Technical Guide
Simple Linear Measurement Instruments

Third Edition July 2020

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Contents

1 Introduction

Linear measurements are made for a variety of reasons by many different people. Some merely need to establish an approximate length by means of a steel rule while others who need a higher degree of accuracy may use a micrometer. Whatever the reason, the instrument used must be able to provide the needed level of accuracy.

This IANZ Technical Guide seeks to provide some general advice on the use, care and calibration of simple linear measurement instruments.

2 The Measuring System

A measuring instrument is only one component of any measuring system. Usually the instrument is the most predictable part of the system if it is properly cared for and calibrated. Its intrinsic “accuracy” can be well known i.e. the value of what it reads is known to defined physical limits.

The same cannot be said for the other components of the measuring system such as the object being measured, the environment, and the people making measurements.

Awkward shapes, rough surfaces, difficult access for measuring instruments are typical of the difficulties which can be encountered with the object. In linear measurement particularly, the size of the object can influence the result as well as non-parallel faces or tapers in cylindrical shapes. Each in its own way can lead to errors in the measurement and must be taken into account when deciding how a measurement will be made and how good the result is likely to be.

Environment is equally important. Cramped and fatiguing work conditions or even lack of reasonable temperature control can lead to significant measurement errors.

The level of success of the measuring system, however, depends heavily upon the people. It is their decision which instrument is to be used, how it will be applied to the job and whether or not the desired result can be achieved in the prevailing environment. This demands experience, skill, thoroughness and, above all, judgement. Nevertheless, being human, in spite of these qualities, errors can and will occur.

All these components conspire to make the result uncertain. Just how uncertain is a matter for careful assessment. In the final analysis, for any measurement to have real meaning an “uncertainty” must also be stated. This is usually expressed as a range of values which contains the “true” value of the measurement. It is the whole system which decides the quality of a test or measurement and it is the system which IANZ evaluates in its assessments for accreditation.

The focus of the Guide, however, will be on the component which can be defined and, therefore, provide a benchmark for measurements, i.e. the instrument. It will be assumed that the instrument is in good condition, is being used properly and is calibrated.

3 Choosing the Measuring Instrument

In most situations a relatively small range of measuring instruments will be adequate. The best choice for any particular job will be the one which accounts for the following variables:

(a) The size of the job

(b) The geometry of the job

(c) The accuracy required.

Choosing for size and geometry is usually self-evident and need not be elaborated upon here. While the accuracy of the instrument is critical to the quality of the measurement, it is not the only source of error. The other parts noted earlier must be taken into account to assess the overall uncertainty of the measurement. Since these parts can vary widely from job to job, it is not practical to be specific about the uncertainties likely to apply to a particular instrument. Nevertheless, some feel for what can be achieved is useful as a guide to choice. Table 1 provides a guide for a range of simple linear measurement instruments which might be considered typical of those used in a testing laboratory.

Table 1: Choosing the appropriate measuring instrument

Instrument	Common Range (mm)	Typical Scale Markings (mm)	Least Uncertainty of measurement (mm)
Straight edges	Not applicable	Not applicable	0.03
Feeler gauges	1.0 to 0.03	Not applicable	0.02
Steel rules	Up to 2000	0.5	0.5 to 1.0
Steel tapes	Over 1000	1.0	1 mm per metre
Vernier calipers	Up to 1000	0.02 to 0.05	0.1 to 0.2
Micrometers	Up to 300	0.001 to 0.01	0.01 to 0.1
Dial gauges	Up to 50	0.01	0.03 to 0.1

Note: *"Least uncertainty" is synonymous with "best measurement capability". It is the smallest uncertainty of measurement that can realistically be expected under **ideal** conditions. In the above table it is generally assumed to be 10x the scale markings in mm.*

The above estimates of uncertainty could be reasonably expected from an experienced operator, under good laboratory conditions, on a job which poses no particular complications, using the instrument according to the manufacturer's instructions. They should be used with caution because every job must be judged on its own merits.

Reputable manufacturers produce instruments which conform to standards. For example, there are British Standards for all the instruments noted above. The Standard will specify the limits of all the important features of the instrument. By evaluating these features, the instrument's overall performance can be assessed and maintained. The way to ensure that an instrument's accuracy remains within the limits specified for these features is by regular calibration or checking.

4 Care of Measuring Instruments

The condition of an instrument can affect its calibration and hence its suitability for use. While this Guide cannot exhaustively cover all aspects of choice and care of instruments, for the limited list of basic instruments in Table 1, it is possible to provide some general guidelines. In Table 2, the appropriate British Standard is included, but it is appreciated that equivalent standards might apply.

Table 2: Care of measuring instruments

Instrument (British Standard)	Common Problems	Precaution (Visually inspect before use)
Straight edges BS 5204:Part 2:1977	Wear, nicks and damage if left unguarded.	Lightly grease when not in use and clean before use.
Feeler gauges BS 957: Part 1:1941 (1969)	Kinking, bending and tearing.	Lightly grease when not in use and clean before use. Keep in protective container.
Steel Rule BS 4372:1968 – Engineering BS 4035:1966 BS 4484:Part 1:1969 – Construction	Wear or damage to the square end, which is usually the zero graduation. Straightness. Permanent bends and flatness. Obscuring of graduation from wear or corrosion.	Keep in protective sheath.
Steel Tapes BS 4035:1966 BS 4484:Part 1:1969	Kinking or abrasion of the printed scale. Condition of end fittings.	Safe storage and care in use.
Vernier calipers BS 887:1982	Burrs and wear. Straightness of beam. Squareness of the jaws to the beam. Uniformity of alignment and fit of sliding units.	Keep in a properly designed case. Routine checks (6.5.1).

Instrument (British Standard)	Common Problems	Precaution (Visually inspect before use)
Micrometers BS 870:1950	Burrs on anvils, distortions of the frame. Backlash.	Keep in protective case. Routine checks (6.6.1)
Dial gauges BS 907:1965	“Stickiness” or roughness in the movement. Inspect damage to pivots, bearings or gears. Bent, loose or broken needles. Bent needle spindle.	Keep clean at all times. Never lubricate plunger. Routine checks (6.7.1).

The key to care is protection against corrosion and damage.

5 Calibration

All instruments are calibrated by comparing their important features against other instruments or comparison reference standards of known accuracy. Such comparisons on calibrations must be performed by competent people using known procedures. The reference equipment has previously been similarly checked by higher order equipment and so on until finally the chain of successive calibrations ends at the relevant SI unit.

This concept of “traceability” is extremely important in ensuring compatibility of measurement not only nationally but also internationally. The links are maintained between countries by the National Metrology Institutes inter-comparing their measurements with one another. Traceability of measurement and calibration are fundamental measurement practices and are essential elements of IANZ criteria for accreditation. The IANZ policy of traceability of measurement is specified the IANZ publication *AS TP 1: Traceability of Measurement*.

Calibration may be conducted in-house if the necessary facilities (such as certificated references) and appropriately experienced staff are available. Alternatively, the instrument can be referred to an appropriate calibration and metrology laboratory. Generally, it is appropriate to carry out partial calibrations or “routine checks” in-house. Sometimes it is necessary for the instrument to be sent to an appropriate calibration and metrology laboratory for a complete calibration. In any event, the equipment used to check it will be calibrated by an appropriate calibration laboratory in order to confirm and maintain traceability.

Generally speaking, IANZ encourages as much in-house calibration as practical and is always prepared to advise on systems suitable for a particular laboratory’s needs. Alternatively, advice can be obtained from an accredited laboratory or from the Measurement Standards Laboratory.

6 Uncertainty of Measurement

ISO/IEC 17025 requires laboratories, testing laboratories as well as calibration laboratories, to determine the uncertainty of each of their measurements. Obviously, for equipment being used to make measurements in testing, the starting point for this determination will be an awareness of the uncertainty contribution provided from each measuring instrument. Accredited metrology laboratories are required to report the uncertainty for their calibrations and all IANZ endorsed calibration certificates will provide this information. As appropriate, this data can be directly used in the testing laboratory’s own determination of uncertainty of measurement in testing.

When a testing laboratory chooses to carry out its own in-house calibration, the uncertainty of that calibration will need to be determined using appropriate methods. Depending on the degree of rigor required, there are a number of different approaches to this. Various guidance documents are available and testing laboratories should adopt methods appropriated for their purposes.

7 Calibration of Simple Linear Measuring Equipment

Most simple linear measuring instruments are amenable to in-house calibration. Once again, the general criteria for a good measuring system applies and an evaluation of the object being measured, the environment and the people must be considered.

For a calibration system, the instrument being calibrated is usually well defined and far less variable than a general test sample. Nevertheless, the condition of the instrument under calibration can markedly affect the uncertainty associated with the results. Proper care and maintenance of instruments can minimise the problem.

Measuring systems for calibration purposes need more attention to environmental detail than do general test samples. When calibrating linear measuring instruments clean surroundings, freedom from vibration, good lighting and a measure of temperature control are among the more important factors. Temperature can be particularly important. Most linear measuring instruments are certified “correct” at 20 °C. If the temperature at the time of calibration differs from this, its effect must be assessed and, if necessary, the appropriate corrections made. The importance of environment will depend upon the nature of the job. This effect must be carefully judged and the environment adjusted to cater for the reliability of results which is needed.

The person responsible for in-house calibration may need additional skills or different skills from those associated with making general measurements. In terms of skill, an operator’s suitability for the job can be judged on the basis of manual dexterity in handling the instruments, understanding of the physical and technical factors involved and understanding of the procedures applying to the job. Other attributes include care and attention in handling and maintaining instruments, a thorough approach to documentation and record-keeping and a generally fastidious approach to housekeeping. Guidance for the design of documentation to record calibration details is given in Appendix I.

7.1 Calibration of Straight Edges

Straight edges are not readily calibrated in-house. However, if two straight edges of similar lengths are available, a comparison can be done by placing them together and viewing any gap. Any light indicates a gap of at least 0.0025 mm. Straight edges are available in four forms: “I” section, bow-shaped, rectangular (with or without bevel on one edge) and toolmakers or knife edge straight edges.

A careful visual inspection of the working edge each time a straight edge is used is good practice. Any evidence of wear or damage should prompt recalibration or replacement, depending upon the extent of the problem.

7.2 Calibration of Feeler Gauges

Unless special levels of accuracy are required, feeler gauges can be calibrated in-house using a properly calibrated micrometer. Visual inspection each time a gauge is used is good practice and evidence of wear or damage should prompt recalibration or replacement.

7.3 Calibration of Steel Rules

The in-house calibration of steel rules is done by comparison with another rule and straight edge. Suitable rules or graduated straight edges are available up to two metres long. A rigid, flat surface is important for a reliable calibration, and an end-stop or other suitable fitting can facilitate alignment of the zero graduations. A magnifying lens is useful in assessing small discrepancies, especially on finely graduated rules.

The reference rule must not be used for any other purpose. It might have to be periodically calibrated by an appropriate metrology laboratory.

Careful visual inspection of the working rule each time it is used is good practice. Evidence of wear or damage should prompt recalibration or replacement.

7.4 Calibration of Steel Tapes

In common with steel rules, a tape is calibrated by direct comparison, usually with another steel tape. However, a little more attention is needed to the procedure.

The more common tapes, usually referred to as “tape rules”, are available in lengths up to about ten metres. They are usually provided with end fittings, which compensate for “end-on” or “hook over” measurements. While some are marked with etched graduations, most modern varieties are epoxy coated over printed graduations.

Steel measuring tapes available in lengths up to 100 metres are provided with engraved, etched or printed scales. For all except tapes of the highest quality, however, the manufacturing trend is towards epoxy coated, printed scales. End fittings are usually of the “hook over” variety but special end fittings for particular applications are available.

In general, in-house calibration of tapes more than ten metres long is not recommended. Above this length, the facilities needed become rather specialised and external calibration services should be sought. It is always important to know the accuracy to which the tape needs to conform.

For tape rules, no special precautions are necessary and calibration can be carried out on a flat, rigid bed against a steel rule or steel tape scale, usually depending upon the length. Suitable end fittings to provide a datum for “end on” and “hook over” checks are needed.

The accuracy of the higher quality tapes is normally specified with the tape fully supported along its length under a specific tension at 20 °C. The applied tension is typically 50 N but this can vary and the manufacturer’s specification must be checked. Calibration procedures should include instructions for applying the correct tension to both reference and test tapes. Means for ensuring correct zero alignment will be needed, depending upon the type of end fitting provided. Reference tapes should be used for no other purpose and should be calibrated periodically by an appropriate metrology laboratory.

7.5 Calibration of Vernier Calipers

7.5.1 In-house Calibration

Vernier calipers differ from most other measuring instruments in that the line of the scale is offset from the line of measurement. Accuracy, therefore, is very sensitive to consistency in the geometry of an instrument. This is influenced by the straightness of the beam, the squareness of the jaws to the beam and the alignment of the sliding unit.

Scales are normally designed to be read directly to 0.05 mm, with the exception of some dial or electronic calipers which read in 0.02 mm or 0.01 mm. To get the best performance from a Vernier caliper:

(a) Learn to acquire the correct “feel” to ensure that the measuring faces are square to the line of measurement and make firm contact without straining

(b) Avoid “springing” the measuring jaws since errors induced in this way are enhanced by the displacement of the line of measurement from the line of the scale

(c) Always use the locking screw on the sliding unit before taking a reading. This prevents inadvertent movement and, more importantly, ensures consistent alignment with the beam

(d) Do not hold an instrument in the hand any longer than is necessary. Hand heat is sufficient to cause thermal expansion, adding to the inaccuracies inherent in the system

(e) Get into the habit of doing **routine checks** regularly, perhaps even each time the instrument is used, as follows:

    (i) Check that the sliding unit is a good sliding fit on the beam. Any build-up of dirt on the slide should be cleaned off. The clamp should be in working order

    (ii) Check that the beam is straight and that the measuring jaws line up properly. Upper and lower jaws should lie in the same plane and the measuring faces should show no evidence of irregular gaps when they are brought together. Visual inspection is sufficient

    (iii) Check the measuring faces for burrs and wear

    (iv) When the jaws are closed, check that the Vernier indicates correct zero

    (v) Check several points in the working range of the Vernier against reference gauge blocks or length bars.

7.5.2 Features of Vernier Calipers examined by Metrology Laboratories

Flatness and straightness of the beam
Determined by comparison with a calibrated straight edge for straightness and a calibrated surface plate for flatness.

Co-planar relationship of the jaws
Determined using a calibrated straight edge and feeler gauges.

Flatness and parallelism of the measuring faces
Parallelism can be assessed visually with the jaws brought together against a strong light source. Flatness of each jaw can be checked against a calibrated straight edge or against optical flats.

Squareness of the measuring faces to the inner edge of the beam
Determined by comparison with a calibrated square.

Combined width of jaws
This feature is applicable only to instruments manufactured in accordance with British Standards with jaws suited to both internal and external measurements. It may be measured with a calibrated micrometer. Other calipers should have the internal measurement facility calibrated separately, similar to the external, by comparison with gauge blocks.

7.6 Calibration of Micrometers

7.6.1 In-house Calibration

The micrometer is among the most commonly used measuring instruments. Direct readings to 0.01 mm (0.001 inch) are normal, with the addition of a Vernier scale readings to 0.001 mm (0.0001 inch) are possible.

To get the best performance from a micrometer in use:

(a) Never use undue force

(b) Use the ratchet if fitted, or learn to acquire the correct "feel" to give constant measuring force

(c) Make sure the measuring faces are square to the object being measured

(d) Always check that the anvil faces are clean

(e) Do not hold in the hand longer than necessary as hand heat will cause expansion, adding to the inaccuracies inherent in the system

(f) Get into the habit of doing **routine checks** regularly, perhaps even each time an instrument is used as follows:

   (i) Check that the spindle runs freely and smoothly throughout the length of its travel. There should be no perceptible backlash between the spindle screw and nut. Provided wear is relatively uniform along the screw, the accuracy can be restored by adjusting the wear compensating mechanism and re-setting the zero

   (ii) Clean the anvils carefully and examine for burrs

   (iii) Check that the micrometer indicates correct zero

   (iv) Examine for accumulated dirt, especially on the screw. Clean the instrument if necessary and keep the screw very lightly lubricated

   (v) Check several points in the working range of the micrometer using appropriate reference gauge blocks.

7.6.2 Features of Micrometers examined by Metrology Laboratories

(a) Flatness of the anvils. Determined by using optical flats

(b) Parallelism of the anvils. Determined by using optical parallels

(c) Zero reading, range of error for traverse, error of alignment and measuring force. The length of the setting rod is also calibrated if included.

7.6.3 Errors

"Progressive error" is the cumulative error over the total travel of the micrometer. These arise as the thimble is rotated from the zero through variations in the pitch of the thread. They add cumulatively as rotation progresses.

"Periodic error" is an error which occurs through a single revolution of the thimble and does not add up progressively. The usual causes are "drunkenness" of the screw thread or eccentricity of the thimble or its graduations.

The error at any setting of the micrometer is the sum of the progressive and periodic errors found at that setting. These errors can only be determined using reference gauge blocks of selected known sizes.

7.7 Calibration of Dial Gauges

7.7.1 In-house Calibration

Dial gauges are easy to use, accurate and relatively inexpensive instruments. However, because of their mechanical complexity, they need particular care in their use and maintenance. The mechanism consists of a rack on a plunger extension which actuates, through gears, a pinion carrying a pointer. Means for eliminating backlash are incorporated in the mechanism. A tension spring is provided to keep the plunger tip in contact with the workpiece. A revolution counter is fitted when the pointer movement exceeds a single revolution. The plunger of a dial gauge is intended to work dry in its close fitting bush and should never be lubricated. Even light oil will pick up dust which can cause the plunger to stick.

A dial gauge can be used as:

(a) A comparator for the measurement of small differences in dimension

(b) A direct measuring instrument

(c) A stable indicator

(d) A component of a gauge or gauging fixture (dial calipers).

To get the best performance from a dial gauge:

(a) Ensure that the dial gauge mounting is sufficiently rigid. Lack of rigidity in mountings is a very common fault and seriously detracts from the accuracy of the system

(b) Ensure that the dial gauge is square to the axis of measurement

(c) Never release the plunger so that the contact point impacts on the workpiece. This can damage the rack

(d) Avoid sideways force on the plunger

(e) Avoid excessive plunger movement

(f) When clamping a dial gauge over the cylindrically ground stem provided, exercise care not to distort the stem causing the plunger to stick or jam in its bearing

(g) Get into the habit of doing **routine checks** regularly, perhaps even each time an instrument is used as follows:

  (i) Check that the instrument is clean, with no obvious signs of damage

  (ii) Check that the plunger moves smoothly. Be careful not to damage the spring loading

  (iii) Set the adjustable zero and ensure that the pointer returns properly to zero when a displacement is applied to the plunger and released gently.

7.7.2 Features of Dial Gauges examined by Metrology Laboratories

The pointer is checked for position, whether it is firmly attached, whether it suffers from parallax error and whether the spindle is visibly bent.

The plunger is checked for freedom of movement and for the existence of any shake, including rotational.

The measuring force of the dial gauge is also measured.

The dial gauge is checked for repeatability of reading by rolling a suitably sized roller under the dial gauge from several different directions. The dial gauge is also checked by making repeat readings of a flat surface with the spindle being lowered both rapidly and slowly. A dial gauge should repeat readings to better than 1/5th division.

Discrimination is the ability of an instrument to resolve small gradual changes of readings. This is done on dial gauges to BS using an eccentric mandrel having a known runout. The dial gauge should indicate the runout (2½ divisions to British Standards) to within 1/3 division.

Errors of indication are checked over several intervals for compliance to British Standards: these are any ten divisions, any half turn, any one turn, any two turns and over the total travel. This is intended to determine any errors due to a bent needle spindle, eccentric face, damaged gears, etc. This is done by gauge blocks, micrometers or, lastly, by an interferometer.

8 Comparison of Reference Standards

These are used to check the measuring instrument being used to make a measurement.

It is important that they are of similar geometry to the object measured and their size is known to a high enough accuracy.

Comparison or setting gauges may be manufactured in-house or purchased from a manufacturer.

If purchasing or manufacturing in-house, consideration must be given to correctness of geometry; the size can be determined by the calibration laboratory.

Some examples of standards suitable for instruments making measurements are:

Type of measurement	Standard for checking measuring instruments
External diameter	Plug gauges Micrometer setting rods Micrometer check blocks
Internal diameter	Ring gauges Micrometer setting rods Check blocks
Wall thickness by dial gauges	Step gauges
Lengths	Micrometer setting rods Check blocks Step gauges

8.1 Calibration of Standards by Metrology Laboratories

To maintain traceability of measurement, calibration must be performed by appropriate metrology laboratories, which can calibrate comparison or reference standards to at least better than five to ten times the requirements of the instrument being checked against the standard.

9 Frequency of Calibration

The frequency of calibration of instruments is very dependent upon the use and abuse to which they are subjected. Damage calls for immediate recalibration. Heavy use may call for shorter intervals between calibration.

Each situation must be assessed on its own merits and calibration intervals set accordingly. The recommended maximum periods between successive calibrations is likely to apply only to those instruments reserved solely for calibration purposes.

Table 3: Frequency of calibration

Instrument	External Calibrations of Reference Items (Years)	Internal Calibration of Working Items
Straight edges	See text	Initial commissioning calibration, then check for surface damage and "burrs" whenever used.
Feeler gauges	See text	Initial commissioning calibration, then check for surface damage and "burrs" whenever used.
Steel rules	5	Initial commissioning calibration, then visually inspect whenever used.
Steel tapes	5	Initial commissioning calibration, then visually inspect whenever used.
Vernier calipers	3	Check zero, and general conditions whenever used. Regularly check several points in the working range against certificated references.
Dial calipers	3	Check zero, and general conditions whenever used. Regularly check several points in the working range against certificated references.
Micrometer	5	Check zero, and general conditions whenever used. Regularly check several points in the working range against certificated references.
Dial gauges	2	Check zero, and general conditions whenever used. Regularly check several points in the working range against certificated references.
Gauge blocks (or length bars)	4	Initial commissioning calibration, then visually inspect whenever used.

10 Notes to Remember

(a) All reference instruments which are used to carry out in-house calibration will need to have an external calibration by an appropriate metrology laboratory

(b) Proper care and use of instruments will help to maximise the interval between calibrations. Do not use reference instruments in a factory or workshop environment

(c) Rigorous routine checking will alert for maintenance needs and instrument re-calibration needs. It will also provide the necessary assurance that an instrument is remaining in good order

(d) The cost of calibration is easier to recover than is a lost reputation.

Appendix 1: Guidelines for In-house Calibration Certificates

The following guidelines concern documentation designed to confirm traceability as well as reproducibility of any calibration performed.

Administrative Details

(a) Name and serial number of item or any form of unique identification

(b) Date of calibration

(c) Name of person performing calibration

(d) Name of second person who checked any calculations

(e) Name and address of laboratory

(f) Title of certificate

(g) Page numbering (i.e. page ___ of ___ pages)

(h) Report number (on each page) so as to allow easy reference to any inventory, maintenance or calibration reminder schedules.

Procedural Details (available somewhere in the records – not necessarily in the report)

(a) The calibration procedure (if possible, sketch any equipment set-up)

(b) The source of traceability of measurement and calibration (quote reference certificate if appropriate)

(c) Environmental conditions during calibration.

Calibration Results

(a) Reference reading (units)

(b) Item reading (units) (repeat measurements if any and the average)

(c) Difference (units).

Conclusions

(a) Any limitations in use of item

(b) Statement of uncertainty of measurement with 95 % level of confidence.