CHAPTER I

INTRODUCTION

This chapter incorporates the definitions of the most of the terms which have been used throughout the thesis. It also includes the review of the earlier work on various techniques for evaluating the refractive indices of lenses.
INTRODUCTION

1.0 GENERAL:

The refractive index of a medium signifies the nature of the medium especially whether it is denser or rarer. It is a fundamental constant which plays a significant role in optometry, ophthalmometry, glass industry, instrumentation, refractrometry, sugar industry etc. The knowledge of refractive index can easily be used in identifying the material in a specimen or sample. For example, the type of glass in a plate or in an optical element can easily be recognized just by knowing the refractive index of the material.

The refractive index of the optical material in an optical system is of high significance. The change of this index with the wavelength of light is known as dispersion. Thus, the refractive index is a very important constructional parameter. The desired accuracy in its determined value depends upon the various parameters. In general, the position and the use of optical devices affect the accuracy in measuring the refractive indices of the materials. Normally the instruments based on total reflection give the accuracy
of + 0.0002 which is adequate for different purposes. Instrument usually used for finding the refractive indices with sufficient accuracy are,

1. Abbe' refractrometer with accuracy + 3\times 10^{-4}
2. Dipping in refractrometer with accuracy + 2\times 10^{-4}
   (used for liquids only)
3. Crystal refractrometer with accuracy + 1\times 10^{-4}

For using the direct methods of spectrometers and refractrometers, test samples must be prepared with plane surfaces. The refractive index of glass or non-liquid materials is measured by using a contact liquid with the specimen. The refractive index of such a contact liquid should be higher than that of the specimen. However, these methods are limited to shape and size of the samples. These ordinary methods can not be used for measuring the refractive index of glass specimen, if they are of some specified forms, namely

(a) Small in shape and size
(b) consisting of rough surfaces
(c) in the form of refractive focussing element.

This technique can only be employed either by removing small portion or by changing the shape of the
test piece. It is mostly either inadvisable or just impossible to grind or polish optically flat surfaces on specimen. On account of its being an important component of some optical system where it is essential to keep intact, or due to its small size, it is not disturbed. Hence, the author has proposed some non-destructive techniques for determining lens' index. The lens formula is modified for these new methods.

1.1 LENS FORMULA:

The lens has a focussing property and acts as an imaging device consisting of two surfaces which are rotationally symmetrical about the same axis. Considering the paraxial approximation in a thick lens, its imaging aspects can easily be explained.

The front focal length \( f \) and the back focal length \( f' \) are given by Born and Wolf (1984).

\[
f = -n_1 n_2 \frac{r_1 r_2}{D} \quad \text{.... (1.1)}
\]

and

\[
f' = +n_2 n \frac{r_1 r_2}{D} \quad \text{.... (1.2)}
\]

where,

\[
D = (n-n_1)(n_2-n).t-n[(n_2-n)r_1 + (n-n_1)r_2] \quad \text{....(1.3)}
\]
Thus, the back focal length for \( n_1 = n_2 = n_L \), will be represented as

\[
f' = \frac{(n-n_L)\left(\frac{1}{r_2} - \frac{1}{r_1}\right) - (n-n_L)^2 (t/r_1r_2)}{n_L} - \frac{n_L}{n_L+n}
\]

where,

\( n \) - refractive index of the lens

\( n_L \) - refractive index of liquid

The space between the object and the optical centre is called object space. Similarly, the image space exists between the image plane and the optical centre of the lens.

The back focal length is the main parameter to be discussed and measured in the thesis. In the proposed technique of liquid immersion, the test lens is inserted inside a glass cell. Hence, it is clear that the object space as well as image space are almost the free spaces excepting the small parts of the glass container filled with liquid. With the help of ray tracing, lens formula can be derived for the test lens immersed in liquid inside glass cell. Thus, this modified lens formula Kasana and Rosenbruch (1983) is given by
\[
\frac{1}{f} = (n-n_L)(1/r_1-1/r_2)+(n-n_L)^2 \frac{t}{n} \frac{r_1}{r_2} \ldots (1.5)
\]
or,
\[
\frac{1}{f} = (n-n_L)(c_1-c_2) + (n-n_L)^2 \frac{t}{n} \frac{c_1c_2}{n} \ldots (1.6)
\]
where symbols have their usual meanings.

These relations (1.5) and (1.6) have been derived by assuming that the lens' vertices are touching the walls of liquid column lying on both sides of the lens.

The test lens differs from a normal lens as it has many surfaces of different refractive indices. Thus, the effective focal length can be calculated by considering an equivalent optical system of four surfaces. Here, the test lens is sandwiched between the vertical liquid columns.

1.1.1 PARAMETERS AFFECTING THE FOCAL LENGTH:

Many parameters affect the exact focal length measurements because the distance between the focal plane and the back surface of the glass cell is taken as the focal length of the test lens for measuring the exact focal length. The effects due to the thickness of the back of the glass cell, the liquid column between
the lens' vertex and the back of the cell etc., should be taken into account.

1.1.2 THICKNESS OF A PLANO-PARALLEL PLATE:

When a plano-parallel glass plate is inserted in the path of the converging rays, the focusing point is shifted along the optical axis. This shift of focus point increases the focal length and depends on the thickness and the material of the plano-parallel plate. The increase in the focal length can be compensated by taking the air equivalent of the plano-parallel plate, which is given as

\[
\text{air equivalent} = \frac{t_p}{n_p}
\]

Where,

\(t_p\) - thickness of the glass plate

\(n_p\) - refractive index of the plate material.

1.1.3 BACK OF THE CELL:

When the test lens is immersed in the glass cell, the back focal distance is increased by a factor \((t_c/n_c)\) where \(t_c\) and \(n_c\) are the thickness and the refractive index of the back of the cell respectively.
1.1.4 LIQUID COLUMN:

The liquid column between the tangent to the lens' back vertex and the back of the cell also increases the back focal distance by a factor \((t_L/n_L)\), where \(t_L\) is the thickness and \(n_L\) is the refractive index of the plano-parallel liquid plate.

1.2 BALANCE OR MATCHING POINT:

In miscible liquid immersion technique, a lens is immersed in a mixture of two miscible liquids, one of which is of higher refractive index than the lens' index and the other is of lower. When the index of this mixture matches the lens' index, the lens becomes invisible and this stage is known as balance or matching point.

1.3 DEFOCUSING:

When the focus point is shifted to either positive or negative side from the exact focus, this shift is termed as "Focussing Error" or "Defocussing". It may be in focus or out of focus.

In case of Murty shearing interferometer, the
number of fringes appearing in the overlapping region between the sheared wave fronts indicate the amount of the defocussing in the system which corresponds to the defocussed position of the test lens.

1.4 FRINGE FREE SPACE:

When there is no fringe or a fringe of infinite width in the overlapping region, this is known as "fringe free space". In this condition the overlapping region is fully covered with bright or dark illumination. The fully illuminated field is termed as "fringe free space" or flat field of interference.

1.5 MULTIPLE BEAM INTERFEROMETRY:

If the surfaces, bounding a film have a fairly high reflection coefficient, fringes of transmission with very sharp bright maxima on a dark ground may be produced. These fringe are produced by the mutual interference of several beams which have suffered a large number of reflections. This phenomenon is known as multiple-beam interference. Those interferometers which utilized this principle are called multiple beam interferometer.
The multiple beam interference was firstly observed in 1856, when Airy derived an expression for the multiple beam interference pattern that would be produced by a plane parallel plate. However, the idea remained unexploited since high reflectance coating were not available because uncoated glass plate has a reflectance of only 0.04.

Fizeau (1862, 1863) devised his calibrated interferometer. His invention led to idea of studying surface topography by optical interferometry. Lourent (1883) Bouloch (1893) revived Airy's derivation.

A few years later Fabry and Perot (1897) devised an interferometer which consists of two plane parallel surfaces of high reflection coating with variable separation, known as Fabry-Perot interferometer. Today it is still one of the most compact and high resolving instrument. When both the glass plates are fixed keeping their separation as constant, F.P. interferometer is called as F.P. etalon. It performs the same job as that done by F.P. interferometer. However, it is more compact and stable. A F.P. etalon has been used in chapter 3 for calculating the refractive indices of lens' material.
1.6 DOUBLE SLIT:

The focal length of a converging lens is directly proportional to the separation between the diffraction dots produced by the double slit arrangement. Interestingly, the focal length of the test lens immersed in liquid changes with liquid. In other words for different liquids, the focal length will be different. Thus, if the focal length is altered by pouring various liquids in glass cell, the distance between diffraction dots would also be changed. This property has been utilised in the present thesis.

1.7 REVIEW OF THE EARLIER WORK:

In view of the utmost importance of refractive of refractive index, many attempts have been made by various workers to discover easy, economic, quick and improved techniques for measuring the refractive indices.

1. CHARSTIANSEN'S METHOD (1884-85):

In 1884 Christiansen made first attempt in this direction by measuring the refractive index of fine powders. He had used a fine glass powder, a mixture of (CS$_2$+C$_6$H$_6$) and hollow prism of 60° & 45°. Sodium light was used as a source of light.
It has certain limitations as it is valid for fine powder only. It also needs interpolation or Cauchy's dispersion relation. Owing to the necessity of interpolation and its inapplicability to coarse powder, this method is limited to a particular form of specimen.

2. **CHALMER'S METHOD (1905):**

Chalmer found the lens' index by using a thin lens formula when it is immersed in the liquid. This approach was not satisfactory as it was limited to thin lens approximation and involvement of many parameters.

3. **MARTIN'S METHOD (1916):**

Martin revised the old concepts by placing the specimen in a prismatic cell, however, this method was also restricted because of the large number of factors were involved. He has used CS$_2$ or Hg (KI) and alcohol as diluent. Liquid concentration is varied until the spectrum line is visible.

4. **CHESHIRE'S METHOD (1916):**

At almost the same time Cheshire developed a method based on Foucault's shadow method for figuring the optical surface. However, it is not adequate for producing the accuracy in a satisfactory way.
5. **FABRY'S METHOD (1919):**

Fabry suggested a method using a reference prism. He used five prisms for this purpose. His method is time consuming and difficult to perform in comparison to others. The formula used by Fabry was very lengthy and inconvenient.

6. **ANDERSON'S METHOD (1920):**

Anderson took up the subject again proposing a new technique to achieve the balance point or matching point changing the concentration of liquid so that its index becomes equal to the refractive index of the specimen. Four different methods could be employed for the investigations. His technique requires large scale instrumentation, and it is very difficult to obtain the balance point.

7. **SMITH'S APPROACH (1982):**

There had been hardly any communication on the measurement of refractive indices of lenses, between 1920 to 1980.

In 1982, Smith added a new modified method which is based on the vertometric principle. Owing to the
repeatability, trials and inherent errors, it is also limited in many respects. As it is not accurate enough, it will probably be seldom used.

8. MURTY SHEARING INTERFEROMETER:
(Plano-Parallel Glass Plate)

Bates (1947), Drew (1957), Brown (1954, 1955), Boyd and Gordon (1955), Bennett (1962), Murty (1964) have considered shearing interferometry for various purposes. However, their attention was centered on workshop aspects especially the testing of optical element. Murty (1983) has reported a simple method for measuring the refractive index of a liquid or glass wedge by using two plano parallel glass plates.

Recently Kasana and Rosenbruch (1983, 1984) have applied a planoparallel glass plate as a locator for an exact focal plane of a lens. If there is any defocussing involved, it can be directly observed in terms of shearing interference fringes. The amount of defocussing can also be calculated by counting the number of fringes. The shearing factor of Murty shearing plate is given by Kasana and Rosenbruch (1983).

\[ s = \frac{t \cdot \sin w}{\sqrt{n^2 - \sin^2 w}} \]
where,

\[ s = \text{shearing between two laterally displaced wavefronts}, \]
\[ t = \text{thickness of shearing plate}, \]
\[ n' = \text{refractive index of the shearing plate}, \]
\[ w = \text{angle of incidence of a plane wave-front}. \]

The above equation shows that the shearing factor \( s \) depends upon the thickness of the glass plate and the angle between the incident beam and its normal to the surface of the plate.

In Kasana and Rosenbruch's approach, the refractive index of a lens immersed in single liquid at a time has been determined by using a plano-parallel glass plate. This avoids the use of two miscible liquids commonly used in the liquid immersion method. Wavefront shearing interferometer is very sensitive device for searching the exact focal point. The accurate value of the focal length has been obtained by this method which is quick to perform and expedient to produce high accuracy as compared with the results obtained from the existing techniques.

The lens' index formula has been derived which includes the focal lengths of the lens in two different
liquids and their refractive indices. For N liquids, there are N(N-1)/2 ways of calculating the lens index. For the best location of the focal plane, defocussing formula can be used which is given as below

$$\Delta f = (\lambda/s)(1/w)f^2$$

where,

\[\Delta f\] - defocussing
\[\lambda\] - wavelength of light used
\[w\] - fringe width
\[f\] - focal length of the lens.

9. GRATING SHEARING INTERFEROMETER:

When a grating is of a low frequency, the orders diffracted by such a grating overlap and produce the interference fringes. Such gratings are termed as Ronchi gratings after the name of their discoverer, Vasco Ronchi (1923, 1964). Ronchi fabricated these gratings and tested the lenses of Galelean telescope placed in the museum of Florence, Italy. Ronchi gratings act as spherical wave front shearing interferometer. It is superior to other shearing interferometers because it is achromatic in nature. This property of Ronchi grating makes it simple and economic because an incoherent light source may be used.
Ronchi had initially used these gratings as testing tool for optics. The quality of optical components can be easily checked as it indicates inherent defects.

The focussing error is directly visualized and measured by observing and counting the number of fringes in the common region between two laterally displaced spherical wave fronts. The amount of defocussing can be represented as Briers (1979), Kasana & Rosenbruch (1984).

\[ \Delta f = \frac{R \cdot e}{w} \]

where,

R - distance between the focal point and the sheared wave fronts,

e - grating element,

w - fringe width.

Apart from these developments, the techniques reported in the present thesis are new which may be termed as latest methods for evaluating the refractive indices of lenses and liquids. These non-destructive techniques are,
1. Shearing interferometric method
2. F.P. etalon method
3. Diffraction method.

The very simple concept of changing the focal length of the test lens has been used in association with different types of optical means. We conclude that such iotas looking very familiar, have been implemented totally in new contexts. In other words, known and existing concepts have been used first time to determine the refractive indices of lenses which plays a significant role in instrumentation and lens industry.