Chapter 1

Introduction

Science is completely dependent on measurement. Measurement is the determination of the size or magnitude of something. Measurement is not limited to physical quantities, but can extend to quantifying almost any imaginable thing such as degree of uncertainty. The availability of measuring equipment and the ability to use it are essential if scientists are to be able to objectively document the results they achieve. The science of measurement - Metrology is probably the oldest science in the world and knowledge of how it is applied is a fundamental necessity in practically all science-based professions.

The subject of measurement and testing is of great interest experimentally, theoretically as well as from an applied perspective It is of specific interest to manufacturing industries where quality control is of importance. Testing is a technical investigation of a product as to whether it fulfils its specified performance. Measurements are made for a variety of reasons, and these reasons shape and refine the type of measurement techniques and equipment that are available. There are many measurement and testing techniques available in the literature, among them optical interferometric techniques are comparatively more sensitive and accurate.

Interference phenomenon has important practical uses in spectroscopy, metrology and testing. The application of interference to measurement is known as interferometry. One of the applications of interferometry is measurement of small object displacements, diffusion co-efficient of liquids, phase transition in liquid crystals etc. Many non-interferometric techniques are also used for these measurements. The invention of lasers has made it possible for the optical interferometric techniques to provide results having accuracy up to few nanometers. Also, the application of interference phenomenon includes testing of optical surfaces, optical elements, roughness measurement, determination of index of refraction etc[1]–[7]. The quality of the optical components play very important role in sensitive optical experiments like holography, interferometry, phase conjugation etc[1]. For example, optical components like beamsplitters with proper splitting, lenses for proper beam expansion, collimation and focusing, mirrors and glass plates for reflection etc. are necessary to improve the accuracy of results[1, 3].

1.1 Optical methods for Measurement and Testing

There are many well known optical measurement and testing techniques like Michelson Interferometer, Twyman-Green Interferometer, Murty's lateral shearing Interferometer, Holographic Interferometer, Speckle Interferometer etc. All these techniques have respective merits and demerits when implemented.

The Michelson Interferometer makes use of a broad source of quasi-monochromatic radiation. The incident beam is split into two by a beam splitter which is oriented at 45^o with the direction of the beam[3]. The two beams, reflected and transmitted, proceed to two mirrors, which reflect them back. The reflected beams are combined by the beam splitter and gives rise to interference pattern which varies when the distance or angle of one of the mirrors is changed with respect to the beamsplitter.

The Twyman-Green interferometer is a modification of the Michelson interferometer used to test optical components. It was invented and patented by F. Twyman and A Green[8] for the testing of prisms and microscope objectives and was later adapted and applied to the testing of camera lenses[9]. In the basic Twyman-Green configuration, the system is illuminated with a quasi-monochromatic point light source; the light is collimated by means of lens in order to form flat wavefronts. The wavefront is then divided in amplitude by means of a beam splitter. After reflection, light from both mirrors impinges again on the beam splitter. Two interference patterns are then formed, one going to lens and the other going back to the light source. Lens permits all of the light from the aperture to enter the eye so that the entire field can be seen. The observed fringes are of the equal thickness type[1].

Lateral shearing interferometry is an important field of interferometry and has been used extensively in diverse applications such as the testing of optical components and systems and the study of flow and diffusion phenomena in gases and liquids Basically the method of lateral shearing interferometry consists of displacing the defective wavefront laterally by a small amount and obtaining the interference pattern between the original and the displaced wavefronts. If the wavefront is nearly a plane, the lateral shear is obtained by displacing the wavefront in its own plane. If the wavefront is nearly spherical, the lateral shear is obtained by sliding the wavefront along itself by rotation about an axis passing through the center of curvature of the spherical wavefront[1]

Holographic interferometry is a powerful technique of whole field mapping which uses special nature of holograms to detect displacement by recording both phase and amplitude. This is done by making laser incident on surface with roughness of the order of wavelength that creates grainy appearance called speckle pattern. The speckle pattern changes due to deformation of surface of the object under test when a tension is applied to it. When a reference picture is brought on top of this, an interference pattern is formed. This pattern makes a whole field out of plain strain map. It is accurate to fraction of a wavelength.

Speckle Interferometry is another interference technique that measures in plane displacement. Two exposures are used with the object being deformed, rotated or moved between these exposures. The first exposure records the speckle pattern and the second exposure records a similar speckle pattern but slightly shifted according to the deformation of the object. This creates a Young's fringe pattern when the laser light is projected through the developed specklegram

Though holographic and speckle interferometry are very similar, interference between an object and test beam are recorded in both cases. For speckle interferometry, the speckles are usually resolved by the recording system; however, this is not a necessary condition [10]. The major difference between the techniques is that for speckle techniques an intermediate holographic recording is not required. Electronic storage and processing can take the place of the intermediate hologram in real-time techniques. Another difference between speckle and holographic techniques is that the object and reference beams are usually in line with one another in a speckle system; whereas, for holographic interferometry, they can have any angle between them[11].

Digital Speckle Pattern Interferometry (DSPI) is another improvement of speckle interferometry and is the most useful and powerful tool in measuring displacements as well as deformation. It is simple and can be used to measure in plane and out of plane movement. It is whole field, non destructive, accurate and real time method. DSPI is different as it has a high resolution monitor instead of a camera to display the results that the computer to processes. Computer software and frame grabber hardware takes picture of the first specklegram and digitally mix another (second) specklegram. This creates a correlation fringes.

Moiré pattern is an interference pattern caused by diffraction. Moiré is an interaction of two identical line patterns. These lines act as diffraction grating. It can be used to measure in plane strain measurement.

1.2 Aim of the present work

Most of the existing optical methods for measurement and testing are found to be much sensitive and expensive, while the industrial organizations require methods which are accurate, cost-effective and capable of functioning even in noisy conditions For example, the high sensitivity of holographic interferometry which is basis for its usefulness also leads to certain difficulties in testing, particularly in non-laboratory environment. In interferometry mechanical stability is required, this is difficult to achieve when noise due to building or machine vibrations are present. Considerable ingenuity has been displayed in alleviating problems associated with lack of mechanical stability[7]. The main aim of the work presented in this thesis is to develop new methods for measurement and testing which are simple, real-time, cheap, easy to implement, accurate and use minimal optics Some new optical techniques are proposed for measurement of diffusion coefficient of two transparent liquids, hairiness of textiles yarns, phase transition studies in liquid crystals etc. and testing of optical components like lenses, polarizers etc.

1.3 Synopsis of the present work

The thesis is divided into four chapters. Chapter 1 reviews the existing techniques for measurement and testing. Chapter 2 deals with new optical methods developed to determine diffusivity of transparent liquids, hairiness measurement of textile yarn and phase transition study of liquid crystals. Chapter 3 discusses new optical interferometric techniques for testing collimation of laser beam, polarizer, beamsplitter and to determine refractive index of biconvex lens.

The diffusion of two solutions with different concentration is an important phenomenon for industries making standard equipments using chemicals. Diffusion coefficient is the key parameter characterizing a chemical system[12]–[18]. Three new optical methods to measure diffusivity in transparent binary liquid solutions are discussed in sections 2.1.8 to 2.1.10. Section 2 1.8 discusses a new method using Michelson Interferometer geometry to determine the diffusion co-efficient[12, 15]. A transparent cell filled with diffusion liquid is kept in one arm of the Michelson interferometer. The resultant interference pattern is obtained through a CCD camera connected to computer via frame grabber card. The interferograms thus obtained from the interferometer are saved as digital bitmaps and are used to find the diffusion coefficients.

In section 2.1.9, another method using Multiple Beam Interferometer is discussed where an expanded and collimated laser beam is allowed to fall on a glass plate, which acts as a multiple beam interferometer. The laser beam which enters the front surface will be multiply reflected within the glass plate. After the glass plate, the interference pattern is found by adjusting the collimating lens. The interferometer is adjusted for straight fringes which then are captured by a CCD camera and stored in a PC[12]–[15]. Then in section 2.1.10, a new method using white light to determine diffusion coefficient. In this method, the light from white light source was allowed to fall on an artificial fringe pattern drawn on a diffuser (plane paper). This fringe pattern was produced using a PC and was printed on a normal paper. This artificial fringe pattern was then pasted on one of the transparent sides of the cell. When the white light passes through the glass cell containing the diffusing solutions, it will bend towards region of higher refractive index changing the fringe shape. The variation in the fringe patterns with time is used to study diffusion[12, 15, 16].

In all these methods various concentrations of aqueous solutions of Ammonium Dihydrogen Phosphate were used as the experimental solution. The obtained diffusivity values using these methods were compared with literature values[19, 20] and were found to match with other experimentally calculated values.

Another important measuring technique discussed in chapter 2 is the determination of hairiness of textile yarns. A textile yarn is made up of fibers, but some of the fibers are not contained in the yarn body and these fibers represent the hairiness of the surface[21, 22]. Today in the textile mills, yarn hairiness measurement is a routine test. In optical methods of measuring hairiness, the yarn profile is projected onto a screen or enlarged through a microscope to examine the image of the yarn. Section 2.2 discusses a new method to measure the hairiness in textile fibers by measuring the scattered light using the yarn hairs.

In section 2.3, another important application related to liquid crystals is discussed. Liquid crystals are one of the most developing and fascinating fields of current research. Liquid crystalline compounds have found ways for numerous potential applications because of their characteristic physical and optical properties. Nowadays liquid crystals are used in many fields, particularly in the field of electro-optical applications[23]. Phase transition study of liquid crystals are important for potential applications. A new method using laser speckles to measure the phase transition temperatures of liquid crystals is discussed in section 2.3.Objects viewed in highly coherent light acquire a peculiar granular appearance. This granular form is called laser speckles [24]. Liquid crystal shows granular nature when it is not in liquid crystalline or isotropic phase. scattering the incident laser light thereby forming speckles. This nature has been utilized to study their phase transitions in present study.

In chapter 3, some new optical testing techniques developed for precise qualitative and quantitative analysis of optical component are discussed. Testing of optical components is important from the view of design of optical techniques and other applications involving optical elements. The accurate quality measurement of optical components such as beamsplitters, lenses, polarizers, optical flats etc are important for present day optical techniques. Optical testing is usually done using the Fizeau, the Ronchi and the Foucault tests[1]. But the present day scenario requires precise quality testing of optical components.

Normally, plane waves are produced from an unexpanded beam of laser light. This unexpanded laser beam is passed through convex lens of short focal length such as a microscope objective. After passing through the focal point, the rays diverge to form a spherical wave. To get a plane wave out of this spherical wave, another convex lens of larger focal length is placed such that the focal points of both the lenses overlap. This so called collimation process should be able to generate a plane wave, but in practice it should be checked that proper collimation has been obtained or not. There are various methods available for testing collimation[7]. In section 3.1, a new method has been discussed for testing collimation of a laser beam using an optically active medium.

A change in medium is characterized by changes in refractive index, which may be either abrupt or continuous. When the light enters a different medium, there may occur any or all of three processes i.e. reflection, refraction and absorption. In reflection, light does not enter the different medium, but is return to the original medium through an abrupt change in direction. Refractive processes involve changes in the direction of propagation with change in the refractive index. Absorption is the change in intensity of the light as a result of the interaction between the light and the medium supporting the propagation. Light is partially reflected whenever there is an abrupt change in the medium[25]. A new technique for measurement of refractive index of thin biconvex lenses using Michelson Interferometer is presented in section

3.2. The dispersion and chromatic aberration in singlet convex lenses is also studied using this method. In this technique, low power He-Ne laser are used as sources. The dispersion curve for the material of the lens is constructed using this method and was found to match closely the literature data.

Another important property of light is polarization. Polarized light is important in real-time interferometry. Laser source used for holography is usually linearly polarized in the vertical direction[7]. A highly accurate qualitative and quantitative method to test linear sheet polarizers is discussed in section 3.3. This method uses Michelson interferometer geometry and real fringes. The extinction ratio and the open transmittance were calculated from the visibility of the interference fringes. The visibility was obtained by scanning the interferogram using a photo detector.

Finally, a new technique to test the beamsplitters using the Michelson Interferometer experimental setup is discussed in section 3.4. A beam splitter is a glass plate with partially reflecting coating. It is possible to use a glass plate to split the laser beam. A beamsplitter is used to divide the incoming laser beam in to an object beam and a reference beam. Better quality beamsplitter are available commercially; they are made by vacuum deposition of a thin metallic film on a glass substrate which is polished flat to $\lambda/4$ or better. The front (metallic) surface may be coated with a protective dielectric layer and the back surface has a dielectric antireflection coating. Beamsplitters can be manufactured with any desire ratio of transmission to reflection. Beamsplitters are commonly supplied with ratios of 70/30 and 50/50. The ratio varies somewhat with angle of incidence. Commercially available variable beamsplitters are usually glass disk with reflective coatings whose thickness varies circumferentially. By rotating the disk about its axis, a variety of transmission/reflection ratios can be obtained. This device is particularly useful for holographic interferometry[7]. Testing of beamsplitters for their splitting ratios as well as quality is important for setting up of optical experiments.