13

INTERFEROMETRY

Introduction

Wavelength of light as a standard of measurement possess is the advantage of being accurate and a very small unit of measure. The wave nature of light is ever present but not apparent under ordinary conditions. Only when the light waves interact with each other the wave effect is visible and thus made use of for measuring purposes. The phenomenon of interaction of light is called interference.

When light is made to interfere it produces a pattern of dark bands, which correspond to very accurate scale of devisions. The value of this scale is exactly one half wavelength of light used. Because this length is so constant, it was used to be considered as international standard of length ; a few years ago.

The use of interferometric technique enables the size of slip gauges and end bars to be determined directly in terms of the wavelength of light sources whose relationship to the international Krypton standard is known to a high order of accuracy. The interferometrically calibrated reference grade slip gauges form the basis of controlling the size of subsidiary length standards, such as inspection and workshop grade slip gauges, setting masters etc., used in manufacturing industries.

Monochromatic lights

The light is a form of energy being propagated by electromagnetic waves which may be represented by a sine curve. The high point of the wave is called the crest and the low point is called rough. The distance between two crests or two troughs is called the wavelength λ. Light travels along the axis (*OX*) as shown in Fig. 13.1 and the time taken in travelling one

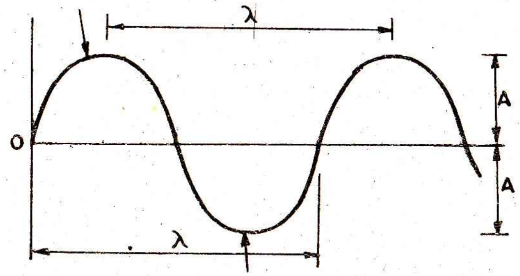

Fig.13.1

wavelength λ is called the time period (*T*). The maximum disturbance of the wave is called the amplitude (*A*), and the velocity of transmission is λ/T, $1/T$ being called the frequency.

A ray of ordinary light can be considered as composed of an infinite number of wavelengths. The value of wavelength λ determines the colour of light and the amplitude '*A*' determines the intensity of light.

White light is a combination of all colours of visible spectrum, red, orange, yellow, green, blue, indigo and violet. Each colour band consists of a group of similar wavelengths. Since, white light is a combination of all the wavelengths of the visible spectrum, it is not in a form suitable for length measurement by interferometry. To overcome this difficulty monochromatic light source such as mercury isotope 198 discharge lamp is used. A ray having a single frequency and wavelength produces monochromatic light. The advantages of monochromatic light are :

Its characteristics are virtually independent of any ambient conditions.

Its wavelength has precise value.

It is exactly reproducible (*e.g.*, Mercury 198, Krypton 86).

It has an accuracy of about one part in one hundred million.

Principle of Interference

As stated earlier light is a form of energy being propagated by electromagnetic waves which may be represented by a sine curve. When two rays of the same wavelength meet at some point, a mutual interference occurs and the nature of interference will depend upon the phases of two waves at their meeting point.

If the waves are in same phase, they will reinforce each other and the resulting intensity will be the sum of the two intensities. However, if two waves are out of phase, the resultant intensity (also amplitude) will be the difference of two. If both the waves having same amplitude are in phase, the resultant amplitude and hence the intensity becomes twice, and the result will be a bright spot. However, if these two waves (with same amplitude) are out of phase the resultant intensity will be zero and the result will be a dark spot.

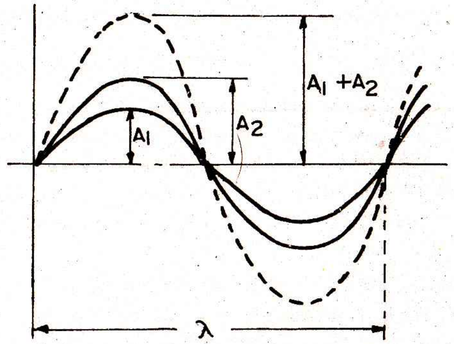

Fig.13.2. Two rays in phase

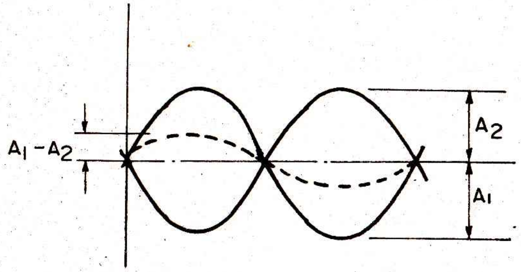

Fig. 13.3. Two rays out of phase

The interference can occur only when two light rays are coherent, that is the two rays maintain their phase relationship for an appreciable length of time. This is possible only when the two rays are originated from the same point of the light source at the same time.

A method for production of interference bands is shown in Fig. 13.4, Light-passes through the very narrow slit *A* and then through the slits *B* and *C* which are close together. Thus two separate sets of rays (beams) of light are formed which pass through and cross one another in the same medium. In such a case the effects produced by one are totally independent of the effects due to other, and interference band pattern is produced.

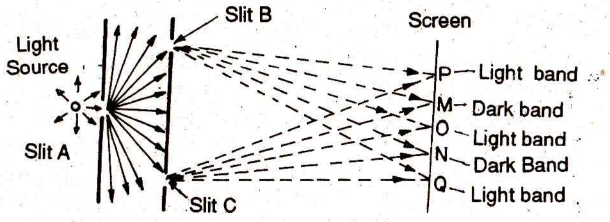

Fig. 13.4. Method of producing intergerence pattern

If the paths *BO* and *CO* are exactly equal then the rays on these paths will be in phase. A constructive interference takes place producing the maximum intensity. At some point *M* the ray path difference will be equal to 1/2 wavelength, *i.e.*, $CM - BM = \frac{1}{2}\lambda$. Thus at the screen the waves will be 180° out of phase *i.e.*, the resultant intensity will be zero and a destructive interference takes place producing total darkness at *M* and at *N*. At point *P*, the ray path difference will be one wavelength, and the rays again will be in phase and a bright band will be produced. Thus a series of bright and dark bands are produced. These bands are known as interference bands.

It is not possible to produce interference with two independent sources. This is because, with two independent sources or with two separate portions of the same source, the phases of the two waves emanating from them will be changing independently of each other so that the phase

difference cannot be constant. This results in rapid alternations of brightness and darkness and hence general illumination.

Light Sources of Interferometry

To obtain interference over large path differences, it is essential to use a source with very narrow lines. It means that the temperature and pressure of the discharge must be low and so that the surface brightness will be moderate. A wide variety of light sources is available for interferometry. The selection of proper source for an application depends on the results to be obtained by interferometer, cost and convenience. For simple applications like testing of surface geometry, where the difference between interfering path is of the order of few wavelengths only, a tungsten lamp with a filter transmitting only a narrow band of wavelength would be adequate.

However, sophisticated application requires the use of light sources such as mercury 198, cadmium, krypton 86, thallium, helium, hydrogen, neon, sodium, potassium, zinc, laser mixed radiations etc. In these sources the discharge lamp is charged with one particular element and contains means to vapourise them. The atoms of these elements are excited electrically, so that they emit radiation at certain discrete wavelengths.

Optical flat

The simplest illustration of the interference is the use of official flat. It provides precision as well as accuracy in the measurement of flatness. Optical flats are cylindrical pieces 25 to 300 mm in diameter with a thickness of about $1/6^{th}$ of the diameter. They are made of transparent material such as quartz, glass, sapphire etc. Optical flats made of quartz are more commonly used because of its hardness, low coefficient of expansion, resistance to corrosion and much longer useful life. One or both surfaces of optical flats may be highly polished. An arrow is made on the flat to indicate finished surface. For measuring flatness, in addition to optical flat, a monochromatic light source, emitting light of single wavelength is also required. The yellow orange light radiated by helium gas is most satisfactory for use with optical flat.

Sometimes the optical flats are coated with a thin film of titanium oxide. This reduces the loss of light due to reflection which makes the band more clear. The coating is so thin that it does not affect the position of the fringe band but such a flat requires greater care. For greater accuracy optical flat must be used in an area where the temperature is constant. It is advisable to use lintfree paper for cleaning the optical flat and the surface of the part to be checked.

Optical flats are of two types :

Type A. It has single flat working surface. It is used for testing flatness of precision measuring surfaces of flats, slip gauges, measuring tables etc.

Type B. It has both working surfaces flat and parallel to each other. It is used for test measuring surfaces of micrometer, measuring anvils, meters and similar measuring devices for testing flatness and parallelism.

In each type there are two grades. Reference grade or Grade I and working grade or Grade II. The tolerance on flatness for grade I is 0.05 μm and for grade II is 0.10 μm., tolerance on parallelism (type B) is 0.15 μm and 0.20 μm respectively and tolerance on thickness (type B) 0.20 μm and 0.30 μm respectively (IS. 5440 – 1969).

The flats are marked clearly on the cylindrical surface with the grade and type and an identifying serial number together with the manufacturer's trade marks. For example :

1. Grade I type A flat of diameter 250 mm is designated by : Optical flat IA 25 – IS : 5440.
2. Grade II type B flat of thickness 12.125 mm is designated by : Optical flat II B 12.125 – IS : 5440.

A grade I flat is identified by a black dot about 1 mm in diameter on the cylindrical surface of the flat and away from other markings.

Optical flats are used to test the flatness of lapped surfaces such as gauge blocks, gauges, micrometer anvils etc. When an optical flat is placed on workpiece surface it will not form an intimate contact, but will be at slight inclination to the surface, forming at air wedge between the surfaces.

If optical flat is now illuminated by monochromatic source of light, interference fringes will be observed. These are produced by the interference of light rays reflected from the bottom face of the optical flat and top face of the work piece being tested through the layers of air.

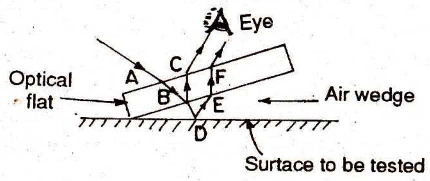

Fig. 13.5. Optical flat

Consider a ray of light incident at '*A*' on optical flat placed over a work piece to be tested. It passes through the optical flat and its bottom face is divided into two components. One component of the incident ray gets reflected from the bottom of the optical flat at '*B*' in the direction *BC* and the other portion, transmitted through the layer of the entrapped air will be reflected by the top face of the workpiece at *D* in the direction DEF.

The paths travelled by both the reflected rays differ by an amount BDE *i.e.*, the second component of the ray lags behind the first by an amount equal to twice the air gap. Though both the components have the same wavelength and start, the difference in their paths causes them to be either in phase or out of phase at *C* and *F*.

As explained earlier, if the path difference between the reflected rays is even multiple of half wavelength, they will be out of phase and dark band will be observed. If the path difference is odd multiple of half wave length they will be in phase with each other and will reinforce each other. So brightness will be observed. Depending upon the air gap between surfaces, we will get alternate dark and bright bands due to interference of light.

Limitations of optical flat

The optical flat suffers from the following limitations for precise work :

1. It is difficult to control the lay of the optical flat and thus orient the fringes to the best advantage.
2. The fringe pattern is not viewed from directly above and resulting obliquity can cause distortion and errors in viewing.

Interferometers

The interferometer incorporates the extension of the application of optical flat. Its use overcomes the disadvantages of optical flat by incorporating refined arrangement.

Interferometers are optical instruments used for measuring flatness and determining the length of slip gauges. They are based upon the interference principle and employ wavelength of light as their measuring units. The interferometers make use of some type of beam divider that splits an incoming ray into two parts. These two parts of the ray travel along different paths until they are recombined, usually in the same beam divider.

In interferometers the lay of optical flat can be controlled and the fringes can be oriented to the best advantage. Secondly, an arrangement to view the fringes directly from top and above the fringes, is also incorporated.

Types of Interferometers

The various types of interferometers are :

1. Michelson Interferometer
2. Fabry-Perot Interferometer
3. Fringe counting Interferometer
4. N.P.L. flatness Interferometer
5. Pitter N.P.L. Gauge Interferometer
6. Zeiss gauge block Interferometer
7. Multiple beam Interferometer
8. Laser Interferometer etc.

1. **Michelson Interferometer.** This is the oldest type of interferometer. It utilizes monochromatic light from an extended source. The monochromatic light falls on a beam splitter *D* consisting of semi-reflecting layer. Thus the light ray is divided into two paths. One is transmitted through compensating plate *P* to the mirror M_1 and the other is reflected through beam splitter *D* to mirror M_2. From both these mirrors, the rays

are reflected back and these reunite at the semi-reflecting surface from where they are transmitted to the eye as shown in Fig. 13.6 and thus the fringes can be observed.

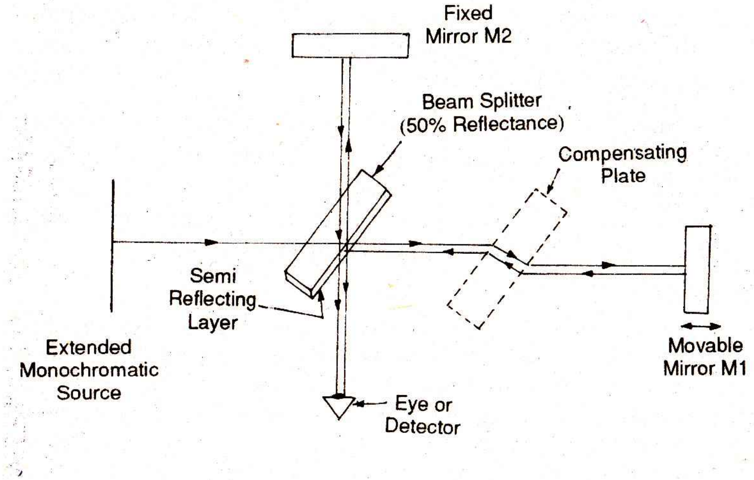

Fig. 13.6. Michelson Interferometer

Mirror M_2 is fixed and mirror M_1 is movable *i.e.*, it is attached to the object whose dimension is to be measured.

Twyman-Green Specialisation of Michelson Interferometer

In the Michelson interferometer the rays actually describe a cone, giving rise to various types of fringe patterns which may be difficult to interpret. The two beam interferometer as modified by Twyman-Green (Fig. 13.7) consists of a pair of collimating lenses L_1 and L_2. The collimating lenses render the light beam from it parallel combined with a pinhole source diaphragm. Thus all the rays describe the same path, this makes the fringe patterns to be interpreted easily.

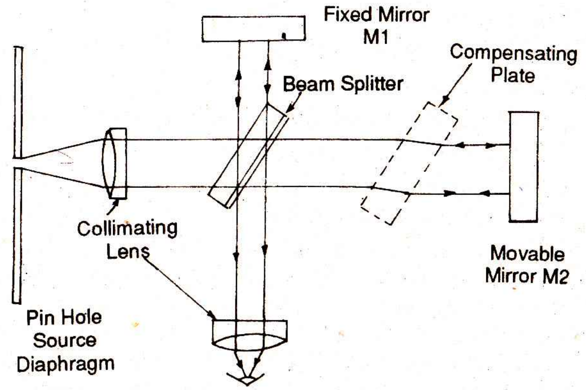

Fig. 13.7. Michelson Interferometer

2. **Fabry-Perot Interferometer.** These consist of two optical flats coated with a high efficiency semi-transperent film on the two facing surfaces. These flats are kept exactly parallel by means of a carefully designed spacer. When illuminated, a series of very sharply defined bright circles resulting from interference is seen on the screen.

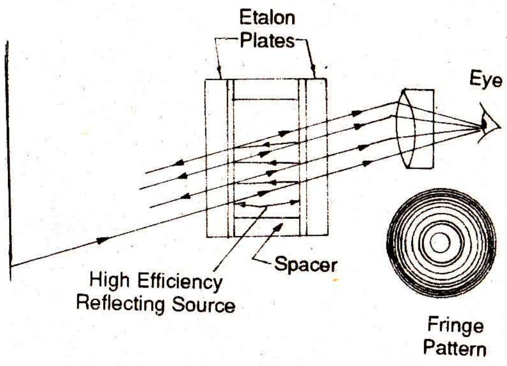

Fig. 13.8. Fabry-Perot Interferometer

3. **Fringe Counting Interferometer.** These are used to measure linear mechanical motion directly in terms of wavelenth of light. Every motion by λ/2of the moving mirror will move the parallel fringes by one fringe. This can be counted by eye or with photo detectors.

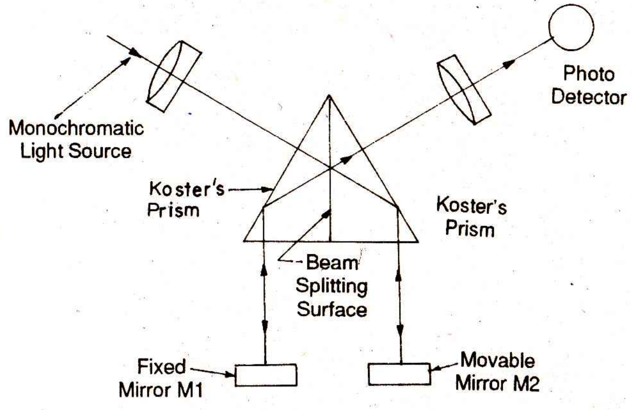

Fig. 13.9. Fringe counting Interferometer

Kosters prism used in this consists of two 50° – 60° – 90° prisms mounted back to back, semi-silvered on the joint faces and with an oil film between them. The monochromatic light incident normally on the upper 60° face is partly transmitted and partly reflected at the joint face and then comes as parallel beams.

4. **N.P.L. Flatness Interferometer.** Fig. 13.10 shows optical arrangement of the N.P.L. flatness interferometer. This instrument as the name suggests, is mainly used for checking the flatness of flat surfaces. In this

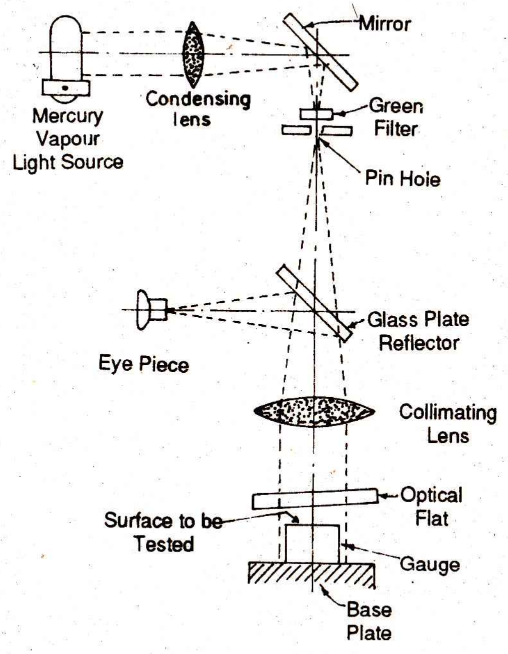

Fig. 13.10(*a*). N.P.L. Flatness Interferometer

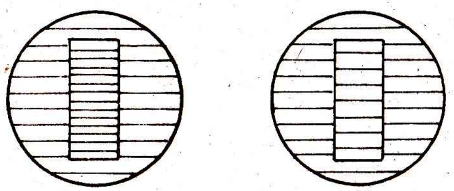

Fig. 13.10 (*b*)

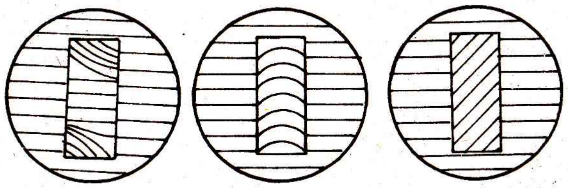

Fig. 13.10 (*c*)

instrument mercury vapour lamp is used as a light source whose radiations are passed through a green filter and thus leaving a green monochromatic light. The wavelength of resulting monochromatic radiation is of the order of 0.5 μm (0.0005 mm). This radiation is then brought to focuss on pin hole in order to obtain an intense point of source of monochromatic light, which is in the focal plane of a collimating lens, and is thus projected as a parallel beam of light.

This beam is directed on to the gauge to be tested which is wrung on the base plate, via an optical flat so that optical fringes are formed across the face of the gauge, the fringes being viewed from directly above by means of a thick glass plate semi-reflector set at 45° to the optical axis.

If the gauge face is flat and parallel to the base plate, the fringe pattern produced will be straight, parallel and equally spaced.

In case taper is present, then the fringe pattern obtained is as shown in Fig. 13.10 (*b*).

When the gauge surface is convex or concave then fringe pattern as shown in Fig. 13.10 (*c*) is obtained.

5. **The Pitter-N.P.L. Gauge Interferometer.** This is also called as the gauge length interferometer, as it is used for determining actual dimensions or absolute length of the gauges. Fig. 13.11 shows the schematic arrangement of N.P.L. Gauge Interferometer. The light from the sources falls on slit A through lens L_1. After collimation by lens L_2 it goes through constant deviation prism P whose rotation determines wavelength passed, through reference flat (F) to upper surface of gauge block G and base plate B to which it is wrung. Light is reflected back in mirror P and its patterns are observed through a telescope. The field of view is also shown in Fig. 13.11.

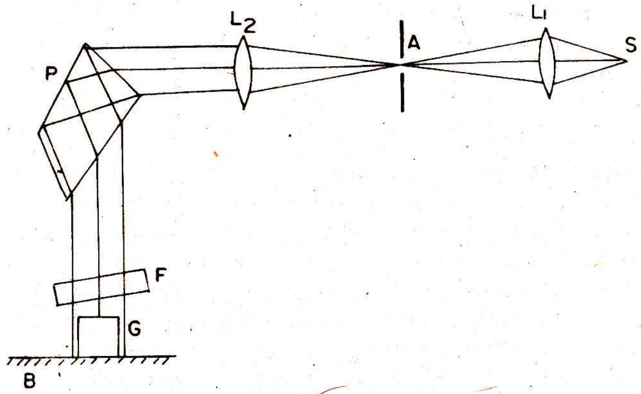

Fig. 13.11. N.P.L. Gauge Interferometer

This instrument should be used in standard conditions of temperature and pressure.

6. Zeiss gauge block interferometer. The working principle of this type of interferometer is shown in Fig. 13.11. The light source S falls on slit A through condensing lens L_1 and after passing through glass compensator plate B is reflected by mirror M_1 through collimator objective L_2. The light rays emerging from this lens are parallel and pass through the dispersion prism P to beam splitter C which divides the light rays into two paths. One side of the beam falls on mirror M_2 after passing through the inclinable measuring plane M and compensator plate B and then on reference mirror M_3. From here it is reflected back and goes back to the beam splitter C. The other portion of the rays is reflected from beam splitter C and fall on mirror M_4 through measuring plate D. The rays reflected from mirror M_4 fall on the gauge block G wrung to an optical flat E. After reflection it goes back to beam splitter C.

The two rays from H travel together and are reflected by mirror M_5 and then pass through objective lens L_3 and fall on M_6. The reflected light passes through inverted prism S and is seen by the eye at exit slit (F). Two sets of interferometer fringes are thus obtained.

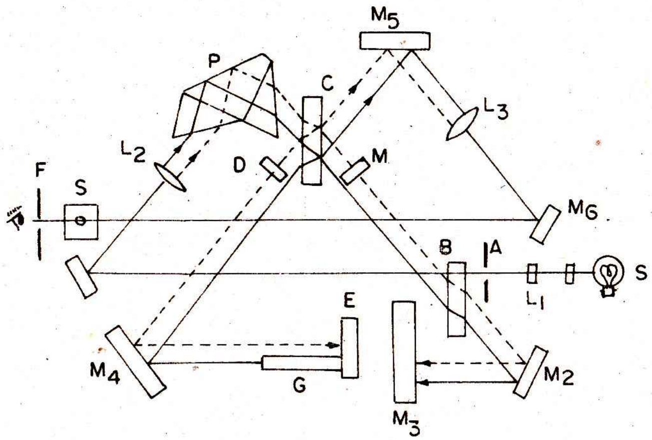

Fig. 13.12. Zeiss gauge block interferometer

7. **Multiple Beam Interferometer.** In ordinary methods the interference bands obtained are broad in themselves and the shapes of irregularities cannot be established with certainty. These disadvantages can be overcome by the use of multi beam interferometer. In this type the beams are forced to pass the interference space a great number of times so that the final image is built up from a large number of partial beams with decreasing intensity, in a series. These fringes are sharp. Such an optical system is shown in Fig. 13.13. The light from source S falls on semi-silvered mirror M through the collimating lens L_1 and reflected through a multiple layer interference plate P and on the surface B to be tested. The fringes are observed through the microscope A.

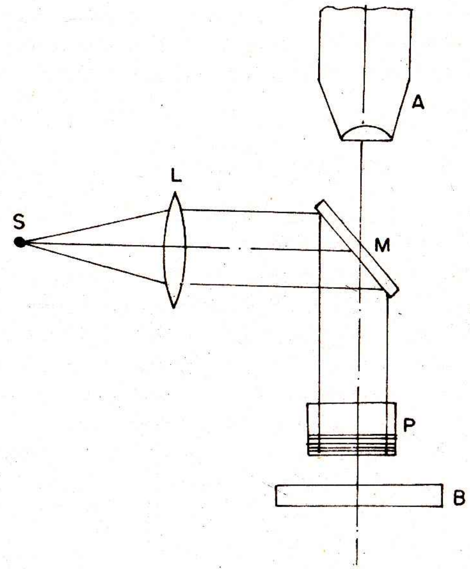

Fig. 13.13. Multiple beam interferometer

8. **Laser Interferometer.** Laser interferometer utilizes the principles of both optical techniques and digital electronics. It uses A.C. laser as the light source and thus enables the measurement to be made over longer distances.

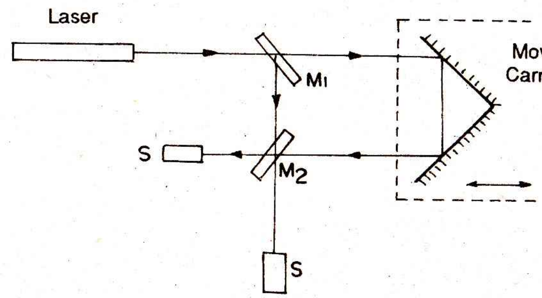

Fig. 13.14. Laser interferometer

Fig. 13.14 shows the arrangement of a laser interferometric system. It is highly accurate and versatile measuring system that can cope with industrial environments. It has high repeatability and resolution of displacement measurement (0.1 μm), high accuracy, long range optical path, easy installation and no change in performance due to ageing or wear and tear. A single laser sources can be used for as many as six simultaneous measurements in different axes.

However, it is very much expensive, since the basic instrument measures physical displacement in terms of wavelength instead of traditional units, conversion instrumentation is required for conventional read out.

SOLVED PROBLEMS

Problem 1. *Explain why monochromatic light is used for interferometry work and not the white light.*

Sol. White colour is a combination of all colours of visible spectrum, red, orange, yellow, green, blue, indigo and violet. Each colour band consists of a group of similar wavelengths and since the pitch of the interference fringes will be different for each, the interference fringes formed will be a mixture of all and it becomes very difficult to distinguish the various dark and bright fringes. The whole pattern looks quite blurred and as the air gap between optical flat the surface to be tested increases, it becomes absolutely impossible to distinguish the dark and bright fringes at any one point. To overcome this difficulty monochromatic light source such as mercury isotope 198 discharge lamp is used.

In case of monochromatic light, the spread of wavelength is very small and thus fringes are formed at considerable separations of optical flat and surface. The interference fringe pattern is thus much more clearly defined.

Problem 2. *Describe the care to be taken while using optical flat.*

Sol. Before using optical flat, both the optical flat and the workpiece to be tested must be perfectly clean and free from dirt, dust, oil or finger prints. Surfaces should therefore be cleaned with petrol or benzene and clean chamois or soft clean piece of linen.

Optical flat should never be wrung on workpiece because it may produce scratches. It should only be carefully and firmly pressed down evenly on workpiece with two fingers, till interference bands become visible.

Optical flat should never be slid over the workpiece but lifted from it. Sliding, creeping and wringing of flat and workpiece are extremely harmful and should be avoided. It can only be rocked and pressed.

Problem 3. *By using optical flat and monochromatic light explain the procedure to determine whether the given surface is flat or curved.*

Sol. When an optical flat is placed on a surface to be tested and illuminated by a monochromatic light, interference fringes *i.e.*, alternate dark and bright bands are observed. These are produced by the interference of the light rays reflected from the bottom face of the optical flat and top surface of the test piece through a very thin layer of air entrapped between the two surfaces. If the surface under test is perfectly flat there will be patterns of alternate light and dark straight, parallel and equally spaced bands on the surface and even after applying light pressure at any edge there will not be change in the fringe pattern.

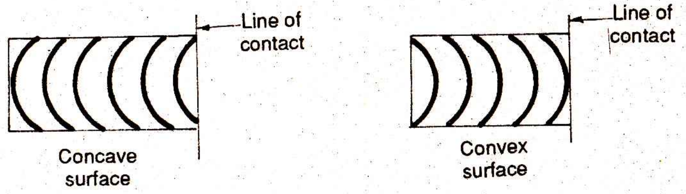

Fig. 13.15

However, if the surface to be tested is not flat the bands obtained will be curved, as shown in Fig. 13.15. If the bands curve around the point or line of contact, the surface is convex and if the bands curve in opposite direction, the surface is concave. If the curvature of bands is more it indicates more convexity and vice-versa.

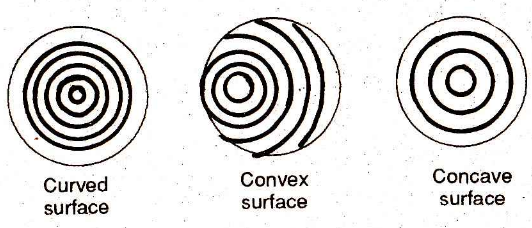

Fig. 13.16

When the surface under test is curved, circular bands with a central bright spot at the point of contact are observed (Fig. 13.16). To determine whether the surface is concave or convex, it is pressed lightly with finger tip at one edge. If the centre of the bands is displaced and the fringes come closer, the surface under test is convex. If the application of light pressure at edge makes no change, then light pressure is applied at the centre. If the bands move apart and number of bands is reduced the surface to be tested is concave.

Problem 4. *Explain the method of checking the height of a component with the help of optical flat.*

Sol. The height of a given component can be checked against a known standard by the use of an optical flat.

The component C and the standard gauge block G are wrung to a reference surface, at a known distance x apart (Fig. 13.17) An optical flat is placed over the two as shown. As the height of the reference gauge is slightly different from that of the component being tested the optical flat will be inclined at a small angle thus producing an air wedge.

If N number of dark fringes are observed over the width L mm of the block G.

x = distance in mm