STUDY OF THERMAL VARIATION OF ALUMINUM PLATE USING HOLOGRAPHIC INTERFEROMETRY

PROJECT REPORT

Submitted by

NANDINI MOL P K

(AB21PHY018)

Under the guidance of Dr.FRINCY FRANCIS

Assistant professor

Department of Physics,

St.Teresas's College (Autonomous),Ernalulam.

In the partial fulfilment of the requirements of award of bachelor's degree of science in physics.

ST.TERESA'S COLLEGE (AUTONOMOUS)

ERNAKULAM

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(AUTONOMOUS)
ESTD 1925

CERTIFICATE

This is to certify that the project "Study of Thermal Variation of An Aluminum Plate Using Holographic Interferometry" embodies the work done by NANDINI MOL P K (Reg No: AB21PHY018), student of department of Physics, St.Teresas's College (Autonomous), Ernakulam, for the partial requirements for the award of Degree of Bachelor of Science in Physics during the academic year 2023-24. The work presented in this dissertation has not been submitted for any other degree in this or any other university.

Supervising Guide
Dr.Frincy Francis
Assistant professor

St. Teresa's College (Autonomous) ★ Department of Physics ★ Ernakulam

Head of the Department
Dr. Priya Parvathy Ameena Jose
Assistant professor

Place:Ernakulam
Date: 29/4/24

ST.TERESA'S COLLEGE (AUTONOMOUS),ERNAKULAM

THE FEAR OF THE LORD IS THE BEGINNING OF WISDOM

ST. TERESA'S COLLEGE (AUTONOMOUS) ESTD 1925

B.Sc. Physics

PROJECT REPORT

Name: NANDINI MOL PK

Register number:AB21PHY018

Year of work: 2023-24

This is to clarify that this project work entitled, 'STUDY OF THERMAL VARIATION AN ALUMINUM PLATE USING HOLOGRAPHIC INTERFEROMETRY' is an authentic work done by NANDINI MOL P K.

Date: 29/4/24

St. Teresa's College (Autonomous) ★ Department of Physics ★ Ernakulam

Examiner:

MARY LINSA K.S.

DECLARATION

NANDINI MOL P K, final year B.Sc. Physics student, Department of Physics, St. Teresa's ollege (Autonomous), Ernakulam, do hereby declare that the project work entitled "STUDY OF HERMAL VARIATION AN ALUMINUM PLATE USING HOLOGRAPHIC NTERFEROMETRY ", has been originally carried out under the guidance and supervision of nt. Dr.FRINCY FRANCIS, Assistant Professor, Department Of Physics, St.Teresa's College Autonomous), Ernakulam, in partial fulfilment for the award of the degree of Bachelor of hysics. I further declare that this project is not partially or wholly submitted for any other urpose and the data included in the project is collected from various sources and is true to be the est of my knowledge.

lace:Ernakulam

ate: 29/4/24

ABSTRACT

This project Focuses specifically on an aluminum plate as the subject of thermal scrutiny, the experimental protocol involved subjecting the material to controlled heating followed by meticulous hologram recording during a subsequent cooling period. Through precise analysis of the holographic reconstructions, the thermal behavior of the aluminum plate was scrutinized, offering valuable insights into its response to temperature fluctuations. Although the direct calculation of the coefficient of thermal expansion was not performed in this study, the observed trends in fringe patterns provide indirect evidence of thermal behavior. The proportional relationship between temperature difference and the number of fringes suggests that the material undergoes significant thermal expansion or contraction in response to temperature fluctuations. Furthermore, the remarkable alignment between the observed trends in fringe patterns and established principles of thermal behavior underscores the reliability and robustness of the digital holographic interferometry employed in this study. The observed trends provide valuable insights into the material's thermal response and offer implications for future research and industrial applications.

MOTIVATION

The motivation behind the project arises from the demerits of analog holography and the need to study about an object without any damage. On the Digital holography represents a groundbreaking advancement in imaging technology, offering unprecedented capabilities in the recording and numerical reconstruction of holographic images . Unlike traditional holography methods that rely on photochemical processes. By the evolution the application of digital holography like Digital Holographic Microscopy, Digital Holographic Particle Analysis , Digital Holographic Interferometry (DH) we could easily crack our research work, This project Focuses specifically on an aluminum plate as the subject of thermal scrutiny, the experimental protocol involved subjecting the material to controlled heating followed by meticulous hologram recording during a subsequent cooling period.

STUDY OF THERMAL VARIATIONAN OF ALUMINUM PLATE USING HOLOGRAPHIC INTERFEROMETRY

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CHAPTER-1

INTRODUCTION

1.1 INTRODUCTION

A photograph represents a two-dimensional recording of a three-dimensional scene. What is recorded is the intensity distribution that prevailed at the plane of the photograph when it was exposed. The light sensitive medium is sensitive only to the intensity variations and hence while recording a photograph, the phase distribution which prevailed at the plane of the photograph is lost. Since only the intensity pattern has been recorded, the three-dimensional character (e.g., parallax) of the object scene is lost. Thus, one cannot change the perspective of the image in the photograph by viewing it from a different angle or one cannot refocus any unfocussed part of the image in the photograph.

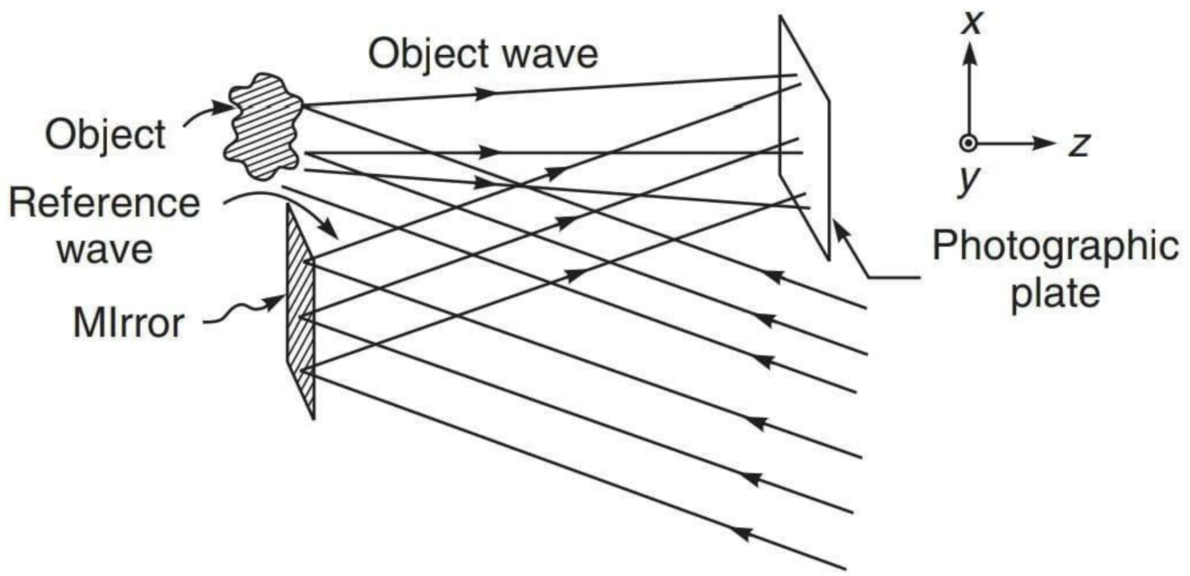
1.2 HOLOGRAPHY

Holography is a method invented by Dennis Gabor in 1947, in which one not only records the amplitude but also the phase of the light wave; this is done by using interferometric techniques. Because of this, the image produced by the technique of holography has a true three-dimensional form. Thus, as with the object, one can change one's position and view a different perspective of the image or one can focus on different distances. The capability to produce images as true as the object itself is what is responsible for the wide popularity gained by holography.

The basic technique in holography is the following: In the recording of the hologram, one superimposes on the object wave another wave called the reference wave and the photographic plate is made to record the resulting interference pattern.

1.2.1 HOLOGRAPHIC PRINCIPLE

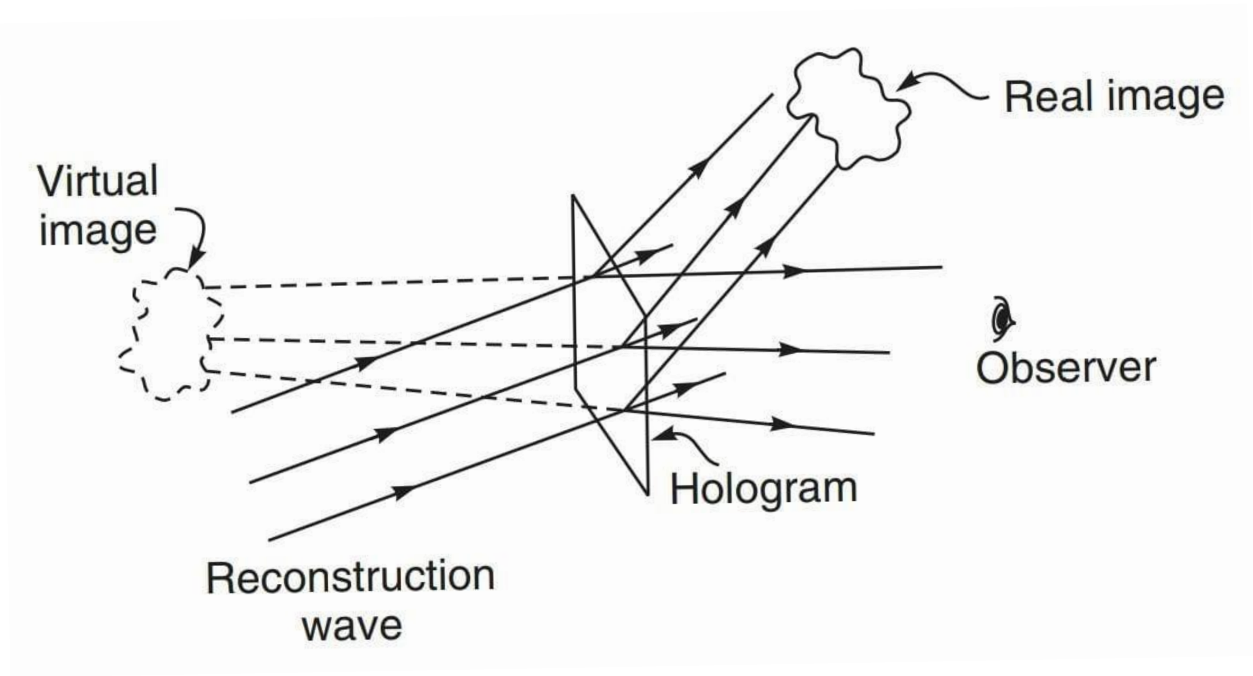
See in Fig 1.1,



Recording of a hologram

(Fig 1.1)

The Holographic Principle, a fundamental concept in holography, involves the recording of holograms using a laser light source that is both spatially and temporally coherent. This coherence ensures the uniformity and consistency of the light waves emitted by the laser, crucial for the creation of high-quality holographic images. The process begins 10 by splitting the coherent laser light into two distinct beams: the object beam and the reference beam. The object beam carries the informational content pertaining to the object being recorded, while the reference beam serves as a secondary coherent source against which the object beam interacts. These two beams are then carefully directed to overlap precisely onto the holographic recording medium. As they intersect, they create an interference pattern, a complex spatial arrangement of alternating light and dark regions, encoding the intricate details of the object. This interference pattern, also known as the hologram, is captured and stored within the recording medium. Each microscopic region of the medium bears a unique imprint of this interference pattern, preserving the entirety of the object's informational content.



Reconstruction process

Fig (1.2)

This recorded interference pattern forms the hologram and (as will be shown) contains information not only about the amplitude but also about the phase of the object wave. Unlike a photograph, a hologram has little resemblance to the object; in fact, information about the object is coded into the hologram. To view the image, we again illuminate the hologram with another wave, called the **reconstruction wave** (which in most cases is identical to the reference wave used during the formation of the hologram); this process is termed as **reconstruction** (see Fig. 1.2). The reconstruction information not only about the amplitude but also about the phase of the object wave. Unlike a photograph, a hologram has little resemblance to the object; in fact, information about the object is coded into the hologram. To view the image, we again illuminate the hologram with another wave, called the reconstruction wave (which in most cases is identical to the reference wave used during the formation of the hologram); this process is termed as **reconstruction process**

leads, in general, to a virtual and a real image of the object scene. The virtual image has all the characteristics of the object like parallax, etc. Thus, one can move the position of the eye and look behind the objects or one can focus on different distances. The real image can be photographed without the aid of lenses just by placing a light sensitive medium at the position where the real image is formed.

1.3 DIGITAL AND ANALOG HOLOGRAPHY

Digital and analog holography are two different approaches to creating and viewing holograms, each with its unique characteristics and applications.

1.3.1 ANALOG HOLOGRAPHY:

Analogue holography is a technique for capturing and reconstructing three- dimensional images using optical interference patterns recorded on light-sensitive materials, such as photographic plates.In analogue holography, the recording process involves the interference of the object beam and the reference beam on a light-sensitive medium, such as a photographic plate. This interference pattern is captured and stored within the medium, preserving the intricate details of the object. Subsequently, to reconstruct the holographic image, the recorded hologram is illuminated with the reference beam, allowing the object beam to be reproduced faithfully.

To facilitate analogue holography, it is imperative to employ photosensitive recording materials capable of capturing and retaining the interference pattern. These materials include silver halide, dichromated gelatin, photoresists, and photopolymers, each offering unique properties suited to specific applications.

In contrast, digital holography diverges from its analogue counterpart in both recording materials and reconstruction methods. Rather than relying on traditional photosensitive mediums, digital holography employs electronic light-sensitive matrix detectors. These detectors convert the interference pattern captured by the hologram into digital information, which can be processed and manipulated by a computer.

The reconstruction process in digital holography is entirely mathematical, eschewing the need for physical gratings or materialized mediums. This computational approach allows for precise control and adjustment of holographic parameters, enhancing flexibility and accuracy in image reconstruction.

One notable advantage of digital holography lies in the use of image sensors like CCD (Charge-Coupled Device) sensors and CMOS (Complementary Metal-Oxide-Semiconductor) sensors. Unlike traditional photographic plates, these sensors facilitate rapid image acquisition without the need for chemical development, thereby reducing time consumption and increasing efficiency. Moreover, digital holographic plates are reusable, offering cost- effective and environmentally friendly alternatives to traditional recording medium.

1.3.2 DIGITAL HOLOGRAPHY:

Digital holography is the process of digital recording and numerical reconstruction of holograms. Digital holography became a reality with the advent of solid-state CCDs consisting of an array of large number of small detectors. The major benefits of digital holography over analogue are

i) it does not need wet chemical processing,

ii) the time delay between the holographic recording and reconstruction is very much less and iii) it does not require complex set up for recording and reconstruction. The holograms are recorded using CCDs or CMOSs and the reconstruction is done numerically by a PC. Further information on digital holography is presented in Chapter 2

Creation Process: Digital holography captures the interference pattern using a digital sensor, such as a CCD (Charge-Coupled Device) or CMOS (Complementary Metal-Oxide-Semiconductor) sensor. This pattern is then processed by a computer to reconstruct the image.

Medium: The holographic data is stored digitally, allowing for post-processing, digital enhancement, and easy sharing.

Resolution: The resolution of digital holograms is limited by the pixel size and the number of pixels of the digital sensor. While improving, it generally does not match the resolution of analog holograms.

Viewing: Digital holograms can be reconstructed either numerically for viewing on digital displays or by using spatial light modulators to recreate the optical wavefront for viewing in physical space.

1.3.3 COMPARISON

Flexibility: Digital holography offers more flexibility in processing and sharing, plus the ability to manipulate the hologram after capture.

Resolution and Quality: Analog holography typically offers higher resolution and potentially higher quality images, due to the finer granularity of the recording mediums and the coherence of laser light.

Accessibility: Digital holography is more accessible and versatile, as it leverages digital technology and can be easily integrated with other digital imaging processes.

In summary, the choice between digital and analog holography depends on the specific requirements of the application, including the desired resolution, the flexibility of image processing and manipulation, and the practical considerations of creating and viewing the hologram.

1.3.4 MERITS AND DEMERITS

Digital Holography Merits:

Flexibility in Processing: Allows for computational reconstruction and manipulation of holograms.

Ease of Storage and Sharing: Digital files can be easily stored, copied, and shared electronically.

Real-Time Imaging: Enables real-time imaging and analysis, beneficial in dynamic measurements and monitoring.

Compatibility with Digital.

Technologies: Integrates well with other digital imaging and computational analysis technologies.

Digital holography Demerits:

Resolution Limitations: Resolution is limited by the pixel size and count of the digital sensor.

Computational Requirements: Requires significant computational resources for reconstructing images from the captured holograms.

Sensitivity to Noise: Digital sensors and processing can introduce noise, affecting image quality.

Analog Holography Merits:

High Resolution: Capable of extremely high resolution and fine detail, limited only by the light source and the recording medium.

High-Quality Images: Produces high-quality images with depth and realism that can be viewed with simple light sources.

No Digital Artifacts: Lacks the digital artifacts that can arise in digital holography, providing a pure optical reconstruction.

Analog holography Demerits:

Complex Processing: Requires chemical processing (for photographic emulsions) and precise setup, which can be time-consuming and less flexible.

Limited Manipulability: Once the hologram is recorded, altering the image requires a complete redo of the holographic recording process.

Storage and Reproduction: Physical holograms are more challenging to copy and distribute than digital files.

Both digital and analog holography have unique advantages and drawbacks, making them suitable for different applications depending on the requirements for image quality, flexibility, and processing capabilities.

1.4 APPLICATIONS OF HOLOGRAPHY

Holography, with its versatility and precision, permeates various facets of science and technology, offering a plethora of applications.

1) DISPLAY TECHNOLOGY: Holograms serve as captivating and immersive displays, providing three-dimensional visual representations that captivate audiences in diverse settings.

2)AUTHENTICATION AND SECURITY: Widely integrated into credit cards, tickets, and software CD covers, holograms serve as robust authentication features, deterring counterfeiters and ensuring the integrity of valuable documents and products.

3)ANTI-COUNTERFEITING MEASURES: Holography's ability to produce intricate and visually striking patterns makes it a cornerstone of anti-counterfeiting efforts, safeguarding products, currency, and sensitive documents against illicit replication.

4) RETAIL AND INVENTORY MANAGEMENT: In retail environments, holographic bar code readers streamline inventory management, enhancing efficiency and accuracy in shops, warehouses, and libraries.

5) HOLOGRAPHIC OPTICAL ELEMENTS (HOES): Holography enables the fabrication of sophisticated optical components such as diffraction gratings, lenses, and mirrors, offering tailored solutions for diverse applications in imaging, telecommunications, and spectroscopy.

6) NON-DESTRUCTIVE TESTING (NDT): By analyzing the fringe patterns formed on objects, holography facilitates non-destructive testing, enabling engineers to assess 15 structural integrity and detect flaws or deformities without compromising the object's integrity.

7)HOLOGRAPHIC MICROSCOPY: This technique enables detailed analysis of biological specimens by capturing both intensity and phase distributions, unlocking insights into cellular structures and dynamics with unparalleled clarity.

8) X-RAY HOLOGRAPHY: With X-ray holography, researchers gain unprecedented access to the three-dimensional architecture of live cells and microscopic structures within them, revolutionizing our understanding of cellular biology and pathology.

9) MILITARY APPLICATIONS: Holography plays a pivotal role in target recognition systems, offering precise and reliable identification capabilities crucial for military operations and defense strategies.

10) HEAD-UP DISPLAYS (HUDS): In aviation, holographic technology powers Head-Up Displays (HUDs), projecting critical flight data onto the windshield, empowering pilots with real-time information without the need to divert their gaze from the external environment.

11) HOLOGRAPHIC DATA STORAGE: This emerging technology promises vast storage capacities and rapid data retrieval rates, offering a promising solution for the ever- growing demands of data-intensive applications in fields ranging from research to entertainment.

1.5 OBJECTIVES OF THE WORK

The overarching objective of this study is to comprehensively investigate the thermal behavior of an aluminum metal sheet through the utilization of holographic techniques, with a focus on constructing and reconstructing holograms under controlled thermal conditions. The study comprises several interconnected aims:

(a) Construction and Reconstruction of Holograms: The primary objective is to construct holograms of an aluminum metal sheet using holographic techniques. This involves the coherent recording of light waves scattered from the object onto a photosensitive medium, creating an interference pattern that encodes three-dimensional information about the object's surface. Subsequently, the hologram will be reconstructed to visualize the object in three dimensions, providing a baseline reference for further analysis.

(b) Exposure to Thermal Variations: The aluminum metal sheet will be subjected to controlled thermal variations to induce changes in its temperature. By exposing the material to heating and cooling cycles, thermal expansion and contraction effects will be induced, causing alterations in the surface morphology of the object. The objective is to capture holograms at various intervals of time during these thermal variations, allowing for the investigation of the material's thermal response over time.

(c) Analysis of Thermal Variation and Fringe Patterns: Through meticulous analysis of the reconstructed holograms, particularly focusing on the observed fringe patterns, the study aims to elucidate the thermal variation exhibited by the aluminum metal sheet. Fringe patterns, resulting from interference between the reference beam and the light scattered from the object, provide valuable insights into surface deformations induced by thermal stress. By analyzing changes in fringe patterns at different temperature intervals, the thermal behavior of the aluminum sheet will be characterized with precision

The study draws upon the fundamental principles of holography and thermal physics to explore the intricate relationship between temperature variations and surface deformations in metallic materials. Thermal expansion and contraction, inherent properties of materials in response to temperature changes, manifest as changes in fringe patterns observed in holograms. By leveraging holographic techniques, which offer high precision and sensitivity to surface morphology changes, the study aims to capture and analyze these subtle variations induced by thermal stress. Furthermore, the investigation of thermal behavior in metals holds significant implications for various engineering and scientific applications. Understanding how materials respond to temperature fluctuations is crucial for optimizing design processes, enhancing structural integrity, and improving performance in diverse industrial settings. By elucidating the thermal behavior of an aluminum metal sheet through holographic analysis, this study aims to contribute valuable insights to the broader field of materials science and engineering, paving the way for advancements in thermal characterization and materials research.

CHAPTER- 2

DIGITAL HOLOGRAPHY

Digital holography and Digital Holographic Interferometry (DHI) have garnered significant attention owing to their multifaceted applications across various scientific and technological domains. This chapter serves as a comprehensive exploration of the theory, experimentation, and practical applications of digital holography and digital holographic interferometry.

2.1 DIGITAL HOLOGRAPHY

2.1.1 INTRODUCTION

Digital holography represents a groundbreaking advancement in imaging technology, offering unprecedented capabilities in the recording and numerical reconstruction of holographic images Unlike traditional holography methods that rely on photochemical processes, digital holography harnesses electronic imaging techniques, enabling rapid and precise hologram acquisition without the need for wet processing. This transition to digital technology has been made possible by the advent of solid-state CCDs (charge-coupled devices) and high-speed computers, facilitating real-time hologram recording and reconstruction with minimal time delay.

Digital holography enables the comprehensive extraction of information both along the x and y directions and across the z-direction of an object, providing a holistic representation of its three-dimensional structure. The process involves two fundamental steps: hologram recording and numerical reconstruction of wavefronts. Initially, the holographic interference pattern is optically generated through the superposition of object and reference beams. This interference pattern is then digitally captured by a CCD camera and transferred to a computer as an array of numerical data.

The propagation of optical fields in digital holography adheres to diffraction theory, allowing for the numerical reconstruction of the holographic image. This reconstruction yields an array of complex numbers representing the amplitude and phase of the optical fields, enabling the faithful reproduction of the original object. Digital holography boasts several key advantages over conventional holography, including fast acquisition of holograms, availability of complete amplitude and phase information, and flexibility in interferometric and image processing techniques. Additionally, digital holograms can be stored for reconstruction at a later time, a capability unavailable in analogue holography. Despite its numerous benefits, digital holography faces limitations in terms of pixel count and resolution of imaging devices. Nevertheless, it finds extensive applications in metrology, microscopy, interferometry, 3D object recognition, particle measurement, and beyond. Moreover, digital holography facilitates pattern recognition and encryption, broadening its scope in various scientific and engineering disciplines. This chapter encompasses experimentation, fundamental principles, and the significance of non-destructive testing (NDT) using digital holography.

2.1.2 Theory

Digital holography is a method to obtain complete information of an object along and across the plane of the object. The method consists of two steps: recording and reconstruction of wave fronts in the holograms. In the first step, two coherent beams are superimposed on a digital sensor array to form an interference pattern, known as digital hologram. The beam which is generated by the scattering of the incident ray from the object, called the object wave, stores the information of the object under study. The object beam interferes with another beam called the reference beam on CCD sensor camera. The sensor records the digital hologram and stored in a computer for further process.

For complex amplitudes of object beam E_O and the reference beam ER, the resultant intensity at the hologram plane is represented as:

$$\mathbf{I = |E_0+E_R|\hat{}2}$$

$$\mathbf{I = |E_0|\hat{}2 + |E_R|\hat{}2 + E_0E_R + E_0E_R}\text{...................................}\mathbf{(2.1)}$$

Where, $|E_O|$^2 + $|E_R|$^2 represents dc term, E_OE_R represents object beam and E_OE_R represents complex conjugate of object beam. The complex amplitudes of object beam E_O and reference beam E_R is mathematically represented as,

$$\mathbf{E_0\ (x, y) = A_0\ (x, y)\ \exp\ (i\varphi_0\ (x, y)\ )}$$

$$\mathbf{E_R\ (x, y) = A_R\ (x, y)\ \exp\ (i\varphi_R\ (x, y)\ )\ ....(2.2)}$$

From equation 2.1,

$$\mathbf{I = |A_0|\hat{}2 + |A_R|\hat{}2 + 2A_0A_R\cos\ (\varphi_R(x, y) - \varphi_0(x, y))...............................(2.3)}$$

Here, $|A_0|$^2 + $|A_R|$^2 term is constant dc term and AOAR cos (φR (x, y) – φO (x, y)) contains the information of the object in terms of amplitude and phase modulations. The resultant intensity represents the optical field E (x, y, 0) recorded by the CCD digital sensor at hologram plane. The interference of object beam and reference beam is as shown in Figure 2.1.

In the second step, the wave front recorded in the form of digital hologram at the sensor plane is reconstructed using numerical computation on computer. For reconstruction, the recorded field E (x, y, 0) needs to be propagated back to the image plane corresponding to the original position of the object during the recording of hologram at distance ‘z’ as shown in Figure 2.2

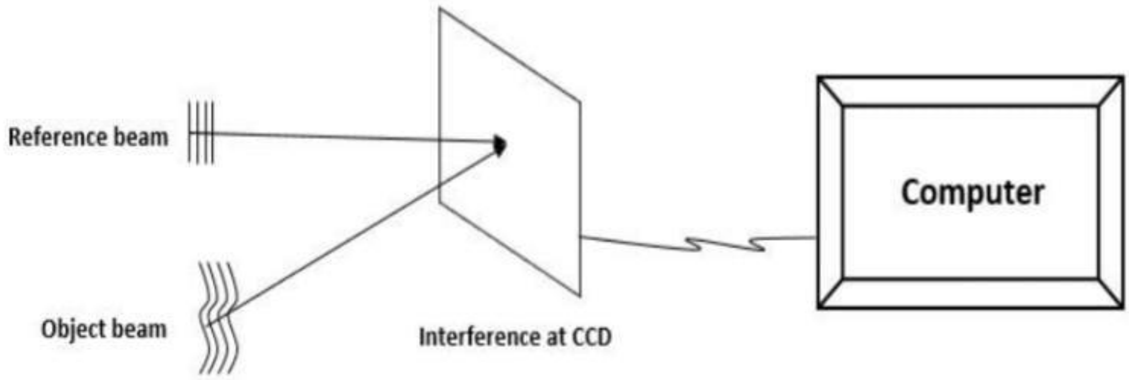


Figure 2.1: Schematic representation of the process of interference of object beam and reference beam at CCD. The recorded interference pattern known as digital hologram is stored in PC for further processing

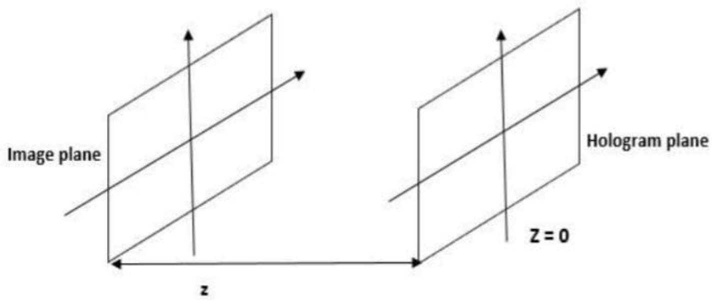


Figure 2.2: Schematic representation of image plane and hologram plane. The hologram plane is the plane of CCD digital sensor where digital hologram is recorded. The image plane is the object's plane where recorded wavefront of the object is reconstructed by back propagating the wavefront using numerical reconstruction technique

Several reconstruction methods have been proposed which are the approach of Fresnel transform, convolution and Fourier transform and the wavelet transform of the real function of amplitude transmission of the object. Here, Fresnel diffraction method is used to reconstruct the wave front. The reconstructed wave front at a distance 'z' in the image can be computed using Fresnel diffraction method as,

$$E(x,y,z)=(jk_0\exp(-k_0z)/2\pi z)\exp(-jk_0/2z(x^2+y^2))FT[E(x,y,0)\exp(-jk_0/2z(x^2+y^2))] \quad \text{.....................................(2.4)}$$

Where, E (x, y, z) is the diffracted field at a distance z in the image plane, E(x, y, 0) is the complex amplitude of recorded wave front at hologram plane (z=0) and k0 is the wave number (2π/λ), where λ is the source wavelength.

The resolution of the reconstructed image depends on the information stored in the hologram. However, the information recorded in the hologram is influenced by the size and the spatial resolution of the recording material and the light source parameter and so on

2.1.3 Applications of Digital Holography

Digital holography includes the capture of digital holograms, storage of the holograms in the computer memory and reconstruction of the recorded hologram by numerical propagation. This approach can be employed in various holographic measurement methods e.g. microscopy, particle analysis, interferometry and deformation assessment.

Digital Holographic Microscopy

Digital holographic microscopy (DHM) is an interesting method, if the object to be recorded by digital holography is small. It can measure the intensity and phase distributions of viz. biological specimen or microelectromechanical systems. In traditional microscopy, where a reference wave front is not used, only intensity information is recorded and essential information about the object is used. Digital holographic microscopy is used in material science academic research and industrial labs. It is also used for quantitative phase imaging of living cells. It provides information regarding many underlying biological processes.

Digital Holographic Particle Analysis Holographic particle analysis has been reported as an effective tool for the measurement of the position, size distribution, or speed of particles or other micro-objects suspended in fluids. It provides three-dimensional volume information from a single hologram recording. The exact location of the particle can be determined by the reconstruction of the recorded holograms at different depths. Holography does not encounter the problem of out-of-focus particles as classical imaging tool. With digital holography, also the phase of the reconstructed object wave can be calculated. The velocities of the particles can be obtained by using double pulse exposures or laser pulses of defined duration leading to particle tracks whose lengths are proportional to the speed. However, the experiments showed that the dimension of the recording, the wavelength of the light used and the distance between object and recording system are still limiting factors for lateral and depth resolution.

Digital Holographic Interferometry (DHI) Digital Holographic Interferometry is a non-contact, non-destructive technique which can measure the phase differences on the surface of the test object caused by deformations resulting from external loading such as mechanical loading or thermal stress. In digital holographic interferometry, two digital holograms are captured corresponding to two different states of object i.e. before and after the application of external load. The complex amplitude recorded before external loading is represented as:

$$\mathbf{E_1(x,y) = A_1(x,y)\exp(i\varphi_1(x,y))} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(2.5)}$$

Where $A1(x, y)$ and $\varphi 1(x, y)$ are amplitude and phase of wavefront recorded before the application of external load. The complex amplitude of the object after loading can be represented as

$$E_2(x,y) = A_2(x,y)\exp(i\varphi_2(x,y)) \quad \text{..............................(2.6)}$$

Where A2(x, y) and φ2(x, y) are the amplitude and phase of the wavefront recorded after application of external load. The phase φ2(x, y) is represented as'

$$\varphi_{2\,2}(x,y) = \varphi_{1\,1}(x,y) + \Delta\varphi . \quad \ldots \quad \text{......................................(2.7)}$$

Where, Δφ is the change in phase occurs due to the applied external load. Thus, from equation 2.7 the phase variation Δφ due to external loading is calculated as,

$$\Delta\varphi = \varphi_2(x,y) - \varphi_1(x,y) \text{...(2.8)}$$

Where, φ1(x, y) and φ2(x, y) are calculated as,

$$\varphi_1(x,y) = \arctan[\mathrm{Im}(E_1(x,y))/\mathrm{Re}(E_2(x,y))] \quad \text{............................(2.9)}$$

$$\varphi_2(x,y) = \arctan[\mathrm{Im}(E_1(x,y))/\mathrm{Re}(E_2(x,y))]$$

With values between –π and π. Digital holographic interferometry detects the defects on the surface of materials as phase differences in the reconstructed wavefront corresponding to the deformation. DHI can detect deformations down to sub-micron range. The magnitude of external loading is much below the damage threshold, but sufficient to produce detectable fringe pattern. Interference phase maps can be directly generated by digital holographic interferometry. Irregularities in the interference pattern are indicators of defects in the object under investigation. Thus, the phase maps are used for flaw detection in DHI. It is not only used for deformation measurement, but also for form determination, vibration analysis, measurement of refractive index variations and has several applications in metrology also. DHI also leads to the development of holographic 3D

2.2 NON-DESTRUCTIVE TESTING USING DHI

Digital holography has emerged as a formidable online inspection tool for non-destructive testing (NDT), offering a wide array of applications in the realms of science and engineering. Its versatility spans across disciplines such as fluid mechanics, microscopy, profile measurement, 3D object recognition, deformation measurement, and vibration analysis, among others. This technology harnesses the advancements in laser technology to leverage optical holography as a potent instrument for examining specimens in both laboratory and industrial environments.

In the domain of holographic non-destructive testing (HNDT), specimens undergo controlled stress or excitation, with their responses meticulously scrutinized through holographic interferometry. HNDT serves as an invaluable means to quantify the mechanical and thermal behavior of components within their operational milieu. It presents a simple and cost- effective approach to validate designs or simulations, shedding light on the intricate interplay between materials and their surrounding environment. Remarkably, HNDT has the capability to detect deformations at exceptionally small scales, discernible down to the sub-micrometer range, by analyzing detectable fringe patterns. These fringe patterns serve as indicators of induced flaws within the material, offering insights into surface deformations and structural integrity.

The ongoing investigation in this study focuses on employing holographic non-destructive testing techniques to analyze metals commonly employed in industrial settings. The primary objectives include examining the metals' responses to thermal stress. This endeavor is poised to enhance our comprehension of material behavior under varying conditions, facilitating the optimization of industrial components and systems for improved performance and reliability.

CHAPTER-3

DIGITAL HOLOGRAPHIC INTERFEROMETRY IN THERMAL STRESS ANALYSIS

3.1 DIGITAL HOLOGRAPHIC INTERFEROMETRY IN THERMAL AND STRESS ANALYSIS

Digital holographic non-destructive testing (NDT) represents a non-invasive approach to analyzing thermal stress in materials. Leveraging the principles of double exposure digital holographic interferometry, this technique allows for the comparison of an object's state at two different time points. By recording two holograms of the same object under different thermal conditions, the evolution of thermal stress and deformation patterns can be studied over time. In the present study, the focus is on observing the evolution of fringe patterns during heating in various metals utilized across diverse applications. Through meticulous analysis of these fringe patterns using digital holographic interferometry, researchers aim to Study of Thermal variation of Aluminum plate. This investigation not only sheds light on the thermal behavior of these materials but also underscores the utility of digital holographic interferometry in studying dynamic processes such as thermal expansion

Apparatus used

- Laser source
- Spatial filter

- Beam expander
- Sample
- Mirrors and lenses
- Digital camera
- Computer (Analysis software)

Digital holography is an advanced optical technique used for measuring the thermal expansion of metals with high precision. The experimental setup typically involves the following key components and steps:

Laser Source: A coherent light source, usually a laser, illuminates the metal sample. The wavelength of the light should be chosen carefully to ensure high contrast and resolution in the hologram.

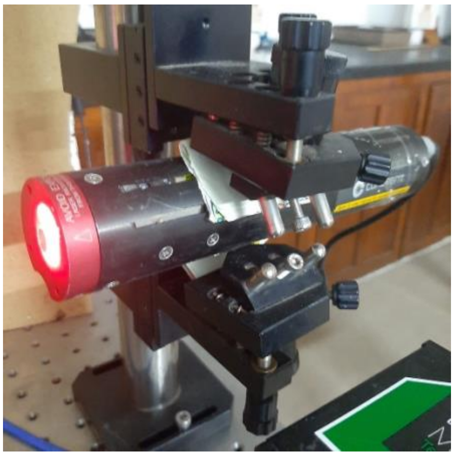
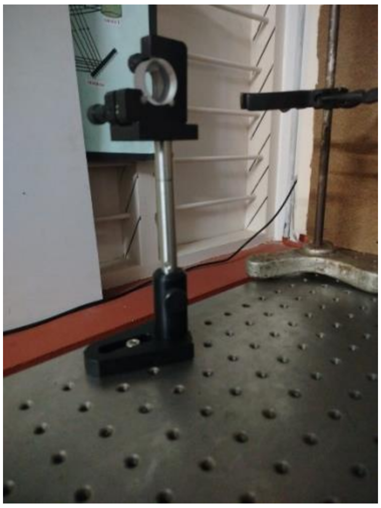


Fig (3.1) Laser

Spatial filter: A spatial filter is an optical device which uses the principles of Fourier optics to alter the structure of a beam of light or other electromagnetic radiation, typically coherent laser light. Spatial filtering is commonly used to "clean up" the output of lasers, removing aberrations in the beam due to imperfect, dirty, or damaged optics, or due to variations in the laser gain medium itself.

Fig (3.2) Spatial filter

Beam Splitter: The laser beam is divided into two parts by a beam splitter. One beam (the object beam) is directed towards the metal sample, while the other beam (the reference beam) is directed such that it bypasses the sample.



Fig(3.3) Beam splitter

Neutral density filter: Neutral density filters are often used in holography to control the intensity of the laser light reaching the holographic recording medium. This helps in adjusting the exposure time and ensures optimal hologram quality by preventing overexposure. Additionally, neutral density filters can aid in achieving the desired contrast and dynamic range in holographic recordings

Metal Sample: The sample is placed on a stage where its temperature can be precisely controlled. Heating elements or a temperature-controlled chamber is used to systematically vary the temperature of the metal sample. Here we are using aluminum as sample. The material selected for study is an aluminium sheet. For making the surface of the object diffusively reflecting, it was painted using white colour.

Fig (3.4) aluminum sample

Mirrors and Lenses: These are used to properly direct and focus the beams. The object beam reflects off the metal sample, carrying information about its surface topography and any changes due to thermal expansion.

Interference: The object beam and the reference beam are recombined to produce an interference pattern. This pattern, or hologram, encodes three-dimensional information about the surface of the metal sample.

Vibration isolation table: The whole optical set up should be mounted on a vibration isolation table for recording good quality holograms. A slight disturbance during the recording of a hologram can cause a shift in the microscopic fringes which destroys the image quality. The two types of vibrations viz., high frequency vibrations caused by materials like wood, sand etc and low frequency vibrations caused by isolation of the table from the environment by use of inner tubes, pneumatic hydraulic isolation system etc. The vibrations are overcome by using tables of high mass to achieve a very low natural frequency and filtering out most vibrations.

Fig (3.5) vibration isolation table

Digital Recording: In digital holography, the recording medium refers to the device or system used to capture and store the interference pattern created by the interaction of the object beam and reference beam. This interference pattern contains all the information necessary to reconstruct the holographic image. Common recording mediums in digital holography include charge- coupled device (CCD) cameras, complementary metal-oxide-semiconductor (CMOS) sensors, and other digital imaging devices capable of recording the intensity and phase of light field. These digital recordings are then processed using computational techniques to reconstruct the holographic image. Here we are using CCD camera as recording medium.

Fig (3.6) CCD camera

Thermal Expansion Measurement: By comparing holograms taken at different temperatures, it is possible to measure the change in dimensions of the metal sample with high accuracy. This change, normalized by the original dimension and the change in temperature, gives the coefficient of thermal expansion (CTE) of the metal.

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3.2 EXPERIMENTAL SETUP

The laser source used for the study was 648 nm DPSS red laser. The laser beam is passed through a spatial filter with beam expander where the unwanted noise of the beam gets eliminated. The expanded beam then passes through a neutral density filter then allows the object under study to fall on the subject as well as the partial reflector located beside the object. The beam emerging from the object is the object beam and the beam reflected by the mirror is the reference beam. The position of the object and the mirror should be such that both the object beam and the reference beam should be directed towards the CCD camera. The two beams interfered at the CCD and the holograms are recorded using the software 'IC capture'. The hologram is then reconstructed numerically by a PC with which the CCD is connected. The reconstruction has been done using a software named 'H-Digital'. The distance between the object and the CCD was fixed as 75 cm through trial-and-error method. Single as well as double reconstruction can be possible using digital holography.\

3.2.1 Single reconstruction:

In single reconstruction, the hologram of the object is reconstructed, and the 3D image of the object is generated in the system. In double reconstruction, the holograms recorded at two different instances of time can be reconstructed so that the condition of two-time instances can be compared. The recording of the hologram can be done manually or a sequence timer can be set inside the software to capture holograms for a particular time duration at specified intervals.

3.2.2 Double reconstruction

To get the double reconstructed image the object was heated using a blow dryer for 15 minutes. The digital holographic software was preset for 15 minutes at an interval of 30 second to automatically record the holograms over the cooling time of the object. When two holograms recorded at two different time instances were reconstructed digitally, fringe patterns were obtained which were superimposed on the image of the object. The temperature of the object was measured using a thermocouple arrangement connected with a multimeter. The thermocouple was connected to a multimeter and we get the value of temperature in degree Celsius. By counting accurately the number of fringes, the Thermal Variation of Aluminum plate can be Studied.

Fig (3.8) Blow dryer

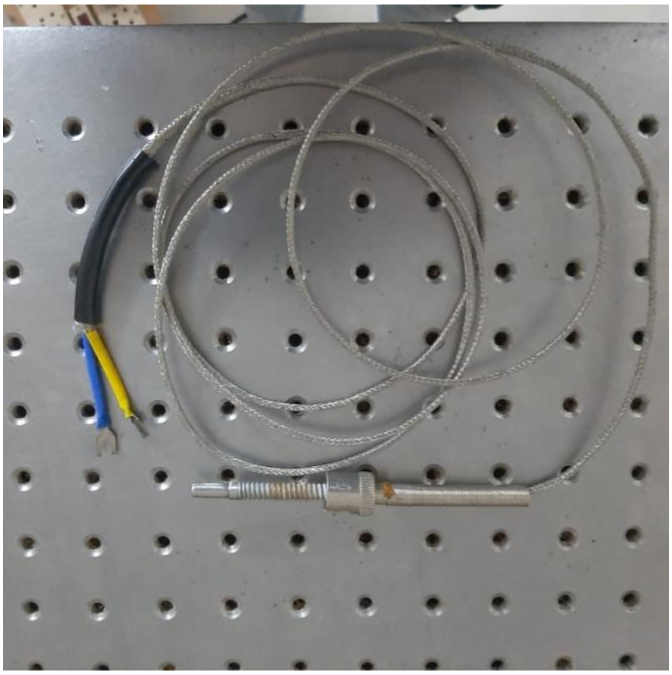


Fig (3.9) thermocouple

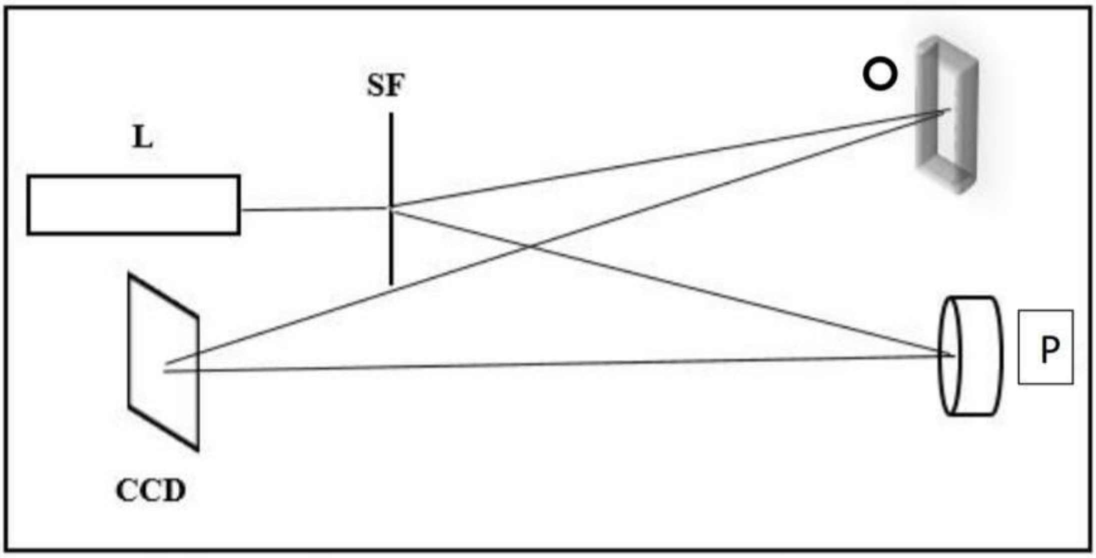


Fig (3.9) diagram for experimental setup.

L: Laser, P: Partial reflector, O: Object, SF: Spatial filter

Fig(3.10) Entire experimental setup for non-destructive testing

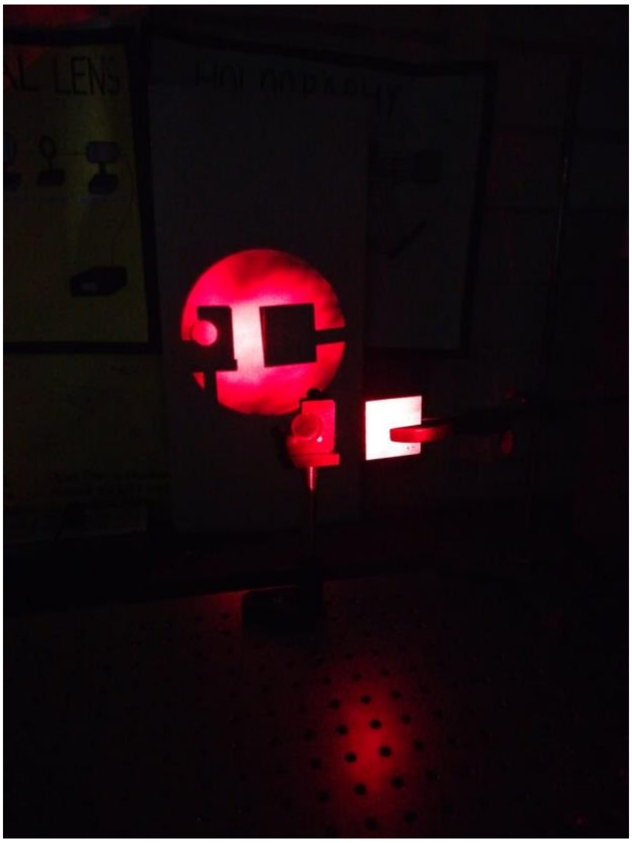


Fig (3.11) Laser expansion on the screen

3.3 Obtaining the result

Analysis Software: Sophisticated software is used to analyze the holograms, allowing for the extraction of quantitative data on the thermal expansion of the sample. This includes changes in length, volume, and even the detection of anisotropic expansion behaviors if present. This experimental setup enables researchers to measure thermal expansion with high spatial resolution and sensitivity, making it ideal for investigating the thermal properties of metals and other materials. Digital holography offers advantages over traditional methods, such as the ability to measure small and complex shapes and the provision of three-dimensional surface profiles, which can be crucial for understanding material behavior under thermal stress.

Chapter 4

FRINGE ANALYSIS AND NON-DESTRUCTIVE TESTING USING DIGITAL HOLOGRAPHY FOR STUDY OF THERMAL VARIATIONS ON A METAL PLATE

4.1 EXPERIMENT

The aim of our experiment is to study the formation of fringe pattern by heating and to Analyse thermal variation on aluminum metal.

4.1.1 obtaining the fringe pattern

A hologram is generated by capturing the interference pattern created by two coherent light beams onto a photosensitive medium, typically a digital sensor in modern applications. This interference pattern encodes information about both the phase and amplitude of the light waves, enabling the reconstruction of a three-dimensional image when illuminated with a reference beam. Through the process of holographic reconstruction, the encoded information within the interference pattern is decoded.

Capturing a hologram using holographic interferometry begins with the meticulous setup and calibration of optical components in a controlled environment to ensure precise alignment and minimal external interference. Coherence of the light source, typically a laser, is verified and adjusted as needed to maintain optimal conditions for hologram generation. Calibration of mirrors, beamsplitters, and lenses is performed to achieve accurate beam alignment and focus, crucial for producing clear interference patterns.

Once the setup is calibrated, the object to be holographically recorded is prepared, ensuring stability and appropriate positioning within the optical setup. Surface treatments or coatings may be applied to enhance contrast or highlight specific features of interest on the object. The hologram is generated by illuminating the object with two coherent light beams: the reference beam and the object beam. These beams interfere with each other, creating an interference pattern that encodes information about the object's phase and amplitude.

Careful adjustment of beam intensity and angle is necessary to produce well-defined interference patterns on the photosensitive medium, typically a CCD sensor. Adequate exposure time is allowed for the interference pattern to be effectively captured by the CCD sensor. Multiple holograms may be captured with varying parameters to optimize image quality or facilitate comparison.

Capturing the hologram involves directing the interference pattern onto the CCD sensor, ensuring proper alignment and focus to maximize image clarity. The CCD camera's exposure settings are adjusted to capture the interference pattern with optimal contrast and resolution. 34 Software tools like IC Capture are employed to control the CCD camera settings and facilitate the capture of holographic images. The captured holograms are saved in digital format for further processing and reconstruction.

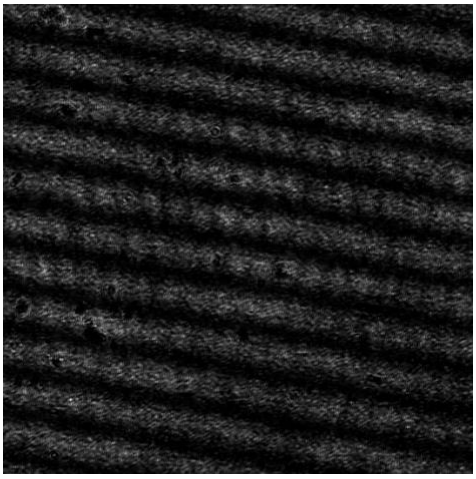


Fig 4.1 captured fringe pattern of the hologram from CCD using IC capture

4.1.2 Single and Double reconstruction of hologram

The interference pattern captured by the CCD camera provides valuable information about the object's characteristics, such as shape, deformation, or displacement. On the other hand, double reconstruction involves the use of two holograms recorded under different conditions, such as varying temperatures. These holograms are then reconstructed individually, resulting in two distinct interference patterns. When overlaid or compared, these interference patterns reveal fringe patterns indicative of any changes that occurred between the two conditions. The fringe patterns represent the interference between the object wavefronts recorded at different times or under different environmental conditions.

Once the double reconstructed image is obtained the fringes are counted. By counting the fringes, we Analyse the changes that happens like deformation in shape or displacement.

Single reconstruction focuses on reconstructing the object wavefront from a single hologram, double reconstruction compares interference patterns from two holograms recorded under different conditions to assess changes in the object's characteristics.

Captured images

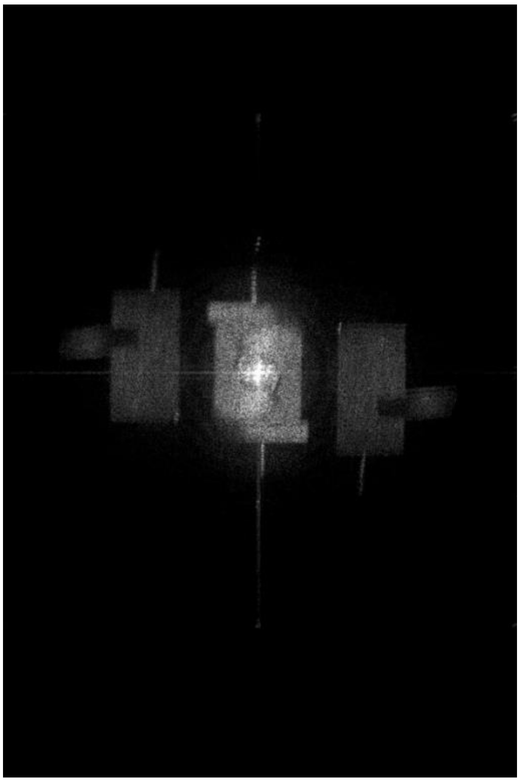


Fig (4.2) image obtained from single reconstruction of aluminum metal

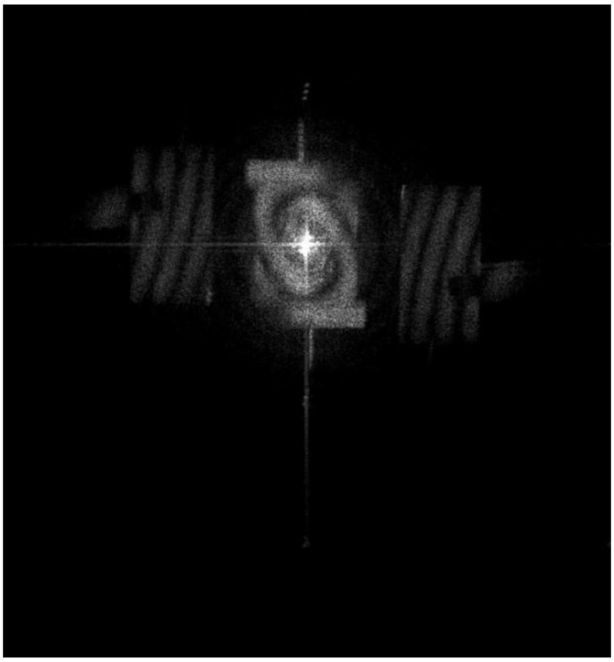


Fig (4.3) double reconstructed image, cooling profile from 30°c to 28°c

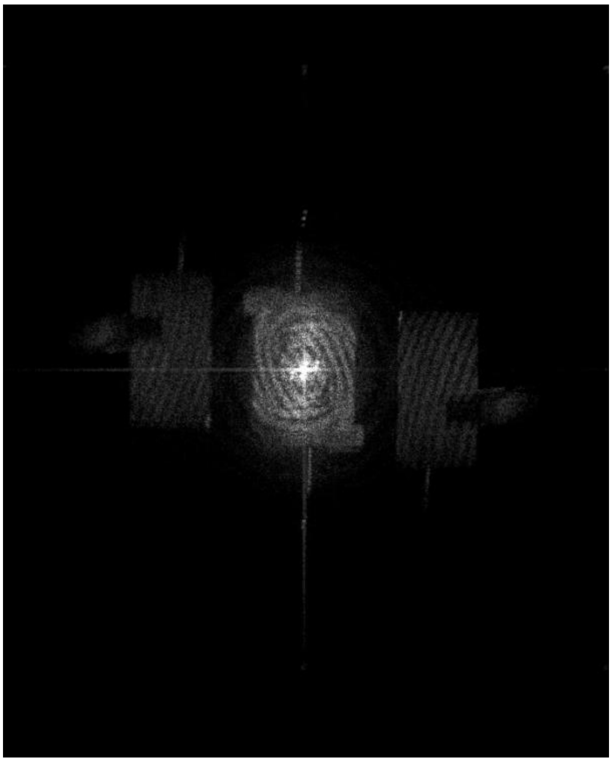


Fig (4.4) double reconstructed image, cooling profile from 31°c to 27°c

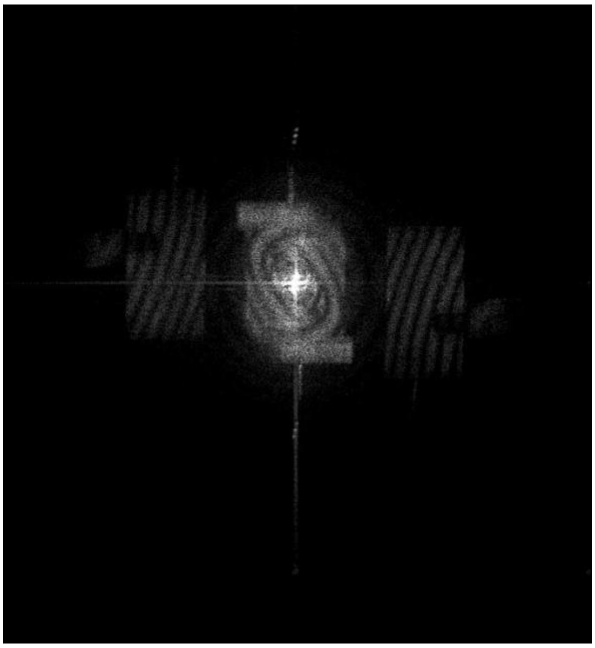


Fig (4.5) double reconstructed image, cooling profile from 30°c to 27°c

Conclusion: It was found that the number of fringes increases as the temperature difference (ΔT) increases. That is, the fringe pattern decreased over the cooling time and reached the minimum at lowest temperature difference.

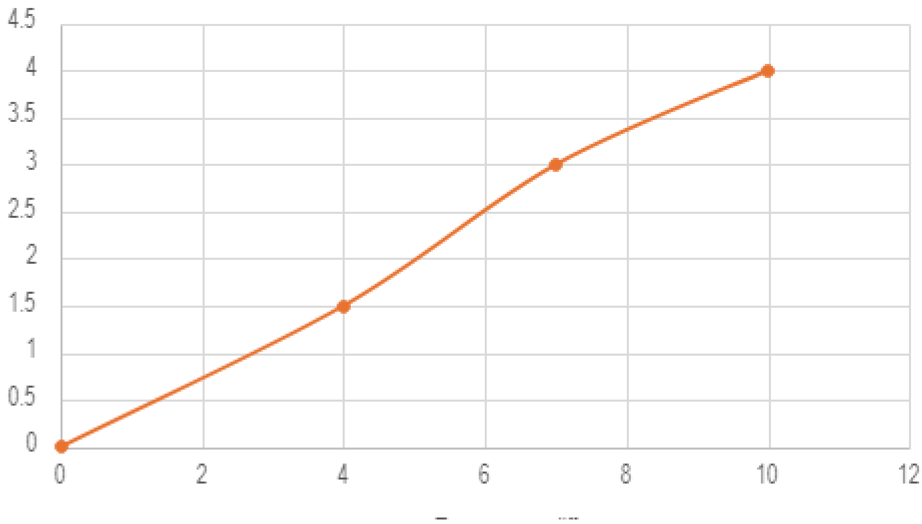
4.2 RELATION BETWEEN NUMBER OF FRINGES AND THE TEMPERATURE DIFFERNCE

From the result obtained from double reconstructed image, the fringe pattern changes with the temperature difference. As the temperature changes dimensions of the object changes this causes alternations in the interference pattern. formed by the interaction of the reference beam and the beam reflected from the object. This results in shifts in the position and spacing of the fringes in the hologram, providing information about temperature-induced deformations or strains on the object's surface.

From comparing double reconstruction images at different temperatures, we found that the number of fringes increases with temperature Difference because changes in temperature can cause fluctuations in the physical properties of materials, such as their refractive index or expansion/contraction, which can impact the interference patterns recorded in holography. As a result, variations in temperature may lead to changes in the spacing or number of fringes in the holographic image.

4.2.1 temperature difference vs number of fringes (graphical representation)

<u>Number of fringes</u>



Temperature difference

4.2.2 Conclusion

This relationship reflects the effect of thermal expansion or contraction induced by changes in temperature. When the temperature difference is large, the material undergoes significant expansion or contraction, resulting in a larger number of fringes in the holographic interference pattern. Conversely, when the temperature difference is small, the observed fringe pattern may exhibit fewer fringes due to minimal thermal deformation. factors such as the material's coefficient of thermal expansion, the geometry of the sample, and the sensitivity of the holographic interferometry setup can influence the exact shape of the graph.

This relation provides valuable insights into the thermal behavior of the material under study and can be instrumental in characterizing its thermal properties, such as the coefficient of thermal expansion.

4.3 INFERENCE

The comprehensive exploration outlined in this chapter unveils a meticulous methodology for studying thermal variation in metals, utilizing the advanced technique of digital holographic interferometry. Focused specifically on an aluminum plate as the subject of thermal scrutiny, the experimental protocol involved subjecting the material to controlled heating followed by meticulous hologram recording during a subsequent cooling period. Through precise analysis of the holographic reconstructions, the thermal behavior of the aluminum plate was scrutinized, offering valuable insights into its response to temperature fluctuations. The examination of the Temperature vs. Time graph during the cooling phase revealed intriguing trends in the material's thermal response. As the aluminum plate gradually cooled, the temperature exhibited a steady decrease over time. Concurrently, the number of fringes observed in the double reconstructed images demonstrated a proportional increase with temperature difference. This correlation underscores the influence of temperature on the observed fringe patterns, indicative of the material's thermal expansion characteristics. Although the direct calculation of the coefficient of thermal expansion was not performed in this study, the observed trends in fringe patterns provide indirect evidence of thermal behavior. The proportional relationship between temperature difference and the number of fringes suggests that the material undergoes significant thermal expansion or contraction in response to temperature fluctuations. This aligns with the fundamental principles of thermal expansion and validates the effectiveness of digital holographic interferometry in capturing and analyzing temperature-induced deformations. Furthermore, the remarkable alignment between the observed trends in fringe patterns and established principles of thermal behavior underscores the reliability and robustness of the digital holographic interferometry employed in this study. The observed trends provide valuable insights into the material's thermal response and offer implications for future research and industrial applications. 41 In conclusion, the findings presented herein contribute to our understanding of thermal variation in materials and highlight the potential of digital holographic interferometry as a sensitive measurement tool. By analyzing trends in fringe patterns, researchers can gain valuable insights into the thermal behavior of materials, paving the way for advancements in materials science and engineering applications

Chapter 5

CONCLUSION AND SIGNIFICANCE OF NON-DESTRUCTIVE TESTING

5.1 WHY NON-DESTRUCTIVE TESTING?

Non-destructive testing (NDT) using digital holography is a powerful technique with significant implications for various industries, including manufacturing, aerospace, automotive, and civil engineering. This method involves using laser beams to create holograms of objects under inspection, which are then analyzed to detect defects or changes without

Digital holography, when applied to study thermal variations on a metal plate, provides insightful data on how temperature changes affect the material at a microscopic level. This capability can be leveraged in various fields for different applications:

5.2 PURPOSE OF STUDY

The Purpose of studying thermal variation using holographic interferometry extends across various fields and applications, primarily due to its nondestructive nature facilitated by digital holography. Let's incorporate this aspect into the significance of the study: Certainly, let's delve deeper into the expanded significance of the

5.3 APPLICATIONS IN VARIOUS FIELDS

Material Science and Engineering: Thermal Expansion Analysis: By observing how a metal plate expands and contracts under varying temperatures, researchers can gain a deeper understanding of material properties and behaviors. This helps in designing materials that can withstand extreme temperatures.

5.3.1Manufacturing:

Quality Control: During the manufacturing process, digital holography can be used to monitor and measure the thermal deformations that occur in metal parts as they cool or are exposed to heat treatments. This ensures that the parts are manufactured within specified tolerances and are free from thermal-induced defects such as warping or residual stresses.

Process Optimization: By understanding how heat affects metal during processes like welding, casting, or forging, manufacturers can optimize these processes to enhance product quality.

5.3.2 Aerospace and Automotive Industries:

Component Testing: Components subjected to high thermal variations, such as engine parts, exhaust systems, and brake discs, can be tested under simulated operating conditions. Digital holography helps in identifying potential failure points by observing how components react to thermal stress.

Safety and Performance EnhanCements: Improving the safety and performance of aerospace and automotive components by studying their behavior under different thermal conditions, ensuring that they can withstand the extreme temperatures they encounter during operation.

5.3.3Electronics Industry:

Thermal Management: As electronic devices become smaller and more powerful, managing heat becomes increasingly critical. Digital holography can help analyze how heat spreads across electronic boards and components, aiding in the design of more efficient heat sinks and cooling solutions.

5.3.4 Civil Engineering:

Infrastructure Monitoring: Monitoring the thermal stress and expansion in metal structures, such as bridges and buildings, can provide valuable data for maintenance and safety assessments. This is particularly important in environments with large temperature swings which could compromise structural integrity over time.

5.3.5 Research and Development:

Experimental Physics and Chemistry: Scientists use digital holography to study the effects of heat on materials at a granular level. This aids in developing new materials with optimized thermal properties for use in various high-demand applications.

5.4 CONCLUSION

The nondestructive property of digital holography significantly enhances the significance of the study of thermal variation using holographic interferometry across diverse fields and applications. By providing a noninvasive means of characterizing thermal expansion coefficients, holographic interferometry enables engineers and scientists to optimize designs, improve performance, and ensure the reliability of critical systems and structures in industries ranging from transportation and aerospace to electronics and healthcare.

The application of digital holography to study thermal variations provides a unique, non-intrusive method to analyze and predict the behavior of metal plates under thermal stress. This is critical in optimizing material properties and enhancing the safety and functionality of components across a broad spectrum of industries.

5.5 REFERENCES

CHAPTER 1

1. P.Hariharan. “Basics of Holography”, Cambridge University Press, (2002).

2. Tung H. Jeong,.“Fundamentals of Photonics”, University of Connecticut (2008).

3. Pedrotti, Leno S., and Frank L. Pedrotti, “Introduction to Optics”, 2nd edition. Prentice-Hall, Inc., (1993).

4. Saxby, Graham, “Practical Holography”, 3rd edition. Prentice-Hall, Inc., (1996).

5. Robert Collier, C.B. Burckhardt, L.H.Lin. “Optical Holography”, Academic Press Inc.(London) LTD, (1971).

6. H.J.Caulfield. “ Handbook of Optical holography”, Academic Press Inc.(London) LTD, (1979).

7. Pacheco, Katherine. "Holographic Memory Photopolymer Materials.", Atomic Physics [physics.atom-ph]. Université d'Angers, (2007).

8. John Beena Mary. "Fabrication and characterization of dye sensitized polymer films for holographic applications." (2008).

9. J.R. Lawrence, F.T. O’Neill and J.T. Sheridan. “Photopolymer holographic recording material”. Optic 112. No. 10 449-463, (2001).

10. Myung Kim, Chau-Jern Cheng, Jinwoong Kim and Wolfgang Osten. “Digital Holography and 3D Imaging’, Applied Optics, Vol.53, Issue 27, (2014).

11. A.E.Ennos, “Holography and its Applications”, Contemporary Physics, Vol.8, Issue 2, (2006).

12.Ajoy Ghatak ,"OPTICS" sixth edition

CHAPTER 2

1. Kim, Myung K. "Principles and techniques of digital holographic microscopy." SPIE reviews 1.1 (2010): 018005.

2. Kreis, T.. "Applications of Digital Holography: From Microscopy to 3D-Television." Journal of the European Optical Society - Rapid publications [Online], 7 (2012): n. pag. Web. 12 Feb. 2021.

3. Darakis, Emmanouil, et al. "Microparticle characterization using digital holography." Chemical Engineering Science 65.2 (2010): 1037-1044.

4. Dwivedi, Gaurav, and Raj Kumar. "Analyzing Thermal Stress Distribution in Metallic Components Using Digital Holography." Progress in Optomechatronics. Springer, Singapore, 2020. 53-64.

5. Asundi, A., Singh, V.R., 2006. Circle of holography-digital in-line holography for imaging, microscopy and measurement. J. Holography Speckle 3 (2), 106–111.

6. D. Gabor, "A new microscope principle," Nature 161, 777–778 (1948). 47

7. J.W. Goodman and R.W. Lawrence, "Digital image formation from electronically detected holograms," Appl. Phys. Lett. 11, 77–79 (1967).

8. S. Grilli, P. Ferraro, S. De Nicola, A. Finizio, G. Pierattini, and R. Meucci, "Whole optical wavefields reconstruction by digital holography," Opt. Express 9, 294–302 (2001).

9. C. Minetti, N. Callens, G. Coupier, T. Podgorski, and F. Dubois, "Fast measurements of concentration profiles inside deformable objects in microflows with reduced spatial coherence digital holography," Appl. Opt. 47, 5305–5314 (2008)