5.4 LASER INTERFEROMETERS

In recent times, laser-based interferometers are becoming increasingly popular in metrology applications. Traditionally, lasers were more used by physicists than engineers, since the frequencies of lasers were not stable enough. However now, stabilized lasers are used along with powerful electronic controls for various applications in metrology. Gas lasers, with a mixture of neon and helium, provide perfectly monochromatic red light. Interference fringes can be observed with a light intensity that is 1000 times more than any other monochromatic light source. However, even to this day, laser-based instruments are extremely costly and require many accessories, which hinder their usage.

More importantly, from the point of view of calibration of slip gauges, one limitation of laser is that it generates only a single wavelength. This means that the method of exact fractions cannot be applied for measurement. In addition, a laser beam with a small diameter and high degree of collimation has a limited spread. Additional optical devices will be required to spread the beam to cover a larger area of the workpieces being measured.

In interferometry, laser light exhibits properties similar to that of any 'normal' light. It can be represented by a sine wave whose wavelength is the same for the same colours and amplitude is a measure of the intensity of the laser light. From the measurement point of view, laser interferometry can be used for measurements of small diameters as well as large displacements. In this section, we present a simple method to measure the latter aspect, which is used for measuring machine slideways. The laser-based instrument is shown in Fig. The fixed unit called the laser head consists of laser, a pair of semi-reflectors, and two photodiodes. The sliding unit has a corner cube mounted on it. The corner cube is a glass disk whose back surface has three polished faces that are mutually at right angles to each other. The corner cube will thus reflect light at an angle of 180°, regardless of the angle at which light is incident on it. The photodiodes will electronically measure the fringe intensity and provide an accurate means for measuring displacement.

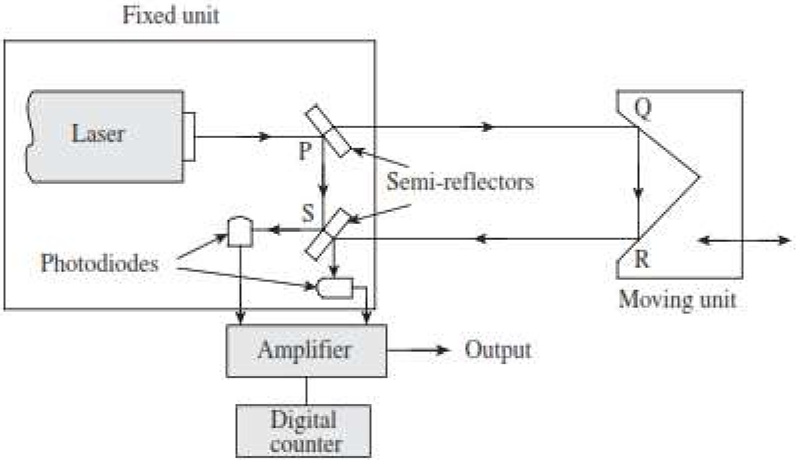

Fig. 5.17 Fringe Pattern

Laser light first falls on the semi-reflector P, is partially reflected by 90° and falls on the other reflector S. A portion of light passes through P and strikes the corner cube. Light is turned through 180° by the corner cube and recombines at the semi-reflector S. If the difference between these two paths of light (PQRS − PS) is an odd number of half wavelengths, then interference will occur at S and the diode output will be at a minimum. On the other hand, if the path difference is an even number of half wavelengths, then the photodiodes will register maximum output.

It must have now become obvious to you that each time the moving slide is displaced by a quarter wavelength, the path difference (i.e., PQRS − PS) becomes half a wavelength and the output from the photodiode also changes from maximum to minimum or vice versa. This sinusoidal output from the photodiode is amplified and fed to a high-speed counter, which is calibrated to give the displacement in terms of millimetres. The purpose of using a second photodiode is to sense the direction of movement of the slide.

Laser interferometers are used to calibrate machine tables, slides, and axis movements of coordinate measuring machines. The equipment is portable and provides a very high degree of accuracy and precision.

5.3.1 Components Laser Interferometry

1. Two frequency Laser sources
2. Optical elements
3. Laser head’s measurement receiver

iv. Measurement display

i. Two frequency Laser sources

It is generally He-Ne type that generates stable coherent light beam of two frequencies, one polarized vertically and another horizontally relative to the plane of the mounting feet. Laser oscillates at two slightly different frequencies by a cylindrical permanent magnet around the cavity. The two components of frequencies are distinguishable by their opposite circular polarization. Beam containing both frequencies passes through a quarter wave and half wave plates which change the circular polarizations to linear perpendicular polarizations, one vertical and other horizontal. Thus, the laser can be rotated by 90°about the beam axis without affecting transducer performance. If the laser source is deviated from one of the four optimum positions, the photo receiver will decrease. At 45° deviation the signal will decrease to zero.

ii. Optical elements

a) Beam splitter

Sketch shows the beam splitters to divide laser output along different axes. These divide the laser beam into separate beams. To avoid attenuation, it is essential that the beam splitters must be oriented so that the reflected beam forms a right angle with the transmitted beam. So that these two beams: are coplanar with one of the polarisation vectors of the input form.

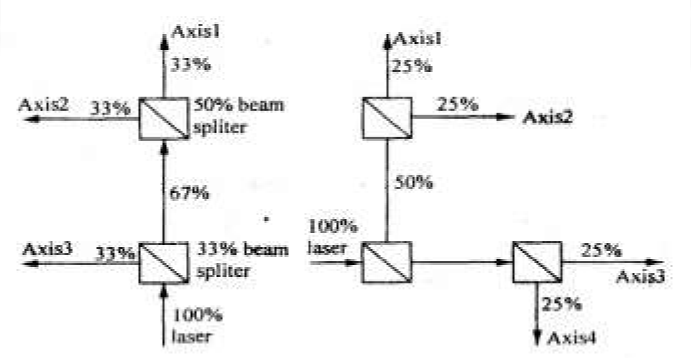

Fig.5.18 Beam splitter

b) Beam benders

Fig. 5.19 Beam benders

These are used to deflect the light beam around corners on its path from the laser to each axis. These are actually just flat mirrors but having absolutely flat and very high reflectivity. Normally these are restricted to 90° beam deflections to avoid disturbing the polarizing vectors.

c) Retro reflectors

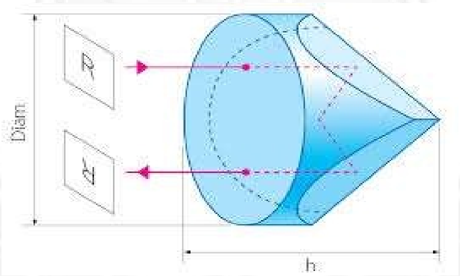

Fig. 5.20 Retro reflectors

These can be plane mirrors, roof prism or cube corners. Cube corners are three mutually perpendicular plane mirrors and the reflected beam is always parallel to the incidental beam. Each ACLI transducers need two retro reflectors. All ACLI measurements are made by sensing differential motion between two retro reflectors relative to an interferometer. Plane mirror used as retro reflectors with the plane mirror interferometer must be flat to within 0.06 micron per cm.

(iii) Laser head's measurement receiver

During a measurement the laser beam is directed through optics in the measurement path and then returned to the laser head is measurement receiver which will detect part of the returning beam and a doppler shifted frequency component.

(iv) Measurement display

It contains a microcomputer to compute and display results. The signals from receiver and measurement receiver located in the laser head are counted in two separate pulse converter and subtracted. Calculations are made and the computed value is displayed. Other input signals for correction are temperature, co-efficient of expansion, air velocity etc., which can be displayed.

5.4.1 TYPES OF LASER INTERFEROMETER

The following are the types of laser interferometer:

1. AC Laser Interferometer
2. DC Laser Interferometer

i) AC Laser Interferometer

It is possible to maintain the quality of interference fringes over longer distance when lamp is replaced by a laser source. Laser interferometer uses AC laser as the light source and the measurements to be made over longer distance. Laser is a monochromatic optical energy, which can be collimated into a directional beam AC. Laser interferometer (ACLI) has the following advantages.

- High repeatability
- High accuracy
- Long range optical path
- Easy installations
- Wear and tear

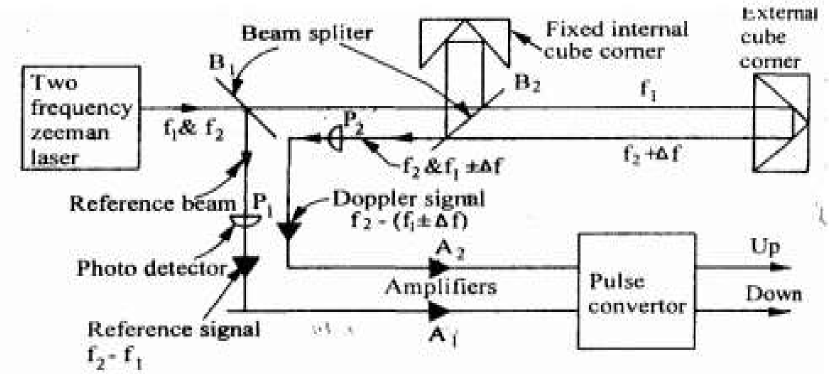

Fig. 5.21 AC Laser Interferometer

Schematic arrangement of laser interferometer is shown in fig. Two-frequency Zeeman laser generates light of two slightly different frequencies with opposite circular polarisation. These beams get split up by beam splitter B One-part travels towards B and from there to external cube corner here the displacement is to the measured.

This interferometer uses cube corner reflectors which reflect light parallel to its angle of incidence. Beam splitter B2 optically separates the frequency J which alone is sent to the movable cube corner reflector. The second frequency from B2 is sent to a fixed reflector which then re-joins f1 at the beam splitter B2 to produce alternate light and dark interference flicker at about 2 Mega cycles per second. Now if the movable reflector moves, then the returning beam frequency Doppler-shifted slightly up Thus the light beams moving towards photo detector P2 have frequencies f2 and (f1 ± Δf1) and P2 changes these frequencies int signal from beam splitter B2 and changes the reference beam frequencies f1 and f2 into electrical signal. An AC amplifier A separates frequency. Difference signal f2 –f1 and A2 separates frequency difference signal. The pulse converter extracts i. one cycle per half wavelength of motion. The up-down pulses are counted electronically and displayed in analog or digital form.

5.4.2 Types of AC Laser Interferometer

a) Standard Interferometer

- Least expensive.
- Retro reflector for this instrument is a cube corner.
- Displacement is measured between the interferometer and cube corner.

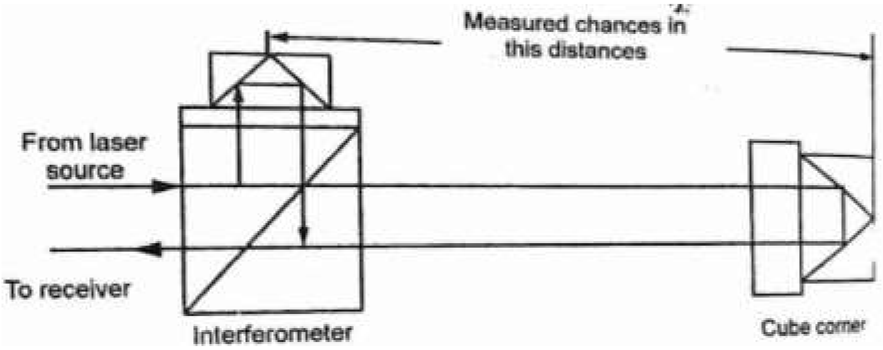

Fig. 5.22 Standard Interferometer

b) Single beams Interferometer

- Beam traveling between the interferometer and the retro reflector.

- Its operation same as standard interferometer.
- The interferometer and retro reflector for this system are smaller than the standard system.
- Long range optical path
- Wear and tear.

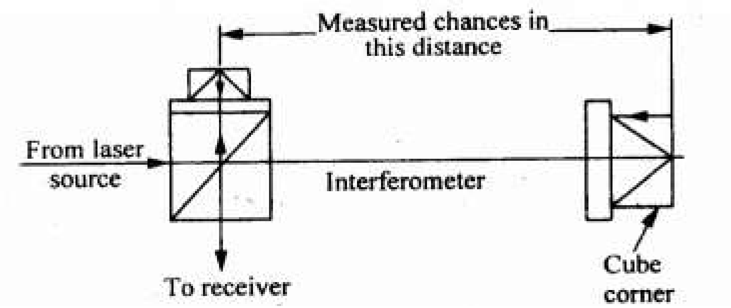

Fig. 5.23 ingle beams Interferometer

ii) DC Laser Interferometer

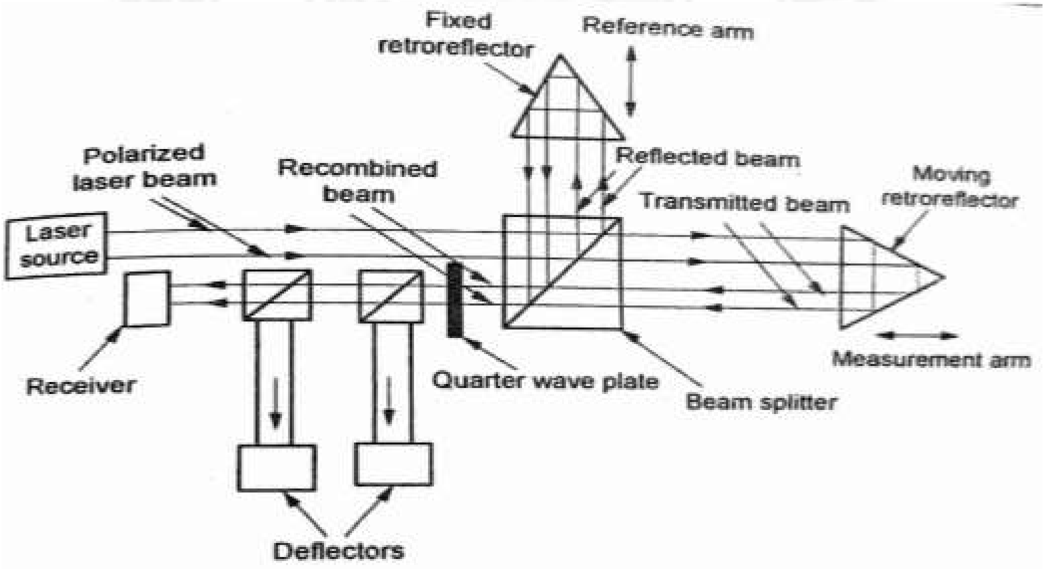

Fig. 5.24 DC Laser Interferometer

It is much improved system over the Michelson simple interferometer. It uses a single frequency circular polarised laser beam. On reaching the polarising beam splitter, the beam splits into two components, the reflected beam being vertically polarised light and the transmitted beam being horizontally polarised light. These two beams referred to as reference arm and measurement arm respectively travel to their retroreflectors and are then reflected back towards the beam splitter. The recombined beam at beam splitter consists of two superimposed beams of different polarisation ; one component vertically polarised having travelled around reference arm and other component horizontally polarised having travelled around the measurement arm. These two beams being differently polarised do not interfere. The recombined beam then passes through a quarter waveplate which causes the two beams to interfere with one another to produce a beam of plane polarised light. The angular orientation of the plane of this polarised light depends on the phase difference between the light in the two returned beams.

The direction of plane of polarisation spin is dependent on the direction of movement of the moving retroreflector. The beam after quarter waveplate is split into three polarisation sensitive detectors. As the plane of polarised light spins, each detector produces a sinusoidal output wave from. The polarisation sensitivity of the detectors can be set so that their outputs have relative phases of 0°, 90°, and 180°. The outputs of three detectors can be used to distinguish the direction of movement and also the distance moved by the moving retroreflector attached to the surface whose displacement is to be measured.

For linear measurements (positional accuracy or velocity), the retroreflector is attached to the body moving along the linear axis. For angular measurement. For pitch and yaw), the angular beam splitter is placed in the path between the laser head and the angular reflector. In this way it is possible to measure flatness, straightness, rotatory axis calibration. Arrangements also need to be made for environmental compensation because the refractive index of the air varies with temperature, pressure and humidity. Heterodyne interferometer, an a.c. device avoids all the problems encountered in above d.c. device, i.e., effect of intensity level change of source, fringe contrast changes and d.c. level shifts which can cause fringe miscounting. Interferometry is now an established and well-developed technique for high accuracy and high-resolution measurement.

Uses of Laser Interferometer:

- Since laser interferometer produces very thin, straight beam, they are used measurement and alignment in the production of large machines.
- They are also used to calibrate precision machine and measuring devices.

- They can also be used to check machine setup. A laser beam is projected against the work and measurements are made by the beam and displayed on a digital readout panel.
- Because of their very thin, straight beam characteristics, lasers are extensively used in constructions and surveying. They are used to indicate the exact location for positioning girders on a tall building or establishing directional lines for a tunnel being constructed under a river.
- Laser interferometers can also used in a glass feature.

Other types of interferometers

The following are the other types of interferometers:

i) Michelson interferometer
ii) Twyman-green specialisation of Michelson interferometer
iii) Dual frequency laser interferometer

5.4.3 Michelson interferometer

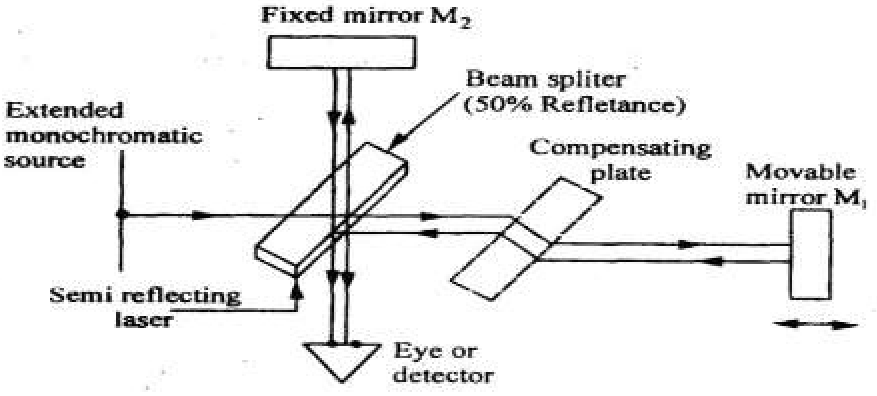

Fig. 5.24 Michelson interferometer

Michelson interferometer consists of a mono chromatic light source a beam splitter and two mirrors. The schematic arrangement of Michelson interferometer is shown in fig. The monochromatic light falls on a beam splitter, which splits the light into two rays of equal intensity at right angles. One ray is transmitted to mirror M1 and other is reflected through beam splitter to mirror M2. From both these mirrors, the rays are reflected back and these return at the semi reflecting surface from where they are transmitted to the eye. Mirror M2 is fixed and mirror M1 is movable. If both the mirrors are at same distance from beam splitter, then light will arrive in phase and observer will see bright spot due to constructive interference. If movable mirror shifts by quarter wavelength, then beam will return to observer 1800 out of phase and darkness will be observed due to destructive interference.

Each half - wavelength of mirror travel produces a change in them measured optical path of one wave length and the reflected beam from the moving mirror shifts through 360° phase change. When the reference beam reflected from the fixed mirror and the beam reflected from the moving mirror re-join at the beam splitter, they alternately reinforce and cancel each other as the mirror moves. Each cycle of intensity at the eye represents l/2 of mirror travel. When white light source is used then a compensator plate is introduced in each of the path of mirror M1 So that exactly the same amount of glass is introduced in each of the path.

To improve the Michelson interferometer

- Use of laser the measurements can be made over longer distances and highly accurate measurements when compared to other mono chromatic sources.
- Mirrors are replaced by cube - corner reflector which reflects light parallel to its angle of incidence.
- Photo cells are employed which convert light intensity variation in voltage pulses to give the amount and direction of position change.

5.4.4. Dual frequency Laser Interferometer

This instrument is used to measure displacement, high-precision measurement of lengths, angles, speeds and refractive indices as well as derived static and dynamic quantities. It operates on heterodyne principle. The two resonator modes (frequencies ft and ft) are generated in a laser tube such that ft – ft = 640 MHz. These are controlled so that their maxima are symmetrical to the atomic transition. This permits a long reliable stability. The frequency stability of He-Ne laser is responsible for outstanding performance of the interferometer.

An amplitude beam splitter branches off part of the laser output create a reference beam, which an optical fibre cable relays to a photodetector

1. This detects the beat signal of the 640 MHz frequency difference produced by the heterodyning of the two modes. The other portion of the light serves as measuring beam. Via an interferometer arrangement it is directed to a movable measuring mirror and a stationary reference mirror, which reflects it on to a photo-detector

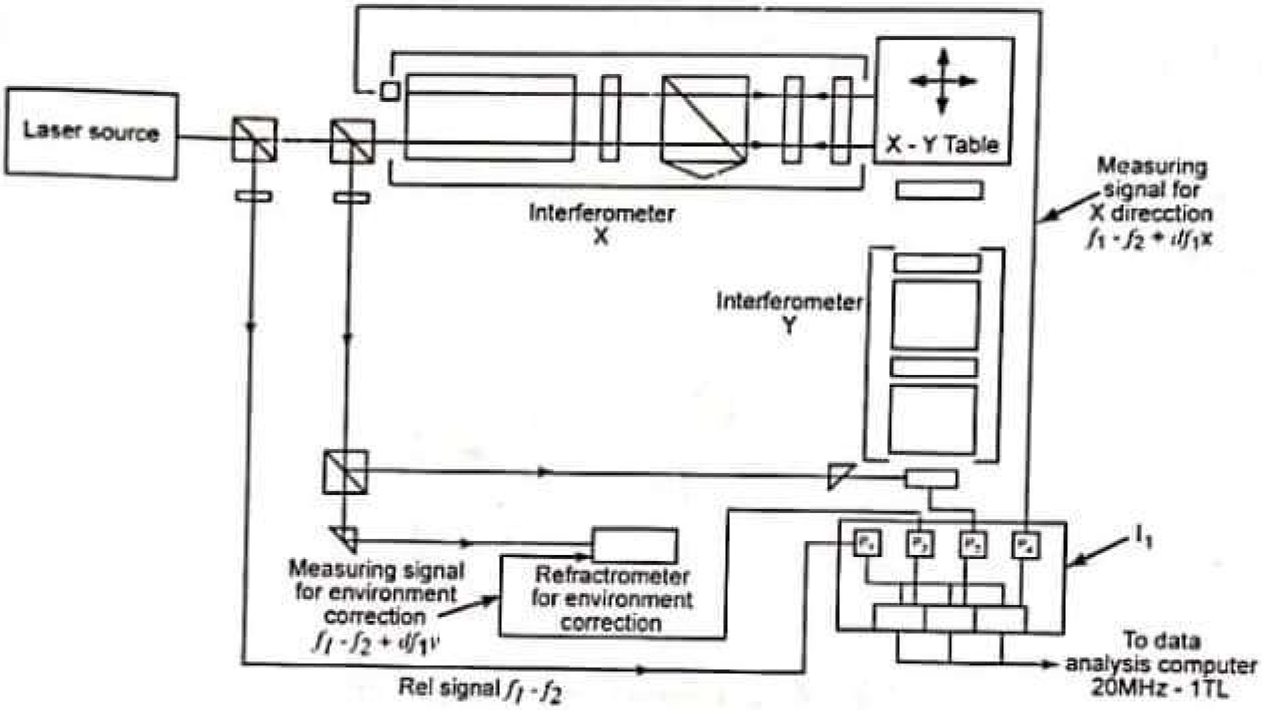

Fig. 5.25 Dual frequency Laser Interferometer

2. The two frequencies in the measuring beam are separated by a polarisation- sensitive beam splitter so that the measuring mirror receives light of frequency $\bar{\imath}$ only, whereas the light that strikes the reference consists exclusively of frequency f_2. With the measuring mirror at rest, detector 2 also senses the laser differential frequency of i – f_2 = 640 MHz. If the measuring mirror is being displaced at a speed v, the partial beam of frequency/i reflected by it is subjected to a Doppler shift dfx; where dfx = (2v)/Xx- Accordingly, detector 2 now receives a measuring frequency of f_x-f_2± dfx (+ dfx or – dfx) depending on the direction of movement of the measuring mirror. The reference frequency $\bar{f}$—fi ana the measuring frequency $\bar{f}$—f%± dfx are compared with each other by an electronic counting chain. The result is the frequency shift ± dfx due to the

Doppler effect, a measure of the wanted displacement of the measuring mirror. In a fast, non-hysteric comparator, the

Pl = Photo detector for reference signal

P2, P3 and P4 = photo detectors for measuring

Ix = Basic Instrument signals with HF signal processing and interpolation facilities.

Doppler frequency d$\bar{f}$is digitised and then fed to a counter, which registers the number of zero passages per unit time.

The forward and return movements of the measuring mirror can be distinguished by outcoupling the measuring signal $\bar{i}$ – f_2 + dfx at 'n' phase angles, via a delay line and feeding to 're' mixers. The mixers are connected with the reference signal $\bar{f}$—f_2 (common feeding point for all mixers). Thus, n Doppler frequencies get shifted in phase by at the mixer outputs. They are symmetrical relative to zero. After comparison they are made available to low-frequency counting logic as TTL signals. The n phase angles and their tolerances are implemented by the geometry of the delay line. This system can be used for both incremental displacement and angle measurements. Due to large counting range, it is possible to attain a resolution of 2 nm in 10 m measuring range. Means are also provided to compensate for the influence of ambient temperature, material temperature, atmospheric pressure and atmospheric humidity fluctuations.

5.4.5 Twyman–Green Interferometer:

Twyman–Green interferometers, named after Frank Twyman and Arthur Green, are interferometers which are used for characterizing optical surfaces.

The optical setup is similar to that of a Michelson interferometer, but a Twyman–Green interferometer works with collimated beams which are expanded to a substantial diameter. In the simplest case, such an expanded beam is directly sent to the inspected surface, and the resulting interference pattern is imaged such that it can either be directly observed through an eyepiece (ocular lens) or registered with a monochrome electronic image sensor.

The inspected surface can be that of a mirror or some other kind of optical element; for use as an end mirror, one just requires some significant reflectivity of the surface, and there should be no additional reflection which could spoil the interference pattern. Some elements (e.g. lenses, prisms and mirror substrates) can also be inserted in the beam path for inspection in transmission, i.e., they are combined with a suitable kind of mirror.

For inspecting aspheric optics, one will usually require a high-quality reference surface (made e.g. from an optical flat) with which further devices can be inspected, because the deviation from a spherical mirror, for example, may be too high to measure.

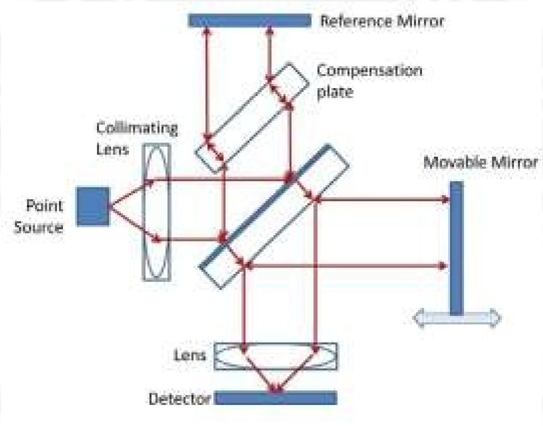

Fig. 5.25 Twyman–Green Interferometer

The inspected surface must be imaged to the detector, such that each point in the image corresponds to a point on the inspected surface.

The object under test or the reference mirror is intentionally very slightly tilted e.g. by turning a micrometer screw, so that one obtains an interference pattern with regular stripes having an appropriate spacing. These stripes are perfect lines if the test surface exactly matches the reference surface. Any deviations between the surface shapes lead to distortions of those stripes (Fizeau curves). For topographic deviations of several wavelengths, one may simply count the number of stripes in order to measure the height.

Recorded digital images may be more closely analyzed with suitable computer software, which may allow detailed measurements of surface shape deviations.

The used reference mirror as well as the beam splitter and other optical components should have a very high optical quality, so that any observed distortions are only due to imperfections of the investigated objects.

5.5 Machine Tool Measurement Using Laser Interferometer

When the machine tool is idle and unloaded, tests performed are called as alignment tests.

Alignment test is carried out 'to check grade of manufacturing accuracy of the machine tool'. It consists of checking the relation between various machine parts or elements (such as bed, table, spindle etc.)

5.5.1 Alignment Testing on Machine Tools and its importance

The accurate production of the component parts depends on the accuracy of the machine tools. The quality of workpiece depends on the following factors:

- Rigidity and stiffness of machine tool and its components.
- Alignment of various components in relation to one another,
- Quality and accuracy of the control devices and the driving mechanism.

Precise alignment of machine tool components has the following advantages:

- It produces high quality machined components.
- It reduces power consumption of machinery.
- It increases machine reliability and productivity.
- It reduces machine repair costs.
- It minimizes the machine installation and repair time.
- It reduces machine down time and increases machine availability.
- It decreases wear on bearings, seals, shafts and couplings.
- It reduces vibrations in machine tools.
- It significantly reduces the damage to machine tool components.

Various types of alignment tests conducted on machine tools are as follows

a) Straightness
b) Flatness
c) Parallelism, Equidistance and Coincidence
    i. Parallelism of Lines and Planes
    ii. Parallel Motion
d) Squareness of straight lines and planes
e) Rotation
    i. Concentricity or out of round
    ii. Eccentricity
    iii. Out of true running
    iv. Periodical axial slip
    v. Radial throw of an axis at a given point
f) Movement of all working components

In general, the following alignment test for applied to any Machine tools

- Test for levelling the installation of a machine tool in horizontal and vertical plane
- Test for perpendicularity of guideways to other guideways
- Test for flatness of machine bed straightness and parallelism of bed ways on the bearing surface
- Test for true running of the main spindle and its Axis movements
- Test for a line of moment of various members such as spindle tables and cross slides
- Test for parallelism of spindle axis to guideways for the bearing surfaces

Laser as means of alignment checking

Laser alignment checking can be used for the following purposes

- To Align horizontal boring Mills, Vertical boring Mills, vertical machining centres, vertical turret lathe, gantries, surface grinder, injection moulding machines, presses, high Precision laser and water Jet cutting machines.

- To verify and correct roll parallelism in paper mills, printing presses, film line and blown film lines
- To measure and align the flatness of almost any surface (square, frames, ways, flanges, circles Etc.).
- To ensure the squareness up to three surfaces
- To ensure the straightness of horizontal and vertical surfaces
- To ensure the parallelism of horizontal and vertical surfaces
- for other applications such as checking the plumpness of a vertical surface Checking way twist and parallelism between horizontal surfaces and checking way twist and parallelism between vertical surfaces.

Laser systems can be used to measure a great number of geometric and dynamic properties of a machine tool. Following measurements can be performed using laser interferometer

a. linear positioning accuracy and repeatability of Axis
b. straightness of Axis
c. squareness between Axis
d. flatness of surface
e. levelness of the plane surface
f. parallelism between surface
g. testing accuracy of rotary axis

5.5.2 Straightness testing using laser interferometer

Straightness error is one of the fundamental geometric tolerances that must be strictly controlled for precision guideways or stages. Several methods used for straightness measurements are: laser interferometer with straightness optics, a straight edge with displacement sensors such as linear variable displacement transducer and gap sensor, and incremental angular measurements using autocollimator or angular measurement optics, etc. Among these methods, the laser interferometer has been widely adopted to obtain high precision straightness measurement.

Some commercial instruments have been successfully developed, such as the Agilent 5529A interferometer and the Renishaw ML10 interferometer a common disadvantage in these instruments is that they cannot provide information about the relative position of the measured straightness errors Therefore in practice it is inconvenience to repair the guideways or to adjust the stages because the users do not know the exact position of the straightness error. a new interferometer design based on heterodyne interferometry for measuring straightness and its position is proposed, which can overcome the disadvantage described above. The theory and optical configuration of this new interferometer are developed and subjected to experimental testing with a linear stage to verify the feasibility of the interferometer as well as a flexure-hinge stage to demonstrate the interferometer's capability of nanometer measurement accuracy.

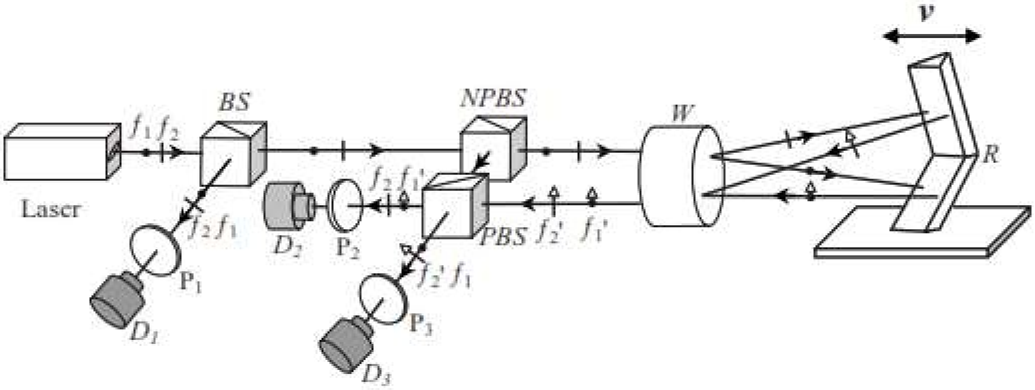

Fig. 5.26 schematic diagram of the laser interferometer for measuring straightness and its position based on heterodyne interferometry.

A stabilized laser as light source emits a orthogonally linearly polarized laser beam with dual frequencies (f_1 and f_2). The laser beam is divided by a beam- splitter (BS) into two beams. One beam, as the reference beam, passes through the first polarizer (P1) and projects on to the first photodetector (D1), and then a reference signal is produced. Another beam, as the measurement beam, is divided by a nonpolarizing BS into a reflected beam (RB) and a transmitted beam (TB). The RB incidents onto a polarizing BS (PBS). The TB passes through a Wollaston prism (W) and is split into two divergent beams containing f_1 and f_2 separately. The two divergent beams are then incident onto a retroreflector (R) which is composed of two right-angle prisms.

The R is placed on the measured object which straightness is required to be tested. The R reflects the two divergent beams, whose frequencies become f1±f1 and f2±f2 caused by the Doppler effect, back into the W where they are recombined into one beam at another point of the W. After passing through the W, the combined beam incidents onto the PBS. Then, (a) the beam with frequency of f1 ±f1 transmitting through the PBS and the beam f2 of the RB reflected by the PBS recombine into one beam (BI). The BI passes through the second polarizer (P2) and projects onto the second photodetector (D2). So, the first measurement signal is produced. (b) The beam with frequency of f2 $\pm\Delta$f2 reflected by the PBS and the beam f1 of the RB transmitting through the PBS recombine into another one beam (BII). The BII passes through the third polarizer (P3) and projects onto the third photodetector (D3). So, the second measurement signal is produced.

Use of Laser for Alignment Testing

The alignment tests can be carried out over greater distances and to a greater degree of accuracy using laser equipment.

- Laser equipment produces real straight line, whereas an alignment telescope provides an imaginary line that cannot be seen in space.
- This is important when it is necessary to check number of components to a predetermined straight line. Particularly if they are spaced relatively long distances apart, as in aircraft production and in shipbuilding.
- Laser equipment can also be used for checking flatness of machined surface by direct displacement. By using are optical square in conjunction with laser equipment squareness can be checked with reference to the laser base line.

5.5.3 ALIGNMENT TESTS ON MILLING MACHINE

5.5.3.1. Cutter Spindle Axial Slip or Float:

Axial slip is defined as, "an axial movement of spindle, which may repeat positively with each revolution". Clamp the dial gauge stand to table, such that, the plunger or feeler of dial gauge indicator is touching the face of locating spindle shoulder.

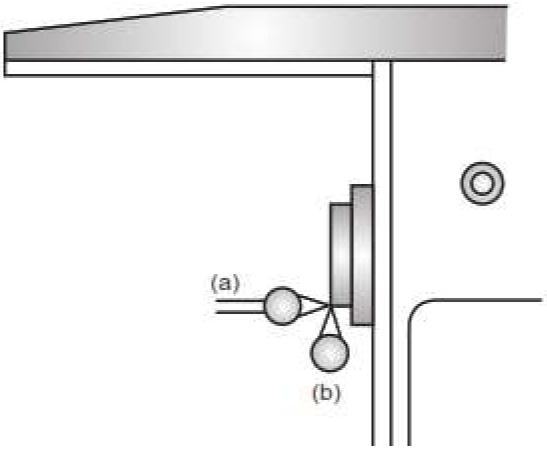

Fig. 5.27 Cutter Spindle Axial Slip or Float

- Now rotate the spindle about its centre and note down the variations observed in the readings shown on dial gauge indicator.
- This is to be tested at two points 180° apart from each other. It is expected that, the value of maximum variation in dial gauge readings should not be more than specified permissible range.

5.5.3.2. Transverse Movement Parallelism with Spindle Axis:

- Fig. shows the arrangement required to carry out test, using a dial gauge indicator along with its mounting stand arrangement.

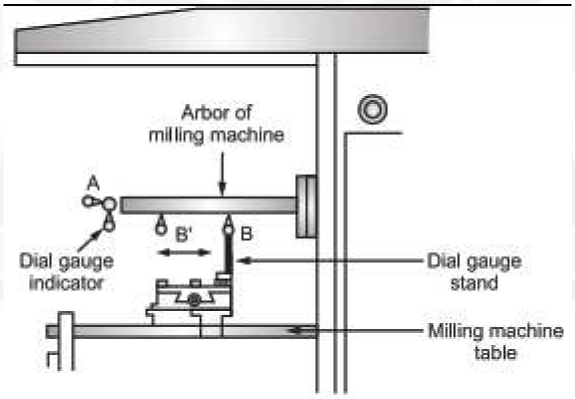

Fig. 5.28 Transverse Movement Parallelism with Spindle Axis

- Mount and fix the dial gauge indicator with the help of its stand, on the table of milling machine.
- Use Arbor of milling machine as shown in Fig. A stationery mandrel can also be used instead of Arbor.

- Initially, place the plunger (or feeler) of dial gauge indicator touching the Arbor at point 'B' to check along vertical plane. Note down the reading of dial gauge indicator (1st reading).
- Now move the dial gauge indicator along with its stand in transverse direction up to point B' and note down the second reading of dial gauge indicator (2nd reading).
- If no variation is found in first (1st) and second (2nd) reading, then transverse movement is parallel with spindle axis.

5.5.3.3. True Running of Internal Taper:

• Fix a mandrel as shown in Fig.

•Dial gauge indicator is mounted with the help of dial gauge stand, in such a way that, plunger will touch the surface of mandrel.

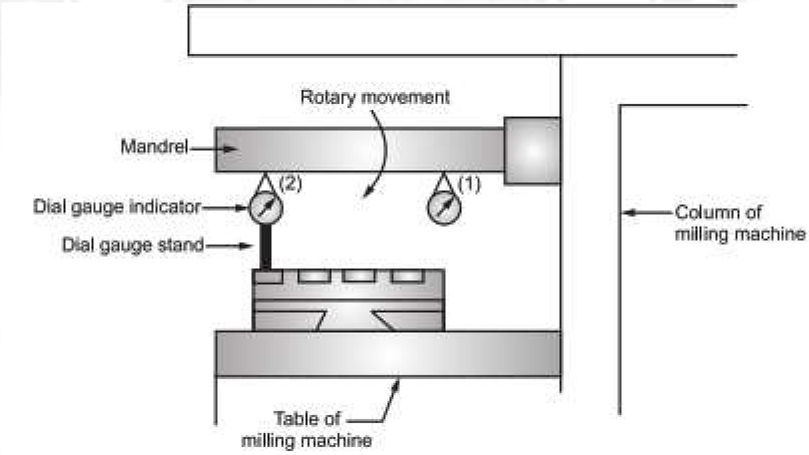

Fig. 5.29 Transverse Movement Parallelism with Spindle Axis

- It is ensured that, plunger remains in contact with mandrel, while carrying the test.
- This test is carried out at two places, given below:

  (i) Near to spindle nose, refer position (1).

  (ii) At a distance of 300 mm from spindle nose, refer position (2).

- Consider that plunger of dial gauge indicator is at position (1). Now, rotate the mandrel and observe the readings shown on dial indicator, to find out the value of maximum variation (if present) is noted down as 1st reading.

- Now, dial gauge indicator is mounted with the help of its stand at position (2), which is 300 mm away from position (1). Repeat the same procedure and note down 2nd reading.
- Difference between 1st and 2nd readings indicates an error in true running of internal taper.
- This error should not exceed the specified permissible value.

5.5.3.4. Surface Parallelism with Longitudinal Movement:

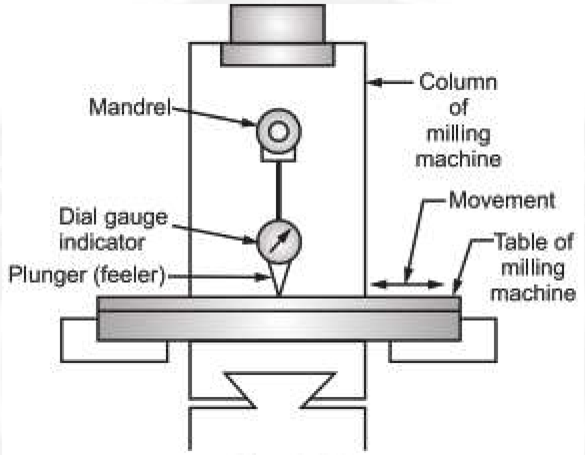

Fig. 5.30 Transverse Movement Parallelism with Spindle Axis

- Fix a mandrel and a dial gauge indicator in such a way that, the plunger of dial gauge indicator will touch the table surface. Also, plunger is slightly pressed against the table surface, so that, it will be always in contact with table surface throughout the test. Refer Fig.
- Test the table surface for maximum travel.
- Readings shown by dial gauge indicator are observed to find out maximum variation, i.e., error in parallelism of surface during horizontal movement. This error should not exceed more than the specified permissible value.

5.6 Ball Bar Tests

Ball bar testing popularity has been built on the simplicity of the test, speed of use and the large amount of quantitative data generated.

If you program a CNC machine to trace out a circular path and the positioning performance of the machine was perfect, then the actual circle would exactly match the programmed circle. In practice, many factors in the machine geometry, control system and wear can cause the radius of the test circle and its shape to deviate from the programmed circle.

If you could accurately measure the actual circular path and compare it with the programmed path, you would have a measure of the machine's accuracy.

5.6.1 Stages of Ball bar Testing

Ball bar Testing Consists Of 3 Simple Stages. They are

1. Set-up
2. Data capture: 360° testing
3. Data analysis and diagnosis

5.6.1.1 Set-up

1. Connecting to your QC20 ball bar is simple, thanks to its *Bluetooth* connectivity. Test set-up is quick and easy with Ball bar 20 software guiding the operator through each step. The 'part programme generator' will help you set up the corresponding programme on your machine tool.
2. The powerful file administration feature lets you search and access existing test templates quickly.
3. The centre pivot is positioned on the machine table. Using a setting ball provided in the QC20 ball bar kit, the spindle is moved to a reference point, and the test 'zero' coordinates set.
4. The spindle is moved to the test start position and the QC20 ballbar is mounted between two kinematic magnetic joints.
5. A simple G02 and G03 command program is all that's required to start the test.

5.6.1.2 Data capture: 360° testing

1. The 'classic' test calls for the machine tool to perform two consecutive circles; one in a clockwise direction, the other counter-clockwise.
2. In practice there is an extra arc added before and after the test circle to allow for the machine accelerating and then slowing down.

3. With the use of extension bars the test radius can be selected to reflect the size of the machine and the sensitivity to particular issues (e.g. large radius circles are better at highlighting machine geometry errors, smaller circles are more sensitive to servo mismatch or lag).
4. Data capture is shown live on screen, so any errors or problems can be detected as the test progresses and the test stopped without wasting additional time (important if you are carrying out a large radius test with a slow feed rate).

5.6.1.3 Data analysis and diagnosis

1. The user has a choice of several report formats according to international standards (e.g., ISO, ASME) and the comprehensive Renishaw diagnostics (including volumetric analysis) with a number of different screens views and links to the help manual.
2. These reports give a value for a single overall indicator of machine positioning performance, e.g., circular deviation.
3. Many reports can be customised and can deliver an in-depth diagnosis of a machine's errors; all from a single test.

5.7 Computer Aided Metrology

5.7.1 Role of Computers in Metrology

1. **Computer based in Inspection**

Computer Aided Inspection (CAI) is a new technology that enables one to develop a comparison of a physical part to a 3D CAD model. This process is faster, more complete, and more accurate than using a Coordinate Measuring Machine (CMM) or other more traditional methods. An automatic inspection method and apparatus using structured light and machine vision camera is used to inspect an object in conjunction with the geometric model of the object. Camera images of the object are analyzed by computer to produce the location of points on the object's surfaces in three dimensions.

Point-cloud data is taken from a laser scanner or other 3-D scanning device. During a setup phase before object inspection, the points are analyzed with respect to the