Measuring Principles

YORK COLLEGE & UNIVERSITY CENTRE

Measuring Device Characteristics

- There are several characteristics of a measuring device which determine how and when it is used

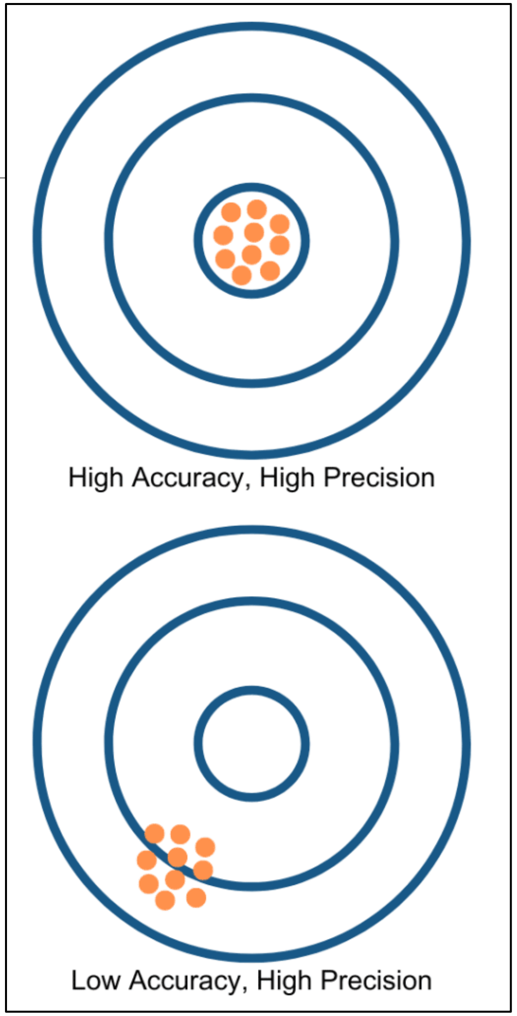
- These are:

  - Precision
  - Accuracy
  - Uncertainty
  - Resolution
  - Calibration
  - Tolerance

Precision

- **Definition:**
  - Precision is the degree of consistency or repeatability in a series of measurements.
  - It shows how close measurements are to each other, not necessarily to the true value.

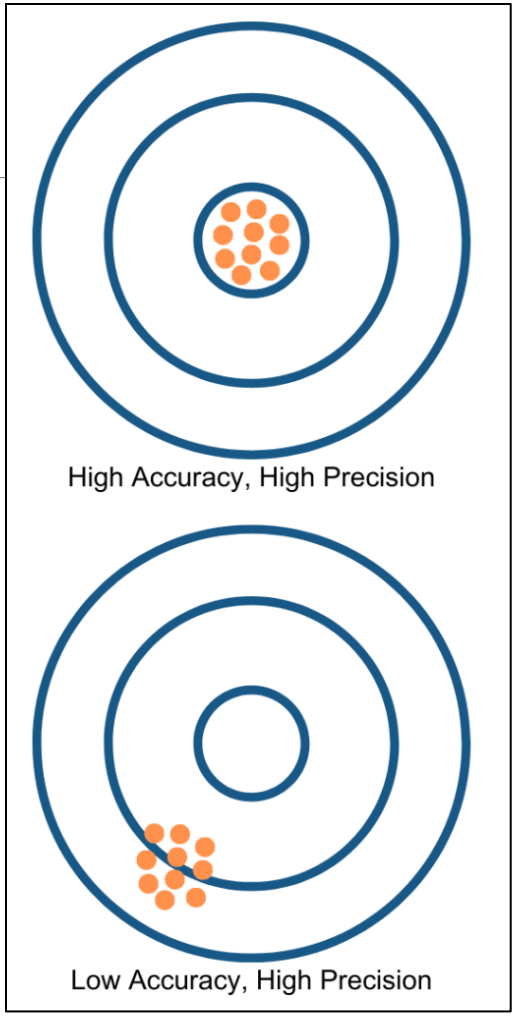
- **Key Points:**
  - A precise instrument produces similar readings each time under the same conditions.
  - Precision depends on resolution, measurement technique, and operator consistency.
  - Precision ≠ Accuracy – you can be precise but still wrong (if there's systematic error).



Precision

- **Example:**
  - Measuring a 10 mm pin:
    - Readings of 9.98 mm, 9.99 mm, 9.98 mm → High precision
    - Readings of 9.85 mm, 10.15 mm, 9.90 mm → Low precision

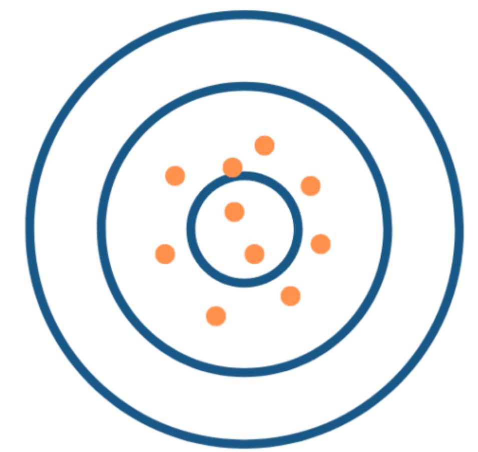
- **Improving Precision:**
  - Use instruments with finer resolution (e.g., micrometer over a rule).
  - Keep steady measuring force (use ratchet stop when available).
  - Maintain constant temperature and clean surfaces.
  - Repeat measurements and calculate the mean value.



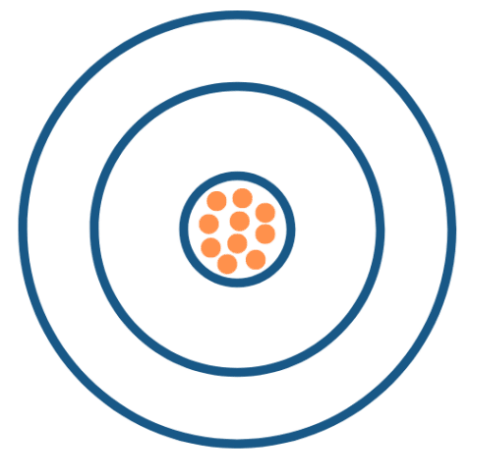
Accuracy

- **Definition:**
  - Accuracy is how close a measured value is to the true or accepted value.
  - It shows correctness, not repeatability.

- **Key Points:**
  - An accurate measurement is free from systematic error.
  - High accuracy requires proper calibration and error reduction.
  - Accuracy ≠ Precision – you can be accurate once but not consistent.



High Accuracy, Low Precision

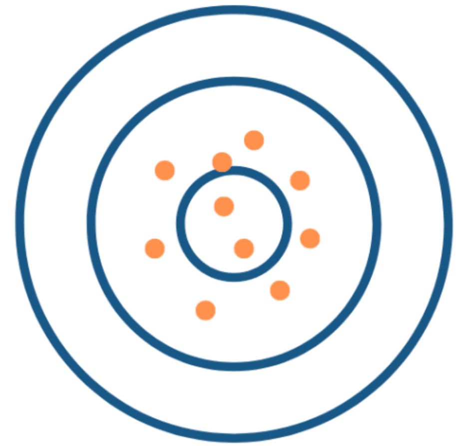


High Accuracy, High Precision

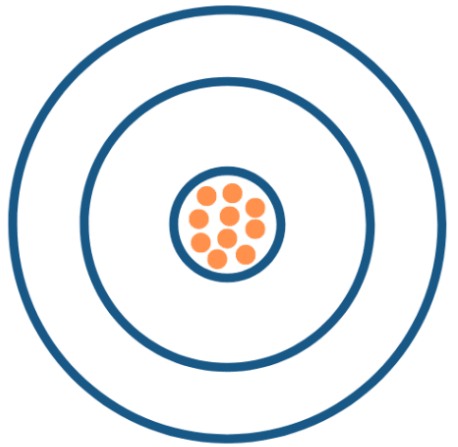
Accuracy

- **Example:**
  - True dimension: 10.00 mm
    - Measurements: 9.99 mm, 10.01 mm, 9.98 mm → Accurate and precise
    - Measurements: 10.00 mm, 10.20 mm, 10.40 mm → Accurate once, not precise
    - Measurements: 9.80 mm, 9.81 mm, 9.80 mm → Precise but not accurate

- **Improving Accuracy:**
  - Regularly calibrate instruments against known standards (e.g., slip gauges).
  - Zero instruments before each use.
  - Minimise parallax and operator bias.
  - Control environmental factors like temperature and vibration.



High Accuracy, Low Precision



High Accuracy, High Precision

Uncertainty

- **Definition:**
  - Uncertainty is the doubt that exists about the result of any measurement.
  - It expresses the range within which the true value is expected to lie.

- **Key Points:**
  - Every measurement has some uncertainty — no measurement is perfectly exact.
  - It combines errors from:
    - Instrument resolution (e.g., smallest scale division)
    - Calibration error (difference from reference standard)
    - Environmental effects (temperature, vibration, dirt)
    - Human error (reading, alignment, pressure)

$$123 \pm 1cm$$

Could be any value from 122cm to 124cm

Uncertainty

Written as:

$$Measured\ Value = Best\ estimate\ \pm Uncertainty$$

$$\mathbf{123 \pm 1}\boldsymbol{cm}$$

- **Reducing Uncertainty:**
  - Use instruments with higher resolution.
  - Calibrate before and after measurements.
  - Take multiple readings and calculate the mean.
  - Control measurement conditions (temperature, cleanliness, technique).

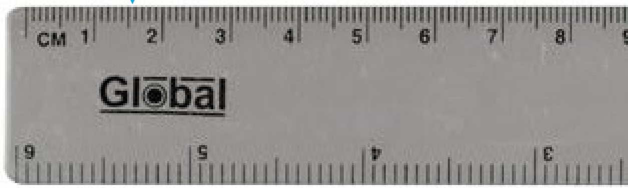
Could be any value from 122cm to 124cm

Resolution

- **Definition:**
  - Resolution is the smallest change in quantity that an instrument can detect or display.
  - It determines how “fine” or “granular” a measurement can be.

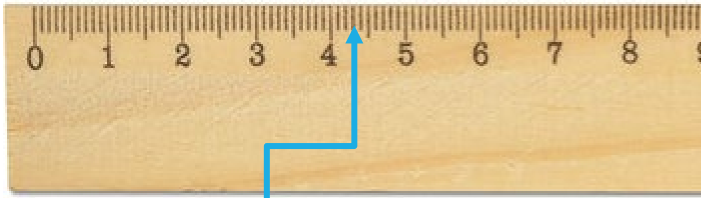
- **Key Points:**
  - Higher resolution = smaller detectable increments.
  - Resolution limits how precisely you can record a measurement, even if accuracy is high.
  - Digital instruments typically show resolution directly (e.g., 0.01 mm).
  - Analogue instruments depend on scale spacing and operator judgement.

Smallest measurement (resolution) = 1mm



Ruler

Meter Stick



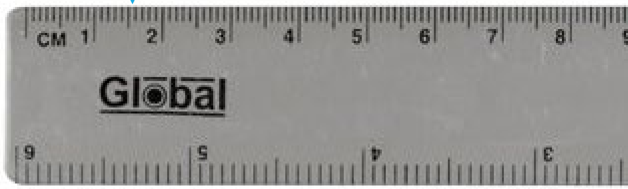
Smallest measurement (Resolution) = 1cm

Resolution

- **Examples:**
  - Steel rule: typically, 1 mm resolution → cannot reliably measure smaller changes.
  - Digital calliper: 0.01 mm resolution → detects much finer differences.
  - Micrometer: often 0.001 mm resolution → very high precision work.

- **Why Resolution Matters:**
  - A measurement can never be more precise than the instrument's resolution.
  - Low resolution increases uncertainty and reduces precision.
  - Choosing the wrong resolution for a task leads to poor data and bad decisions.

Smallest measurement (resolution) = 1mm



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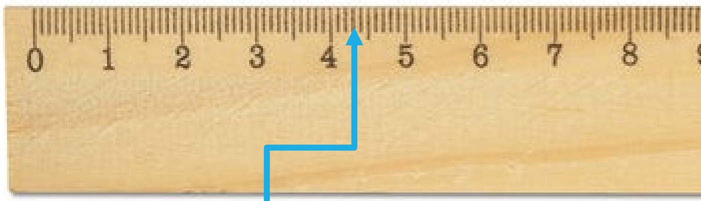


Smallest measurement (Resolution) = 1cm

Calibration

- **Definition:**
  - Calibration is the process of comparing a measuring instrument against a known, traceable standard to ensure its readings are accurate.
  - Adjustments are made if the instrument shows consistent error.

- **Key Points:**
  - Ensures measurements are accurate, reliable, and traceable to national/international standards.
  - Calibration identifies:
    - Systematic errors (consistent offset)
    - Wear or damage to measuring surfaces
    - Drift over time
  - Critical for tools used in quality control, inspection, and tight-tolerance work.

Calibration

- **Examples of Calibration:**
  - Using slip gauges to check/adjust zero on callipers or micrometers.
  - Checking a DTI against a gauge block to confirm it reads equal movement.
  - CMMs performing automated probe calibration routines before measuring a part.

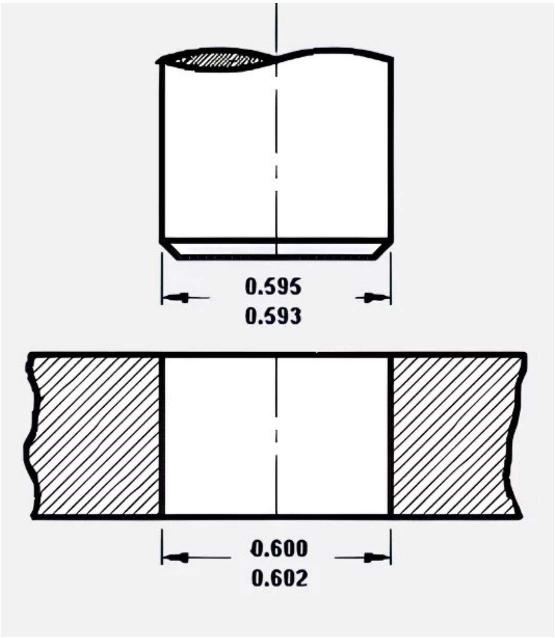
- **When to Calibrate:**
  - On a regular schedule (e.g., every 6–12 months).
  - After damage, dropping, or suspected error.
  - Before critical inspection tasks.
  - When environmental conditions change significantly.

- **Why Calibration Matters:**
  - Prevents inaccurate measurements, scrap parts, and inspection failures.
  - Ensures compliance with ISO quality standards.
  - Supports the chain of measurement traceability in engineering.

Tolerance

- **Definition:**
  - Tolerance is the permissible limit of variation in a physical dimension.
  - It defines how much a measured value can deviate from the nominal (design) size and still be acceptable.

- **Key Points:**
  - No part can be made exactly to size — tolerances allow for manufacturing variation.
  - Specified as plus/minus limits or upper and lower bounds.
  - Ensures parts fit and function correctly (e.g., clearance or interference fits).
  - Smaller tolerance = tighter control, higher cost.



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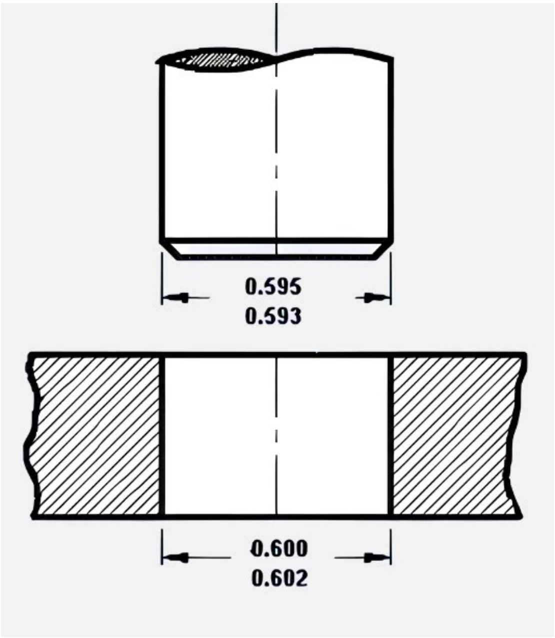
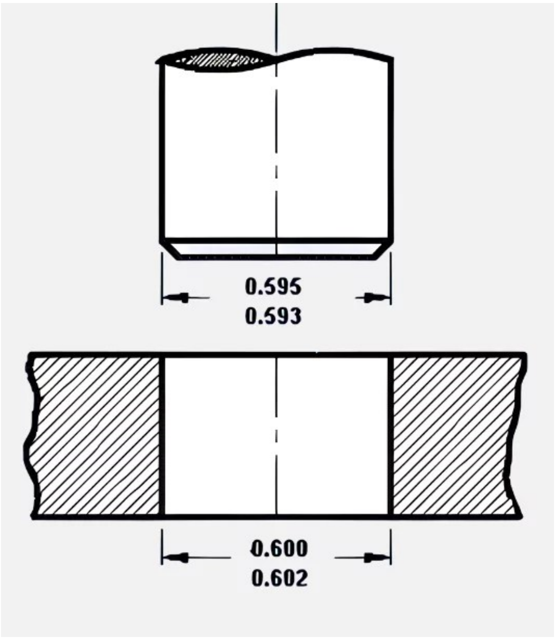


Tolerance

- **Why Tolerance Matters:**
  - Allows interchangeability of parts.
  - Prevents assembly failure or excessive looseness.
  - Balances manufacturing cost and functional requirement.
- **Connection to Principles:**
  - Precision and accuracy ensure the part stays within tolerance.
  - Calibration and resolution affect how tolerance is verified.
  - Uncertainty must be smaller than the tolerance band to ensure confidence in results.



Typical Tolerances (3D Printing)

Desired Fit	Clearance Gap (in)	Clearance Gap (mm)
Press Fit	Line to Line	Line to Line
Tight Fit	0.005	0.127
Normal Fit	0.010	0.254
Loose Fit	0.020	0.508

Typical Tolerances (Metal)

LINEAR DIMENSIONS:

Permissible deviations in mm for ranges in nominal lengths	f (fine)	Tolerance class designation (description)		v (very coarse)
		m (medium)	c (coarse)	
0.5 up to 3	±0.05	±0.1	±0.2	-
over 3 up to 6	±0.05	±0.1	±0.3	±0.5
over 6 up to 30	±0.1	±0.2	±0.5	±1.0
over 30 up to 120	±0.15	±0.3	±0.8	±1.5
over 120 up to 400	±0.2	±0.5	±1.2	±2.5
over 400 up to 1000	±0.3	±0.8	±2.0	±4.0
over 1000 up to 2000	±0.5	±1.2	±3.0	±6.0
over 2000 up to 4000	-	±2.0	±4.0	±8.0

Parallax Error

- **Definition:**
  - Parallax is the apparent shift in a reading when the observer's eye is not directly in line with the measurement scale and pointer.
  - It causes incorrect readings on analogue instruments or scales.

- **Example:**
  - Looking at a rule or dial from an angle makes the reading appear higher or lower than the true value.

- **How to Avoid It:**
  - Keep your eye directly above the scale mark or pointer.
  - Use instruments with mirror-backed scales (reflection lines up with pointer).
  - For digital tools, parallax is eliminated.