Chapter 1

Introduction

1.1 Introduction

Holography is an optical technique to record and reconstruct optical wave fields. The term holography comes from the Greek meaning whole writing. It is a two-step process: (1) an object illuminated by coherent light is made to produce interference fringes in a photosensitive medium, and (2) reillumination of the developed interference pattern by light of the same wavelength produces a three-dimensional image of the original object. The invention of optical holography furnished a radically new solution to the problem of preserving video information on the three-dimensional objects and of visualizing this information. The past twenty years have seen a rise of interest in optical holography because of several major advances in its technology. Holography is now firmly established as a display medium as well as a tool for scientific and engineering studies, and it has found a remarkably wide range of applications for which it is uniquely suited. Perhaps the most important is holographic interferometry for nondestructive testing and precision measurement of deformation or refractive index variations. Holographic interferometry is a method for measuring all changes in physical quantities that can be transformed into a variation of the phase of an optical wave.

In the early days of holography, the holograms were recorded on photographic films or plates. These films have a very high resolution (e.g., 5000 lines/mm) but have the disadvantage that they need wet chemical development. After the hologram was recorded on such a film, the physical reconstruction of the recorded wave field was obtained by illuminating the film with a laser. The procedure is time consuming. Therefore, more than 30 years ago, researchers have investigated the possible use of fast electronic recording with sufficient resolution to record and evaluate holograms and holographic interferograms in nearly real-time.

A first response to this demand was the development of the Electronic Speckle Pattern Interferometry (ESPI) and Digital Speckle Pattern Interferometry (DSPI) techniques of speckle metrology [1], which was invented independently by several groups [2,3], where analog TV-cameras or digital charge-couple-device (CCD) cameras are employed. In order to achieve speckles of resolvable size and to prevent high frequency micro-interference, the reference wave is co-linear to the object wave. The object surface is imaged onto the camera target and the superposition of the co-linear reference wave gives a speckle field. The speckle fields of two states of the object surface, produced and recorded in this way, are then subtracted point wisely one from the other, the resulting correlation fringes indicate the interference phase distribution belonging to the surface deformation.

Contrary to these techniques the digital holography approaches directly investigates the micro-interference pattern produced by the reference and the object waves, which is recorded on the CCD-target. The emerging computer technology of the last decade – increasing processing speed and memory capacity, as well as the CCD cameras having more and smaller pixels – make this technique better suited to an industrial environment than are photographic films. Therefore a digital recording of the primary holograms and a numerical reconstruction of the complex wave fields from the recorded intensity fields would offer real advantages to holographic metrology.

The present work is an attempt to develop the first digital holography system in this laboratory. This study includes investigating the working conditions and requirements for direct recording of Fresnel holograms on to the CCD-sensor, developing the numerical reconstruction algorithm and software, and finally testing the utility of the system in an application to laser metrology.

1.2 Organization of the Dissertation

The work is organized into six chapters. The main body of this work is contained in chapters 3, 4 and 5. Chapter 2 presents a review and the basic principle of holography. The concept of holographic imaging is introduced, describing such effects as interference and diffraction, followed by a historical development of optical holography and finally discussion on the development of recording materials from the silver halide emulsion to the CCD cameras.

In chapter 3 the basic formulation of holography, wavefront reconstruction is presented. The optical foundation of holography in term of light wave, intensity, interference and diffraction are introduced. Further discussions center on the Fresnel-Kirchhoff integral and classification of hologram. Detailed discussion on digital holography and digital holographic interferometry, in term of recording the Fresnel hologram on the CCD-sensor and the numerical reconstruction of digitally sampled Fresnel hologram are presented.

Chapter 4 described the experimental implementation of digital holography and digital holographic interferometry. The digital recording procedure and storing image file format are also presented. The application of digital holographic interferometry to the measurement of the coefficient of linear thermal expansion is presented in Chapter 5. Three common materials, namely aluminium, brass and stainless steel, are tested and the results are compared to the standard values.