Production & Industrial Engineering

Quality and Reliability

Comprehensive Theory
with Solved Examples *and* Practice Questions

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CONTENTS

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CHAPTER 3

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CHAPTER 01

Metrology and Inspection

INTRODUCTION

Metrology is a science of measurement. Metrology may be divided depending upon the quantity under consideration into: metrology of length, metrology of time etc. Depending upon the field of application it is divided into industrial metrology, medical metrology etc.

- Engineering metrology is restricted to the measurement of length, angles and other quantities which are expressed in linear or angular terms.
- For every kind of quantity measured, there must be a unit to measure it. This will enable the quantity to be measured in number of that unit. Further, in order that this unit is followed by all; there must be a universal standard and the various units for various parameters of importance must be standardized.
- It is also necessary to see whether the result is given with sufficient correctness and accuracy for a particular need or not. This will depend on the method of measurement, measuring devices used etc.
- Thus, in a broader sense metrology is not limited to length and angle measurement but also concerned with numerous problems theoretical as well as practical related with measurement such as:

1. Units of measurement and their standards, which is concerned with the establishment, reproduction, conservation and transfer of units of measurement and their standards.
2. Methods of measurement based on agreed units and standards.
3. Errors of measurement.
4. Measuring instruments and devices.
5. Accuracy of measuring instruments and their care.
6. Industrial inspection and its various techniques.
7. Design, manufacturing and testing of gauges of all kinds

1.1 Need of Inspection

The need of inspection can be summarized as:

1. To ensure that the part, material or a component conforms to the established standard.
2. To meet the interchangeability of manufacture.
3. To maintain customer relation by ensuring that no faulty product reaches the customers.
4. Provide the means of finding out shortcomings in manufacture. The results of inspection are not only recorded but forwarded to the manufacturing department for taking necessary steps, so as to produce acceptable parts and reduce scrap.

5. It also helps to purchase good quality of raw materials, tools, equipment which governs the quality of the finished products.
6. It also helps to co-ordinate the functions of quality control, production, purchasing and other departments of the organization.

1.2 Objectives of Metrology

1. Thorough evaluation of newly developed products, to ensure that components designed is within the process and measuring instrument capabilities available in the plant.
2. To determine the process capabilities and ensure that these are better than the relevant component tolerance.
3. To determine the measuring instrument capabilities and ensure that these are adequate for their respective measurements.
4. To minimize the cost of inspection by effective and efficient use of available facilities and to reduce the cost of rejects and rework through application of Statistical Quality Control Techniques
5. Standardization of measuring methods. This is achieved by laying down inspection methods for any product right at the time when production technology is prepared.
6. Maintenance of the accuracies of measurement. This is achieved by periodical calibration of the metrological instruments used in the plant.
7. Arbitration and solution of problems arising on the shop floor regarding methods of measurement.
8. Preparation of designs for all gauges and special inspection fixtures.

1.3 Standards of Measurement

For linear measurements, various standards known are:

1. Line standard
2. End standard
3. Wavelength standard

1.3.1 Characteristics of Line Standard

1. Accurate engraving on the scales can be done but it is difficult to take full advantage of this accuracy. For example, a steel rule can be read to about ± 0.2 mm of true dimension.
2. It is easier and quicker to use a scale over a wide range.
3. The scale markings are not subject to wear although significant wear on leading end leads to undersizing.
4. There is no 'built in' datum in a scale which would allow easy scale alignment with the axis of measurement, this again leads to undersizing.
5. Scales are subjected to the parallax effect, a source of both positive and negative leading errors.
6. For close tolerance length measurement (except in conjunction with microscopes) scales are not convenient to be used.

1.3.2 Characteristics of End standards

Characteristics or end standards:

1. Highly accurate and well suited to close tolerance measurements.
2. Time-consuming in use.
3. Dimensional tolerance as small as 0.0005 mm can be obtained.
4. Subjected to wear on their measuring faces.
5. To provide a given size, the groups of blocks are "wrung" together. Faulty wringing leads to damage.

6. There is a "built-in" datum in end standards, because their measuring faces are flat and parallel and can be positively located on a datum surface.
7. As their use depends on "feel" they are not subject to the parallax effect.

End bars. Primary end standards usually consist of bars of carbon steel about 20 mm in diameter and made in sizes varying from 10 mm to 1200 mm. These are hardened at the ends only. They are used for the measurement of work of larger sizes.

Slip gauges. Slip gauges are used as standards of measurement in practically every precision engineering works in the world. These were invented by C.E. Johanssom of Sweden early in the present century. These are made of high-grade cast steel and are hardened throughout. With the set of slip gauges, combinations of slip gauge enables measurements to be made in the range of 0.0025 to 10 mm but in combinations with end/length bars measurement range upto 1200 mm is possible.

NOTE

The accuracy of line and end standards is affected by temperature changes and both are originally calibrated at $20 \pm 1/2°C$. Also care is taken in manufacture to ensure that change of shape with time is reduced to negligible proportions.

1.3.3 Characteristics of Wavelength Standards

The following are the advantages of using wavelength standard as basic unit to define primary standards:

1. It is not influenced by effects of variation of environmental temperature, pressure, humidity and ageing because it is not a material standard.
2. There is no need to store it under security and thus there is no fear of its being destroyed as in the case of yard and metre.
3. It is easily available to all standardising houses, laboratories and industries.
4. It can be easily transferred to other standards.
5. This standard can be used for making comparative statement of much higher accuracy.
6. It is easily reproducible.

Table. Relative characteristics of line and end standard

Sr. No.	Characteristic	Line Standard	End Standard
1.	Principle	Length is expressed as the distance between two lines.	Length is expressed as the distance between two flat parallel faces.
2.	Accuracy	Limited to ±0.2 mm for high accuracy, scales have to be used in conjunction with magnifying glass or microscope.	Highly accurate for measure-ment of close tolerances upto ±0.001 mm.
3.	Ease and time & measurement	Measurement is quick and easy.	Use of end standard requires skill and is time consuming.
4.	Effect of wear	Scale markings are not subject to wear. However, significant wear may occur on leading ends. Thus, it may be difficult to assume zero of scale as datum.	These are subjected to wear on their measuring surfaces.
5.	Alignment	Cannot be easily aligned with the axis of measurement.	Can be easily aligned with the axis of measurement.
6.	Manufacture & cost	Simple to manufacture at low cost.	Manufacturing process is complex and cost is high.
7.	Parallax effect	They are subjected to parallax error.	They are not subjected to parallax error.
8.	Examples	Scale (yard, meter, etc.)	Slip gauges, end bars, V-caliper, micrometers, etc.

1.4 Performance Terminology of Measurement

Precision

– The terms precision and accuracy are used in connection with the performance of the instrument. Precision is the repeatability of the measuring process.

– It refers to the group of measurements for the same characteristics taken under identical conditions. It indicates to what extent the identically performed measurements agree with each other. If the instrument is not precise it will give different (widely varying) results for the same dimension when measured again and again. The set of observations will scatter about the mean. The scatter of these measurements is designated as 0, the standard deviation. It is used as an index of precision. The less the scattering more precise is the instrument. Thus, lower, the value of 0, the more precise is the instrument.

Accuracy

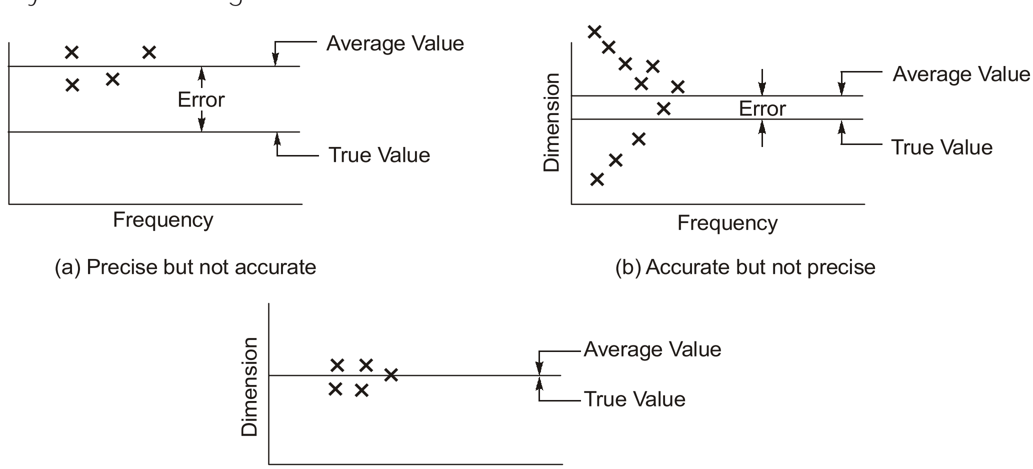
– Accuracy is the degree to which the measured value of the quality characteristic agrees with the true value. The difference between the true value and the measured value is known as error of measurement.

– It is practically difficult to measure exactly the true value and therefore a set of observations is made whose mean value is taken as the true value of the quality measured.

Distinction between Precision and Accuracy

– Accuracy is very often confused with precision though much different. The distinction between the precision and accuracy will become clear by the following example. Several measurements are made on a component by different types of instruments (A, B and C respectively) and the results are plotted.

– In any set of measurements, the individual measurements are scattered about the mean, and the precision signifies how well the various measurements performed by same instrument on the same quality characteristic agree with each other.



(a) Precise but not accurate

(b) Accurate but not precise

(c) Accurate & Precise

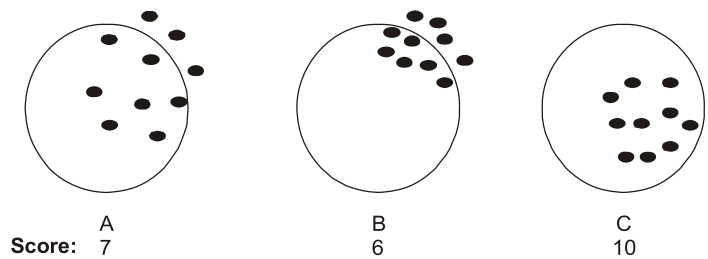
Fig. Accuracy and Precision

Repeatability

- It is the ability of a measuring system to reproduce output readings when the same input is applied to it consecutively, under the same conditions, and in the same direction.
- Imperfections in mechanical systems can mean that during a Mechanical cycle, a process does not stop at the same location, or move through the same spot each time. The variation range is referred to as repeatability.

Reliability of Measurement

- It is a quantitative characteristic which implies confidence in the measured results depending on whether or not the frequency distribution characteristics of their deviations from the true values of the corresponding quantities are known. It is the probability that the results will be predicted.



Example: A change in one variable, such as wind, alters the results as shown. Does this show which shooting was the most reliable?

Calibration

- It is the setting or correcting of a measuring device usually by adjusting it to match or conform to a dependably known value or act of checking.
- Calibration determines the performance characteristics of an instrument, system or reference material. It is usually achieved by means of a direct comparison against measurement standards or certified reference materials.
- It is very widely used in industries.
- A calibration certificate is issued and, mostly, a sticker is provided for the instrument.

Drift: It is a slow change of a metrological characteristics of a measuring instruments

Resolution: It is the smallest change of the measured quantity which changes the indication of a measuring instruments

Sensitivity: The smallest change in the value of the measured variable to which the instrument respond is sensitivity. It denotes the maximum changes in an input signal that will not initiate a response on the output.

Rule of 10 or Ten-to one rule: That the discrimination (resolutions) of the measuring instrument should divide the tolerance of the characteristic to be measured into ten parts. In other words, the gauge or measuring instrument should be 10 times as accurate as the characteristic to be measured.

1.5 Errors in Measurement

The error in measurement may be expressed or evaluated either as an absolute error or as a relative error.

Absolute Error

- True absolute error: It is the algebraic difference between the result of measurement and the conventional true value of the quantity measured.
- Apparent absolute error: If the series of measurement are made then the algebraic difference between one of the results of measurement and the arithmetical mean is known as apparent absolute error.

Relative Error

- It is the quotient of the absolute error and the value of comparison used for calculation of that absolute error. This value of comparison may be the true value, the conventional true value or the arithmetic mean for series of measurement. The accuracy of measurement, and hence the error depends upon so many factors, such as:

  – Calibration standard – Work piece – Instrument

  – Person – Environment etc. as already described.

1.5.1 Types of Error During Measurement

Several types of error may arise, these are

1. Static errors which includes
   - Reading errors
   - Characteristic errors
   - Environmental errors.
2. Instrument loading errors.
3. Dynamic errors.

1. **Static errors:** These errors result from the physical nature of the various components of measuring system. There are three basic sources of static errors. The static error divided by the measurement range (difference between the upper and lower limits of measurement) gives the measurement precision.
   (i) **Reading errors:** Reading errors apply exclusively to the read-out device. These do not have any direct relationship with other types of errors within the measuring system. Reading errors include: Parallax error, Interpolation error. Attempts have been made to reduce or eliminate reading errors by relatively simple techniques. For example, the use of mirror behind the readout pointer or indicator virtually eliminates occurrence of parallax error.
   (ii) **Interpolation error:** It is the reading error resulting from the inexact evaluation of the position of index with regards to two adjacent graduation marks between which the index is located. How accurately can a scale be read this depends upon the thickness of the graduation marks, the spacing of the scale division and the thickness of the pointer used to give the reading Interpolation error can be tackled by increasing; using magnifier over the scale in the vicinity of pointer or by using a digital read out system.
   (iii) **Characteristic Errors:** It is defined as the deviation of the output of the measuring system from the theoretical predicted performance or from nominal performance specifications. Linearity errors, repeatability, hysteresis and resolution errors are part of characteristic errors if the theoretical output is a straight line. Calibration error is also included in characteristic error.
2. **Dynamic Errors:** Dynamic error is the error caused by time variations in the measurand. It results from the inability of the system to respond faithfully to a time varying measurement. It is caused by inertia, damping, friction or other physical constraints in the sensing or readout or display system. For statistical study and the study of accumulation of errors, these errors can be broadly classified into two categories
   1. Systematic or controllable errors, and
   2. Random errors.

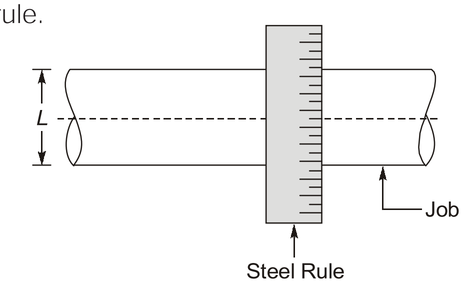
Table. Comparison between systematic and random errors

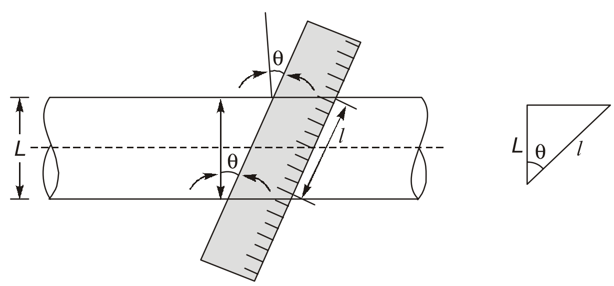
Systematic Errors	Random Errors
These errors are repetitive in nature and are of constant and similar form.	These are non-consistent. The sources giving rise to such errors are modern.
These errors result from improper conditions or procedures that are consistent in action.	Such errors are inherent in the measuring system or measuring instruments.
Except personal errors, all other systematic errors can be controlled in magnitude and sense.	Specific causes, magnitudes and sense of these errors cannot be determined from the knowledge of measuring system or condition.
If properly analyzed these can be determined and reduced or eliminated.	These errors cannot be eliminated, but the results obtained can be corrected.
These include calibration errors, variation in contact pressure, variation in atmospheric conditions, parallax errors, misalignment errors etc.	These include errors caused due to variation in position of setting standard and work-piece, errors due to displacement of lever joints of instruments, errors resulting from backlash, friction etc.

Some other types of measurement error

(1) Alignment error (Cosine error): This error is based on Abbes principle of alignment which states that the line of measurement of the measuring component should coincide with the measuring scale or axis of the measuring instrument. These errors are caused due to non-alignment of measuring scale to the true line of dimension being measured. Cosine errors will be developed generally while measurement of a given job is carried out using dial gauge or using steel rule.

The axis or line of measurement of the measured portion should exactly coincide with the measuring scale or the axis of measuring instrument, when the above thing does not happen then cosine error will occur. To measure the actual size of the job L, using steel rule it is necessary that the steel rule axis or line of measurement should be normal to the axis of the job as shown in adjoining figure. But sometimes due to non-alignment of steel rule axis with the job axis, the size of job 1 measured is different than the actual size of job L. as shown in figure.





(a) (b)

From above figure (b), L = actual size of job, l = measured size of job, e = error induced due to non-alignment.

$$e = l - L$$

Therefore from the geometry,

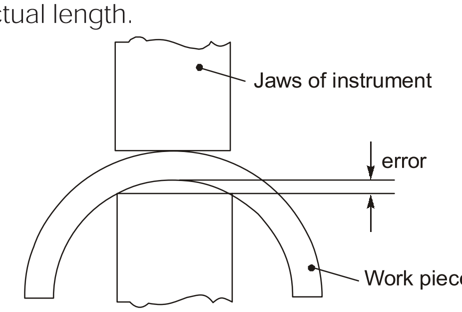
$$\cos\theta = \frac{L}{l}$$

$$L = l\cos\theta$$

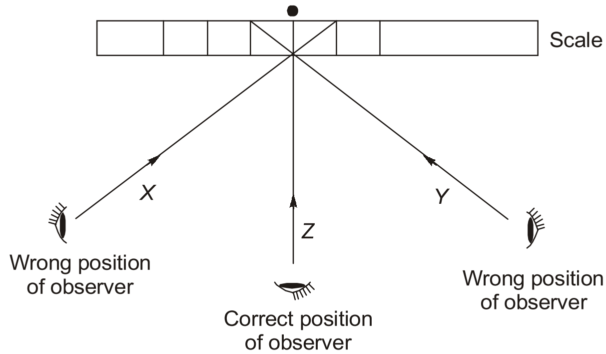
But as $e = l - L = l - l\cos\theta = l(1 - \cos\theta)$

The equation of error consist of cosine function, hence error is called cosine error. In this type of errors, the length measured is always in excess of the exact or actual length.

(2) Contact error: The rings as shown in adjoining figure whose thickness is to be measured. Number of times, the contact of jaws with work piece plays an important role while measure in laboratory or work shops. The following example shows the contact error. If the jaws of the instrument are placed as shown in figure the error 'e' is developed, which is because of poor contact only.



(3) Parallax error (Reading error): The position of the observer at the time of taking a reading (on scale) can create errors in measurement. For this two positions of the observers are shown (X and Y), which will be the defect generating positions. Position Z shows the correct position of the observer i.e., he should take readings by viewing eye position exactly perpendicular to the scale.



1.6 Limits, Fits and Tolerance

Nominal size. A 'nominal size' is the size which is used far purpose of general identification. Thus the nominal size of a hole and shaft assembly is 60 mm, even though the basic size of the hole may be 60 mm and the basic size of the shaft 59.5 mm.

Basic dimension. A 'basic dimension' is the dimension, as worked out by purely design considerations. Since the ideal conditions of producing basic dimension, do not exist, the basic dimensions can be treated as theoretical or nominal size, and it has only to be approximated. A study of function of machine part would reveal that it is unnecessary to attain perfection because some variations in dimension, however small, can be tolerated on size of various parts. It is, thus, general practice to specify a basic dimension and indicate by tolerances as to how much variation in the basic dimension can be tolerated without affecting the functioning of the assembly into which this part will be used.

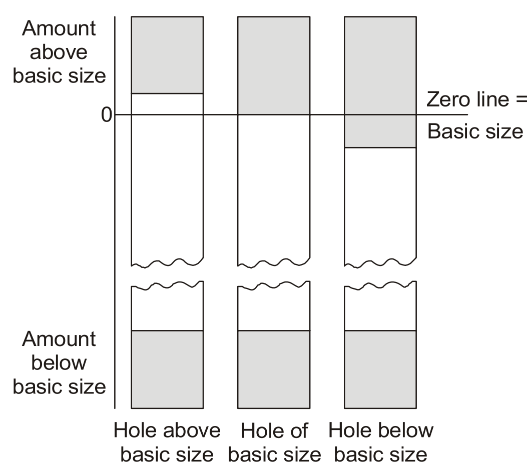
1.6.1 Important Terminology

Shaft. The term shaft refers not only to diameter of a circular shaft but to any external dimension on a component.

Hole. This term refers not only to the diameter of a circular hole but to any internal dimension on a component.

Actual size of the shaft. This is the measured dimension of the part.

Basic size. The basic size is the standard size far the part and is the same for both the hole and its shaft. Example : A 60 mm diameter hole and shaft. (see adjoining fig.)



Zero line. This is the line, which represents the basic size so that the deviation from the basic size is zero. (see adjoining fig.)

Limits of size. These are maximum and minimum permissible sizes of the part.

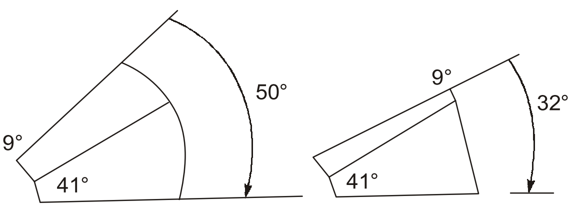
Minimum limit of size. The minimum size permitted for the part. (see below fig.)

Maximum limit of size. The maximum size permitted for the part. (see below fig.)

Tolerance. The difference between the maximum and minimum limits of size. (see below fig.)

Solution :

Part (a) use two angle gauges of 41° and 9° to make 50°. Part (b) use two angle gauges of 41° and 9 .in part (b) 9° angle gauge is put in opposite direction. Thus 41 ° – 9° = 32°. Part (c) uses four angle gauges shown in below figure to make the required angle.



(a) (b)

Degree	Minutes	Second
+ 41	+27	+27
+9	–9	+3
–3	–1	
–1		
46°	17′	30″

(c)

Example 1.49 Calculate the CLA value of a surface for the following data:

The sampling length is 0.8 mm and the graph drawn to a vertical magnification of 15000 and horizontal magnificent of 100 and areas above and below the datum line are 160, 90, 180, 50 mm^2, and 95, 65, 170, 150 mm^2 respectively.

Solution :

$$\Sigma A = \frac{\text{Sum of all the areas}}{\text{Vertical magnification} \times \text{Horizontal magnification}}$$

$$= \frac{(160+95+90+65+180+170+50+150)}{15000 \times 100} = \frac{960}{15000 \times 100}$$

$$= 0.00064 \text{ mm}^2$$

$$\text{CLA value} = \frac{\Sigma A}{L} = \frac{0.00064}{0.8} = 0.0008 \text{ mm} = 0.0008 \times 1000 \text{ }\mu\text{m} = 0.8 \text{ }\mu\text{m}$$

Student's Assignments 1

Q.1 A master gauge is
(a) A new gauge
(b) An international reference standard
(c) A standard gauge for checking accuracy of gauges used on shop floors
(d) A gauge used by experienced technicians

Q.2 Standards to be used for reference purposes in laboratories and workshops are termed as
(a) Primary standards
(b) Secondary standards
(c) Tertiary standards
(d) Working standards

Q.3 Which one of the following instruments is a comparator?
(a) Tool Maker's Microscope
(b) GO/NO GO gauge
(c) Optical Interferometer
(d) Dial Gauge

Q.4 A sine bar has a length of 250 mm. Each roller has a diameter of 20 mm. During taper angle measurement of a component, the height from the surface plate to the centre of a roller is 100 mm. The calculated taper angle (in degrees) is
(a) 21.1 (b) 22.8
(c) 23.6 (d) 68.9

Q.5 To measure the effective diameter of an external metric thread (included angle is 60°) of 3.5 mm pitch, a cylindrical standard of 30.5 mm diameter and two wires of 2 mm diameter each are used. The micrometer readings over the standard and over the wires are 16.532 mm and 15.398 mm, respectively. The effective diameter (in mm) of the thread is
(a) 33.366 (b) 30.397
(c) 29.366 (d) 26.397

Q.30 Function of Jigs is to
(a) Holds the workpiece
(b) Position the workpiece
(c) Guides the tool
(d) All of above

Q.31 The nominal size (in cm) of the GO plug gauge to inspect a 1.500 ± 0.030 cm diameter hole, the wear allowance is 2% of the entire tolerance band for inspected feature, is______. (Correct up to 4 decimal places)

Q.32 The sampling length is 0.8 mm, the graph is drawn to a vertical magnification of 10000 and horizontal magnification of 100 and the areas above and below the datum lines are 240, 180, 90, 100 mm^2 and 65, 125, 270, 350 mm^2, respectively. The CLA value (in mm) of a surface for the given data is ______.

Q.33 The higher limit of a 20 *f* 8 shaft with following data is_______ mm.
Given: i(microns) = $0.45\ D^{1/3} + 0.001D$
Upper deviation of *f* shaft (in microns) = $-5.5\ D^{0.41}$
20 mm falls in diameter step of 18 mm to 30 mm.

$$IT7 = 16i$$

Q.34 In a rectilinear pen recording of a diamond turned surface, a sampling length of 0.8 mm is selected and V/H magnification ratio was 5000/100. The R_a value if the area (in mm^2) above and below datum line are 60, 115, 96 and 92, 109, 70 respectively is _______ μm.

Q.35 If the micrometer reading with two wires of standard cylinder is 15.64 mm, micrometer reading over the gauge with two wires as 15.26 mm and pitch of thread is 2.5 mm, wire diameter is 2.0 mm and standard cylinder is 18 mm then the effective diameter of a screw thread is __ mm.

Q.36 Calculate the balanced bilateral tolerance on of dimensions (in mm) *D* given in the following figure. If assume that tolerance on each dimension giving the location of the along the x-axis is ±0.01 mm except '*D*' and tolerance in overall length is ±0.01 mm ________.

ANSWERS

1. (c)	2. (d)	3. (d)	4. (a)
5. (c)	6. (b)	7. (d)	8. (d)
9. (b)	10. (a)	11. (c)	12. (d)
13. (a)	14. (c)	15. (d)	16. (d)
17. (d)	18. (c)	19. (d)	20. (a)
21. (c)	22. (b)	23. (a)	24. (1.154)
25. (40)	26. (54.46)	27. (d)	28. (d)
29. (b)	30. (d)	31. (1.4712)	32. (1.775)
33. (19.980)	34. (1.355)	35. (17.785)	36. (0.04)

HINTS

18. (c)
Tolerance is total permissible variation from a specified dimension.

20. (a)
Jigs holds and position the work, locate and guide the tool.

21. (c)
Rotary cradle is used to rotate the rotary fixture. It consist of rotary drive at one side and tailstock at another side. In Rotary drive we can rotate the fixture in 360 degree.

22. (b)
Cam operated clamp is a quick action side clamp.

24. (1.154)(1.150 to 1.160)

$$d_p = \frac{p}{2}\sec\theta$$

$$= \frac{2}{2}\sec 30° = 1.154 \text{ mm}$$

25. (40)

Allowance = LL of hole – HL of shaft
= 30.00 – (30 – 0.04)
= 0.04 mm = 40 mm

26. (54.46)(53 to 56)

$h = L \sin\theta = 100 \sin 33°$
$= 54.46390$ mm

28. (d)
Taylor's principle of gauging
- A Go gauge will check all the dimension of the work piece in the maximum metal condition (indicating the presence of the greater amount