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DEPARTMENT OF MECHANICAL ENGINEERING

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UNIT – V ADVANCES IN METROLOGY

Lasers in metrology - Advantages of lasers – Laser scan micrometers; Laser interferometers – Applications – Straightness, Alignment; Ball bar tests, Computer Aided Metrology - Basic concept of CMM – Types of CMM – Constructional features – Probes – Accessories – Software – Applications – Multisensor CMMs. Machine Vision - Basic concepts of Machine Vision System – Elements – Applications - On-line and in process monitoring in production - Computed tomography – White light Scanners

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5.1. BASIC CONCEPT OF LASER

After having derived the quantum mechanically correct susceptibility for an inverted atomic system that can provide gain, we can use the two-level model to study the laser and its dynamics. After discussing the laser concept briefly we will investigate various types of gain media, gas, liquid and solid-state, that can be used to construct lasers and amplifiers.

Principle of Lasers

Laser stands for light amplification by stimulated emission of radiation

• Lasers for measurement are low power gas lasers that emit light in the visible range

• Laser light beam is:

– Highly monochromatic - the light has a single wave length

– Highly collimated - the light rays are parallel

• These properties have motivated many applications in measurement and inspection

Advantages of Lasers

1. The installation is easy
2. Accuracy is high
3. It has a long-range optical path.
4. It has high repeatability of displacement measurement
5. There is virtually no wear and tear.
6. As many as six measurements can be made simultaneously by a single laser source.

Disadvantages of Lasers

1. It is expensive
2. The measurement is not in traditional units
3. Conversion instrumentation is required as the measurement is in terms of wavelength.

5.1.1 Types of Lasers

5.1.1.1 Gas Lasers

Helium-Neon Laser

The HeNe-Laser is the most widely used noble gas laser. Lasing can be achieved at many wavelengths 632.8nm (543.5nm, 593.9nm, 611.8nm, 1.1523µm, 1.52µm, 3.3913µm). Pumping is achieved by electrical discharge

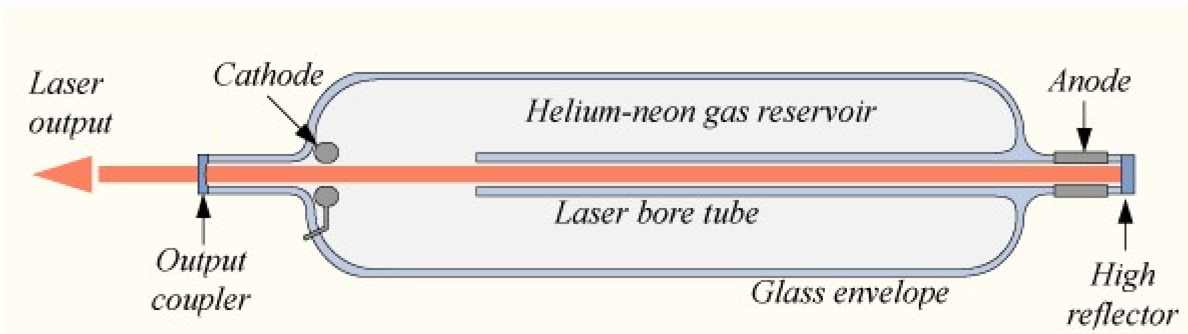

Fig. 5.1 Schematic diagram of a helium–neon laser

The helium is excited by electron impact. The energy is then transferred to Neon by collisions. The first HeNe laser operated at the 1.1523µm line. HeNe lasers are used in many applications such as interferometry, holography, spectroscopy, barcode scanning, alignment and optical demonstrations.

Argon and Krypton Ion Lasers

Similar to the HeNe-laser the Argon ion gas laser is pumped by electric discharge and emits light at wavelength: 488.0nm,514.5nm,351nm,465.8nm, 472.7nm, 528.7nm. It is used in applications ranging from retinal phototherapy for diabetes, lithography, and pumping of other lasers. The Krypton ion gas laser is analogous to the Argon gas laser with wave length: 416nm, 530.9nm, 568.2nm, 647.1nm, 676.4nm, 752.5nm, 799.3nm.

Pumped by electrical discharge. Applications range from scientific research. When mixed with argon it can be used as "white-light" lasers for light shows.

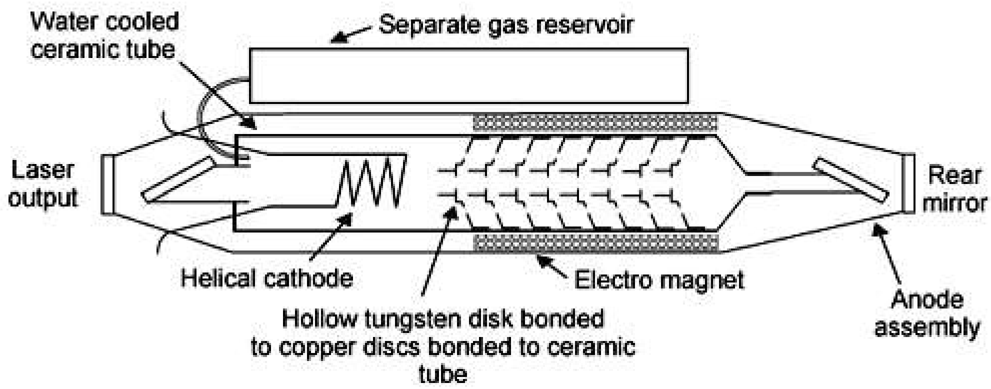

Fig. 5.2 Argon Ion Lasers

Carbon Lasers

In the carbon dioxide (CO2) gas laser the laser transistions are related to vibrational rotational excitations. CO2 lasers are highly efficient approaching 30%. The main emission wavelengths are 10.6µm and 9.4µm. They are pumped by transverse (high power) or longitudinal (low power) electrical discharge. It is heavily used in the material processing industry for cutting, and welding of steel and in the medical area for surgery. Carbon monoxide (CO) gas laser: Wavelength 2.6 - 4µm, 4.8 - 8.3µm pumped by electrical discharge. Also used in material processing such as engraving and welding and in photoacoustic spectroscopy. Output powers as high as 100kW have been demonstrated.

Fig. 5.3 Carbon Lasers

Excimer Lasers:

Chemical lasers emitting in the UV: 193nm (ArF), 248nm (KrF), 308nm (XeCl), 353nm (XeF) excimer (excited dimer). These are molecules that exist only if one of the atoms is electronically excited. Without excitation the two atoms repell each other. Thus, the electronic ground state is not stable and is therefore not populated, which is ideal for laser operation. These lasers are used for ultraviolet lithography in the semiconductor industry and laser surgery.

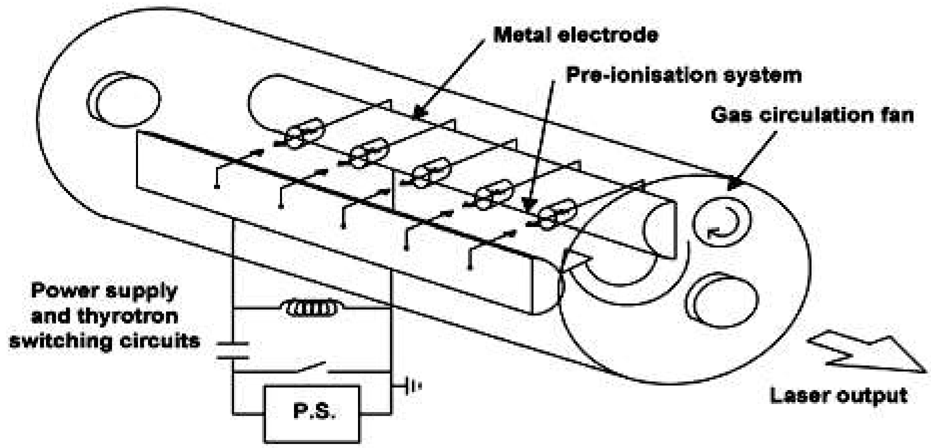

Fig. 5.4 Excimer Lasers

5.1.1.2 Dye Lasers

The laser gain medium are organic dyes in solution of ethyl, methyl alcohol, glycerol or water. These dyes can be excited by optically with Argon lasers for example and emit at 390-435nm (stilbene), 460-515nm (coumarin 102), 570-640 nm (rhodamine 6G) and many others. These lasers have been widely used in research and spectroscopy because of there wide tuning ranges. Un fortunately, dyes are carcinogenic and as soon as tunable solid state laser media became available dye laser became extinct.

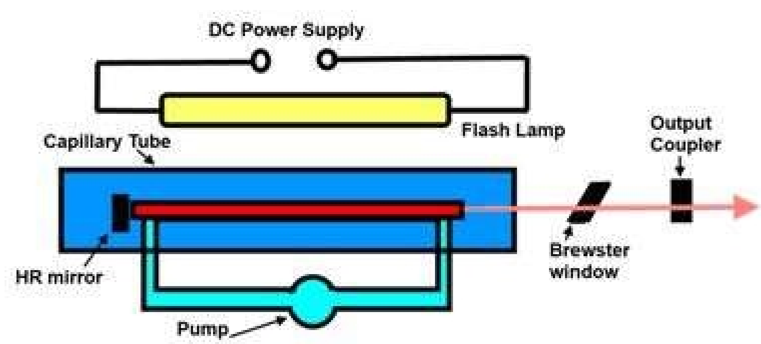

Fig. 5.5 Dye Lasers

5.1.1.3 Solid-State Lasers

Ruby Laser

The first laser was indeed a solid-state laser: Ruby emitting at 694.3nm. Ruby consists of the naturally formed crystal of aluminium oxide (Al2O3) called corundum. In that crystal some of Al^{3+} ions are replaced by Cr^{3+} ions. It's the chromium ions that give Ruby the pinkish colour, i.e., its flourescence, which is related to the laser transisitons.

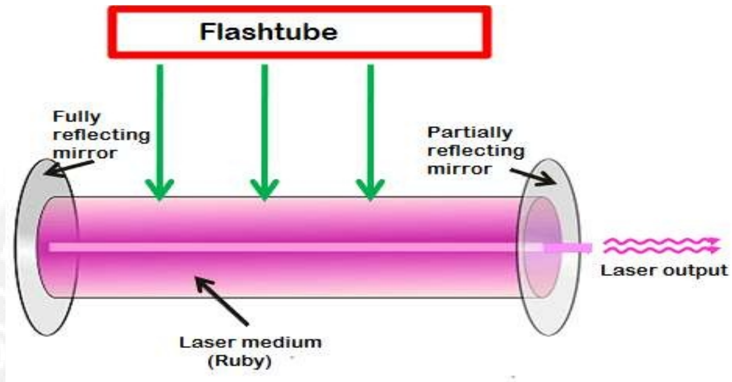

Fig. 5.6 Ruby Laser

Neodymium YAG (Nd: YAG)

Neodymium YAG consists of Yttrium-Aluminium-Garnet (YAG) $Y_3Al_5O_{12}$ in which some of the Y^{3+} ions are replaced by Nd^{3+} ions. Neodymium is a rare earth element, where the active electronic states are shielded inner 4f states. Nd: YAG is a four-level laser. The main emission of Nd: YAG is at 1.064µm. Another line with considerable less gain is at 1.32µm. Initially Nd: YAG was flashlamp pumped. Today, much more efficient pumping is possible with laser diodes and diode arrays. Diode pumped versions which can be very compact and efficient become a competition for the CO_2 laser in material processing, range finding, surgery, pumping of other lasers in combination with frequency doubling to produce.

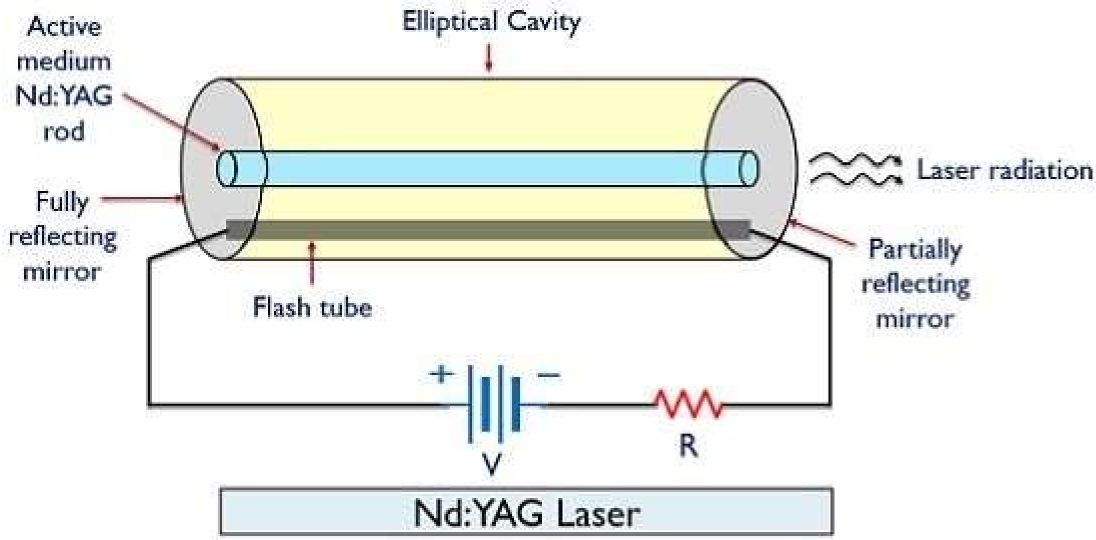

Fig. 5.7 Neodymium YAG laser

Ytterbium YAG

Ytterbium YAG is a quasi-three level laser, see Figure 303 emitting at 1.030μm. The lower laser level is only 500-600cm1 (60meV) above the ground state and is therefore at room temperature heavily thermally populated. The laser is pumped at 941 or 968nm with laser diodes to provide the high brightness pumping needed to achieve gain.

However, Yb:YAG has many advantages over other laser materials:

- Very low quantum defect, i.e. difference between the photon energy necessary for pumping and photon energy of the emitted radiation, (hfP - hfL) /hfP ˜ 9%.
- long radiative lifetime of the upper laser level, i.e. much energy can be stored in the crystal.
- high doping levels can be used without upper state lifetime quenching
- broad emission bandwidth of Δ_{fFWHM} =2.5THz enabling the generation of sub picosecond pulses.
- with cryogenic cooling Yb: YAG becomes a four-level laser.

Due to the low quantum defect and the good thermal properties of YAG, Yb: YAG lasers approaching an optical-to-optical efficiency of 80% and a wall plug efficiency of 40% have been demonstrated.

Titanium Sapphire (Ti:sapphire)

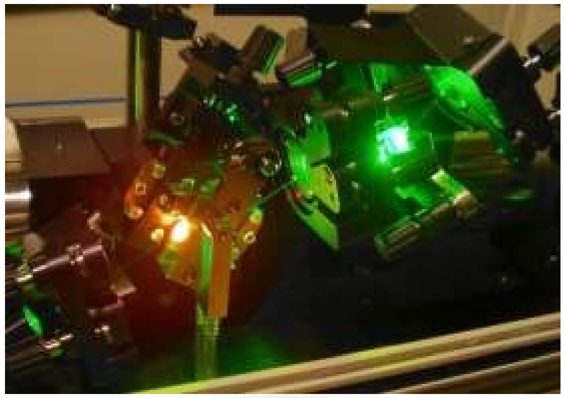

Fig. 5.8 Titanium Sapphire laser

In contrast to Neodymium, which is a rare earth element, Titanium is a transition metal. The Ti^{3+} ions replace a certain fraction of the Al^{3+} ions in sapphire (Al2O3). In transistion metal lasers, the laser active electronic states are outer 3s electrons which couple strongly to lattice vibrations. These lattice vibrations lead to strong line broadening. Therefore, Ti:sapphire has an extremely broad amplification linewidth $\Delta f_{FWHM} \approx 100THz$. Ti:sapphire can provide gain from 650-1080nm. Therefore, this material is used in today's highly-tunable or very short pulse laser systems and amplifiers. Once Ti:sapphire was developed it rapidly replaced the dye laser systems.

5.1.1.4 Semiconductor Lasers

An important class of solid-state lasers are semiconductor lasers. Depending on the semiconductor material used the emission wavelength can be further refined by using band structure engineering, 0.4 µm (GaN) or 0.63-1.55 µm (AlGaAs, InGaAs, InGaAsP) or 3-20 µm (lead salt). The AlGaAs based lasers in the wavelength range 670nm-780 nm are used in compact disc players and therefore are the most common and cheapest lasers in the world. In the semiconductor laser the electronic band structure is exploited, which arises from the periodic crystal potential, see problem set.

There is usually a highest occupied band, the valence band and a lowest unoccupied band the conduction band. Electronics states in a crystal can usually be characterized by their quasi-momentum k.

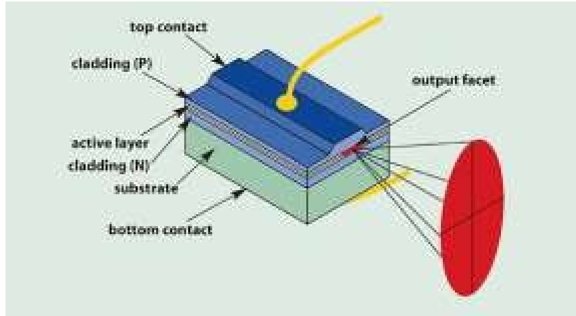

Fig. 5.9 Semiconductor Lasers

3=5.1.1.5 Quantum Cascade Lasers

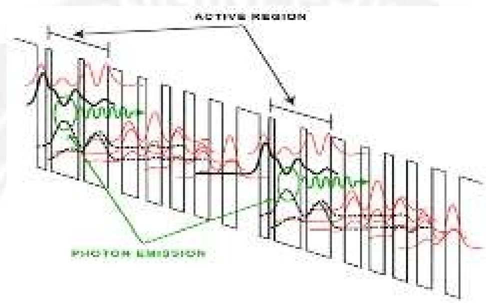

Fig. 5.10 Semiconductor Lasers

A new form of semiconductor lasers was predicted in the 70's by the two russian physicists Kazarinov and Suris that is based only on one kind of electrical carriers. These are most often chosen to be electrons because of there higher mobility. This laser is therefore a unipolar device in contrast to the conventional semiconductor laser that uses both electrons and holes. The transitions are intraband transistions.

5.2 Laser in Metrology

Metrology lasers are low power instruments. Most are helium-neon type. Wave output laser that emits visible or infrared light. He-Ne lasers produce light at a wavelength of 0.6μm that is in phase, coherent and a thousand times more intense than any other monochromatic source. Laser systems have wide dynamic range, low optical cross talk and high contrast. Laser fined application in dimensional measurements and surface inspection because of the properties of laser light. These are useful were precision, accuracy, rapid non-contact gauging of soft, delicate or hot moving points.

5.2.1 Advantages of Laser in Metrology

Compared to conventional contact measurement, laser measurement needs few moving parts to manipulate the part or the contact device. It will increase the durability and of any manufacturing cell.

The advantages of lasers in metrology applications can be summarised as follows:

i. High precision and accurate measurement are possible.
ii. Improvement in quality of manufacturing is ensured as absolute references are used for measurements.
iii. Fast data acquisition is possible without the potential distortion.
iv. There are no contact and hot moving parts. Hence, it ensures higher durability and longevity.
v. Laser instruments have few moving parts. Hence, it leads to less wear and tear.

5.2.2 Lasers Scan Micrometers

Micrometers are measurement tools for making fine measurements. The most common micrometers have a C-shaped frame with a calibrated screw that can be used to extend or contract a spindle to a known distance. The object to be measured is placed between the frame and spindle and the spindle closed until it is held securely.

Manual micrometers are easy-to-use and can provide measuring accuracies of ~ 0.01 mm. However, a micrometer screw gauge is not accurate enough for many applications. Instead, for very high accuracy measurements, a laser micrometer can be used.

A laser micrometer works by scanning a laser beam between an emitter and a receiver. The laser beam is scanned at a constant speed and any object in the beam will cause a shadow for an amount of time proportional to its size. By counting the amount of time the receiver does not receive light and knowing the scan speed, it is then possible to calculate the object's size.

The advantages of laser scan micrometers are their accuracy, fast scan speeds and relative ease of operation. Laser micrometers can be used for object sizing and as helpful auxiliary tools in measurement – such as measuring the displacement of delay stages more precisely

5.2.3 Applications of Laser Micrometers

- One of the key applications of laser micrometers is for non-contact testing.
- The ability to perform two-dimensional and higher scans with laser micrometers means they can be used to reconstruct an object in multiple dimensions.
- The ability to rapidly scan objects without interrupting any industrial processing means on-the-fly feedback systems can be implemented for advanced process control.
- The high spatial resolution of laser micrometer measurements makes them ideal for complex manufacturing tasks that demand a high degree of precision.

5.3 APPLICATIONS OF LASER IN MEASUREMENT

5.3.1 LASER TELEMETRIC SYSTEM

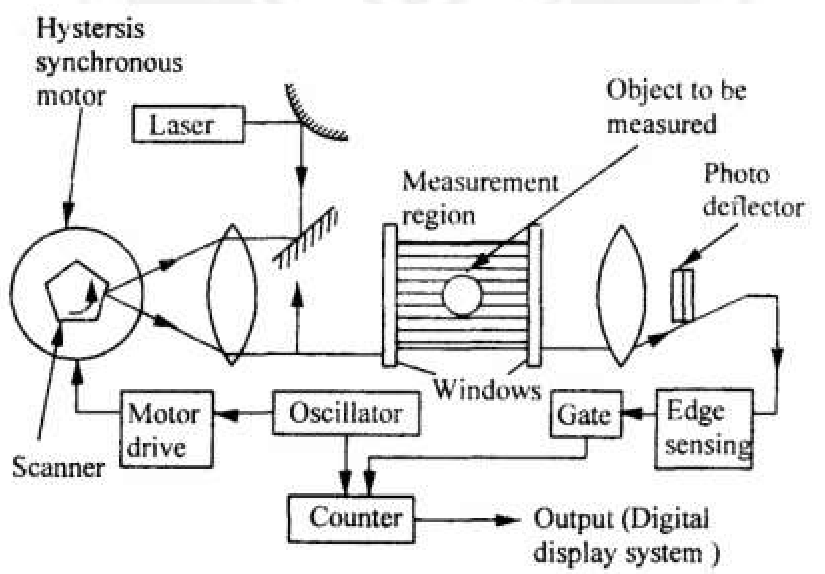

Fig. 5.11 Laser Telemetric System

Construction:

The Laser telemetric system consist of three components.

- Transmitter
- Receiver
- Processor electronics

Laser telemetric system is a non-contact gauge that measures with a collimated laser beam. It measures at the rate of 150 scans per second. It basically consists of three components, a transmitter, receiver and processor electronics. The transmitter module produces a collimated parallel scanning laser beam moving at a high, constant, linear speed. The scanning beam appears as a red line. The receiver module collects and photoelectrically senses the laser light transmitted past the object being measured. The processor electronics takes the received signals to convert them to a convenient form and displays the dimension being gauged.

The transmitter contains a low-power helium-neon gas laser and its power supply, a specially designed collimating lens, a hysteresis synchronous motor, a mutli-faceted reflector prism, a synchronous pulse photodetector and a protective replaceable window. The high speed of scanning permits on-line gauging and thus it is possible to detect changes in dimensions when components are moving or a continuous product such as in rolling process moving at very high speed. There is no need of waiting or product to cool for taking measurements.

This system can also be applied on production machines and control them with closed feedback loops. Since the output of this system is available in digital form, it can run a process controller, limit alarms can be provided and output can be taken on digital printer. It is possible to write programs for the microprocessor to take care of smoke, dust and other airborne interference around the workpiece being measured.

ADVANTAGES

- It is possible to detect changes in dimensions when the product is in continuous processes.

- It can be applied on production machines and controlled then with closed feedback loops.

5.3.2 Laser Scanning Gauge

The scanning laser gauge is used for dimensional measurements.

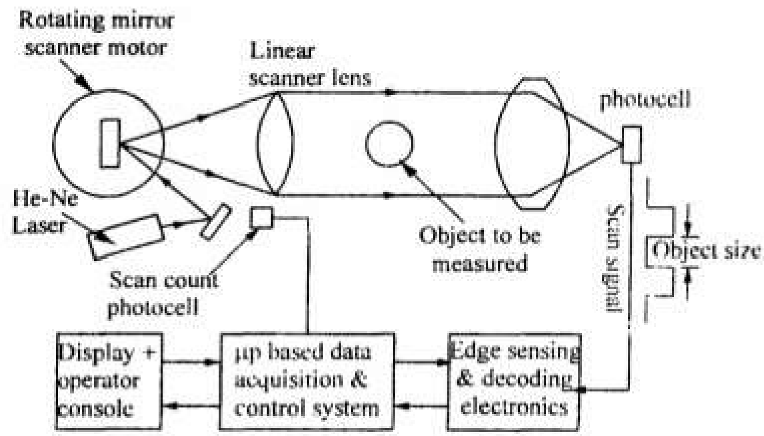

Fig. 5.12 Laser Scanning Gauge

Metrology lasers are low-power instruments. Most are helium-neon continuous-wave output lasers that emit visible or infrared light. He-Ne lasers produce light at a wavelength of 6328 A (0.6 pi) that is in phase, coherent, and a thousand times more intense than any other monochromatic source.

Laser inspection systems enable measurement of a part as it is produced, thus permitting 100% quality. Laser systems have wide dynamic range, low optical cross talk, and high contrast.

Lasers find applications in dimensional measurements and surface inspection because of the properties of laser light (bright, unidirectional, collimated beam, with a high degree of temporal and spatial coherence). These are useful where precision, accuracy, rapid non-contact gauging of soft, delicate, hot or moving parts is called for.

Various technique for dimensional measurements are:

It basically utilises a transmitter, receiver and processor electronics. A thin band of scanning laser light is made to pass through a linear scanner lens to render it parallel beam. The object placed in a parallel beam, casts a time-dependent shadow. Signals from the light entering the photo cell (receiver) are processed by a microprocessor to provide display of the dimension represented by the time difference between the shadow edges. It can provide results to an accuracy of + 0.25 um for 10-50 mm diameter objects. It can be used for objects 0.05 mm to 450 mm diameter and offers repeatability of 0.1 um.

5.3.3 PHOTODIODE ARRAY IMAGE

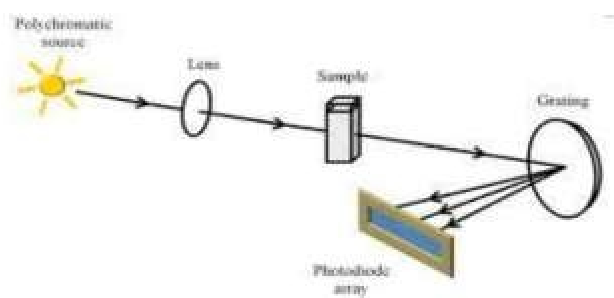

Fig.5.13 Photodiode Array Image

In this method, shadow of stationary part is projected on a solid-state diode array image sensor. The system comprises of laser source, imaging optics, photodiode array, and signal processor and display unit. For large parts, two arrays, one for each edge are used. Accuracies as high as + 0.05 um have been achieved.

A Photodiode Array Detector is a microprocessor controlled multi-channel detector that permits simultaneous access to spectral data for several wavelengths simultaneously. In comparison the conventional UV-Visible detector has only a single channel detector.

Simultaneous multi-wavelength measurement

In a conventional spectrophotometer a single wavelength is recorded at any given point of time. On the other hand all wavelengths can be measured simultaneously in the diode array detector and this feature is a great time saver when several wavelengths are to be monitored simultaneously.

Wavelength precision

The required wavelength is selected on a conventional spectrophotometer either manually or using a stepper motor. On the other hand in the photodiode array data is acquired at each wavelength simultaneously. This eliminates repeatability errors that result from mechanical wear of moving parts.

High sensitivity

Diode array systems have fewer optical surfaces as a result of which the light throughput is high and results in improved sensitivities. An added benefit is time averaging feature to get several fold improvements of spectral sensitivity.

Minimal Stray Light

A photodiode array spectrophotometer has reverse optics design which minimizes stray light which is a common interfering component in conventional spectrophotometers. In case of photodiode array system, the sample is placed before the polychromator (reverse optics) whereas in case of conventional spectrophotometer sample is positioned after the monochromator. As the measurements are unaffected by stray light observations can be made with the sample chamber open without interference from outside light. This feature also permits analysis on a wider range of sample sizes and use of special sampling accessories

Ruggedness

The reliability and ruggedness is higher for photodiode array detector due to absence of moving parts and mechanical simplicity. This also eliminates virtually need for maintenance or re-calibration. As photodiode array detector is a solid-state device it is more reliable and secure than the photomultiplier tube. A polychromator gives consistent performance as the light dispersion element is locked in its position whereas in case of conventional spectrophotometer scanning requires movement of the grating inside the monochromator.

5.3.4 Diffraction Pattern Technique

These are used to measure small gaps and small diameter parts. In this method, a parallel coherent laser beam is diffracted by a small part, and the resultant pattern is focussed by a lens on a linear diode array. Since diffraction is not suitable for diameters larger than a few millimetres, its use is restricted to small wires, etc. The measurement accuracy is more for smaller parts. The distance between the alternating light and dark bands in the diffraction pattern is a direct function of the wire diameter, wavelength of laser beam, and the focal length of the lens.

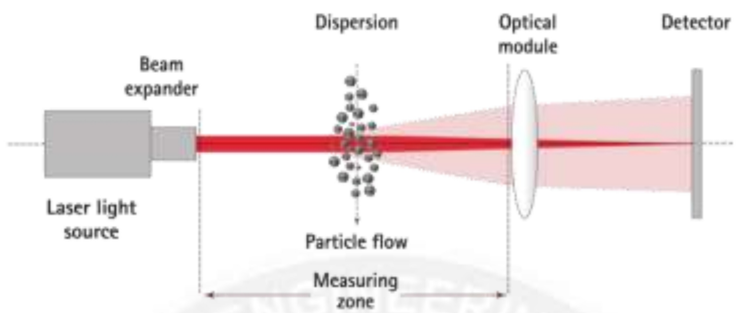

Fig. 5.14 Diffraction Pattern Technique

5.3.5 Laser Triangulation Sensors

In this sensor a finely focused laser of light is direct at the part surface and this light comes from the laser source.

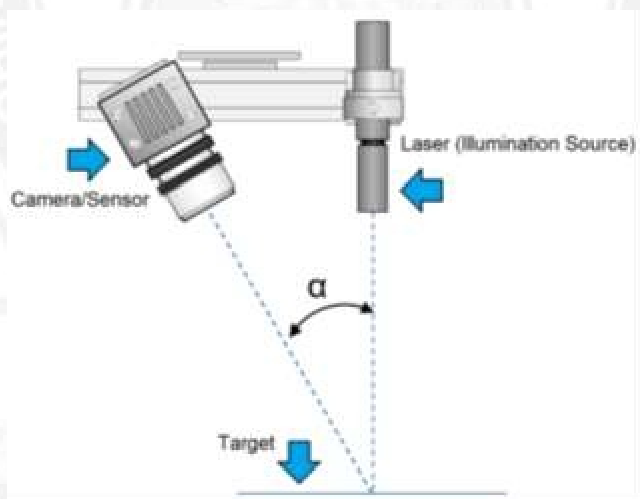

Fig. 5.15 Laser Triangulation Sensors

Laser Triangulation is a machine vision technique used to capture 3-dimensional measurements by pairing a laser illumination source with a camera. The laser beam and the camera are both aimed at the inspection target, however by adopting a known angular offset (α) between the laser source and the camera sensor, it is possible to measure depth differences using trigonometry.

The red, green, and blue dotted lines in Figure 2 illustrate how the reflected laser light will strike different sensor locations, depending on the distance between the laser source and the inspection target (or "surface"). Notice that the position where the reflected laser light strikes the sensor's surface is dependent on the vertical offset of the target from the laser/camera assembly. In other words, as the distance between the laser light source and inspection point changes, so changes the location on the sensor where the light is detected. Changes from the nominal vertical distance will produce proportional changes in position (d') at the sensor. Larger changes in vertical distance will result in a larger positional deflection at the sensor.

Advantages:

- Quick measurement of deviations is due to change in surface.
- it can perform automatic calculation on shell metal stampings.

Two- frequency laser interferometer

This consists of two frequency laser head, beam directing and splitting optics, measurement optics, receivers, and wavelength compensators and electronics. It is ideally suited for measuring linear positioning straightness in two planes, pitch and yaw.

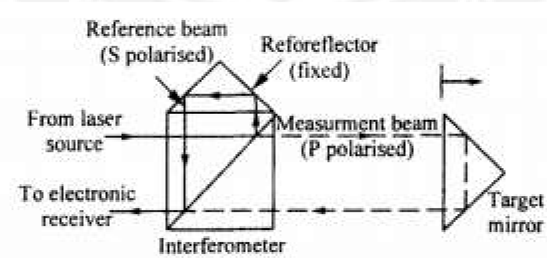

Fig. 5.16 Two- frequency laser interferometer

The two-frequency laser head provides one frequency with P-polarization and another frequency with S-polarization. The laser beam is split at the polarizing beam splitter into its two separate frequencies. The measuring beam is directed through the interferometer to reflect off a target mirror or retro reflector attached to the object to be measured. The reference beam is reflected from fixed retro reflector. The measurement beam on its return path recombines with the reference beam and is directed to the electronic receiver.

Gauging wide diameter from the diffraction pattern formed in a laser

Figure shows a method of measuring the diameter of thin wire using the interference fringes resulting from diffraction of the light by the wire in the laser beam. A measure of the diameter can be obtained by moving the photo detector until the output is restored to its original value. Variation in wire diameter as small as 0.2% over wire diameter from 0.005 to 0.2mm can be measured.

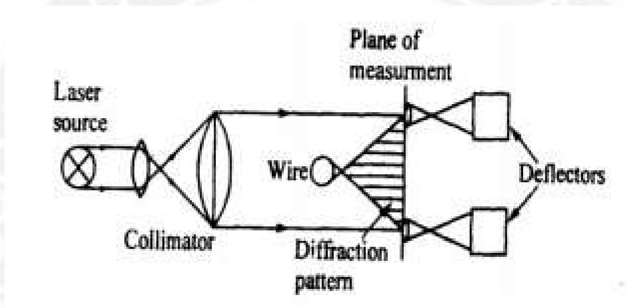

Fig. 5.16 Diffraction Pattern

Figure shows the length measurement by fringe counting. The laser output, which may be incoherent illumines three slits at a time in the first plane which form interference fringes. The movement can be determined by a detector. The total number of slits in the first plane is governed by the length over which measurement is required.

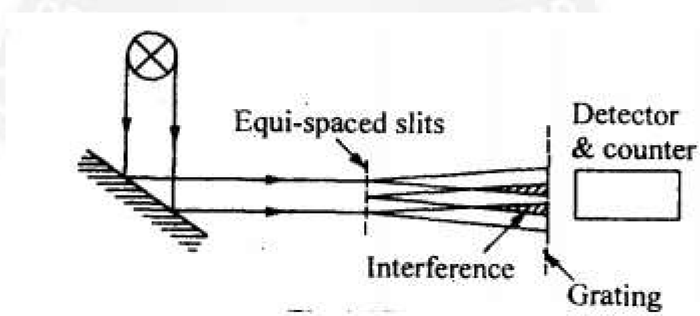

Fig. 5.16 Laser interferometer

The spacing between the slits and distance of the slit to the plane of the grating depend on the wavelength of the light used.