Literature survey of holographic interferometry

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ABSTRACT

The Holographic Interferometry is the most important and revolutionary application of holography. It's an extension of classical interferometry measurement techniques which at least one of the waves which interfere is reconstructed by hologram. This precision technique can be able to measure all the types of complicated objects without mechanically disturbed like as Non- Destructive Testing. Through the use of off-axis holography, opaque objects diffused reflections appear to be overlaid by interference fringes that can be indicative of deformation, displacement or rotation of the object. Similarly in the case of transparent objects fringe patterns can be formed which are indicative of changes in refractive index or object thickness variations. Accordingly in the Holographic Interforometry the hologram was records wavefront of diffused objects and then compares with the complex wavefront. This can be stored and reconstructed at a later time. A hologram itself is an interferometer in the sense and it can be record of comparison between two wavefronts. The classical interformetry of Michelson's Interferometry was limited measurements of small path length difference of optically polished and reflecting plane or spherical surfaces. At the same time the Holographic Interferometry as becomes possible to measure path lengths and vector displacement of diffusely reflecting surface of complicated shapes. Holography offers not just only one technique, there is number of methods like Real-Time Holographic Interferometry, Time-Average Holographic interferometry and Double-Exposure Holographic Interferometry. Apart from this technique the opaque object's Non-Destructive Testing to be find the detection of material or manufacturing imperfection like cracks, voids, vibration analysis, inhomogeneous material properties, residual stress imperfect fits or incorrect dimensions. And also the opaque objects in the use find the Non-Destructive Testing of medical and dental research, solid mechanics also in the transparent objects like aerodynamic and flow visualizations, plasma diagnostics, heat and mass transfer, stress analyses etc. Even non visualized measurements also can be done with the help of Holographic Interferometry. This review paper will discuss about the Holographic Interferometry techniques and its applications in industrial measurement. The basic three types of interferomety will be outlined with advantages and limitations. Ultimate aim of this literature survey to basic and depth study about Holographic Interferometry and create new ideas to fabricate new types of holographic interferogram for objects measurements in industrial applications.

KEYWORDS: Holography; Holographic Interferometry; Hologram; Refractive Index; Interference Pattern; Wavefront.

INTRODUCTION

This technique of Holographic Interferometry has been established at 1965 by Stetston and Powell [1]. Two interfering beams are recorded in a light sensitive material called as hologram. But the optical interferometry is basic one of used to measure optical path length changes in plane surface optical elements like lenses, prisms and mirrors which must have to be high equality of plane or spherical. The small phase changes or deviations from the ideal wavefronts are successfully measured by this method. But in this case the optical interfering wavefrons only compared not recorded and hence it's always at in real time. In the advantages of Holographic Interferometry recording wavefront of diffused objects will be compares the wavefront, which are complex and the stored wavefronts can be reconstructed at later time. A hologram can play as an interferometer in the sense of recording and comparison of one or more wavefronts. If the original interference wavefronts are available with respect to the hologram, the small changes of the wavefronts become the evident as interference pattern of the hologram. Hence it could be use as more proper term is "Holographic Interferometry". These advanced set off an efficient growth of activity and optical holography very soon found large number of scientific applications.

- Character recognition [2]
- Multiple imaging [3]
- High resolution imaging of aerosols [4]
- Diffusing and observing media [5]
- Computer generated holograms [6]
- The production and correction of optical elements [7]
- Image doublurring [8]

The Holographic Interferometry is concerned with formation and interpretation of fringe pattern, which appears when a wave generated at earlier time and saved in a hologram at later reconstructed by interfering with a comparison of interference wavefornt [9]. There are most important three types of holographic fringes of frozen fringe, live fringe, time average fringe detail studies are given below.

DOUBLE-EXPOSURE HOLOGRAPHIC INTERFEROMETRY

This first type of recording especially called as frozen fringes. This has two exposures on the holographic plate with the displacement fringes, permanently recorded in the holographic plate. Typically the first exposure recorded of the unstressed initial object and the second exposure can be made up with applied stress on the object and recorded on the same holographic plate. At reconstruction that hologram is illuminated with reference beam it will gives two images, the first one is unstressed state fringes and the second one is stressed fringes of the objects image. At the end of process the result will be changes in the shape of the objects interference pattern between the two exposures on the single hologram. In this technique the pulse laser can be used for "freeze" of fast motion exposure. It is very helpful to the recording of fast moving objects. For example the turbine blade in a jet engine has been tested with this technique.

The intensity of the recording plate during first exposure will be

$$I_1(x, y) = | r(x, y) + O(x, y) |^2 \qquad (1)$$

And the second exposure is

$$I_2(x, y) = | r(x, y) + O'(x, y) |^2 \qquad (2)$$

Amplitude transmittance of the hologram is

$$t(x, y) = t_0 + \beta T (I_1 + I_2) \qquad (3)$$

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Once again the hologram illuminated with the same reflected wave, the transmitted amplitude of the hologram plane is

$$u\,(x, y) = r\,(x, y)\;\; t\,(x, y) \qquad (4)$$

The expansion of equation 4 gives two superimposed primary images, so that complex amplitude is

$$U_3\,(x, y) = \beta T r^2\,|O\,(x, y)\,|\,\{\exp\,[-\,i\,\phi\,(x, y)]|>(x, y)] + \exp\,[-i\,\phi'(x, y)]\} \qquad (5)$$

The resultant intensity of the $I_3\,(x, y)$ is proportional to

$$|O\,(x, y)\,|^2\,\{1 + \cos\,[\phi\,(x, y) - \phi'(x, y)]\} \qquad (6)$$

The Double-Exposure Holographic Interferometry recording, don't move the object and recording plate, the two interference beams are reconstructed at exact register at all time. The thing is we need to take care of the emulsion side while illuminating light on the hologram. If that emulsion has some distortion it will affect both images on the hologram.

Hilton & Mayville has been recorded with multi exposure technique under stressed between two exposures on flat metal plate.

The Double-Exposure Holographic Interferometry has some limitations

- Once we move the object between exposure times the result will be spoil, so the object needs to be stable between the exposures.
- To observe small displacements are too difficult because of the reconstructed waves showing equal phase shift and it will gives a bright image. [10, 11]

REAL-TIME HOLOGRAPHIC INTERFEROMETRY

Haines and Hildebrand have been given more attention and made lots of contributions on the real-time holographic techniques [12, 13]. In this method the recording of live fringes of the object can be record in single shoot and replaces the hologram at exactly original location in which it was recorded. After processing the illumination of the reference beam and the virtual image are coincidence on the object. If the recording object is placed under stress that object will be caused to deformation or after it released from the stress to rest state tat surface will be automatically changed to expand of the optical path from the exact original position to any point. So phase shift is created in-between the original wavefornt of the object and displaced objects wavefront. But those two wavefronts have coherence with best interference wavefront. If continuously displaced the object wave, the fringes will be continue to change the magnitude and direction of motion. That every tinny change in the object surface cans simultaneously changes in fringe patterns of the object also and it will be observed well and those fringe patterns are time depended that's why this method calls as Real-Time Holographic method. This method is very similar to the frozen fringe, used to determine precise movement in live recording but this type recording is very slow movement due to the optical difficulties. Most uses of Real-Time Holographic Interferometry is adopt with accurate displacement calibration of thermal expansion systems.

Consider a reflected hologram of diffused reflection object. Complex amplitude at normal state

$$O(x, y) = | O (x, y) \exp [-I \phi (x, y) |$$

r (x, y) is the complex amplitude of the reference beam the objects' diffused intensity recorded on the holographic plate becomes

$$I(x, y) = | r (x, y) + O (x, y) |^2 \qquad (7)$$

Amplitude transmittance of the hologram after processing the holographic recording plate written as

$$t (x, y) = t_0 + \beta T I (x, y) \qquad (8)$$

Where, β is negative slope of amplitude transmittance and exposure characteristic of the holographic recording material t_0 represents the uniform background of transmittance.

After processing the hologram is placed in the original position in which it was recorded, and illuminated by the beam from the deformed object and also the reference beam. The complex amplitude of transmitted beam by the hologram becomes,

$$u(x, y) = [O'(x, y) + r(x, y)]\, t(x, y) \qquad (9)$$

The complex amplitude of deformed object beam is 0'(x, y), small changes in shape can be assumed phase distribution of object beam so that,

$$O'(x, y) = | 0(x, y) | \exp. [-I \phi (x, y)] \qquad (10)$$

Expansion of the equation (9) If the $| r(x, y) |^2 = r^2$, then the complex amplitude becomes,

$$u'(x, y) = PTr2\ 0<x, y) + (4 + PTr2)\ 0'(x, y) \qquad (11)$$

Resultant intensity is,

$$I'(x, y) = | O (x, y) |^2 \{\beta^2 T^2 r^2 + (t_0 + \beta Tr^2)^2 + 2\beta Tr^2 (t_0 + \beta Tr^2) \cos[\phi'(x, y) - \phi (x, y)]\} \qquad (12)$$

Since β represents negative or a dark fringe corresponds to the condition is

$$\phi' (x, y) - \phi (x, y) = 2n\pi \qquad (13)$$

Where, n mentioned as an integer. The interference wave pattern is a maximum when it was

$$| \beta Tr^2 | = | t_0 + \beta Tr^2 | \qquad (14)$$

Already we known the p is negative which corresponds to the condition of

$$| \beta Tr^2 | = t_0 / 2 \qquad (15)$$

The setup arrangement of Real-Time Holographic Interferometry is used by AlWang et al. [14] recording of mechanically deformed turbine blades and its fringes can be obtained with this recording arrangement setup. Role of angle is playing as to be very small for obtain this type of fringes. After processing the hologram should be precise repositioning can be avoid the creation of extra noise fringes. At the drying process the emulsion also need to take care of non uniform drying [15]. Real-Time technique have one problem of when the diffracting light from the hologram is remains linearly polarized and the scattered light from the diffused by the reflecting object is large depolarized light.

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This happens in the viewing time visibility fringes will be dropping. While photographing or viewing time polariser is must to avoid this problem. Deformations and strain displacements can be easily investigated by this technique. Experimental setup arrangement of study about the turbine blades is shown in figure 1.

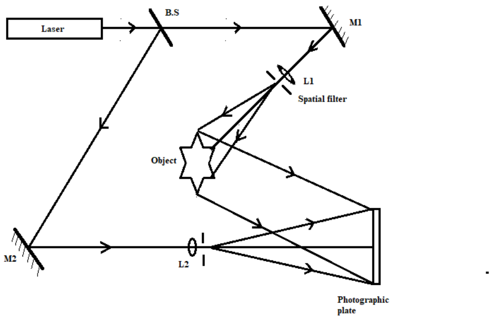

Figure 1. Experimental arrangement for Holographic Interferometry

There is some examples of Real-Time Holographic Interferometry to clearly study about the live fringes of forced mass tranfer techniqe with the air jet on swollen polimer method. Following figure shows the fringes created by the shrinkage because of the removal happens of swelling agent on the polymer.

TIME-AVERAGE HOLOGRAPHIC INTERFEROMETRY

Time-Average fringe method is used to determine the vibration structure and amplitude of the vibration objects with the help of single long exposure. This method also first discovered by Powell and Stetson and holograms made by the vibrating objects at its resonant frequency. At the reconstruction illumination of reference beam on the object a set of superimposed fringes can be seen on the object. Those fringes can be shows the same amplitude of vibrations. The brightest area of the hologram indicates the nodal area of the hologram we can easily determine. From these fringes we can determine the mode of shapes and vibrations of the object. This can be applicable for the regular displacement vibrations but no displacements since have long exposures are required. The main applications of Time-Averaged fringes are use to analysis of the loudspeaker cabinets and sound systems of musical instruments. But the disadvantage is the mode of vibrations can determine after developing and re-illumination of the hologram.

To determine the vibration of an object the time average method has been used with the holographic method. The maximum amplitude of the vibration is limited for particular length of the corresponding lights wavelength. Once we illuminating the hologram it will create the fringes of the surface it depends to nodal region. For example that can be act as stationary during vibrating the object, fringes other than nodal fringes shows the contour irrational amplitudes [16].

Consider (x, y) are the points on the object, displacement time is given by the relation of

$$D(x, y, t) = D(x, y) \sin \omega t \quad (16)$$

Where ω angular frequency of the vibration and phase shift of the light is scattered
From the point of (x, y) then the function of time can be comes as,

$$\Delta\phi\ (x, y, t) = k\ D\ (x, y) \sin \omega t \qquad (17)$$

The k denotes sensitivity factor.

If the object will be stationery in its equilibrium position means and the scattered light of the point 'p' gives the complex amplitude is

$$O(x,y) = |O(x, y)| \exp [-I\ \phi\ (x, y)] \qquad (18)$$

Scattered light of the vibrating object and its complex amplitude at any instant is

$$O\ (x, y, t) = |O\ (x, y)| \exp \{-\ i\ [(\phi\ (x, y)] + k\ D\ (x, y) \sin \omega t]\} \qquad (19)$$

Observation shows that phase of the object beam is very slowly changing with compare to electric field. At recording time the holographic process supposed to be large number recording of superposed hologram, that can be slight displace variation of each one compare to object. The linear holographic recording complex amplitude is u(x, y) of the reconstructed beam by the hologram is proportional to time average of 0(x, y, t) over the recording exposure interval T. So we can write as,

$$u\ (x, y) = 1/T \int_0^T |0(x, y)| \exp \{-\ i\ [\phi\ (x, y)]\ k\ D(x, y) \sin \omega t\}\ dt$$

$$= O\ (x, y)\ M_T\ (x, y) \qquad (20)$$

Hence, the M_T (x, y) is called as the characteristic function. If the period of vibration is less than exposure time means i.e. T>>2π/ω! e>, so we have T

$$M_T\ (x, y) = \lim_{T \to \infty} 1/T \int_0^T \exp [i\ k\ D\ (x, y) \sin \omega t]\ dt$$

$$= J_0\,[k\ D\ (x, y)] \qquad (21)$$

Where, J_0 is first kind Zero-order Bessel function. So the reconstruction image and its intensity becomes,

$$I(x, y) = |\ O\ (x, y)\ M_T\ (x, y)\ |^2$$

$$= I_0\ (x, y)\ J_0^2\ [k\ D\ (x, y)] \qquad (22)$$

Where, I - is the intensity of the object at rest. And equation (22) gives the Vibration amplitude varies across the object at reconstruction the fringes are superimposed. Fringes on the hologram shows the dark fringes denote value of zero of the function J_0^2 (Ω) and the bright fringes gives maximum value of the function J_0^2 (Ω). The Time-Average holograms used to measure the vibration amplitude of the diffusely reflection objects. This technique [17] gives more details of the object than other techniques. The vibration models and accurate measurement of objects vibration amplitude can be easily identify by this method.

This method also has some limitations of

- Very small vibrations of <A/8 vibration amplitudes are cannot to be measure by this method.
- This method is that the study is done with blindly because only after processing we can see the fringes on holograms.
- We cannot get any information of the relative phase vibration at different point on the object.

THE FRINGE LOCALIZATION

The fringe formation is creating by rotation, translation, bending, twisting of the object. Fringe patterns can be found with contrast variation of dark and bright fringes with shape modulation. Fringes are localized on the surface it depends upon with viewing angle, object illumination and object deformation. The fringes are localized because of the changing by the viewing angle that means not affect the position of the fringes patterns. An object with rough surface, the visible interference fringes are peak at particular position of observed plane, called as plane localization. Scattered light from all points of the object creating phase difference fringes at some places zero at that particular point called point of localization. If we focus on the surface means this point localization will be possible. Otherwise the change of phase difference between the object and reference beams at interfering; it will be gives shifted fringes. At the end these fringes only can use to find the means of motion [18, 19] and also diffusing reflected objects visible interference patterns gives maximum at particular position of the plane observation.

THE HOLOGRAPHIC INTERFEROMETRY

Over the years lots of methods have been developed to analyse of measuring the vibrating object. Yet limited methods have been used for the interferometry application. The basic one of optical interferometry used to be characterization of vibrating objects total surface with particular mode shape. Until this classical interferometric system suitable for only the plane surfaces and flat optical object measurements. With the help of Holographic Interferometric application can easily analyse vibration study of all complicated shape objects.

The optical interferometry has been developed by Osterberg to find the vibrating modes and amplitude of a vibrating object. The holographic basic principles were discovered by Dennis Gabor at 1948. Unfortunately the practical limitations (of coherence light) no more further works carried out until the lasers invention in 1958, which gives the very high power coherence light source to the holographic requirement. After that Leith and Upatnieks [20] takes holography as their practical tool and made that research on to practical applications. With their suggestion Powell and Stetson were applied the holography in to the vibration analysis. Powell and Stetson start up with Time-average method to use a film to record its bottom vibration at various frequencies. After more practical works they take to determine possibilities of real time method. After development of variety of laser techniques and holographic recordings the holograms were concerned and the holographer’s also attracted to this methods for knowing about to flaws and defects in materials.

Vibration analysing method was first introduced by Powell and Stetson at the year of 1965. They use to do with Time-average method of vibrating film at its resonant frequency and developed fringe formation formula. Again Stetson and Powell going for the Real-time method by a hologram of the stationary object was made with accurate repositioned after processing [21]. This hologram gives parallel fringe pattern at when the object was excited at a resonant frequency and observed with continuous illumination. After a year Stetson and Powell [22] create a complete detailed theoretical analysis of the fringe formation and gives clear equations about Real-time and Time-average fringe patterns. Then only the researchers start to working in this field independently. At 1967 Monahan [23] worked the theoretical outline for displacement of the object in terms of geometry of the system. He developed that same formula given by the Stetson and Powell and taken to verify calculations of amplitude and vibrations of the same object and by a modify Twyman-Green Interferometer were used under same condition. Bradford [24] discussed about Time-average method and its practical requirement of holographic recording setup. He used quartz bar to study of the oscillations and also worked with Double-exposure method to measure creep in that materials.

Archbold and Ennos [25] discussed about Real-time and Time-average holographic methods. They used strobing light source in Real-time technique. That strobing system consists of adrilled soften drive with turbine air compressor setup arrangement. They used 7 inches diameter aluminium disc as an object by a piezo-electric transducer have bolted at the middle of the aluminium disc. Amplitude of vibration and the mode of the shapes could be determined by the Real-time holographic technique. Watrasiewicz and Spicer [26] discussed of Real-time Holographic Interferometry of synchronous motor with drove a slotted disc to strobe that laser beam and they used a signal generator to excite object and also drive the motor. Weddell and Kennedy [27] study about the vibration modes of cylinders and thick steel plates by using Time-average method and their results used to apply in holographic engineering components. Wall [28] did an extensively study of Time-average Holographic Interferometry on large steel plates. He investigated the vibration and temperature of the system and drives a detail formula to show the effect of the system geometry on that displacement.

Wuerker and Heflinger [29] used to study of the transient mechanical vibration of the brass plate its impact with a steel ball. He used a pulsed laser source in their practical work; this helped him to freeze two different positions of that object. Peter, A.F [30] investigated the vibration modes of the turbine blades with help of Time-average holographic technique. He did arrangement of Time-average method to find various mode shapes and the uses of mechanical impedance to find resonance of the turbine blades. W.G. Alvang et al. [31] detail study of the Time-average method to determine the mode shape of compressor blades and turbine and vanes (100 Hz to 22 KHz), the mode shapes and structures are response of acoustically driven flat plate. They had very good pictures of various components vibrating at resonant frequencies. Ravindran [32] had successfully done with applied holographic Non-Destructive Testinf method for mechanical loading in low modulus materials. For the practical applications purpose a theoretical data is introduce by fringe spacing analysis method. Considered a long slim plate with a circular through hole is a theoretical model. This gives the representative data for surface displacement disturbance around through hole. The method is amenable for automation through image analysis of consequent improvement in the accuracy of sizing of the defect. Tu, M et al., [33] used the Holographic Interferometry method for combining an image hologram with a grating model. This work is proposed on opaque plain object surface and taken a 3 dimension deformation measurements of that object. In this setup the holographic plate and object surface are very closed in their position, on to which a high frequency crossed-line diffraction grating has been replicated. The hologram of Double-exposed hologram's reconstruction at multi off-axis angle and the four independent of high contrast fringes are extracted simultaneously. The recording and reconstruction optical system is much simplified compare with conventional interferometry.

Paolett, A. [34] worked in Holographic Interferometry technique for the detection of the presence of flaws in layered composites made by ceramic coatings on metallic substrates. The Double-exposed method has been used to tested and carryout of the samples under adding thermal stress. Also the work done of qualitative analysis of the fringe pattern portray to the state of integrity of the layer coating. At the result defects of cracks, cavities, disbanding and inclusion are successfully able to detect in the ceramics of metallic substrate. Zhao Zhimin et al. [35] has been used the Real-time technique for studied the applications of the synthetic Holographic Interferomtry measurements. The rotating prism multiple holography and a Real-time method is the base of this method. The synthetic holographic interferometry technique can be record both of the Double-exposure hologram and single – exposure holograms on a single holographic film. To record multiple holograms, using of rotating prism can be modulating as plane reference beam. Observation of simultaneously interferograms at standard position to recorded by Double-exposure interfrometry method and leaving the fringes provided by the Real-time interferometry. We can compare the changes of the standard state with states of different times in the result.

Dirksen [36] carries the studies of the phase shifting Double-exposure holographic interferometry of the fast photo refractive crystals. With this method studied of quasi Real-time holographic interferometry with reflection types of objects. This is based on the fast sequences of Double-exposure holographic interferograms are recorded in sillenite type of photorefractive Bissmuth Titanyl Oxide crystals. Panasyuk and coworkers [37] used the method of Double-exposure holographic interferometry on deformed surface of photothermoplastic media. During the recording session a peculiarity of the surface relief development is arising with changing of two cycles are determined. To optimise the process the optical recommendations are given. Cabruineren [38] used the photorefractive crystal Real-time and Double-exposure holographic phase shifting interferometer to study the photorefractive crystals. Once the system is calibrated, the simultaneous acquisition of two phase shifted interferograms allows the Real-time quantitative measurement of displacements of a scattering object.

Emina Petrovic [39] et all present a paper about Holographic Interferometry for the use of analysing vibrations in mechanical system. As well as the Time-average electronic holography is used for non-contact, interferometric whole-field vibration measurement. This method is based on the recording of images of a vibrating object is illuminated by the laser light with Charge-Coupled Device camera. In this paper the application of 3D pulsed ESPI is showed well and Time-average electron holography is developed for testing of vibrating break disc and vibrating wall of the truck. The same method is useful to apply in other examination of all the mechanical parts of the system. A.R. Ganesan [40] study about the holographic laser speckle method to find the Non-Destructive Testing of the defects such as voids, cracks, delimitation and deboning on the surface as well as in sub-surfaces. Holographic Non-Destructive Testing is used to study an object under stress or excitation and its behaviour. Double-pulsed Ruby laser used as the recording source in this Double-exposure method. And the Electronic Speckle Pattern Inreferometry used to find the speckles pattern of rough surface produced by an object illuminating with a laser, to carry out the correlation between the speckle patterns of the object before and after deformation with the help of image processing techniques.

CONCLUSSION

In this paper, the survey about Holographic Interferometry is reported. A number of research papers investigation regarding Holographic Interferometry in Double-exposure, Time-average and Real-time Holographic Interferometry details have been described. However the every individual method can be used in different kinds of industrial applications. Increasing the modern technology there are several techniques are used in complicated measurement but the Holographic Interferometry is unique.The all three types of interferograms constitute an accurate record of optical path length changes over a broad range of directions. The resulting reconstructed interferograms contain more information than conventional interferograms because they are three dimensional virtual images of the original scene, superimposed upon which is the complete record of the interference phenomena. There are lots of requirements for either precision alignment or quality optical components is exemplified by the fact that the interferometer. The Double-exposure Holographic Interferometry, Time-average Holographic Interferometry and the Real-time Holographic Interferometry are individually mentioned for easy understanding. From this report we came to known there would be lots of applications are creating for future technology in industrial applications. Thus, we strongly encourage new research in this field. Our future work is to find the disconnection in power circuit board with the help of Holographic Interferometry method to find in simple way.

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