Production & Industrial Engineering

Quality and Reliability

Comprehensive Theory

with Solved Examples and Practice Questions

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Corporate Office: 44-A/4, Kalu Sarai (Near Hauz Khas Metro Station), New Delhi-110016
E-mail: infomep@madeeasy.in
Contact: 011-45124660, 8860378007
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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 ± 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.

Example 1.19 Calculate all the relevant dimensions of 35H7/*f*8 fit, dimension 35 mm falls in the step of 30-50 mm. The fundamental deviation for *f* shaft is 5.5D0.41. *i* (in microns) = 0.45(D)1/3+0.001*D*, IT7 = 16*i* and IT8 = 25*i*.

Solution :

The given size of 35 mm lies in the diameter step of 30-50 mm.

$$\therefore \quad D = \sqrt{30 \times 50} = 38.7 \text{ mm}$$

The value of fundamental tolerance unit $i = 0.45\sqrt[3]{D} + 0.001D$ microns

$$\text{i.e.} \quad i = 0.45\sqrt[3]{38.7} + 0.001(38.7) = 1.56\ \mu$$

For a hole of quality 7, (i.e. IT 7) the standard tolerance value is =16 i.

$\therefore$ Tolerance $16 \times 1.56 = 25\mu = 0.025$ mm

For the H hole, the fundamental deviation (FD) is zero.

Hence, the hole limits are 35 mm and (35 + 0.025) = 35.025 mm (Or $35^{+0.025}_{-0.000}$ mm)

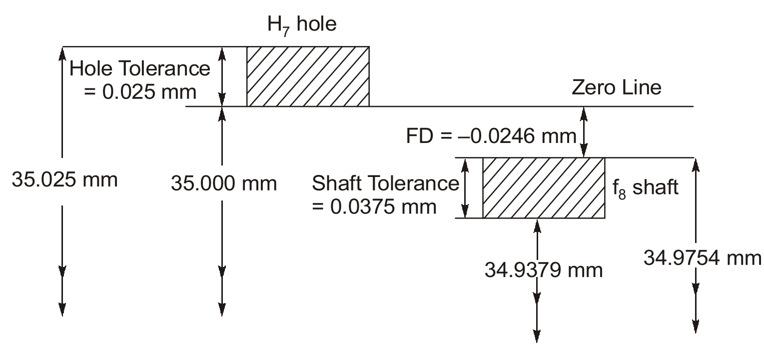
$\therefore$ Hence, tolerance on the hole = (50.025 – 50) = 0.025 mm

For quality 8 shaft, tolerance = IT8 = 16i =16 × 1.56 = 25μ = 0.025 mm

For *g* shaft the FD is $-5.5D^{0.41} = -5.5(38.7)^{0.41} = -24.63\mu = 0.025$ mm

$\therefore$ The shaft limits are (35 – 0.0246) = 34.9754 mm

and 35 – (0.0246 + 0.0375) = 34.9379 mm (OR $35^{-0.0246}_{-0.0621}$ mm)



Example 1.20 Calculate the dimensions of plug & ring gauges to control the production of 50 mm shaft & hole pair of H_7d_8 as per IS specifications. The following assumptions may be made: 50 mm lies in diameter step of 30-50 mm. Upper deviation for '*d*' shaft is $-16D^{0.44}$ and lower deviation for hole *H* is zero. Tolerance unit in '*i*' in microns is = $0.45\sqrt[3]{D}$ + 0.001 D and IT6 = 10*i* and above IT6 grade, the tolerance is multiplied by 10 at each 5th step.

Solution :

(i) The given size of 50 mm lies in the diameter step of 30-50 mm.

$$\therefore \quad D = \sqrt{30 \times 50} = 38.7 \text{ mm}$$

(ii) The value of fundamental tolerance unit

$$i = 0.45\sqrt[3]{D} + 0.001D \text{ microns}$$

$$\text{i.e.} \quad i = 0.45\sqrt[3]{38.7} + 0.001(38.7) = 1.56\mu$$

(iii) Given that for quality 6, i.e.

$$\text{IT } 6 = 10i$$

and tolerance is 10 times at 5th Step

$\Rightarrow$ $IT7 = IT6 \times 10^{1/5} = 10i \times 10^{0.2} = 15.84i$

$\therefore$ Tolerance for IT7 $= 15.84 \times 1.56 = 0.0247$ mm

For the H hole, the fundamental deviation (FD) is zero.

$\therefore$ Work tolerance on the hole = (50.0247 – 50) = 0.0247 mm (Or $50^{+0.0247}_{-0.000}$ mm)

(iv) For quality 8 shaft, tolerance $= IT8 = IT6 \times 10^{0.4} = 10i \times 10^{0.4}$

$\therefore$ Work tolerance for shaft $= (10 \times 1.56) \times 10^{0.4} = 0.0391$ mm

For *g* shaft the FD is $-16D^{0.44} = -16(38.73)^{0.44} = -80\ \mu = -0.08$ mm

Hence lower deviation = –0.08 – 0.0391 = –0.1191 mm

Design of Plug gauge (for checking limits of hole):

(i) Allowing 10% of work tolerance on hole as gauge tolerance

i.e. gauge tolerance = 10% of 0.0247 = 0.0247 mm

and neglecting wear tolerance (As work tol < 0.09 mm)

(a) For GO plug gauge,

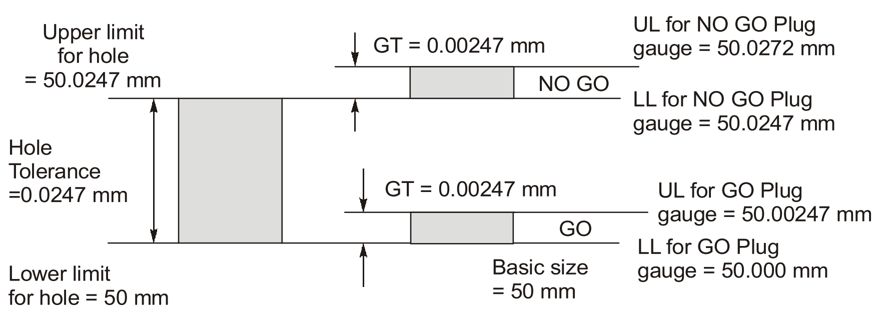
Limits for GO plug gauge are;

50.000 + 0.000 = 50.000 mm and 50.000 + 0.00247 = 50.00247 mm

(b) For NO GO plug gauge,

$\therefore$ Limits for NO GO plug gauge are;

50.000 + 0.0247 = 50.0247 mm and 50.0247 + 0.00247 = 50.0272 mm



GO and NO GO Plug Gauges (for checking hole tolerance)

Design of Ring gauge (for checking limits of Shaft):

(ii) Allowing 10% of work tolerance on shaft as gauge tolerance

i.e. gauge tolerance = 10% of 0.0391 = 0.000391 mm

and neglecting wear tolerance (As work tol <0.09 mm)

(a) For GO Ring gauge:

Limits for GO Ring gauge are;

50.000 – 0.08 = 49.92 mm

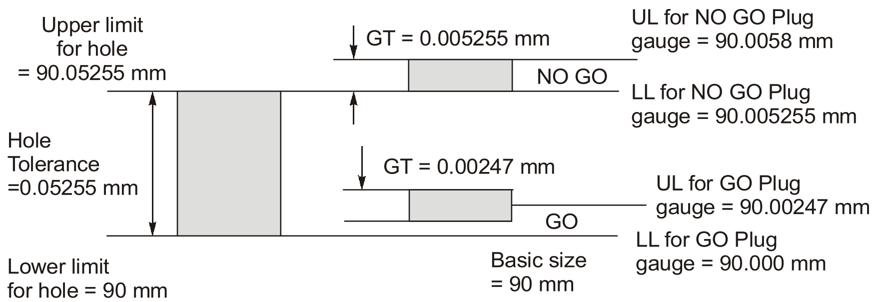
and 49.92 – 0.0039 = 49.9161 mm

(b) For NO GO ring gauge:

Limits for NO GO ring gauge are;

50.000 – (0.08 + 0.0391) = 49.8809 mm

and (49.8809 – 0.0039) = 49.8770 mm



GO and NO GO Plug Gauges (for checking hole tolerance)

Design of Ring gauges (for checking limits of shaft)

(i) Allowing 10% of work tolerance on shaft as gauge tolerance

i.e., gauge tolerance = 10% of 0.08408=0.0084 mm

and wear allowance = 10% of GT = 0.00084 mm

(a) GO ring gauge,

Limits for GO ring gauge are;

LL 90.000 – (0.0695 – 0.00084 – 0.0084) = 89.9213 mm and

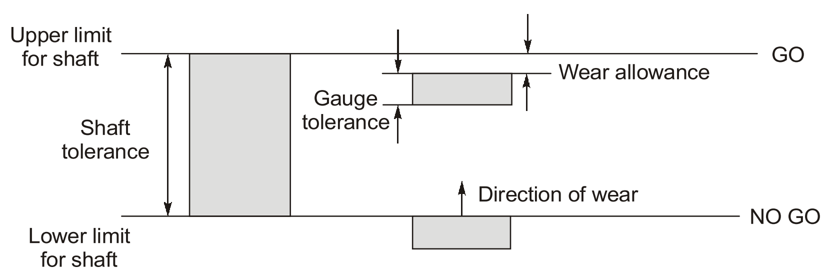
UL 90.000 – (0.0695 – 0.00084) = 89.9297 mm

(b) For NO-GO plug gauge,

Limits for NO GO ring gauge are;

LL(90.000 – 0.0695 – 0.08408 – 0.008408) =89.838 mm

and UL (90.000 – 0.0695 – 0.08408) = 89.88465 mm



GO and NO GO Ring Gauges (For checking shaft tolerance)

Example 1.22 To obtain the dimension of 73.728 using slip gauges, the most appropriate combination is

(a) 1.028 + 1.5 + 1.2 + 70.00
(b) 1.22 + 1.5 + 1.008 + 70.00
(c) 70.0 + 3.0 + 0.7 + 0.02 + 0.008
(d) 1.008 + 1.36 + 1.36 + 70.000

Solution :

The most appropriate combination is

1.008
1.22
1.5
70.0
73.728

∴ Correct answer is (b)

Example 1.44 Outside micrometer is calibrated with the help of

(a) inside micrometer (b) depth micrometer

(c) ring gauges (d) slip gauges

Solution : (d)

Accuracy of slip gauges is better than outside micrometer.

Example 1.45 A hole and shaft have a basic size of 30 mm and are to have a clearance fit with max. clearance of 0.04 mm and a minimum clearance of 0.02 mm. The hole tolerance is to be 1.5 times the shaft clearance. Determine limits for both hole and shaft using.

(a) A hole basic system (b) A shaft basic system

Solution :

Given, Basic size = 30 mm; δ_{max} (max. clearance) = 0.04 mm,

δ_{min} (min. clearance) = 0.02 mm; Shaft tolerance = x,

Hole tolerance = 1.5 shaft clearance

(a) Hole Basis System

$$\delta_{max} = \delta_{min} + 1.5x + x$$

$$0.04 = 0.02 + 2.5x$$

$$x = 0.008 \text{ mm}$$

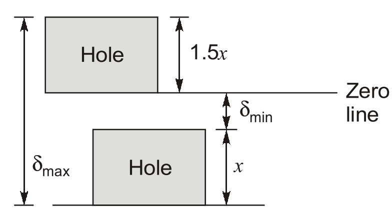
Hole → max. size = $30 + 1.5x = 30.012$ mm

min. size = 30.00 mm

Shaft → max. size = $30 - \delta_{min} = 30 - 0.02$

= 29.98 mm

min. size = $29.98 - x = 29.98 - 0.008 = 29.972$ mm



(b) Shaft basis system

x = 0.008 mm

Hole → max. size = $30 + \delta_{min} + 1.5x$

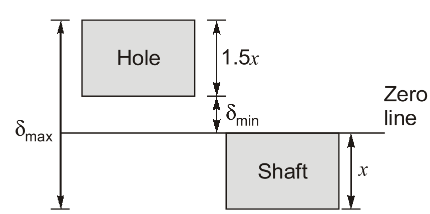
= 30.032 mm

min. Size = $30 + \delta_{min}$

= 30.02 mm

Shaft → max. size = 30 mm

min. size = $30 - x = 29.992$ mm



Example 1.46 Bars of length $\frac{20.05}{19.95}$ mm are in stock. From each, piece of $\frac{5.03}{4.98}$ mm are cut. Determine the lengths of the remaining parts.

Solution :

Case I: Let the bar selected is of length 20.05 mm

(i) Pieces cut out are of 5.03 mm

Then length of remaining bar = 20.05 – 5.03 × 3 = 4.96 mm

(ii) Pieces cut out are of 4.98 mm

Then length of remaining bar = 20.05 – 4.98 x 4 = 0.13 mm

(iii) Let two pieces cut out are of 5.03 mm and remaining two of 4.93 mm.

Then length of remaining bar = 20.05 – 2 × 5.03 – 4.98 × 2 = 0.03 mm

Hence it can be concluded that minimum wastage is when pieces cut out are two of 5.03 mm and remaining two of 4.98 mm.

Case II: Let the bar selected is of length 19.95 mm

(i) Pieces cut out are of 5.03 mm
Length of remaining bar = 19.95 – 3 × 5.03 = 4.86 mm

(ii) Pieces cut out are of 4.98 mm
Length erf remaining bar = 19.95 – 4 × 4.93 = 0.03 mm

(iii) Pieces cut out are mix of 5.03 mm and 4.98 mm
Length of remaining bar = 19.95 – 4.98 × 1 – 5.03 × 2 = 4.91 mm

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Example 1.47 A 20 mm diameter shaft and bearing are to be assembled with a clearance fit. The tolerance and allowances are as under:

Allowance = 0.002 mm, Tolerance on hole = 0.005 mm, Tolerance on shaft = 0.003 mm

Find the limits of size for the hole and shaft, if

(i) the hole basis system is used

(ii) the shaft basis system is used.

The tolerances are disposed off unilaterally.

Solution :

(i) Snap gauges are used to measure external dimensions.

(ii) Gauge blocks can be assembled in many different combinations to reach desired lengths.

(iii) Pneumatic gauges can be used to measure the linear dimensions of machines and mechanism parts.

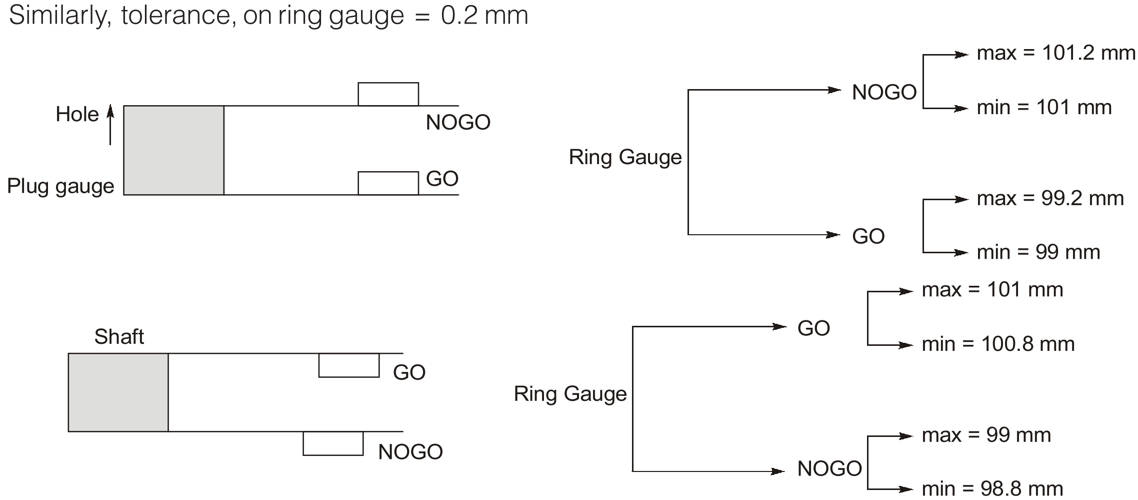
Hole size is 100 ± 1 mm and shaft size is 100 ± 1 mm.

Tolerance on hole = 2 mm

Tolerance on shaft = 2 mm

Tolerance on plug gauge = 10% of work tolerance = 0.2 mm

Similarly, tolerance, on ring gauge = 0.2 mm



If the tolerance are changed to ±1.2 mm, the tolerances on the gauges which are dependent on the work tolerance will also change.

Example 1.48 Use angle gauges to contract the following angles:

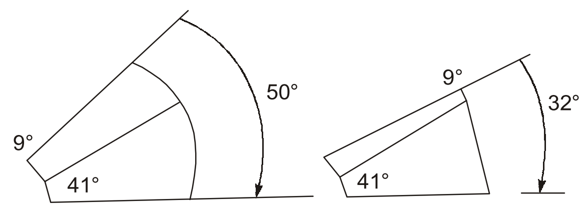
(a) 50°

(b) 32°

(c) 46° 17′ 30″

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 :

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

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

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

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

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)

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

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

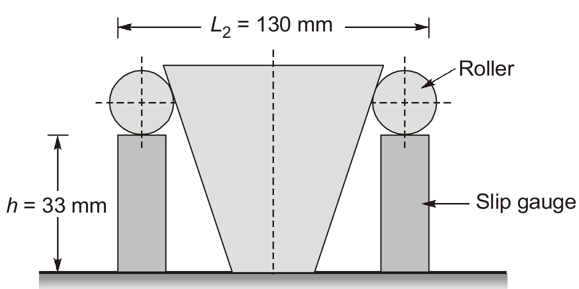
of material permitted at a prescribed surface). It should check the size of the component also the geometrical shape.

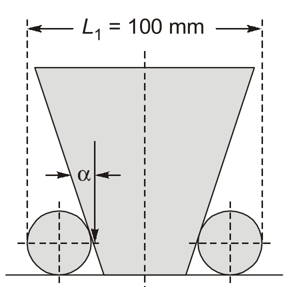
- NOT GO gauges will check only one dimension of the work piece at a time, for the minimum metal conditions (indicating the presence of the least amount of material permitted at a prescribed surface.)

In case of hole, the maximum metal condition is obtained when the hole is machined to the low limit of size, and minimum metal condition results when the hole is made to the high limit of size.

29. (b)

From question, taper plug gauge





where α = taper angle or half the included cone angle from geometry,

$$L_2 - L_1 = 2h \tan\alpha$$

$$\tan\alpha = \frac{L_2 - L_1}{2h} = \frac{115 - 100}{2 \times 75}$$

$$\tan\alpha = 0.1$$

$$\alpha = 5.71°$$

30. (d)

Jig: holds and position the workpiece and guide the tool.

31. (1.4712) (1.4710 to 1.4715)

Tolerance band = 0.060 cm

Wear allowance = 0.02 × 0.060 = 0.0012 cm

GO gauge will inspect minimum hole dia

= 1.500 – 0.030 = 1.470 cm

As the gauge wears, the dimension will decrease and allow unacceptable parts, so the wear allowance is added to it.

Nominal GP gauge size

= 1.470 + 0.0012 = 1.4712 cm

32. (1.775) (1.77 to 1.78)

$$\text{CLA} = \frac{\Sigma A}{L} \times \frac{1}{\text{Vertical scale}} \times \frac{1}{\text{Horizontal scale}}$$

$$= \frac{(240 + 180 + 90 + 100) + (65 + 125 + 272 + 350)}{0.8 \times 10000 \times 100}$$

$$= \frac{1420}{0.8 \times 10000 \times 100}$$

$= 1.775 \times 10^{-3}$ mm = 1.775 mm

33. (19.980)(19 to 21)

$$D = \sqrt{18 \times 30} = 23.2379$$

$$i = 0.45(23.2379)^{1/3} + 0.001 \times 23.2379$$

$$= 1.3074 \text{ mm}$$

$$IT7 = 16 \times 1.3074 = 20.918 \text{ mm}$$

$$= 0.021 \text{ mm}$$

Upper deviation of shaft

$$= -5.5(23.2379)^{0.41}$$

$$= -19.975 \text{ mm}$$

$$= -0.019975 \text{ mm}$$

Higher limit of shaft

= 20 – 0.019975 = 19.980 mm

34. (1.355)(1.30 to 1.40)

$$R_a = \frac{\Sigma A}{L} \times \frac{1}{\text{Vertical scale}} \times \frac{1}{\text{Horizontal scale}}$$

$$= \frac{(60 + 115 + 96 + 92 + 109 + 70)}{0.8} \times \frac{1}{5000} \times \frac{1}{100}$$

$= 1.355 \times 10^{-3}$ mm = 1.355 mm

35. (17.785)(17 to 19)

Effective diameter,

$$E = T + P$$

T = Diameter under the wires

$$= S - (R_1 - R_2)$$

$$P = 0.866p - d$$

Here, S = 18 mm, R_1 = 14.64 mm,

R_2 = 15.26 mm

d = 2 mm, p = 2.5 mm