Industrial Maintenance

Dimensional Metrology

Precision Measurement

Course Sample

8130681

Order no.: 8130681 (Printed version) 8130682 (Electronic version)
First Edition
Revision level: 12/2020

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Internet: www.festo-didactic.com
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Printed in Canada

ISBN 978-2-89789-909-7 (Printed version)
ISBN 978-2-89789-904-2 (Electronic version)
Legal Deposit – Bibliothèque et Archives nationales du Québec, 2020
Legal Deposit – Library and Archives Canada, 2020

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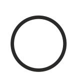
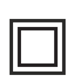
General Safety Symbols and Procedures

The following table lists the safety and common symbols that may be used in this course and on the equipment. Before performing manipulations with the equipment, you should read all sections regarding safety in the Safety Instructions and Commissioning manual accompanying the equipment.

If applicable, following subsections give general procedures related to the tasks you will be asked to perform in this course. Additional safety procedures are given before any task requiring specific safety precautions.

Symbol	Description
DANGER	**DANGER** indicates a hazard with a high level of risk, which, if not avoided, will result in death or serious injury.
WARNING	**WARNING** indicates a hazard with a medium level of risk, which, if not avoided, could result in death or serious injury.
CAUTION	**CAUTION** indicates a hazard with a low level of risk, which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the "Caution, risk of danger" sign, indicates a hazard with a potentially hazardous situation, which, if not avoided, may result in property damage.
	Caution, risk of danger. Consult the relevant user documentation.
	Caution, risk of electric shock.
	Caution, lifting hazard.
	Caution, hot surface.
	Caution, risk of fire.

Symbol	Description
	Caution, risk of explosion.
	Caution, belt drive entanglement hazard.
	Caution, chain drive entanglement hazard.
	Caution, gear entanglement hazard.
	Caution, hand crushing hazard.
	Static sensitive contents. Observe precautions for handling electrostatic discharge sensitive devices.
	Notice, non-ionizing radiation.
	Consult the relevant user documentation.
	Radio Equipment Directive (RED) geographical restrictions – consult the relevant user documentation.
	Direct current.

Symbol	Description
	Alternating current.
	Both direct and alternating current.
	Three-phase alternating current.
	Earth (ground) terminal.
	Protective conductor terminal.
	Frame or chassis terminal.
	Equipotentiality.
	On (supply).
	Off (supply).
	Equipment protected throughout by double insulation or reinforced insulation.
	In position of a bi-stable push control.

Symbol	Description
	Out position of a bi-stable push control.

Preface

Metrology is a scientific discipline concerned with the study of measurements. Although we may not notice it, measurements are present in many day-to-day activities, as well as in a variety of fields, such as in medical sciences, sports, military and industrial applications. Measuring consists of determining the value of a physical quantity. This makes it possible to evaluate the suitability of a product or system. For a measurement to be reliable, it is necessary to have the appropriate measuring instruments and to know how to correctly use them. It is also important to have standards to ensure that the instruments used are suitable for measurements.

Dimensional metrology is one specific field of metrology concerned with linear and angular measurement. Linear measurement is a critical task, especially in today's globalized world, where many complex subassemblies are manufactured in different parts all over the world and then assembled in a completely different place, which is usually very far from where the subassemblies have been manufactured. Results of linear measurements not only allow for quality control during all stages of the manufacturing process, but they also are a valuable source of information to evaluate the capability of a manufacturing process.

The Metrology Learning System is designed for students to learn important concepts related to dimensional metrology and to be able to use and read semi-precision, precision, and advanced dimensional measurement instruments. Using a practical approach, the courses associated to the Metrology Learning System present the use of several dimensional measurement instruments used in today's manufacturing environments. The main goal is that students are able not only to use the instruments but also to develop competencies to select the appropriate instrument according to practical situations.

Tips, feedback, and suggestions

We invite readers to send us their tips, feedback, and suggestions for improving the course.

Please send these to:

services.didactic@festo.com

The authors and Festo Didactic look forward to your comments.

About This Course

Course objectives

When you have completed this course, you will be able to select and use various precision measuring instruments for measuring dimensions in various types of components. You will also be able to combine the reading of technical drawings with the use of precision dimensional instruments to evaluate the conformity of workpieces.

Augmented reality content

The objects represented by some of the images in this course can be seen in augmented reality. To access this content, you need a smartphone or a tablet and the FESTO DIDACTIC AR application. Refer to Appendix B for information on how to download the FESTO DIDACTIC AR application.

When the icon shown below appears near an image, the associated object is available in augmented reality.

The images, or markers, of this course that are linked to an object in augmented reality are shown from Appendix C to Appendix H. To see the objects in full 3D, you must open the FESTO DIDACTIC AR application and point your device's camera at a printed or a digital version of the images. The printed version provides the best results. However, the results depend also on the ambient lighting, the quality of the print, and the type of camera.

System of units

Units are expressed using the International System of Units (SI) or the U.S. customary system of units. The use of one system or both systems depends on the topic studied.

To the Instructor

You will find in this instructor version of the course all the elements included in the student version together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to the instructor is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to the next. For this reason, the results and answers given in this course should be considered as a guide. Students who correctly perform the exercises should expect to demonstrate the principles involved and to make observations and measurements similar to those given as answers.

Time requirements

At the beginning of each section in this course, you will find an indication of the time required by an average student to perform the section. This time indication is for reference purposes only. The actual time required by students may vary significantly from one class to another, and from one student to another.

To prevent inconsistencies in the times required to complete sections, it is recommended that the instructor perform the tasks in the section beforehand to obtain a general idea of the time required to complete the section. The instructor can then better estimate the time required for his or her class to perform the tasks.

Sample

Extracted from

Instructor Guide

Precision Dimensional Measurement

Precision dimensional measurement

9 min.

Learning outcomes

After completing this section, you will be able to:

- Define precision dimensional measurement.
- Realize the importance of precision measurement in modern production.

In modern industry, it is essential to meet dimensional tolerances in order to ensure the proper fit and interchangeability of the components being produced. For this reason, the measuring instruments used for inspection and quality control of dimensions must be capable of providing adequate precision according to the application.

Precision dimensional measurement refers to the measurement of dimensions more precise than 1°, 0.5 mm, 1/64", or 0.01". To give an idea of how small a precision length measurement of 0.001" or 0.025" is, think about the diameter of an average human hair, and divide that diameter by three. The following are examples of precision dimensional measurements:

- 30° 15'
- 0.8573" (0.8573 in)
- 0.275" (0.275 in)
- 1/128" (1/128 in)
- 8.13 mm
- 18.015 mm

In scientific style, inches can be represented by using "in" or by the symbol ("). As far as possible, "in" is used in this course, but the symbol (") is retained in many cases to lighten the text and because in technical fields, it is the most widely used.

Readings in inches with three decimal places, like some of the ones shown previously, are quite common in precision measurement. They are read in terms of thousandths of an inch or thousandths. In addition, when a reading in inches has four decimal places, it is read in terms of ten-thousandths or tenths. For example, 0.8573" can be read as eight hundred fifty-seven and three tenths.

Need for precision dimensional measurement has increased greatly since the first industrial revolution until today's modern industrialized production, where Industry 4.0 has started to become the norm and will surely continue to spread further. As a result, several modern dimensional measurement instruments have been developed to meet the needs of modern smart factories.

Industry 4.0 refers to the current trend toward automation and digitization. This transformation is so significant that it represents a fourth industrial revolution, hence the name.

Precision measuring instruments

Learning outcomes

After completing this section, you will be able to:

- Explain what a precision measuring instrument is.
- List common precision measuring instruments.

Precision dimensional measuring instruments, simply called precision instruments or precision tools, are used to perform measurements more precise than 1°, 0.5 mm, 1/64", or 0.01". This type of instrument is widely used for quality control and inspection to ensure that the produced pieces coincide with the design specifications.

The following are the most common precision instruments or tools used to perform dimensional measurements:

- Vernier caliper
- Standard micrometer
- Vernier micrometer
- Vernier protractor
- Gage blocks
- Dial indicator

Calipers

Learning outcome

After completing this section, you will be able to:

- Realize the importance of precision calipers in the industry.

Measurement of internal and external features is very common in the manufacture of precision mechanical parts. During the whole manufacturing process, it is necessary to control the dimensions in order to ensure that the design specifications are respected. Within precision measuring instruments, the precision calipers are among the best known and most used.

Calipers used in precision measurement are very versatile and relatively easy to use. They are used in machine shops and manufacturing industries to measure internal and external features on workpieces. The correct use of these instruments is key to work in trades related to the machining of components, quality control, metrology, and many others.

The major types of precision calipers are the following:

- Vernier caliper
- Dial caliper
- Digital caliper

Each of these types of calipers can be used to measure the same features. What differentiates them is the mechanism of amplification of the measurements. While the vernier and dial are based on mechanical systems to amplify measurements, the digital caliper uses electronic components.

Although the electronic caliper is the most advanced of these tools, the others are still widely used, especially the vernier caliper.

Vernier Calipers

Principle of the vernier scale

201 min.

Learning outcomes

After completing this section, you will be able to:

- Explain the principle of the vernier scale.
- Explain what the least count is.
- Compute the least count of a vernier instrument.

Although instruments like the ruler are still widely used in manufacturing, they are limited to precisions up to 0.5 mm, 1/64", or 0.01". This limitation is not due to a lack of precision, but to a lack of amplification. For example, on a ruler featuring 0.5 mm divisions at least, there is not enough space to include smaller divisions that are still readable. Although the rule is precise, its lack of amplification limits the precision to 0.5 mm.

The lack of amplification is solved using more precise instruments, known as vernier instruments, which are based on the principle of the vernier scale. This principle consists of using a main scale and an auxiliary scale on the same instrument. The auxiliary scale, known as the vernier scale, amplifies the measurements of the main scale. The vernier steel protractor shown in the following figure is an example of a vernier instrument.

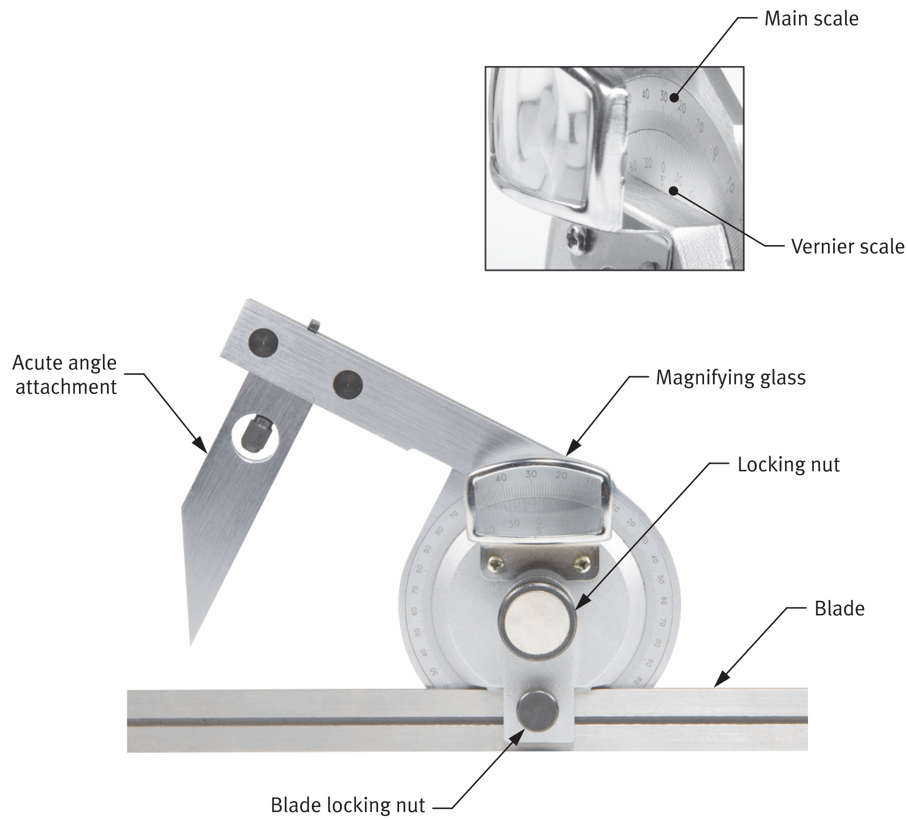


Figure 1: Protractor featuring a vernier scale.

To implement the principle of the vernier scale, instruments include a main scale and a vernier scale. The vernier scale is a sliding scale that divides the smallest divisions of the main scale into smaller pieces or increments.

The number of smaller pieces in which the vernier scale divides the smallest divisions of the main scale is equal to the number of divisions of the vernier scale. For example, if a vernier scale has 20 divisions, then the smallest division of the main scale is divided in 20 pieces, which increases the accuracy of the instrument.

The vernier steel protractor shown in Figure 1 is an example of a vernier instrument.

Least count

The smallest division in the main scale of the protractor shown in Figure 1 is 1°, which is also equal to 60 minutes. On the other hand, the vernier scale has 12 divisions, graduated from 0 to 60 minutes. Thus, every graduation on the vernier scale is equal to 5 minutes, since 60 min/12 = 5 minutes.

As a result, the vernier scale divides each degree of the main scale into 12 smaller increments of 5 minutes each. The vernier steel protractor is thus capable of providing measurements within 5 minutes of a degree.

The smallest measurement that an instrument can measure is known as the least count. In the example of the vernier protractor, the least count is 5 minutes.

The least count can be calculated as the ratio of one smaller division on the main scale (SDMS) to the number of vernier scale divisions (NVSD), as follows:

$$\text{Least count} = \frac{\text{SDMS}}{\text{NVSD}}.$$

The least count is also defined as the difference between the smallest division on the main scale and one division of the vernier scale. This definition leads to the same result as the one given previously.

For example, let us suppose that each smallest division on the main scale of a vernier instrument is 1 mm, and the vernier scale features 50 divisions, which coincide exactly with 49 divisions of the main scale. Thus, one vernier division is equal to 1/50 of 49 main scale divisions. This can be written as: 1/50 x 49 x 1 mm = 0.98 mm. Therefore, the least count, which is the difference between the smallest division on the main scale (1 mm) and one division of the vernier scale, equals 1 mm - 0.98 mm = 0.02 mm.

The same result is obtained using the first definition given, which in this case leads to 1 mm/50 = 0.02 mm.

In the example, when the zero of the main scale and the zero of the vernier scale are aligned, the first vernier division reads 0.02 mm less than the first small division of the main scale. The second vernier division reads 0.04 mm less than the second small division of the main scale, and so forth.

Vernier caliper

Learning outcomes

After completing this section, you will be able to:

- Describe a vernier caliper and list its main uses.
- Identify the main components of a vernier caliper.
- Recognize M-type and CM-Type vernier calipers.
- Read the inch scales on a vernier caliper.
- Read the metric scales on a vernier caliper.
- Explain the Abbe's principle.
- Describe general guidelines for proper use of vernier calipers.

A vernier caliper is a precision measuring instrument used to measure external and internal features, external diameters, internal diameters (bores), lengths, and depths as small as 0.02 mm or 0.001". The instrument consists of a solid L-shaped jaw, where a main scale is engraved, and of a movable jaw, where a vernier scale is also engraved. The vernier scale, or nonius, can slide over the entire length of the main scale to take measurements.

The main scale on a typical vernier caliper is essentially a ruler graduated in millimeters and inches. The caliper includes a vernier scale in millimeters and a vernier scale in inches. Both vernier scales are inscribed on the movable jaw. The metric vernier scale features graduations of 0.02 mm, and the inch vernier scale features graduations of 0.001" or 1/128". Figure 2 shows the main components of a typical vernier caliper graduated in thousandths of an inch and millimeters.

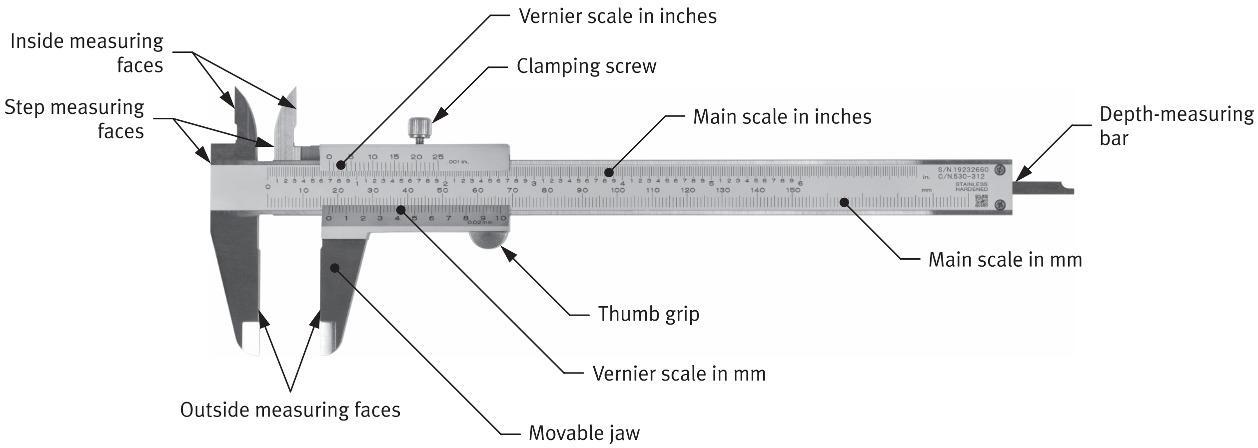


Figure 2: Vernier caliper.

Whenever the movable jaw of a caliper slides over the main scale, the depth-measuring bar also slides in and out of the caliper. This practical attachment is used to measure depths.

Vernier calipers come in standard sizes of 6", 12", 24", 36", 48", and 72"; 150 mm, 300 mm, 600 mm, and 900 mm. They can be graduated in fractional inches, in thousandths of an inch, in metric units, or both in inches, either fractional or decimal, and millimeters. The smaller versions of the vernier caliper, as the one shown in Figure 2, are the most commonly used for general measurements.

Figure 3 and Figure 4 show applications of vernier calipers. In Figure 3, the vernier caliper is used to measure the diameter of a shaft bore.

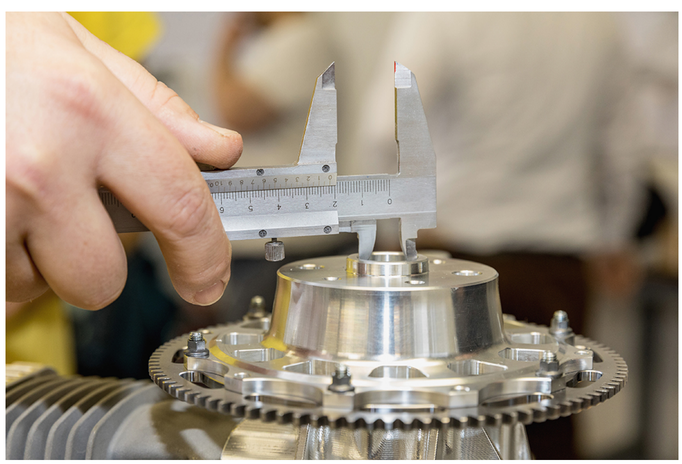


Figure 3: Measuring an internal feature using a vernier caliper.

Figure 4 shows a typical application of the vernier caliper, in which the caliper is used to measure an external diameter on a finished component.

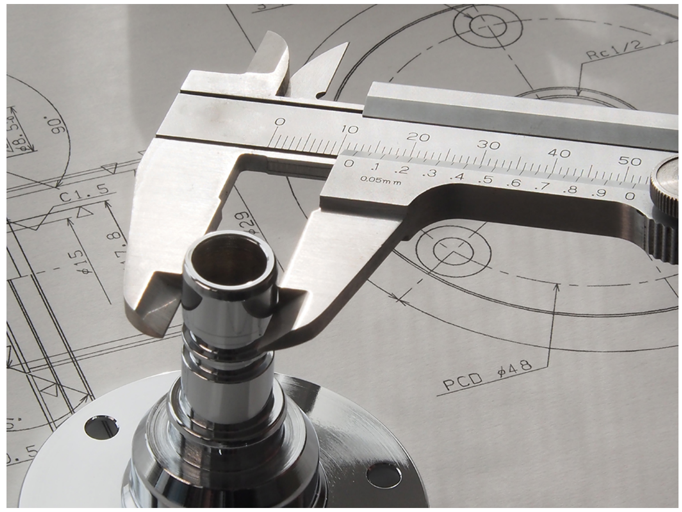


Figure 4: Measuring an external feature using a vernier caliper.

Types of vernier calipers

Two main types of vernier calipers are available: the M-type and the CM-type. The M-type caliper is the typical vernier caliper, which features independent jaws for internal and external measurements. The caliper shown in Figure 2 is an example of CM-type caliper.

In the CM-type calipers, the inside and outside measuring faces are on the same jaws, as shown in the following figure. Other types of calipers are the dial caliper and the digital caliper, which are covered in separate sections.

Figure 5: CM-type caliper.

Reading the inch scales on a vernier caliper

The inch vernier scale on a vernier caliper can feature 25 divisions or 50 divisions.

In vernier calipers featuring a 25-division inch vernier scale, each inch in the main scale is divided into 40 smaller divisions measuring 0.025" each, as shown in Figure 6. The series of large numbers marked from 0 to 6 on the main scale in inches represent inches. For example, 1 represents 1", 2 represents 2", and so forth. The shorter marks between these numbers represent 0.025" each.

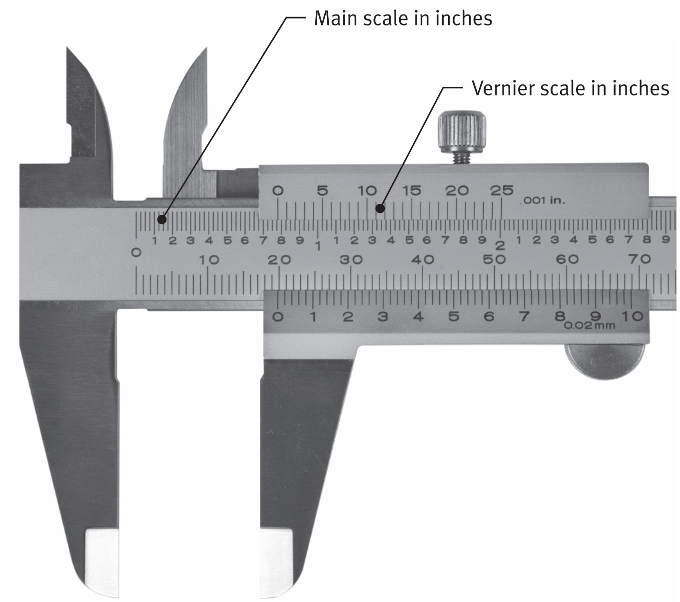


Figure 6: Inch scales on a vernier caliper.

The small number divisions from 1 through 9 between consecutive inch-graduations on the main scale are placed every four smaller divisions, as shown in Figure 7. Thus, each small number division represents 0.100". For example, 2 represents 0.200", 3 represents 0.300", and so forth. Also, each of the four smaller divisions between two small number divisions measures 0.025".

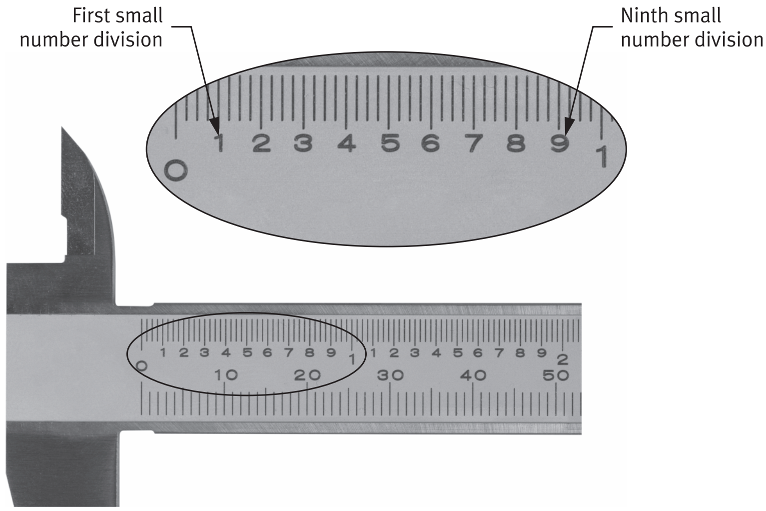


Figure 7: Small number divisions on the inch main scale of a vernier caliper.

By the principle of the vernier scale, and because in this case, the vernier scale has 25 divisions, it divides the 0.025" main scale divisions into 25 divisions. As a result, the smallest measurement the caliper can measure (least count) is 0.001", since 0.025"/ 25 = 0.001", which also means that every graduation on the inch vernier scale is 0.001".

Reading vernier calipers is a matter of practice that requires being familiar with the instrument and the principle of vernier scales. The knowledge of this important principle can also be applied to other measuring instruments, like protractors and micrometers. In order to correctly read any vernier caliper, it is important to recognize the different types of divisions on the instrument.

The following figure shows a sample measurement on the inch scale of a vernier caliper. The reading for the sample measurement shown in the figure is obtained by following the steps indicated in Table 1.

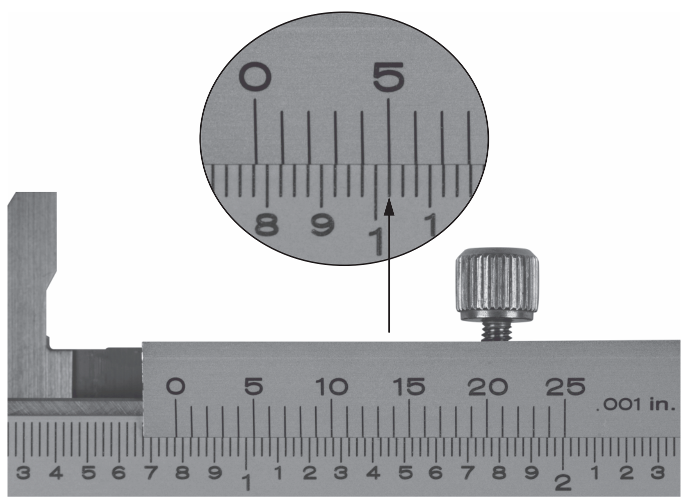


Figure 8: Sample measurement on a vernier caliper with a 25-division inch vernier scale.

The following table describes the basic steps for reading a vernier caliper that features a 25-division inch vernier scale. The measurement corresponding to point A on Figure 8 is determined as follows:

Table 1: Guided reading of the inch scales on a vernier caliper.

Reading step	Result in the example	Recorded value
1. Identify the first large number on the inch main scale that is to the left of the zero on the inch vernier scale or that is perfectly aligned with that zero. Multiply this large number by 1" and record the result.	First large number: 0	0
2. Identify the small number division on the inch main scale that is at the left of the zero on the inch vernier scale or that is perfectly aligned with that zero. Multiply this small number division by 0.100" and record the result.	Small number division: 7	7 x 0.100" = 0.700"
3. Count the number of smaller divisions between the small number division identified in the previous step and the last smaller division that is to the left of the zero on the inch vernier scale or that is perfectly aligned with that zero. Multiply this number by 0.025" and record the result.	Counting of smaller divisions: 3	3 x 0.025" = 0.075"
4. On the inch vernier scale, count how many lines are between the zero and the line that lines up perfectly with any line on the inch main scale. Multiply this number of lines by 0.001" and record the result. The value of the inch main scale division does not matter.	Counting of lines on the vernier scale: 5	5 x 0.001" = 0.005"
5. Add all the results to obtain the final measurement.	0 + 0.700" + 0.075" + 0.005" = 0.780"	0.780" (final measurement)

In calipers for which the inch vernier scale has 50 divisions, the smaller divisions on the main scale are 0.050". The vernier scale divides each increment on the main scale in 50 pieces. Thus, the smallest measurement this instrument can measure (least count) is 0.001", since 0.05"/50 = 0.001". The steps for reading this type of caliper are essentially the same as with the caliper that features the 25-division inch vernier scale.

Reading the metric scales on a vernier caliper

The metric vernier scale on a vernier caliper can feature 25 divisions or 50 divisions.

In vernier calipers that feature a 50-division metric vernier scale, like the one shown in Figure 9, the large numbers on the main scale represent increments of 10 mm each. The smallest graduations on the metric main scale measure 1 mm.

The metric vernier scale has 50 divisions. By the principle of the vernier scale, each 1 mm division on the main scale is divided into 50 pieces. Consequently, the smallest measurement in metric units that the caliper can measure (least count) is 0.02 mm, since 1 mm/50 = 0.02 mm, which also means that every graduation on the metric vernier scale is 0.02 mm.

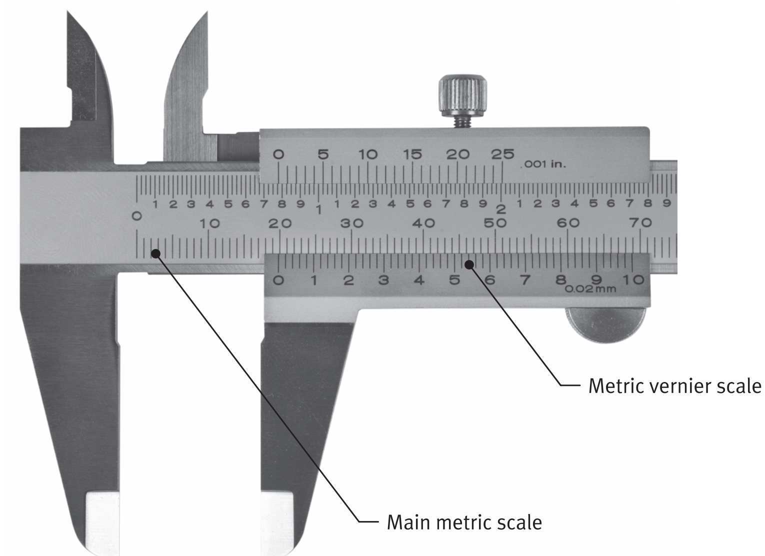


Figure 9: Metric scales on a vernier caliper.

Reading the metric scales on a vernier caliper is quite similar to reading the inch scales. What must be considered is that the measurements of the different divisions of the metric scale are not the same as those of the inch scales.

The following figure shows a sample measurement on the metric scale of a vernier caliper. The sample measurement shown in the figure is obtained by following the steps indicated in Table 2.

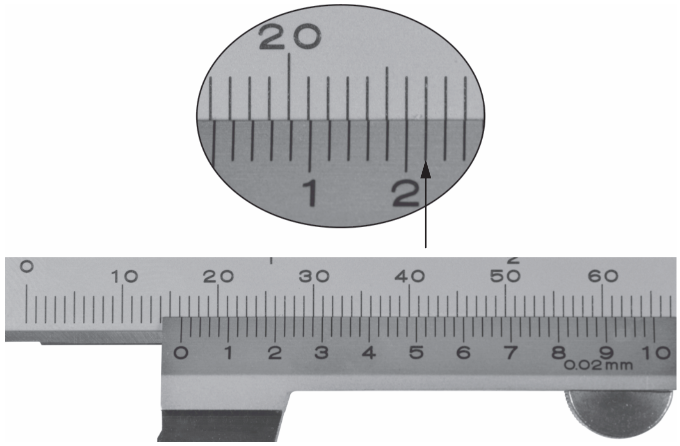


Figure 10: Sample measurement on a vernier caliper that features a 50-division metric vernier scale.

The following table describes the basic steps for reading a vernier caliper that features a 50-division metric vernier scale. Based on the steps indicated in the table, the measurement corresponding to point B on Figure 8 is determined as follows:

Table 2: Guided reading of the metric scales on a vernier caliper.

Reading step	Result in the example	Recorded value
1. Identify the first large number on the metric main scale that is to the left of the zero on the metric vernier scale or that is perfectly aligned with that zero. Record this number.	First large number: 10	10 mm
2. On the metric vernier scale, count how many lines are between the zero and the line that lines up perfectly with any line on the metric main scale. Multiply this number of lines by 0.02 mm and record the result.	Counting of smaller divisions: 6	6 mm
3. Count the number of smaller divisions between the large number division identified in the previous step and the first smaller division that is to the left of the zero on the metric vernier scale or that is perfectly aligned with that zero. Record this number.	Counting of lines on the vernier scale: 11	11 x 0.02 mm = 0.22 mm

Reading step	Result in the example	Recorded value
4. Add all the results to obtain the final measurement.	10 mm + 6 mm + 0.22 mm = 16.22 mm	16.22 mm (final measurement)

Abbe's principle

Although vernier calipers and other types of calipers are quite versatile and provide accurate measurements, they do not conform to an important design principle for measurement instruments, known as Abbe's principle. This principle establishes that the scale of a measuring instrument should lie in the same straight line as that in which measurements are performed.

Abbe's principle is illustrated in Figure 11 for a vernier caliper. Because vernier calipers do not respect the Abbe's principle, taking measurements at the tips of the jaws should be avoided unless necessary. This is because the possibility of error increases as the distance between the axis of the reading scale of the caliper and the axis of measurement on the workpiece increases. Measurement errors can be thus minimized by measuring as close to the beam as possible.

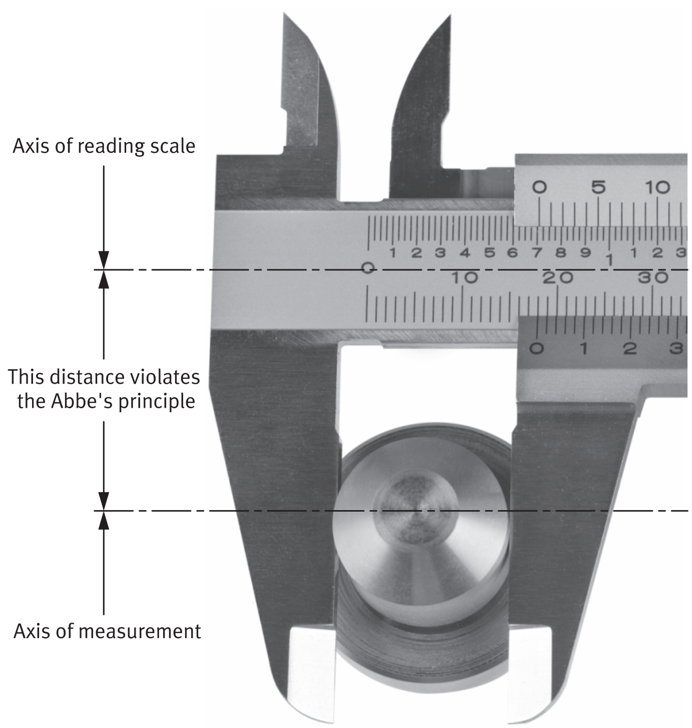


Figure 11: Abbe's principle.

Proper use of vernier calipers

Calipers are subject to conditions of use that can lead to wear and tear. Therefore, it is important to follow usage practices that will keep the instrument in good condition and ensure that it is still reliable. The following guidelines should be followed for proper use of vernier calipers. These guidelines are also applicable to dial and digital calipers.

- Before measuring a workpiece with a caliper, clean the workpiece and the caliper. Check for burrs on the workpiece to be measured.
- Do not use a caliper to measure holes smaller than 4 mm. The reason is that the inside jaws of the caliper are offset, which prevents them from being placed in the center of holes.
- Make sure that when you close the caliper, the measurement is zero. If not, the caliper must be removed from service until it is repaired.
- When you finish using the caliper, wipe it with a clean cloth to remove dirt and fingerprints. Store the caliper in its housing and with the jaws slightly open.
- Strictly respect the calibration and maintenance schedules of the caliper. The frequency of calibration depends on the frequency of use.
- When measuring external features, wiggle the caliper until finding the minimum reading. For internal features, find the maximum reading.

These guidelines are also applicable to dial calipers and digital calipers.

Proper care and adjustment of vernier calipers

Learning outcomes

After completing this section, you will be able to:

- Describe the general procedure to adjust the movable jaw on a caliper.
- Describe the type of inspections to ensure calipers are in good condition.
- List general guidelines for proper care of calipers.

Adjustment of the movable jaw on a caliper

The condition of the measuring surfaces and the adjustment of the movable jaw of a vernier, electronic or dial caliper are critical factors affecting the accuracy of the instrument.

It is important to make sure that the movable jaw of a caliper can slide easily and without play. However, with continuous use and excessive force applied on the jaws of calipers, it may happen that readings change depending on the point of the jaws where the workpiece is placed for measurement.

Calipers include two screws used to adjust the movable jaw, as shown in the following figure. These screws adjust a gib that holds the movable jaw against the inside surface of the rule to give the proper friction when the jaw slides.

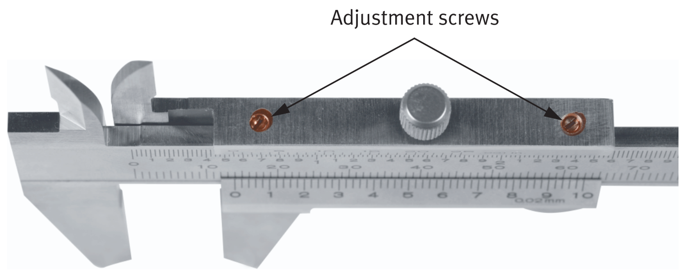


Figure 12: Adjustment screws on the sliding scale of a vernier caliper.

It is possible to check the adjustment of the movable jaw on a caliper using a gage block. To do this, the block must be measured by inserting it in both the upper and lower part of the jaws.

If there is a difference between the two measurements when varying the pressure applied to the movable jaw, the pressing screw and the setscrew should be checked for maladjustment. Should an adjustment be necessary, it can be carried out as follows:

1. Use a jewelers' screwdriver to tighten the pressing screw and setscrew. Then, loosen them and turn them counterclockwise, approximately 1/8 of a turn (45°).
2. Check the slide action of the movable jaw. Continue adjusting the angular position of the screws until the jaw slides smoothly without play.
3. Close the caliper and check the zero reading.
4. Measure a gage block or a piece of known size in both the upper and lower part of the jaws. Apply a moderate pressure during measurement.
5. Make sure the reading does not change significantly up and at the tip of the jaws. Repeat the previous steps if the measurement is not as expected.

Periodic inspection of calipers

Calipers should be calibrated at least once a year, though this can change depending on the frequency of use. As previously stated, the condition of the measuring surface is one important factor that can affect the accuracy of a vernier caliper. For this reason, it is important to inspect periodically the measuring surface of vernier calipers for wear and distortion.

A daily inspection that can be easily carried out on a caliper to detect wear on the measuring surfaces is to tightly close the jaws holding the caliper against a light source. If the light passes evenly through the caliper jaws, the caliper is suitable for use. If the light is cut off when passing through the jaws, the caliper needs to be further inspected to determine whether the amount of wear is acceptable or not.

Calibration is another important activity to be performed on calipers to ensure the quality of measurements. The frequency of calibration depends on the frequency of use and the history of previous calibrations. Calibration must be performed at least once a year by an accredited laboratory.

Calipers can be checked for instrumental error using a set of gage blocks or a set of pieces of known size. This is done by placing gage blocks between the outside measuring faces or between the inside measuring faces and comparing the measurement with the known value of the gage blocks. The test should ideally be performed at least at five equally spaced positions in such a way that the measuring range of the instrument is covered.

A gage block is an extremely accurate-sized block with very smooth surfaces that can be used to check the accuracy of precision measuring instruments.

The parallelism of the measuring surfaces on a caliper can also be tested by placing a gage block between the jaws. When a caliper is in good condition, the parallelism is not affected when tightening the clamping screw or when varying the pressure while the gage block is between the jaws.

Care of calipers

Calipers, whether vernier, dial, or digital, are precision instruments and as such they must be cared for to ensure accurate measurements and durability. The following are general guidelines for the proper care of calipers:

- Before using a caliper, make sure it is calibrated. A calibrated caliper should have a sticker indicating that is calibrated.
- Always use the thumbwheel or thumb grip to open and close the caliper.
- Avoid throwing or dropping calipers.
- Do not immerse the caliper in water or other liquids, unless the caliper is waterproof.
- Keep the caliper away from metal chips, magnets, and grinding grit.
- Calipers are intended to take measurements only on stationary pieces. Never use a caliper for measuring moving pieces.
- Always clean calipers after use.
- Do not try to measure workpieces that exceed the measurement range of the caliper.
- Calipers are exclusively for measurement, so do not use them to substitute other tools, like scribers and screwdrivers.
- When not in use, always keep calipers in their case and do not put them on work surfaces with heavy pieces that can break and bend the caliper or its case.

Dial caliper

Learning outcomes

After completing this section, you will be able to:

- Describe a dial caliper and list its main uses.
- Identify the main components of a dial caliper.

Dial calipers are precision measurement instruments used to measure external and internal features, external diameters, internal diameters (bores), lengths, and depths. These are the same types of measurements that can be taken with a vernier caliper, but dial calipers are easier to read when compared with vernier calipers. Figure 13 shows a dial caliper and its main components.

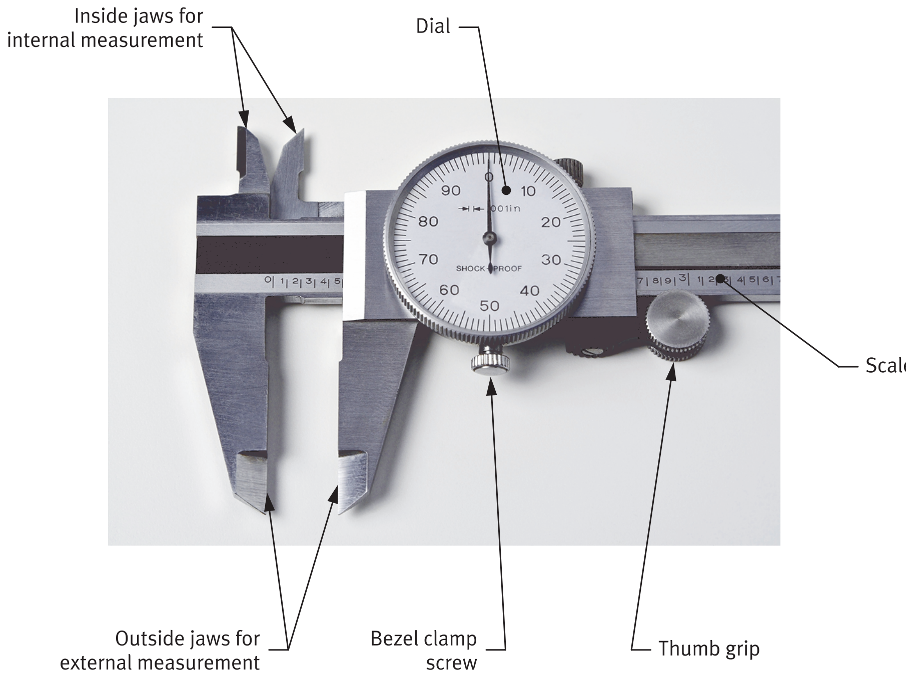


Figure 13: Dial caliper.

Dial calipers use a rack and pinion system to amplify the linear displacements of the main scale. This system has the same amplification function as a vernier scale. The rack and pinion system of dial calipers is quite delicate, which makes the caliper subject to malfunctioning. For this reason, great care must be taken when using a dial caliper to avoid damaging the instrument.

The least count on a dial caliper is indicated on the face of the dial. Readings are taken by adding the reading on the main scale to the reading on the dial. To read the dial, the number of divisions indicated by the pointer must be multiplied by the least count of the instrument. Dial calipers are available in English and metric units. The least count can be 0.05 mm, 0.02 mm, 0.01 mm, or 0.001".

Measurement with a vernier caliper

Learning outcomes

After completing this section, you will be able to:

- Prepare and set up a vernier caliper.
- Identify the appropriate contact between the measuring faces of a caliper and a workpiece.
- Measure different dimensional features using a vernier caliper.

In this procedure, you will set up and prepare a vernier caliper before using it for measurement. You will then use the vernier caliper to measure internal and external features on a pump shaft. A pump shaft is a mechanical component used to transmit torque to impellers or to displacement elements on different types of pumps. Figure 14 shows a pump shaft on a centrifugal pump.

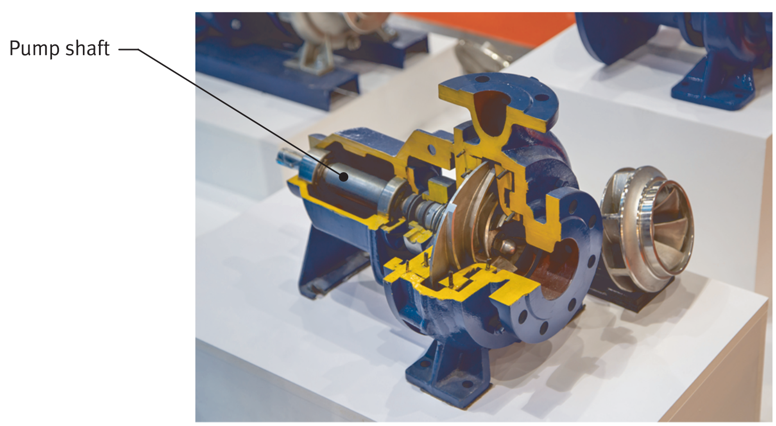


Figure 14: Pump shaft on a centrifugal pump.

1. Locate the pump shaft (piece E) included in the learning system. Refer to Figure 15.

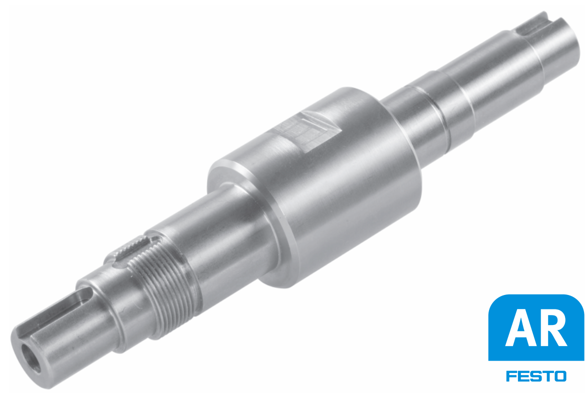


Figure 15: Pump shaft (piece E).

2. Locate the vernier caliper provided with the learning system.

	NOTICE
	Never use a damaged caliper.

3. Use a clean lint-free paper or cloth to wipe the measurement faces and sliding surfaces of the caliper. Make sure to wipe off any dust and oil.

4. Slightly loosen the clamping screw and insert a clean piece of paper between the outside jaws. With the jaws closed, pull the piece of paper to clean up the measuring surfaces, as shown in Figure 16.

Figure 16: Cleaning up the measuring surfaces on a vernier caliper.

5. Inspect the measurement surfaces for signs of damage.

6. Close the jaws holding the caliper against a light source and check that light passes evenly through the caliper jaws.

7. Check the zero reading of the caliper. To do this, loosen the clamping screw and close the caliper until the jaws are together, as shown in Figure 17.

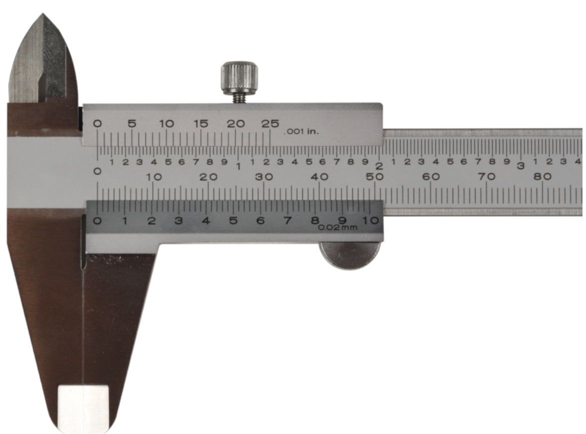


Figure 17: Checking the zero reading on a vernier caliper.

If the caliper does not indicate zero, it should be cleaned, repaired or recalibrated. In that case, inform your instructor.

8. Take the 10-mm gage block provided with the learning system and clean it using a clean lint-free paper or cloth.

9. Insert the gage block at the top and at the tip of the jaws, as shown in Figure 18 and Figure 19. Slightly vary the pressure while the block is between the jaws, and check if the reading changes when you vary the pressure on the jaws.

Figure 18: Checking the adjustment at the top of the jaws.

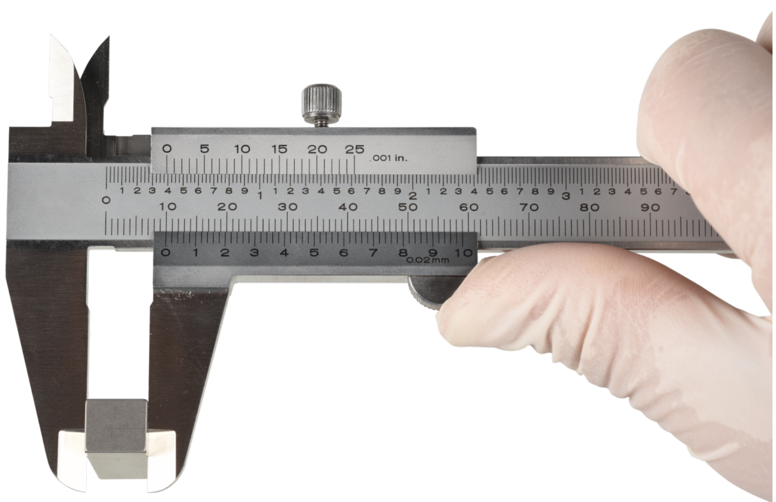


Figure 19: Checking the adjustment at the tip of the jaws.

If the reading changed, inform your instructor as it may be necessary to adjust the movable jaw of the caliper, as explained in the theory of this exercise (Adjustment of the movable jaw on a caliper).

Measurement skills with a vernier caliper

10. Put on a pair of cotton gloves.

11. Locate the 25-mm master ring gage provided with the learning system, shown in Figure 20.

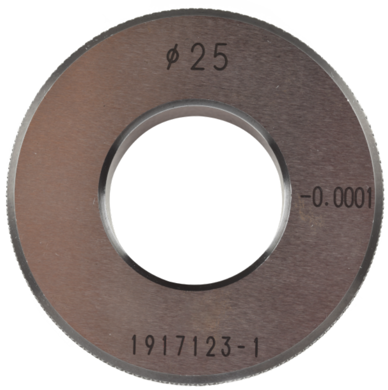


Figure 20: 25-mm master ring gage.

12. Clean the inside walls of the master ring using a clean lint-free paper or cloth and lay the master ring on the work surface.

13. Insert the inside jaws of the caliper inside the master ring and use the thumbwheel to pull the caliper away against the diameter, as shown in Figure 21.

Figure 21: Measuring an inside diameter on a 25-mm master ring gage using a vernier caliper.

14. Slightly rotate the master ring until you make positive contact with the inside jaws. Take your reading when you feel the positive contact.

15. Repeat your measurements until you obtain 25 mm. Do not force the caliper to obtain the 25-mm reading. It is important that you identify the correct positive contact ("feel"), as this will prepare you to measure unknown inside dimensions.

16. Locate the 6-mm master ring gage provided with the learning system, shown in Figure 22.

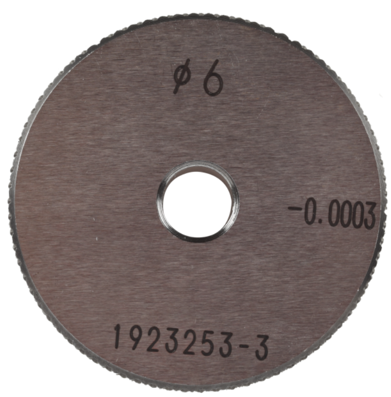


Figure 22: 6-mm master ring gage.

17. Practice measuring the 6-mm master ring as you did with the 25-mm master ring. Refer to Figure 23.

Figure 23: Measuring an inside diameter on a 6-mm master ring gage using a vernier caliper.

Linear measurement using a vernier caliper

18. Identify in the pump shaft the features shown in Figure 24. Familiarize yourself with the identification letters and numbers, as you will use them as reference to perform your measurements on the pump shaft.

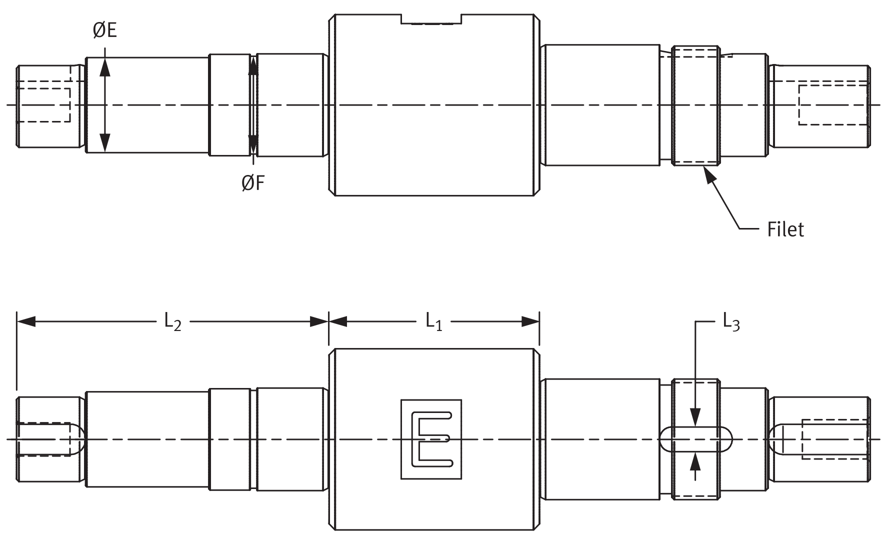


Figure 24: Features to be measured on the pump shaft using a vernier caliper.

19. Inspect the pump shaft for dust, burrs and cutting chips. Wipe the shaft using a clean piece of cloth.

20. Loosen the clamping screw of the caliper and slide the movable jaw until the distance between the jaws is slightly wider than length L1.

21. Place the fixed jaw on one side of the feature you are measuring and align the main scale with the central axis of the shaft to ensure that the main scale is parallel to the shaft.

When measuring with calipers, it is recommended to place the measured piece on a work surface. However, because work surfaces are not always available, it is often necessary, although not ideal, to hold the piece with one hand and take the measurement with the other.

22. Lightly press the thumb grip against the main scale and slide the movable jaw closer to the other end of the measured feature until you have established light contact between the caliper jaws and the shaft, as shown in Figure 25.

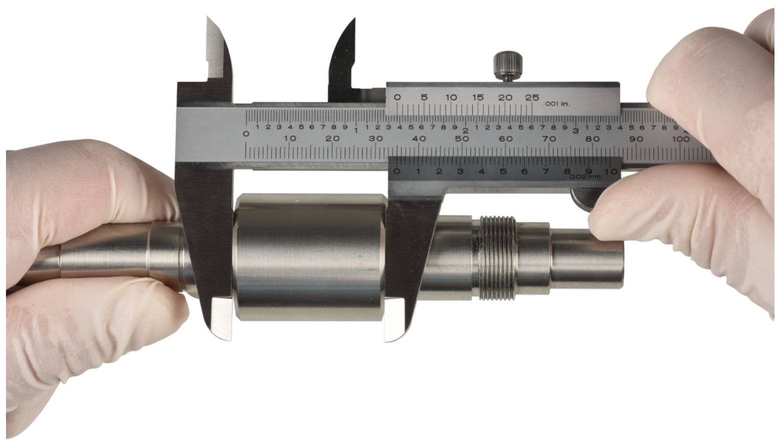


Figure 25: Measuring length L_1 on the pump shaft.

23. Take the reading directly while the caliper jaws are in contact with the piece, making sure to hold the graduations of the caliper perpendicular to the line of sight to avoid the parallax error.

24. Repeat the measurement several times until you have obtained three consecutive readings that are equal or practically equal. Make sure to recheck the zero reading of the caliper after each measurement.

25. According to your readings, what is the measure of length L_1?

Length L_1 (mm) = __________ mm

Length L_1 (in) = __________ in

Length L_1 (mm) = [34.90 mm, 35.10 mm]

Length L_1 (in) = [1.374 in, 1.382 in]

Before performing each of the next measurements, you must recheck the zero reading of the caliper, as explained earlier in this procedure.

26. Hold the pump shaft with your left hand making sure the threaded size of the shaft is at your left.

27. Place the step measuring face of the movable jaw against the end of the pump shaft at your right. Operate the thumb grip to slide the other step measuring face against the central seat on the shaft, as shown in Figure 26.

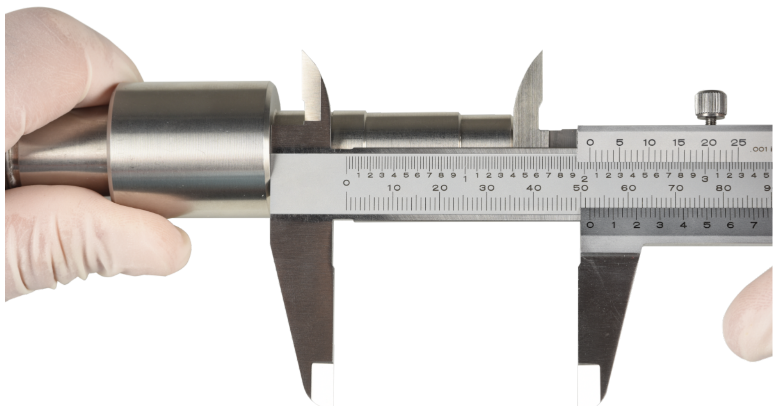


Figure 26: Step measuring (length L_2) on the pump shaft using a vernier caliper.

28. Take your reading while the vernier caliper is still in contact with the measured step. Repeat the measurement until you have obtained three equal consecutive readings.

29. What is the measure of length L_2?

Length L_2 (mm) = ________ mm

Length L_2 (in) = ________ in

Length L_2 (mm) = [51.90 mm, 52.10 mm]

Length L_2 (in) = [2.043 in, 2.051 in]

30. Place the tip of the fixed jaw at one point of diameter F and bring the tip of the movable jaw into contact with another point of the diameter, as shown in Figure 27.

Do not apply excessive force, as this can bend the jaws.

Figure 27: Measuring outside diameter F on the pump shaft using a vernier caliper.

31. Repeat the measurement until you have obtained three equal consecutive readings.

32. What is the measure of diameter F?

    Diameter F (mm) = ________ mm

    Diameter F (in) = ________ in

    Diameter F (mm) = [16.17 mm, 16.23 mm]

    Diameter F (in) = [0.6366 in, 0.6380 in]

33. Place the fixed jaw of the vernier caliper at one point of diameter E and operate the thumb grip to bring the movable jaw into contact with another point of the diameter.

Make sure to place the shaft between the jaws as close as possible to the main scale of the caliper.

34. Gently wiggle the caliper in all directions until you find the minimum reading. This minimum reading is the measure of the outside diameter. Repeat the measurement until you have obtained three equal consecutive readings.

35. What is the measure of diameter E?

Diameter E (mm) = ________ mm

Diameter E (in) = __________ in

Diameter E (mm) = [15.74 mm, 15.76 mm]

Diameter E (in) = [0.6197 in, 06205 in]

36. Identify in the shaft pump the keyway for which the width is identified as L_3 in Figure 24. Hold the shaft on a work surface or use your hand to hold it.

37. Close the caliper and insert the inside jaws into the keyway. Next, place the inside measuring face of the movable jaw at one edge on the keyway, and bring the other inside jaw into contact with the other edge of the keyway, as shown in Figure 28.

Figure 28: Measuring the width of a keyway (L_3) on the pump shaft using a vernier caliper.

38. Repeat the measurement until you have obtained three equal consecutive readings.

39. What is the measure of length L_3?

Length L_3 (mm) = _______ mm

Length L_3 (in) = ________ in

Length L_3 (mm) = [4.00 mm, 4.20 mm]

Length L_3 (in) = [0.158 in, 0.166 in]

40. Clean the caliper and the pieces you have used.

41. Inspect the caliper for wear and damage.

42. Lay the caliper on its case leaving a separation of about 2 mm between the measuring faces of the outside jaws. Do not clamp the movable jaw.

43. Return the pieces and tools back to their housings in the learning system.

Review questions

1. Which of the following measurements corresponds to the reading in inches shown in Figure 29? The small arrow shows a detail of the vernier scale.

   a. 0.458 in

   b. 0.408 in

   c. 0.418 in

   d. 0.885 in

   b

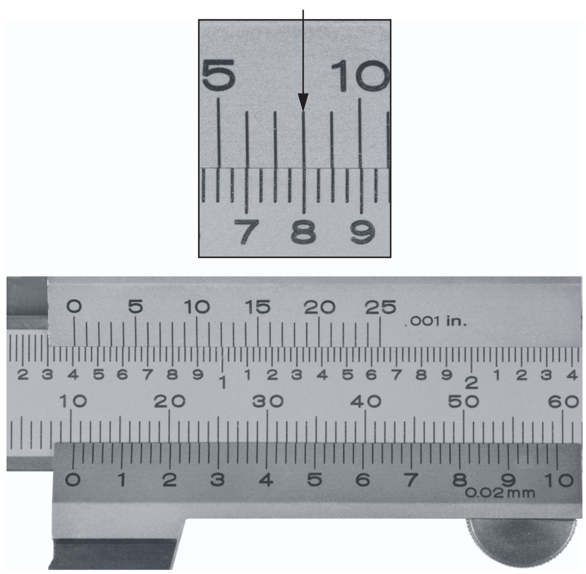


Figure 29: Reading a vernier caliper.

2. Which of the following measurements corresponds to the reading in inches shown in Figure 30? The small arrow shows a detail of the vernier scale.

   a. 0.890 in

   b. 0.856 in

   c. 0.835 in

   d. 0.881 in

d

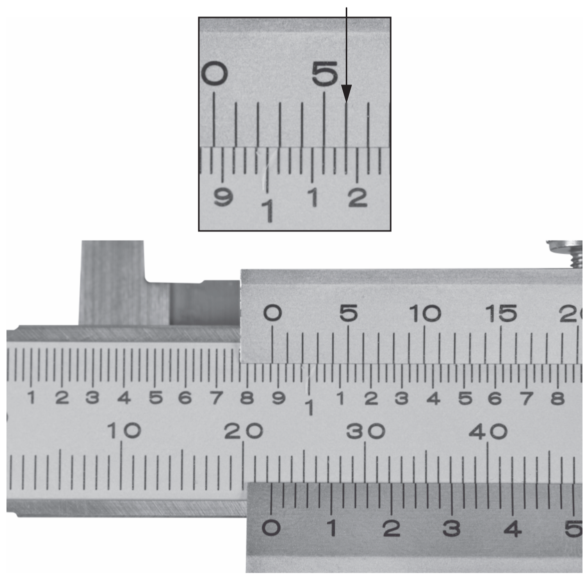


Figure 30: Reading a vernier caliper.

3. Which of the following measurements corresponds to the reading in inches shown in Figure 31? The small arrow shows a detail of the vernier scale.

   a. 0.534 in

   b. 0.535 in

   c. 0.590 in

   d. 0.515 in

c

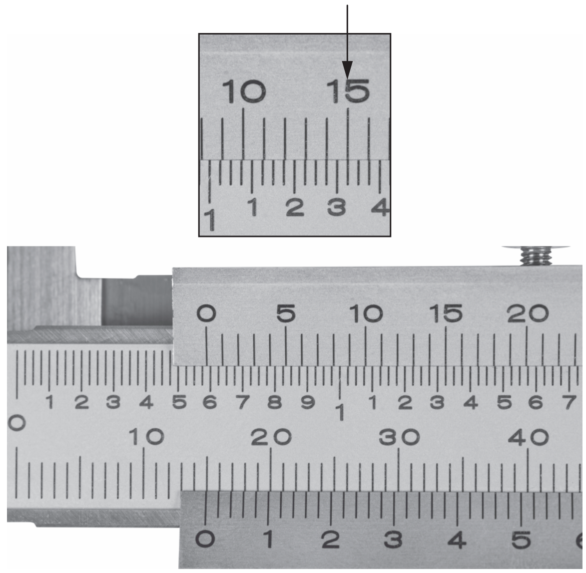


Figure 31: Reading a vernier caliper.

4. Which of the following measurements corresponds to the reading in inches shown in Figure 32? The small arrow shows a detail of the vernier scale.

   a. 0.248 in

   b. 0.222 in

   c. 0.210 in

   d. 0.212 in

a

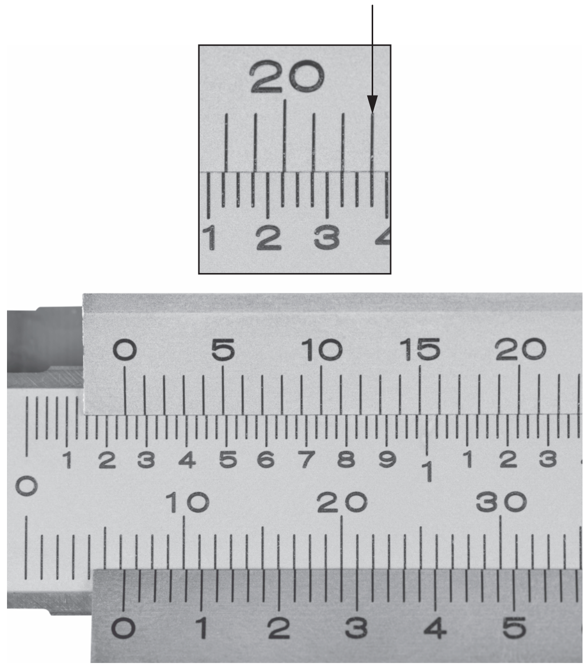


Figure 32: Reading a vernier caliper.

5. Which of the following measurements corresponds to the reading in millimeters shown in Figure 33? The small arrow shows a detail of the metric vernier scale.

   a. 0.30 mm

   b. 0.36 mm

   c. 0.60 mm

   d. 0.24 mm

c

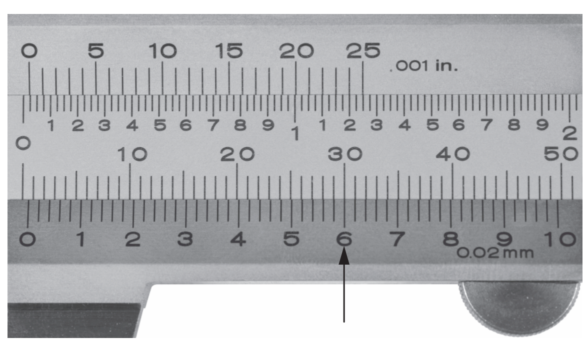


Figure 33: Reading a vernier caliper.

6. Which of the following measurements corresponds to the reading in millimeters shown in Figure 34? The small arrow shows a detail of the metric vernier scale.

   a. 10.23 mm
   b. 10.21 mm
   c. 10.25 mm
   d. 10.26 mm

d

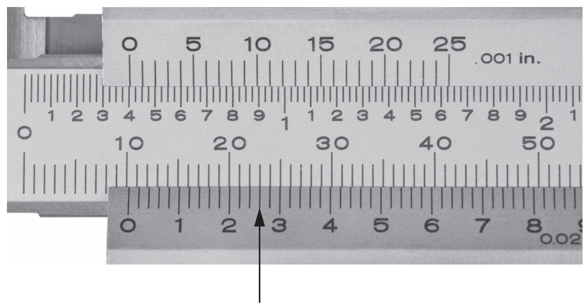


Figure 34: Reading a vernier caliper.

7. Which of the following measurements corresponds to the reading in millimeters shown in Figure 35? The small arrow shows a detail of the metric vernier scale.

   a. 27.37 mm
   b. 27.50 mm
   c. 25.70 mm
   d. 27.20 mm

d

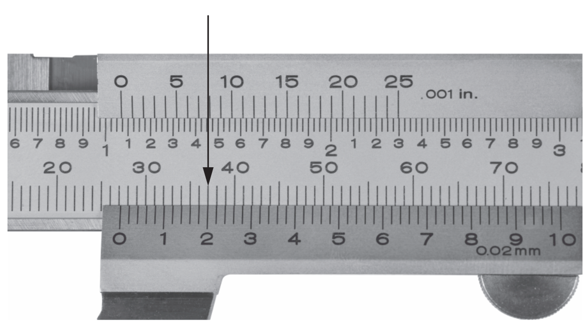


Figure 35: Reading a vernier caliper.

8. Which of the following measurements corresponds to the reading in millimeters shown in Figure 36? The small arrow shows a detail of the metric vernier scale.

   a. 51.00 mm

   b. 51.02 mm

   c. 51.98 mm

   d. 50.20 mm

a

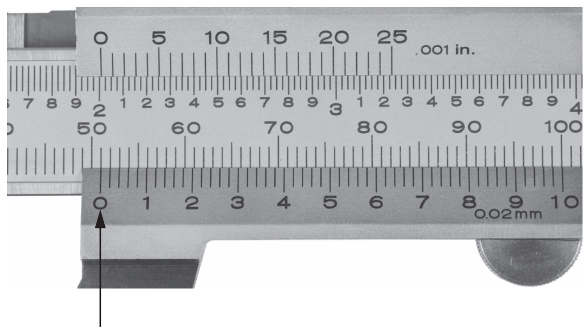


Figure 36: Reading a vernier caliper.

