Application of digital holography for NDE of metallic tubes using thermal loading

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Abstract

Optical Non-Destructive Evaluation (NDE) techniques are attractive because of its diverse application and non-hazardous nature. These techniques are widely used for measuring surface deformations of objects with and without load applied to the specimen. With the advancement of laser technology, Optical Holography and Speckle techniques are used as powerful inspection tools for NDE of specimens both in laboratory and industrial environments. Digital holography is a feasible optical tool to measure thermally induced deformation fields. This paper demonstrates the application of wave front splitting holographic set up for evaluating thermally loaded metallic tube having holes drilled in it. Holographic interferograms are recorded at different stages of thermal loading using a CMOS camera with a pixel size of 220μm.The present study employs H-Digital Holographic Software which supports Fresnel approximation technique for numerical reconstruction and processing of these digitally sampled holograms. Intensity and corresponding interference phase of the double exposure fringe patterns are acquired through subtraction of the reconstructed intensity and phases respectively of the unloaded and the loaded holographically recorded object wavefronts.

Keywords: digital holography, thermal loading, Fresnel approximation, numerical reconstruction

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1. Introduction

Digital holography has turned out to be a powerful online inspection tool for non-destructive testing and has been broadly applied in both Science and Engineering such as fluid mechanics, microscopy, profile measurement, 3D object recognition, deformation measurement, vibration analysis and so on. This category of holography usually incorporates recording an optical field emanating from an illuminated specimen in a diffraction plane and numerically estimating the optical wave field dispersion in the reconstruction plane [**1**]. During the numerical reconstruction process, not only the intensity, but also the phase information of the recorded wavefield can be calculated from the digitally sampled hologram [**2**]. One of the most significant contributions of digital holography from a practical viewpoint is holographic interferometry, to which the broad

area of Holographic Non Destructive Testing (HNDT) is linked. In HNDT, the specimen under investigation is subjected to a very small stress or excitation and its behavior is studied using Holographic Interferometry [3]. HNDT is a productive tool for quantifying the mechanical and thermal response of a component to its design environment, offering a simple, inexpensive way to substantiate a design or simulation. Holographic NDT indicates deformations down to the sub micrometer range as detectable fringe patterns. The induced flaws in the material are perceived as an inhomogeneity in the fringe pattern corresponding to the surface deformation [4].

In the present work, the digital holograms are recorded using a revised form of Holographic Interferometry setup devised Yuri Denisyuk [5]. The setup projected is very simple and needs the least number of optical components. This paper reports qualitative illustration of material response to an applied thermal load using Holographic Interferometry. In order toenhance the quality of the reconstructed images, certain image processing algorithms such as Histogram Equalization (HE) is performed on digital holograms prior to the numerical reconstruction.

2. TheoreticalDescription

2.1 Digital holographic recording and Reconstruction

In holography the entire optical wave field is recorded by coding the information with the help of a reference wave which is mutually coherent with the object wave field [6]. The object wave field U_O (x, y) scattered by the specimen to be evaluated is superposed to the reference wave field U_R (x, y). The resulting intensity distribution H (x, y) recorded by the CCD/CMOS target is written as

$$H = |U_r + U_o|^2 = |U_r|^2 + |U_o|^2 + U_r^* U_o + U_r U_o^* \tag{1}$$

Here '*' denotes complex conjugation and the spatial (x, y) coordinates are omitted for clarity. Equation [1] constitutes what is classically called the digital hologram. It includes three orders: the 0-order is composed of terms$|U_r + U_o|^2$ commonly referred as DC; the +1 order is the term $U_r^* U_o$ and the −1 order term$U_r U_o^*$is denoted as the twin image. Further optical reconstruction of the wave field is done numerically by pointwise multiplication of the recorded hologram data with a numerical model of the reference wave and propagation of the resulting complex field.

$$H.U_r = (|U_r|^2 + |U_o|^2)U_r + U_o^* U_r^2 + |U_r|^2 U_o \tag{2}$$

In the numerical reconstruction process, the complex amplitude of the diffracted wave field at thereal image plane is describedby Fresnel-Kirchoff integral foundfrom the Fourier transform of the product of the transmittance and the quadratic phase factor [7]. The resulting modulus of the complex amplitude gives the intensity of the real image.

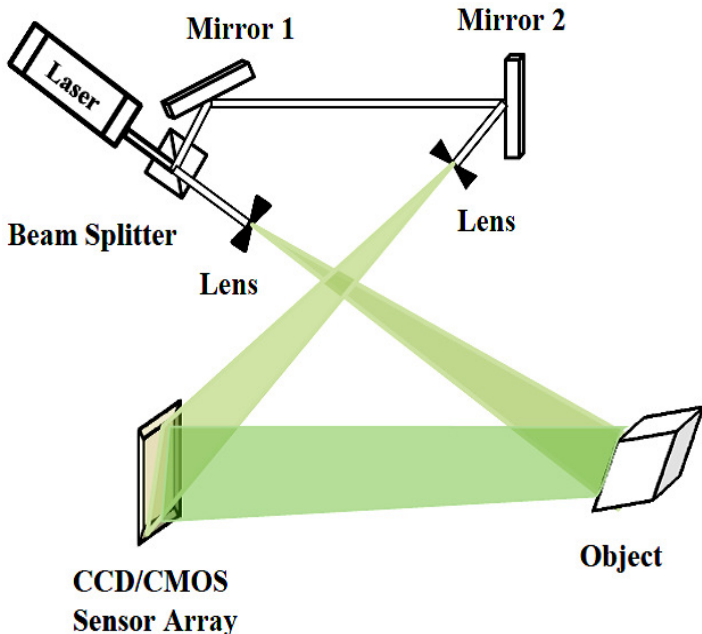### 2.2 Optical schematics of holographic Interferometry

A digital hologram is an interferometric mixing between a reference wave and a wave from the object of interest at the surface of a pixel matrix imaging sensor devices (CCD/CMOS camera) [8].The holographic interference patterns thus constructed is digitally sampled and stored by a CCD/CMOS camera and the image is reconstructed numerically on a computer by deploying the

results from the scalar diffraction theory. The sensor targetbasically records microinterference pattern where the information about both the amplitude and the phase distributions of the optical field are coded. At the microstructure level, a digital hologram is composed of microfringes, on the one hand, and light grains, on the other hand. These light grains are referred as speckles that are due to the random nature of the light reflected from the object surface [9].With digital holographic interferometry, holograms corresponding to theundeformed and deformed states of the object are recorded digitally and estimated numerically. Based on the method of obtaining reference and object beams, schematically two fundamental holographic Interferometry layoutsare implemented for recording the wavefield from the object's surface [10].In the first layout, the division of object and reference wave isachieved by wavefront division. This is done by illuminating the part of the expanded laser beam on the mirror and a part on the objectface and these two beams are directed to interact at the plane of CCD/CMOS sensors as shown in figure 1.
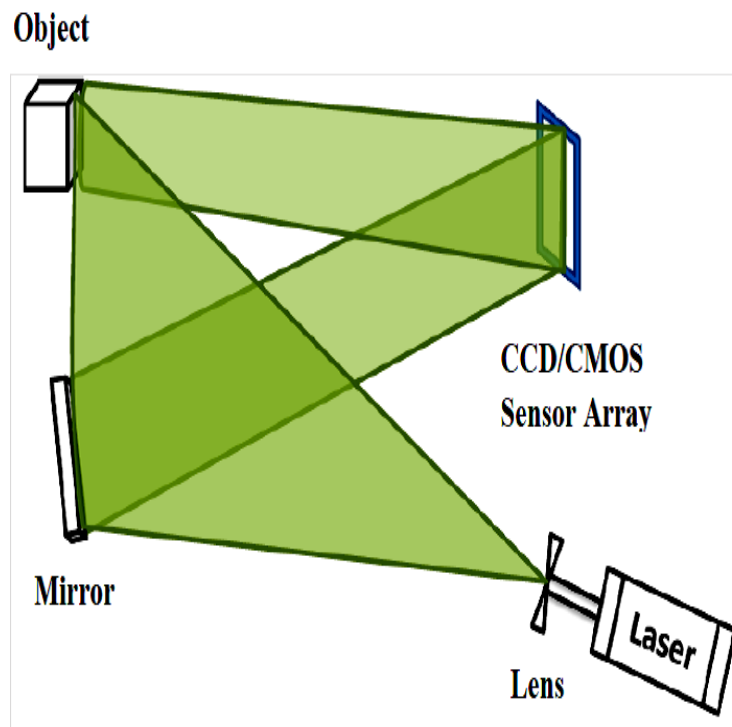
Figure 1
Wavefront Division Hologram Construction

The second configuration shown in figure 2 is categorized as amplitude division hologram construction. This layout makes use of a beam splitter to divide the laser beam into two coherent beams and subsequently expanded using a regular divergent lens. One beam illuminates the object and the other beam enters the sensor target directly which forms the reference wave. Thus the object wave is coherently mixed with a reference wave, and their interferences are recorded in the recording plane.

Figure 2
Amplitude Division Hologram Construction

3. Experimental details

The schematic of holographic interferometry setup used for the static deformation experiment is shown in figure 3.
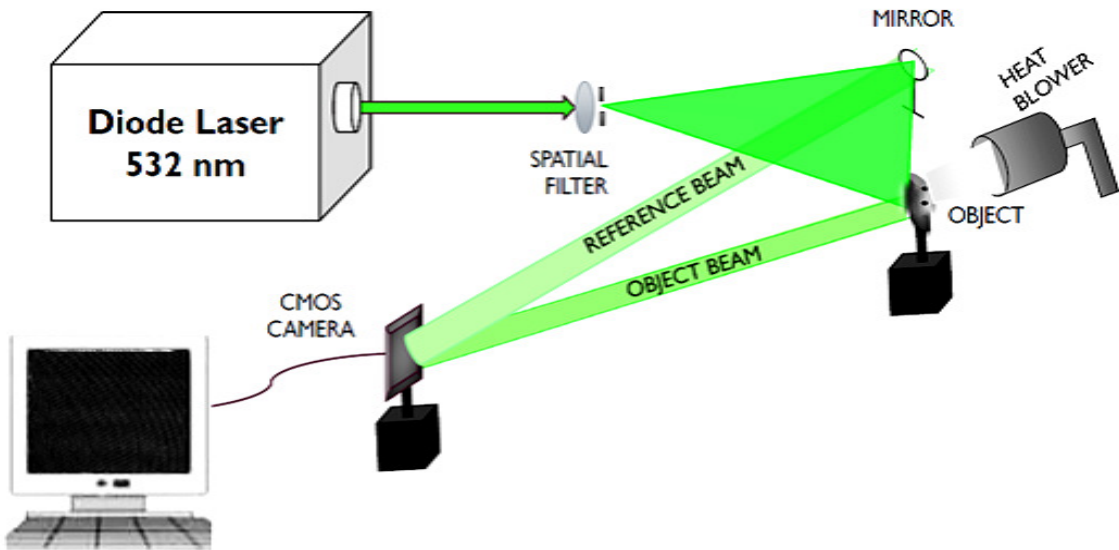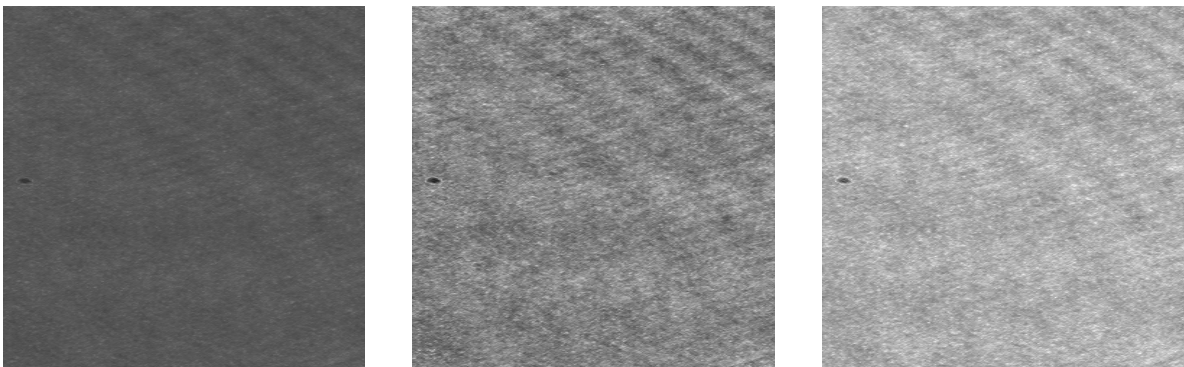

Figure 3
Layout of experimental setup

This setup makes use of a narrow laser beam with sufficient coherence length originating from a 532 nm diode pumped laser is expanded and filtered by using a spatial filter assembly. The spatial filter assembly is primarily encompasses a microscope objective lens and pinhole. It has three major functions .The first function is to diverge the laser beam since microscope objective employed is typically a double concave lens, the second is to eliminate noise on the holograms caused by the dust and scratches on the optics and the last function is to partially annihilate internal noise created in the laser cavity that travels along with the beam. Hence the resulting filtered beam is made to fall directly on the object and a plane mirror placed in proximity. The scattered waves from mirror and object interfere each other at the surface of CMOS sensor which is the hologram plane. A holed metallic tube shown in figure 4 is used as test specimen which is thermally loaded using a heat blower device.
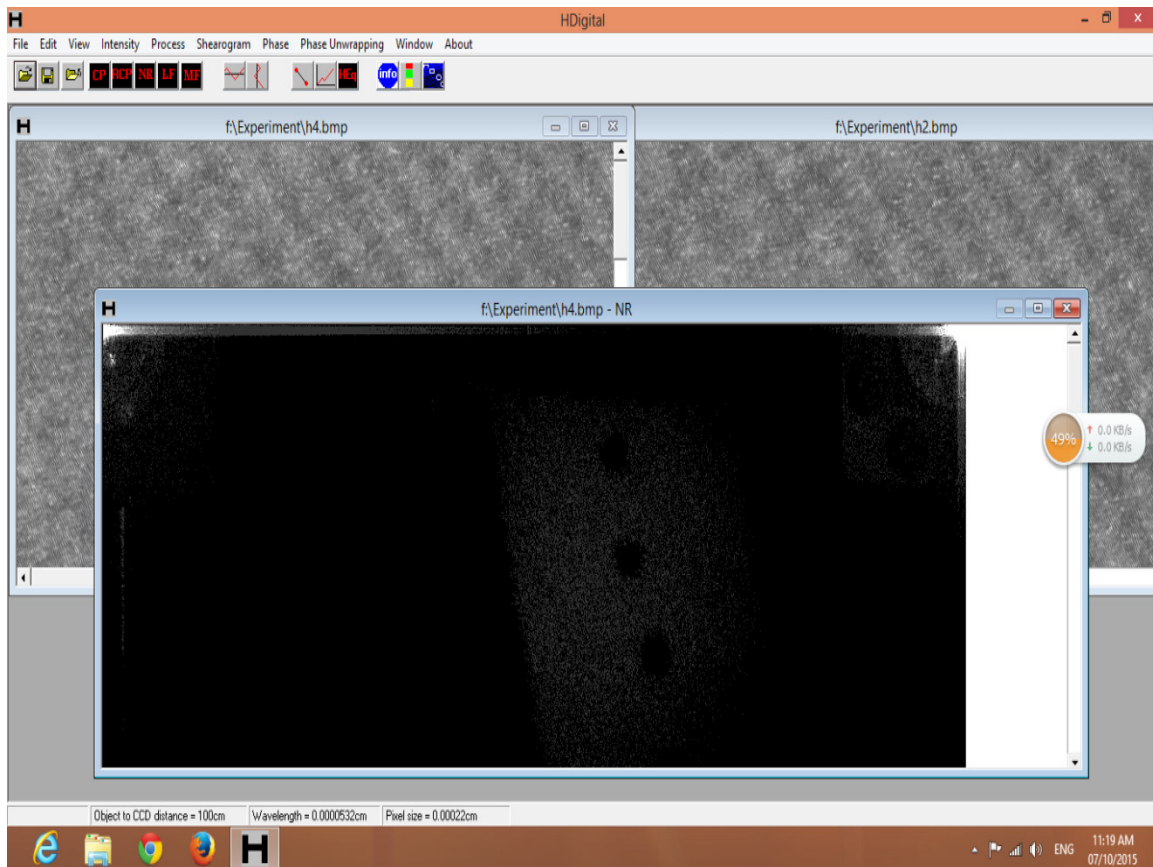

Figure 4
Snapshot of test specimen

Initially a reference hologram is recorded and subsequently the successive holograms are continuously recorded at different static conditions of the test specimen. The modulations of hologram microfringe patterns are recorded on the CMOS camera can be inferred in terms of the phase and amplitude changes caused by the specimen. Figure 5 exhibits some selected snapshots of the holograms captured during the heating up process.

Figure 5
Snapshots of the captured holograms

The numerical reconstruction of double exposure holographic fringe patterns from the single exposure holograms is done by using patented H-Digital holographic software. The intensity of the double exposure fringe patterns and equivalentinterference phase are realized via subtractionof the mathematicallyreconstructed intensity and phases respectively of the undeformed and the deformed object wavefronts. HDigital© environment shown in figure 6 thus eliminates the requirement of a laser for reconstruction of holograms.

Figure 5
H-Digital© software environment

4. Results and Discussions

Figure 6 shows holographic interference fringes developed from the double exposure numerical reconstruction of individual single exposure holograms with reference state. These fringe patterns indicate contours of equal displacement caused when the object is loaded. From the fringe spacing, the displacement level can be estimated approximately equal to λ/2.
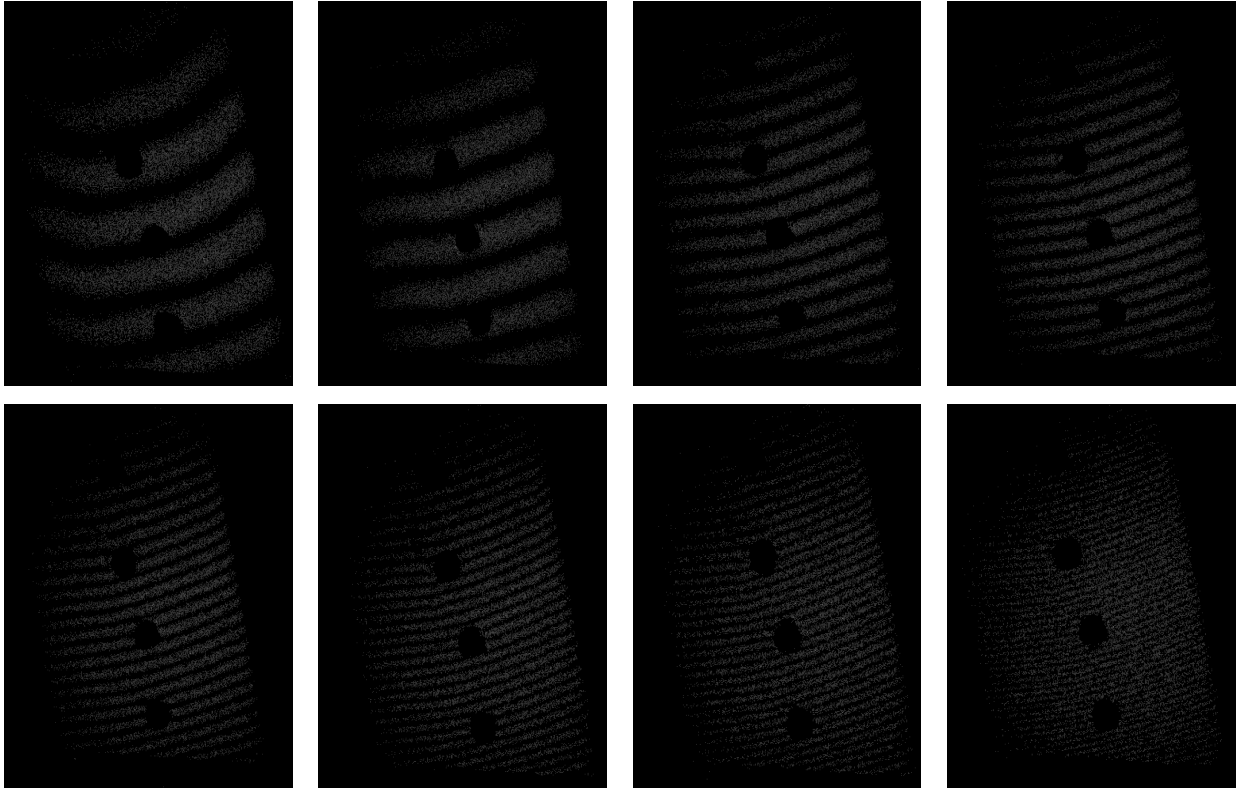
Figure 6
Holographic fringes developed during thermal loading process

Imperfection in the object produces local fluctuations in the surface displacement and in turn forms fringe anomaly in the otherwise uniformly varying fringe pattern. The fringe pattern is very sensitive and subject to the object geometry and experimental setup. During the heating up process, the temperature contrast developed on the surface of the specimen starts to produce thermal deformation phenomenon. It has been comprehended that with the addition of heat, the fringe width becomes smaller and smaller but the uniformity is preserved. The thermal loading process produces a higher fringe density since the expansion of the heated specimen has led to thermal deformation which initiates an increase in optical path difference. The result visibly indicates that the metal tube with the holes has been heated uniformly and has no flaw registered since the testing temperature levels are so low. In traditional holography, holograms cannot be enhanced once they are recorded and developed, and hence any imperfection in recording will directly deteriorate the quality of hologram reconstruction. This limitation can be overcome in digital holography because several image processing techniques can be applied to digital holograms to achieve the optimization of reconstructed images. To enhance the overall brightness and contrast of reconstructed fringe pattern, Histogram Equalization (HE) technique is done on the individual holograms prior to the double exposure numerical reconstruction.

From the reconstructed image shown in figure 7, it can be observed that, although the overall brightness is increased, the reconstructed image is roughly contaminated with noisy flecks.
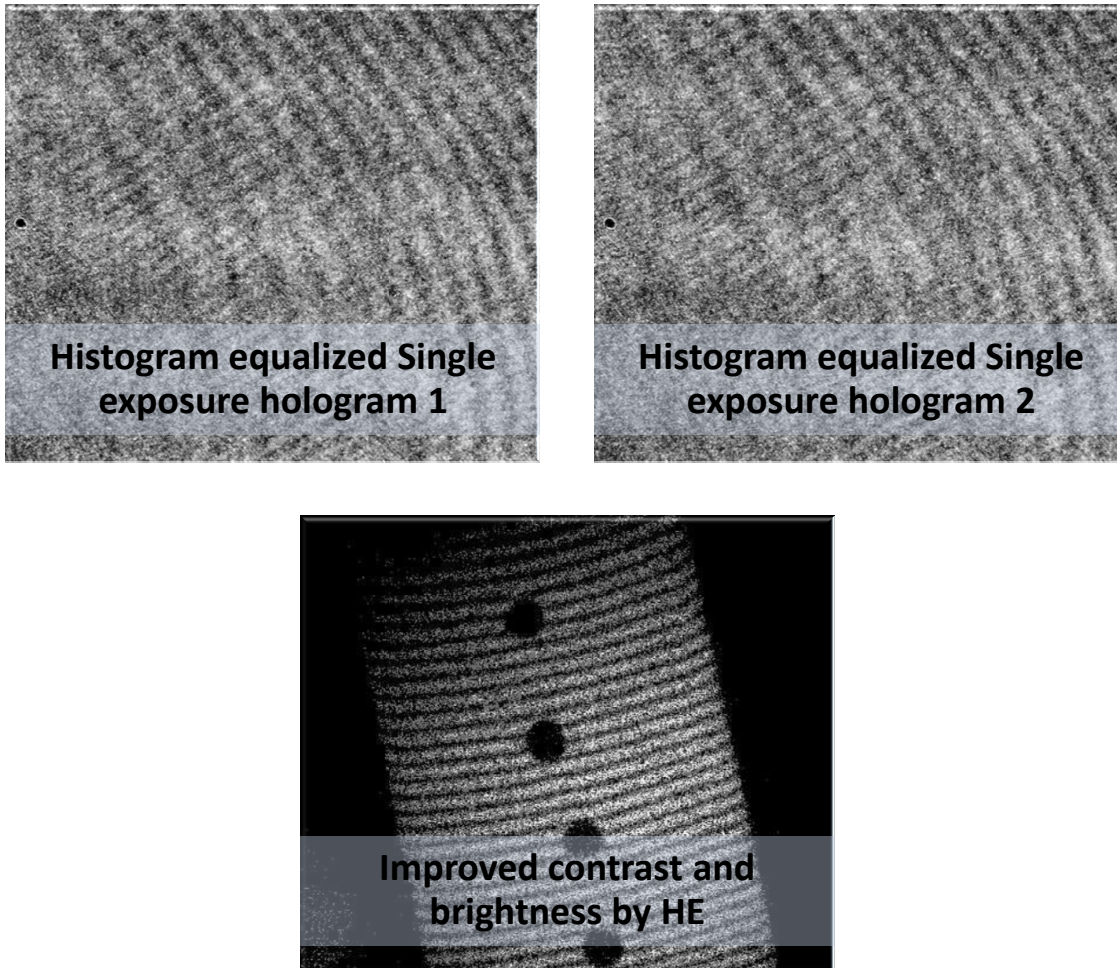

Figure 7

Effect of Histogram Equalization on holographic fringe contrast and brightness

5. Concluding remarks

The experimental results demonstrate that the present laser HNDT system incorporated with the thermal loading technique is sensitive enough to detect deformations in micrometer level. The experiment interprets the fringe density as the physical quantity which clearly reveals the states of thermal deformations in the metallic tube. Moreover the results also reveal the behavior of the fringe pattern under thermal load.

6. References

[1]. Verrier, Nicolas, and Michael Atlan. "Off-axis digital hologram reconstruction: some practical considerations." Applied optics 50.34 (2011): H136-H146.

[2]. Schnars, Ulf, and Werner PO Jüptner. "Digital recording and numerical reconstruction of holograms." Measurement science and technology 13.9 (2002): R85.

[3]. Ganesan, A. R. "Holographic and laser speckle methods in non-destructive testing." Proceedings of the national seminar and exhibition on non-destructive evaluation. Vol. 5. 2009.

[4]. Schnars, Ulf, et al. Digital Holography and Wavefront Sensing. Springer, Berlin, Heidelberg, 2015.

[5]. Caulfield, H. John, Y. N. Denisyuk, and E. N. Leith. "The art and science of holography." A Tribute to Emmett Leith and Yuri Denisyuk (2003).

[6]. Kreis, Thomas. "Application of Digital Holography for Nondestructive Testing and Metrology."

[7]. Thomas, B. P., K. V. Rajendran, and S. AnnamalaPillai. "Wholefield NDT of Porous Materials Using Digital Holography." Proc. National Seminar on Non-Destructive Evaluation. 2006.

[8]. Picart, Pascal, ed. New Techniques in Digital Holography. John Wiley & Sons, 2015.

[9]. Goodman, Joseph W. "Statistical properties of laser speckle patterns." In Laser speckle and related phenomena, pp. 9-75. Springer Berlin Heidelberg, 1975.

[10]. Kreis, Thomas. "Application of Digital Holography for Nondestructive Testing and Metrology."