Cooperation Centre for Scientific Research Relative to Tobacco

CORESTA Guide N° 10

A User Guideline for the Measurement of Diameter of Tobacco Products and Filter Rods

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Physical Test Methods Sub-Group

CORESTA TECHNICAL GUIDE N° 10

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A User Guideline for the Measurement of Diameter of Tobacco Products and Filter Rods

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1. Introduction

1.1 Purpose

The diameter of tobacco products and filter rods has a direct effect on the pressure drop and the ventilation and therefore on the smoking performance or user experience of the assembled product. Furthermore differences in the diameter of tobacco rod and of filter rod, and all internal segments more generally, might cause assembly problems. The diameter of the final product will also influence the packing. The diameter is a principal measure for the quality control of tobacco product manufacture. This guideline is intended as a reference for manufacturers of tobacco products and filter rods as to the best practice for the measurement of diameter, so as to consistently obtain the most accurate and most reliable measurements despite the many external influences that can affect the measured value.

1.2 Outline

Work done within the ISO/TC126/WG2, from 2005 to 2008, quantified the environmental influences on the measured diameter and additional work carried out since has highlighted a number of other potential causes for variation in the measured diameter of a filter rod or tobacco product sample. This work resulted in the publication of ISO 2971:2013 and this standard was reconfirmed as current in 2019.

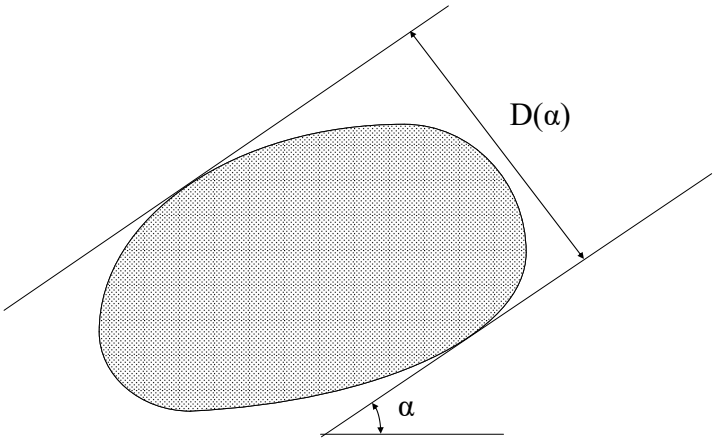
In order to maintain the validity of diameter measurements, attention needs to be given to all of the factors that impact their accuracy. This can only be done by understanding the nature and magnitude of the influences and how they might be minimised and controlled.

2. The Diameter measurement process

2.1 Introduction

Diameter measurement brings together several factors, including samples, instruments, calibration standards, instrument adjustment and various procedures and techniques. Each of these factors must be optimised if they are not to disturb or corrupt the measurement process. Hence, it is important to understand the effect that external influences might have on each of these factors and the influence of each factor on the overall process. Where optimisation is not practicable or possible, allowance needs to be made for potential errors incurred.

2.2 Definitions



- The cross-section of a tobacco product or filter rod is assumed to be a convex curve.

The diameter D is defined as the mean of the apparent diameters measured on a full rotation of the rod.

$$D = \frac{1}{2\pi} \int_0^{2\pi} D(\alpha)\, d\alpha$$

- The perimeter P is the diameter multiplied by π.

$$P = \pi D$$

Note 1: Both perimeter and circumference are acceptable terms to describe the boundary of a convex cross-section; indeed the latter is the common term in the industry.

Note 2: The perimeter of a non-convex curve, e.g. a gear wheel, would not be measured correctly using this approach. This can be relevant to tobacco products, e.g. if the lap is not glued down tightly.

2.3 Properties

- It can be demonstrated that the perimeter of a convex curve is equal to the mean of the apparent diameters multiplied by π. In other words the mean of the apparent diameters of a tobacco product or filter rod is equal to its perimeter divided by π and is independent of its shape so long it remains convex.
- This method requires that the sample is rotated through an integer multiple of 180 º to avoid the shape of the sample biasing the result.
- The above diameter definition is based on an infinite number of diameter scans. Any practical instrument makes a finite number of diameter scans, which affects the accuracy of the measurement. A theoretical study undertaken by the Working Group (WG2) showed that 36 individual scans performed on a full rotation at constant angular interval of an elliptical shape whose relative ovality is less than 40 %, provided 1 µm accuracy on the diameter and 1 point accuracy on the relative ovality determination. An experimental study using a laser device showed that 64 individual scans performed on a full rotation at a constant angular speed of a test piece whose ovality is less than 30 %, yielded differences of less than 1 µm on the mean diameter and 0,2 point on the relative ovality determination when compared with a determination based on 1024 individual scans.

  On the basis of these studies it is recommended to carry out a minimum of 64 scans on a full rotation, or 32 scans on a half rotation, at constant angular interval of the test piece.
- The above diameter definition is based on a constant angular rotation speed and not a constant peripheral rotation speed. It has been demonstrated that in the case of a constant peripheral rotation speed an error on the diameter of oval test pieces is made. For example on an oval rod having 30 % of ovality and 8 mm of diameter this error on the measured diameter will be 0,1 mm.

2.4 Most widely used systems

2.4.1 Laser

The laser beam emitted by a semiconductor laser is cast on and reflected from an octagonal mirror and a reflection mirror. The diffused laser beam is then parallelized by a collimator lens and thrown upon the object to be measured. The beam moves in the scan path at a constant speed and parallel to itself. After scanning the object the laser beam is focussed by a receiver lens to a receiver element. An edge detection device generates a pulse when the beam reaches the object and another one when it leaves the object. The elapsed time between the two pulses is proportional to the size of the object.

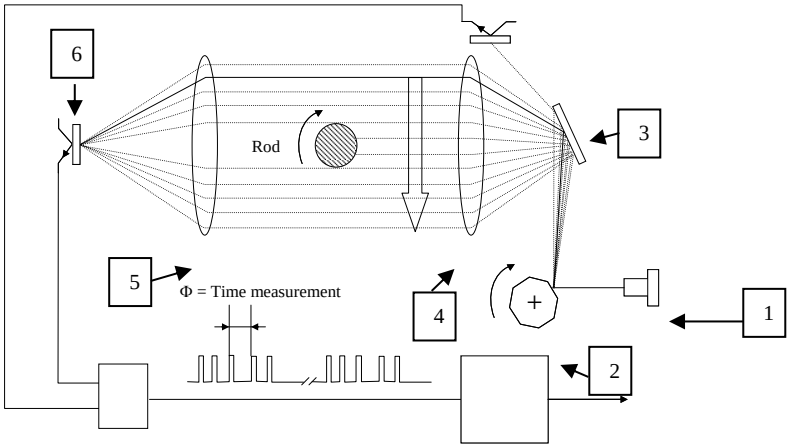


Figure 1 – Diagram of a laser gauging system

Key:

1 Laser emitter	3 Reflection mirror	5 Receiver lens
2 Octagonal mirror	4 Collimator lens	6 Receiver element

2.4.2 CCD (Charge-Coupled Device)

The light beam emitted by a LED is parallelized by a collimator lens and thrown upon the object to be measured. After scanning the object the beam is converged by a converging lens and parallelized onto a CCD array. The size of the shadow projected on the CCD array is proportional to the size of the object.

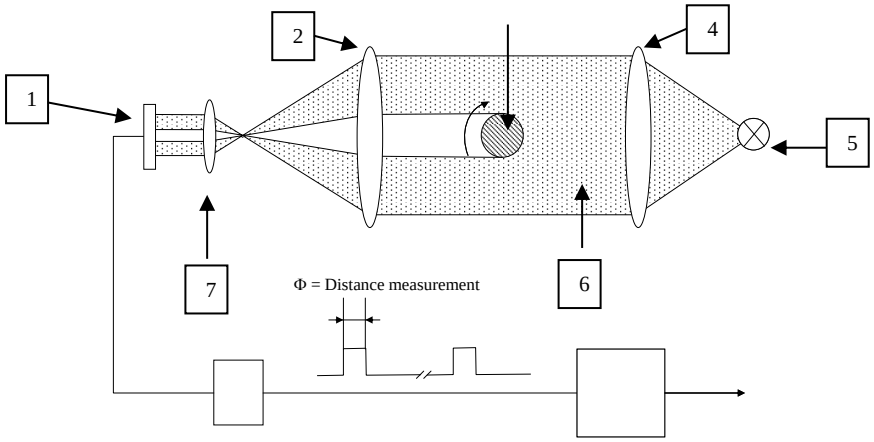


Figure 2 – Diagram of a CCD gauging system

Key:

1 CCD array	4 Collimator lens	6 Parallelized light beam
2 Converging lens	5 LED	7 Receiving lens
3 Test piece		

2.4.3 Video camera

The object is rotated in the field of view of a digital video camera. An appropriate device is used to maintain the rod perpendicular to the scan path and to rotate the rod along its longitudinal axis.

The object is imaged onto the digital imaging sensor within the camera. The digital images are scanned and captured by a digital image processing system with image processing software.

The size of the object in the image is determined by reference to similar images captured from a series of calibration standards.

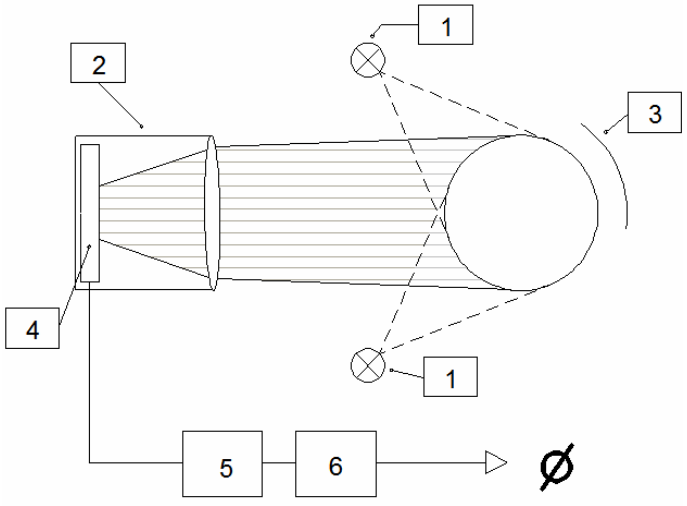


Figure 3 – Diagram of a video camera and digital image processing system

Key:

1 Sample illumination
2 Video camera
3 Sample and rotation device
4 Digital imaging device
5 Digital image processing hardware
6 Digital image processing software

2.5 Factors affecting the measured diameter

The measured diameter can be affected by the following factors:

- ambient conditions at the time of measurement
- sample temperature and moisture content at the time of measurement
- position of measurement along the sample
    - position is obviously significant for measurements made on the filter or tobacco sections of cigarettes and it can also be a factor for multi-segment filters and other tobacco products, e.g. heated tobacco products, so that comparisons must be made on the same region of the product
    - for homogeneous products, e.g. monoacetate filters, it has been shown that measurement position does not significantly affect diameter over a range of 10 mm along the sample
- nature of the sample surface
    - non-wrapped (NWA) filter sections have traditionally been measured using a contact device (tape gauge) due to their open surface structure but more recent samples that exhibit a dense (and often textured) outer surface may be suitable for non-contact measurement provided the instruments in use are appropriately correlated

- temperature of standards and ambient conditions at the time of calibration or adjustment of the measuring instrument
- temperature of standards and ambient conditions at the time of calibration checks

In addition, any errors within the instrument that affect the measurement and any errors in the marked value of the calibration standard (e.g. damage or contamination) will also have an effect on the measured value.

Finally, when expressing and interpreting measurement results, it is necessary to have a knowledge of the capability and uncertainty of the measurement process. This will ensure that valid inferences are drawn from the results.

2.5.1 Sources of error that are common to laser, CCD and camera systems

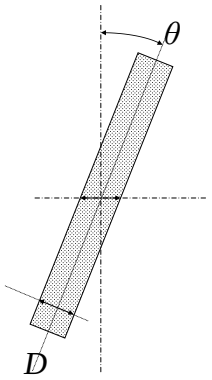
- Sample rod not perpendicular to beam

  The error magnitude is: $D \times \left(\frac{1}{\cos\theta} - 1 \right)$

  Where

  D is the actual diameter;

  θ is the angle of tilt by comparison with the perpendicular to the scan path.



- Incorrect measurement position along sample rod length
- Sample surface roughness
- Aberrations due to poor optics
- Sample rod rotation is not a multiple of 180°
- Angular rotation speed not constant
- Angular interval between two successive scans not constant
- Acquisition rate not constant
- Number of scans per rotation not high enough
- Dirt in system can cause incorrect edge interpretation
- Selection of test pieces that have raised seams (bad laps)
- Incorrect placing of the test piece in the measurement area of the system
- Use of test piece with ill-defined edge characteristics such as some non-wrapped acetate filter plugs
- Trembling or oscillation of the sample rod

2.5.2 Sources of error that are specific to laser systems

- Collimated beam may not be exactly parallel
- Instability of the lateral beam speed
- Very narrow beam width can result in high sensitivity to measurement position along rod
- Very narrow beam width can result in errors due to detection of small artefacts (fibres) on surface of test piece

2.5.3 Sources of error that are specific to CCD systems

- Collimated beam may not be exactly parallel
- Very narrow measurement width can result in high sensitivity to measurement position along rod
- Very wide measurement width can result in low sensitivity to measurement position along rod
- Absolute resolution not appropriate for measurement resolution

2.5.4 Sources of error that are specific to camera systems

- Variations in sample range
- Shadows due to poor lighting
- Calibration based on a product's diameter, colour, brightness or contrast that is different from the measured product
- Colour variations of the product due to poor lighting
- Colour changes of the product from one measurement area to another
- Distance variation between the optics and the product
- Very narrow measurement width can result in high sensitivity to measurement position along rod
- Very wide measurement width can result in low sensitivity to measurement position along rod
- Sensor resolution not appropriate for measurement resolution

3. Confirming correct instrument function

3.1 Introduction

Checks for diameter instrument function are aimed to ensure that all instrument components and systems are set up and operating correctly. They are separate from any measures of instrument performance and are a necessary pre-condition for all of the following checks and validations.

3.2 Methods of checking and assuring instrument function

The first step in assuring correct function should be a programme of regular preventative maintenance. Instrument manufacturers provide information and guidance on instrument maintenance and offer programmes of planned maintenance. These should include attention on a regular basis (e.g. say daily, weekly and annually). Differences between instruments of different manufacture mean that there will necessarily be some differences in their planned maintenance programmes. However, routine daily and weekly tasks should include:

- Checks on instrument supplies
    - Check that all air and vacuum levels are set correctly (if any)
    - Blow down air set filter bottles to remove collected moisture (if any)
- Checks of wear parts and consumables
    - Protective filters should be changed in good time (if any)
- Checks of the fixture for rotating the test piece
- Checks for build-up of contamination within the instrument
    - Remove all tobacco fall out and clean out tobacco traps
    - Clean lenses if necessary
- A test measurement run to confirm correct operation following any maintenance or adjustment

Planned maintenance should be supplemented by regular functional checks to provide early warning of faults. Many instruments have a self-diagnostic mode or a system of built-in diagnostics that may be used for this purpose. Alternatively, critical observation of key instrument functions under normal operating conditions of use can show up developing faults. Such observation can usefully be carried out as part of a test measurement run following routine preventative maintenance.

4. Care and maintenance of diameter calibration standards

4.1 Introduction

This is a key area since the ultimate accuracy of any measurements will be directly affected by the accuracy of the diameter standards used to make the instrument calibration.

4.2 Essential properties of calibration standards

Calibration standards are used to calibrate measuring instruments for the determination of the diameter (or circumference) of cigarettes and filter rods.

The reference calibration standard shall be a cylindrical rod made of a rigid, stable material (according to the instrument manufacturer's recommendations) with a ground surface finish of about 0,5 µm average roughness and with a known and repeatable value of the diameter.

The working calibration standard shall be calibrated against a traceable reference standard under standard laboratory conditions of (22 ± 2) °C. The thermal expansion coefficient of the material shall be known.

The working calibration standard shall be checked for shape properties (ovality, constancy…) by measuring the diameters of a minimum of three cross-sections, situated near the middle and two ends respectively.

The calibration standards shall be certificated with their measured value quoted to a minimum accuracy of the diameter of 0,003 mm absolute and have a unique identification.

Standards must have the following properties:

- They are stable and chemically inert
- They have repeatable values with a low uncertainty of the calibrated value

All calibration standards should be provided with a certificate that:

- Provides traceability to the International System of Units (SI)
- Records the value(s) and unique identification of the standard
- Gives information about the conditions of calibration and the uncertainty of the assigned value
- Defines the method and validity of the calibration, quoting any limits or restrictions to the use of the standard

4.3 Recommendations for the management of standards

Diameter calibration standards, being made of metal for example, are susceptible to damage by careless handling. Dust or oil particles may contaminate the surface. Calibration standards should therefore be stored and handled with care to avoid damage and contamination.

The validity of diameter measurements can be improved if a suitable regime is used for the management of diameter calibration standards. In particular:

- Store and handle standards carefully and appropriately
- Carry out a visual check on a regular basis. In particular check for:
    - Damage (blemishes, chips, cracks)
    - Contamination (rust, dust).
- Maintain a master set of diameter standards to allow for simple cross checking of standards. The set should cover the range of diameter values of interest – a range of 5 mm to 9 mm is suggested, with the lower size reduced to 4 mm if ‘micro slim’ products are tested
- Introduce a documented programme of checking for calibration standards against the reference set, including:
    - Any standard suspected of damage or contamination
    - Any new standard before it is released for use
    - All standards at regular, fixed intervals
- Any standard found to be damaged, contaminated or out of value should be withdrawn from service until it can be replaced or cleaned and recalibrated
- Recalibrate standards regularly. The interval chosen should reflect the type of duty to which the standards are put - heavily used standards will require recalibration more frequently than lightly used ones. Set a maximum interval for recalibration.

- Maintain the reference standard set within its validity period – recalibrate it at least every 2 years

4.4 Procedure for calibration of instruments

The calibration and performance testing of instruments for the determination of the diameter of tobacco products and filter rods should be conducted in accordance with instrument manufacturer's instructions.

The standards shall be maintained under the requirements of Section 6.3.

During calibration, the standards shall be positioned perpendicular to the scan path to prevent calibration errors (see section 4.5.1).

5. Checking the validity of measurements

This process comprises the following stages:

- The calibration/adjustment process
    - Calibration checking (establishing the accuracy of measurements of calibrated standards)
    - Adjustment (adjusting the output of the instrument to bring the accuracy within the required specification)
    - Calibration check following calibration (in particular to check that any adjustment has been applied correctly)

Note: The output of a calibration process can be either a set of correction(s) to be applied to the instrument's output or that the instrument's output is adjusted to meet defined requirements. For diameter measurement instrumentation it is normally that the instrument is adjusted.

- Checking instrument performance

5.1 The calibration process

5.1.1 The purpose of calibration checking

Calibration checking is an essential part of the overall calibration process and is made to confirm whether the instrument is measuring within the required limits of accuracy. A calibration check should be carried out at regular intervals and frequently enough to detect changes in instrument calibration due to the known influences. These influences include:

- The effects of measurement system drift
- The effects of changes in ambient conditions

As a minimum, it is recommended that a calibration check is carried out every manufacturing period or shift and at least once per day.

If a calibration check shows that an instrument is measuring outside the required limits then it shall be recalibrated or adjusted.

5.1.2 Precautions when checking calibration

A calibration check of an instrument can be made by measuring a calibration standard in the instrument. The measured value of the standard will indicate how closely the instrument is measuring to the true value. A decision can then be made as to whether to recalibrate or adjust the instrument.

When carrying out calibration checking it is necessary to ensure that the measured value is not corrupted and so avoid unnecessary or corrupt recalibration. In particular:

- The standard should be in thermal equilibrium with the measurement environment.
- Always include a check for non-linearity within the measurement device.

  Note: This can be most easily achieved by checking with two different values of calibration standard, one at or near the calibration point and one at about half this value. Any non-linearity indicates possible problem with the unit or with one or both of the standards. Confirm the error using additional calibration standard(s) and rectify it before proceeding.
- Ensure that the instrument is stable before checking

  Note: Allow sufficient warm-up and settling time after switching on – see the recommendations of the instrument manufacturer

5.1.3 A recommended process for checking calibration

To carry out a calibration check, proceed as follows:

- Referring to the manufacturer's instructions, place the instrument into the correct mode to check the calibration
- Insert the calibration piece into the instrument measurement head
- Observe the measured value and note the value
- Compare the measured value with the assigned value of the standard – if the measured value differs from the assigned value by more than the allowable limit, then the instrument should be recalibrated or adjusted.

  Note: The allowable limits should be set by reference to the uncertainty of the measurement and the capability of the process. This is most easily determined by regular use of a Shewhart Chart (control chart) to plot the measured values for the calibration standards. [3,4]. For additional information on setting limits of uncertainty, please see section 7.2

  If the measured value is within the allowable limit then the instrument does not require recalibration or adjustment.

5.1.4 Adjustment

The process for adjustment is given in ISO 2971. Reference should also be made to the instrument manufacturer's instructions. The essential points for adjustment are given here for convenience:

- Only adjust the instrument if there is a good cause:
  - The calibration check is out of limits
  - After major work or disturbance to the instrument

Note: Refer to Shewhart chart. Unnecessary adjustment can lead to a worsening of the measurement variability and hence of the manufacturing process that is being controlled

- Always ensure that the value of the calibration standard is larger than the largest value of sample diameter that is to be measured.

  Where the range of values of the sample diameter is not known in advance, use calibration standards that are as close as possible to the full scale range of the instrument. This will ensure the best possible accuracy across the complete range of the instrument.

- Observe the same precautions against bias and environmental effects as for calibration checking

  Note: The easiest way to achieve this is to make adjustment immediately following a calibration check – this will use the standard in its previously equilibrated state and will require the minimum amount of handling of the standard.

- Carry out a calibration check ***after*** adjusting to confirm that no error has been made and that the instrument is now measuring within the allowable limits.

  Note: Always check with at least two standards of different values to ensure correct calibration.

5.2 Checking instrument performance

This is a means of assessing the dynamic measurement performance of a measuring instrument. It should be carried out periodically and particularly after any significant service work or repairs to the instrument.

The purpose of this check is to confirm:

- That the instrument is functioning and operating correctly
- The instrument is adjusted correctly for the product being measured and is capable of measuring the product correctly
- The measurement capability of the instrument, in particular it may be used to assess the measurement:
  - Repeatability
  - Instrument-to-instrument variability

  Note: These figures allow an assessment of the allowable limits for calibration checking.

  An instrument cannot be more accurate or precise than its uncertainty of measurement

5.2.1 Measuring repeatability

Repeatability is defined as: “The maximum difference to be expected between repeat measurements of a sample, made on one instrument, by one operator and within a short period of time”.

Repeatability is normally tested by measuring a series of samples twice in quick succession in one instrument without any adjustment of the instrument.

The samples used should be stable and should closely represent the actual samples normally measured on the instrument (i.e. of similar diameter). Depending upon the type of instrument being tested, suitable samples are:

- Cured filter rods
- Artificial cigarettes
- Actual cigarettes
- Other tobacco products
- Calibration standards

Precautions should be taken to avoid sample degradation and hence to avoid the diameter changing from measurement to measurement; depending upon the type of sample, these include:

- Minimising the amount of handling of the samples
- Providing a cushion in the sample collection bin to minimise damage as the samples are dropped through the instrument
- Avoiding significant moisture loss from cigarettes

To obtain a truly representative figure, the repeatability test should be carried out in the same location in which the instrument is normally used. This figure will then include any environmental effects that are present.

Note: Before carrying out any testing of repeatability or instrument-to-instrument variability, users should ensure that the instruments concerned have been properly adjusted and the calibration checked, as described in section 7.1.

5.2.2 Measuring instrument-to-instrument variability

Tests of instrument-to-instrument variability are a means of assessing the maximum difference to be expected between the measured values of a sample when measured on two different instruments. It can be influenced by many different factors, including the instrument repeatability, differences between the calibration standards used to calibrate each instrument and local differences in operator procedure and technique.

Instrument-to-instrument variability testing is carried out in a similar way to repeatability testing, except that the two measurements are made on different instruments and may be carried out over an extended period of time.

In addition, there may be several measurement runs, each on a different instrument. This allows testing across a population of instruments within an organisation and allows comparison between any one instrument and the mean of all the instruments. This can be used to determine any biases between the instruments.

Samples for instrument-to-instrument variability testing can be the same as those for repeatability testing. However, cigarettes are not normally robust enough to be used and samples are generally confined to filter rods or artificial cigarettes

Note: The actual instrument-to-instrument variability cannot be better than the repeatability of the individual instruments and will also include any differences between the calibration standards used to calibrate each instrument. These values will depend upon local conditions and hence the limits tabulated above are for guidance only and do not imply definitive limits.

6. Making Diameter measurements

The exact procedure for measuring the diameter of samples will depend not only on the type of sample to be measured but also on the type of instrument used. There are a number of points, however, that need to be checked for all diameter measurements:

- The instrument used should be suitable for the type of product to be measured. Generally, the measuring position should be adjusted.
- For multi-segment filter-rods it is recommended to set the measuring position on a segment that is to be assembled to the tobacco rod of the manufactured cigarette.
- Samples should be handled carefully and as little as possible to avoid damage and changes of sample moisture and temperature.
- Calibration checks should be made frequently enough to avoid errors in measurement due to diameter calibration changes with ambient conditions.

7. Glossary and abbreviations

°C	Degrees Celsius
RH	Relative humidity
ISO	International Organization for Standardization
ISO TC 126	ISO technical committee for standardisation of terminology and test methods for unmanufactured tobacco, all types of tobacco products, materials used for manufacturing tobacco products and tobacco smoke including environmental tobacco smoke aspects.
CCD	Charge-Coupled Device
CORESTA	Cooperation Centre for Scientific Research Relative to Tobacco
CRM	CORESTA Recommended Methods
Artificial Cigarette	A test piece with similar physical properties to a cigarette but constructed so that its primary physical parameters (i.e. weight, length, circumference, pressure drop and ventilation) are both stable and repeatable. There are generally two types of such a device: 1. Articles made from plastics or light metals with the appropriate dimensions and primary physical parameters to approximately match those found in "real" cigarettes – these can offer almost indefinite stability of measurements. 2. Cigarettes in which the tobacco column has been replaced with a piece of filter rod material of suitable diameter and pressure drop - these can closely mimic the properties of actual cigarettes.
Shewhart Chart	A statistical tool in the form of a control chart intended to assess the nature of variation in a process.

8. References

[1] International standard ISO 2971:2013 – Cigarettes and filter rods – Determination of nominal diameter – Method using a non-contact optical measuring apparatus

[2] CORESTA Guide N° 4 – A User Guideline for the Measurement of Pressure Drop of Cigarettes and Cigarette Filter Rods (January 2019)

[3] Evaluating the Measurement Process – Wheeler & Lyday. SPC Press

[4] Understanding Statistical Process Control – Wheeler & Chambers. SPC Press