Chapter 14

Laser based Instrumentation

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14.1 Introduction

Laser based instrumentation deals with the design and development of instruments that use laser for sensing a physical parameter or variable. Laser is an excellent tool in instrumentation as it offers the advantage of non-contact, non-destructive and fast measurement. Laser based instruments are replacing many conventional measuring instruments in industrial and scientific areas, at the same time also finding new applications. Laser is actually a light beam with a special property of coherence. Due to this special property, laser exhibits characteristics like high degree of collimation, high intensity, sharp focus, monochromaticity etc. One or more of these characteristics is/are utilized to develop an instrument.

A laser based instrument consists of following important components:

- Optoelectronic components like laser, photodetector
- Optical components like lens, mirror and other such components
- Optomechanical components for precisely mounting optical and optoelectronic components and aligning them
- Electronic components for processing of photodetector output, computation of result and user interface through keyboard and display.

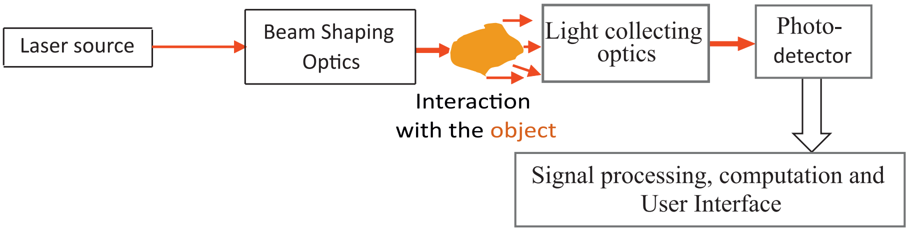


Figure 14.1: Generalized block diagram of a laser based instrument.

In a typical laser based instrument, the laser source produces laser beam that is suitably shaped and directed towards the object on which measurement is to be performed. Laser beam could be continuous wave (CW) or pulsed depending on the application i.e. if low power is sufficient for an application then CW laser of mW power could be used while when high power is required then pulse laser is used which gives very high peak power, could be in mega or giga watts. Laser interacts with the object and then scattered/reflected/transmitted light is collected by the receiving optics, which directs/focuses it on to the photodetector. The photodetector converts optical signal into electrical signal, which is processed by the electronic circuit to compute the result. Electronic circuit can also interact with the user through keyboard and display and at the same time transmit data to a data-logging device.

The most commonly used laser for instrumentation is a semiconductor diode laser because of its compact size, low cost, low power requirement and availability at various wavelengths; in fact diode lasers are behind the rapid growth of laser based instrumentation. Diode laser is used in module form, which along with semiconductor diode also carries beam shaping optics and driving electronic circuit, thus making it easy to operate and use. A laser pointer used by a speaker during his/her presentation is a typical example of diode laser module. Special beam shaping optics to produce line (sheet), cross-hair, ring, dot patterns from laser beam have been developed and can be integrated in a diode laser module which makes them structured light source. Due to these special optics, diode lasers are finding new applications in instrumentation.

Photodetector used in a laser based instrument may be one or more of the following opto-electronic component(s): photoresistor, photodiode, phototransistor, avalanche photodiode, position sensitive detectors (linear and segmented), photo-multiplier tube (PMT). To detect fast signals with ns rise time, small active area photodiode having diameter of 0.5 mm or less is useful as the size of active area determines its capacitance. Small active area means lower capacitance enabling faster response. For low intensity (nano-watt to pico-watt) detection, a PMT or avalanche photodiode is preferred. Different types of photodetectors are commercially available from M/s OSI Inc. and M/s Hamamatsu Inc. Photodiodes of different active area sizes are also indigenously developed by Electronics Division, BARC.

The electronic circuit, which processes the output of photodetector, typically consists of amplifiers, filter, ADC/counter, logic circuit, microcontroller/microprocessor/PC, keyboard and display. The required software for performing the calculation and interfacing with the user runs on the processor and can be developed in either assembly language or high level language.

Optical techniques are more useful generally in hazardous and toxic environment where human intervention is very difficult. Among the large number of laser based optical techniques, few of the following will be discussed now:

- Pulse shadow technique for diameter measurement;
- Specular reflection technique for surface roughness measurement;
- Time of flight technique for projectile speed measurement and particle image velocime-

try (PIV);
- Optical triangulation technique for distance/displacement/vibration measurement;
- Interferometric techniques for Vibration measurement.

14.2 Pulse Shadow Technique based Diameter Measurement

Measurement of dimension through laser based technique can also be used when continuous monitoring and in situ control of product dimension is required. Being a non-contact technique, it can also be used for measurement of soft and flexible objects like rubber tubes, enameled wire etc.

A narrow beam of light from laser diode scans a vertical plane using a rotating mirror mounted on the shaft of a DC motor and collimating lens (plano-convex), with the point of reflection being the focal point of the collimating lens (Fig. 14.2 and photograph of the instrument shown in Fig. 14.3). Thus any beam after reflection from mirror and emerging from collimating lens during scan time, becomes parallel to the optical axis of the lens. It is as if a horizontal beam is moving vertically in the measuring plane, at the rate proportional to the motor's rotational speed. A cylindrical object kept horizontally in the measuring plane, perpendicular to the vertical scanning beam (in Fig. 14.2 seen as perpendicular to the plane of paper), cause obstruction of the scanning beam for the time proportional to the

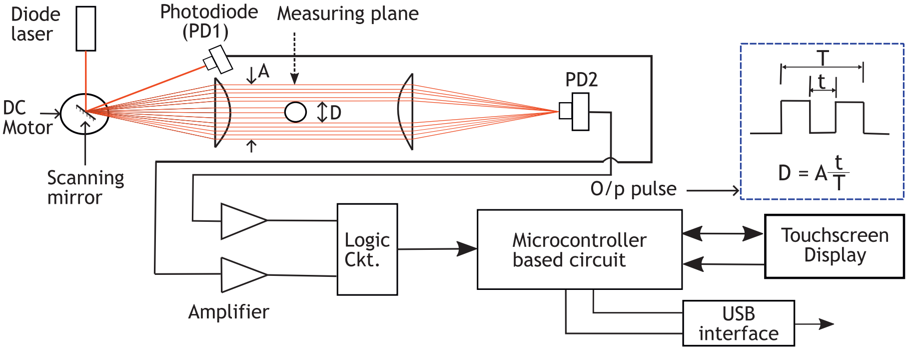


Figure 14.2: Schematic of laser based diameter measurement.

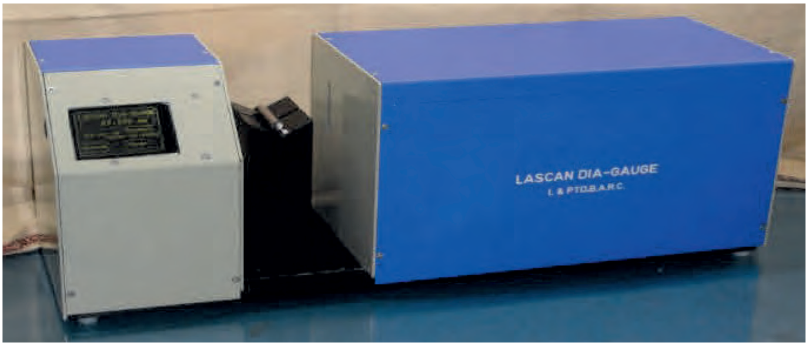


Figure 14.3: Photograph of laser scan Dia-Gauge.

diameter of the object [151]. The scanning beam is then focused by a receiving lens on a photodiode, the output of which generates shadow pulse of the object. The shadow pulse width 't' and the total scan time 'T' are measured using a high speed electronic counter. As shown in the Fig. 14.2, the ratio of the two when multiplied by the aperture 'A' of the lens gives the diameter 'D' of the object. A microcontroller based circuit can be used to calculate the diameter and interface with user through display and keyboard. Data can be transmitted through serial interface to PC for logging purpose. Thus the instrument becomes standalone. As the beam becomes parallel after collimating lens, hence the separation between the two lenses can be increased as per requirement (up to 1 meter).

14.2.1 Multipoint diameter measurement

The same scanning technique (14.2) can be used for simultaneous measurement of diameter of a cylindrical object at multiple locations with relevant modifications in the scanning configuration, optics, photodetectors and associated electronics. For diameter measurement at multiple locations of a tube, a laser line is used for scanning the measuring vertical plane (Fig. 14.4). A horizontal collimated laser line when scans the measuring plane, is obstructed by the tube for the time proportional to the diameter of the tube. The scanning line is then bent towards an array of aligned photodiodes, where each photodiode corresponds to a point on the tube. If the photodiodes are spaced at 3 mm intervals, the shadow pulse width of each photodiode output is proportional to the diameter of the tube at 3 mm interval.

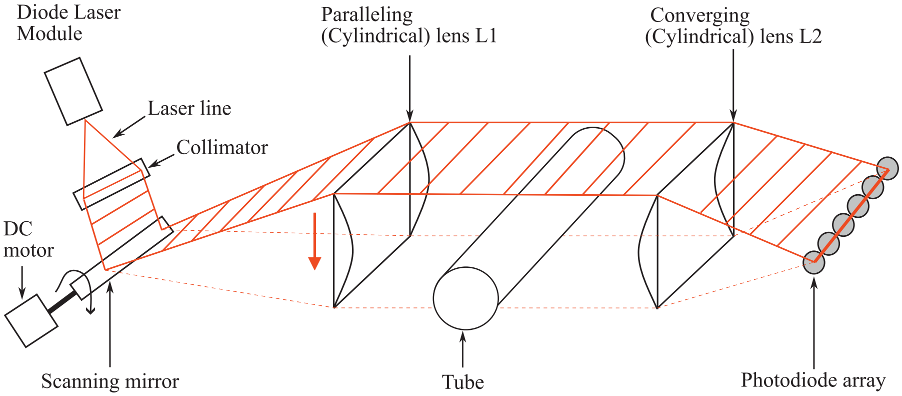


Figure 14.4: Schematic of multipoint diameter measurement.

14.3 Specular Reflection based Surface Roughness Measurement

All surfaces have some degree of unevenness, even if only at the atomic level, which can be expressed in terms of a surface roughness parameter. Average Roughness (R$_a$) of a surface is defined as the average deviation of a surface profile about its mean line [152]:

$$R_a = \frac{1}{L}\int_0^L |y(x)|\, dx \tag{14.1}$$

where x – distance along the surface; y(x) – the height of the surface profile about the mean line; L – Sampling length. Another parameter used for roughness representation is RMS roughness (R_q), also known as σ in optics and statistics, is defined by [152]:

$$R_q = \sqrt{\left[\frac{1}{L}\int_0^L y^2(x)dx\right]} \tag{14.2}$$

R_q is equal to one standard deviation of the profile about the mean line. R_q is always greater than or equal to R_a. The techniques for roughness measurement [152] can be categorised into:

1. Profiling technique and
2. Parametric technique.

In profiling technique such as interferometer based or the diamond stylus based, the surface profile information is obtained by point to point scanning of surface height as a function of distance 'x'. The resulting profile is then analysed to derive the roughness parameters. A parametric technique gives a measurable parameter (like R_a or R_q) of the surface topography averaged over the illuminated area. Parametric techniques are fast and more suitable for routine comparison of similar surfaces. One of the optical parametric techniques for roughness measurement is based on measurement of specular reflectance (Fig. 14.5). Optical RMS roughness, σ_0, of a surface is related with specular reflectance for range of incidence angles (near grazing) by the formula [153]:

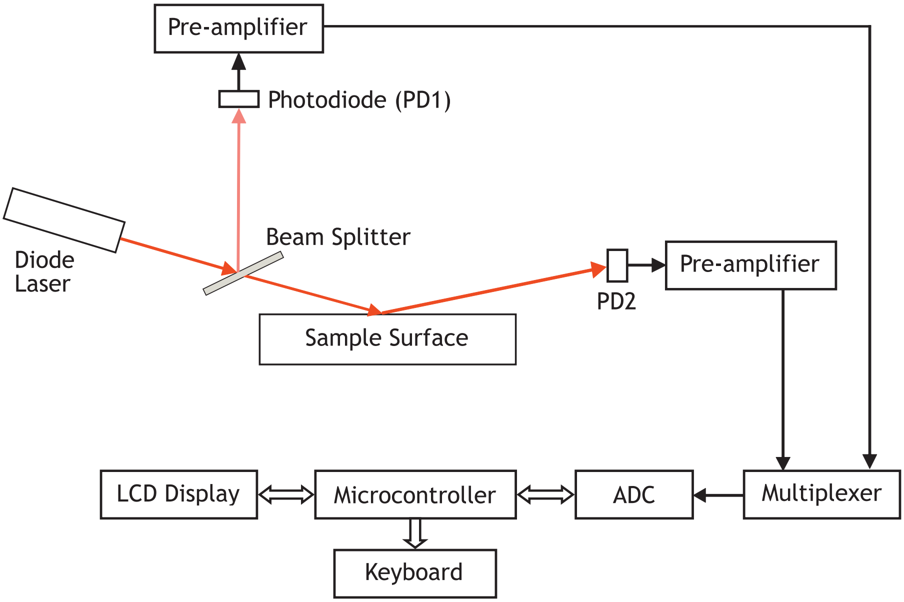


Figure 14.5: Schematic diagram of laser based roughness measuring instrument.

$$\frac{I_x}{I_0} = exp\left[-\frac{4\pi{\sigma_0}^2}{\lambda}\cos^2\alpha\right] \tag{14.3}$$

where I_x = specularly reflected intensity from relatively smooth surface; I_0 = specularly reflected intensity from perfectly smooth surface or incident intensity for near grazing angle of incidence to smooth surfaces; σ_0 = optical RMS roughness; λ = wavelength of the incident beam; α = incident angle. Further from σ_0, value the corresponding value of R_a can be determined using a calibration curve generated from experimental data.

A laser based instrument for roughness measurement uses diode laser and measures incident as well as specularly reflected intensity is shown in Fig. 14.5 (photograph of the instrument is shown in Fig. 14.6). The output of PD1 represents incident intensity and PD2 represents specular reflected intensity. The specular reflection technique is useful for surfaces whose average roughness is very less than the wavelength, λ, of the incident beam [152–156]. Thus a diode laser of 670 nm can be used for measurement of surface R_a less than 0.25 μm.

Figure 14.6: Photograph of laser surf-check.

14.4 Time of Flight based Projectile Speed Measurement and PIV

14.4.1 Laser based projectile velocity measurement

It is based on time of flight principle. A projectile moving horizontally, interrupts two parallel vertical optical screens separated by a distance, D, (Fig. 14.8) and the time between two interruptions is measured by a high speed counter to calculate the speed. The optical screen

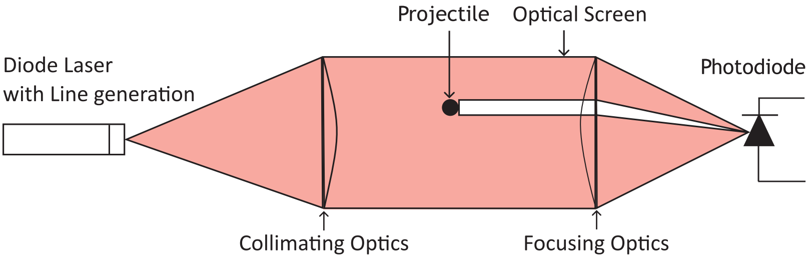


Figure 14.7: Optical screen generation.

is a collimated laser line that is obtained from a diode laser (635 nm, 15 mW) with a uniform intensity line generating optics and a spherical lens for collimation (Fig. 14.7). The size of optical screen takes care of little variations in the path of the projectile. The collimated line is then focused at the receiving unit using a plano-convex lens on a photodiode. The output of the photodiode represents the total intensity of the collimated line. When any projectile crosses the optical screen, it obstructs the intensity of the laser line falling on the photodiode by the value which is proportional to its dimension. The sensitive electronic circuit amplifies this change in the attenuated intensity level and its output is connected to a comparator to generate a shadow pulse. Shadow pulse generated at optical screen-1 gives the start pulse and the one generated at optical screen-2 gives the stop pulse to an electronic counter (Fig. 14.8 and photograph of the instrument shown in Fig. 14.9). Distance (D) between two optical screens is known (can be varied). The count value of the counter, representing time of flight i.e. time taken by the projectile to travel from screen-1 to screen-2 is read by the microcontroller, which then calculates the projectile speed utilizing Eq. (14.4):

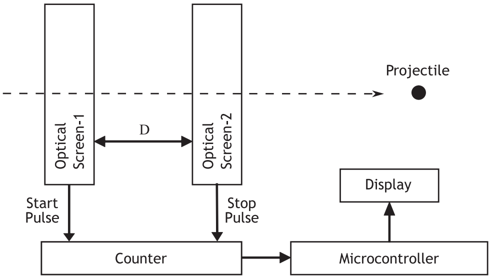


Figure 14.8: Block diagram of the laser velocity meter.

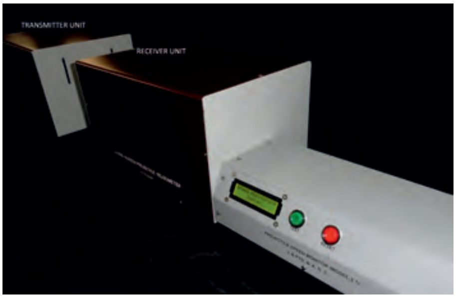


Figure 14.9: Photograph of laser screen projectile velocimeter.

$$S = \frac{D}{C\ T} \tag{14.4}$$

where S is speed; D is the distance between two optical screens; C is no. of counts; T is counter clock period. The ruggedness of the instrument is due to the use of laser line to create the optical screen and use of optics which is larger compared to length of laser line. This instrument can be used for measurement of projectile velocity in material studies.

14.4.2 Rebound velocity measurement

Rebound velocity meter is another instrument to measure an object velocity based on time of flight principle. Unlike the technique described in 14.4.1, here a single narrow sheet of light is used. Here the time taken by the object of known dimension to cross the light sheet is measured to calculate its velocity. The main advantage of this method is that the single optical sheet can be placed very near to the target to measure its instantaneous velocity. The other important feature of the rebound velocity meter is that it can measure falling as well as rebound velocities, calculate their ratios and display them (Fig. 14.10).

The instrument consists of a transmitting unit carrying the laser diode with light sheet optics and a receiving unit carrying the focusing optics with processing electronics as shown in Fig. 14.10. The laser line between transmitter and receiver units forms the horizontal rectangular optical sheet. The laser sheet is generated as shown in Fig. 14.7. Since the laser line is collimated, the separation between the two units can be suitably increased. The collimated line is then focused on a photodiode at the receiving unit using cylindrical lens. The output of the photodiode represents the total intensity of the collimated line. When any

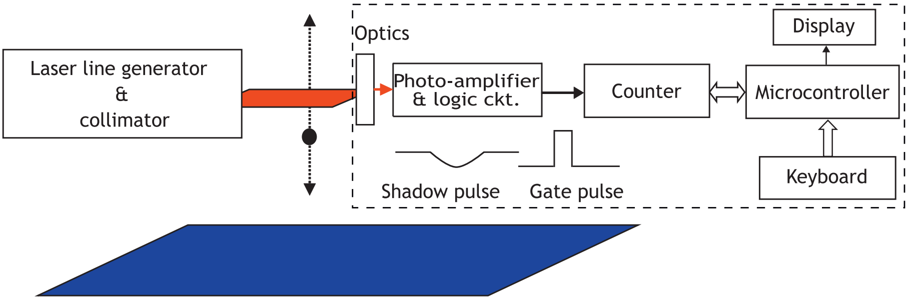


Figure 14.10: Block diagram of the instrument.

projectile crosses the optical screen, it causes a reduction in the intensity of the light falling on the photodiode for the time it is crossing the screen. This change in the intensity level (shadow pulse) generates a TTL pulse which is used as a gate pulse for a high speed counter (Fig. 14.10 and its photograph is shown in Fig. 14.11). The counter measures the width of the pulse. The counter value is acquired by the microcontroller to calculate the speed using Eq. (14.5):

$$S = \frac{D}{N\ T} \tag{14.5}$$

where S is speed; D is Diameter of the object; N is no. of counts; T is Counter clock period. These measurements continue for the falling and first re-bounce of the object and then the logic circuit disables further processing of generated shadow pulse due to multiple passing of the object, if it occurs.

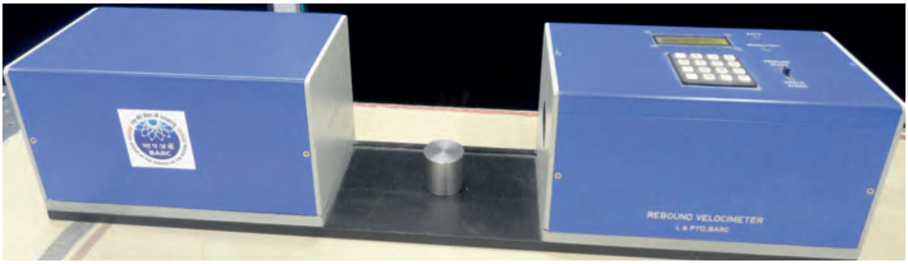


Figure 14.11: Photograph of the rebound velocity meter.

14.4.3 Particle image velocimetry

There are different non-contact methods for measurement of velocity of a fluid flow. Among them, the important optical techniques for flow measurement are:

1. Laser Doppler Anemometry;
2. Particle image velocimetry.

Laser Doppler Anemometry is a single point measurement technique in which the velocity of the fluid is calculated by the measuring the Doppler shift of the laser beam passing through it. However, it has the limitation of single point measurement, due to which spatial dynamics of the flow at a given time cannot be determined. In contrast to that, PIV is an instantaneous whole field measurement technique, which determines spatial flow distribution.

In a PIV setup (Fig. 14.12), light sheet produced from the pulsed laser beam illuminates the tracer particles in a plane, parallel to direction of flow of the fluid and a CCD camera, kept perpendicular to the plane of light sheet, records the positions of particles in that plane. After a fixed delay, second laser pulse illuminates the same plane, generating one more particle image. Two consecutive images thus generated can be stored in the same frame of a digital camera for fast moving fluid if the camera is slow, then calculation of autocorrelation function on the recorded images frame will give the flow velocities at different points. If consecutive images are captured in separate frames (in case of a fast camera or if flow velocity is slow) then velocity vectors can be determined by calculation of cross-correlation function between two images. The triggering of laser pulses is synchronized with the camera operation by the PC to capture the two images. The images are then analyzed in a PC to calculate particle displacements at various points along the flow. The velocity at each point is determined using formula, S = D/T; where 'S' is velocity of the particle at that point, 'D' is the particle displacement during time interval 'T' (delay between the two laser pulses). Nd:YAG Q-switched pulse laser is of nanosecond pulse width is commonly used to illuminate the tracer particle. The tracer particles also known as seeding particles are silver coated glass particles of about 20 μm size. These are neutrally buoyant particles and using them, complete velocity field of the flow can be determined, if there are enough seeding particles in the area of flow being imaged. Most important aspect of PIV is that it provides velocity field which is near-instantaneous. PIV provide valuable quantitative information in addition to all the advantages of a flow visualization method.

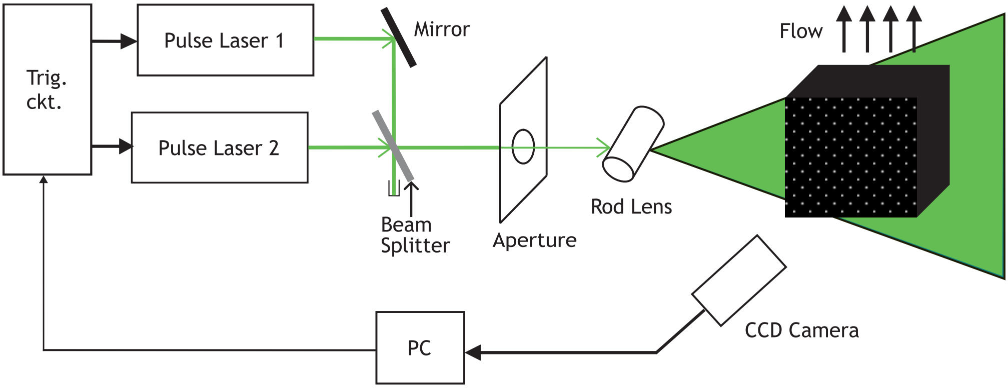


Figure 14.12: Schematic diagram of PIV setup.

14.5 Optical Triangulation based Measurements of Distance/Displacement/Vibration

The optical triangulation technique uses geometry of a triangle to calculate the displacement of a target. The three points of a triangle in it are light source (LASER), reflecting surface of the target and the detector. Using the symmetric triangle formula, displacement of the surface (Δ) is determined by measuring the displacement of focused spot (δ) on the detector (Fig. 14.13). In this technique, a laser beam falls on the surface of a target. The target scatters back light in many directions, some of the back scattered light is captured by a lens and focused on to a detector. The position of the focused light onto the detector depends on the distance between the lens and target. The lens-object distance is calculated using symmetrical triangles formed between surface, lens and detector. An accuracy of better than

0.5% can be obtained. Real-time study of moving or vibrating objects can be done as the measurement takes few milliseconds. The light source should be compact and should produce an intense, small spot of light with minimal divergence. In order to avoid the effect of ambient light, amplitude modulation of light source can be done. Preferred light source for triangulation sensors is diode laser as it gives collimated beam in both visible and near infrared wavelengths, which can be modulated easily. A triangulation based optical probe typically consists of a laser diode module, a focusing lens and a linear position sensitive detector. There are two configurations in which optical triangulation technique can be implemented.

14.5.1 Laser falling normal to the surface

The ray diagram and the schematic of the optical probe is shown in Fig. 14.13. The probe is oriented in such a way that the laser beam falls perpendicular to the plane of surface whose position is to be determined. As the surface moves vertically, the image spot on the linear position sensitive detector (PSD) proportionately moves horizontally. The relation between the two motions is (Fig. 14.13):

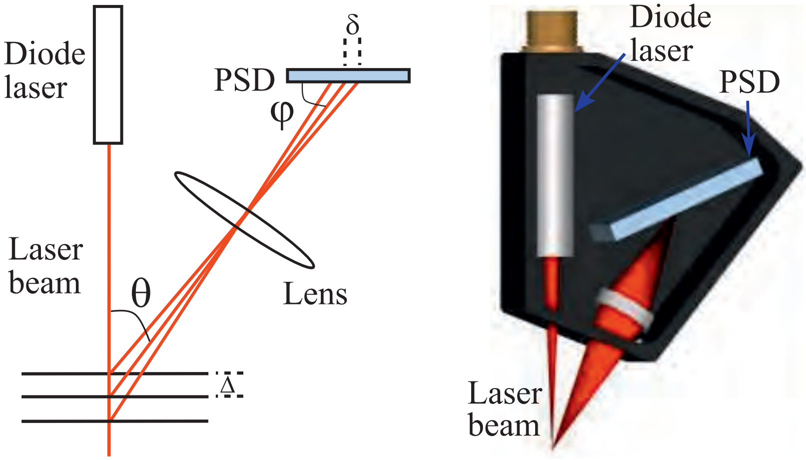


Figure 14.13: Schematic of optical triangulation based sensor (left), and its 3D layout (right).

$$\delta = m\frac{sin\theta}{sin\varphi}\Delta \tag{14.6}$$

where δ is movement of laser spot on PSD; Δ is displacement of the target; m is the magnification of the lens; θ is the angle between the laser beam and the optical axis of the lens; φ is angle between the detector and the optical axis. The output of PSD is amplified by a configuration of amplifiers and then converted to digital value using ADC. These values are read by PC or microcontroller to calculate δ and then using Eq. (14.6), the value of Δ is determined for known values of m, θ and φ. The position sensitive detector has an accuracy of 0.2% of the spot size. This corresponds to an accuracy of 2 μm for a spot size of 1 mm. Averaging of successive readings enhances the measurement accuracy. The linear region of the PSD limits the total range. This is about 75% of the PSD length.

14.5.2 Laser falling oblique to the surface

Laser beam from a diode laser falls on the target at an inclined angle and the backscattered light is captured by focusing optics whose axis is normal to the surface. The captured light is focused on a PSD as shown in Fig. 14.14 (and photograph of the instrument is shown in Fig. 14.15). Due to similarity of triangle, position of focused spot on the PSD is related to the distance of the target from the lens. The detector is positioned normal to the optical axis of the lens. As the object displaces vertically (vibrates), the image spot on the linear detector proportionately moves. The relation between the two motions is:

$$\Delta = \frac{\delta.\sin\varphi(L_0)}{L_i.\tan\theta + \delta.\cos\varphi.\tan\theta + \delta.\sin\varphi} \tag{14.7}$$

where L_0 is the standoff distance or distance between lens and target; L_i is the image distance = 2 f, with f as focal length of the lens; θ is the angle between the laser beam and the optical axis of the lens; φ is angle between the plane of detector and the optical axis; δ displacement of the focus spot from center of PSD; Δ displacement of the target from standoff distance.

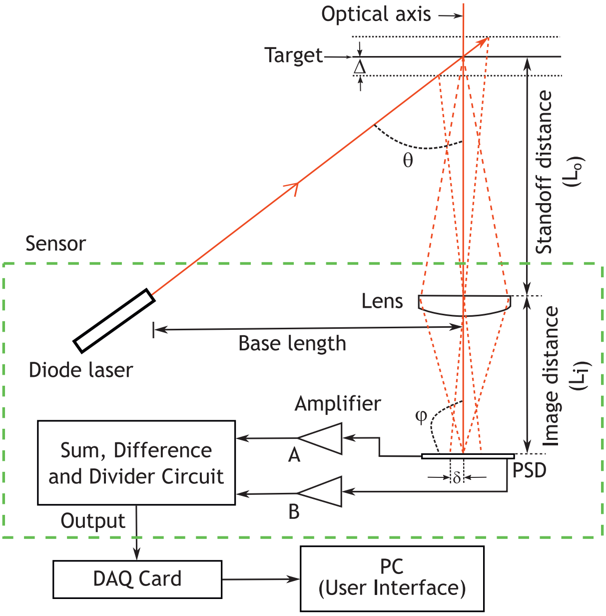


Figure 14.14: Schematic of optical triangulation based vibrometer.

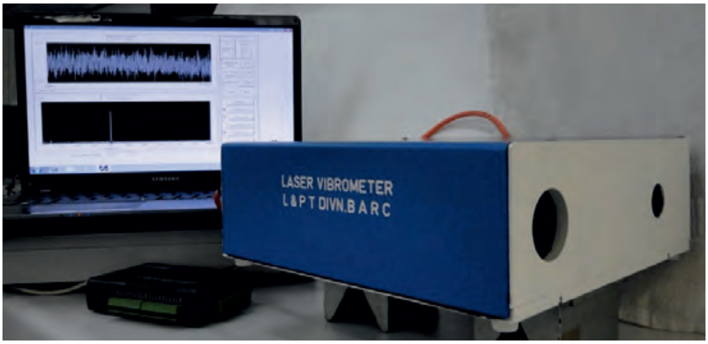


Figure 14.15: Photograph of laser vibrometer.

As the scattered light converge on the PSD, the position of the laser spot on the PSD is given by:

$$\delta = \frac{A - B}{A + B} \times \frac{L}{2} \tag{14.8}$$

where A and B are the voltages proportional to the output currents at two ends of PSD and L is the length of the active area on the PSD. Thus δ is measured electronically and corresponding Δ is calculated using Eq. (14.7): If $\varphi = 90°$, $\theta = 45°$, $L_i = L_o$ with $L_o = 2f$ and $\delta \ll L_i$, then Eq. (14.7) reduces to:

$$\delta \approx \Delta \tag{14.9}$$

Thus the output voltage signal of the sensor is proportional to the displacement of the target from its center position.

14.5.3 Vibration measurement

Vibration can be measured using a triangulation probe which records displacement as a time varying signal, Δ calculated from Eq. (14.7) gives amplitude of vibration and frequency of the displacement signal gives vibration frequency. This signal generated at the output of sensor in Fig. 14.14, can be used to extract the vibration amplitude Δ and vibration frequency of the object using suitable software on PC. It can also be used for level measurement in a place where other methods cannot be used like in a high temperature, vacuum, narrowly accessible target location. The optical triangulation probe can also be used to replace the mechanical touch probe of a CMM. The probe can be used to register reference surfaces in precision motion. Two of these optical probes can be counterpoised to measure the thickness of various materials. Since there is no mechanical contact involved, this can be used to monitor moving objects e.g. metal plates being extruded etc.

14.5.4 Fueling machine tilt measurement system

This is another application of optical triangulation technique. In a Pressurized Heavy Water Reactor (PHWR), the fuel handling system performs on-line refueling frequently. For this, precise alignment of the End Fitting of the coolant channel with the Fueling Machine head within a tolerance band is required. Traditionally, LVDT based contact sensors are being used, which is time consuming, and can cause damage to the coolant channel due to operator's misjudgment. The optical triangulation based non-contact tilt measurement sensor in quad sensor configuration is all fiber solution to measure tilt in X & Y directions. It provides the last mile solution in the alignment process in radiation environment.

Sensor design

The sensor consists of a laser, lens and a collinear optical fiber bundle. The PSD in Fig. 14.14 is replaced by a collinear optical fiber array. The triangulation geometry is configured to measure at 70 mm standoff distance and in the range of ±10 mm. Collinear optical fiber bundle is 20 element fused fibers with 135 μm pitch, its one end is connected to the imaging optics and other end to the camera at remote location. The laser is coupled to the sensor using fiber optics and GRIN lens fiber collimator. The image obtained by the camera is processed by the controller to find the location of the centroid of the laser using a Fourier series based algorithm. The sensor provides position of the coolant channel with reference to fuelling machine. Figure 14.16 shows the block diagram of tilt measurement system for alignment of Fuel Machine with the end fitting of the coolant channel. Four units of the sensor are required to measure the x-tilt and the y-tilt value unambiguously.

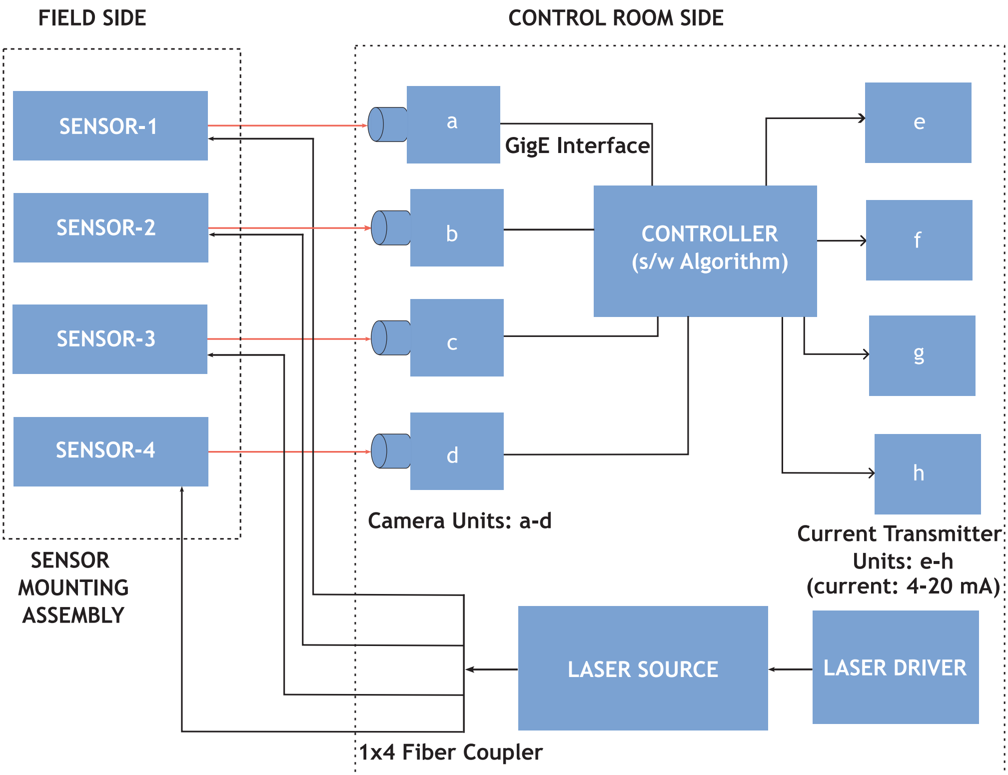


Figure 14.16: Block diagram of the tilt measurement system. Here, about 50 m length fiber-optic cable each is used for control room to field sides.

14.5.5 Surface profile measurement system

Here a non-contact depth measurement system for metrology of various industrial components is described. The system uses line triangulation technique with an imaging system to measure the precise depth profiles of component under test and thus it can be used to check the tolerance margins for acceptance / rejection criteria.

Working principle

Triangulation is a commonly used technique for determining spatial relations. Laser triangulation is an Active Structured Light (ASL) technique, in which a laser dot (in case of point triangulation) is observed (through a lens) by a line sensor. The position of the laser spot on the sensor is related to the position of the surface (along the beam) by using triangulation. In case of line triangulation, a laser line generator is used instead of point source as it produces a line on the surface being inspected. The image of this line is captured using a CCD area scan camera. The laser line falls on the surfaces at an oblique angle and creates an image on camera in which the areas where the object is lower, the beam is slightly shifted. By image processing, this displacement of the bright laser lines can be determined. The Fig. 14.17 represents the working principle of optical triangulation technique, in which triangular geometry is formed between laser source, object and detector. If the angle between camera and laser is known, the component height can be calculated using trigonometric formulae (Fig. 14.18). In order to capture depth profile of a surface, one needs to move the object being

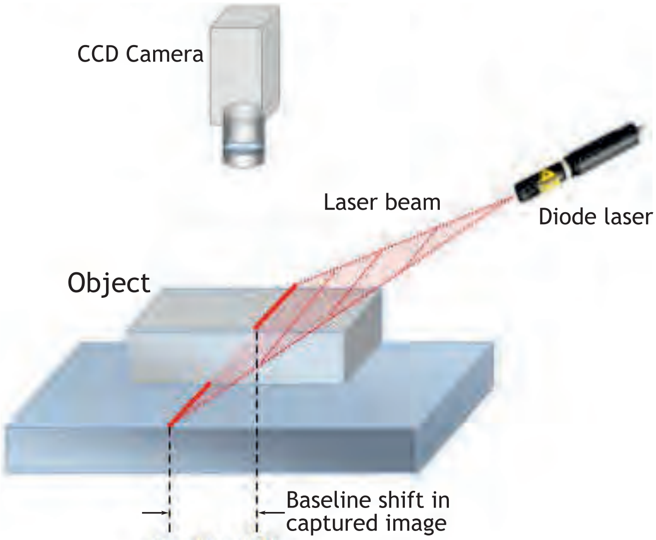


Figure 14.17: Block diagram of the working principle of line triangulation technique [157].

scanned laterally in multiple steps. The camera captures depth profile at every intermediate step. The depth profiles of all steps are combined together to generate a 3D map of the depth of the surface being scanned. The step size chosen determines the lateral resolution of the scanned surface. In case of curved object, a rotational motion is required around the central axis of the curved surface. Here, the angular displacement of the object in individual step determines the lateral resolution of the 3D profile of unfolded surface of the object under test.

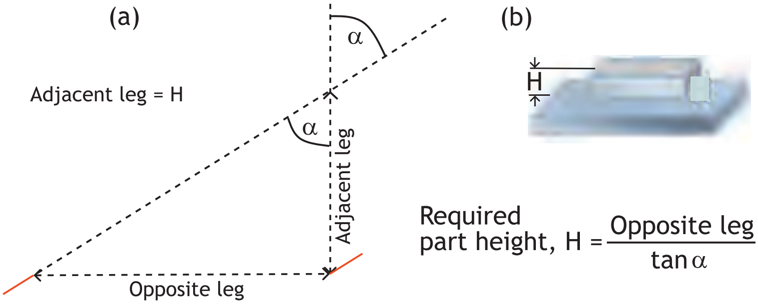


Figure 14.18: Schematic diagram for height calculation: (a).Baseline shift in captured image, and (b) Object whose height is to be measured [157].

System design

The surface depth profiling setup essentially consists of an imaging sensor (CCD area scan camera), light line generator, and the image acquisition and analysis software. The laser line generator consists of diode laser along with line generator optics. The line generator projects a light line at an angle of 30° with respect to camera on the object whose depth profile has to be measured. The object is placed in such a manner that it is in the focal plane of the camera and the laser line is tightly focused on its surface. The CCD camera captures an image of the object. This image is then processed to compute the surface profile of the object under test. Selection of imaging components play important role in generating high quality depth profile. The choice of components should be such that the entire depth range should be covered with desired resolution. The block diagram of the system is as shown in the Fig. 14.19 and the Fig. 14.20 shows GUI interface of the depth profiling system. If the camera is placed at a distance of 100 mm from the object and the laser line is projected at an angle of 30° with respect to camera which has pixels of size 4.6 μm. The theoretical calculations indicate that these parameters should provide a depth resolution of $\sim$33 μm and 5 mm depth range.

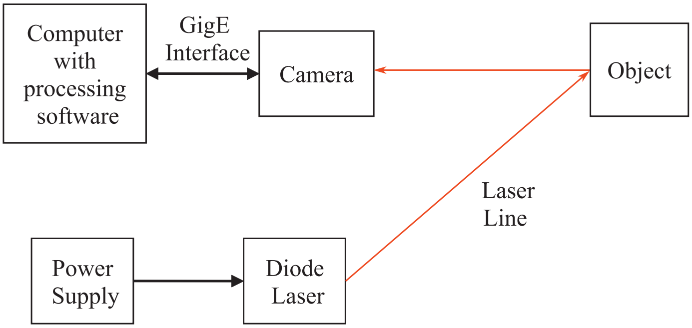
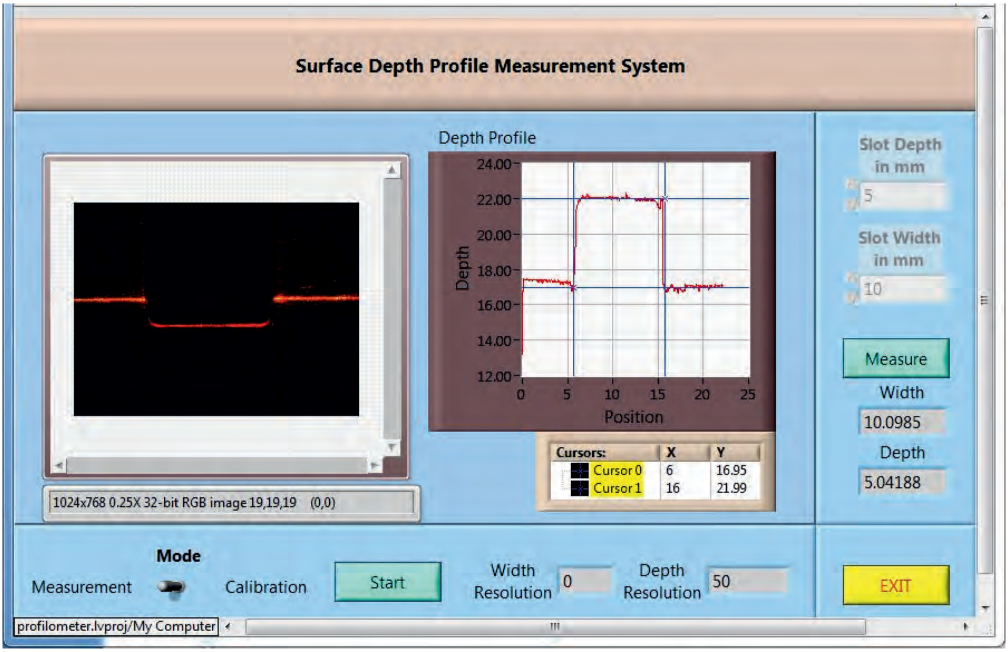


Figure 14.19: Schematic diagram of the system.



1024x768 0.25X 32-bit RGB image 19,19,19 (0,0)

Cursors:	X	Y
Cursor 0	6	16.95
Cursor 1	16	21.99

Slot Depth in mm: 5

Slot Width in mm: 10

Width: 10.0985

Depth: 5.04188

Width Resolution: 0

Depth Resolution: 50

profilometer.lvproj/My Computer

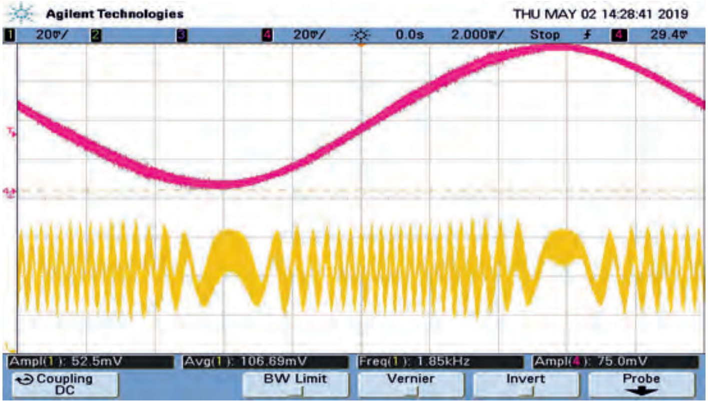
Figure 14.20: GUI of the depth profiling system.

14.6 Fiber Optic Interferometer based Vibration Sensor

Fiber Optic Fabry Perot Interferometer (FPI) based vibration sensor is an instrument (Fig. 14.22) that uses a fiber optics probe to remotely measure vibration very precisely.

14.6.1 Working principle

The FPI is an etalon which consists of two parallel flat semi-transparent reflectors separated by a fixed distance. Mirrors, fiber tips or fiber Bragg gratings can be used as reflectors. Monochromatic light like laser beam when falls at an inclined angle on one of the reflector, undergoes multiple reflections within the cavity and thus generates an interference pattern. The spatial and temporal nature of the interference pattern depends on the wavelength of incident beam, length of etalon, refractive index of the etalon and reflectivity of reflectors. If all other parameters are kept constant, an FPI based vibration sensor will be sensitive to change in etalon length. For the interferometer to be set in an extrinsic configuration, etalon is formed between the fiber tip and an external reflective vibrating target. The target vibration which modifies the etalon length generates a time varying interference pattern. The intensity variation of the interference pattern can be expressed as:



Ampl(1): 52.5mV
Avg(1): 106.69mV
Freq(1): 1.85kHz
Ampl(4): 75.0mV

Figure 14.21: Typical waveforms of vibration signal and interferometer signal.

$$I\left(t\right) = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\left(\frac{4\pi n x\left(t\right)}{\lambda} + \varphi_o\right) \tag{14.10}$$

where I(t) is the intensity of the interference fringe; I_1 is intensity of laser beam reflected from sensor head and I_2 is intensity reflected from external target; x(t) is the displacement of the vibrating target (for sinusoidal vibration it is $a\cos\left(\omega t\right)$); n is the refractive index of the etalon (air for extrinsic FPI); λ is the wavelength of laser; φ_o is the phase offset due to ambient temperature fluctuations and initial cavity length. Figure 14.21 shows typical interference signal, I(t), corresponding to a periodic vibration signal x(t). In the above instrument, the sensor employed is an FPI with a double pass sensor head [156]. Due to this configuration, the sensitivity achieved is twice to what obtained in a typical FPI sensor. The relation between phase variation of the target and dynamic displacement is given by [156]:

$$\varphi_x\left(t\right) = 2 \times \frac{4\pi n}{\lambda} a\cos\left(\omega t\right) \tag{14.11}$$

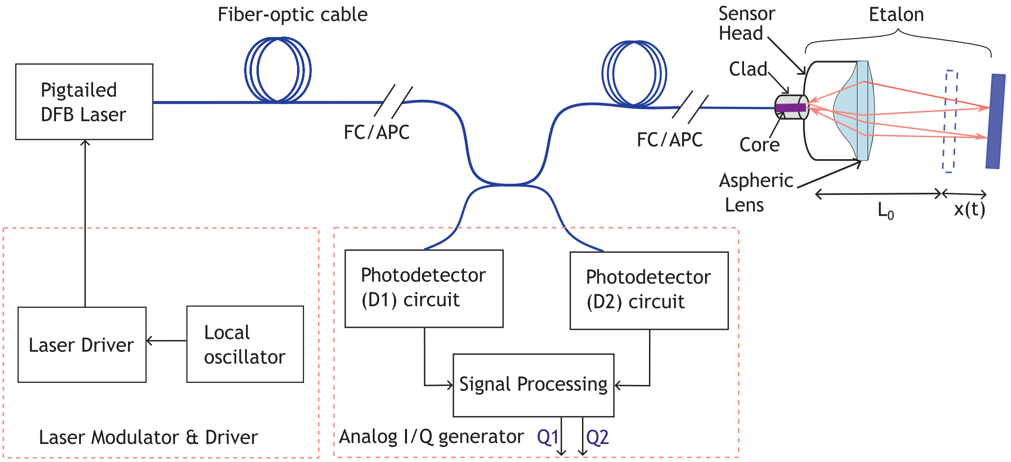


Figure 14.22: Block diagram of the sensor configuration.

where a is the amplitude of dynamic displacement in μm and ω is frequency of excitation in rad/s. The direction ambiguity is resolved by using Frequency modulated - phase generated carrier (FM-PGC) method and the phase is demodulated to obtain dynamic displacement.

14.7 Conclusion

The above described methods are but a few of large number of applications of laser based instruments. Laser based Instrumentation is an upcoming field and it has wide range of metrology applications. The developments in diode laser technology have benefited the laser based instrumentation as it becomes possible to makes compact, portable and low cost instruments.

Frequently Asked Questions

Q1. Why is laser useful in measurement application?

Q2. Explain the principle of pulse shadow technique for non-contact diameter measurement using laser? What will be the diameter of an object if the width of the shadow pulse is 100 μs and total time to scan the aperture of 40 mm is 408 μs?

Q3. What are the different applications of optical triangulation technique? Describe its application for vibration measurement?

Q4. How is laser useful for non-contact projectile velocity measurement? What are the sources of error in such measurement?

Q5. Which is an whole field measurement technique for flow visualization? How is it different from Doppler shift based flow measurement technique?

Q6. Explain working principle of FPI based vibration sensor?