Karelia University of Applied Sciences
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Investigating Cost-Effective Calibration Methods for Handheld Measurement Devices: A Study on Vernier & Digital Calipers and Micrometers

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To measure physical quantity, the instrument being used should be reliable. Reliability of the instrument is achieved by calibration. Calibration of the instruments may cost a huge amount of financial burden in the small and medium companies. Therefore, this thesis aimed to investigate economical ways to calibrate precision measurement tools such as micrometers, vernier calipers, and digital calipers, in compliance with ISO.
In this study, ISO 3611:2023, ISO 13385-1:2019, ISO/IEC GUIDE 98-3:2008(E), ISO 14978:2019, ISO 14253-5, NPL Good Practice Guides, Mitutoyo Guides and some other online contents were utilized for research methodologies. This research was quantitative research method. Therefore, a hands-on lab experiment was conducted in the laboratory of Karelia University of Applied Sciences for calibration. Basically, gauge blocks were used at various ranges of devices to collect samples. Next, these samples were compared with true sizes of blocks then accuracies were computed. After that accuracies were further compared with MPEs of the devices. This determines acceptance or not acceptance. Then, standard deviation and uncertainties were calculated to check the precision of the devices. All these calibration data, and time keeping were recorded on excel templates. To assess these data graphs and normal distribution curves were plotted, this gave insights on accuracy, precision, and nature of observed samples. Next, quotations were obtained from various companies, and compared their prices against in-house price to obtain the most economical way of calibration.
It was discovered that in-house calibration was the most cost-effective calibration way to keep instruments calibrated. The results of this thesis suggest that the developed calibration practice helps to save time and cost as well as assures the measurement reliability of the device. Besides, this study indicates this calibration methodologies may be fruitful for SMEs, quality departments and engineering schools.

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Handheld Tools, Precision Measurement, Calibration, ISO 3611:2023, ISO 13385-1:2019, ISO/IEC GUIDE 98-3:2008(E), ISO 14978:2019, ISO 14253-5, Accuracy and Precision, Uncertainty of measurement, Vernier Caliper, Micrometer, Gauge Block, In-house calibration, Accredited laboratory calibration

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1 Introduction

The significance of metrology grew during the era of industrialization. Improvements in technology are increasingly demanding enhancements in this sector. We all use metrology in our daily life, sometimes even without realizing it. All the activities related to everything such as industrial, commercial, scientific, and human natures are linked to measurement. In the 21st century, measurements are the fundamental elements for science, technology, healthcare, education, farming, manufacturing, and other areas of human lives. Precision and accuracy in measurements assure the reliability and quality of standards, foster scientific and technical breakthroughs, and increase effectiveness and prosperity of many sectors. The use of exact measures has become essential to modern advancement and excellence.

Therefore, whenever it comes to measuring a physical quantity, the equipment/ instrument that is being used is incredibly important to be calibrated first. Any calibration activity is aimed at assuring accuracy, precision, and reliability of the measuring instrument. It makes sures that measurement equipment provides correct measurement, which is necessary for products and services to be of high quality, safe, and innovative. Calibration relies heavily on ISO (International Organization for Standardization) standards. These standards describe calibration procedures that are recognized in the industry. For a laboratory to prove that their work is precise and of a high caliber, adherence to ISO standards is frequently necessary.

1.1 The goal of the thesis

This thesis delved into the calibration methods of handheld measurement tools, specifically focusing on vernier and digital calipers, as well as micrometers. A comprehensive study of calibration practices and standards was conducted. The study involves hands-on practical experiments conducted in the laboratory of Karelia University of Applied Sciences, and price comparison of both in-house calibration and the outsourcing calibration approach. Finally, recommendation offered for the most economical way to keep instruments calibrated.

1.2 The significance and utilization of the thesis

This thesis offers insights into precision measurement with handheld tools in several areas.

I. Engineering universities: This study gives an idea of the calibration processes of handheld tools along with practical ability. Students who have been studying metrology, mechanical engineering, industrial engineering or related study, this thesis has the potential to advance their knowledge on calibration.

II. Small and Medium-Sized Businesses (SMEs): Small and medium-sized enterprises (SMEs) face challenges in calibrating their precision measurement tools. These SMEs find difficult to set up in-house calibration laboratories, as they lack dedicated metrology departments and skilled lab personnel. Utilizing the thesis can assist them in in-house calibration and in making informed decisions by gaining insights into the financial implications.

III. Departments of Quality Assurance: This study provides comprehensive calibration methodologies based on ISO. This can be used to establish calibration standards and practices. Moreover, it provides insights into cost-effective calibration techniques. This guides them in deciding whether conducting calibration in-house or outsourcing the task makes better financial sense.

2 Calibration in literature

In science, calibration is crucial part. It helps to decide whether the device is reading or measuring correct data or not. These data are used by researchers for further study for some creation and innovation. Therefore, it is important to have some crucial technical jargon and concepts about calibration. This chapter provides a comprehensive introduction to calibration, with an emphasis on accuracy and precision measuring devices such as micrometers, digital calipers and vernier calipers. It also emphasizes how important it is to follow ISO guidelines when calibrating instruments.

2.1 Metrology and measurement

The word metrology is derived from the Greek word ‘metrologia’ which means measure. (Raghavendra and Krishnamurthy, 2013, 5.) In different forms, metrology has existed since antiquity. Early metrological methods used standards that were subjective or arbitrary, determined by local or regional authorities, and frequently taken from practical measurements like an arm's length. According to the International Bureau of Weights and Measures, BIPM (2021, 7), metrology is “the science of measurement, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology.” Similarly, Raghavendra and Krishnamurthy (2013, 5), metrology literally means science of measurements. In real-world contexts, this refers to the implementation, confirmation as well as endorsement of predetermined guidelines. For engineering purposes, metrology is limited to linear and angular values such as dimensions, angles, and other measurements; nevertheless, metrology encompasses a wider range of applications, including industrial inspection, automation, and product creation. In short, metrology deals with both setting up, reproducing, protecting, and maintaining units of measurement and their standards, as well as ensuring their accuracy.

On the other hand, measurement is the act, or the result, of a quantitative comparison between a predetermined standard and an unknown magnitude (Sathyabama Institute of Science and Technology 2020). In a simple term, measurement is the process of comparison of an unknown physical quantity with a similar known standard quantity (Labh and Shrivastav 2019, 3). Whether it is mass, time, length, temperature, or another measurable attribute, a measurement provides a quantitative understanding of that property. Precise and exact measurements are essential in many domains, such as research, engineering, business, and daily life, as they affect decision, quality assurance, and the growth of information and technology.

2.2 Using the International System of Units (SI)

In 1960 AD an international conference held in France decided to use units to make similarities in measurement all over the world. These units are called "System International de units" or SI units in short. The units are extended from MKS system of measurement. (Labh and Shrivastav 2019, 6.) The International System of Units (SI) is a globally adopted and standardized measurements system. This system practice guarantees that measurements performed across various countries maintain uniformity and compatibility.

Therefore, using the right SI units is important in calibrating. It aids to make better measurement. In this thesis, base SI unit “millimeter (mm)” is used for all the measurements taken in the university lab.

2.3 Accuracy and precision

Accuracy is a qualitative term that describes how close a set of measurements are to the actual (true) value while precision describes the spread of these measurements when repeated - a measurement that has high precision has good repeatability. (Auty, Bevan, Hanson, Machin, and Scot 2016, 16). Accuracy is the degree of closeness between a measurement and the true or actual value, while precision indicates the consistency of measurements, but does not guarantee their accuracy.

In addition, the difference between the mean value (or indicated value) and the true value of the set of known standards on the same component is termed as an error (Raghavendra and Krishnamurthy, 2013, 7-8). According to Raghavendra and Krishnamurthy (2013, 8), accuracy of an instrument is always assessed in terms of error. Greater accuracy is associated with a lower magnitude of error in the instrument. Formula for the error and relative error:

$E = V_m - V_t$

Where **E** is the error, **V_m** the measured value, and **V_t** the true value.

% error (Relative error) = (Error / True value) × 100

(Raghavendra and Krishnamurthy, 2013, 8).

Furthermore, figure 1 illustrates the difference between accuracy and precision. It depicts several tests taken on a workpiece using several types of equipment and the same instrument, and the graphs plotted. In Figure 1 numerous measurements represent precision rather than a single measurement. In a set of measurements on one component using the same instrument, precision reflects the consistency and agreement among individual values dispersed around the mean. The scatter of these measurements is designated as **σ**, the standard deviation (SD). It is used as an index of precision. The less the scattering the more precise is the instrument. Therefore, the more accurate the instrument, the smaller the SD value. (Sathyabama Institute of Science and Technology 2020). Figure 2 illustrates formula of ungrouped data mean and sample standard deviation (for precision).

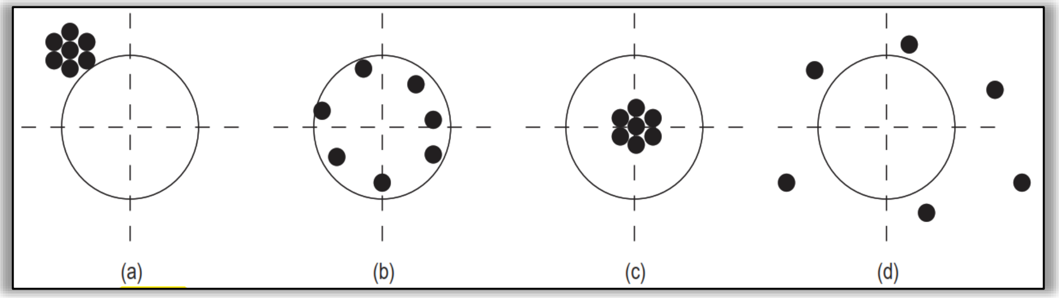
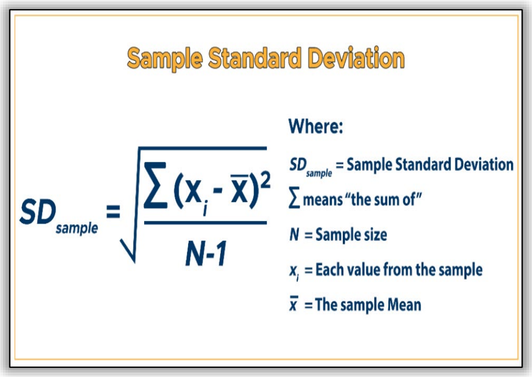
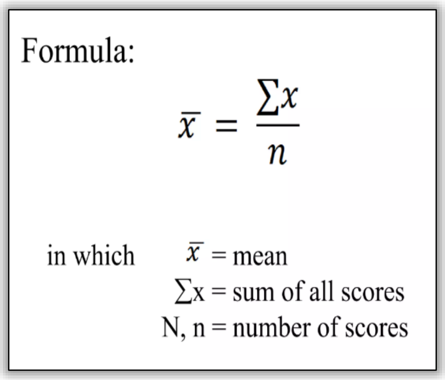


Figure 1. Distinction between accuracy and precision – (a) Precise but not accurate (b) Accurate but not precise (c) Precise and accurate (d) Not precise and not accurate (Raghavendra and Krishnamurthy, 2013, 7)



$$SD_{sample} = \sqrt{\frac{\sum (x_i - \bar{x})^2}{N-1}}$$



$$\bar{x} = \frac{\sum x}{n}$$

(a) (b)

Figure 2. Formula for precision calculation (a) Sample Standard Deviation (Curvebreakers 2023) and (b) Mean (Sanchez and Soriano 2018)

2.4 Common measuring concept and traceability

Three fundamental elements of measurements are measurand, comparator, and reference. See figure 3. First, measurand is a physical quantity that needs to be measured, such weight, length, or angle. Second, comparator, to assess the measurand (physical quantity) by comparing it to a recognized reference or standard. Third, reference, a physical quantity or property with which to make quantitative comparisons. All these three elements would be considered to explain the direct measurement using a calibrated fixed reference. (Raghavendra and Krishnamurthy, 2013, 10.) For instance, to measure the length of the workpiece (measurand) or device under test (DUT), it is conducted by comparison process with a universally known standard (reference). Measurement by scales, protractors, vernier instruments, micrometers and a variety of other direct methods are widely used in industrial and production environments.

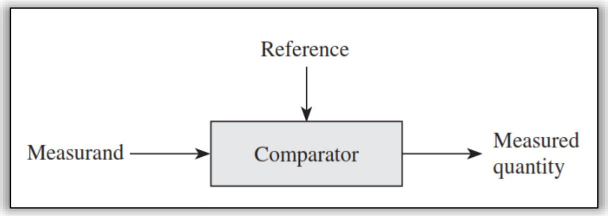


Figure 3. Elements of measurements (Raghavendra and Krishnamurthy, 2013, 10)

It is crucial to use validated instruments to measure. The process of validating measurements can be achieved by traceability of the standards. Measurement traceability refers to the unbroken chain of calibrations linking an instrument or standard to primary standards (Auty et al. 2016, 20). Traceability is essential in the measurements to assure consistency and reliability. It involves creating an unambiguous, confirmed link between measurement and believed norm. Using this standard, measurements are assured to be trackable to a known reference point, which is often a national or international standard. The chain of traceability of standards is shown in figure 4.

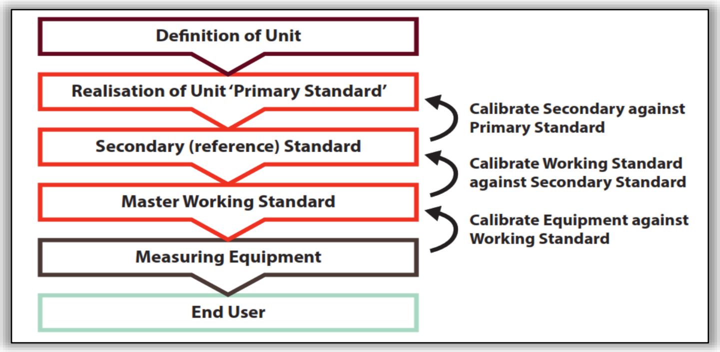
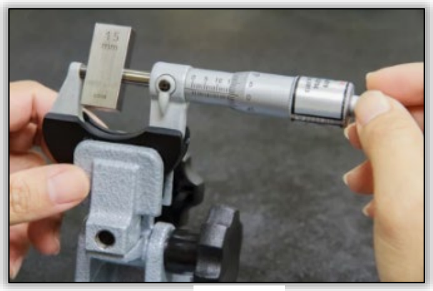


Figure 4. Traceability Chain (Auty et al. 2016, 20)

2.5 Definition of calibration

Calibration is the comparison of a test instrument or artefact against a more accurate standard (Auty et al. 2016, 20). Similarly, Cable (2005, 1), in the International Society of Automation (ISA) defines calibration as “a test during which known values of measurand are applied to the transducer and corresponding output readings are recorded under specified conditions.” According to Raghavendra and Krishnamurthy (2013, 11), calibration is a means of achieving traceability. Calibration is conducted in hierarchical order. As a result, errors are reduced and observed data remain consistent. It is an essential practice in many different industries. Moreover, it keeps devices accurate and reliable. It entails measuring an unknown-accuracy device against a known-accuracy standard.

The main objective of calibration is to make sure that the measuring device realizes its accuracy and function accurately. It can be achieved by comparing the precision measuring equipment with these: a primary standard, a secondary standard, a working standard or a known source that is fed as an input which has higher accuracy than the equipment. (Raghavendra and Krishnamurthy, 2013, 11.) For instance, picture 1 depicts a direct comparison method of calibration where micrometer (a) and vernier caliper (b) are being calibrated with slip gauge blocks. Calibration of one instrument against another with known precision may be adequate in certain situations. Future performance is regarded as being within an acceptable margin of error for a predetermined amount of time under the same operating process following the calibration of an instrument.



(a) (b)

Picture 1. (a) Micrometer calibration with slip gauge (Picture: Testcal Plus 2023) and (b) Vernier caliper calibration with slip gauge (Picture: Kimtaro).

Calibrations are performed under controlled and specified conditions therefore external environment cannot affect the outcome. The calibration of measuring systems requires a heightened focus on environmental conditions compared to general test samples. When calibrating linear measuring instruments, essential considerations include keeping cleanliness in the surroundings, ensuring freedom from vibrations, providing adequate lighting, and implementing a degree of temperature control. These are significant factors for accurate and reliable calibration practice.

There are many advantages in calibration that provide strong proof that the device is performing at optimal efficiency. It helps to meet the essential traceability requirements and increases confidence level, trust, and device reliability. Additionally, calibration prevents equipment failure, perfects performance, reduces rework and scrap, extend lifespan of the equipment, productivity is increased when rejection and failure rates are decreased, thus, results in cost savings. Customers are satisfied as a result of enhanced product and service quality and enhanced interchangeability.

2.5.1 Significance of calibration

Calibration has a notable impression on accuracy, precision, reliability, and compliance of the operational performance in various sectors. These are some important significances of calibration:

I. **Precision and accuracy:** It determines whether measurements made before the calibration were valid. It gives confidence that the future measurements will be accurate. (Eren 2005, 272.)

II. **Reliability and consistency:** In the process industry, calibration of devices assures that the processes are well controlled and that the products meet expected specifications. Frequent calibrations can provide a graphical view of the equipment uncertainty over time, thus leading to reliability of performance. This gives in-service life analysis; hence, depreciation and replacements can be predicted in an informed manner. (Eren 2005, 272.)

III. **Compliance with standards and regulations:** The use of validated and verified devices is required by compliances and standards in several areas. By assisting industries to adhere to these requirements, calibration aids them stay out of problem with the law, avoid fines, and assure the quality and safety of their products and services. Measurements made within international standards promote global acceptance, thus increasing competitiveness (Eren 2005, 272).

2.5.2 Calibration standards

The previous chapter covers the significance of traceability and gives a brief idea on standards. Now, this chapter discusses detailed standards for calibration.

A traceable calibration standard is one that has a direct link to a national or international standard. In order for calibration results to be accurate and reliable, traceable calibration standards must be used. Figure 5, below, depicts hierarchical pyramid of standards where national standard comes from SI Units, reference standard refers to primary standards and secondary standards, and factory standards/ working standards are tertiary/working standards.

I. **Primary standards:** There will only be one material standard used to properly define the unit. Primary standards are kept in specified air temperature so that this prevents them changing their values. These are utilized only in secondary standard comparisons. (Raghavendra and Krishnamurthy, 2013, 26).

II. **Secondary standards:** These are derived from higher standards like primary. Secondary standards closely resemble primary. A high precision comparator is used to compare secondary reference standards to primary standards for calibration, and any necessary adjustments are made for imperfect measurement conditions. (Raghavendra and Krishnamurthy, 2013, 27; NIST 2023).

III. **Tertiary standards:** These are mainly used for reference purposes. National Physical Laboratory (NPL) employed these standards, which are used as the first standard in laboratories and workshops. These standards are copies of secondary standards and used as references for working standards. (Raghavendra and Krishnamurthy, 2013, 27; Jass 2024).

IV. **Working standards:** These are generally found in laboratories and workshops and derived from higher standards. In comparison to the other three, materials used in these standards are low in grade and cheap. Working standards suffer from deterioration since they are used frequently compared to the higher standard for measurement comparison. Moreover, it is generally used for calibration. (Raghavendra and Krishnamurthy, 2013, 27; Jass 2024).

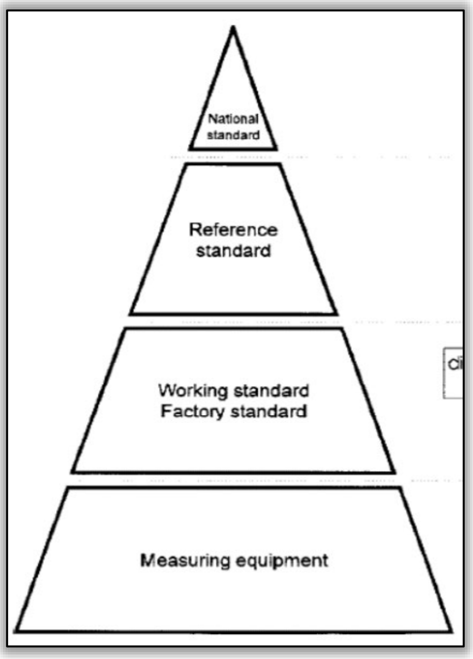


Figure 5. Hierarchy of standards (Leachman 2016).

2.5.3 Types of equipment calibration

Equipment calibration can be of many types. There are a wide range of industries in which each serves a specific need. In picture 2, equipment calibration types are briefly presented.

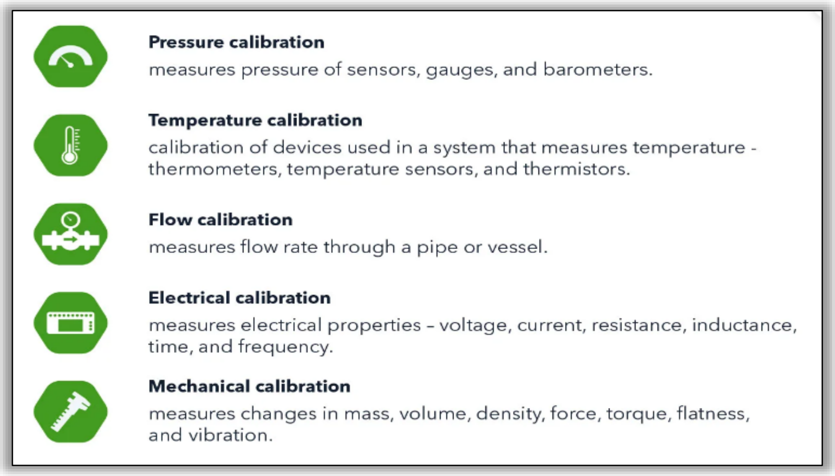
I. **Pressure Calibration:** This type of calibration is required for companies who work with gauge gas, steam, and hydraulic pressure levels. Devices like barometers, pressure gauges, pressure sensors and indicators, pressure switch, safety valve, and vacuum gauge need pressure calibration. (Chan 2023; ETS Solution 2021).

II. **Temperature Calibration:** This calibration is performed in a system where temperature reading is crucial. Resistance temperature devices (RTDs) are basically utilized for calibration. Devices like thermal cameras, , thermometer, infrared meters, and thermocouples need calibration. (Balasubramanian 2023; Chan 2023; ETS Solution 2021).

III. **Flow calibration:** This calibration measures the rate of the flow by the flow meter. Thermal mass flowmeters, rotameters, and turbine meters need calibration. (Balasubramanian 2023; Chan 2023; ETS Solution 2021).

IV. **Electrical Calibration:** It means verifying the functions of electrical devices that measure electrical properties like resistance, voltage, current, capacitance, inductance, time, and frequency. Devices like multi-meters, electrical meters, loop testers, frequency counters, and speedometers are calibrated. (Balasubramanian 2023; Chan 2023; ETS Solution 2021).

V. **Mechanical calibration:** It is used to correct devices that measure dimensions, angles, mass, volume, force, vibration, torque, and flatness. It experiences drift in accuracy over time due to constant use, mechanical impact, and atmospheric conditions. Devices like scales, calipers, and micrometers need mechanical calibration. (Balasubramanian 2023; Chan 2023; ETS Solution 2021).



Picture 2. Types of equipment calibration (Picture: Chan 2023)

2.6 Linear measurement tools (Mechanical tools)

Linear measurements are the measures of length, thickness, height, and diameter. These measurements can be internal and external. (Sathyabama Institute of Science and Technology 2020; Jass 2021; Abulila 2023,1). Distance is measured between two points, two surfaces or between points and surfaces. When the distance between two points is measured, it is called line measurement/standard whereas distance measured between two surfaces, it is called end measurements/standard. In the line measuring instruments, there are a series of lines that are spaced accurately. For instance, scale or ruler is used for line measure where dimensions are aligned with scale graduations.

However, in end measurements two end surfaces are measured using micrometers and slip blocks. Either line or end measurements can be taken with linear measuring devices. (Raghavendra and Krishnamurthy 2013, 28 & 80; Sathyabama Institute of Science and Technology 2020; Jass 2021).

In machine shops and tool rooms, the most commonly utilized linear measuring equipment are the vernier caliper and the vernier micrometer. They are accurate and precise. Moreover, this thesis covers only vernier caliper and digital caliper, and micrometer. These are the instruments used as instruments under test (IUT) during in-house calibration.

2.7 Vernier instrument

Vernier scale was invented by the French mathematician, Pierre Vernier (1580-1637) in 1631. (Raghavendra and Krishnamurthy 2013, 94). Therefore, the instrument is called Vernier (Doshi 2009, 17). It consists of two distinct graduated scales: a main scale like a ruler and a specifically graduated supplementary scale, known as the vernier, which moves in parallel to the main scale. This allows readings to be taken with precision, down to a fraction of a division on the main scale. (Doshi 2009, 17; Raghavendra and Krishnamurthy 2013, 94). A vernier scale increases measurement precision by offering the least count of up to 0.01 mm or less (Raghavendra and Krishnamurthy 2013, 94). For quality control measures, Vernier calipers are frequently used in scientific labs and in manufacturing.

The basic principle of vernier is that the main scale could be a centimeter scale where each centimeter is subdivided into ten parts, i.e., millimeters. The Vernier scale comprises ten divisions that equate to nine millimeters on the main scale. (Doshi 2009, 17; Raghavendra and Krishnamurthy 2013, 94). The amplified part of vernier scale is shown in figure 7.

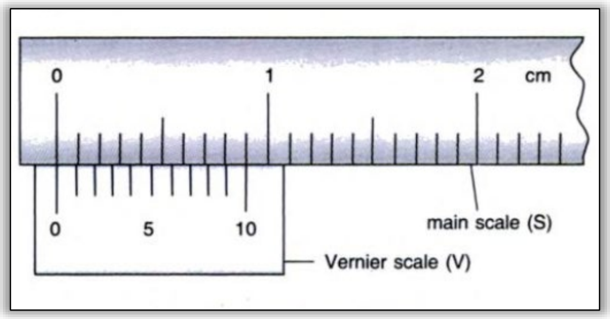


Figure 7. Principle of Vernier (Doshi 2009, 17)

According to principle, let us consider the size of a single division on the main scale as “MSD” units and on the Vernier scale as “VSD” units. Additionally, assume that the length of “x” Vernier divisions equals the length of (x - 1) main scale divisions, given that “x” Vernier divisions align with (x - 1) main scale divisions. Consequently, the length of (x - 1) main scale divisions is equivalent to the length of “x” Vernier scale divisions. In equation,

$$(x-1) * MSD = x * VSD$$

Or $$x * MSD - MSD = x * VSD$$

Or $$x * MSD - x * VSD = MSD$$

Or $$x * (MSD - VSD) = MSD$$

Or $$MSD - VSD = MSD/x$$

Thus, Vernier Constant (or Least count) = One Main Scale Division (MSD) – One Vernier Scale Division (VSD) or Value of One Main Scale Division / Total number of divisions on Vernier Scale. (Doshi 2009, 17-18; Raghavendra and Krishnamurthy 2013, 94). i.e.,

$$LC = MSD - VSD = MSD/x$$

Also, vernier scale reading,

$$VSR = LC * VC$$

Therefore,

$$\text{observed reading} = MSR + LC * VC$$

Where, MSR is the main scale reading, LC is the least count and VC is the vernier coinciding division. (Raghavendra and Krishnamurthy 2013, 94).

Today, several instruments manufacturing companies produce modern calipers such as dial calipers and electronical/digital calipers. In spite of this, the basic idea of vernier measurement is still crucial to metrology, and many different industries continue to use devices with vernier scales, like vernier calipers, vernier micrometers, vernier height gauges, and vernier depth gauges.

2.7.1 Vernier caliper

The vernier caliper comprises two scales: the main scale and the vernier scale. The main scale is immobile, situated within an L-shaped frame, and features fixed jaws (both an outer and an inner jaw) at each end. However, the vernier scale is a sliding scale with two distinct jaws (an outer and an inner jaw). It can be adjusted at various positions of the main scale beam. It has clamping screw that helps to fix the position and allows operator to observe accurate measurements. Moreover, a thumbwheel is used to obtain closeness of the jaws for accuracy. The external jaws measure external dimensions like diameter and length, whereas the internal jaws measure internal dimensions like length and diameter of hollow objects. Additionally, the depth bar's is for depth measurement. (Doshi 2009, 18-19; Raghavendra and Krishnamurthy 2013, 95-96). Figure 8 illustrates all the main parts of the vernier caliper.

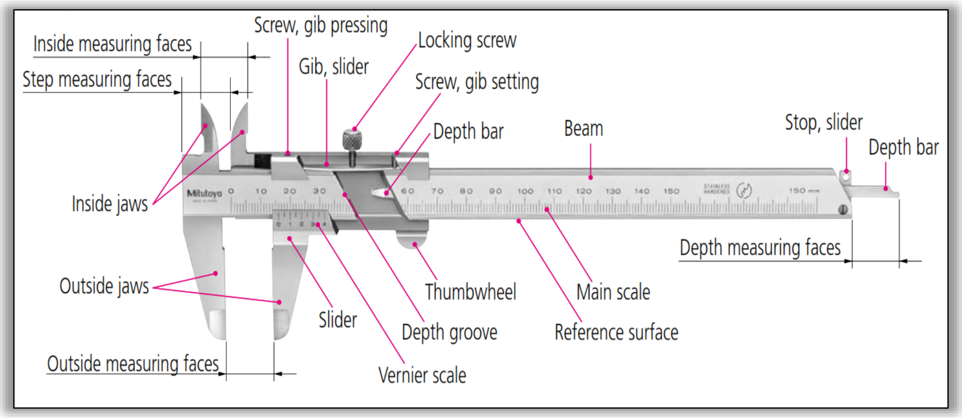


Figure 8. Main parts of a vernier caliper (Mitutoyo 2023, 16)

I. Reading vernier caliper:

a) Integer reading: Checked the position of the “0” of the vernier scale on the main scale. If the “0” is perfectly lined-up with any graduations on the main scale, then it is an integer reading. Therefore, there was no further reading required from the vernier scale side. For instance, figure 9 illustrates an integer reading of vernier scale. The zero mark on the vernier scale and 35 mm mark (or graduation/division) on the main scale are lined up (or aligned/coincided) perfectly. Therefore, the correct reading is 35 mm. (Doshi 2009, 18; Flack 2014, 12-14)

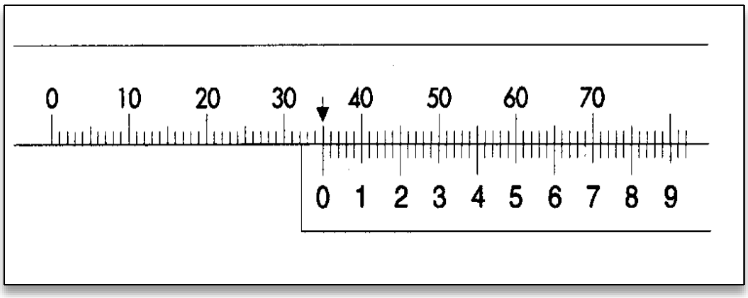


Figure 9. Integer reading on vernier scale (Flack 2014, 12-14).

b) Non-integer reading: Checked the position of the "0" of the vernier scale on the main scale. If the position of the "0" of the vernier scale on the main scale is not lined-up or the position of the "0" of the vernier scale is between the graduations of main scale (see figure 10), then further vernier scale reading is required.

- Reading was taken from the main scale first. For instance, figure 10, the "0" mark from vernier scale lies between 20 mm and 21 mm on the main scale. Always take the first number in such cases. Therefore, the main scale reading (MSR) to use is 20 mm.
- Second, read vernier scale coinciding (VC). Looked along which vernier scale graduation line-up with a main scale graduation. In this case, the operator can count graduations of vernier scale from zero to lined-up graduation. For instance, 32 graduations - see there is double arrow indicator on the figure 10. Calculated vernier scale reading (VSR). i.e., VSR = LC*VC, where VSR is vernier scale reading, LC is least count and VC is vernier coinciding division. In this case, VSR = 0.02*32 = 0.64 mm. Finally, observed reading of vernier caliper = MSR + VSR. So, total reading for this case is 20 mm + 0.64 mm = 20.64 mm.

(Doshi 2009, 18; Flack 2014, 12-14; Ryan 2003)

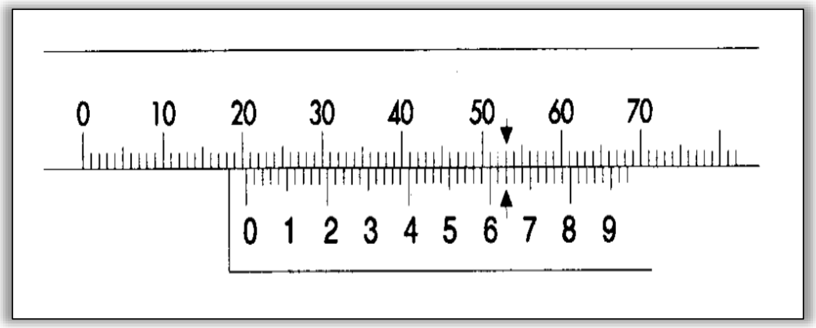


Figure 10. Non-integer Reading (Flack 2014, 12-14).

Besides, mathematical method this can be determined by direct observation and experience. Figure 11 illustrates direct reading of vernier caliper. Where main scale reading shows 16 mm. That is because vernier scale “0” mark is after 16 mm of main scale. And vernier scale reading shows coinciding on the third division, and given length of each division is 0.05 mm. Thus, vernier scale reading is 0.15 mm. Finally, total vernier caliper reading is 16.15 mm.

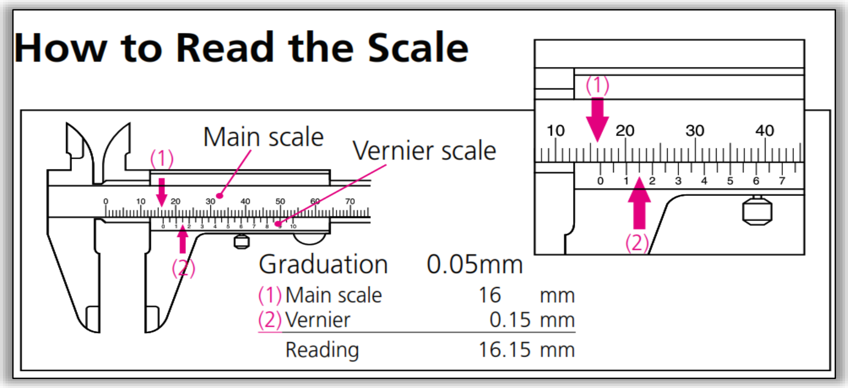


Figure 11. How to read the scale (Mitutoyo 2023, 16)

II. **Determination of zero error:** When movable jaw comes in contact with fixed jaw then the zero mark of vernier scale and zero mark of main scale must line-up. If it is so, the vernier caliper is free from zero error. However, sometimes due to mechanical issues these zero marks of both scales do not coincide. Thus, vernier caliper suffers from zero error. Figure 12 makes it easier to understand zero error and its correction. There are two types of zero errors.

a) **Positive zero error:** When both jaws touch each other and zero mark of vernier scale lies towards the right side of the zero mark of the main scale then it is called positive zero error (see figure 12). In this case, observed reading will be more than the actual reading, therefore positive zero error must be deducted from observed reading.

b) **Negative zero error:** In contrast, when both jaws touch each other and zero mark of vernier scale lies towards the left side of the zero mark of the main scale then it is called negative zero error (see figure 12). In this case, observed reading will be less than the actual reading, therefore negative zero error must be added from observed reading.

To calculate zero error, zero error = (with sign) VC * LC.

If VC is positive, then (+) sign and for negative it should be (-) sign.

Finally, correct reading = Observed reading – Zero error (with sign).

(Doshi 2009, 19-20; Cyber Physics 2023)

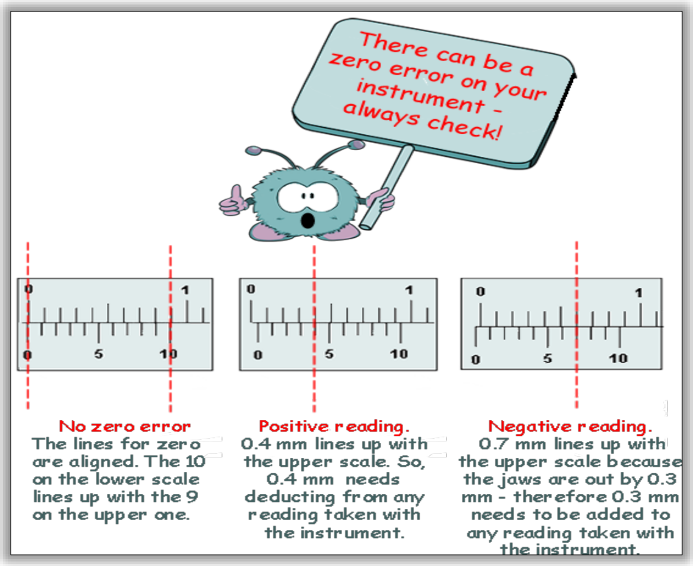
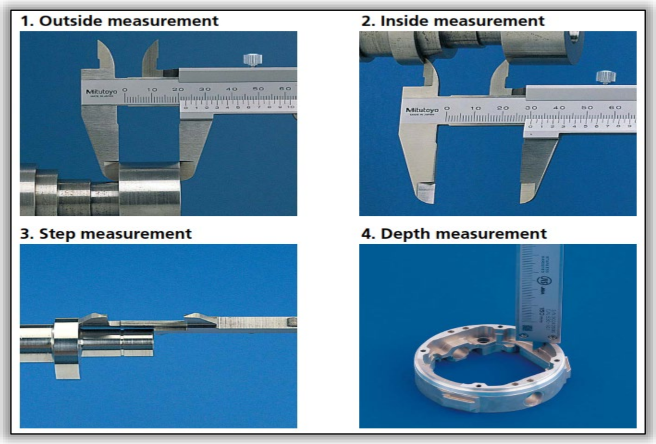


Figure 12. Zero error and its correction (Cyber Physics 2023)

III. **Types of measurement examples:** According to Flack (2014, 11-12) , vernier calipers are versatile instruments and can be used for several types of measurements. Some measurements styles are given below in picture 7.



Picture 7. Applications of vernier caliper (Picture: Mitutoyo 2023).

IV. **Handling and storing:** The state of the equipment affects measurement, and calibration. Therefore, handling and storing vernier calipers is crucial. Flack (2014, 18-19), and Raghavendra and Krishnamurthy (2013, 96) general handling and storing methods as follows:

- **a)** Clean calipers with cleaning solution and lint free cloth.
- **b)** Keep out of damp, dust, chemicals, high humidity, and temperature fluctuations area.
- **c)** Avoid keeping caliper outside for lengthy periods of time.
- **d)** Place the calipers to ensure the beam of main scale does not bend and to provide sufficient safety for the vernier, preventing damage.
- **e)** Make sure to not to make contact of measuring faces while storing in a case or box. A minimum 2 mm gap is recommended.
- **f)** Do not clamp it while storing.
- **g)** Apply rust preventives such as lubricants.
- **h)** Put it in the case or box provided by the manufacturer.
- **i)** Keep a record of stored calipers and check timely.

2.7.2 Digital caliper

An electronic digital caliper uses battery to operate and has a liquid crystal display (LCD) screen that shows reading and functional setting. Moreover, it employs a linear encoder that aids in detection of displacement. This linear encoder could have a magnetic, inductive, or capacitive component. The benefits of this digital caliper are simplicity of reading without any calculation, operation, and enhanced settings. (Flack 2014, 11; Raghavendra and Krishnamurthy 2013, 97-98). Flack (2014, 6) states conventional vernier calipers have a resolution of 0.05 mm, dial calipers have a resolution of 0.02 mm, and digital calipers have a resolution of 0.01 mm. Hence, digital calipers can measure more precisely than vernier or dial caliper. Figure 13 illustrates all the main parts of the electronic digital caliper.

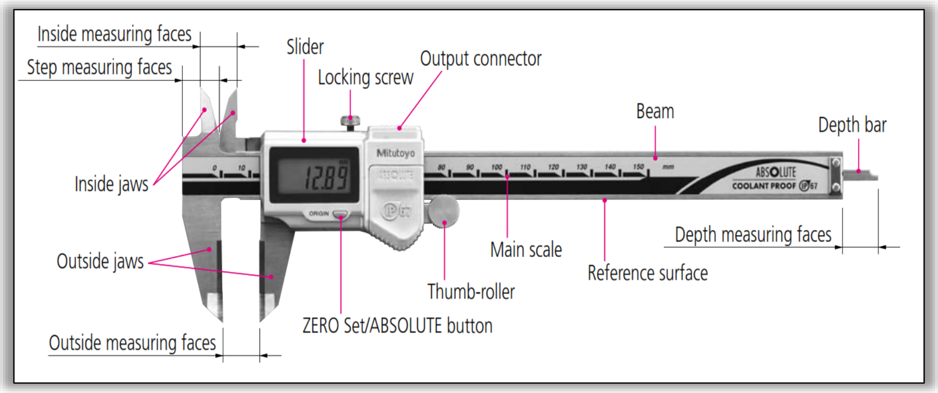


Figure 13. Main parts of electronic digital caliper (Mitutoyo 2023, 16).

Digital caliper screens can be switched on or off with a control button. To set zero, measuring faces are brought into contact and pressed zero set button. Besides, it can also be set zero within the caliper range. Therefore, this electronic caliper is easy and can be used to measure any linear dimensions. Moreover, these calipers have functions to switch between metric and imperial units- centimeter or millimeter to inch. When discussing the importance of this caliper, its electronic calculator function, and its capability to interface with other devices take precedence. It can be interfaced with a dedicated recorder, computers, and printers. So, that reading data can be utilized for meaningful output. Additionally, its features enable recording and storing of measurement data that enhances record reliability. (Raghavendra and Krishnamurthy 2013, 98).

Since these calipers are digital, no calculation is required. Their application is the same as vernier caliper. In terms of handling, it does require careful attention, handling, and storage, just like vernier caliper. For instance, free from dust, damp, unsuitable air condition and temperature, cleaning with lint free cloth and solution, and storing in case. However, battery level must be checked throughout the process and after the process as well. Overall, these take very little reading ability but greatly simplify the process.

2.8 Micrometer instruments

It is believed that the word “micrometer” originated from Greece. Its meaning in Greek is “small.” In 17th century, William Gascoigne, England, invented first ever micrometer screw for the telescope. Later, in 1867, Browne & Sharpe Company started to commercialize modern versions of micrometers. (Raghavendra and Krishnamurthy 2013, 99; Mitutoyo 2024, 4-11) Since then, micrometers have had a long and admirable history in the metrology sector. Today, there are many several types of micrometers available in the markets. Such micrometers are external micrometers, internal micrometers, depth micrometers, digital micrometers, laser scan micrometers, dial micrometers, disk micrometers, screw-thread type, blade type. For quality control measures, micrometer instruments are frequently used in scientific labs and in manufacturing. Figure 14 below shows various micrometer instruments and their applications.

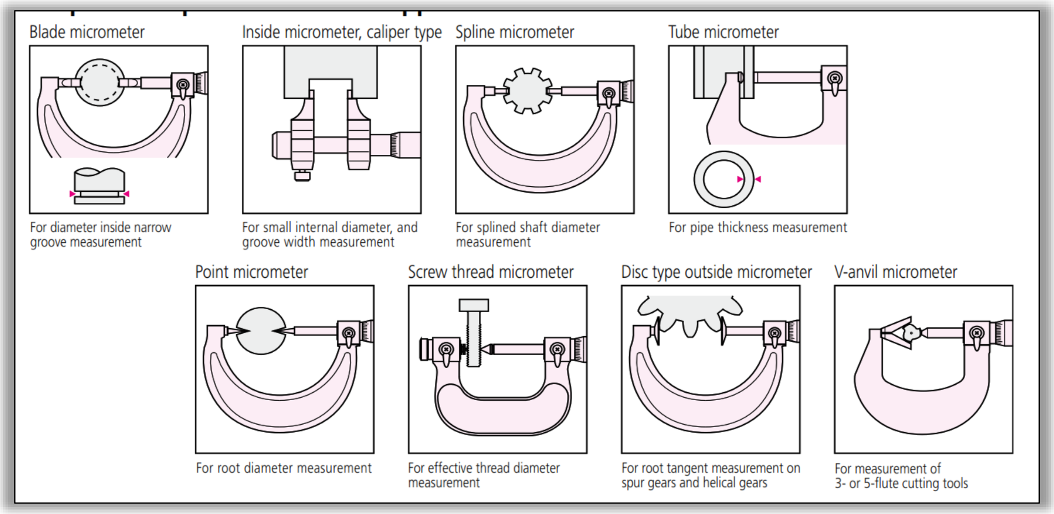


Figure 14. Applications of various micrometers (Mitutoyo 2023, 6)

Screw-based mechanism is the principle behind those micrometers’ mechanism. (Flack 2014, 32; JSS Science and Technology University 2018, 55; Raghavendra and Krishnamurthy 2013, 99). Each revolution makes screw to move one pitch distance. It means each rotation of the pitch is equivalent to the length that moves linearly.(JSS Science and Technology University 2018, 55).

For instance, micrometer smallest division on main scale is 0.5 mm. If circular scale rotates then the spindle advances by 0.5 mm. (Raghavendra and Krishnamurthy 2013, 101). Raghavendra and Krishnamurthy (2013, 99) claims that vernier calipers are not capable of providing better least count, accuracy, and precision than micrometers. Better accuracy is obtainable using micrometer as the line of measurement is in line with the axis of the instrument. (Raghavendra and Krishnamurthy 2013, 99). This fact is concreted by Abbe's law, states that "maximum accuracy is obtained when the scale and the measurement axes are common." (Raghavendra and Krishnamurthy 2013, 99-100; Mitutoyo 2023, 8). See figure 15 that shows conformity to Abbe's law on both micrometer and vernier caliper.

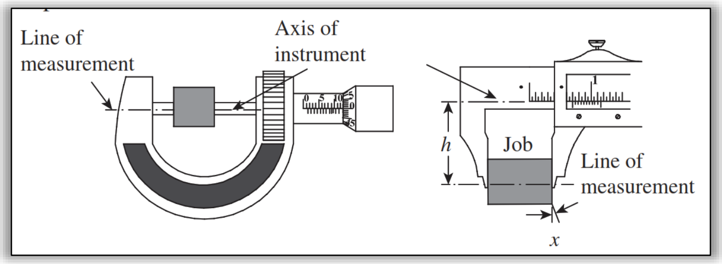


Figure 15. Conformity to Abbe's law on micrometer and vernier caliper (Raghavendra and Krishnamurthy 2013, 99-100).

This chapter on micrometer instruments is going to focus on outside micrometer, vernier micrometer and digital micrometer.

2.8.1 Outside micrometer

This outside micrometer is the most common micrometer that operators encounter in all lab rooms and workshops. It consists of a semicircular (C-shaped) frame with a fixed anvil located at one end and a movable spindle at another end. Anvil serves as stationary measuring face whereas spindle has another measuring face, is attached to other parts such as inner sleeve, lock, and thimble. It is able to rotate clockwise and anticlockwise for measuring, adjusting, and holding purposes. The outer sleeve (main scale) and thimble (circular scale) both have graduated scales engraved. Locknut prevents spindle unnecessary moves while taking a reading. The ratchet has a knurled thumb grip that allows the spindle to be rotated in the proper direction for the purpose of measuring. A ratchet action prevents the micrometer from being overtightened across the measured item and guarantees that each measurement is made with a constant pressure. (Doshi 2009, 21-22; Flack 2014, 33; Raghavendra and Krishnamurthy 2013,100-101; Mechanical Measuring 2017). Figure 16 represents the main parts and cross section of the outside (OD) micrometer.

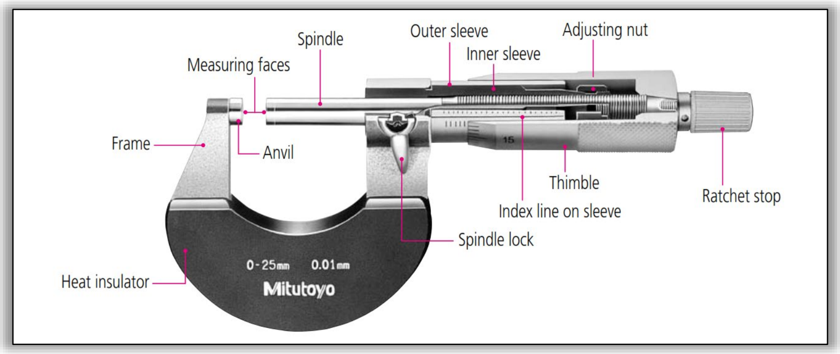


Figure 16. Cross section view with main parts of OD micrometer (Mitutoyo 2023, 5).

I. **Reading OD micrometer**: To read OD micrometer operator must know three things, viz. the pitch of screw, least count of the screw and observed reading method.

   a) Pitch of screw (P or smallest division on main scale) = Distance moved by the screw on the main scale / Number of rotations

   b) Least count (LC) = Pitch of screw / Number of divisions on the circular scale

   c) Observed reading = MSR + LC*CC, where MSR is a main scale reading, LC is least count and CC is circular scale coinciding division.
   (Doshi 2009, 22-24; Raghavendra and Krishnamurthy 2013,101; Mahato 2018, 217-219).

This can be figured out by observation method as well. Direct reading of divisions and subdivisions on the main scale is possible. In metric micrometer, usually 1 mm divisions and 0.5 mm subdivisions are engraved. From picture 8, division 5 and subdivision 0.5 is visible. So, the main scale reading is 5.5 mm. Suppose circular scale has 50 divisions. Now, LC is 0.5/50 = 0.01 mm. In picture 8, the 28th division on the thimble coincides with the reference line of the sleeve (main scale). So, circular scale reading is 0.28 mm. Now, observed reading is 5.5 mm + 0.28 mm. i.e., 5.78 mm.

Picture 8. Reading micrometer (Picture: Wikipedia 2024)

II. **Determination of zero error:** When movable spindle comes in contact with fixed anvil then the reference line (or center line/datum line/base line/ line of graduation) of the main scale (sleeve) and zero mark of circular scale (thimble) must coincide. If it is so, the micrometer is free from zero error (see figure 17a). However, sometimes due to mechanical issues these zero marks of both scales do not coincide. Thus, micrometer suffers from zero error. There are two types of zero errors. (Doshi 2009, 22-24; Mahato 2018, 218-219; Samantaray 2021).

a) **Positive zero error:** When both measuring faces are brought in contact with each other and zero mark on the circular scale (thimble) lies below the reference line of the main scale (sleeve) then error is called positive zero error (see figure 17b). In this case, observed reading will be more than the actual reading, therefore positive zero error must be deducted from observed reading. i.e., correct reading = observed reading – positive zero error. (Doshi 2009, 22-24; Mahato 2018, 218-219; Samantaray 2021).

b) **Negative zero error**: When both measuring faces are brought in contact with each other and zero mark on the circular scale (thimble) lies above the reference line of the main scale (sleeve) then error is called negative zero error (see figure 17c). In this case, observed reading will be less than the actual reading, therefore negative zero error must be added from observed reading. i.e., correct reading =

observed reading + negative zero error. (Doshi 2009, 22-24; Mahato 2018, 218-219; Samantaray 2021).

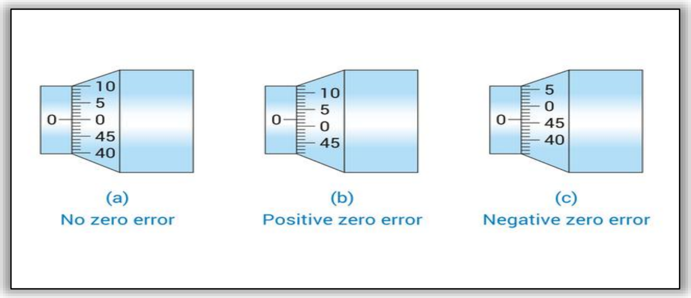


Figure 17. Zero error (Samantaray 2021).

III. **Handling and storing**: It is a versatile instrument for measuring. However, the state of the equipment affects measurement, and calibration. Therefore, handling and storing of micrometers is crucial. Flack (2014, 46), and Raghavendra and Krishnamurthy (2013, 104) general handling and storing methods are as follow:

a) Clean measuring faces with cleaning solution and lint free cloth.

b) Keep out of damp, dust, chemicals, high humidity, and temperature fluctuations area.

c) Avoid keeping the micrometer outside for lengthy periods of time.

d) Do not clamp it tightly while storing.

e) Apply rust preventives such as lubricants.

f) A micrometer comes with an adjusting wrench, which can be used to fix coinciding issues.

g) Put it in the case or box provided by the manufacturer.

2.8.2 Digital micrometer

These digital micrometers have become popular in recent times among engineers, and manufacturers. The reason behind this is reading can be taken with ease. It employs a photoelectric or capacitance type rotary encoder that aids in detection of spindle rotation and electronically transforms this to a digital readout of spindle displacement. (Flack 2014, 38). The benefits of digital micrometers are simplicity of reading without any calculation, operation, and enhanced settings. Flack (2014, 38), and Raghavendra and Krishnamurthy

(2013, 104-105) states digital micrometers have a resolution of 0.001 mm. Hence, digital micrometers can measure more precisely than conventional micrometers. Figure 18 represents an electronic digital micrometer.

It has an LCD screen that displays reading output. Moreover, push buttons control is provided. On/off button gives power to instrument, unit changing button changes metric to imperial and vice-versa, zero button sets zero at any range, hold button holds taken measurement, and origin button sets minimum value for the micrometer, and alarm indicator indicates low power and errors. (Raghavendra and Krishnamurthy 2013, 104-105).

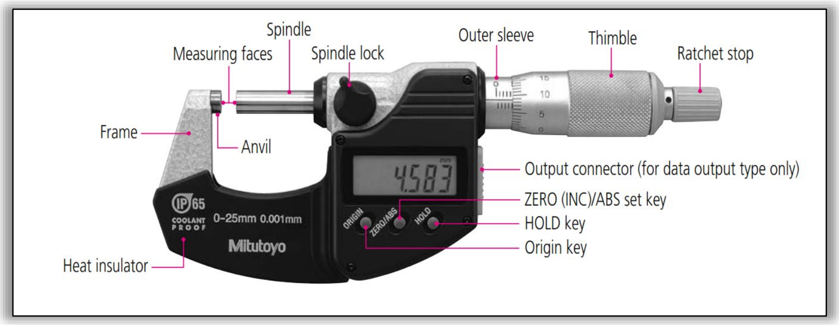


Figure 18. Parts of digital micrometer (Mitutoyo 2023, 5).

Some digital micrometers can be integrated into automatic measurement, data processing systems, computers, and printers. (Flack 2014, 38; Raghavendra and Krishnamurthy 2013, 104). These micrometers are capable of recording series of data and can evaluate statistical information like mean, range, and standard deviation. (Raghavendra and Krishnamurthy 2013, 104). There is no need for computation because these micrometers are digital. These micrometers offer more applications than the standard micrometer. It can measure outside, inside, depth and step which means no need to buy separate instruments (STATUS 2024). In addition, it eliminates human error greatly. (Flack 2014, 38). In terms of handling, it requires careful attention, handling, and storage. For instance, free from dust, damp, unsuitable air condition and temperature, cleaning with lint free cloth and solution, and storing in case. But battery level needs to be monitored both during and after the procedure. Overall, these drastically streamline the procedure while requiring very little reading comprehension.

2.9 ISO in calibration

2.9.1 ISO - Length standard gauge block

Gauge blocks are used to calibrate engineering equipment, (e.g., micrometers and Vernier calipers). (Bailey, Lewis, Whiting, & Lingard 2017, 2; SFS-EN ISO 13385-1:2019, 10; SFS-EN ISO 3611:2023, 10). See picture 10. There are many forms of grades. According to Raghavendra and Krishnamurthy (2013, 109) slip gauges are designated into five grades viz. grade 2, grade 1, grade 0, grade 00 and calibration grade. Similarly, there are other types of grades such as A, AA, AAA, and B. (Raghavendra and Krishnamurthy 2013, 109). For various purposes, slip gauges are manufactured in distinct precision levels, or grades.

Picture 10. Gauge blocks set (Picture: Bailey et. al. 2017, 14).

Typically, high grades are used as a known standard to calibrate lower grades of block. (Bailey et. al. 2017, 4). However, SFS-EN ISO 3650 (1998, 10) has mentioned four types of grades and the marking for each. They are calibration grade K as K, grade 0 as 0, grade 1 as hyphen (-), and grade 2 as equal sign (=). Figure 19 illustrates the lowest grade, 2, has the largest tolerances, and the highest grade, K, has the smallest. While grade 2 gauge blocks are used in the workshop to test various pieces of equipment, grade K gauge blocks are mostly used to calibrate other gauge blocks using a comparator. (Bailey et. al. 2017, 4). Moreover, see table 1 for grades and applications of gauge blocks. The length unit of a gauge block is meter (or millimeter/micrometer). (SFS-EN ISO 3650 1998, 6 & 8). The reference condition of gauge block viz. temperature and pressure are 20° C and 101325 Pa, respectively. However, standard pressure may be ignored under normal air conditions. (SFS-EN ISO 3650 1998, 8).

Measuring faces of gauges must wring readily. Fine scratches with no burrs are accepted, however wringing property must not be impaired. (SFS-EN ISO 3650 1998, 11).

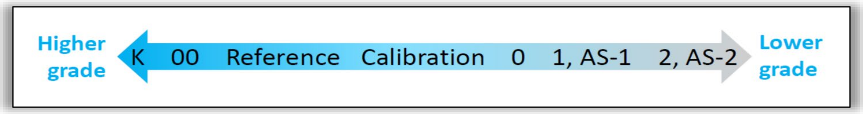


Figure 19. Grades of gauge blocks (Bailey et. al. 2017, 4).

	Applications	Grade
Workshop use	• Mounting tools and cutters	2
	• Manufacturing gages • Calibrating instruments	1 or 2
Inspection use	• Inspecting mechanical parts, tools, etc.	1 or 2
	• Checking the accuracy of gages • Calibrating instruments	0 or 1
Calibration use	• Checking the accuracy of gauge blocks for workshop • Checking the accuracy of gauge blocks for inspection • Checking the accuracy of instruments	K or 0
Reference use	• Checking the accuracy of gauge blocks for calibration • For academic research	K

Table 1. Gauge block grades and applications (Mitutoyo 2024, 9).

2.9.2 ISO - Vernier and digital calipers

Vernier and digital calipers are explained in earlier chapters. Moreover, reading of calipers, zero errors, and handling procedure are emphasized. In accordance with SFS-EN ISO 13385-1:2019, this chapter will detail metrological characteristics, conformity to accuracy specification, and calibration related guidelines.

I. Metrological characteristics:

a) The most significant metrological characteristics of calipers are covered by two accuracy specifications. They are partial surface contact error (E_{MPE}) and shift error (S_{MPE}). (Mitutoyo 2018, 1). The MPE (maximum permissible error) values must not be less than the digital step size or the scale interval specified on the circular or vernier scale. (SFS-EN ISO 13385-1:2019, 10).

b) The manufacturer stated operating conditions should be followed. Otherwise, the atmospheric condition for the test values should be adjusted to 20°C to determine the error the caliper would have produced at that temperature. (SFS-EN ISO 13385-1:2019, 10).

c) Calipers with digital displays must have an adjustable zero-point capability. Digital calipers should be capable of zeroing at any position within their measuring range. When external measuring faces are brought into contact for zero setting, the metrological characteristics described in the ISO 13385-1:2019 apply. When evaluating metrological properties, this position is considered fixed for the reference point. While calipers lacking adjustable zero points may introduce errors when their external measuring faces make contact. The assessment of metrological characteristics must take these inaccuracies into account without making any adjustments for them. (SFS-EN ISO 13385-1:2019, 10).

d) Measurement standards or appropriate instruments with a reasonable measurement uncertainty, such as gauge blocks in accordance with ISO 3650, must be used to test the indicator errors. Test points shall cover the range of caliper. (SFS-EN ISO 13385-1:2019, 10).

e) When using the outside measuring faces for any measurement, the **partial surface contact error** (**E_{MPE}**) is applied. To test E_{MPE}, the user must measure known standards at multiple test points across caliper range, and on the outside jaw faces at different distances viz. near the tip and close to the beam. Picture 11, below, represents the testing points - near the tip and close to the beam at different ranges. In addition, refer to figures 4 and 5 for test point diagrams on page 11 and refer to table 2 for the minimum number of test points of the caliper on page 12 of SFS-EN ISO 13385-1:2019. To illustrate, calipers up to 150 mm may be tested at 5 different test points. These test points must include at least one point measured at 90% or greater of the caliper range.

Besides, for the longest and shortest measurement standards in the test, two distinct test points viz. near to the beam and near to the tip must be obtained. To compute this error, differences are taken between observed value and reference value. The partial surface contact error is aimed to locate caliper errors like scale errors, measuring force effects, beam deflection, play between the beam and slider, and external measuring face parallelism and flatness. (SFS-EN ISO 13385-1:2019, 11-12).

Picture 11. Testing near the tip and close to the beam at different ranges (Picture: Mitutoyo 2018, 2).

f) For acceptance tests, manufacturers must state MPE values in accordance with ISO 13385-1 document. If MPE values are not stated by manufacturers, then Annex B (Table B.1) shall be applied for calipers with a range up to 1000 mm, and with analog scale interval or digital step of 0.01 mm, 0.02 mm, and 0.05 mm. In addition, for reverification of MPE values a specification sheet (Table 3) for meteorological characteristics shall be used by the user or manufacturer. (SFS-EN ISO 13385-1:2019, 14, 15 & 17). For instance, Mitutoyo America Corporation, the manufacturer company had published their MPE values in 2018 for the calipers ranging from 0 to 1000 mm, see table 2. These values are adopted from ASME B89.1.14 standard which is similar to Annex B (Table B.1) SFS-EN ISO 13385-1:2019.

Measured Length, L		Digital Resolution / Dial or Vernier Scale Interval									
		0.0005 in.		0.001 in.		0.01 mm		0.02 mm		0.05 mm	
mm	in.	E_{MPE} in.	S_{MPE} in.	E_{MPE} in.	S_{MPE} in	E_{MPE} mm	S_{MPE} mm	E_{MPE} mm	S_{MPE} mm	E_{MPE} mm	S_{MPE} mm
$0 \le L \le 50$	$0 \le L \le 2$	± 0.0010	± 0.0010	± 0.001	± 0.001	± 0.02	± 0.03	± 0.02	± 0.04	± 0.05	± 0.05
$50 < L \le 100$	$2 < L \le 4$	± 0.0010	± 0.0020	± 0.001	± 0.002	± 0.03	± 0.05	± 0.04	± 0.06	± 0.05	± 0.10
$100 < L \le 150$	$4 < L \le 6$	± 0.0010	± 0.0020	± 0.001	± 0.002	± 0.03	± 0.05	± 0.04	± 0.06	± 0.10	± 0.10
$150 < L \le 200$	$6 < L \le 8$	± 0.0015	± 0.0020	± 0.002	± 0.003	± 0.03	± 0.05	± 0.04	± 0.06	± 0.10	± 0.10
$200 < L \le 300$	$8 < L \le 12$	± 0.0015	± 0.0025	± 0.002	± 0.003	± 0.04	± 0.06	± 0.04	± 0.06	± 0.10	± 0.10
$300 < L \le 400$	$12 < L \le 16$	± 0.0020	± 0.0025	± 0.002	± 0.003	± 0.04	± 0.06	± 0.04	± 0.06	± 0.10	± 0.10
$400 < L \le 500$	$16 < L \le 20$	± 0.0020	± 0.0030	± 0.002	± 0.003	± 0.05	± 0.07	± 0.06	± 0.08	± 0.10	± 0.10
$500 < L \le 600$	$20 < L \le 24$	± 0.0020	± 0.0030	± 0.002	± 0.003	± 0.05	± 0.07	± 0.06	± 0.08	± 0.15	± 0.15
$600 < L \le 700$	$24 < L \le 28$	± 0.0025	± 0.0035	± 0.003	± 0.004	± 0.06	± 0.08	± 0.06	± 0.08	± 0.15	± 0.15
$700 < L \le 800$	$28 < L \le 32$	± 0.0025	± 0.0035	± 0.003	± 0.004	± 0.06	± 0.08	± 0.06	± 0.08	± 0.15	± 0.15
$800 < L \le 1000$	$32 < L \le 40$	± 0.0030	± 0.0040	± 0.003	± 0.004	± 0.07	± 0.09	± 0.08	± 0.10	± 0.15	± 0.15

- For complete definitions of E_{MPE} and S_{MPE} please see the ASME B89.1.14-2018 standard.
- These specifications are a function of the measured length, L, not the overall measuring range of the caliper.
- The decision rule that applies for these specifications is Simple Acceptance with a test uncertainty ratio, TUR ≥ 4.
- All specifications apply at 20°C.

Table 2. Published MPE values by Mitutoyo as per ASME B89.1.14. (Mitutoyo 2018, 1).

II. Conformity to specifications: For conformity to specifications, given MPEs are used to compare observed errors. The rule for decision is that given specifications must be followed for - compliance and non-compliance. For instance, the MPE values provided in Annex B (Table B.1) on page 17 can be used for decision rule - acceptance and rejection. Also, measurement uncertainty shall be evaluated as per the ISO/IEC Guide 98-3. (SFS-EN ISO 13385-1:2019, 14, 15 & 17). The user or operator must possess sound skills for the operation of caliper to determine conformity with specifications. In accordance with ISO 14253-5, when the user is experienced, it eliminates skill related to any test values variation contributing to the measurement uncertainty. (SFS-EN ISO 13385-1:2019, 10 & 15).

III. **Calibration guidelines:** According to Annex A of SFS-EN ISO 13385-1 (2019, 16), the calibration of a caliper should generally include the evaluation of the performance of the caliper within its measuring range. The calibration should include verification testing of all metrological characteristics across the measuring range. Additionally, task-related calibration of the caliper should be considered, depending on its intended application. For instance, it may not be necessary to assess any metrological characteristics related to shift error (S_{MPE}) for a caliper that is meant to be used exclusively for external diameter measurements. (SFS-EN ISO 13385-1:2019, 16). Thus, metrological characteristic of partial surface contact error (E_{MPE}) is assessed in such a case.

Similarly, Mitutoyo America Corporation, manufacturer company (2018, 2) states that the most important aspect of the calibration of a caliper is to verify conformance with stated accuracy specifications. These specifications are MPE values of indicator errors. Thus, they have explained the conformance verification tests for partial surface contact error (E_{MPE}) in accordance with ASME B89.1.14 in their technical bulletin "Calipers – Accuracy, Calibration & Calibration Accuracy." This aligns precisely with the content outlined in SFS-EN ISO 13385-1:2019. Additionally, a video guide is available, "Caliper Calibration - How to Calibrate a Caliper."

2.9.3 ISO – Micrometers (External measurement)

Previous chapters have explained micrometers. Moreover, reading of micrometers, zero errors, and handling procedure are emphasized. In accordance with SFS-EN ISO 3611:2023, this chapter will detail metrological characteristics, conformity to accuracy specification, and calibration related guidelines.

I. **Metrological characteristics:**

a. The maximum permissible error (MPE) must not be less than the digital micrometer step size. On the other hand, MPE values might be smaller than the scale interval. (SFS-EN ISO 3611:2023, 10)

b. The manufacturer stated operating conditions should be followed. Otherwise, the atmospheric condition for the test values should be adjusted to 20°C to determine the error the micrometer for external measurement would have produced at that temperature. (SFS-EN ISO 3611:2023, 10).

c. External measuring micrometers must have functions to set zero-point or to the reference point. When evaluating metrological properties, this position is considered fixed for the reference point. Periodic monitoring of the zero or reference point of the micrometer is recommended. (SFS-EN ISO 3611:2023, 10 & 17).

d. Measurement standards such as gauge blocks in accordance with ISO 3650, must be used to test the indicator errors. Test points shall cover the range of the micrometer. (SFS-EN ISO 3611:2023, 10 & 16).

e. The goal of the length measurement error is to identify a variety of micrometer errors related to external measurements, such as scale errors, measuring spindle rotation, the impact of applied force, and frame deflection. In the case of external measurements, the **length measurement error** (**E_{MPE}**) is the indication error when the entire measuring face of the micrometer is fully in contact with a measurement standard, like gauge blocks. To compute this error, differences are taken between observed value and reference value. Once zero is set, it is required to take at least five test points throughout the measuring range. 90% of the measuring span or more must be achieved by at least one test point in relation to the reference point. In addition, it must cover different angular positions of thimble, three test points is sufficient. In order to maximize testing efficiency, the test points obtained over the micrometer's measuring range for external measurements may be the same test points at various thimble angular positions. (SFS-EN ISO 3611:2023, 11 & 16).

f. By default, 5 N and 15 N are the minimum and maximum measuring forces. However, the maker must specify it. (SFS-EN ISO 3611:2023, 12).

g. For acceptance tests, manufacturers must provide specification values (MPE). On the other hand, for reverification user shall indicate it. Additionally, Table 2 of SFS-EN ISO 3611:2023 serves as a specification sheet for users for recording of metrological characteristics. Furthermore, MPE values are defined for each micrometer class. In accordance with SFS-EN ISO 3611:2023, there are four classes of micrometers viz. class 0, Class 1, Class 2, and Class 3. Thus, MPE values from Tables 3, 4, and 5 of SFS-EN ISO 3611:2023 can be used to check conformity or nonconformity of these classes. The decision rule that applies is simple acceptance or rejection. (SFS-EN ISO 3611:2023, 12).

II. **Conformity to specifications:** For conformity to specifications, given MPEs are used to compare observed errors. The rule for decision is that given specifications must be followed for - compliance or non-compliance. For instance, the MPE values provided in Tables 3, 4, and 5 on page 12 to 14 can be used for decision rule - acceptance and rejection. Also, measurement uncertainty shall be evaluated as per the ISO/IEC Guide 98-3. (SFS-EN ISO 3611:2023, 12-15). In addition, the user or operator must possess sound skills for the operation of micrometer to determine conformity with specifications. In accordance with ISO 14253-5, when the user is experienced, it eliminates skill related to any test values variation contributing to the measurement uncertainty. (SFS-EN ISO 3611:2023, 10 & 15).

III. **Calibration guidelines:** According to Annex A of SFS-EN ISO 3611 (2023, 16), the calibration of a micrometer should generally include the evaluation of the metrological characteristics of the micrometer within its measuring range. The calibration should include verification testing of all metrological characteristics across the measuring range. Additionally, task-related calibration of the micrometer should be considered, depending on its intended application. (SFS-EN ISO 3611:2023, 16). Therefore, to confirm the quality of the micrometer calibration, checking either the length measurement error or the variation in length measurement error will be effective. Further testing guidelines can be found in Annex A (A.3 and A.4) of SFS-EN ISO 3611:2023. Furthermore, Mitutoyo America Corporation has published a video guide, "Outside Micrometer Calibration – How to Calibrate." This video guide is based on ASME B89.1.13. though this aligns precisely with the content outlined in SFS-EN ISO 3611:2023.

2.9.4 ISO – Uncertainty of measurement

Calibration certificates capture the recorded outcomes. When these results consistently match reference values within acceptable differences, no further actions are necessary. In cases of notable disparities, adjustments are essential to align the instrument's measurements. At times, fine-tuning the instrument is possible to guarantee precise readings, and these adjustments are noted in the certificate. Every calibration mandates an accompanying declaration specifying the related uncertainties. (Auty et al. 2016, 20).

According to Bell (2001, 1), uncertainty of measurement is the doubt that exists about the result of any measurement. Precise and accurate measurement is one that is near to the true measurement. However, in practice achieving true measurement is not possible. Many calibrations are prone to uncertainties. Type A evaluation and type B evaluation can evaluate these measurements uncertainties (MU). Type A uncertainty evaluations applies to both random error and bias, and carried out by statistical methods, usually from repeated measurement readings whereas type B uncertainty evaluations can apply to both random error and bias, are carried out using any other information (not based on a statistical) such as past experiences, calibration certificates, manufacturers specifications, from calculation, from published information and from common sense. (Auty et al. 2016, 25; Eren 2005, 272; ISO/IEC GUIDE 98-3:2008(E), 2-3 & 6-7.)

Moreover, MU are not - tolerances (are acceptance limits chosen for the process or product), specifications (tell what to expect from a product), accuracy (is a qualitative term), and mistakes (made by calibration personnel which can be avoided). (Auty et al. 2016, 18-20; Bell 2001, 10-11.) These uncertainties can be determined by using ISO/IEC GUIDE 98-3:2008(E). However, guides by National Physical Laboratory (NPL) viz. Good Practice Guide 11 and Good Practice Guide 131 are easy to interpret and outlines exactly same contents. Thus, equations are taken from both guides.

Type A evaluations, Standard uncertainty = Standard Deviation / √n
Where **n** is **n^{th}** number of readings. (See chapter 2.3 for standard deviation evaluation.)

Type B evaluations, Standard uncertainty = a / √3
Where **a** is half range between upper and lower limits.

Combined Standard uncertainty = $\sqrt{(\text{Type A})^2 + (\text{Type B})^2}$

Expanded Standard uncertainty, U = Coverage factor k * Combined Standard uncertainty

Refer to Annex G (Table G.1) on page 70 of ISO/IEC GUIDE 98-3:2008(E) for coverage factor. Mostly **k** is chosen in the range of 2 to 3. (ISO/IEC GUIDE 98-3:2008(E), 24). However, many operators scale expanded uncertainty by taking **k=2**, to get confidence level of 95%. (Bell 2001, 16). That means 95% certain that true value lies within stated uncertainty. (Auty et al. 2016, 20).

3 Methodology for calibration

There are distinct types of research methods such as quantitative, qualitative, descriptive, analytical, applied, fundamental, conceptual, empirical. (Kothari 2004, 2-4). The purpose of the research method is to discover answers to questions through the application of scientific procedures (Kothari 2004, 2). This study aimed to find out the most economical calibration method for handheld tools by comparing and analyzing prices between in-house and outsourcing calibration. Besides, this task required hands-on laboratory experiment, numerical data collection and computations, and price computations and cost analysis. This was entirely experimental research that includes numerical data and mathematical operations. Therefore, this research strategy is a form of quantitative research method (Hudgikar 2021, 27).

3.1 Data collection strategies for quantitative research

Data collection strategies were:

- **a)** Seven calipers and eight micrometers were chosen to calibrate. The foundation of the laboratory experiment was based on SFS-EN ISO 14978:2019 (see 3.2). It describes how to assess metrological characteristics of the devices. For this thesis, partial surface contact error and length measurement error were selected for calipers and micrometers, respectively. It suggests how to carry out lab experiments for both devices. In addition, calibration procedures are outlined below for both devices (see 3.3 & 3.4).
- **b)** To manipulate data, they should be compiled in an easily read form (Walliman 2011, 114). Therefore, created a data set worksheet in Excel - for all blocks sets, device sets, and calibration data.
- **c)** As a rule of thumb, 20 samples were collected from each gauge block for each device. Note that five distinct gauge blocks were used to cover various ranges of calipers (ISO 13385-1:2019, 12) & micrometers (ISO 3611:2023, 11). That means a total of 100 samples for each device collected.
- **d)** For acceptance test, their accuracies were computed and compared to manufacturers stated MPEs values or against stated MPEs values in ISO 3611:2023 (micrometer) & ISO 13385-1:2019 (caliper). If observed accuracies did not meet stated MPEs values than they were pronounced as “Rejected” otherwise “Accepted.”
- **e)** Standard deviations, type A & B uncertainties, combined uncertainties, and expanded uncertainties with coverage factor of two (k=2) were

computed for all devices as per ISO/IEC GUIDE 98-3:2008(E), Good Practice Guide 11 and Good Practice Guide 131. These parameters are used to observe precision, dispersion, and level of confidence. These measures do not mean much on their own unless they are compared with some expected measures or those of other variables. Graphical options make comparisons between variables clearer. (Walliman 2011, 118.) Therefore, bar graphs were plotted in Excel to show variability among observed value, corrected value, and true value. Likewise, normal distribution curves (bell curves) were plotted in Minitab for all devices to show samples dispersion within specification limits.

f) Karelia University of Applied Sciences, in-house rates for both student and laboratory staff were obtained, and total in-house calibration cost for both were computed by multiplying total project time and respective rates of both student and laboratory staff including VAT of 24%.

g) Karelia University of Applied Sciences provided quotations of Kiwa Inspecta and Jamk. Basically, the duration of the calibration, labor rates, device range rates, shipment charges were the factors computed for calibration price.

h) For Kiwa Inspecta, analyzed how many calipers and micrometers falls under the given quotation device range and rates applied accordingly, and summed up both costs, then shipment charge was added (for both up and down) with 24% VAT to determine total calibration cost of Kiwa Inspecta.

i) While Jamk had no range threshold. For both devices had two distinct fixed prices. Besides, calibration certificate cost separate charge for each device. To calculate total calibration cost without calibration certificate, micrometer rate and caliper rate were multiplied to the total number of micrometers and calipers, and summed up both costs, then VAT of 24% added. Since no shipment charge was added as there was none in given quotation. However, to determine economical method, shipment charge was assumed (both up & down) and recalculated price with 24% VAT.

j) Finally, costs analysis for in-house and outsourcing were analyzed on five calibration prices – Karelia student price, Karelia laboratory staff price, Kiwa Inspecta price, Jamk without calibration certificate price and

Jamk without calibration certificate price but with assumed shipment price. Comparison bar graphs were created to show initial and final prices for all five calibration prices. As a result, economical method of calibration determined.

3.2 Calibration by determining conformance

In accordance with SFS-EN ISO 14978:2019, calibration and verification of measuring instruments involves two methods viz. **calibration by determining reference values** and **calibration by determining conformance (verification).** Refer to Clause 6.1.4 and Figure 6 of SFS-EN ISO 14978:2019 for extensive information on the same. However, this study will employ "**calibration by determining conformance (verification)**" method for calibration of handheld instruments. Based on this method, calibration events are presented below, figure 20. Basically, its insights into how this calibration will be conducted for both devices.

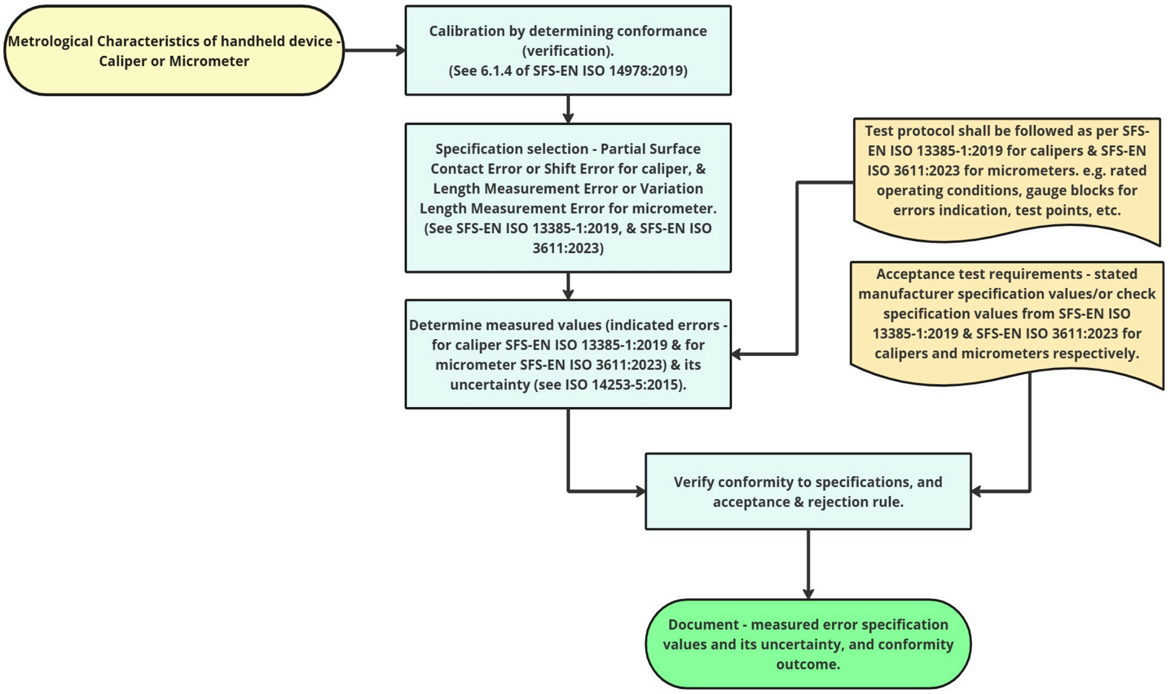


Figure 20. Calibration by determining conformance.

3.3 Calibration procedure for calipers

By now, use of calipers, and SFS-EN ISO 13385-1:2019 the readers must have acquired requirements. Now, this procedure provides a set of concrete steps of caliper calibration.

a) Should abide by the manufacturer's stated operating conditions for MPE values. Otherwise, the atmospheric condition for the test values should be adjusted to 20°C to determine the error. (SFS-EN ISO 13385-1:2019, 10; Mitutoyo 2024, 3).

b) Gauge blocks are perfect standard to test the indicator errors of calipers. (SFS-EN ISO 13385-1, 2019, 10; Bailey et. al. 2017, 2). For caliper calibration, partial surface contact error will be determined. (SFS-EN ISO 13385-1, 2019, 16). Therefore, five distinct gauge blocks of many sizes will be used. Refer to Table 2 on page 12 of SFS-EN ISO 13385-1:2019 to know more about test points.

c) Should clean the measuring faces, sliding scale and gauge blocks with cleaning solutions and tools (oil, dirt, and dust with lint free cloth or brush - wipe off or remove foreign substances). Besides, should observe the measuring faces for burrs, scratches, nicks, wear, or other issues to maximize instrument productivity. Overall, the device should be in good condition. (Flack 2014, 14; IANZ 2020, 10; Mitutoyo 2024, 3-4, 30). In addition, operators should avoid holding devices when not necessary as this can cause thermal expansion and inaccuracies. (IANZ 2020, 10; Mitutoyo 2024, 6).

d) Should initiate by closing the jaws and setting to zero (reference point). Should observe that there are no gaps between the jaws when closed. (Flack 2014, 15; IANZ 2020, 10; Raghavendra and Krishnamurthy 2013, 96; ISO 13385-1, 2019, 10; Mitutoyo 2024, 4).

e) Should open the jaws wide enough to feed the gauge block then the fixed jaw should come in contact with the workpiece. It should be close to the main scale for accuracy. Then, the beam of caliper and the line of measurement should be aligned. Next, should slide the caliper's jaw for even contact with the workpiece and fine adjustment screw should be used for the good contact. To prevent distortion of the tools, should not use excessive force. If there is a clamping screw present, should utilize it to minimize angularity errors. However, operators should avoid relying on it as a memory device. (Flack 2014, 15; IANZ 2020, 10; Raghavendra and Krishnamurthy 2013, 96).

f) Record the caliper reading. Repeat the measurement numerous times in the same setting. As a rule of thumb, 20 times is sufficient, so that it will increase the confidence of measurement. However, these test points must include at least one point measured at 90% or greater of the caliper range. Besides, for the longest and shortest gauge blocks in the test, two test points viz. one close to the beam and one close to the jaws' tip must be collected. (SFS-EN ISO 13385-1:2019, 11). See Picture 11.

g) To compute this error, differences are taken between observed value and reference value. (SFS-EN ISO 13385-1:2019, 10)**.**

h) For acceptance test, these error values are compared with the manufacturer stated MPE values. If otherwise not stated, then Annex B (Table B.1, SFS-EN ISO 13385-1:2019) shall be applied for calipers with a range up to 1000 mm - with analog scale interval or digital step of 0.01 mm, 0.02 mm, and 0.05 mm. (SFS-EN ISO 13385-1:2019, 14 & 17). Furthermore, measurement uncertainty shall be evaluated as per the ISO/IEC Guide 98-3 (see 2.9.4). Finally, conformity to specifications, every indicator error has to match the given MPE values, and the decision rule that comes with the specifications must be followed for proving compliance or non-compliance. (SFS-EN ISO 13385-1:2019, 14-15).

3.4 Calibration procedure for micrometers

By now, use of micrometers, and SFS-EN ISO 3611:2023 the readers must have acquired requirements. Now, this procedure provides a set of concrete steps of micrometer calibration.

a) Operators must abide by the manufacturer’s stated operating conditions for MPE values. Otherwise, the atmospheric condition for the test values should be adjusted to 20°C to determine the error. (SFS-EN ISO 3611:2023, 10; Mitutoyo 2024, 3).

b) Gauge blocks are perfect standard to test the indicator errors of external measurement micrometers. (SFS-EN ISO 3611:2023, 10-11; Bailey et. al. 2017, 2). For micrometer calibration, length measurement error will be determined. (SFS-EN ISO 3611:2023, 16). Therefore, five distinct gauge blocks of many sizes will be used. (SFS-EN ISO 3611:2023, 11).

c) Before using the micrometer, the operator should completely clean the spindle, anvil, and the measurement faces. Clean, lint-free cloth or paper should be used. Additionally, the measuring faces for burrs, and scratches should be on checklist. Besides, observation should include spindle, thimble and ratchet rotate or turn smoothly and freely. Overall, the device should be in working condition. (Flack 2014, 46; IANZ 2020, 11; Mitutoyo 2024, 3-4). Moreover, never hold calipers and blocks in hands for longer than is absolutely required, avoid sunlight, and air currents. Thermal expansion can be caused by these factors, which increases the system's inherent errors. (Flack 2014, 47; IANZ 2020, 11; Mitutoyo 2024, 6). If possible, use micrometer stand to minimize operator’s measurement errors. (Flack 2014, 49).

d) Should initiate by closing the jaws and setting to zero (reference point). (Flack 2014, 46; IANZ 2020, 11; SFS-EN ISO 3611:2023, 10).

e) Should open the spindle wide enough to bring gauge block near the desired opening. Then, feeding should be done by rotating thimble only for spindle. Next, the ratchet should be used gently to bring measuring faces in contact with gauge block and stop turning ratchet with a click as overturned may give false reading. Moreover, operators should use locknuts for precise measurement reading. (Raghavendra and Krishnamurthy 2013, 103-104; Flack 2014, 46-47).

f) Readings should be taken from correct angle to minimize parallax error. i.e., view the datum line on the outer sleeve directly from above. (Flack 2014, 47; Mitutoyo 2024, 11). Record the micrometer reading. Should repeat the measurement numerous times in the same setting. As a rule of thumb, 20 times is sufficient, so that it will increase the confidence of measurement. However, these test points must include at least one point measured at 90% or greater of the micrometer range. In addition, it must cover different angular positions of thimble, three test points is sufficient. (SFS-EN ISO 3611:2023, 11).

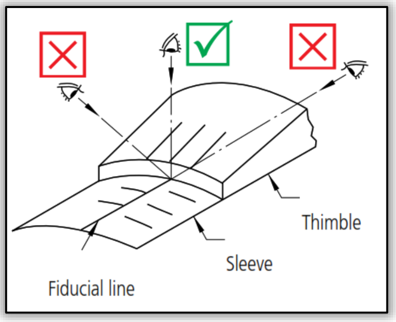


Figure 21. Correct reading angle (Mitutoyo 2024, 6)

g) To compute this error, differences are taken between observed value and reference value. (SFS-EN ISO 3611:2023, 11).

h) For acceptance test, these error values are compared with the manufacturer stated MPE values. If otherwise not stated, MPE values from Tables 3, 4, and 5 of SFS-EN ISO 3611:2023 can be used to check conformity or nonconformity. The decision rule that applies is simple acceptance or rejection. (SFS-EN ISO 3611:2023, 12-14). Furthermore, measurement uncertainty shall be evaluated as per the ISO/IEC Guide 98-3 (see 2.9.4). Finally, conformity to specifications, every indicator error has to match the given MPE values, and the decision rule that comes with the specifications must be followed for proving compliance or non-compliance. (SFS-EN ISO 3611:2023, 15).

4 In-house calibration

4.1 Schematic of test process

Before proceeding with lab experiments new operators (or even experienced ones) should make schematic of the test process (figure 22). It expresses the idea of what is stated in clause 3 page 6-9 of SFS-EN ISO 14253-5:2015. It increases the confidence level of the process from start to end. Besides, keeping these procedural steps in mind, it aided in instruments practice as well as in actual calibration.

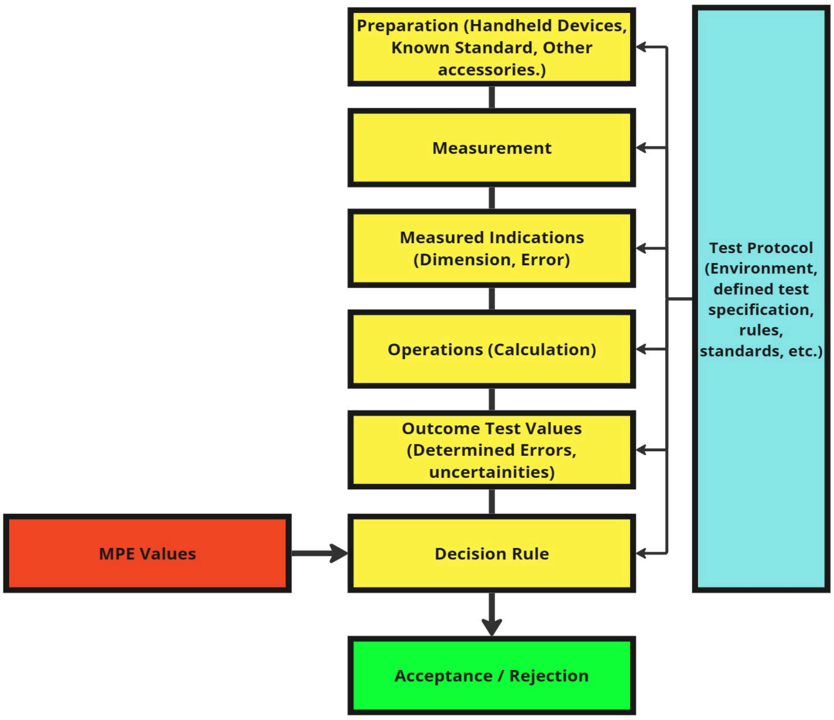


Figure 22. Schematic of test process

4.2 Calibration worksheet

To carry out calibration, lab personnel must record information such as date, temperature, device information, measurement, time taken. Therefore, to store this data worksheets were created. See table 3, below, for specs.

SN	Caliper Worksheets	SN	Micrometer Worksheets
1	Gauge Block Sets for Calipers – records make, range, the number of blocks, the time taken for cleaning, and the observation of blocks.	1	Gauge Block Sets for Micrometers – records make, range, the number of blocks used, the time taken for cleaning, and the observation of blocks.
2	Caliper Sets for Calibration – records make, range, number of calipers tested, time taken for cleaning, and observation of calipers, calibrated time for each caliper, total calibration time, and calibrated status for all calipers.	2	Micrometer Sets for Calibration – records make, range, number of micrometers tested, time taken for cleaning, and observation of micrometers, calibrated time for each micrometer, total calibration time, and calibrated status for all micrometers.
3	Caliper Calibration Data – records date, temperature, device information, measurements, time taken, operations, and calibration conformity status.	3	Micrometer Calibration Data – records date, temperature, device information, measurements, time taken, operations, and calibration conformity status.

Table 3. Calibration sheets specific for calipers and micrometers.

Many accredited laboratories have their own calibration/recording sheets. In this case, Excel application was used to prepare calibration/recording sheets. A total of six distinctive styles of sheets were created for both micrometer and caliper. Tables 4a, 4b, and 4c were created to fill in “Gauge Block Sets for Micrometers”, “Micrometer Sets for Calibration”, and “Micrometer Calibration Data” respectively. On the other hand, tables 5a, 5b and 5c were created to fill in “Gauge Block Sets for Calipers”, “Caliper Sets for Calibration”, and “Caliper Calibration Data” respectively.

S.N.	Make	Block Size (mm)	No. of pieces	Observation & Cleaning Time (min)
Time Taken				

Table 4a. Gauge Block Sets for Micrometers worksheet

S.N.	Make	Micrometer Range (mm)	No. of pieces	Observation & Cleaning Time (min)	Calibration Time Taken
Total Time Taken					

Table 4b. Micrometer Sets for Calibration worksheet

Date: 21.3.2024								Zero Error (mm):			Coverage Factor:	
Make:			Range (mm): 0-25		LC (mm):		Temperature: 20°C		Accurcy (mm): ±		Calibration:	Accepted
MICROMETER	Gauge block length size to cover micrometer range (true values, mm)		2		4		8		10		20	
	No. of observations on measuring faces	S.N.	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected
		1										
		2										
		3										
		4										
		5										
		6										
		7										
		8										
		9										
		10										
		11										
		12										
		13										
		14										
		15										
		16										
		17										
		18										
		19										
		20										
	Mean (mm)											
	SD (σ) mm											
	Accuracy (mm)=Mean-True											
	Type A Standard Un. (mm)											
	Type B Standard Un. (mm)											
	Combined Standard Un. (mm)											
	Expanded Standard Un. (mm)											
	Accuracy Limit Check											
	Time Taken (min)											
	Total Time Taken (min)											

Table 4c. Micrometer Calibration Data worksheet

S.N.	Make	Block Range (mm)	No. of pieces	Observation & Cleaning Time (min)
Total Time Taken				

Table 5a. Gauge Block Sets for Calipers worksheet

S.N.	Make	Caliper Range (mm)	No. of Caliper	Observation & Cleaning Time (min)	Calibration Time Taken
Total Time Taken					

Table 5b. Caliper Sets for Calibration worksheet

Date: 22.03.2024								Zero Error (mm):		Coverage Factor:	
Make:		Range (mm): 0-150		LC (mm):		Temperature: 20°C		Accurcy (mm): ±		Calibration:	Accepted
CALIPER	Gauge block length size to cover caliper range (true values, mm)	4		10		60		90		125	
No. of observations at different jaw positions (eg. Tip, Center, Near beam, etc.)	S.N.	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected
	1										
	2										
	3										
	4										
	5										
	6										
	7										
	8										
	9										
	10										
	11										
	12										
	13										
	14										
	15										
	16										
	17										
	18										
	19										
	20										
Mean (mm)											
SD (σ) mm											
Accuracy (mm)=Mean-True											
Type A Standard Un. (mm)											
Type B Standard Un. (mm)											
Combined Standard Un. (mm)											
Expanded Standard Un. (mm)											
Accuracy Limit Check											
Time Taken (min)											
Total Time Taken (min)											

Table 5c. Caliper Calibration Data worksheet

4.3 Micrometer calibration

4.3.1 Apparatus/resources

The apparatus/resources used to conduct micrometer calibration were:

a. Known standard - C.E. Johansson steel 40-gauge block set (picture 13a).
b. Micrometer stand - for stability (picture 13b).
c. Clean and flat surface - desk
d. Clean cloth to wipe off dust, dirt, or oil.
e. Cleaning alcohol

f. Record sheets (see table 4a, 4b and 4c)
g. Timer
h. Micrometers (range 0-25, 25-50 & 50-75 mm)
   - Diesella Outside Micrometer – 2x
   - Mitutoyo 102-301 Outside Micrometer
   - VIS Outside Micrometer
   - Mitutoyo 292-240-30 Digital Outside Micrometer
   - Mauser Outside Micrometer
   - USSR Outside Micrometer
   - Mauser Outside Micrometer

Picture13a. C.E. Johansson steel 40-gauge block set (Picture: Sunil Lamichhane)

Picture 13b. Micrometer stand (Picture: Sunil Lamichhane)

4.3.2 Block sets in calibration

Eight distinct ranges of micrometers were calibrated using 51 blocks of varying dimensions. See table 6. Some blocks were repetitive to cover a greater range of micrometers. Besides, surface cleaning with alcohol and cloth, along with observing the measuring faces, took 30 seconds (0.5 min) for each block. Hence, the total time taken for cleaning and observing during calibration was 20.5 minutes. This data was recorded in the “Gauge Block Sets for Micrometers” worksheet.

Diesella Micrometer 0-25 mm (I)					Diesella Micrometer 0-25 mm (II)				
S.N.	Make	Block Size (mm)	No. of pieces	Observation & Cleaning Time (min)	S.N.	Make	Block Size (mm)	No. of pieces	Observation & Cleaning Time (min)
1	CE Johansson	2	1	0.5	1	CE Johansson	2	1	0.5
2	CE Johansson	4	1	0.5	2	CE Johansson	4	1	0.5
3	CE Johansson	8	1	0.5	3	CE Johansson	8	1	0.5
4	CE Johansson	10	1	0.5	4	CE Johansson	10	1	0.5
5	CE Johansson	20	1	0.5	5	CE Johansson	20	1	0.5
Time Taken				2.5	Time Taken				2.5
Mitutoyo 102-301 EM 0-25 mm					VIS Micrometer Poland 0-25 mm				
S.N.	Make	Block Size (mm)	No. of pieces	Observation & Cleaning Time (min)	S.N.	Make	Block Size (mm)	No. of pieces	Observation & Cleaning Time (min)
1	CE Johansson	2	1	0.5	1	CE Johansson	2	1	0.5
2	CE Johansson	4	1	0.5	2	CE Johansson	4	1	0.5
3	CE Johansson	8	1	0.5	3	CE Johansson	8	1	0.5
4	CE Johansson	10	1	0.5	4	CE Johansson	10	1	0.5
5	CE Johansson	20	1	0.5	5	CE Johansson	20	1	0.5
Time Taken				2.5	Time Taken				2.5

USSR Micrometer 25-50 mm					Mauser Micrometer 25-50 mm				
S.N.	Make	Block Size (mm)	No. of pieces	Observation & Cleaning Time (min)	S.N.	Make	Block Size (mm)	No. of pieces	Observation & Cleaning Time (min)
1	CE Johansson	4	1	0.5	1	CE Johansson	4	1	0.5
2	CE Johansson	8	1	0.5	2	CE Johansson	8	1	0.5
3	CE Johansson	10	2	0.5	3	CE Johansson	10	2	0.5
4	CE Johansson	20	2	0.5	4	CE Johansson	20	2	0.5
5	CE Johansson	40	3	0.5	5	CE Johansson	40	3	0.5
Time Taken				2.5	Time Taken				2.5
Mauser Micrometer 50-75 mm					Mitutoyo 292-240-30 Digital Micrometer 0-25 mm				
S.N.	Make	Block Size (mm)	No. of pieces	Observation & Cleaning Time (min)	S.N.	Make	Block Size (mm)	No. of pieces	Observation & Cleaning Time (min)
1	CE Johansson	4	1	0.5	1	CE Johansson	2	1	0.5
2	CE Johansson	8	1	0.5	2	CE Johansson	4	1	0.5
3	CE Johansson	10	1	0.5	3	CE Johansson	8	1	0.5
4	CE Johansson	40	1	0.5	4	CE Johansson	10	1	0.5
5	CE Johansson	60	3	0.5	5	CE Johansson	20	1	0.5
6	CE Johansson	70	1	0.5	Time Taken				2.5
Time Taken				3					
Total no. blocks used		51							
Total Time taken (min)		20.5							

Table 6. Block sets used against micrometers for calibration recorded in "Gauge Block Sets for Micrometers" worksheet.

4.3.3 Micrometers sets for calibration

Eight distinct ranges of micrometers were chosen as devices under test for calibration. The range varies from "0" to "25" mm, "25" to "50" mm and "50" to "70" mm. Table 7 shows the variation in times for cleaning and observation of all eight micrometers. Prior to being selected for calibration, every micrometer was carefully cleaned and examined. The time was then noted in the "Micrometer Sets for Calibration" worksheet. Thus, the total time taken for this task was 57 minutes.

S.N.	Make	Micrometer Range (mm)	No. of pieces	Observation & Cleaning Time (min)	Calibration Time Taken
1	Diesella O.Micrometer (I)	0-25	1	5	49
2	Diesella O.Micrometer (II)	0-25	1	6	31
3	Mitutoyo 102-301 O.Micrometer	0-25	1	10	33
4	VISO.Micrometer	0-25	1	5	34
5	Mitutoyo 292-240-30 Digital	0-25	1	5	30
6	Mauser O.Micrometer	25-50	1	7	39
7	USSRO.Micrometer	25-50	1	5	31
8	Mauser O.Micrometer	50-75	1	14	42
Total Time Taken				**57**	**289**

Table 7. Micrometers under test for calibration recorded in “Micrometer Sets for Calibration” worksheet.

Similarly, variation in the time taken for calibration (last column) can be observed across all micrometers. The sources of the outputs in this column are the worksheets labeled "Micrometer Calibration Data" for each particular micrometer. Hence, the total time for calibrating all micrometers was 289 minutes (4 hour, 49 minutes).

4.3.4 Diesella micrometer (I): Lab calibration, calculations, and graphs

A list of eight micrometers can be found in table 7. An identical calibration procedure was used for all. Thus, as a representative of all of them, one will be discussed here. That is Diesella Outside Micrometer (I). The calibration worksheet layout, computations, bar graphs, and normal distribution curves will be the key topics of discussion when it comes to the calibration output.

For Diesella micrometer, the "Micrometer Calibration Data" worksheet (see table 4c) was utilized to record temperature, measurements, computations, and device information. Primarily, micrometer details such as date, make, range, LC, accuracy were filled in. Next, temperature and zero error were checked and noted. For calibration, each micrometer was calibrated against five sets of gauge blocks. Blocks measuring 2 mm, 4 mm, 8 mm, 10 mm, and 20 mm were used to calibrate the Diesella outside micrometer (table 8). From each gauge block, 20 samples were obtained at different measuring faces. These samples are called observed measurements.

Date: 21.3.2024								Zero Error (mm): Positive error 0.005		Coverage Factor:	2
Make: Diesella O.Micrometer (I)		Range (mm): 0-25		LC (mm): 0.01		Temperature: 20°C		Accurcy (mm): ± 0.004		Calibration:	Rejected
MICROMETER	Gauge block length size to cover micrometer range (true values, mm)	2		4		8		10		20	
	S.N.	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected
No. of observations on measuring faces	1	2.005	2	4.005	4	8.005	8	10.005	10	20.005	20
	2	2.005	2	4.005	4	8.005	8	10.005	10	20.005	20
	3	2.005	2	4.005	4	8.005	8	10.005	10	20.005	20
	4	2.005	2	4	3.995	8.005	8	10.005	10	20.005	20
	5	2.005	2	4.005	4	8.005	8	10.005	10	20.005	20
	6	2.005	2	4.005	4	8.005	8	10.005	10	20.005	20
	7	2.005	2	4.005	4	8	7.995	10.005	10	20.005	20
	8	2.005	2	4	3.995	8	7.995	10.005	10	20.005	20
	9	2.005	2	4	3.995	8	7.995	10.005	10	20.005	20
	10	2.005	2	4.005	4	8	7.995	10.005	10	20.005	20
	11	2.005	2	4	3.995	8	7.995	10.005	10	20.005	20
	12	2.005	2	4.005	4	8	7.995	10.005	10	20.005	20
	13	2.005	2	4	3.995	8	7.995	10.005	10	20.005	20
	14	2.005	2	4	3.995	8	7.995	10.005	10	20.005	20
	15	2.005	2	4	3.995	8.005	8	10.005	10	20.005	20
	16	2.005	2	4.005	4	8.005	8	10.005	10	20.005	20
	17	2.005	2	4	3.995	8.005	8	10.005	10	20.005	20
	18	2.005	2	4	3.995	8.005	8	10.005	10	20.005	20
	19	2.005	2	4.005	4	8.005	8	10.005	10	20.005	20
	20	2.005	2	4.005	4	8	7.995	10.005	10	20.005	20
	Mean (mm)	2.005	2	4.00275	3.99775	8.00275	7.99775	10.005	10	20.005	20.0
	SD (σ) mm	0	0	0.002552	0.002552	0.002552	0.002552	0	0	0	0
	Accuracy (mm)=Mean-True	0.005	0	0.00275	-0.00225	0.00275	-0.00225	0.005	0	0.005	0
	Type A Standard Un. (mm)	0		0.000570664		0.000570664		4.07524E-16		0	
	Type B Standard Un. (mm)	0.002886751		0.002886751		0.002886751		0.002886751		0.002886751	
	Combined Standard Un. (mm)	0.002886751		0.002942616		0.002942616		0.002886751		0.002886751	
	Expanded Standard Un. (±mm)	0.005773503		0.005885233		0.005885233		0.005773503		0.005773503	
	Accuracy Limit Check	Rejected		Accepted		Accepted		Rejected		Rejected	
	Time Taken (min)	11		10		10		10		8	
	Total Time Taken (min)	49									

Table 8. Diesella outside micrometer (I) calibration data recorded in "Micrometer Calibration Data" worksheet

The observed readings were subtracted by positive zero error to yield the corrected measurements. See table 8. Then, the mean and standard deviation were calculated for each (see 2.3 for manual compute). Following that, the accuracy was computed by subtracting the observed value from the true value (gauge block size). Accuracy limit checker checks obtained accuracy and compares with actual accuracy of the micrometer. If the values are in between ±0.004 mm, it gives "Accepted" otherwise "Rejected." For Diesella micrometer, block length size of 2 mm yields observed accuracy of 0.005 mm. Thus, it rejects. Note that all "Accepted" responses are required from each block for the acceptance test. Here, Diesella micrometer failed to be "Accepted."

Type A and B uncertainties, combined uncertainties, and expanded uncertainties with coverage factor computed (see 2.9.4). It is important to express these uncertainties result. For instance, this micrometer measured the length of gauge block of 2 mm as,

2.005±0.0057 mm. (Likewise, the rest of observed mean values and uncertainties can be expressed for this micrometer.)

This should be reported as "The reported uncertainty is based on a standard uncertainty multiplied by coverage factor k = 2, providing a level of confidence of approximately 95 %, assuming normality (Auty et al. 2016, 30; Bell 2001, 17

). With this uncertainty, Diesella micrometer (I) cannot produce an acceptable range of measurements.

In addition, each block of “Observed Vs Corrected” values (samples, n=20) were compared on the bar graph. See bar graph figures 23a, 23b, 23c, & 23d. It makes it easier to interpret how accurate both observed and corrected values are. Micrometer has positive zero error of ±0.005 mm. Even after correction, there can be seen variation of length sizes for 4 and 8 blocks. Besides, the accuracy limit is ±0.004 mm. It can be seen most of observed values are out of specification limit for all block sizes. Hence, the Diesella micrometer is not stable for measurement.

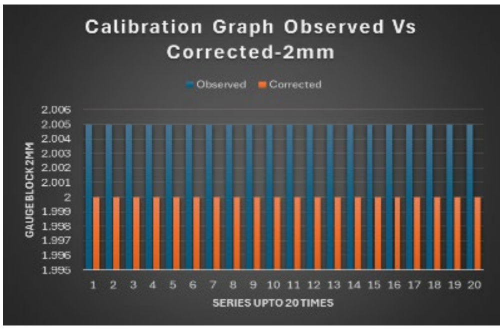


Figure 23a. Observed Vs Corrected of 2mm (n=20)

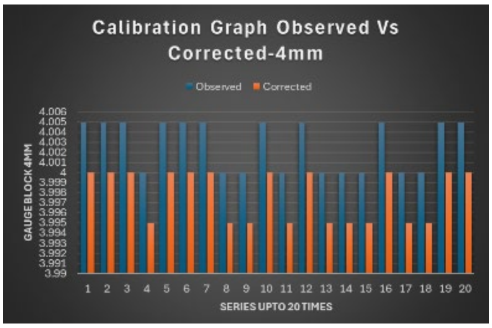


Figure 23b. Observed Vs Corrected of 4mm (n=20)

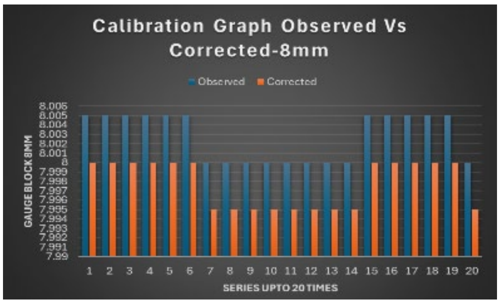


Figure 23c. Observed Vs Corrected of 8mm (n=20)

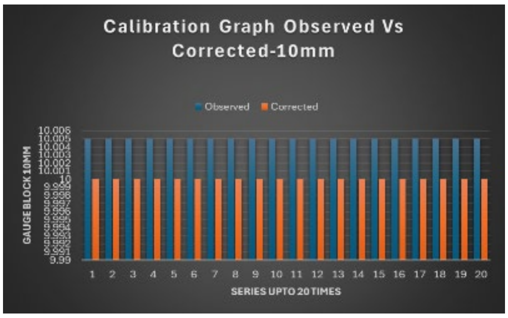


Figure 23d. Observed Vs Corrected of 10mm (n=20)

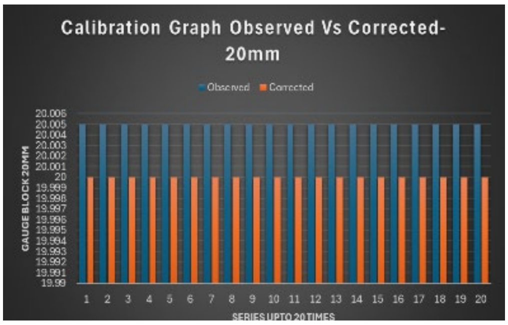


Figure 23e. Observed Vs Corrected of 20mm (n=20)

Moreover, master bar graph was prepared that compares “Observed Vs Corrected Vs True” length sizes of all gauge blocks. Figure 24 shows 2.005 mm as the measured value, but after correction, it displays 2 mm. True size of gauge block is 2 mm as well. It essentially displays the degree to which the measured and corrected value agrees with the true value. Clearly, observed mean size is out of specification limit and not even close to the true value. Thus, micrometer is out of calibre. Likewise, rest of the observed, corrected and true sizes are laid out for 4, 8, 10 and 20. Most of observed mean sizes are out of specification limits as well.

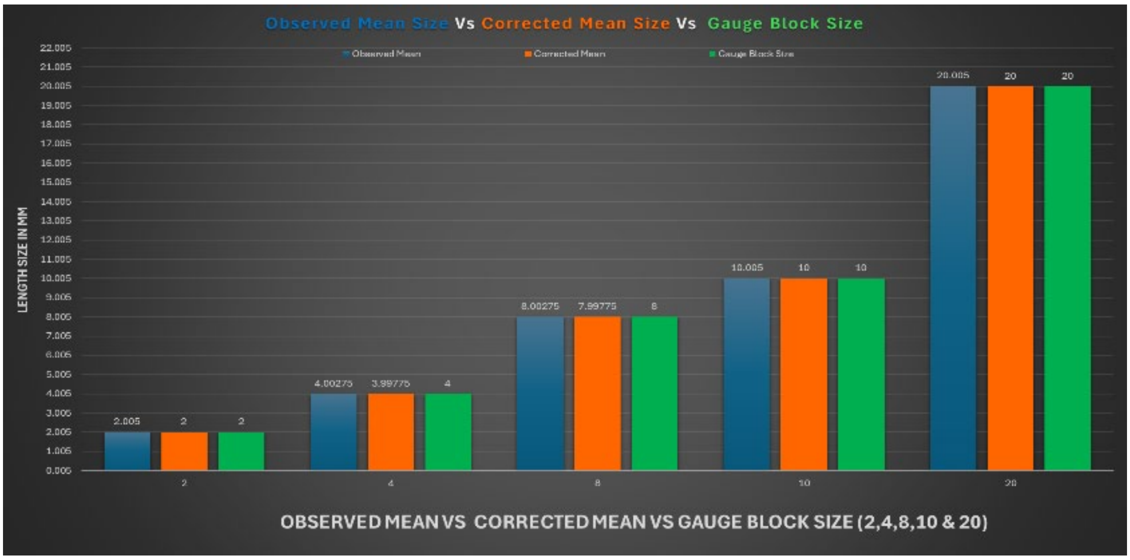
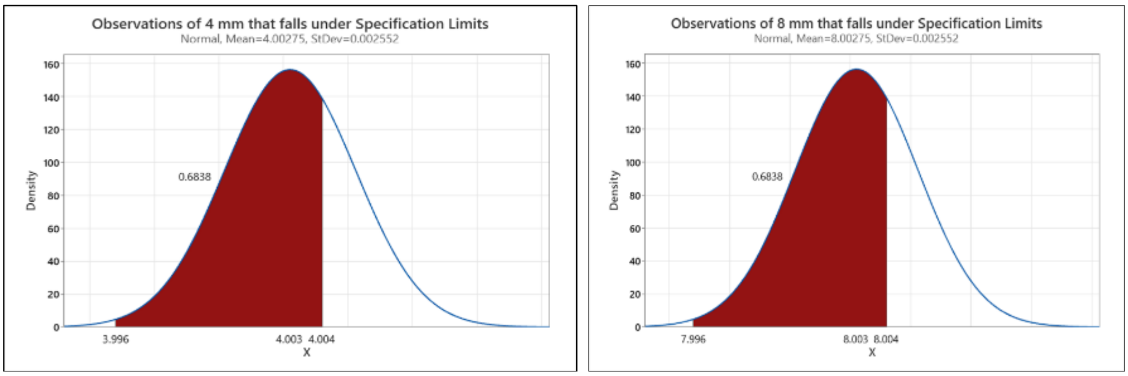


Figure 24. Observed Vs Corrected Vs True” length sizes comparison of all gauge blocks - Disella micrometer (I).

Furthermore, a normal distribution curve was plotted to check how many observed samples fall between the specification limit for each block. Below, figures 25a, and 25b represent normal distributions curves of observed samples of 4 mm, and 8 mm, respectively. According to empirical rule (3Sigma), 68% data falls within 1 standard deviation, 95% falls within 2 standard deviations, and 99.7% falls within 3 standard deviations (Minitab 2024, 5-6). Target of this calibration was to achieve 95% for each observation; however, both curves show 68.38% of observations within specification limits, and the rest of observations are out of specification limits. Besides, these curves indicate process spreads wider than specification limits. Therefore, the process is not stable and cannot produce accurate measurements. (Note that standard deviation of the observed 2mm, 10mm and 20mm is zero - see table 8. Therefore, plotting a normal distribution curve is impossible.)



Figures 25a & 25b. The normal distribution curves of the observed 4 mm and 8 mm shows 68.38% of samples within specs limit.

Consequently, in the calibration test the Diesella micrometer (I) was "Rejected." Then, the rejected micrometer was tagged with “Rejected” sticker. See picture 14. To sum up, calculations, bar graphs, and normal distribution curves show that the Diesella outside micrometer (I) was unable to take precise measurements.

Picture 14. Conformity sticker (Accepted/Rejected) tagged on micrometers (Picture: Sunil Lamichhane)

4.3.5 Remaining micrometers: Calibration status

The calibration outcomes for all eight micrometers, where seven rejected and one accepted, are shown in table 9. Each micrometer exhibits zero error issues, with some also presenting defects.

S.N.	Make	Micrometer Range (mm)	No. of pieces	Accuracy Limit(±mm)	Issues		Visible defects	Calibration Stattus
1	Diesella Outside Micrometer (I)	0-25	1	0.004	Positive Zero Error	0.005 mm		Rejected
2	Diesella Outside Micrometer (II)	0-25	1	0.004	Positive Zero Error	0.005 mm		Rejected
3	Mitutoyo 102-301 Outside Micrometer	0-25	1	0.002	Negative Zero Error	0.005 mm		Rejected
4	VIS Outside Micrometer	0-25	1	0.004	Negative Zero Error	0.005 mm		Rejected
5	Mitutoyo 292-240-30 Digital	0-25	1	0.001	Positive Zero Error	0.001 mm		Accepted
6	Mauser Outside Micrometer	25-50	1	0.004	Positive Zero Error	0.02 mm		Rejected
7	USSR Outside Micrometer	25-50	1	0.004	Positive Zero Error	0.01 mm	Ratchet broken/creaking Noise	Rejected
8	Mauser Outside Micrometer	50-75	1	0.005	Positive Zero Error	0.01 mm	Spindle rotates in irregular motion	Rejected

Table 9. Calibration status of all calibrated micrometers

Calibration worksheets and graphs for the remaining calibrated micrometers are presented below:

Diesella Micrometer (II): It was rejected in the calibration test as accuracies for blocks 2 mm and 8 mm exceeded accuracy limit. Besides, expanded standard uncertainties are higher which means no precise. Moreover, bar graphs show variation of observed values, corrected values, and true values. Similarly, distribution plots show around 50% of samples within specification limits and the rest of samples out of specification limits.

Date: 22.3.2024							Zero Error (mm):	Positive error 0.005		Coverage Factor:	2
Make: Diesella O.Micrometer (II)	Range (mm): 0-25		LC (mm): 0.01		Temperature: 20°C		Accurcy (mm): ± 0.004			Calibration:	Rejected
MICROMETER — Gauge block length size to cover micrometer range (true values, mm)	2		4		8		10		20		
No. of observations on measuring faces — S.N.	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	
1	2.005	2	4.005	4	8.005	8	10	9.995	20	19.995	
2	2.005	2	4.005	4	8.005	8	10	9.995	20	19.995	
3	2.005	2	4.005	4	8.005	8	10.005	10	20	19.995	
4	2.005	2	4.005	4	8.005	8	10.005	10	20	19.995	
5	2.005	2	4.005	4	8.005	8	10.005	10	20.005	20	
6	2.005	2	4.005	4	8.005	8	10	9.995	20.005	20	
7	2.005	2	4	3.995	8.005	8	10	9.995	20.005	20	
8	2.005	2	4	3.995	8.005	8	10.005	10	20.005	20	
9	2.005	2	4.005	4	8	7.995	10.005	10	20.005	20	
10	2.005	2	4.005	4	8.005	8	10.005	10	20.005	20	
11	2.005	2	4.005	4	8	7.995	10	9.995	20.005	20	
12	2.005	2	4.005	4	8.005	8	10	9.995	20.005	20	
13	2.005	2	4.005	4	8.005	8	10.005	10	20.005	20	
14	2.005	2	4.005	4	8.005	8	10.005	10	20.005	20	
15	2.005	2	4.005	4	8.005	8	10	9.995	20.005	20	
16	2.005	2	4.005	4	8.005	8	10.005	10	20.005	20	
17	2.005	2	4.005	4	8.005	8	10.005	10	20.005	20	
18	2.005	2	4	3.995	8	7.995	10.005	10	20	19.995	
19	2.005	2	4	3.995	8.005	8	10	9.995	20.005	20	
20	2.005	2	4.005	4	8.005	8	10	9.995	20.005	20	
Mean (mm)	2.005	2	4.004	3.999	8.00425	7.99925	10.00275	9.99775	20.00375	19.99875	
SD (σ) mm	0	0	0.002052	0.002052	0.001832	0.001832	0.002552	0.002552	0.002221	0.002221	
Accuracy (mm)=Mean-True	0.005	0	0.0040	-0.001	0.00425	-0.00075	0.00275	-0.00225	0.00375	-0.00125	
Type A Standard Un. (mm)	0		0.000458831		0.000409589		0.000570664		0.0004967		
Type B Standard Un. (mm)	0.002886751		0.002886751		0.002886751		0.002886751		0.002886751		
Combined Standard Un. (mm)	0.002886751		0.002922988		0.002915664		0.002942616		0.002929171		
Expanded Standard Un.(±mm)	0.005773503		0.005845976		0.005831328		0.005885233		0.005858342		
Accuracy Limit Check	Rejected		Accepted		Rejected		Accepted		Accepted		
Time Taken (min)	5		6		7		6		7		
Total Time Taken (min)	31										

Table 10a. Diesella micrometer (II) calibration data recorded in "Micrometer Calibration Data" worksheet

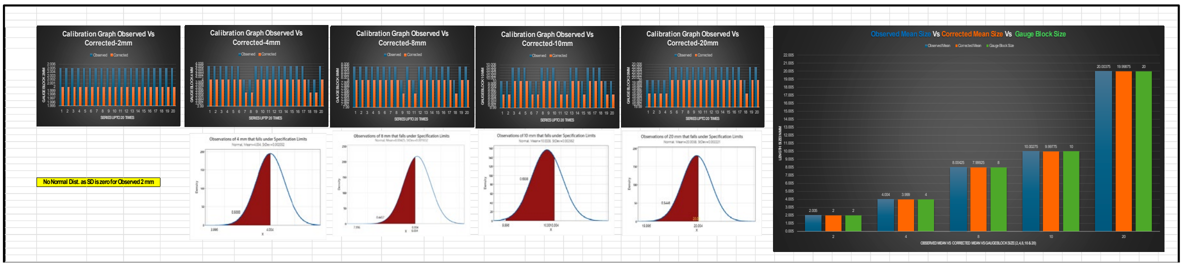


Figure. 26a. Diesella micrometer (II) – bar graphs & normal distribution plots

Mitutoyo 102-301 Micrometer: It was rejected in the calibration test as accuracies for all blocks exceeded accuracy limit. Besides, expanded standard uncertainties are higher which means no precise. Moreover, bar graphs show variation of observed values, corrected values, and true values. Similarly, distribution plots show around 30% of samples within specification limits and the rest of samples out of specification limits.

Date: 27.3.2024							Zero Error (mm): Negative error 0.005		Coverage Factor: 2	
Make: Mitutoyo 102-301 O.M	Range (mm): 0-25		LC (mm): 0.01		Temperature: 20°C		Accurcy (mm): ± 0.002		Calibration:	Rejected
MICROMETER — Gauge block length size to cover micrometer range (true values, mm)	2		4		8		10		20	
No. of observations on measuring faces — S.N.	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected
1	1.995	2	3.995	4	8	8.005	9.995	10	19.995	20
2	1.995	2	4.000	4.005	8	8.005	9.995	10	19.995	20
3	2	2.005	3.995	4	7.995	8	9.995	10	19.995	20
4	1.995	2	4.000	4.005	7.995	8	9.995	10	19.995	20
5	2	2.005	4.000	4.005	7.995	8	9.995	10	20	20.005
6	1.995	2	4.000	4.005	8	8.005	9.995	10	19.995	20
7	1.995	2	3.995	4	7.995	8	9.995	10	20	20.005
8	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
9	1.995	2	4.000	4.005	8	8.005	9.995	10	19.995	20
10	1.995	2	4.000	4.005	7.995	8	10	10.005	19.995	20
11	1.995	2	4.000	4.005	7.995	8	10	10.005	19.995	20
12	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
13	2	2.005	3.995	4	8	8.005	10	10.005	19.995	20
14	2	2.005	4.000	4.005	7.995	8	10	10.005	20	20.005
15	1.995	2	4.000	4.005	7.995	8	10	10.005	20	20.005
16	1.995	2	3.995	4	7.995	8	9.995	10	20	20.005
17	2	2.005	4.000	4.005	8	8.005	9.995	10	20	20.005
18	2	2.005	3.995	4	8	8.005	9.995	10	19.995	20
19	2	2.005	3.995	4	7.995	8	9.995	10	19.995	20
20	2	2.005	4.000	4.005	7.995	8	10	10.005	19.995	20
Mean (mm)	1.997	2.002	3.99775	4.00275	7.99675	8.00175	9.9965	10.0015	19.9965	20.0015
SD (σ) mm	0.002513	0.002513	0.002552	0.002552	0.002447	0.002447	0.002351	0.002351	0.002351	0.002351
Accuracy (mm)=Mean-True	-0.003	0.002	-0.00225	0.00275	-0.00325	0.00175	-0.0035	0.0015	-0.0035	0.0015
Type A Standard Un. (mm)	0.000561951		0.000570664		0.000547122		0.000525657		0.000525657	
Type B Standard Un. (mm)	0.002886751		0.002886751		0.002886751		0.002886751		0.002886751	
Combined Standard Un. (mm)	0.002940939		0.002942616		0.002938141		0.00293422		0.00293422	
Expanded Standard Un.(±mm)	0.005881878		0.005885233		0.005876283		0.005868441		0.005868441	
Accuracy Limit Check	Rejected		Rejected		Rejected		Rejected		Rejected	
Time Taken (min)	6		6		7		8		6	
Total Time Taken (min)	33									

Table 10b. Mitutoyo 102-301 micrometer calibration data recorded in “Micrometer Calibration Data” worksheet

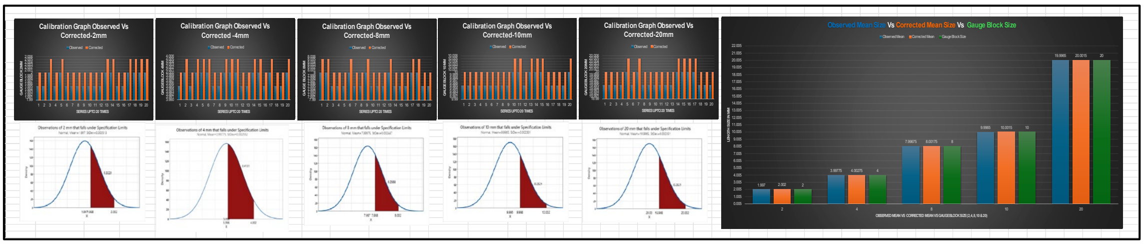


Figure 26b. Mitutoyo 102-301 micrometer – bar graphs & normal distribution plots

VIS Micrometer: It was rejected in the calibration test as accuracies for all blocks exceeded accuracy limit. Besides, expanded standard uncertainties are higher which means no precise. Moreover, bar graphs show variation of observed values, corrected values, and true values. Distribution plots were not plotted as SD is zero.

Date: 27.3.2024						Zero Error (mm):	Negative error 0.005		Coverage Factor:	2
Make: VIS O.Micrometer Poland	Range (mm): 0-25		LC (mm): 0.01		Temperature: 20°C		Accurcy (mm): ± 0.004		Calibration:	Rejected
MICROMETER — Gauge block length size to cover micrometer range (true values, mm)	2		4		8		10		20	
No. of observations on measuring faces — S.N.	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected
1	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
2	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
3	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
4	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
5	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
6	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
7	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
8	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
9	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
10	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
11	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
12	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
13	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
14	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
15	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
16	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
17	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
18	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
19	1.995	`	3.995	4	7.995	8	9.995	10	19.995	20
20	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
Mean (mm)	1.995	2	3.995	4	7.995	8	9.995	10	19.995	20
SD (σ) mm	0	0	0	0	0	0	0	0	0	0
Accuracy (mm)=Mean-True	-0.005	0	-0.005	0	-0.005	0	-0.005	0	-0.005	0
Type A Standard Un. (mm)	0		0		0		0		0	
Type B Standard Un. (mm)	0.002886751		0.002886751		0.002886751		0.002886751		0.002886751	
Combined Standard Un. (mm)	0.002886751		0.002886751		0.002886751		0.002886751		0.002886751	
Expanded Standard Un.(±mm)	0.005773503		0.005773503		0.005773503		0.005773503		0.005773503	
Accuracy Limit Check	Rejected		Rejected		Rejected		Rejected		Rejected	
Time Taken (min)	7		6		6		6		9	
Total Time Taken (min)	34									

Table 10c. VIS micrometer calibration data recorded in “Micrometer Calibration Data” worksheet

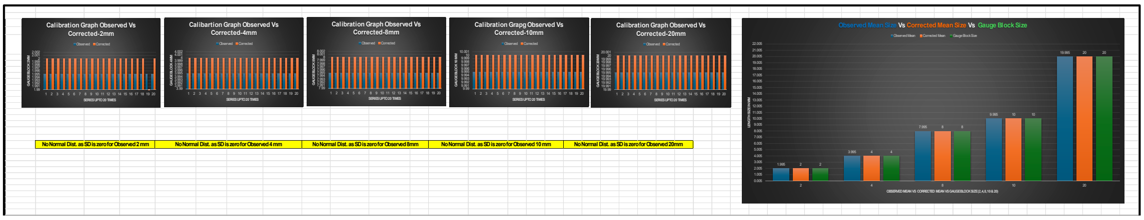


Figure 26c. VIS micrometer - bar graphs & normal distribution plots

Mitutoyo 292-240-30 Digital Micrometer: It was accepted in the calibration test as accuracies for all blocks were within accuracy limit. Besides, expanded standard uncertainties are slightly lower which means about precision. Moreover, bar graphs show variation of observed values, corrected values, and true values. Similarly, distribution plots show around 62% of samples within specification limits and the rest of samples out of specification limits. This is not acceptable for calibration. However, this still needs standard calibration.

Date: 28.3.2024							Zero Error (mm):	Positive error	0.001	Coverage Factor:	2
Make: Mitutoyo 292-240-30 Digi		Range (mm): 0-25		LC (mm): 0.001		Temperature: 20°C		Accurcy (mm): ± 0.001		Calibration:	Accepted
MICROMETER	Gauge block length size to cover micrometer range (true values, mm)	2		4		8		10		20	
No. of observations on measuring faces	S.N.	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected
	1	2.001	2	4.001	4	8.001	8	10.001	10	20.001	20
	2	2.001	2	4.001	4	8.001	8	10.001	10	20.001	20
	3	2.001	2	4.001	4	8.001	8	10.001	10	20.001	20
	4	2.001	2	4.001	4	8	7.999	10.001	10	20.001	20
	5	2.001	2	4.001	4	8.001	8	10	9.999	20.001	20
	6	2	1.999	4.001	4	8.001	8	10.001	10	20	19.999
	7	2.001	2	4.001	4	8.001	8	10	9.999	20.001	20
	8	2.001	2	4.001	4	8.001	8	10.001	10	20.001	20
	9	2.001	2	4.001	4	8.001	8	10.001	10	20.001	20
	10	2	1.999	4.001	4	8.001	8	10.001	10	20.001	20
	11	2	1.999	4.001	4	8.001	8	10.001	10	20.001	20
	12	2.001	2	4.001	4	8.001	8	10.001	10	20.001	20
	13	2.001	2	4.001	4	8.001	8	10.001	10	20.001	20
	14	2.001	2	4.001	4	8.001	8	10	9.999	20.001	20
	15	2.001	2	4.001	4	8.001	8	10.001	10	20.001	20
	16	2.001	2	4.001	4	8	7.999	10.001	10	20	19.999
	17	2.002	2.001	4.001	4	8.001	8	10.001	10	20.001	20
	18	2.001	2	4.001	4	8.001	8	10.001	10	20.001	20
	19	2.001	2	4.001	4	8.001	8	10.001	10	20.001	20
	20	2.001	2	4.001	4	8.001	8	10.001	10	20.001	20
	Mean (mm)	2.0009	1.9999	4.001	4	8.0009	7.9999	10.00085	9.99985	20.0009	19.9999
	SD (σ) mm	0.0004472	0.000447	0	0	0.0003078	0.000308	0	0.000366348	0.0003078	0.000308
	Accuracy (mm)=Mean-True	0.0009	-0.000100	0.001	0	0.0009	-0.0001	0.00085	-0.00015	0.0009	-0.0001
	Type A Standard Un. (mm)	0.000100		0		0.0000688		0		0.00006882	
	Type B Standard Un. (mm)	0.000288675		0.000288675		0.000288675		0.000288675		0.000288675	
	Combined Standard Un. (mm)	0.000305505		0.000288675		0.000296766		0.000288675		0.000296766	
	Expanded Standard Un. (±mm)	0.000611010		0.00057735		0.000593532		0.00057735		0.000593532	
	Accuracy Limit Check	Accepted		Accepted		Accepted		Accepted		Accepted	
	Time Taken (min)	5		5		6		7		7	
	Total Time Taken (min)	30									

Table 10d. Mitutoyo 292-240-30 Digital Micrometer calibration data recorded in “Micrometer Calibration Data” worksheet

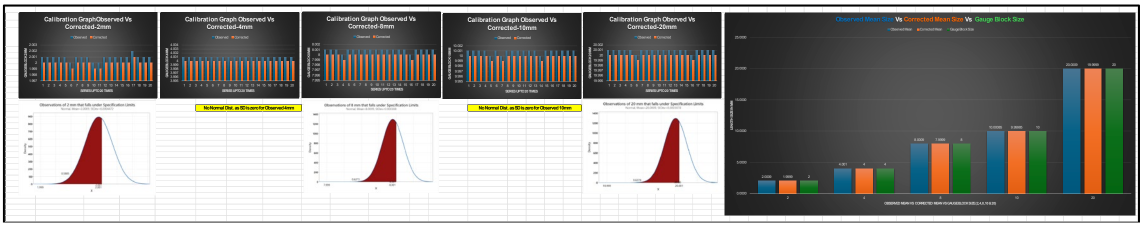


Figure 26d. Mitutoyo 292-240-30 digital micrometer - bar graphs & normal distribution plots

Mauser Micrometer: It was rejected in the calibration test as accuracies for all blocks exceeded accuracy limit. Besides, expanded standard uncertainties are higher which means no precise. Moreover, bar graphs show variation of observed values, corrected values, and true values. Besides, distribution plot shows all the samples were out of specification limits.

Date: 27.3.2024						Zero Error (mm): Positive Error	0.02		Coverage Factor:	2
Make: Mauser O.Micrometer	Range (mm): 25-50		LC (mm): 0.01		Temperature: 20°C		Accurcy (mm): ± 0.004		Calibration:	Rejected
MICROMETER — Gauge block length size to cover micrometer range (true values, mm)	28		30		40		44		50	
No. of observations on measuring faces — S.N.	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected
1	28.02	28	30.015	29.995	40.015	39.995	44.02	44	50.02	50
2	28.02	28	30.015	29.995	40.015	39.995	44.02	44	50.02	50
3	28.02	28	30.02	30	40.015	39.995	44.015	43.995	50.02	50
4	28.02	28	30.02	30	40.015	39.995	44.015	43.995	50.02	50
5	28.02	28	30.015	29.995	40.015	39.995	44.015	43.995	50.02	50
6	28.02	28	30.02	30	40.015	39.995	44.015	43.995	50.02	50
7	28.02	28	30.015	29.995	40.015	39.995	44.02	44	50.015	49.995
8	28.02	28	30.02	30	40.015	39.995	44.02	44	50.015	49.995
9	28.02	28	30.015	29.995	40.015	39.995	44.015	43.995	50.015	49.995
10	28.02	28	30.015	29.995	40.015	39.995	44.015	43.995	50.015	49.995
11	28.02	28	30.015	29.995	40.015	39.995	44.015	43.995	50.015	49.995
12	28.02	28	30.015	29.995	40.015	39.995	44.015	43.995	50.02	50
13	28.02	28	30.015	29.995	40.015	39.995	44.015	43.995	50.02	50
14	28.015	27.995	30.015	29.995	40.015	39.995	44.02	44	50.015	49.995
15	28.015	27.995	30.02	30	40.015	39.995	44.02	44	50.015	49.995
16	28.015	27.995	30.02	30	40.015	39.995	44.02	44	50.015	49.995
17	28.02	28	30.02	30	40.015	39.995	44.015	43.995	50.015	49.995
18	28.02	28	30.02	30	40.015	39.995	44.015	43.995	50.015	49.995
19	28.02	28	30.02	30	40.015	39.995	44.02	44	50.015	49.995
20	28.02	28	30.015	29.995	40.015	39.995	44.015	43.995	50.015	49.995
Mean (mm)	28.01925	27.99925	30.01725	29.99725	40.015	39.995	44.017	43.997	50.017	49.997
SD (σ) mm	0.00183	0.00183	0.00255	0.00255	0	0	0.00251	0.00251	0.00251	0.00251
Accuracy (mm)=Mean-True	0.01925	-0.00075	0.01725	-0.00275	0.015	-0.005	0.017	-0.003	0.017	-0.003
Type A Standard Un. (mm)	0.000409589		0.000570664		0		0.000561951		0.000561951	
Type B Standard Un. (mm)	0.002886751		0.002886751		0.002886751		0.002886751		0.002886751	
Combined Standard Un. (mm)	0.002915664		0.002942616		0.002886751		0.002940939		0.002940939	
Expanded Standard Un. (±mm)	0.005831328		0.005885233		0.005773503		0.005881878		0.005881878	
Accuracy Limit Check	Rejected		Rejected		Rejected		Rejected		Rejected	
Time Taken (min)	10		10		5		7		7	
Total Time Taken (min)	39									

Table 10e. Mauser micrometer calibration data recorded in "Micrometer Calibration Data" worksheet

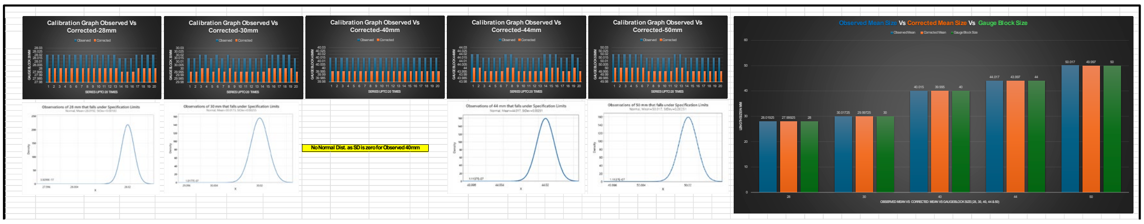


Figure 26e. Mauser micrometer - bar graphs & normal distribution plots

USSR Micrometer: It was rejected in the calibration test as accuracies for all blocks exceeded accuracy limit. Besides, expanded standard uncertainties are higher which means no precise. Moreover, bar graphs show variation of observed values, corrected values, and true values. Similarly, distribution plots show around 20% of samples within specification limits and the rest of samples out of specification limits.

Date: 27.3.2024						Zero Error (mm): Positive Error 0.01		Coverage Factor: 2		
Make: USSR O.Micrometer	Range (mm): 25-50		LC (mm): 0.01		Temperature: 20°C		Accurcy (mm): ± 0.004		Calibration:	Rejected
MICROMETER – Gauge block length size to cover micrometer range (true values, mm)	28		30		40		44		50	
No. of observations on measuring faces – S.N.	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected
1	28.01	28	30.01	30	40.01	40	44.01	44	50.01	50
2	28	27.99	30.01	30	40.01	40	44.01	44	50.01	50
3	28.01	28	30.01	30	40	39.99	44.01	44	50.01	50
4	28.01	28	30	29.99	40.01	40	44.01	44	50.01	50
5	28.01	28	30	29.99	40.01	40	44.01	44	50.01	50
6	28.01	28	30	29.99	40	39.99	44.01	44	50.01	50
7	28.01	28	30.01	30	40	39.99	44.01	44	50.01	50
8	28.01	28	30.01	30	40.01	40	44.01	44	50	49.99
9	28.01	28	30.01	30	40	39.99	44.01	44	50	49.99
10	28.01	28	30.01	30	40.01	40	44.01	44	50	49.99
11	28.01	28	30	29.99	40	39.99	44	43.99	50.01	50
12	28	27.99	30.01	30	40	39.99	44	43.99	50.01	50
13	28	27.99	30.01	30	40.01	40	44.01	44	50.01	50
14	28	27.99	30.01	30	40.01	40	44.01	44	50.01	50
15	28	27.99	30.01	30	40.01	40	44.01	44	50.01	50
16	28.01	28	30.01	30	40.01	40	44.01	44	50.01	50
17	28	27.99	30.01	30	40.01	40	44	43.99	50.01	50
18	28	27.99	30	29.99	40.01	40	44	43.99	50.01	50
19	28	27.99	30.01	30	40	39.99	44.01	44	50.01	50
20	28.01	28	30.01	30	40.01	40	44.01	44	50	49.99
Mean (mm)	28.006	27.996	30.0075	29.9975	40.0065	39.9965	44.008	43.998	50.008	49.998
SD (σ) mm	0.005026	0.005026	0.004443	0.004443	0.004894	0.004894	0.004104	0.004104	0.004104	0.004104
Accuracy (mm)=Mean-True	0.006	-0.004	0.00750	-0.00250	0.0065	-0.0035	0.008	-0.002	0.008	-0.002
Type A Standard Un. (mm)	0.001123903		0.000993399		0.001094243		0.000917663		0.000917663	
Type B Standard Un. (mm)	0.002886751		0.002886751		0.002886751		0.002886751		0.002886751	
Combined Standard Un. (mm)	0.00309782		0.003052896		0.003087183		0.003029099		0.003029099	
Expanded Standard Un.(±mm)	0.006195641		0.006105792		0.006174367		0.006058197		0.006058197	
Accuracy Limit Check	Rejected		Rejected		Rejected		Rejected		Rejected	
Time Taken (min)	7		6		6		6		6	
Total Time Taken (min)	31									

Table 10f. USSR micrometer calibration data recorded in "Micrometer Calibration Data" worksheet

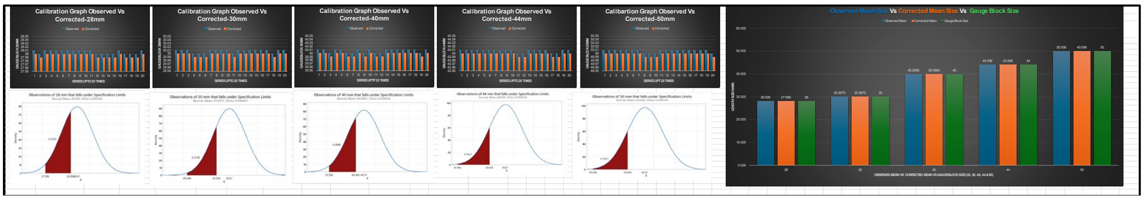


Figure 26f. USSR micrometer - bar graphs & normal distribution plots

Mauser Micrometer: It was rejected in the calibration test as accuracies for all blocks exceeded accuracy limit. Besides, expanded standard uncertainties are higher which means no precise. Moreover, bar graphs show variation of observed values, corrected values, and true values. Besides, distribution plot shows all the samples were out of specification limits.

Date: 27.3.2024							Zero Error (mm): Positive Error 0.01		Coverage Factor: 2	
Make: Mauser O.Micrometer	Range (mm): 50-75		LC (mm): 0.01		Temperature: 20°C		Accurcy (mm): ± 0.005		Calibration:	Rejected
MICROMETER — Gauge block length size to cover micrometer range (true values, mm)	50		60		64		68		70	
No. of observations on measuring faces — S.N.	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected
1	50.01	50	60.01	60	64.015	64.005	68.015	68.005	70.01	70
2	50.01	50	60.01	60	64.015	64.005	68.015	68.005	70.01	70
3	50.01	50	60.01	60	64.015	64.005	68.015	68.005	70.01	70
4	50.01	50	60.015	60.005	64.015	64.005	68.015	68.005	70.01	70
5	50.01	50	60.01	60	64.015	64.005	68.015	68.005	70.015	70.005
6	50.01	50	60.01	60	64.015	64.005	68.015	68.005	70.01	70
7	50.01	50	60.01	60	64.015	64.005	68.01	68	70.01	70
8	50.01	50	60.01	60	64.015	64.005	68.015	68.005	70.01	70
9	50.01	50	60.01	60	64.015	64.005	68.015	68.005	70.01	70
10	50.01	50	60.01	60	64.015	64.005	68.015	68.005	70.015	70.005
11	50.01	50	60.01	60	64.015	64.005	68.015	68.005	70.03	70.02
12	50.01	50	60.005	59.995	64.015	64.005	68.015	68.005	70.02	70.01
13	50.01	50	60.005	59.995	64.015	64.005	68.015	68.005	70.02	70.01
14	50.01	50	60.015	60.005	64.015	64.005	68.015	68.005	70.015	70.005
15	50.01	50	60.015	60.005	64.015	64.005	68.01	68	70.015	70.005
16	50.01	50	60.01	60	64.015	64.005	68.015	68.005	70.01	70
17	50.01	50	60.01	60	64.01	64	68.015	68.005	70.015	70.005
18	50.01	50	60.015	60.005	64.01	64	68.015	68.005	70.02	70.01
19	50.01	50	60.01	60	64.01	64	68.015	68.005	70.02	70.01
20	50.01	50	60.015	60.005	64.015	64.005	68.015	68.005	70.015	70.005
Mean (mm)	50.01	50	60.01075	60.00075	64.01425	64.00425	68.0145	68.0045	70.0145	70.0045
SD (σ) mm	0	0	0.002935715	0.002935715	0.001831738	0.001831738	0.001538968	0.001538968	0.005355764	0.005355764
Accuracy (mm)=Mean-True	0.01	0	0.01075	0.00075	0.01425	0.00425	0.0145	0.0045	0.0145	0.0045
Type A Standard Un. (mm)	0		0.000656446		0.000409589		0.000344124		0.001197585	
Type B Standard Un. (mm)	0.002886751		0.002886751		0.002886751		0.002886751		0.002886751	
Combined Standard Un. (mm)	0.002886751		0.002960448		0.002915664		0.00290719		0.003125307	
Expanded Standard Un. (±mm)	0.005773503		0.005920897		0.005831328		0.00581438		0.006250614	
Accuracy Limit Check	Rejected		Rejected		Rejected		Rejected		Rejected	
Time Taken (min)	10		6		7		9		10	
Total Time Taken (min)	42									

Table 10g. Mauser micrometer calibration data recorded in "Micrometer Calibration Data" worksheet

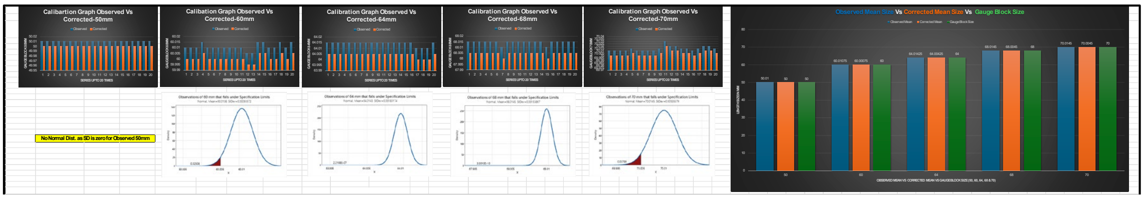


Figure 26g.Mauser micrometer - bar graphs & normal distribution plots

4.4 Caliper calibration

4.4.1 Apparatus/resources

The apparatus/resources used to conduct caliper calibration were:

a. Known standard - C.E. Johansson steel 40-gauge block set (picture 13a).
b. Clean and flat surface - desk
c. Clean cloth to wipe off dust, dirt, or oil.
d. Cleaning alcohol
e. Record sheets (see table 5a, 5b and 5c)
f. Timer
g. Calipers (range 0-150 mm)
    - Whitworth Vernier Caliper (I)
    - MarCal Digi 16EWRi 4103400
    - Mitutoyo Digi 500-181-30
    - Whitworth Vernier Caliper (II)

- Whitworth Digi caliper silver (I)
- Whitworth Digi caliper silver (II)
- Whitworth Digi caliper silver (III)

4.4.2 Block sets in calibration

Five distinct sizes of gauge blocks were used to calibrate seven different calipers. See table 11. All blocks were repetitive to cover a range of each caliper. A total number of 35 blocks were used. Besides, surface cleaning with alcohol and cloth, along with observing the measuring faces, took 30 seconds (0.5 min) for each block. Hence, the total time taken for cleaning and observing during calibration was 17.5 minutes. This data was recorded in the "Gauge Block Sets for Calipers" worksheet.

S.N.	Make	Block Range (mm)	No. of pieces	Observation & Cleaning Time (min)
1	CE Johansoon	4	7	3.5
2	CE Johansoon	10	7	3.5
3	CE Johansoon	60	7	3.5
4	CE Johansoon	90	7	3.5
5	CE Johansoon	125	7	3.5
Total Time Taken				**17.5**
Total no. blocks used			**35**	

Table 11. Block sets used against calipers for calibration recorded in "Gauge Block Sets for Calipers" worksheet.

4.4.3 Calipers sets for calibration

Seven distinct calipers were chosen as devices under test for calibration. The range of all calipers is 0-150 mm. Table 12 shows the variation in times for cleaning and observation of all seven calipers. Prior to being selected for calibration, every caliper was carefully cleaned and examined. The time was then noted in the "Caliper Sets for Calibration" worksheet. Thus, the total time taken for this task was 26 minutes.

S.N.	Make	Caliper Range (mm)	No. of Caliper	Observation & Cleaning Time (min)	Calibration Time Taken
1	Whitworth Vernier Caliper (I)	0-150	1	5	46
2	MarCal Digi 16EWRi 4103400	0-150	1	4	42
3	Mitutoyo Digi 500-181-30	0-150	1	4	39
4	Whitworth Vernier Caliper (II)	0-150	1	4	39
5	Whitworth Digi caliper silver (I)	0-150	1	3	46
6	Whitworth Digi caliper silver (II)	0-150	1	3	42
7	Whitworth Digi caliper silver (III)	0-150	1	3	33
Total Time Taken				26	287

Table 12. Calipers under test for calibration recorded in “Caliper Sets for Calibration” worksheet.

Similarly, variation in the time taken for calibration (last column) can be observed across all calipers. The sources of the outputs in this column are the worksheets labeled "Caliper Calibration Data" for each particular caliper. Hence, the total time for calibrating all calipers was 287 minutes (4 hour, 47 minutes).

4.4.4 Whitworth Vernier caliper (I): Lab calibration, calculations, and graphs

A list of seven calipers can be found in table 12. An identical calibration procedure was used for all. Thus, as a representative of all of them, one will be discussed here. That is Whitworth Vernier Caliper (I). The calibration worksheet layout, computations, bar graphs, and normal distribution curves will be the key topics of discussion when it comes to the calibration output.

For Whitworth vernier caliper, the "Caliper Calibration Data" worksheet (see table 5c) was utilized to record temperature, measurements, computations, and device information. Primarily, caliper details such as date, make, range, LC, accuracy was filled in. Next, temperature and zero error were checked and noted. For calibration, each caliper was calibrated against five sets of gauge blocks. Blocks measuring 4 mm, 10 mm, 60 mm, 90 mm, and 125 mm were used to calibrate the Whitworth vernier caliper (table13). From each gauge block, 20 samples were obtained at different measuring faces. These samples are called observed measurements.

CALIPER

Date: 22.03.2024							Zero Error (mm): No error		Coverage Factor: 2	
Make: Whitworth V.Caliper (I)	Range (mm): 0-150		LC (mm): 0.05		Temperature: 20°C		Accurcy (mm): ± 0.1		Calibration:	Accepted
Gauge block length size to cover caliper range (true values, mm)	4		10		60		90		125	
S.N. (No. of observations at different jaw positions (eg. Tip, Center, Near beam, etc.))	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected
1	4		10		60		90		125.01	
2	4		10		60		90.01		125.01	
3	4		10		60		90.01		125	
4	4		10		60.01		90.01		125	
5	4		10		60		90		125	
6	4		10.01		60		90.005		125	
7	4		10		60		90		125	
8	4		10		60.01		90		125	
9	4		10		60.01		90		125.01	
10	4		10.01		60		90.005		125.01	
11	4		10		60.01		90.005		125	
12	4		10		60		90.005		125.01	
13	4		10		60		90		125.01	
14	4		10		60		90		125.01	
15	4		10		60		90		125	
16	4		10		60.01		90		125	
17	4		10		60		90.005		125.01	
18	4		10.01		60.01		90.01		125.01	
19	4		10.01		60		90.01		125.01	
20	4		10.01		60		90.01		125	
Mean (mm)	4		10.0025		60.003		90.00425		125.005	
SD (σ) mm	0		0.004442617		0.004701623		0.00437547		0.005129892	
Accuracy (mm) = Mean-True	0		0.00250		0.003		0.00425		0.005	
Type A Standard Un. (mm)	0		0.000993399		0.001051315		0.000978385		0.001147079	
Type B Standard Un. (mm)	0.014433757		0.014433757		0.014433757		0.014433757		0.014433757	
Combined Standard Un. (mm)	0.014433757		0.014467902		0.014471994		0.014466878		0.014479265	
Expanded Standard Un. (±mm)	0.02886751		0.028935803		0.028943987		0.028933757		0.028958531	
Accuracy Limit Check	Accepted		Accepted		Accepted		Accepted		Accepted	
Time Taken (min)	7		8		8		13		10	
Total Time Taken (min)	46									

Table 13. Whitworth vernier caliper (I) calibration data recorded in “Caliper Calibration Data” worksheet

There is no zero-error shown in table 13. Therefore, no corrected measurements were noted. Then, the mean and standard deviation were calculated for each (see 2.3 for manual compute). Following that, the accuracy was computed by subtracting the observed value from the true value (gauge block size). Accuracy limit checker checks obtained accuracy and compares with actual accuracy of the caliper. If the values are in between ±0.1 mm, it gives “Accepted” otherwise “Rejected.” For Whitworth vernier caliper, block length size of 4 mm yields observed accuracy of 0 mm. Thus, it accepts. Note that all "Accepted" responses are required from each block for the acceptance test. Here, Whitworth vernier caliper passed to be “Accepted.”

Type A and B uncertainties, combined uncertainties, and expanded uncertainties with coverage factor computed (see 2.9.4). It is important to express these uncertainties’ result. For instance, this caliper measured the length of gauge block of 4 mm as,

4±0.028 mm. (Likewise, the rest of observed mean values and uncertainties can be expressed for this caliper.)

This should be reported as “The reported uncertainty is based on a standard uncertainty multiplied by coverage factor k = 2, providing a level of confidence of approximately 95 %, assuming normality (Auty et al. 2016, 30; Bell 2001, 17).” Given this uncertainty, Whitworth vernier caliper (I) can generate a range of measurements within acceptable limits.

In addition, bar graph was prepared that compares “Observed Vs True” length sizes of all gauge blocks. Figure 27 shows observed value and true value as 4 mm. It essentially displays the degree to which the measured value agrees with the true value. Clearly, observed mean size is within specification limit and even accurate to the true value. Thus, caliper is within calibre. Likewise, rest of the observed, and true sizes are laid out for 4, 10, 60, 90 and 125. Clearly, observed mean sizes are within specification limits as well.

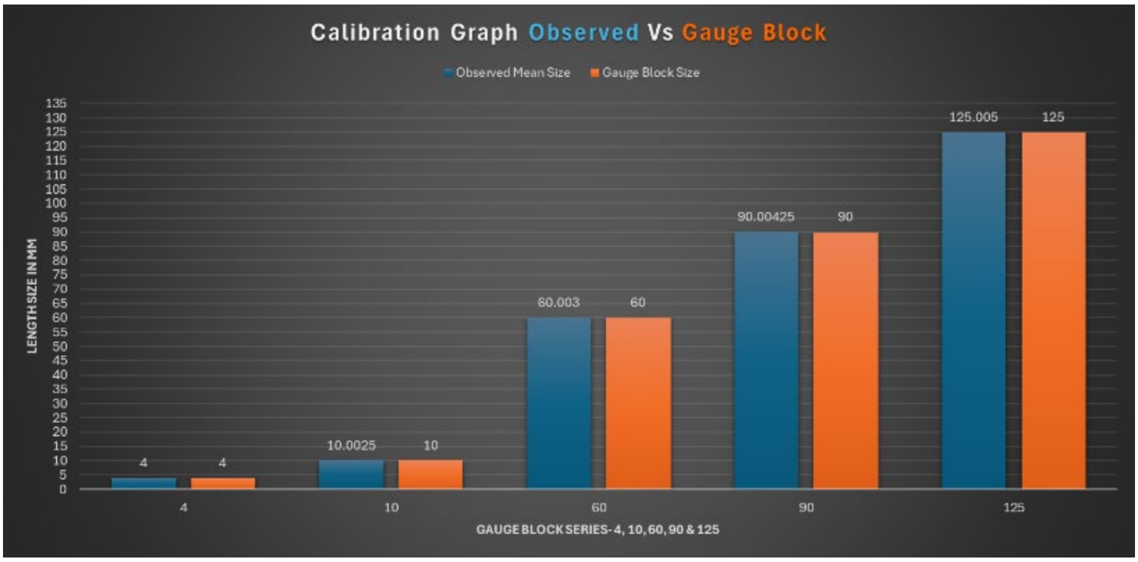
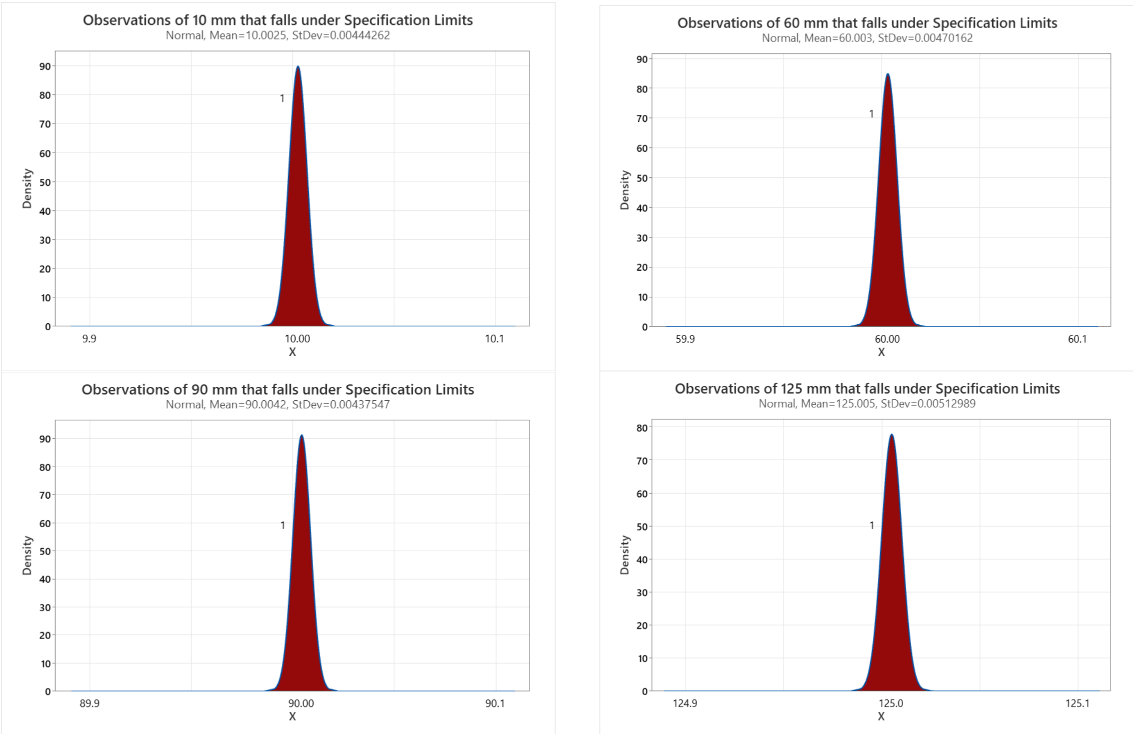


Figure 27. Observed Vs True” length sizes comparison of all gauge blocks – Whitworth micrometer (I).

Moreover, a normal distribution curve was plotted to check how many observed samples fall between the specification limit for each block. Below, figures 28a, 28b, 28c, and 28d represent normal distributions curves of observed samples of 10 mm, 60 mm, 90 mm, and 125 mm, respectively. Target of this calibration was to achieve 95% for each observation; however, all curves show 100% of observations within specification limits. That means all observations are within specification limits. Besides, these curves indicate specification limits are wider than the process spreads. Therefore, the process is stable and can produce accurate measurements. (Note that standard deviation of the observed 4 mm is zero - see table 13. Therefore, plotting a normal distribution curve is impossible.)



Figures 28a, 28b, 28c, & 28d. The normal distribution curves of the observed 10 mm, 60 mm, 90, & 125 mm shows 100% of samples within specs limit.

Consequently, in the calibration test the Whitworth vernier caliper (I) was "Accepted." Then, the accepted caliper was tagged with “Accepted” sticker. See picture 15. To sum up, calculations, bar graphs, and normal distribution curves show that the Whitworth vernier caliper (I) was able to take precise measurements.

Picture 15. Conformity sticker (Accepted/Rejected) tagged on calipers (Picture: Sunil Lamichhane)

4.4.5 Remaining calipers: Calibration status

The calibration outputs for all seven micrometers, each of which has been accepted, are shown in table 14. None of the calipers exhibit zero errors or defects.

S.N.	Make	Micrometer Range (mm)	No. of pieces	Accuracy Limit(±mm)	Issues		Visible defects	Calibration Stattus
1	Whitworth Vernier Caliper (I)	0-150	1	0.1	No zero error	0 mm	No defects	Accepted
2	MarCal Digi 16EWRi 4103400	0-150	1	0.03	No zero error	0 mm	No defects	Accepted
3	Mitutoyo Digi 500-181-30	0-150	1	0.02	No zero error	0 mm	No defects	Accepted
4	Whitworth Vernier Caliper (II)	0-150	1	0.1	No zero error	0 mm	No defects	Accepted
5	Whitworth Digi caliper silver (I)	0-150	1	0.03	No zero error	0 mm	No defects	Accepted
6	Whitworth Digi caliper silver (II)	0-150	1	0.03	No zero error	0 mm	No defects	Accepted
7	Whitworth Digi caliper silver (III)	0-150	1	0.03	No zero error	0 mm	No defects	Accepted

Table 14. Calibration status of all calibrated calipers

Calibration worksheets and graphs for the remaining calibrated calipers are presented below:

MarCal 16EWRi 4103400 Digital: The calibration test was accepted, as accuracies for all blocks were within the accuracy limit. The expanded standard uncertainties are low, indicating precision. Moreover, bar graphs show variation of observed values, and true values. Similarly, distribution plots show around 99% of samples within specification limits.

Date: 22.03.204								Zero Error (mm): No error		Coverage Factor:	2
Make: MarCal 16EWRi 4103400		Range (mm): 0-150		LC (mm): 0.01		Temperature: 20°C		Accurcy (mm): ± 0.03		Calibration:	Accepted
CALIPER	Gauge block length size to cover caliper range (true values, mm)	4		10		60		90		125	
No. of observations at different jaw positions (eg. Tip, Center, Near beam, etc.)	S.N.	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected
	1	4		10		60		90		125	
	2	4		10		60.01		90		125.01	
	3	4		10		60		90		125.01	
	4	4		10		60		89.99		125.01	
	5	4.01		10		60.01		90.01		125.02	
	6	4		10		60		90.01		125	
	7	4		10		60		90.01		125.02	
	8	4		10.02		60.01		90		125.01	
	9	4		10.02		60.01		90.01		125.01	
	10	4		10.01		60.01		90.01		125	
	11	4.01		10		60		89.99		125.02	
	12	4		10		60.01		90		125.02	
	13	4		10		60		90		125	
	14	4		10		60		90.02		125.01	
	15	4.02		10		60.01		90.01		125	
	16	4.02		10.01		60		90.01		125.01	
	17	4.02		10.01		60		90		125	
	18	4		10		60		89.99		125.01	
	19	4.01		10		60		90.01		125	
	20	4		10		60.01		90		125	
Mean (mm)		4.0045		10.0035		60.004		90.0035		125.008	
SD (σ) mm		0.007591547		0.006708204		0.005026247		0.008127277		0.007677719	
Accuracy (mm)=Mean-True		0.0045		0.00350		0.004		0.0035		0.008	
Type A Standard Un. (mm)		0.001697521		0.0015		0.001123903		0.001817314		0.00171679	
Type B Standard Un. (mm)		0.002886751		0.002886751		0.002886751		0.002886751		0.002886751	
Combined Standard Un. (mm)		0.003348867		0.003253204		0.00309782		0.003411153		0.003358676	
Expanded Standard Un.(±mm)		0.006697735		0.006506407		0.006195641		0.006822306		0.006717351	
Accuracy Limit Check		Accepted		Accepted		Accepted		Accepted		Accepted	
Time Taken (min)		6		7		15		8		6	
Total Time Taken (min)		42									

Table 15a. MarCal 16EWRi 4103400 calibration data recorded in “Caliper Calibration Data” worksheet

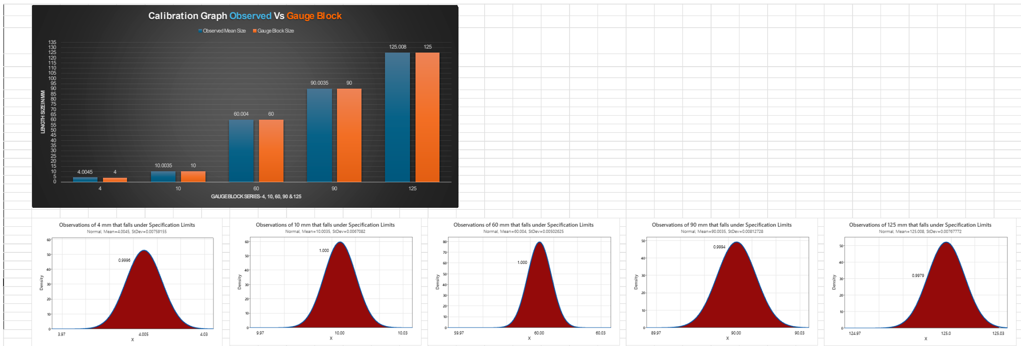


Figure 29a. MarCal 16EWRi 4103400– bar graphs & normal distribution plots

Mitutoyo 500-181-30 Digi: The calibration test was accepted, as accuracies for all blocks were within the accuracy limit. The expanded standard uncertainties are low, indicating precision. Moreover, bar graphs show variation of observed values, and true values. Similarly, distribution plots show around 99% of samples within specification limits.

Date: 28.03.2024								Zero Error (mm): No error		Coverage Factor:	2
Make: Mitutoyo 500-181-30 Digi		Range (mm): 0-150		LC (mm): 0.01		Temperature: 20°C		Accurcy (mm): ± 0.02		Calibration:	Accepted
CALIPER	Gauge block length size to cover caliper range (true values, mm)	4		10		60		90		125	
No. of observations at different jaw positions (eg. Tip, Center, Near beam, etc.)	S.N.	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected
	1	3.99		9.99		60		89.99		125	
	2	3.99		10		59.99		90		125	
	3	4		10		60		89.99		124.99	
	4	3.99		10		60.01		89.99		124.98	
	5	4		10		60		90		124.99	
	6	4		9.99		60		90		125	
	7	4		10		60.01		89.99		125	
	8	4		10		59.99		89.99		124.99	
	9	4		10		60		90		125	
	10	3.99		9.99		60.01		89.99		124.98	
	11	3.99		9.99		60.01		89.99		124.99	
	12	3.99		9.99		60.01		90		125	
	13	3.99		10		60		90		124.99	
	14	4		9.99		60		89.99		124.99	
	15	4		10		59.99		89.99		125	
	16	4		10		59.99		90		125	
	17	4		10		60		90		124.98	
	18	4		9.99		60		90		125	
	19	4		10		60.01		89.99		125	
	20	4		10		59.99		89.99		125	
Mean (mm)		3.9965		9.9965		60.0005		89.9945		124.994	
SD (σ) mm		0.004893605		0.004893605		0.007591547		0.005104178		0.00753937	
Accuracy (mm)=Mean-True		-0.0035		-0.0035		0.0005		-0.0055		-0.006	
Type A Standard Un. (mm)		0.001094243		0.001094243		0.001697521		0.001141329		0.001685854	
Type B Standard Un. (mm)		0.002886751		0.002886751		0.002886751		0.002886751		0.002886751	
Combined Standard Un. (mm)		0.003087183		0.003087183		0.003348867		0.003104185		0.003342969	
Expanded Standard Un.(±mm)		0.006174367		0.006174367		0.006697735		0.00620837		0.006685937	
Accuracy Limit Check		Accepted		Accepted		Accepted		Accepted		Accepted	
Time Taken (min)		8		6		5		10		10	
Total Time Taken (min)		39									

Table 15b. Mitutoyo 500-181-30 Digi calibration data recorded in “Caliper Calibration Data” worksheet

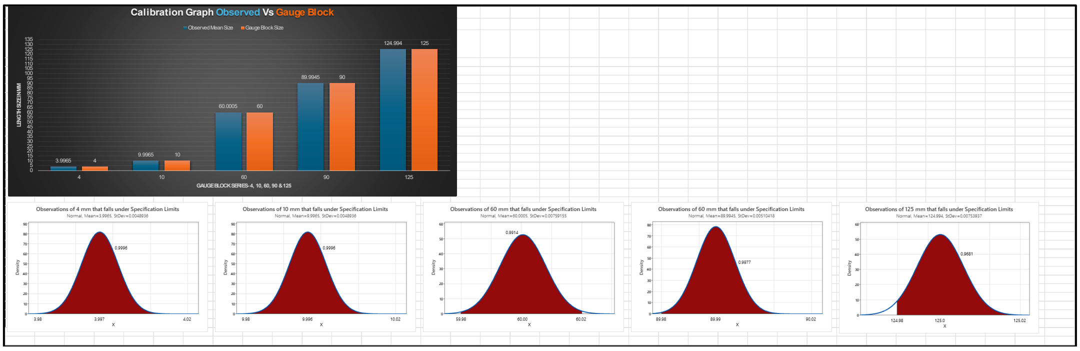


Figure 29b. Mitutoyo 500-181-30 Digi – bar graphs & normal distribution plots

Whitworth Vernier Caliper (II): The calibration test was accepted, as accuracies for all blocks were within the accuracy limit. The expanded standard uncertainties are low, indicating precision. Moreover, bar graphs show variation of observed values, and true values. Similarly, distribution plots show around 99% of samples within specification limits.

Date: 28.03.2024							Zero Error (mm): No error		Coverage Factor:	2
Make: Whitworth V.Caliper (II)	Range (mm): 0-150		LC (mm): 0.05		Temperature: 20°C		Accurcy (mm): ± 0.1		Calibration:	Accepted
CALIPER – Gauge block length size to cover caliper range (true values, mm)	4		10		60		90		125	
No. of observations at different jaw positions (eg. Tip, Center, Near beam, etc.) – S.N.	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected
1	4		10		60		90		125.05	
2	4		10		60.05		90		125	
3	4		10		60.05		90		125.05	
4	4		10		60		90		125.05	
5	4		10		60		90		125	
6	4		10		60		90		125.1	
7	4		10		60		90		125	
8	4		10		60		90.05		125.01	
9	4		10		60		90		125	
10	4		10		60		90		125	
11	4		10		60		90		125.1	
12	4		10		60		90.05		125.1	
13	4		10		60		90.05		125.1	
14	4		10		60		90		125	
15	4		10		60.05		90		125.05	
16	4		10		60.05		90		125	
17	4		10		60		90.05		125.05	
18	4		10		60		90.05		125	
19	4		10		60		90		125.05	
20	4		10		60		90.05		125.05	
Mean (mm)	4		10		60.01		90.015		125.038	
SD (σ) mm	0		0		0.020519567		0.023508117		0.03887903	
Accuracy (mm) = Mean-True	0		0		0.01		0.015		0.038	
Type A Standard Un. (mm)	0		0		0.004588315		0.005256575		0.008693615	
Type B Standard Un. (mm)	0.014433757		0.014433757		0.014433757		0.014433757		0.014433757	
Combined Standard Un. (mm)	0.014433757		0.014433757		0.015145493		0.015361149		0.016849697	
Expanded Standard Un.(±mm)	0.028867513		0.028867513		0.030290986		0.030722299		0.033699394	
Accuracy Limit Check	Accepted		Accepted		Accepted		Accepted		Accepted	
Time Taken (min)	5		6		7		9		12	
Total Time Taken (min)	39									

Table 15c. Whitworth Vernier Caliper (II) calibration data recorded in “Caliper Calibration Data” worksheet

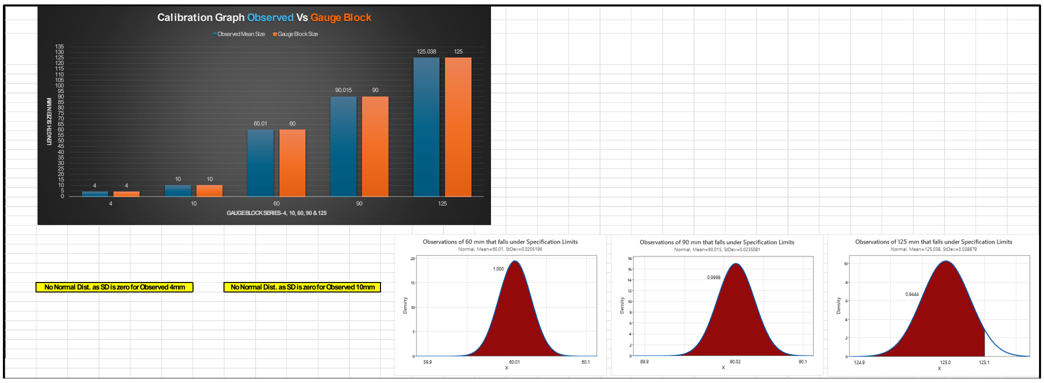


Figure 29c. Whitworth Vernier Caliper (II) – bar graphs & normal distribution plots

Whitworth Digi caliper (I): The calibration test was accepted, as accuracies for all blocks were within the accuracy limit. The expanded standard uncertainties are low, indicating precision. Moreover, bar graphs show variation of observed values and true values. Similarly, distribution plots show 100% of samples within specification limits.

Date: 28.03.2024								Zero Error (mm): No error		Coverage Factor:	2
Make: Whitworth Digi caliper (I)		Range (mm): 0-150		LC (mm): 0.01		Temperature: 20°C		Accurcy (mm): ± 0.03		Calibration:	Accepted
CALIPER	Gauge block length size to cover caliper range (true values, mm)	4		10		60		90		125	
No. of observations at different jaw positions (eg. Tip, Center, Near beam, etc.)	S.N.	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected
	1	3.99		9.99		60		89.99		124.99	
	2	4		9.99		59.99		89.99		124.99	
	3	4		9.99		59.99		89.99		124.99	
	4	4		9.99		60		90		125	
	5	4		9.99		60.01		90		125	
	6	3.99		10		60.01		90.01		125	
	7	3.99		10		60		90.01		125.01	
	8	3.99		10		60		90		125	
	9	4		10		60		90		124.99	
	10	4		9.99		60		90		125	
	11	4		10		60.01		90		125.01	
	12	4		10		60		90		125	
	13	4		10		60		90.01		125	
	14	4		10		60		90		125.01	
	15	4		10		60		89.99		125.01	
	16	3.99		10		60		90		125.01	
	17	4		10		60.01		90.01		125.01	
	18	4		10		60		90		125.01	
	19	4		9.99		59.99		90.01		125.01	
	20	4		10		59.99		90		125.01	
	Mean (mm)	3.9975		9.9965		60		90.0005		125.0025	
	SD (σ) mm	0.004442617		0.004893605		0.006488857		0.006863327		0.007863975	
	Accuracy (mm)=Mean-True	-0.0025		-0.0035		0		0.0005		0.0025	
	Type A Standard Un. (mm)	0.000993399		0.001094243		0.001450953		0.001534687		0.001758438	
	Type B Standard Un. (mm)	0.002886751		0.002886751		0.002886751		0.002886751		0.002886751	
	Combined Standard Un. (mm)	0.003052896		0.003087183		0.003230882		0.003269342		0.003380154	
	Expanded Standard Un.(±mm)	0.006105792		0.006174367		0.006461763		0.006538684		0.006760307	
	Accuracy Limit Check	Accepted		Accepted		Accepted		Accepted		Accepted	
	Time Taken (min)	12		8		8		7		11	
	Total Time Taken (min)	46									

Table 15d. Whitworth Digi caliper (I) calibration data recorded in “Caliper Calibration Data” worksheet

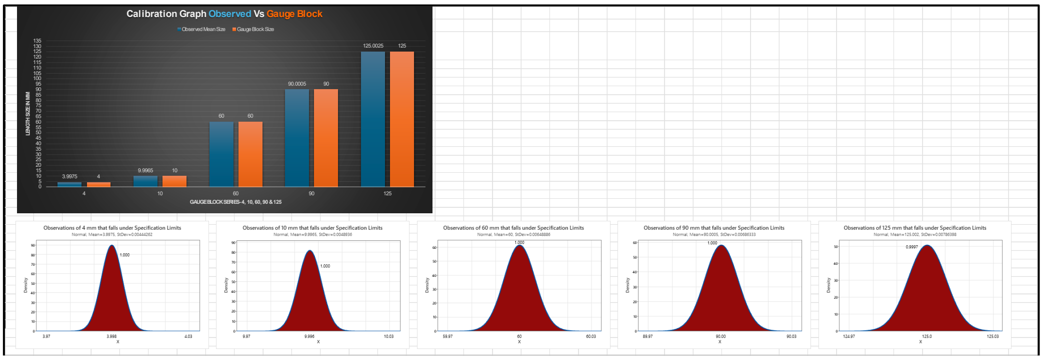


Figure 29d. Whitworth Digi caliper (I) – bar graphs & normal distribution plots

Whitworth Digi caliper (II): The calibration test was acceptable as accuracies for all blocks were within accuracy limit. The expanded standard uncertainties are lower, which indicates precision. Moreover, the bar graphs show variations in observed values and true values. Similarly, the distribution plots show around 99% of samples were within the specification limits.

Date: 28.03.2024								Zero Error (mm): No error		Coverage Factor: 2	
Make: Whitworth Digi caliper (II)		Range (mm): 0-150		LC (mm): 0.01		Temperature: 20°C		Accurcy (mm): ± 0.03		Calibration:	Accepted
CALIPER	Gauge block length size to cover caliper range (true values, mm)	4		10		60		90		125	
No. of observations at different jaw positions (eg. Tip, Center, Near beam, etc.)	S.N.	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected
	1	4.01		9.99		60		89.99		124.99	
	2	4.02		10		60		89.99		125	
	3	4.02		10		60		89.99		124.99	
	4	4.02		10		60		90		125.01	
	5	4.02		9.99		60.01		90		125.01	
	6	4.02		10		60		90		125	
	7	4.02		10		60		90.01		125.01	
	8	4.02		10		60.01		90.01		125.01	
	9	4.02		10		60.01		90.01		124.99	
	10	4.01		10		59.99		90.01		125	
	11	4.02		10		59.99		90.01		125	
	12	4.02		10		60.01		90.01		124.99	
	13	4.02		10		60.01		90.01		125	
	14	4.02		10		60		90.01		125.01	
	15	4.02		10		60.01		90.01		124.99	
	16	4.02		10		60		90.01		125.01	
	17	4.02		10		60		90.01		125	
	18	4.02		9.99		60.01		90.01		125	
	19	4.02		10		60		90.01		125	
	20	4.02		9.99		60.01		90.01		125	
	Mean (mm)	4.019		9.998		60.003		90.0055		125.0005	
	SD (σ) mm	0.003077935		0.004103913		0.006569467		0.007591547		0.007591547	
	Accuracy (mm)=Mean-True	0.019		-0.002		0.003		0.0055		0.0005	
	Type A Standard Un. (mm)	0.000688247		0.000917663		0.001468977		0.001697521		0.001697521	
	Type B Standard Un. (mm)	0.002886751		0.002886751		0.002886751		0.002886751		0.002886751	
	Combined Standard Un. (mm)	0.002967662		0.003029099		0.003239017		0.003348867		0.003348867	
	Expanded Standard Un.(±mm)	0.005935324		0.006058197		0.006478033		0.006697735		0.006697735	
	Accuracy Limit Check	Accepted		Accepted		Accepted		Accepted		Accepted	
	Time Taken (min)	8		7		9		8		10	
	Total Time Taken (min)	42									

Table 15e. Whitworth Digi caliper (II) calibration data recorded in “Caliper Calibration Data” worksheet

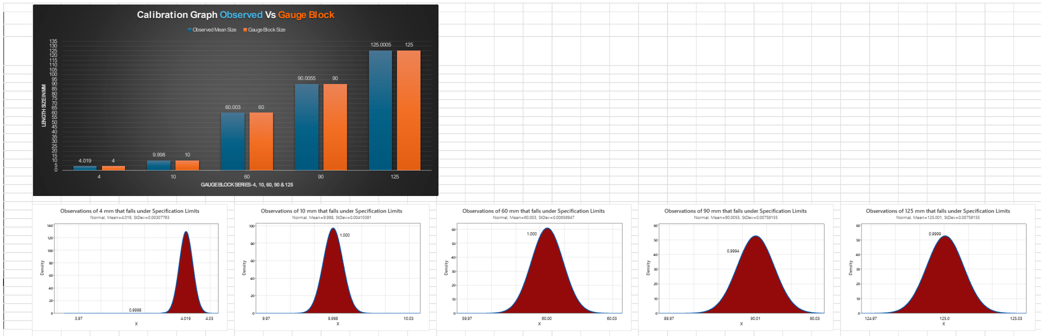


Figure 29e. Whitworth Digi caliper (II) – bar graphs & normal distribution plots

Whitworth Digi caliper (III): This passed the calibration test as accuracies for all blocks are within the accuracy limit. The expanded standard uncertainties are lower, exhibiting precision. The bar graphs show variation of observed values and true value. The distribution plots show around 99% of samples to be within specification limits.

Date: 27.03.2024							Zero Error (mm): No error		Coverage Factor: 2	
Make: Whitworth Digi caliper (III)	Range (mm): 0-150		LC (mm): 0.01		Temperature: 20°C		Accurcy (mm): ± 0.03		Calibration:	Accepted
CALIPER – Gauge block length size to cover caliper range (true values, mm)	4		10		60		90		125	
No. of observations at different jaw positions (eg. Tip, Center, Near beam, etc.) – S.N.	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected	Observed	Corrected
1	4		9.99		59.99		89.99		124.99	
2	4		10		59.99		89.99		124.99	
3	4		10		59.99		90		125.01	
4	4.01		10		60.01		90		125	
5	4.01		9.99		60		90		124.99	
6	4		10		60.01		89.99		124.99	
7	4.01		10		60.01		90		125.01	
8	4.01		10		60.01		90		125.01	
9	4.01		10		60.01		90		125	
10	4		10		59.99		90.01		125.01	
11	4		10		60		90.01		125	
12	4.01		10		60		90		125	
13	4		9.99		59.99		90.01		125.01	
14	4.01		10		60.01		90		125	
15	4.01		10		60.01		90		125.01	
16	4.01		10		60		90		125	
17	4.01		10		60		90		125.01	
18	4.01		10		59.99		90		124.99	
19	4.01		10		59.99		90		125	
20	4.01		10		60		90		125	
Mean (mm)	4.0065		9.9985		60		90		125.001	
SD (σ) mm	0.004893605		0.003663475		0.008583951		0.005619515		0.007880689	
Accuracy (mm)=Mean-True	0.0065		-0.0015		0		0		0.001	
Type A Standard Un. (mm)	0.001094243		0.000819178		0.00191943		0.001256562		0.001762176	
Type B Standard Un. (mm)	0.002886751		0.002886751		0.002886751		0.002886751		0.002886751	
Combined Standard Un. (mm)	0.003087183		0.003000731		0.003466633		0.003148377		0.003382099	
Expanded Standard Un. (±mm)	0.006174367		0.006001462		0.006933266		0.006296755		0.006764199	
Accuracy Limit Check	Accepted		Accepted		Accepted		Accepted		Accepted	
Time Taken (min)	6		6		6		7		8	
Total Time Taken (min)	33									

Table 15f. Whitworth Digi caliper (III) calibration data recorded in “Caliper Calibration Data” worksheet

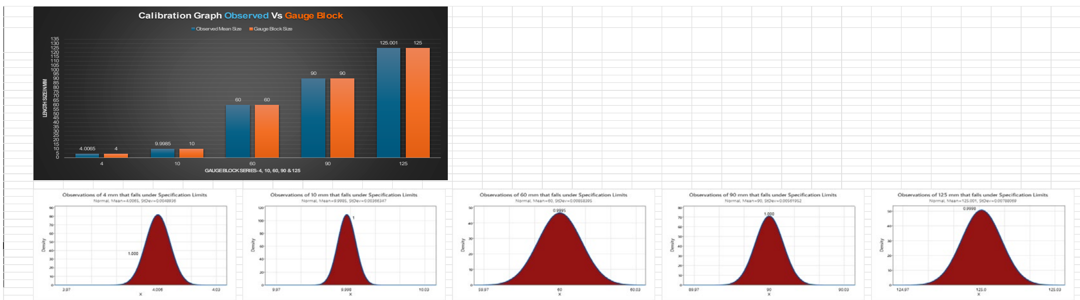


Figure 29f. Whitworth Digi caliper (III) – bar graphs & normal distribution plots

5 Cost analysis: In-house Vs outsourced calibration

5.1 Calibration rates and cost computation methods: In-house, Kiwa Inspecta & Jamk

A. In-house

The two distinct calibration rates that include all overhead costs for both laboratory staff and students at Karelia University of Applied Sciences are shown in table 16. This is the in-house rates without 24% VAT. To compute in-house calibration project cost, time keeping records of entire calibration plays a vital role. These recorded times were multiplied with both rates, then VAT applied for each to get total in-house calibration project cost. See all recorded time breakdown below (tables 17 and 18).

Karelia ammattikorkeakoulu

S.N.	Calibration Conducted By	Charge(eur/hr)
1	Laboratory staff	47.5
2	Student	22.5

Table 16. Karelia University of Applied Sciences rates for calibration

Table 17 breaks down the total calibration time for both devices where the total time taken for calibration of both devices was 11.62 hours. On the other hand, table 18 breaks down the entire calibration project time. The entire calibration project took 24 hours. That means,

24 hours / 7.5 hours =3.2 [7.5 hours working shift per day]

So, the project needs 3.2 shifts to complete the entire calibration project that is equivalent to 24 hours.

In table 18, the remaining 12.38 hours is not calibration time. It is not directly linked to calibration however it is necessary for the operation and the project itself. For instance, arranging laboratory setups, pre-training, preparation time for each calibration, conformity stickers labelling, are some overhead tasks. These tasks consume overhead time and overhead cost.

Device Type	S.N.	Task	Total Time Taken (min)	Total Time Taken (hr)
Micrometer	1	Gauge Blocks used - cleaning & observation	20.5	0.34
	2	All Micrometers Cleaning & Observations	57	0.95
	3	All Micrometers Calibartion	289	4.82
	Total Calibration Time Taken for Micrometers (min)		**366.5**	**6.11**
Caliper	1	Gauge Blocks used - cleaning & observation	17.5	0.29
	2	All Calipers Cleaning & Observations	26	0.43
	3	All Calipers Calibration	287	4.78
	Total Calibration Time Taken for Calipers (min)		**330.5**	**5.51**
Total Time Taken for Calibration of both devices (min, hr)			**697**	**11.62**

Table 17. The total calibration time for both devices

S.N.	Date	Task	Time Taken (hr)
1	19.3.2024	Calibration Setting-up Training	4
2	21.3.2024	Lab Arrangement, 1- Micrometer Calibration	2
3	22.3.2024	1 - Micrometer & 2 - calipers Calibration	3
4	26.3.2024	Additional Micrometers & Calipers Received	1
5	27.3.2024	6 - Micrometers Calibration	6
6	28.3.2024	1- Micrometer & 7- Calipers Calibration	6
7	29.3.2024	Conformity Sticker	1
8	2.4.2024	Conformity Sticker	1
Total Project Time Taken (hr)			**24**
Total Time Taken for Calibration of both devices (hr)			**11.62**
Overhead Time (hr)			**12.38**

Table 18. The entire calibration project time for in-house

To compute entire in-house calibration project cost, mathematically,

1. Micrometers Calibration Cost = Total Calibration Time Taken for Micrometers * Lab Staff Rate or Student Rate (see tables 16 & 17)
2. Calipers Calibration Cost = Total Calibration Time Taken for Calipers * Lab Staff Rate or Student Rate (see tables 16 & 17)
3. Overhead cost = Overhead Time * Lab Staff Rate or Student Rate (see tables 16 & 18)
4. Total in-house calibration project cost = (Micrometers Calibration Cost + Calipers Calibration Cost + Overhead cost) * 24% Vat

Computations with values: Karelia University of Applied Sciences (in-house)

a. Laboratory Staff (€)

1. Micrometers Calibration Cost = (0.34+0.95+4.82)*47.5 = 290.15
2. Calipers Calibration Cost = (0.29+0.43+4.78)*47.5 = 261.65
3. Overhead cost = 12.38*47.5 = 588.21
4. Total in-house calibration project cost = (290.15+261.65+588.21)*0.24 = **1414**

b. Student (€)

1. Micrometers Calibration Cost = (0.34+0.95+4.82)*22.5 = 137.44
2. Calipers Calibration Cost = (0.29+0.43+4.78)*22.5 = 123.94
3. Overhead cost = 12.38*22.5 = 278.63
4. Total in-house calibration project cost = (137.44+123.94+278.63) *0.24 = **669.60**

B. Kiwa Inspecta & Jamk

To investigate the cost-effective calibration approach, a few accredited companies were contacted for the quotation. Below, tables 19 and 20 are the quotation of Kiwa Inspecta Oy (Rauma, Finland) and Jamk (Jyväskylä, Finland) respectively. Both quotations are without 24% VAT.

S.N.	Device Type	Service	Range (mm)	Price
1	Kaari- ja lautasmikrometrit		0-50	126 eur/kpl
2	Kaari- ja lautasmikrometrit		50-200	141 eur/kpl
3	Kaari- ja lautasmikrometrit		200-500	187 eur/kpl
4	Kaari- ja lautasmikrometrit		500-1000	237 eur/kpl
5	Kaari- ja lautasmikrometrit		>1000	319 eur/kpl
6	Kaari- ja lautasmikrometrit	vaihtokärjet		36 eur/kpl
7	Työntömitta		0-300	101 eur/kpl
8	Työntömitta		0-1000	141 eur/kpl
9	Työntömitta		0-2000	292 eur/kpl
10	Syvyystyöntömitta			111 eur/kpl
Pakkaus & toimituskulut				46 eur/lähetys

Table 19. Kiwa Inspecta OY quotation for calibration

In in-house, 0-25 mm, 25-50 mm, and 50-75 mm ranging micrometers as well as 0-150 mm ranging calipers were calibrated. Therefore, in Kiwa Inspecta quotation, some device ranges with rates and services have been emphasized (the micrometers 0-50 mm and 50-200 mm, micrometer part replacement service, caliper 0-300 mm, and shipment) accordingly. This assisted in observing how many in-house calibrated devices fit into quotation's specified device range and replacement categories. Then, the rates applied for both micrometers and calipers along with shipment charge and VAT to obtain Kiwa Inspecta calibration cost. **Mathematically,**

1. Micrometers calibration cost = Total number of the micrometers under the range * Micrometer Range Rate + Total number of micrometer parts replacement * Replacement Rate (see tables 9 or 21 & 19)
2. Calipers calibration cost = Total number of the calipers under the range * Caliper Range Rate (see tables 14 or 21 & 19)
3. Shipment Cost = number of shipments*Shipment Rate
4. Kiwa Inspecta Total Calibration Cost = (Micrometer calibration cost + Caliper calibration cost + Shipment Cost) * 24% Vat

Computations with values: The Kiwa Inspecta Total calibration cost (€)

1. Micrometers calibration cost = 7*126+1*141+0 = 1023
2. Calipers calibration cost = 7*101 = 707
3. Shipment cost = 2*46 = 92
4. Total Kiwa Inspecta Calibration Cost = (1023+707+92)*0.24 = **2259.28**

On the other hand, there are no criteria for the Jamk, like range. Prices are 80 €/kpl for all micrometer types and 65 €/kpl for all caliper types. Besides, each device calibration certificate costs 65 €/kpl. Therefore, prices for both with and without calibration certificates (CC), will be computed with VAT. Moreover, it does not include shipment cost. Thus, it will not be included in calculations. However, it will be emphasized in price comparison evaluation.

jamk		
S.N.	Device Type/ Service	Price
1	Mikrometri	80€/kpl
2	Työntömitta	65€/kpl
3	Kalibrointitodistus	65€/laitetyyppi

Table 20. Jamk quotation for calibration

To compute Jamk calibration cost with CC, mathematically,

1. Cost of micrometers calibration with CC = Total number of micrometers * Micrometer Calibration Rate + Total number of micrometers * CC Rate (see tables 9 or 21 & 20)
2. Cost of caliper calibration with CC = Total number of calipers * Caliper Calibration Rate + Total number of calipers * CC Rate (see tables 14 or 21 & 20)

3. Total cost of calibration for Jamk with CC = (Cost of micrometers calibration with CC + Cost of caliper calibration with CC) *24% Vat

Computations with values: Jamk calibration cost (€) with CC

1. Cost of micrometers calibration with certificate = 8*80 + 8*65 = 1160
2. Cost of caliper calibration with certificate = 7*65 + 7*65 = 910
3. Total cost of Calibration for Jamk with cc = (1160 + 910) * 0.24 = **2566.80**

To compute Jamk calibration cost without CC, mathematically,

1. Cost of micrometers calibration = Total number of micrometers * Micrometer Calibration Rate (see tables 9 or 21 & 20)
2. Cost of caliper calibration = Total number of calipers * Caliper Calibration Rate (see tables 14 or 21 & 20)
3. Total cost of calibration for Jamk = (Cost of micrometers calibration + Cost of caliper calibration) *24% Vat

Computations with values: Jamk calibration cost (€) without CC

1. Cost of micrometers calibration with certificate = 8*80 = 640
2. Cost of caliper calibration with certificate = 7*65 = 455
3. Total cost of Calibration for Jamk with cc = (640 + 455) * 0.24 = **1357.80**

5.2 Price comparison: In-house Vs Kiwa Inspecta Vs Jamk

The calibration cost computations of in-house, Kiwa Inspecta, and Jamk are shown in table 21. On the left side of the table, eight micrometers and seven calipers of various ranges are listed. These devices were calibrated in the in-house laboratory of Karelia University of Applied Sciences. The table then shows each calibration cost computation accordingly. Note that the calibration cost computations in table 21 are based on the methods described in Chapter 5.1.

Device Type	SN	Make	Range (mm)	Nos	Karelia ammattikorkeakoulu: Overhead Time (hr)	Total Calibration Time Taken (hr): Gauge Blocks Cleaning& Observation Time (hr)	Total Calibration Time Taken (hr): Device Cleaning& Observation Time (hr)	Total Calibration Time Taken (hr): Time Taken for Calibration (hr)	Lab Staff (47.5€/h)	Student (22.5€/h)	kiwa Micrometer: 0-50 mm (126 €/kpl)	kiwa Micrometer: 50-200 mm (141 €/kpl)	kiwa Micrometer: Kaari-ja lautasmikrometrit, vaihtokärjet (36 €/kpl)	kiwa Caliper: 0-300 mm (101 €/kpl)	Delivery (46 €/shipment)	jamk: Micrometer (80 € / kpl)	jamk: Caliper (65€/kpl)	jamk: Calibration Certificate,CC (65 € / device type)
MICROMETER	1	Diesella O. Micrometer (I)	0-25	1	12.38	0.34	0.95	4.82	290.15	137.44	126	N/A	0		92	80		65
	2	Diesella O. Micrometer (II)	0-25	1							126	N/A	0			80		65
	3	Mitutoyo 102-301 O. Micrometer	0-25	1							126	N/A	0			80		65
	4	VISO. Micrometer	0-25	1							126	N/A	0			80		65
	5	Mitutoyo 292-240-30 Digi O. Micrometer	0-25	1							126	N/A	0			80		65
	6	Mauser O. Micrometer	25-50	1							126	N/A	0			80		65
	7	USSR O. Micrometer	25-50	1							126	N/A	0			80		65
	8	Mauser O. Micrometer	50-75	1							N/A	141	0			80		65
						Micrometers Cost			290.15	137.44	Micrometers Cost		1023			Micrometers Cost 640		
CALIPER	1	Whitworth Vernier Caliper (I)	0-150	1		0.29	0.43	4.78	261.65	123.94				101			65	65
	2	MarCal Digi 16EWRi 4103400	0-150	1										101			65	65
	3	Mitutoyo Digi 500-181-30	0-150	1										101			65	65
	4	Whitworth Vernier Caliper (II)	0-150	1										101			65	65
	5	Whitworth Digi caliper silver (I)	0-150	1										101			65	65
	6	Whitworth Digi caliper silver (II)	0-150	1										101			65	65
	7	Whitworth Digi caliper silver (III)	0-150	1										101			65	65
						Calipers Cost			261.65	123.94	Calipers Cost			707		Calipers Cost	455	
						Overhead Cost			588.21	278.63								

In-house	Lab Staff	Student	Kiwa Inspecta		Jamk	
Calibration Cost In-house for Lab Staff	1140		Kiwa Inspecta Total Calibration Cost	1822	JAMK Total Calibration Cost	1095
Calibration Cost In-house for Lab Staff + 24% Vat	1414				JAMK Total Calibration Cost + 24% VAT	1357.80
Calibration Cost In-house for Student		540	Kiwa Inspecta Total Calibration Cost + 24% VAT	2259.28	JAMK Total Calibration Cost w CC	2070
Calibration Cost In-house for Student + 24% Vat		669.60			JAMK Total Calibration Cost w CC +24% VAT	2566.80
					JAMK Total Calibration Cost + 24% VAT	1477.80

Table 21. Calibration cost computations of in-house, Kiwa Inspecta, and Jamk

A bar graph was prepared to compare calibration prices (figure 30). This bar graph depicts various calibration prices €669.6, €1414, €2559, €1357.8, and €2566.8 for Karelia student, Karelia laboratory staff, Kiwa Inspecta, Jamk w/o CC, and Jamk w/ CC, respectively.

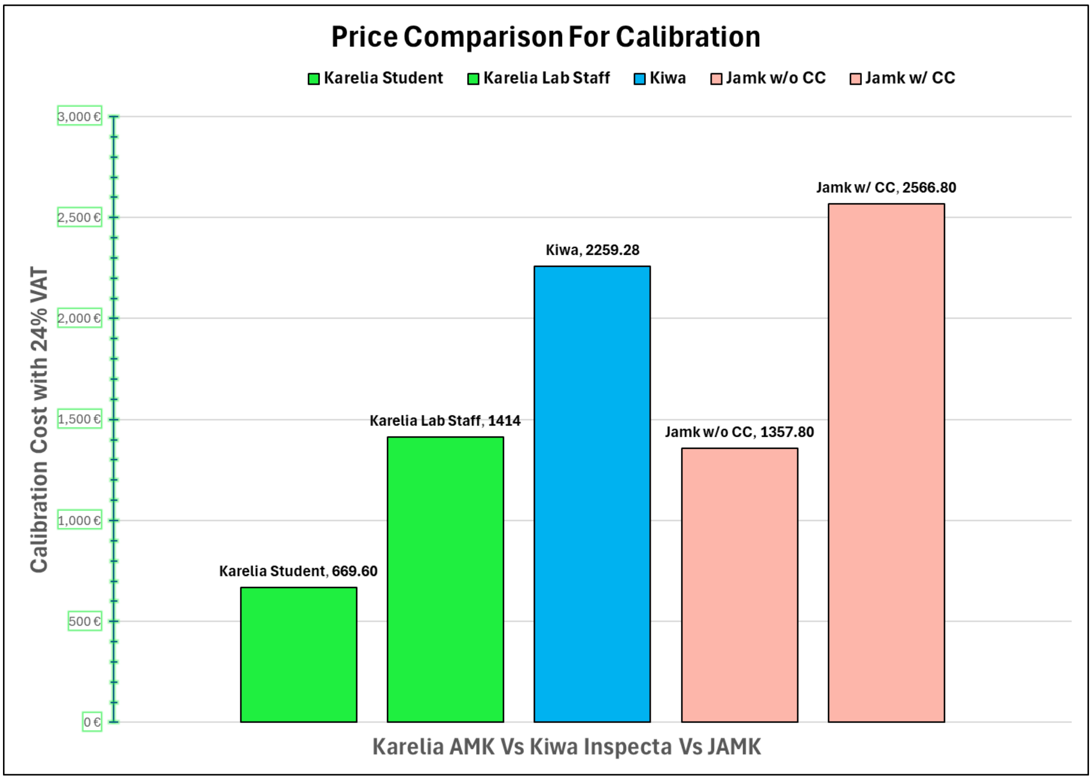


Figure 30. Price comparison for calibration

This visualization tells Karelia University of Applied Sciences student price is the most economical way for calibration than the other options – Karelia lab staff, Kiwa, and Jamk. Sometimes, calibration performed by students comes with certain errors as they tend to misjudge. Tasks require high measurement quality and reliability. Therefore, for standard quality and reliability Jamk w/o CC seems a desirable choice for calibration. This is comparatively lowest price than Karelia lab staff, Kiwa Inspecta and Jamk w/ CC.

However, the issue with this Jamk w/o CC is the shipment cost. No shipment cost was added during computation as there was none in the quotation. To assume shipment cost, for instance, DHL Express charge approx. €60/shipment for 10 kg package (20*20*20 cm^3) from Joensuu to Jamk. If an assumed shipment charge of €60 per shipment, then would it cost over €120 for both up and down. That bulks the calibration price of Jamk w/o CC from €1357.8 to €1477.8. See figure 31.

Now, Karelia lab staff's price has become more economical than Jamk. Therefore, for the same quality and reliability, Karelia lab staff price is the best option. Lab staff calibration at the Karelia University of Applied Sciences is now the second cheapest as well as more efficient, less time-consuming, reliable, and cost-effective than both Kiwa Inspecta and Jamk.

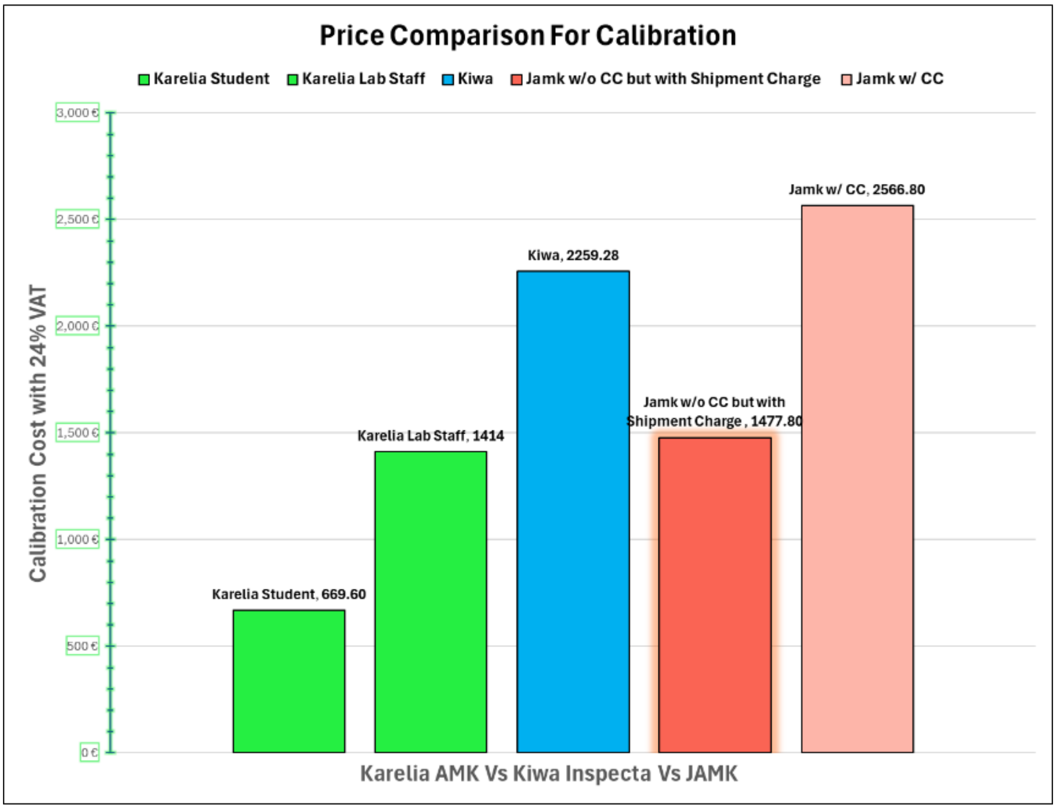


Figure 31. Jamk w/o CC price is bulked by €120 (assumed up/down shipment costs)

If calibration is done in compliance with ISO, it tends to produce less errors. Therefore, both in-house calibrations performed by students and lab staff are suitable options for the handheld device's calibration. Moreover, in-house calibrations save time and cost. For instance, cuts off delivery time, lead time as well as saves expensive calibration cost, shipping cost, calibration certification cost. Furthermore, utilizes in-house resources for calibration such as lab staff, students, standards, and practices.

6 Conclusions

In this thesis, calibration methods for handheld tools such as micrometers, vernier calipers, and digital calipers were studied to explore the most efficient and economical calibration operations. Basically, these calibration methods for both calipers and micrometers were derived from ISO 3611:2023, ISO 13385-1:2019, ISO/IEC GUIDE 98-3:2008(E), ISO 14978:2019, ISO 14253-5, NPL - Good Practice Guides, Mitutoyo Guides, and some other books & online resources. These resources provide methodologies which are robust for calibration.

This research was completely based on the experimental quantitative research method. Therefore, a hands-on lab experiment was conducted in the laboratory of Karelia University of Applied Sciences for calibration. Note that, to ensure compliance with ISO, this entire calibration project was guided all the time. During calibration, seven calipers and eight micrometers were examined by C.E. Johansson steel gauge blocks. Each device was tested by five varied sizes of gauge blocks at various measuring ranges, 20 times. Meanwhile, time keeping was done for both calipers and micrometers calibrations as well as for overhead tasks.

In-house calibration mainly involved device inspection & cleaning, accuracy and precision assessment, and measurement uncertainty evaluation. Thus, one micrometer passed the calibration test, and the other seven failed to pass the calibration test. Most micrometers produced errors out of the error limit and uncertainties were higher for them. To show their accuracies, bar graphs were plotted with measured samples and true sizes. Then, the normal distribution curves were plotted using Minitab to evaluate the precision and confidence of the measurements. Their most samples were out of specification limits and a few of them were within specification limits. Additionally, their processes spreads were wider than the specification limits. However, all the seven calipers passed the calibration test. Their accuracies were within the accuracy limit and uncertainties were lower for them. To visualize their accuracies, bar graphs were created with observed samples and true sizes. Then, the normal distribution curves were developed using Minitab to determine the precision and confidence of the measurements. Almost all samples were within specification limits, about 95-99%. Moreover, their processes spreads were smaller than the specification limits. All the calibration computation data, graphs and normal distribution curves are included in this thesis.

After calibrating devices, the most crucial task was to compute prices for both in-house calibration and outsourcing calibration. Both in-house calibration rates, and quotations for the Kiwa Inspecta, and the Jamk were obtained. First, in-house calibration price was computed - the entire project took 24 hours (11.62 hr. for calibration & 12.38 hr. for overhead task) of work. Then, rates of 22.5 €/hr., and 47.5 €/hr. were applied accordingly for both student and lab staff, and 24% VAT added to compute two distinct calibration prices. Thus, prices were €669.6 and €1414 for both student and laboratory staff, respectively. Second, to compute Kiwa Inspecta calibration price, checked how many in-house calibrated devices fit into quotation's specified device range and replacement categories. (Micrometers ranging from 0-50 mm and 50-200 mm rates are 126 €/kpl and 141 €/kpl, respectively. The micrometer part replacement rate is 36 €/kpl. A caliper ranging from 0-300 mm costs 101 €/kpl, and shipment cost is 46 €/shipment.) After that, each range rate and each replacement rate calculated for all devices along with shipping cost. Then, summed up all prices and applied 24% VAT to obtain Kiwa Inspecta calibration cost. Thus, the total calibration cost of the Kiwa Inspecta was €2259.28. Finally, there are no criteria for the Jamk, like range. Prices are 80 €/kpl for all micrometer types and 65 €/kpl for all caliper types. Besides, each device calibration certificate (CC) costs 65 €/kpl. So, both prices with CC and without CC were computed including 24% VAT. Thus, Jamk calibration cost with CC was €1357.8 and without CC €2566.8.

Next, these various calibration prices were compared in bar graph (figure 30). Where prices were €669.6, €1414, €2559, €1357.8, and €2566.8 for Karelia student, Karelia laboratory staff, Kiwa Inspecta, Jamk w/o CC and Jamk w/ CC, respectively. The Karelia student price was the most economical among other choices for calibration. Calibration requires high accuracy, precision, quality, and reliability. In search of another best option for maximized quality, and reliability Jamk w/o CC price seemed a good option for outsourcing. But the issue with this was the shipment cost. This price had no shipping cost included as there was none in the quotation. Therefore, shipping price was assumed - €60/shipment (based on DHL Express) that makes total shipping cost of €120. Thus, Jamk w/o CC price bulked up to €1477.8. Therefore, this option was opted-out for calibration choice. Due to this reason, Karelia lab staff's price became more economical than Jamk and Kiwa. If offered the same standard of quality and reliability as well as being more efficient, less time-consuming, and cost-effective.

Jamk w/o CC price seemed cheaper than Karelia laboratory staff price. Due to shipment charge add-on, made it slightly expensive. Therefore, the laboratory staff calibration price became affordable and economical in comparison to Kiwa Inspecta and Jamk. This was the second cheapest price. Overall, this study shows that outsourcing calibration was expensive while in-house calibration was more cost-effective. Furthermore, in-house calibration utilizes internal resources such as lab personnel, tools like gauge blocks, lab desk/room, ISO standards. Therefore, in-house calibration saves time, external calibration cost, shipping cost, and calibration certification cost. Hence, in-house calibration in compliance with ISO is the most cost-effective method of calibrating handheld tools like vernier calipers, digital calipers, and micrometers.

7 Recommendation

This thesis recommends carrying out in-house calibration for those organizations who have small to medium laboratory facilities or none. This type of calibration is suitable for handheld tools whose accuracy and precision are easy to determine. It utilizes in-house resources that are easily accessible such as gauge blocks, lab personnel, lab desk/room, ISO standards. For calibration, skilled lab personnel or even amateur but trained personnel fits well. Besides, this practice saves time and cost. For instance, it cuts off long waiting time – lead time, delivery time, and saves cost - shipping cost, external calibration cost, calibration certification cost. Moreover, this practice helps to achieve quality measurement, maintains device, and be able to produce reliable measurements all the time. Hence, this calibration methodologies may be fruitful to SMEs, quality assurance departments, and some engineering schools.

However, this practice has a few limitations. For instance, it can tell device is broken and unusable however it cannot fix its core issues like broken parts. If the operator is skilled, knows how to fix, then it is not a big deal. Otherwise, external calibration is the only solution. External calibration organizations are well equipped with various tools, and techniques. For instance, Kiwa Inspecta offers part replacement services for micrometers, and it charges €36/kpl. Likewise, Jamk offers calibration certification that costs €65/device. Note that when using services from external calibration companies there are shipping costs attached to them. For example, Kiwa Inspecta charges €46/shipment. Thus, this can be expensive.

In-house calibration depends on usage of devices. The more devices used; the more calibration requires.

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