrix surface does decrease the scanning time but, at the same time, the quality of the reconstructed image decreases, as well. I supposed that this is the result of the distortions occurring at the rim in the case of microscope objectives of larger magnification (10×). I have shown that at the correlation based fittings of the imaged sub-holograms, the effect of using areas at the rim of the image results the decrease of correlation unambiguously. Removing increasing areas and observing the quality of the correlation based fittings and the resolution of the reconstructed images I could determine that 1024×1024 pixel is the largest applicable detector matrix surface in the case of a microscope objective of magnification 10×. As a result of this, at 10× increase of the field of view, I could decrease the read-out time to its 1/4 with respect to the 512×512 pixel basic case – at unchanged image quality⁶.

Publications related to theses

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Other publications

Journals

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9. F. Gyímesi, V. Borbély, Sz. Mike, B. Ráczkevi, Z. Füzessy: „Beyond the upper limit of holographic interferometry by scanning”, *Dennis Gabor Commemorative Conference, Symposium on Holography and High Resolution Measurement Techniques*, Budapest, 5-6 June, 2000, Conference CD, Eds. Z. Füzessy, Gy. Ákos (2000)

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