Metrology and Measurements

Short notes for B.Tech Mechanical · GATE ME

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I. Basics of Measurement

- **Metrology** = science of measurement. **Engineering metrology** = measurement of lengths, angles, form and surface finish of parts.
- Need: interchangeability, quality control, inspection, calibration of instruments.

Term	Meaning
Accuracy	How close the reading is to the true value
Precision	How close repeated readings are to each other
Sensitivity	Output change / input change
Resolution	Smallest change the instrument can detect
Least count	Smallest value that can be read on the scale
Range	Min to max values it can measure
Repeatability	Same result by same person, same method, short time
Reproducibility	Same result by different people / labs
Calibration	Comparing an instrument with a known standard

REMEMBER A target with all shots close together but away from the centre = precise but not accurate.

Errors

Type	Cause	Fix
Systematic (fixed)	Zero error, wrong calibration, worn instrument	Calibration, correction
Random	Small unpredictable changes	Many readings, statistics
Gross (blunders)	Human mistakes in reading or noting	Care, training
Environmental	Temperature, humidity, vibration	Controlled room (20°C standard)

- **Abbe's principle**: the measuring axis should be in line with the scale axis, to avoid cosine and offset errors. Micrometer follows it; vernier caliper does not.
- **Parallax error**: reading the scale at an angle.

Standards of length

- **Line standard**: distance between two engraved lines (steel rule, old metre bar).
- **End standard**: distance between two flat end faces (slip gauges, micrometer anvils). More accurate, but wears.
- **Wavelength standard**: the metre is now defined by the speed of light (distance travelled by light in vacuum in 1/299 792 458 s).

2. Linear Measurement

FORMULA Vernier least count = 1 MSD − 1 VSD = value of smallest main scale division / number of vernier divisions.

- Example: 1 MSD = 1 mm, 50 vernier divisions = 49 MSD. LC = 1/50 = 0.02 mm.
- Reading = MSR + (coinciding vernier division × LC) ± zero error correction.

FORMULA Micrometer least count = pitch / number of thimble divisions = 0.5 / 50 = 0.01 mm.

- Micrometer has a **ratchet** for constant measuring pressure.
- Height gauge, depth gauge, dial indicator, bore gauge are other linear instruments.

➤ Slip gauges (gauge blocks)

- Hardened, lapped steel or ceramic blocks with very flat parallel faces. Joined by **wringing** (sliding and pressing together).
- Grades: calibration grade (most accurate), 00, 0, 1, 2 (workshop).
- Common sets: M87 (87 pieces) and M45 (45 pieces).
- Rule to build a size: use the fewest blocks; first remove the smallest last decimal digit.

EXAMPLE Build 58.975 mm with an M87 set: 1.005 + 1.47 + 6.5 + 50 = 58.975 mm (4 blocks).

3. Angular Measurement

- **Bevel protractor**: vernier type, least count 5 minutes.
- **Sine bar**: hardened bar with two rollers at exact centre distance L (100 or 200 mm), used with slip gauges.

FORMULA Sine bar: $\sin\theta = h / L$ (h = height of slip gauges under one roller).

EXAMPLE $L = 200$ mm, $h = 50$ mm. $\sin\theta = 0.25$, $\theta = 14.48°$.

- Sine bar error grows quickly above 45°, so it is not used for large angles (use angle gauges instead).
- **Angle gauges**: a set of 12–13 blocks can build any angle to about 3 seconds by adding and subtracting.
- **Autocollimator**: optical instrument for very small angle changes, flatness and straightness of guideways.
- **Clinometer / spirit level**: angles relative to horizontal.

4. Limits, Fits and Tolerances

- **Basic size**: size from design. **Limits**: max and min allowed sizes. **Tolerance** = upper limit − lower limit.
- **Deviation**: limit − basic size (upper and lower deviation). **Fundamental deviation**: deviation nearest to the zero line; it fixes the position of the tolerance zone (letters A–ZC for holes, a–zc for shafts).

- **Allowance** = min hole − max shaft (intentional difference; min clearance).

➤ Types of fits

Fit	Condition	Example
Clearance	Min hole > max shaft	Shaft in a bearing (H7/g6)
Transition	Can be clearance or interference	Gears, pulleys on shafts (H7/k6)
Interference	Max hole < min shaft	Press-fit bush, wheel on axle (H7/p6)

- **Hole basis system**: hole lower deviation = 0 (letter H); shafts are varied. Mostly used, since holes are made with fixed-size tools (drills, reamers).
- **Shaft basis system**: shaft upper deviation = 0 (letter h); holes are varied.

FORMULA Standard tolerance unit $i = 0.45\ D^{(1/3)} + 0.001\ D$ (i in μm, D = geometric mean of the diameter step in mm). IT6 = 10i, IT7 = 16i, IT8 = 25i, IT9 = 40i, IT10 = 64i, IT11 = 100i.

EXAMPLE For 25 mm (step 18–30), $D = \sqrt{18 \times 30} = 23.24$ mm, $i = 0.45 \times 2.854 + 0.023 = 1.307$ μm. IT7 = 16i = 21 μm, IT8 = 25i = 33 μm.

EXAMPLE Hole 50.000 / 50.025 mm, shaft 49.959 / 49.975 mm. Max clearance = 50.025 − 49.959 = 0.066 mm; min clearance = 50.000 − 49.975 = 0.025 mm. Clearance fit.

5. Limit Gauges

- **GO gauge** checks the maximum material condition (min hole, max shaft); it must go in. **NO-GO gauge** checks the least material condition; it must not go.
- **Plug gauge** checks holes. **Ring / snap gauge** checks shafts.
- **Taylor's principle**: the GO gauge should check all features together (full form, full length); the NO-GO gauge should check one feature at a time (point contact).
- **Gauge maker's tolerance**: usually 10% of the work tolerance.
- **Wear allowance**: given only on the GO gauge (it rubs more), usually about 10% of the gauge tolerance.

6. Comparators

- **Comparator** = measures the difference between the part and a standard, not the absolute size. High magnification.

Type	Principle	Point
Mechanical (dial indicator, Johansson Mikrokator)	Levers, gears, twisted strip	Simple, cheap, friction and inertia
Optical	Lever + light reflection	High magnification, no friction
Pneumatic (Solex)	Air flow / back pressure change	Non-contact, very high magnification, internal bores
Electrical / electronic (LVDT)	Change of inductance	High sensitivity, easy to record

- **LVDT** (linear variable differential transformer): one primary and two secondary coils with a movable core. Output is linear with core movement, and phase shows direction.

7. Surface Finish, Screw Threads and Gears

➤ Surface roughness

- Surface texture = **roughness** (fine marks from the process) + **waviness** (longer waves from vibration, deflection) + **lay** (direction of the main pattern).
- **Ra** (CLA) = average of absolute deviations from the mean line. **Rq** = RMS value. **Rz** = ten-point height (or max peak-to-valley in newer standards).
- **Sampling (cut-off) length**: commonly 0.8 mm. Instruments: stylus profilometer (Talysurf), optical methods.
- Typical Ra: grinding about 0.1–1.6 μm; lapping and polishing finer; rough turning coarser.

➤ Screw thread measurement

- Elements: major, minor and **effective (pitch) diameter**, pitch, thread angle.
- **Three-wire method** for effective diameter. Best wire size (touches at the pitch line): $d = (p/2)\sec(\theta/2) = 0.577\,p$ for a 60° metric thread.

FORMULA Effective diameter $E = M - d\,(1 + \operatorname{cosec}(\theta/2)) + (p/2)\cot(\theta/2)$. For metric 60° thread: $E = M - 3d + 0.866\,p$.

- Pitch: pitch measuring machine. Thread form and angle: optical projector / toolmaker's microscope.

➤ Gear measurement

- **Gear tooth vernier caliper**: chordal thickness at a set chordal addendum.

FORMULA Chordal thickness $w = m\,N\sin(90°/N)$. Chordal addendum $h = m\,[1 + (N/2)(1 - \cos(90°/N))]$.

- **Base tangent (span) method**: measured over several teeth with a flange micrometer; does not need the addendum.
- Composite errors: Parkinson gear tester (rolls the gear against a master gear).

8. Interferometry, CMM and Other Measurements

- **Optical flat**: flat glass disc; with monochromatic light, dark bands (fringes) appear. Each fringe = height change of $\lambda/2$.
- For sodium light ($\lambda \approx 0.589\ \mu m$), one fringe $\approx 0.295\ \mu m$. Straight, parallel, equally spaced fringes = flat surface.
- **Interferometers** (NPL flatness, laser interferometer) measure flatness and length to very high accuracy.
- **CMM** (coordinate measuring machine): probe touches points in X, Y, Z; software builds dimensions and form (flatness, roundness, position). Types: bridge, cantilever, gantry, horizontal arm.
- **Straightness, flatness, roundness**: straight edge and autocollimator; roundness by V-block or rotating-table instruments (Talyrond).

➤ Measurement of force, strain, pressure and temperature

Quantity	Instruments
Strain	Electrical resistance strain gauge + Wheatstone bridge
Force	Load cell (strain gauge based), proving ring
Torque	Strain gauges on a shaft, dynamometers
Pressure	Bourdon gauge, diaphragm, McLeod gauge and Pirani gauge (vacuum)
Temperature	Thermocouple, RTD (Pt100), thermistor, pyrometer
Flow	Venturi, orifice, rotameter, hot-wire anemometer

FORMULA Strain gauge factor $GF = (\Delta R / R) / \varepsilon$. Metallic foil gauges have $GF \approx 2$.

- **Thermocouple**: Seebeck effect (two different metals give a voltage with temperature difference). Common: type K (chromel–alumel), type J (iron–constantan).
- **RTD**: resistance rises with temperature; Pt100 = 100 Ω at 0°C; accurate and stable.
- **Thermistor**: semiconductor; most are NTC (resistance falls as temperature rises); very sensitive but non-linear.
- **Pyrometer**: non-contact (radiation / optical), for very high temperatures (furnaces).

9. Most Asked Questions (practice)

1. Differentiate accuracy and precision. Explain types of errors.
2. Explain line, end and wavelength standards.
3. Find least count and reading of a vernier caliper and micrometer.
4. Explain slip gauges, wringing, and build a given size.
5. Explain the sine bar with a sketch. Why is it not used above 45°?
6. Define tolerance, allowance and fits. Compare hole basis and shaft basis systems.
7. Find limits for a given fit (e.g. 25 H7/g6) and design GO / NO-GO gauges. State Taylor's principle.
8. Explain the working of a pneumatic comparator and an LVDT.
9. Define Ra and Rz. Explain the three-wire method for effective diameter.

10. Explain the working principle of a strain gauge and a thermocouple.

TIP In GATE ME, metrology questions are mostly on limits and fits (clearance / interference values), gauge design, slip gauges, sine bar, three-wire method and optical flat fringes. They are short and scoring.