3.3 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.

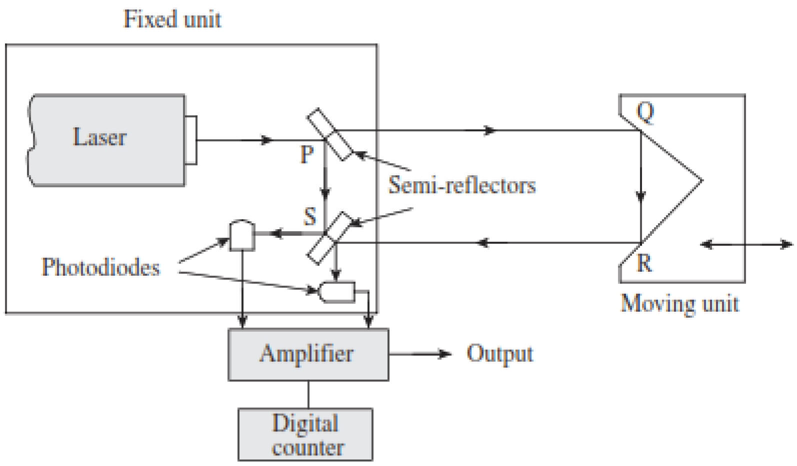

Fig. 3.17 Fringe Pattern

[source: “Engineering Metrology & Measurements”, N.V. Raghavendra., page-181]

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.

3.3.1 Components Laser Interferometry

i. Two frequency Laser sources
ii. Optical elements
iii. 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.

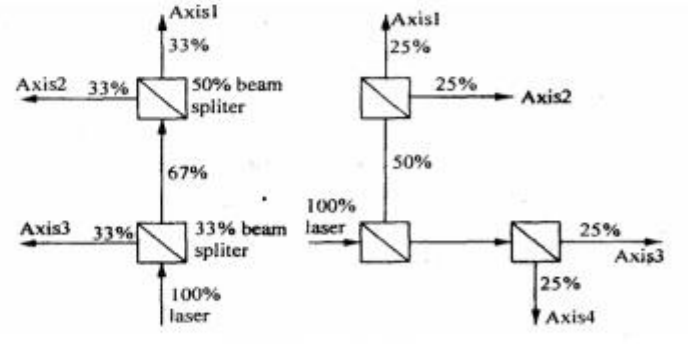

Fig. 3.18 Beam splitter

[source: https://www.brainkart.com/article/Laser-Interferometry_5837/]

b) Beam benders

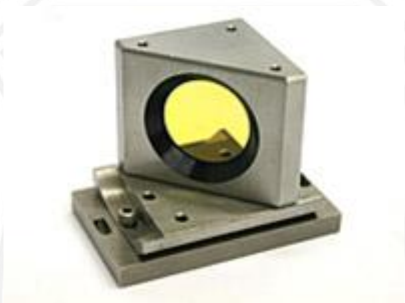

Fig. 3.19 Beam splitter

[source: http://www.motionxcorp.com/beam-benders.html]

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

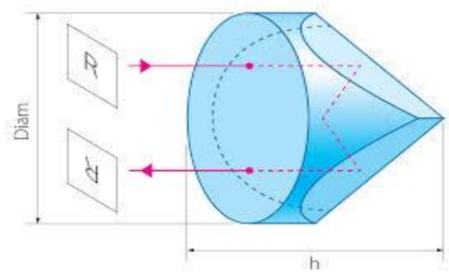

Fig. 3.20 Beam splitter

[source: https://www.altechna.com/products/corner-cube-retroreflector/]

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.

3.3.1 TYPES OF LASER INTERFEROMETER

The following are the types of laser interferometer:

i. AC Laser Interferometer
ii. 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

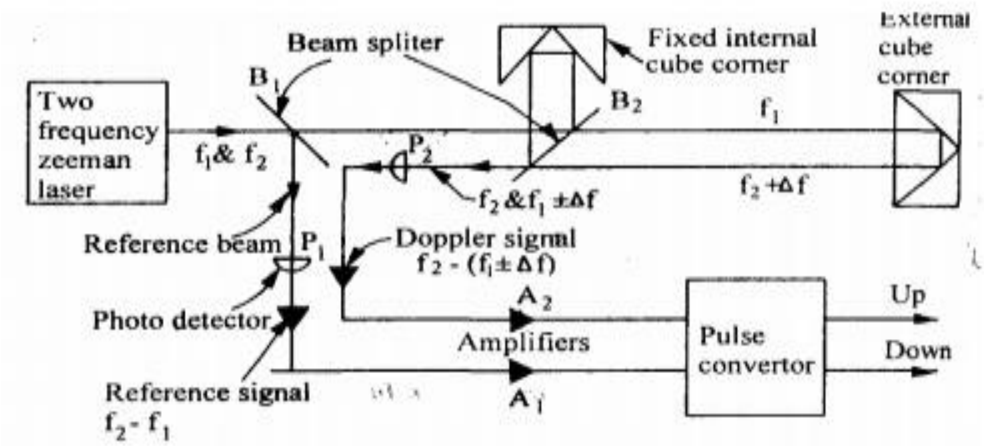

Fig. 3.21 AC Laser Interferometer

[source: https://www.brainkart.com/article/Laser-Interferometer_5838/]

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.

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.

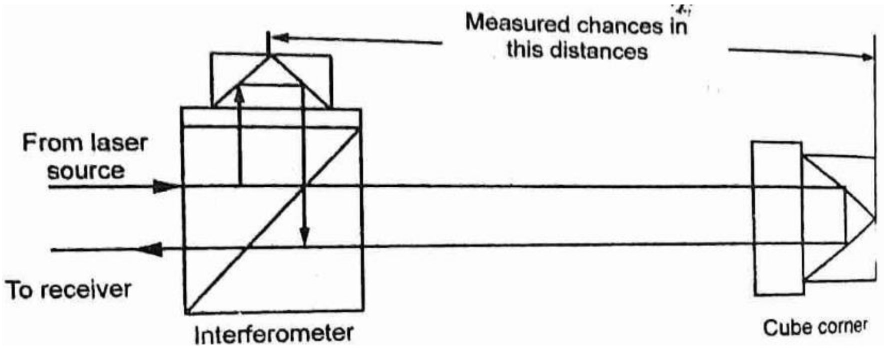

Fig. 3.22 Standard Interferometer

[source: https://www.brainkart.com/article/Laser-Interferometry_5837/]

b) Signal 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.

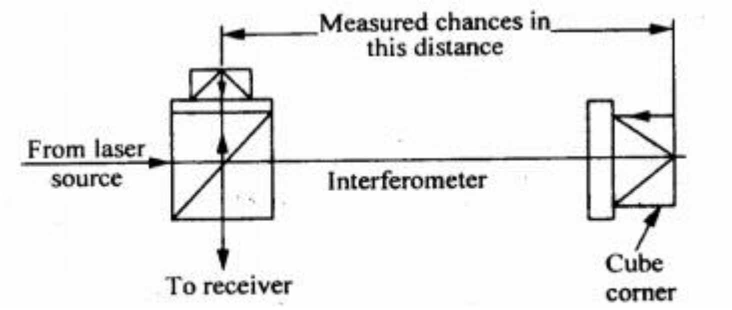

Fig. 3.23 Standard Interferometer

[source: https://www.brainkart.com/article/Laser-Interferometry_5837/]

ii) DC Laser Interferometer

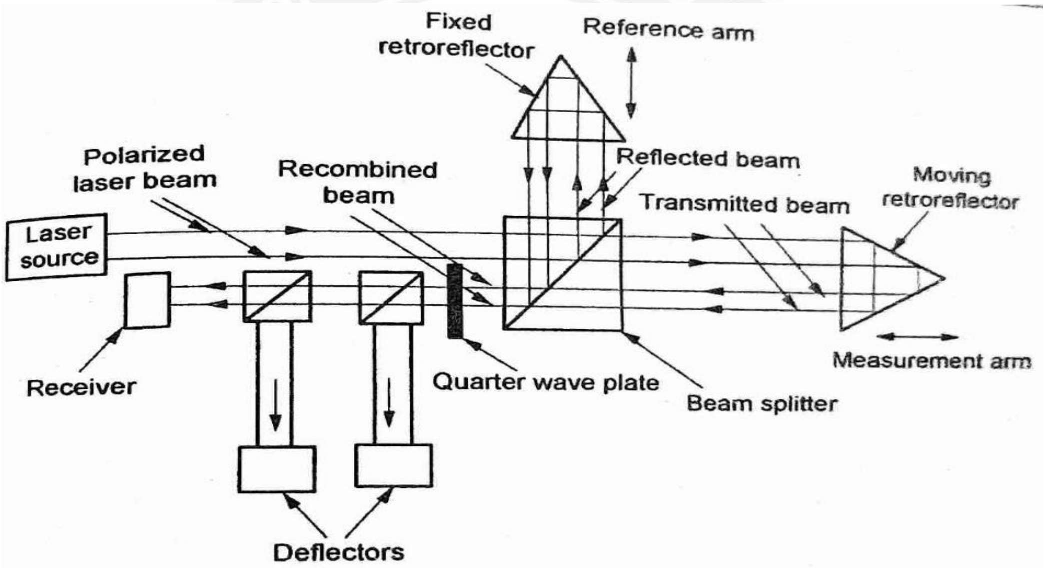

Fig. 3.24 DC Laser Interferometer

[source: http://what-when-how.com/metrology/interferometers-metrology/]

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 interferometer

The following are the other types of interferometer:

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

Michelson interferometer

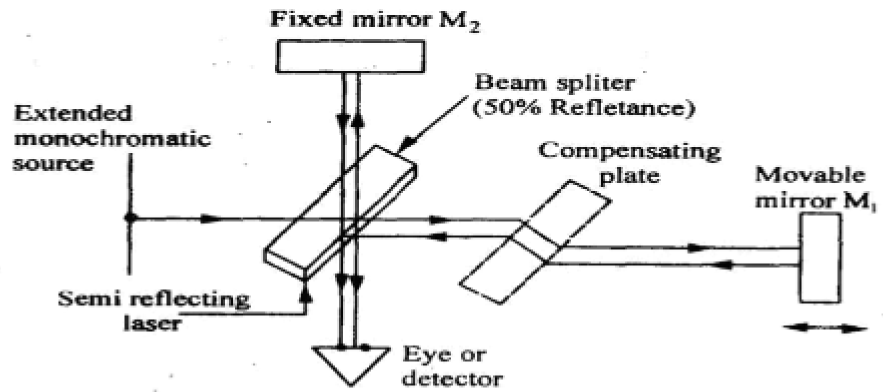

Fig. 3.24 Michelson interferometer

[source: Metrology and Measurements, Dr. G. K Vijayaraghavan pg.no. 3.26]

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.

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

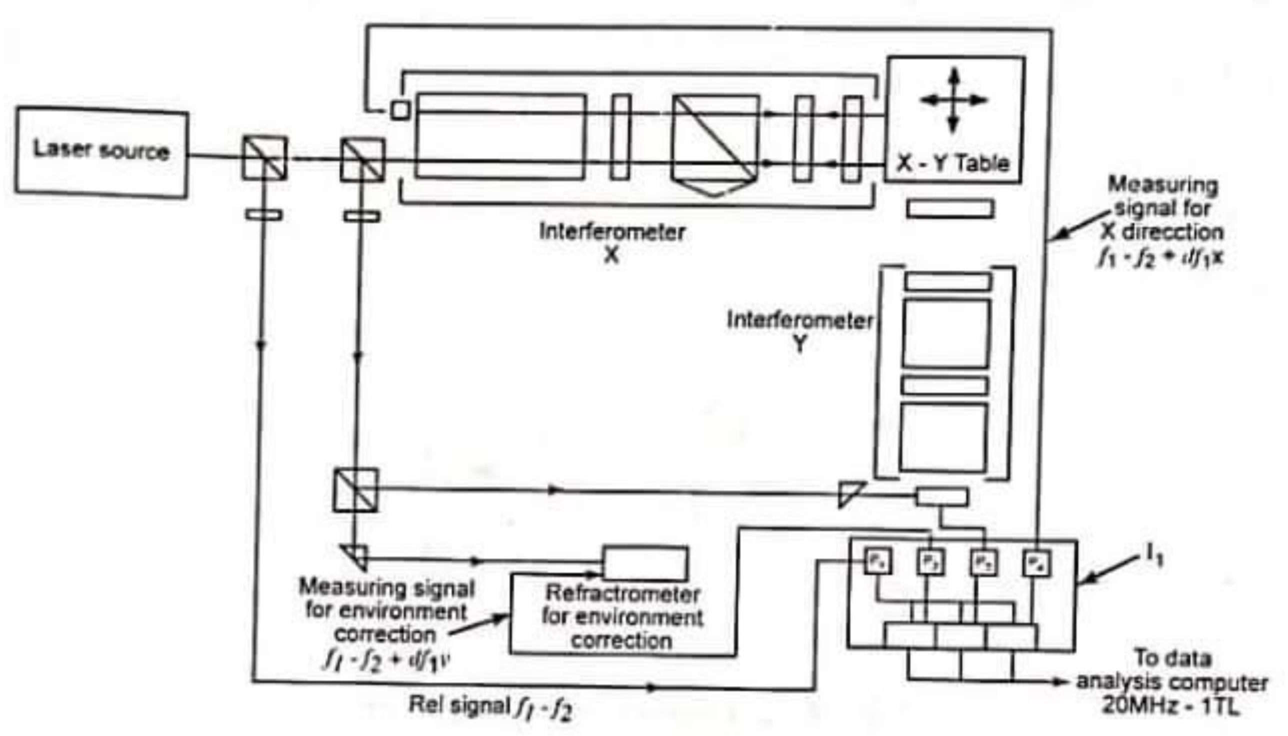

Fig. 3.25 Dual frequency Laser Interferometer

[source: https://what-when-how.com/metrology/heterodyne-interferometry-technique-metrology/]

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 $\bar{i}$ 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.

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.

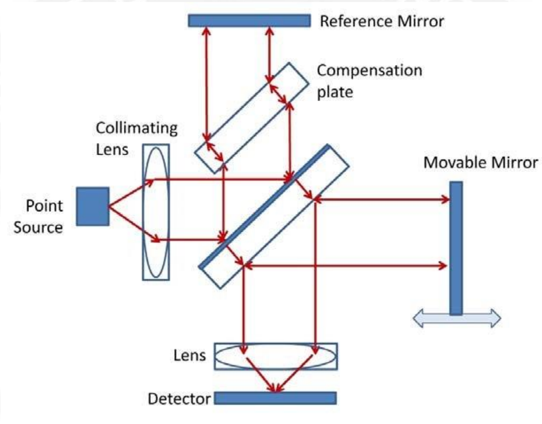

Fig. 3.25 Twyman–Green Interferometer

[source: https://www.researchgate.net/figure/Schematic-of-the-Twyman-Green-Interferometer-Based-on-Born-and-Wolf-1999_fig4_44788333]

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.