DIGITAL HOLOGRAPHIC INTERFEROMETRY FOR THE MEASUREMENT OF TEMPERATURE PROFILE, HEAT DISSIPATION AND CONTOURING

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by

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Submitted

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DEDICATED TO

MY

PARENTS

CERTIFICATE

This is to certify that the thesis entitled **"DIGITAL HOLOGRAPHIC INTERFEROMETRY FOR THE MEASUREMENT OF TEMPERATURE PROFILE, HEAT DISSIPATION AND CONTOURING"** being submitted by **Mr. VARUN KUMAR** to the Indian Institute of Technology Delhi for the award of the degree of "**DOCTOR OF PHILOSOPHY**", is a record of the authentic research work carried out by him under my supervision and guidance. He has fulfilled all the requirements for submission of this thesis, which to the best of my knowledge has reached the required standard.

The material contained in this thesis has not been submitted in part or full to any other University or Institute for the award of any other degree.

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ABSTRACT

Optical interferometric techniques are widely used for scientific and industrial measurements. These techniques have become more powerful after the development of laser and holography. Holography added new dimension to the interferometry and made it a more powerful and useful tool for its applications in industries. Developments in electronic imaging devices and high speed computers have provided more flexibility in recording and reconstruction of holograms in comparison of recording on high resolution recording material for measurement purpose. Recording of holograms by digital imaging devices and reconstruction by numerical methods is termed as digital holography (DH). This has made possible the quantitative measurement of amplitude and phase of an object wavefront from a single recorded digital hologram. By using digital holography interference phase between two states of object wavefronts can be directly calculated from two digital holograms by subtracting the numerically evaluated phases in two different states of the object without using phase shifting interferometry. Thus, digital holographic interferometry (DHI) avoids extra efforts to calculate the interference phase. This provides the flexibility in the measurement and makes the process of measurement faster, robust and almost real time.

The thesis is organized in six chapters.

Chapter I provide the brief introduction of conventional holography and digital holography. This chapter provides the detailed description of digital hologram recording process and different techniques for numerical reconstruction of holograms and its application in metrology. This chapter also provides the brief outlines of the research work presented in this thesis.

Chapter II describes the measurement of natural local convective heat transfer coefficient (h_c) along the surface of electrically heated tungsten wires of different diameters and different heating conditions of wire placed in vertical position using lensless Fourier transform digital holographic interferometry (LLFTDHI).

Chapter III presents the investigations about the heat dissipation process of plate fin heat sink using LLFTDHI under different heating conditions and the effect of fin spacing on the heat dissipation performance of heat sink is also investigated. These investigations may help to make proper choice of heat sink in electronic circuit.

Chapter IV describes a method for contouring of diffused objects using digital holographic moiré interferometry (DHMI) in lensless Fourier transform configuration. Fringe projection moiré technique combined with digital double-exposure holography produces the contours in this method. This method may find important application for shape measurement.

Chapter V deals with a method for the testing (lens height profile, sag height and radius of curvature) of refractive micro-lens using Mach-Zehnder based digital holographic interferometric microscope (DHIM). Height profile of micro-lenses measured by DHIM is compared with Coherence Correlation Interferometer (CCI) from Taylor Hobson Ltd. UK with axial resolution 0.1 A^0. Root mean square deviation between the measurement done by DHIM and CCI is 0.12%.

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X_O	X coordinate in object plane
Y_O	Y coordinate in object plane
X	X coordinate in hologram plane
Y	Y coordinate in hologram plane
X_I	X coordinate in image plane
Y_I	Y coordinate in image plane
$H(X,Y)$	Intensity distribution of the interference pattern at hologram plane
O	Complex amplitude of the object wave
R	Complex amplitude of the reference wave
R^*	Complex conjugate of reference wave
O^*	Complex conjugate of object wave
$E_R(p,q)$	Digital spherical reference wave
$H(p,q)$	Digital hologram
$O(m,n)$	Digital reconstructed object wavefront
d_f	Fringe spacing
d	Distance of object from the camera
d_0	Maximum lateral extension of object
f_{max}	Maximum spatial frequency of CCD detector

$I(m,n)$	Digital reconstructed object intensity
ΔX	Sampling interval along X axis in the hologram plane/pixel size in x direction
ΔY	Sampling interval along Y axis in the hologram plane/pixel size in Y direction
ΔX_I	Sampling interval along X axis in the image plane
ΔY_I	Sampling interval along Y axis in the image plane
λ	Wavelength of the laser light
k	Wave vector
$M \times N$	Number of pixels in the sensor
g	Impulse response of free space propagation
m, n	integers $m = 0,1,2,3,4....M \quad n = 0,1,2,3,4....N$
FFT	Fast Fourier transform
Ψ_{TD}	Digital transmitted wave front
$R_D(p,q)$	Digital Plane reference wave
$\phi(m,n)$	Phase distribution of a reconstructed object wavefront
$IFFT$	Inverse Fast Fourier transformation
d_1, d_2, d_3	Diameter of tungsten wire
$[S]$	Area Matrix
h_c	Convective heat transfer coefficient
K_w	Thermal conductivity of air at surface of heated object

T_w	Surface temperature of wire
T	Ambient Temperature
$n(x,y)$	Refractive index of heated air
$n_o(x,y)$	Refractive index of ambient air
u	Molar mass of air
P	Atmospheric pressure
K	Gladstone-Dale Constant
R	Universal gas constant
$L \times W \times H$	Length×Width×Height of heat sink
h	Thickness of base of heat sink
S	Channel width of heat sink
b	Thickness of heat sink
$Q(x)$	Convective heat flux
$2t$	Detector translation
l_M	Fringe spacing of modified grid
l_r	Fringe spacing of reference grid
Δh	Moiré contour interval
θ	Tilt in object illumination beam
β	Initial object illumination angle

n_s	Refractive index of micro-lens material
h	Sag height of micro-lens
D	Diameter of micro-lens
ROC	Radius of curvature of micro-lens
J	Fringe spacing of sheared interferogram