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Metallic materials — Calibration of extensometer systems used in uniaxial testing

Matériaux métalliques — Étalonnage des chaînes extensométriques utilisées lors d'essais uniaxiaux

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 9513 was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 1, *Uniaxial testing*.

This third edition cancels and replaces the second edition (ISO 9513:1999), which has been technically revised. It also incorporates the Technical Corrigendum ISO 9513:1999/Cor.1:2000.

Introduction

This International Standard sets out criteria for the calibration of extensometer systems, covering general principles, the calibration equipment to be used, pre-calibration inspection and the measurement of gaugelength for various types of extensometer systems. Aspects of the calibration process are addressed, as are the assessment of the results, uncertainties, calibration intervals and reporting. Criteria for calibration apparatus, their calibration and grading are addressed, complemented by a Bibliography covering a number of important papers related to extensometer systems and their application [1] to [10]. Work is in progress to develop processes for dynamic extensometer calibration, however these have not reached, at the time of writing of this International Standard, the level of development appropriate for inclusion within this International Standard. For further information, refer to Reference [6].

Informative annexes address calculation of uncertainties of measurement for an extensometer system calibration (Annex A), calibration of calibration apparatus (Annex B) and an example of a calibration report (Annex C). Subsequent annexes address examples of extensometer system configurations (Annex D), laser extensometry (Annex E), video extensometry (Annex F), full field extensometry (Annex G) and calibration of a crosshead measurement system (Annex H).

Metallic materials — Calibration of extensometer systems used in uniaxial testing

1 Scope

This International Standard specifies a method for the static calibration of extensometer systems used in uniaxial testing, including axial and diametral extensometer systems, both contacting and non-contacting.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
extensometer system
equipment used to measure displacement or strain on the surface of a test piece

NOTE For the purpose of this International Standard, the term “extensometer system” includes the indicator. Some extensometers indicate strain directly (e.g. laser extensometers or digital image correlation techniques). Other extensometers indicate the change in gauge length of a test piece; this is converted into strain by dividing by the relevant gauge length.

2.2
gauge length
portion of a test piece where extension is measured

3 Symbols and designations

Symbols used throughout this International Standard are given in Table 1 together with their designation.

Table 1 — Symbols and designations

Symbol	Designation	Unit
L_e	Nominal gauge length of extensometer	mm
L'_e	Measured gauge length of extensometer	mm
l_{max}	Maximum limit of calibration range	mm
l_{min}	Minimum limit of calibration range	mm
l_i	Displacement indicated by extensometer	µm
l_t	Displacement given by calibration apparatus	µm
q_{L_e}	Relative gauge length error of the extensometer system	%
q_{rb}	Relative bias error of the extensometer system	%
q_b	Absolute bias error of the extensometer system	µm
r	Resolution of the extensometer system	µm

4 Principle

The calibration of extensometer systems involves a comparison of the readings given by the extensometer with known variations in length provided by a calibration apparatus.

NOTE 1 The user can define the displacement range(s) over which the calibration is to be performed. In this way, the performance of the extensometer system can be optimized. For example, for strain-controlled low cycle fatigue, only a small portion of the operating range of the extensometer is typically used. Hence, it would be appropriate, in this case, to concentrate the calibration on the centre portion of the operating range.

The calibration process compares the known displacement from the calibration device with the output of the extensometer system. This output can range from manual readings of high precision dial gauges to the displacement indication of a transducer/electronics/data-logging system. In the latter case, the extensometer system output would include any data curve fitting applied by the electronics/data-logging system.

NOTE 2 For certain types of extensometer systems, the calibration and classification will also be dependent upon the ability of the extensometer system to define the gauge length.

5 Calibration equipment

5.1 Calibration apparatus

The calibration apparatus, which allows a known displacement l_t to be applied to the extensometer, may consist of a rigid frame with suitable coaxial spindles or other fixtures to which the extensometer can be attached. The calibration apparatus shall comprise a mechanism for moving at least one of the axial spindles together with a device for accurately measuring the change in length produced. These variations in length can be measured by, for example, an interferometer, a linear incremental encoder or gauge blocks and a comparator, or a micrometer.

NOTE Special attachments to the calibration apparatus spindles are utilized for the calibration of diametral extensometers.

The calibration apparatus should be calibrated in accordance with Annex B and should meet the performance requirements given in Table B.1.

Annex B gives a recommended calibration procedure for the calibration apparatus and details performance criteria that indicate that the apparatus is suitable for calibrating extensometer systems in accordance with this International Standard.

5.2 Calibration traceability

The calibration apparatus and the supporting equipment (such as micrometers, callipers, optical projection microscopes) shall be calibrated using standards that are traceable to the International System of Units (SI). The uncertainty associated with any measurements made by the supporting equipment shall not exceed one third of the permissible error of the extensometer system being calibrated (see Table 2). The temperature measurement instrument shall have a resolution of 0,1 °C.

6 Pre-calibration inspection

6.1 Objective

Prior to the calibration of the extensometer system it shall be inspected. This shall comprise, but not be limited to, inspection of the mechanical components for, for example, free movement, damaged parts, worn knife edges, and worn gauge length setting pins/fixtures. For extensometer systems incorporating electronic transducers, the cabling and connectors shall be examined for damage, wear, etc.

The extensometer system shall be calibrated in the as-found condition if at all possible. The results shall be assessed and, if necessary, the system shall be adjusted and re-calibrated. In this case, both data sets shall be reported.

6.2 Records of the inspection

Records of the pre-calibration inspection shall be kept, identifying the “as-found” condition of the extensometer system, when the inspection was performed and who performed it. These pre-calibration inspection records can take the form of either a written report or a completed “pro-forma” checklist.

6.3 Identification of extensometer system elements

The extensometer shall be uniquely identified. Parts that may be changed by the user during normal use of the extensometer that affect the calibration of the extensometer shall also be uniquely identified where possible. However, this requirement does not extend to clamping devices used to attach the extensometer to the test piece. These unique identifications form part of the records for the extensometer system.

7 Measurement of extensometer gauge length

7.1 Fixed gauge length extensometry

7.1.1 The measured gauge length, L'_e, of a fixed gauge length extensometer shall be determined by either direct or indirect means. In both cases, the extensometer setting pin or gauge fixture is used to set the extensometer contact points to their pre-set displacement.

NOTE Variability of the measured gauge length might be experienced due to excessive play/wear in the gauge length setting mechanism.

7.1.1.1 Direct measurement of the gauge length, L'_e, is performed between the extensometer contact points, using a calibrated measuring instrument such as a caliper or a shadowgraph/projection microscope.

7.1.1.2 Indirect measurement of the gauge length, L'_e, is performed by placing the extensometer on a soft metal test piece in such a way that the blades or points of the extensometer leave their marks. Once the extensometer is removed, the distance between the marks on the test piece shall be measured, using equipment with an accuracy consistent with the required class of extensometer.

7.1.2 The relative error on the gauge length, q_{L_e}, calculated from Formula (1) shall meet the requirements given in Table 2.

$$q_{L_\mathrm{e}} = \frac{L'_\mathrm{e} - L_\mathrm{e}}{L_\mathrm{e}} \times 100 \qquad (1)$$

7.2 Variable gauge length extensometry

7.2.1 The gauge length of a variable gauge length extensometer shall be measured either directly, or indirectly.

7.2.1.1 Direct measurement of the gauge length is performed by setting the extensometer to the required gauge length using jigs, fixtures or other tools, followed by measurement between the extensometer contact points, using a calibrated measuring instrument such as a calliper or a shadowgraph/projection microscope.

7.2.1.2 Indirect measurement of the gauge length, L'_e is performed by attaching the extensometer to a soft metal test piece in such a way that the blades or points of the extensometer leave their marks. Once the extensometer is removed, the distance between the marks on the test piece is measured, using equipment with an accuracy consistent with the required class of extensometer.

7.2.2 Extensometers commonly used in creep, elevated temperature tensile or stress relaxation testing have their gauge length defined by small ridges machined on the parallel length of the test piece, to which the extensometer is clamped. The gauge length for such extensometers shall be determined directly from the test piece and shall be to an accuracy consistent with the required class of extensometer.

7.2.3 The relative error on the gauge length, q_{L_e}, calculated from Formula (1), shall meet the requirements given in Table 2.

7.2.4 Where an extensometer sets or measures the gauge length, the relative error on the gauge length shall be determined. If features on the test piece define the gauge length, the relative error on the gauge length does not need to be determined.

7.2.5 Where an extensometer automatically sets the gauge length, the maximum and minimum gauge lengths used, plus three more gauge lengths between the minimum and maximum, shall be measured. Where fewer than five gauge lengths are used, all gauge lengths shall be measured.

7.3 Non-contacting extensometry

The gauge length for non-contacting extensometry is established in accordance with the manufacturer's instructions.

7.4 Extensometer gauge lengths established using setting gauges

Where an extensometer gauge length is set using a removable gauge, the relative error on the gauge length, q_{L_e}, calculated from Formula (1) shall not exceed the values given in Table 2.

The uncertainty of measuring the gauge length shall be three times better than the allowable error in gauge length.

8 Calibration process

8.1 Environmental considerations

8.1.1 The ambient temperature during the calibration of the extensometer system shall be recorded.

In general, the calibration of the extensometer system should be carried out at a temperature stable to within ± 2 °C, the target temperature being within the range 18 °C to 28 °C. Temperature changes during the calibration process may add to the uncertainty of the calibration and in some cases may affect the ability to properly calibrate the extensometer.

8.1.2 For extensometers used for uniaxial testing at temperatures outside the range 10 °C to 35 °C, the calibration should be carried out at or near the test temperature, if facilities exist.

8.1.3 The extensometer shall be placed near the calibration apparatus, or be mounted on it, for a sufficient length of time prior to its calibration so that the parts of the extensometer system and of the calibration apparatus which are in contact stabilize at the calibration temperature.

8.2 Position of the extensometer

The extensometer shall be placed, wherever feasible, in the calibration apparatus in a similar orientation to that in which it will be used during uniaxial testing to avoid errors due to loss of equilibrium or to deformation of any part of the extensometer.

The extensometer shall be attached in a similar way as during uniaxial testing.

8.3 Calibration increments

8.3.1 The user shall establish the range of displacements over which the extensometer system shall be calibrated.

8.3.2 The number of calibration points, and the number of ranges over which calibration is performed, shall be based upon the relationship between the minimum displacement at which a property is determined, l_{min}, and the maximum displacement at which a property is determined, l_{max}.

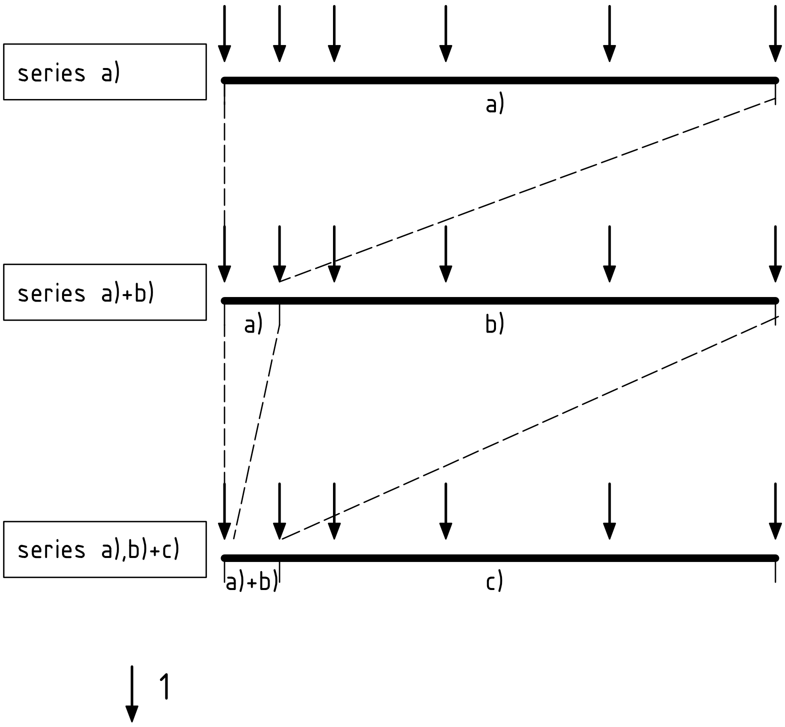
8.3.3 For monotonic tests, the following series of readings shall be made.

a) If (l_{max}/l_{min}) is less than or equal to 10, one range of at least five increments shall be recorded.

b) If (l_{max}/l_{min}) is greater than 10 but less than or equal to 100, two ranges (l_{min} to $10l_{min}$ and $10l_{min}$ to l_{max}), or (l_{min} to $0{,}1l_{max}$ and $0{,}1l_{max}$ to l_{max}), each of at least five increments, shall be recorded.

c) If (l_{max}/l_{min}) is greater than 100, three ranges (l_{min} to $10l_{min}$, $10l_{min}$ to $100l_{min}$, $100l_{min}$ to l_{max}), or (l_{min} to $0{,}01l_{max}$, $0{,}01l_{max}$ to $0{,}1l_{max}$, $0{,}1\ l_{max}$ to l_{max}), each of at least five increments, shall be recorded.

For each of the three categories [a), b), c) above], the increment between any two adjacent points shall not exceed one third of the range. Examples of these increments are shown in Figure 1.



Key

1 calibration points

Figure 1 — Schematic diagram showing calibration point distribution

NOTE 1 A tensile test measuring, from the extensometer, the modulus and proof stresses only, would fall into category a). A tensile test, establishing proof stresses and elongation at failure from the extensometer, or a creep to rupture test, would fall into category b) or category c).

NOTE 2 For fatigue tests, a range of at least five increments (with the increment between any two adjacent points not exceeding one third of the range between l_{min} and l_{max}) is used.

NOTE 3 The values derived from the above calculations can be adjusted to the nearest convenient increments to match those of the calibration apparatus.

8.3.4 When establishing l_{max} and l_{min}, operational factors such as thermal expansion of elevated temperature tests and additional displacement contingencies to cover matters such as test to test set-up variability shall be taken into account.

8.4 Calibration process

8.4.1 The calibration shall be undertaken in the as-found condition without special cleaning.

8.4.2 When the temperature has stabilized, it is recommended that, before calibration and by means of the calibration apparatus, the extensometer be exercised twice over the calibration range of the extensometer system. If possible, the displacement is taken to a slightly negative value and returned to zero. Where appropriate, reset the extensometer system to zero.

8.4.3 The calibration consists of two series of measurements with the increments as defined in 8.3.

— The first series of measurements is performed and recorded; the extensometer is removed and then placed back on the calibration apparatus.

— A second series of measurements is then made in the same manner as the first.

Depending on the expected use of the extensometer, the two series of measurements are made for increases in length or for decreases in length, or for both.

8.5 Determination of the characteristics of the extensometer system

8.5.1 Resolution

8.5.1.1 The resolution, r, is the smallest quantity which can be read on the instrument.

8.5.1.2 For extensometers with analogue scales, the resolution of the indicator shall be obtained from the ratio between the width of the pointer and the centre-to-centre distance between two adjacent scale graduation marks (scale interval), multiplied by the physical dimension which one scale increment represents. The resolution shall not be smaller than one fifth of the physical dimension represented by one scale interval unless the distance between two adjacent marks is greater than or equal to 2,5 mm, in which case the resolution may be as small as one tenth of a scale interval.

8.5.1.3 For extensometer systems with an electronic display, the output shall be observed for 10 s and the maximum and minimum values recorded. One half the difference between the maximum and minimum observed values shall be established and recorded as the resolution, r. Where the minimum and maximum values are equal, the resolution shall be one digit on the display.

8.5.2 Bias error

8.5.2.1 Relative bias error

The relative bias error, q_{rb}, for a given displacement, l_t, is calculated from Formula (2):

$$q_{rb} = \frac{l_i - l_t}{l_t} \times 100 \qquad (2)$$

8.5.2.2 Absolute bias error

The absolute bias error, q_b, for a given displacement, l_t, is calculated from Formula (3):

$$q_b = (l_i - l_t) \qquad (3)$$

9 Classification of the extensometer system

9.1 Input data

The required input data for the classification of the extensometer system are:

a) the relative error of the gauge length (see 7.2.5);

b) the resolution (absolute and/or relative) of the extensometer system (see 8.5.1);

c) for each calibration data point, the bias error (absolute and/or relative) (see 8.5.2);

d) the confirmation that the calibration apparatus fulfilled the requirements of this International Standard for each calibration data point.

9.2 Analysis of the data

The collated data are assessed as follows:

a) the relative error of the gauge length is compared to the limits in Table 2 and a grading is obtained;

b) the resolution of the extensometer system for each calibration data point is compared to the limits in Table 2 and a grading obtained;

c) for each calibration data point, the bias error is compared to the limits in Table 2 and a grading is obtained.

9.3 Classification criteria

Table 2 gives the maximum permissible values for the relative gauge length error, the resolution and the bias error.

Table 2 — Classification of the extensometer system

Class of extensometer system	Relative error of the gauge length	Resolution [a]		Bias error [a]	
		Percentage of reading	Absolute value	Relative value	Absolute value
	q_{L_e}	$(r/l_i)\cdot 100$	r	q_{rb}	$l_i - l_t$
	%	%	µm	%	µm
0,2	±0,2	0,1	0,2	±0,2	±0,6
0,5	±0,5	0,25	0,5	±0,5	±1,5
1	±1,0	0,5	1,0	±1,0	±3,0
2	±2,0	1,0	2,0	±2,0	±6,0

[a] Whichever is greater.

9.4 Assessment of the results

9.4.1 The data specified in 9.2 are collated and the maximum classification value for each of the following is determined:

a) the relative error of the gauge length;

b) for each calibration data point the resolution of the extensometer system;

c) for each calibration data point the bias error;

d) for each calibration data point the classification of the calibration apparatus.

This maximum value of these four parameters is defined as the ISO 9513 classification for the extensometer system.

9.4.2 Whenever adjustments are needed for the extensometer to comply with class requirements for its intended use, the calibration provider can, with laboratory approval, make such adjustments to enhance the extensometer system performance. The records from the initial calibration shall be retained and supplied as part of the calibration documentation. The post-adjustment results shall be reported on the calibration certificate.

10 Uncertainty determination

10.1 Uncertainty of the calibration

Many elements contribute to the uncertainty of the calibration process. The following shall be assessed and incorporated into the uncertainty budget calculation:

a) calibration uncertainty of the calibration device;

b) ambient temperature fluctuations during calibration;

c) inter-operator variability where more than one person performs calibrations within a laboratory;

d) gauge length setting;

e) gauge length measurement equipment.

For further information, refer to Annex A.

10.2 Uncertainty budget determination

The uncertainty shall be determined. An example calculation, showing how to perform an uncertainty evaluation for an extensometer system, is presented as Annex A.

NOTE The requirements of this International Standard limit the major components of uncertainty when calibrating extensometers. By complying with this metrological standard, uncertainty is explicitly taken into account as required by some accreditation standards. Reducing the allowable bias by the amount of the uncertainty would result in double counting of the uncertainty. The classification of an extensometer calibrated and certified to meet a specific class does not ensure that the accuracy including uncertainty will be less than a specific value. For example, an extensometer meeting Class 0,5 does not necessarily have a bias including uncertainty of less than 0,5 %.

11 Extensometer system calibration intervals

11.1 The time between two calibrations depends on the type of extensometer system, the maintenance standard and the number of times the extensometer system has been used. Under normal conditions, it is recommended that calibration be carried out at intervals of approximately 12 months. This interval shall not exceed 18 months unless the test is expected to last more than 18 months; in such a case the extensometer system shall be calibrated before and after the test. Where long-term creep tests are performed according to ISO 204, the calibration interval for their extensometer systems, based upon extensive practical experience, is three years; a similar situation exists for long-term stress relaxation testing. In these cases, the testing standard requirement shall take precedence over the calibration intervals defined in this clause.

11.2 The extensometer system shall be calibrated after each repair or adjustment which affects the accuracy of measurements.

12 Calibration certificate

12.1 Mandatory information

The calibration certificate shall contain at least the following information:

a) reference to this International Standard, i.e. ISO 9513;

b) name and address of the owner of the extensometer system;

c) identification of the extensometer (type, gauge length, mark, serial number and mounting position);

d) type and reference number of the calibration apparatus;

e) temperature during the calibration process;

f) nature of the variations of length for which the calibration was carried out, i.e. either for increases and/or for decreases in length;

g) date of calibration;

h) name of the person who performed the calibration, plus the name or mark of the calibrating organization;

i) all results from the calibration (as-found condition and, if adjusted, after adjustment measurements);

j) a statement of uncertainty;

k) classification for each range of the extensometer.

Items on the certificate may be presented in a referenced report.

12.2 Data presentation

The results of the calibration shall be tabulated in the certificate and shall include individual values of the bias error associated with each calibration point.

A graphical presentation of the results from the calibration may be presented as part of the certificate.

Annex A
(informative)

Uncertainty of measurement

A.1 Introduction

The approach for determining uncertainty, presented in this annex, considers only those uncertainties associated with the overall measurement performance of the length measurements. These performance uncertainties reflect the combined effect of all the separate uncertainties.

The uncertainty of measurement of the reference instruments (calibration equipment) is indicated in the corresponding calibration certificate. Factors influencing these quantities include:

a) environmental effects such as temperature deviations;

b) drift of the displacement standard;

c) interpolation deviation of the reference device.

These quantities should be considered. Depending on the design of the calibration equipment, there is also a need to include the position of the extensometer related to the gauge length axis of the testing machine.

Among the measured variables of the extensometer, which are relevant for the estimation of the uncertainty, the following components should be considered:

— axiality of the extensometer to the calibration device;

— length variation indicator;

— relative uncertainty of measurement due to the resolution of the calibration device;

— gauge length error;

— relative deviation of the calibration device;

— repeatability of the indicator of the extensometer;

— resolution of the extensometer;

— temperature influences.

It is possible to calculate the uncertainty of the extensometer systems for uniaxial testing, at the time of calibration, either from the specification limits or from the readings obtained. These calculations are detailed in the following sections.

Since the accuracy error, as a known bias, is usually not corrected during calibration, if it falls within specifications of Table 2, the range within which the estimated relative error, E, could reasonably be expected to lie, should be $E = q \pm U$, where q is the relative accuracy error defined in 8.5.2 and U is the expanded uncertainty [11][12].

The condition of a calibration is fulfilled if the relative gauge length error, q_{L_e} (see Table 2), lies within the given tolerance.

A.2 Calibration apparatus

The standard uncertainty related to the calibration apparatus, u_{std}, is given by:

$$u_{\mathrm{std}} = \sqrt{u_{\mathrm{cal}}^2 + u_{\mathrm{A}}^2 + u_{\mathrm{B}}^2 + u_{\mathrm{D}}^2} \quad \text{(A.1)}$$

where

u_{cal} is the standard uncertainty, equal to 0,5 times the expanded bias of the calibration apparatus, determined from the calibration certificate or other relevant information;

u_A is the relative standard uncertainty due to the temperature deviation between the calibration temperature of the extensometer and the calibration temperature of the calibration apparatus;

$$u_{\mathrm{A}} = \frac{\alpha \cdot a_{\mathrm{temp}}}{\sqrt{3}} \quad \text{(A.2)}$$

α is the temperature coefficient of the calibration apparatus according to the manufacturer’s specifications;

a_{temp} is the temperature deviation between the calibration temperature of the extensometer and the calibration temperature of the calibration apparatus;

u_B is the relative standard uncertainty due to long-term instability (drift) of the calibration apparatus;

$$u_{\mathrm{B}} = \frac{a_{\mathrm{sensitivity}}}{\sqrt{3}} \quad \text{(A.3)}$$

$a_{\mathrm{sensitivity}}$ is the long-term instability (drift) of the calibration apparatus;

u_D is the relative standard uncertainty due to the linear approximation to the polynomial curve (if required);

$$u_{\mathrm{D}} = \frac{a_{\mathrm{deviation}}}{\sqrt{2}} \quad \text{(A.4)}$$

$a_{\mathrm{deviation}}$ is the relative deviation due the linear approximation of the polynomial curve of the calibration apparatus.

A.3 Resolution

The standard uncertainty related to relative resolution, u_{r}, is derived from a rectangular distribution:

$$u_{\mathrm{r}} = \frac{a_{\mathrm{resolution}}}{2\sqrt{3}} \quad \text{(A.5)}$$

where $a_{\mathrm{resolution}}$ is the relative resolution of the extensometer.

A.4 Repeatability

The standard uncertainty related to repeatability, u_b, is the relative standard deviation of the estimated relative mean error value:

$$u_b = \sqrt{\frac{1}{n(n-1)}\sum_{i-1}^{n}(q_i - \bar{q})^2} \tag{A.6}$$

where

n is the number of readings;

q_i is the measured bias error (%);

$\bar{q}$ is the mean measured bias error (%).

A.5 Relative mean error of the extensometer system

The uncertainty of the relative mean error of the extensometer system, u_q, is given by:

$$\begin{aligned} u_q &= \sqrt{u_r^2 + u_b^2 + u_{std}^2} \\ &= \sqrt{u_r^2 + u_b^2 + u_{cal}^2 + u_A^2 + u_B^2 + u_D^2} \end{aligned} \tag{A.7}$$

A.6 Expanded uncertainty

Once all the relevant standard uncertainties have been allowed for (including the other contributions mentioned above), the combined uncertainty, u_q, is multiplied by a coverage factor, k, to give the expanded uncertainty, U. It is recommended that a value of $k = 2$ be used, although k may also be calculated from the number of effective degrees of freedom based on the principles laid down in ISO/IEC Guide 98-3 [11] (see E.4.2, E.4.3 and G.4.2). Hence, U is given by

$$U = k \cdot u_q \tag{A.8}$$

where

k is the coverage factor;

u_q is the combined uncertainty.

The estimated mean relative error, E, could reasonably be expected to lie within the range:

$$E = q \pm U \tag{A.9}$$

A.7 Typical values of uncertainty

In the past, measurement uncertainty was not taken into account for the purpose of classification. However, the uncertainty should be calculated and may be taken into account. This may affect the classification of existing extensometer systems because the maximum permissible values have not been modified.

To take the uncertainty of measurement into account, it is practical to make use of the newly defined criteria with permissible values of uncertainty, shown in Table A.1. So, the whole range of the maximum permissible bias error can still be applied.

Table A.1 — Typical maximum values of uncertainty for extensometer systems

Class of extensometer system	Typical maximum uncertainty [a]	
	Relative value U %	Absolute value U µm
0,2	0,12	0,3
0,5	0,3	0,8
1	0,6	1,7
2	1,2	3,3

[a] Whichever value is greater.

A.8 An example of an uncertainty budget for an extensometer system

Calibration of a 10 mm extensometer system in the range of 0,1 mm to 10 mm (Tables A.2, A.3 and A.4):

Expanded bias of calibration equipment: 0,2 µm for ≤ 2 mm; and 1,0 µm for > 2 mm

Temperature coefficient of the calibration apparatus: $\alpha = 1 \times 10^{-6}$ 1/K

Temperature of calibration: 25 °C

Temperature of calibration from calibration apparatus: 20 °C

Long-term stability of the calibration apparatus: $a_{\text{sensitivity}} = 4 \times 10^{-4}$

Resolution of the extensometer system: $a_{\text{resolution}} = 0{,}000\,1$ mm

Nominal value of gauge length of extensometer $L_e = 20$ mm

Measured value of gauge length of extensometer $L'_e = 20{,}06$ mm

Number of calibration runs = 2

So, the following can be calculated:

$a_{\text{temp}} = 5$ K

$\alpha \cdot a_{\text{temp}} = 5 \times 10^{-6}$

Relative error on the gauge length $q_{L_e} = 0{,}3$ %

Table A.2 — Results of the calibration of an extensometer system over the range 0,1 mm to 10 mm

Reference value mm	Measured value 1st run mm	Relative bias error of the 1st run %	Measured value 2nd run mm	Relative bias error of the 2nd run %	Average of measured values mm	Average of relative bias %	Average of absolute bias µm	Relative standard uncertainty of resolution u_r acc. (A.5) %	Relative standard uncertainty of repeatability u_b acc. (A.6) %
0,1	0,099 6	-0,40	0,100 2	0,20	0,099 9	-0,10	-0,10	0,03	0,300
0,2	0,199 4	-0,30	0,200 4	0,20	0,199 9	-0,05	-0,10	0,01	0,250
0,4	0,399 6	-0,10	0,401 4	0,35	0,400 5	0,12	0,50	0,01	0,225
0,7	0,698 8	-0,17	0,701 3	0,19	0,700 1	0,01	0,05	0,00	0,179
1	0,997 9	-0,21	1,001 7	0,17	0,999 8	-0,02	-0,20	0,00	0,190
2	2,001 1	0,06	2,008 0	0,40	2,0046	0,23	4,55	0,00	0,172
4	4,008 7	0,22	4,021 9	0,55	4,015 3	0,38	15,30	0,00	0,165
7	7,042 0	0,60	7,063 8	0,91	7,052 9	0,76	52,90	0,00	0,156
10	10,064 6	0,65	10,095 8	0,96	10,080 2	0,80	80,20	0,00	0,156

Table A.3 — Uncertainty calculation for the 0,1 mm displacement of the extensometer system

Quantity	Sources of uncertainty	Uncertainty contribution value	Probability distribution	Divisor	Standard measuring uncertainty u	Sensitivity coefficient [11]	Relative uncertainty contribution
u_{cal}	Measurement	0,1 µm	normal	1	0,1 µm	0,01/ µm	1,00E-03
u_A	Temperature	5,00E-06	rectangular	√3	2,89E-06	1	2,89E-06
u_B	Sensitivity drift	4,00E-04	rectangular	√3	2,31E-04	1	2,31E-04
u_D	Curve fit	0	Single point	1	0	1	0,00E+00
u_r	resolution	0,1 µm	rectangular	√12	0,029 µm	0,01/ µm	2,89E-04
u_b	repeatability	3E-03	normal	1	3,00E-03	1	3,00E-03
relative combined uncertainty					3,18E-03		
expanded relative uncertainty (k = 2)					6,36E-03		

Table A.4 — Results of the expanded uncertainty for the extensometer system

Nominal value mm	Relative bias %	Relative uncertainty %	Absolute bias µm	Absolute uncertainty µm
0,1	−0,10	0,64	−0,1	0,6
0,2	−0,05	0,51	−0,1	1,0
0,4	0,12	0,46	0,5	1,8
0,7	0,01	0,36	0,1	2,5
1	−0,02	0,38	−0,2	3,8
2	0,23	0,35	4,6	7,0
4	0,38	0,33	15	13
7	0,76	0,32	53	22
10	0,80	0,32	80	32

Annex B
(informative)

Calibration of the calibration apparatus

B.1 Procedure

Prior to the calibration, the calibration apparatus should be exercised a minimum of two times over the entire calibration range. The calibration apparatus should then be operated to generate a series of nominal extensions over the required calibration range, with one nominal extension close to a value of 0,33 mm (the transition from absolute to relative performance criteria) if this lies within the range. A measurement of each generated extension should be made by the calibration laboratory, using equipment traceable to the SI, with a known uncertainty of measurement. If possible, no adjustments should be made to the calibration apparatus prior to this initial series of measurements, and if any adjustments are subsequently made, the calibration procedure should be restarted. The measurement process should be repeated a minimum of two times, giving a minimum of three series of results.

B.2 Results and uncertainty calculation

In each series and at each nominal extension, the difference between the value indicated by the calibration apparatus and the extension measured by the calibration laboratory should be calculated. The mean difference at each nominal extension should then be determined.

An expanded uncertainty value should then be calculated at each nominal extension. The steps for calculating this value are as follows.

1) Determine the standard deviation of the differences obtained in all of the measurement series at the nominal extension. This value is an estimate of the standard uncertainty associated with the repeatability of the calibration apparatus.

2) Determine the standard uncertainty associated with the calibration laboratory's measurement of extension at the nominal extension.

3) If the design of the calibration apparatus is such that it is unable to set a nominal extension but instead displays the value of an extension applied to it (for example, by the use of a gauge block), determine a standard uncertainty component relating to the resolution with which this extension can be read. This uncertainty component is equal to $r/\sqrt{6}$ (where r is equal to the resolution of the displayed value).

4) Combine the standard uncertainty components determined in steps 1, 2, and (if applicable) 3 in quadrature (i.e. take the square root of the sum of their squares) and multiply the result by a coverage factor of $k = 2$.

5) Perform a least squares fit (of appropriate order) of mean difference against extension.

6) Add the result from step 4 to the absolute magnitude of the deviation between the mean difference and the value determined from the fit. This is an additional uncertainty contribution associated with the goodness of fit which, due to its systematic nature, cannot be summed in quadrature with the other components

The value thus obtained is the expanded uncertainty associated with using the fitted value to estimate the expected difference at this nominal extension. 95 % of measured differences should lie within the range of the fitted value ± this expanded uncertainty.

This approach is only valid when measurements are made at a sufficient number of extensions, both to avoid the data being overfitted and to enable the use of $k = 2$ to be justified. Where only a small number of extensions are measured, or where there appears to be limited correlation between nominal extension and measured differences, an alternative uncertainty determination approach should be used: follow only steps 1 to 4 above, ignoring steps 5 and 6, but calculate the coverage factor k required in step 4 based on the effective degrees of freedom (for example, if only 3 series of measurements are made and the repeatability is the only significant uncertainty component, a value of $k = 4,53$ is needed).

B.3 Classification

At each nominal extension, the absolute magnitude of the estimated difference obtained from the least squares fit (or, for the alternative uncertainty approach, the absolute magnitude of the mean difference between the extensions measured by the calibration apparatus and the laboratory's equipment) is to be added to the expanded uncertainty value determined in Clause B.2; the sum of these two numbers, termed the "Expanded bias", should not exceed the value given in Table B.1 in order for the calibration apparatus to be classified for the calibration of extensometer systems to the specified class.

Table B.1 — Expanded bias criteria of the calibration apparatus

Class of extensometer system	Expanded bias of the calibration apparatus [a]	
	Relative value %	Absolute value µm
0,2	±0,08	±0,27
0,5	±0,20	±0,67
1	±0,40	±1,3
2	±0,80	±2,7

[a] Whichever value is greater. The expanded bias values include an element for uncertainty of measurement which was not the case in the previous edition of this International Standard.

B.4 Calibration interval

The calibration interval for the calibration apparatus should not exceed 26 months.

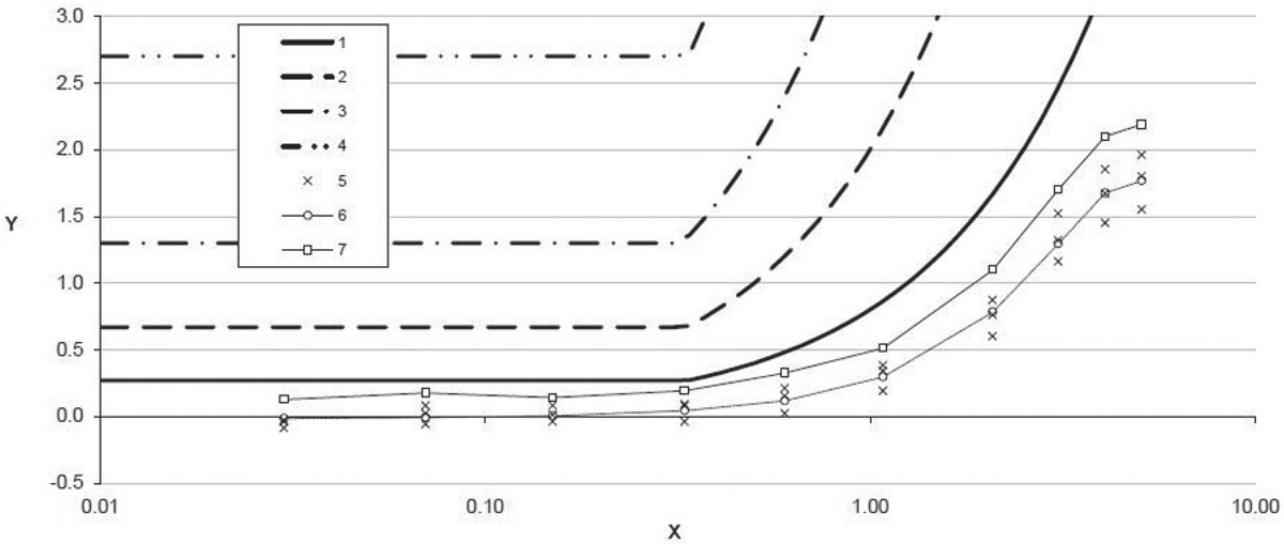
Annex C
(informative)

Example of a report of the calibration of calibration apparatus

C.1 General

This annex contains two examples of how the results from the calibration of calibration apparatus could be presented. Figure C.1 gives example data and an associated graph from a calibration where the standard uncertainty approach is used. Figure C.2 gives example data and an associated graph from a calibration where the alternative uncertainty approach is adopted.

Nominal Extension	Expanded Bias Classification Limit µm				Difference in Readings µm				Standard Deviation	Std. Unc. of Extension	Combined Standard Uncertainty	Fit	Fit Error	Expanded Uncertainty	Expanded Bias	Classification
mm	**Class 0,2**	**Class 0,5**	**Class 1**	**Class 2**	**Run 1**	**Run 2**	**Run 3**	**Mean**	**nm**	**nm**	**nm**	**µm**	**µm**	**µm**	**µm**	
0,03	0,27	0,67	1,30	2,70	-0,04	-0,09	-0,03	-0,05	32	16	36	-0,01	0,04	0,11	0,13	**Class 0,2**
0,07	0,27	0,67	1,30	2,70	-0,06	0,02	0,08	0,01	70	16	72	-0,01	-0,02	0,17	0,18	**Class 0,2**
0,15	0,27	0,67	1,30	2,70	-0,04	0,08	0,01	0,02	60	16	62	0,00	-0,01	0,14	0,14	**Class 0,2**
0,33	0,27	0,67	1,30	2,70	-0,04	0,08	0,09	0,04	72	17	74	0,04	0,00	0,15	0,19	**Class 0,2**
0,60	0,48	1,20	2,40	4,80	0,02	0,21	0,15	0,13	97	17	99	0,12	-0,01	0,21	0,32	**Class 0,2**
1,08	0,86	2,16	4,32	8,64	0,19	0,38	0,34	0,30	100	28	104	0,30	-0,01	0,22	0,51	**Class 0,2**
2,08	1,66	4,16	8,32	16,64	0,60	0,87	0,76	0,74	136	30	139	0,78	0,04	0,32	1,10	**Class 0,2**
3,08	2,46	6,16	12,32	24,64	1,16	1,52	1,32	1,33	180	31	183	1,29	-0,04	0,41	1,70	**Class 0,2**
4,08	3,26	8,16	16,32	32,64	1,45	1,85	1,67	1,66	200	33	203	1,67	0,02	0,42	2,10	**Class 0,2**
5,08	4,06	10,16	20,32	40,64	1,55	1,96	1,80	1,77	207	35	210	1,77	0,00	0,42	2,19	**Class 0,2**

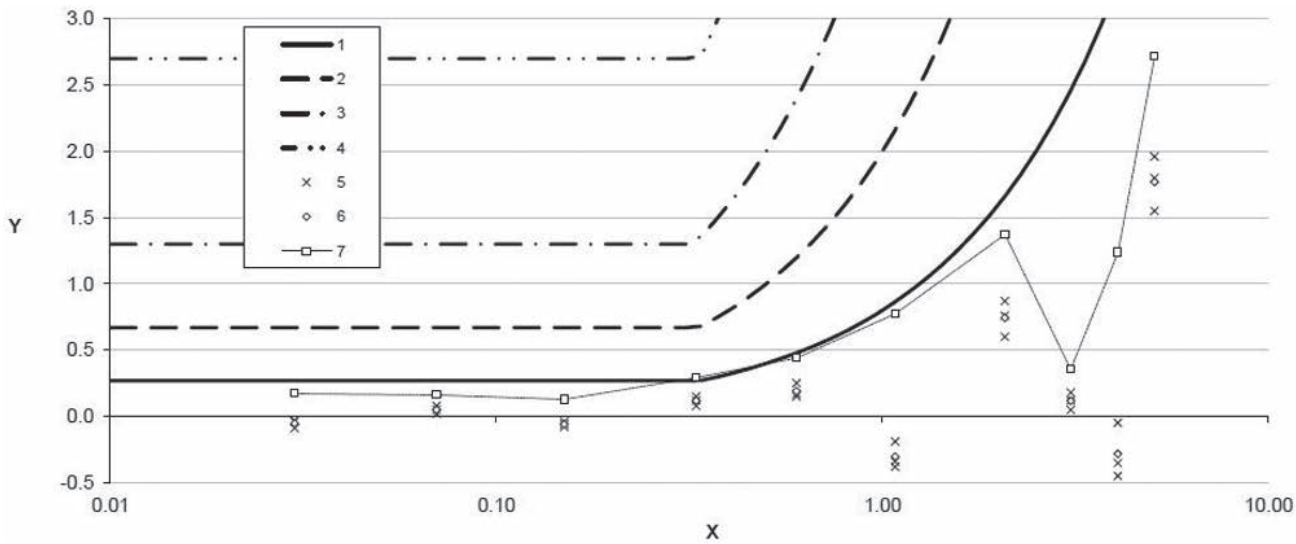


Key

X extension (mm)
Y difference (µm)
1 class 0,2
2 class 0,5
3 class 1
4 class 2
5 readings
6 fit
7 expanded bias

Figure C.1 — Example of results analysis using the standard uncertainty approach

Nominal Ex-tension	Expanded Bias Classification Limit µm				Difference in Readings µm				Standard Deviation	Std. Unc. of Extension	Combined Standard Uncertainty	Fit	Fit Error	Expanded Uncertainty	Expanded Bias	Classification
mm	Class 0,2	Class 0,5	Class 1	Class 2	Run 1	Run 2	Run 3	Mean	nm	nm	nm	µm	µm	µm	µm	
0,03	0,27	0,67	1,30	2,70	-0,04	-0,09	-0,03	-0,05	32	16	36	3,1	3,31	0,12	0,17	**Class 0,2**
0,07	0,27	0,67	1,30	2,70	0,05	0,02	0,08	0,05	30	16	34	3,3	3,31	0,11	0,16	**Class 0,2**
0,15	0,27	0,67	1,30	2,70	-0,04	-0,08	-0,06	-0,06	20	16	26	5,5	2,65	0,07	0,13	**Class 0,2**
0,33	0,27	0,67	1,30	2,70	0,12	0,08	0,15	0,12	35	17	39	3,0	4,53	0,18	0,29	**Class 0,2**
0,60	0,48	1,20	2,40	4,80	0,17	0,25	0,15	0,19	53	17	56	2,4	4,53	0,25	0,44	**Class 0,2**
1,08	0,86	2,16	4,32	8,64	-0,19	-0,38	-0,34	-0,30	100	28	104	2,3	4,53	0,47	0,77	**Class 0,2**
2,08	1,66	4,16	8,32	16,64	0,60	0,87	0,76	0,74	136	30	139	2,2	4,53	0,63	1,37	**Class 0,2**
3,08	2,46	6,16	12,32	24,64	0,05	0,12	0,18	0,12	65	31	72	3,0	3,31	0,24	0,36	**Class 0,2**
4,08	3,26	8,16	16,32	32,64	-0,45	-0,35	-0,05	-0,28	208	33	211	2,1	4,53	0,95	1,24	**Class 0,2**
5,08	4,06	10,16	20,32	40,64	1,55	1,96	1,80	1,77	207	35	210	2,1	4,53	0,95	2,72	**Class 0,2**



Key

X extension (mm)
Y difference (µm)
1 class 0,2
2 class 0,5
3 class 1
4 class 2
5 readings
6 fit
7 expanded bias

Figure C.2 — Example of results analysis using the alternative uncertainty approach

Annex D
(informative)

Examples of extensometer system configurations

D.1 General

Extensometer systems may be categorized as follows:

Type A	Extensometer to be applied on the test piece without reference point on the calibration apparatus
Type B	Extensometer to be applied on the test piece with a fixed reference point on the calibration apparatus
Type C	Extensometer to be applied on the test piece with a movable reference point on the calibration apparatus
Type D	Combination of extensometer systems
Type E	Extensometer used to measure the crosshead travel of piston–stroke. Calibration apparatus of the machine is eliminated.
Type F	Extensometer on compression plates to measure the relative movement between the upper and lower plate. Deformation of the machine is eliminated.

D.2 Type A extensometers

D.2.1 Description

Type A extensometers are clamped on the test piece and supported by it. There is no reference point on the loading frame of the calibration apparatus. Figures D.1 to D.3 show various designs of this type.

The extensometer may be positioned on the measuring system, either one-sided or two-sided. The displacement can be read either as separate values or as a mean value. Figures D.1 to D.3 show one-sided systems only.

D.2.2 Calibration procedure

The movable and fixed contact points of the extensometer are placed on the movable and fixed elements of the calibration equipment (“divided sample” as principle). If the extensometer has two movable contact points, the second contact point is placed on the fixed part of the calibration equipment.

The calibrated range is set by the calibration equipment in a series of 10 stages; the applied and measured displacements being recorded from the calibration equipment and the extensometer system output.

D.2.3 Determination of the extensometer nominal gauge length L_e

The extensometer nominal gauge length, L_e, is verified using a calibrated plug gauge.

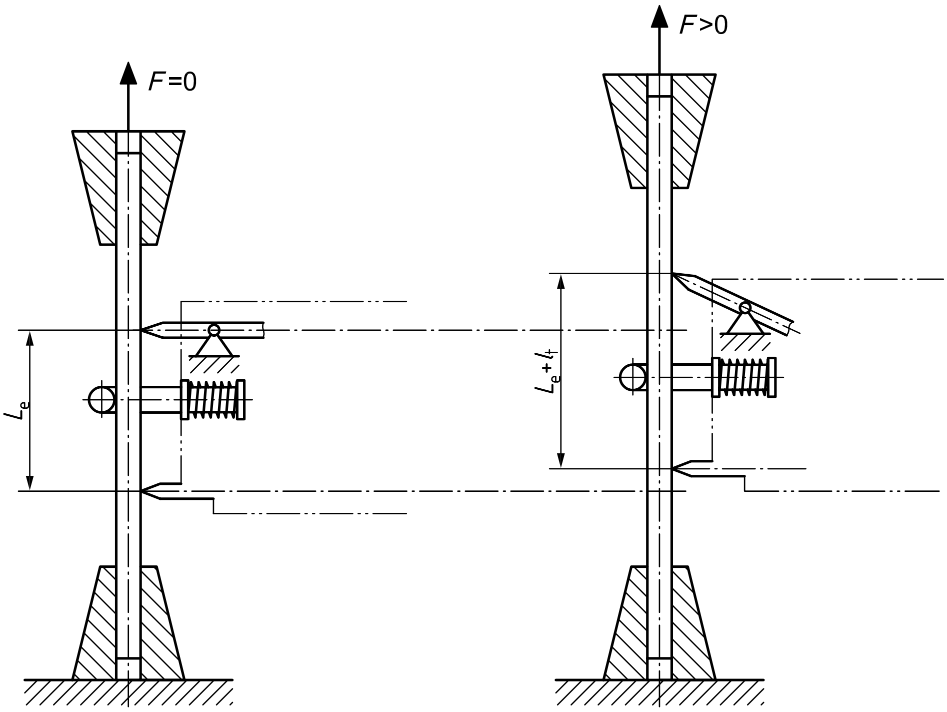


Figure D.1 — Extensometer with a pivoted contact point

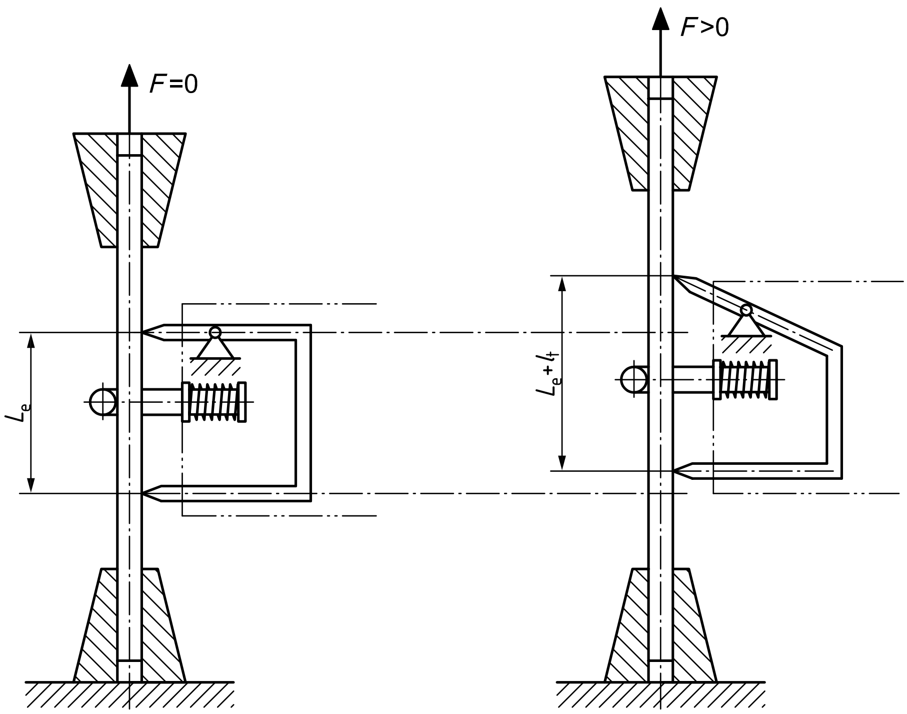


Figure D.2 — Extensometer with a flexure contact point

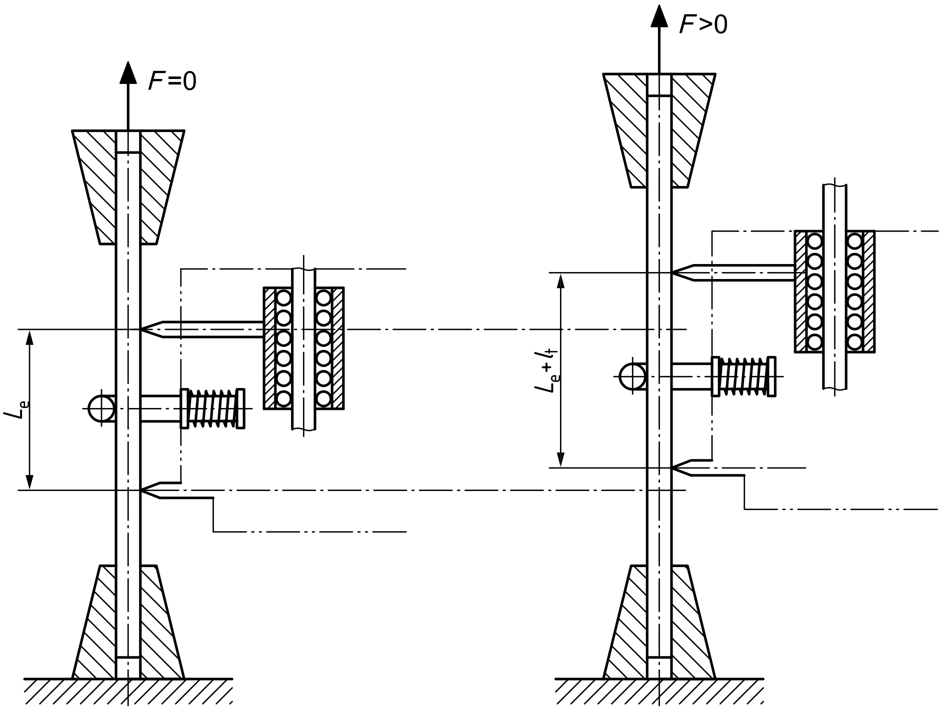


Figure D.3 — Extensometer with a guided contact point in linear bearing

D.3 Type B extensometers

D.3.1 Description

Type B extensometers have two movable contact points or optical sensors mounted on the test piece while the reference point is on the frame. The sensors are aligned with the test piece gauge marks and are displaced as extension occurs.

Figures D.4 to D.8 illustrate various designs of type B extensometers.

Elongation is the difference in length between the contact points G and H caused by test piece loading. As the test piece is held at one end by a fixed grip and at the other by a movable grip, elongations l_1 and l_2 are unequal. Two absolute measurements or one differential measurement are carried out and l_1 is calculated as the difference $l_2 - l_1$.

D.3.2 Calibration procedure

D.3.2.1 Assumptions

For a given distance between grips, S, and an extensometer nominal gauge length, L_e, and assuming that the extensometer is mounted at equal distance between the grips of the calibration equipment and that the strain of the test piece is uniform, the ratio of displacements of the upper and lower blades of the extensometer should be calculated as follows:

$$\frac{l_2}{l_1} = \frac{S + l_e}{S - L_e} \qquad \text{(D.1)}$$

D.3.2.2 Procedure

To verify the performance of the blades individually, place the blade to be verified on the movable part of the calibration equipment and the other blade on the fixed part or if an optical extensometer is being verified, on the gauge marks. For a given verification range, a series of 10 measurements for each blade is to be carried out individually. The relative bias error of the extensometer is then to be calculated for each measurement point by deducting the displacement of the lower blade from the displacement of the upper blade.

EXAMPLE

Verification range = 2 mm

Distance between grips, S = 150 mm

Extensometer nominal gauge length, L_e = 80 mm

$$\frac{l_2}{l_1} = \frac{150 + 80}{150 - 80} = \frac{3,29}{1} \approx \frac{3}{1}$$

l_2 = 3 mm;

l_1 = 1 mm

If an extensometer with two non-averaging transducers (see Figure D.5) is to be verified, a further verification procedure should be carried out to check whether both transducers have the same degree of accuracy. Both blades should be placed on the movable part of the calibration equipment and the equipment used to carry out discrete displacements. If both transducers behave identically, the apparatus should read 0.

The calibration procedure may be simplified by using calibration equipment with two movable parts on which the ratio of displacement l_2 / l_1 may be previously set.

D.3.2.3 Determining the extensometer nominal gauge length between L_e

The extensometer nominal gauge length L_e, can be measured by placing the extensometer on a soft test piece (e.g. copper or cardboard) in such way that the blades of the extensometers leave their marks. Once the extensometer is removed, the distance between the marks should be measured.

If the gauge length of an optical extensometer is to be measured, a device should be used to make marks at desired intervals on the test piece. In order to verify L_e, the distance between the marks may be measured on the device itself (e.g. by using a micrometer gauge).

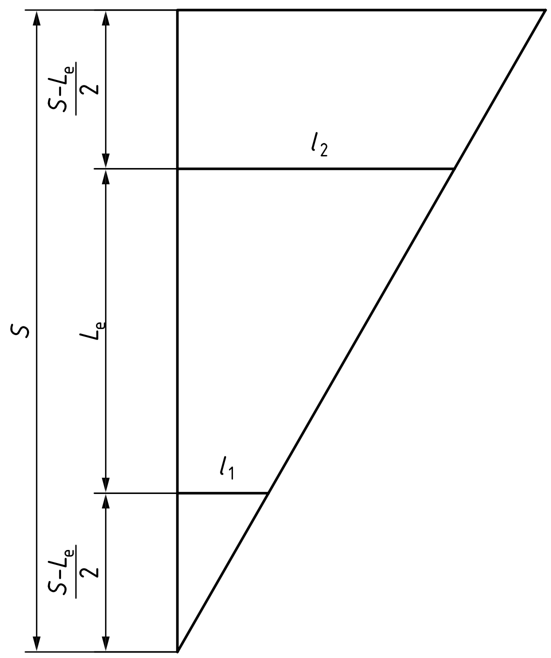


Figure D.4 — l_2 and l_1, ratio, distance between grips, S, and nominal gauge length, L_e

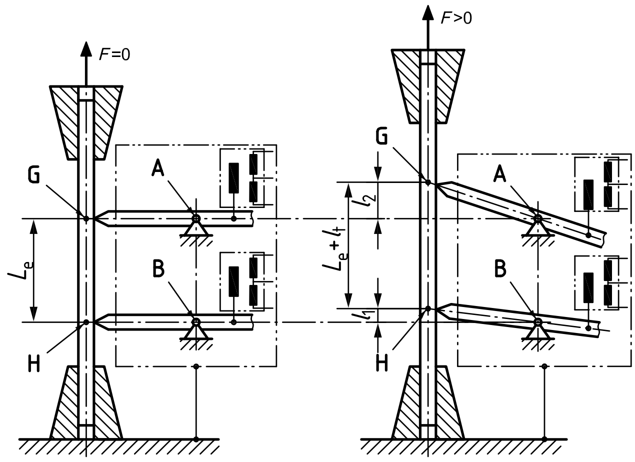


Figure D.5 — Extensometer with two blades and two non-averaging transducers

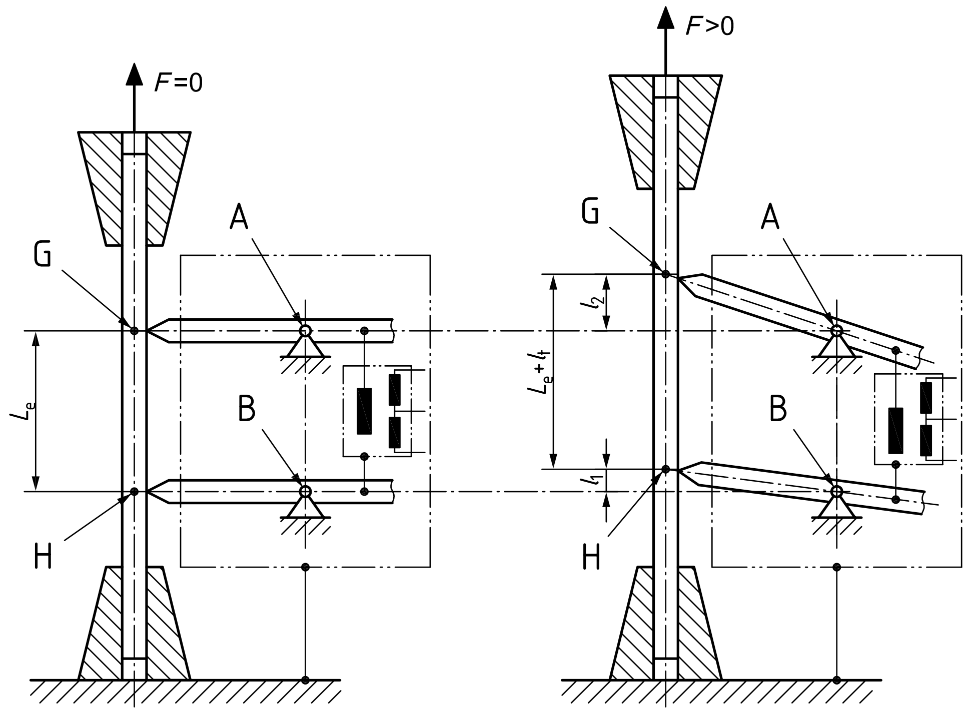


Figure D.6 — Extensometer with two blades and a differential transducer

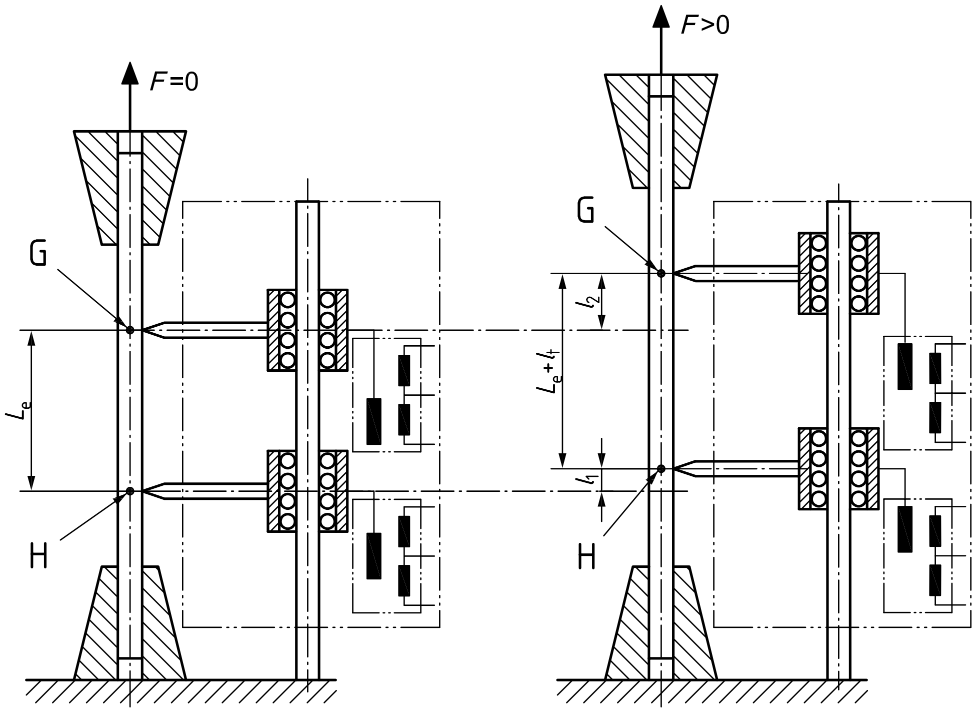


Figure D.7 — Extensometer with two guided blades and two non-averaging transducers

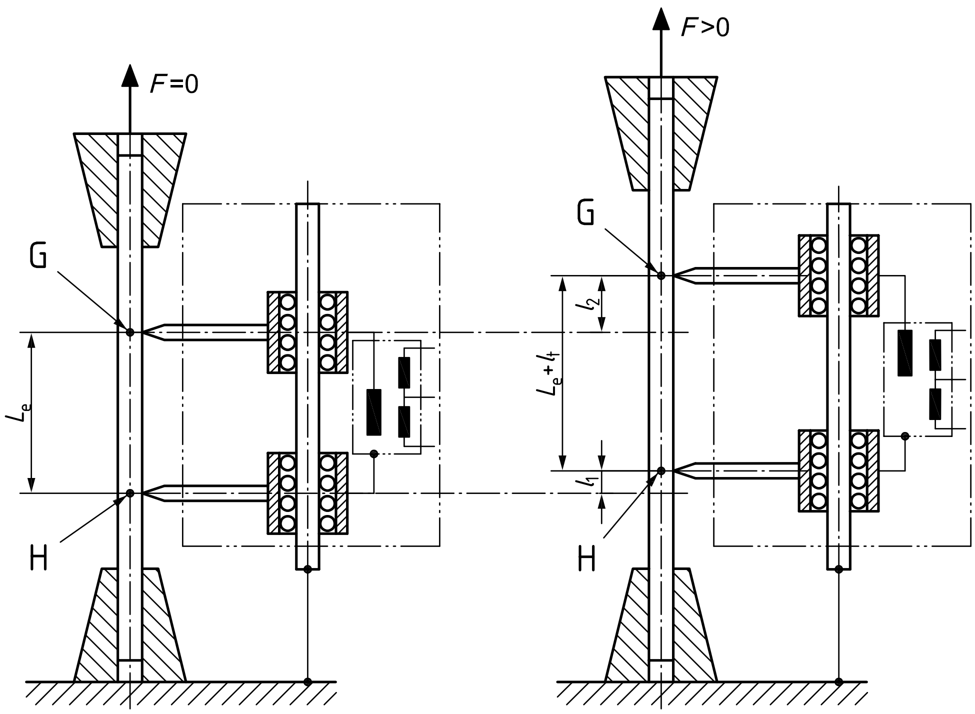


Figure D.8 — Extensometer with two guided movable blades and one differential transducer

D.4 Type C extensometers

D.4.1 Description

Type C extensometers are provided with two movable blades which are displaced as a consequence of test piece elongation. As the tensile stress increases, the blades move apart leaving the transducer at the centre of the test piece.

The movement of the blades may be guided by a roller or by a servomotor which is controlled by the strain or by the travel of the crosshead.

D.4.2 Calibration procedure

The principle for type B extensometers applies. If, for instance, the movement of the blades is linked to a roller (see Figure D.9) and the displacement (travel) of the crosshead is equal to s, then the displacement of the blade is equal to $s/2$.

If the extensometer has been clamped at an equal distance between the grips of the calibration equipment, then l_1 equals l_2.

D.4.2.1 Determining the extensometer nominal gauge length

See D.3.2.3.

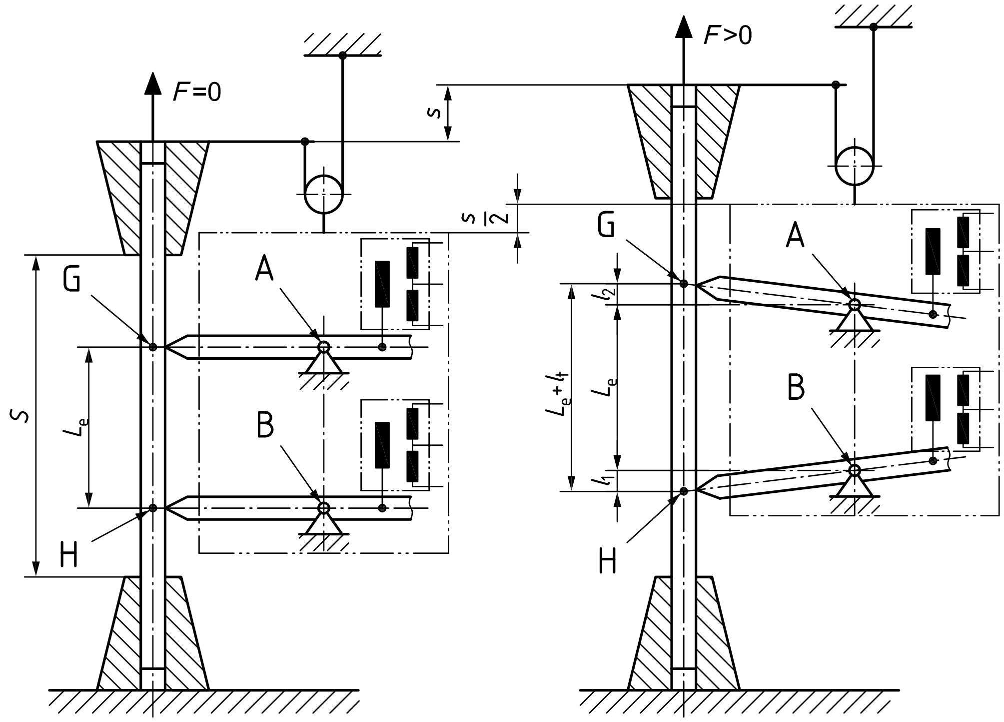


Figure D.9 — Extensometer with two blades and movable reference point

D.5 Type D extensometers

This type of extensometer combines a series of characteristics provided by different systems. The extensometer illustrated in Figure D.10 is provided with a leaf spring for microstrain measurements. Beyond a certain strain level, a displacement transducer is used for averaging measurements.

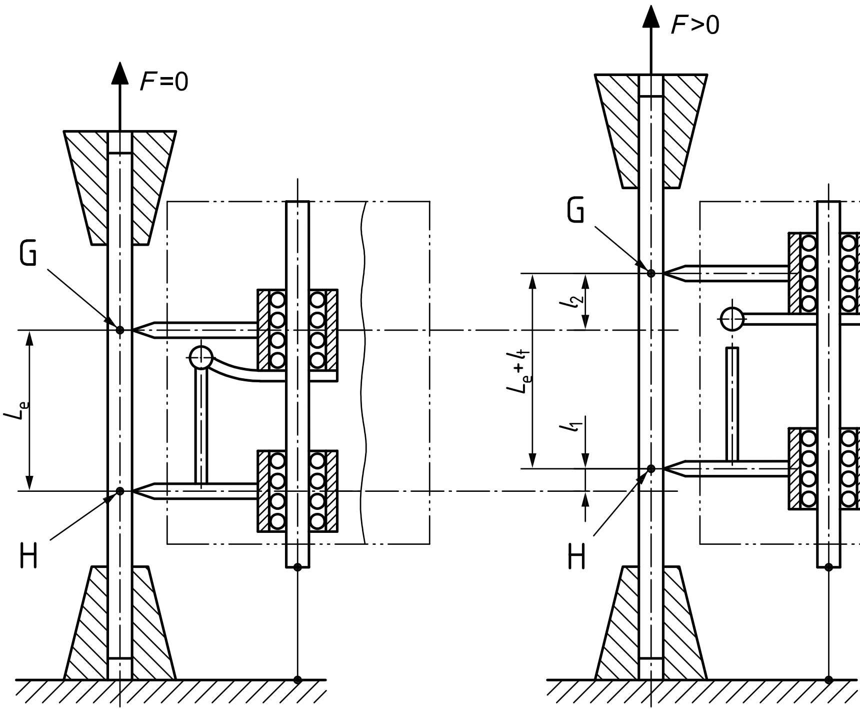


Figure D.10 — Combination of extensometers of type A (cf. Figure D.2) and type B (cf. Figures D.7 and D.8)

For specifications regarding the test principle and accuracy of extensometer nominal gauge length, see D.2.2 and D.2.3.

D.6 Type E extensometers

D.6.1 Description

Type E extensometers are used to measure the piston stroke of hydraulic testing machines or the travel of the crosshead of mechanical testing machines. Owing to the location of the transducers, strain measurements may be falsified by deformation occurring in the loading frame, by load application, or by the force measuring system.

D.6.2 Calibration procedure

Verification is to be carried out using a transducer and measurements are either taken continuously (e.g. using a dial gauge) or in stages (e.g. using gauge blocks).

D.7 Type F extensometers

D.7.1 Description

The transducers are clamped on the compression platens of the loading device and used to measure the change occurring in the distance between the platens. Although a deformation of the loading frame is unlikely, measurements may be compromised if the compression platens are bent.

D.7.2 Calibration procedure

See D.6.2.

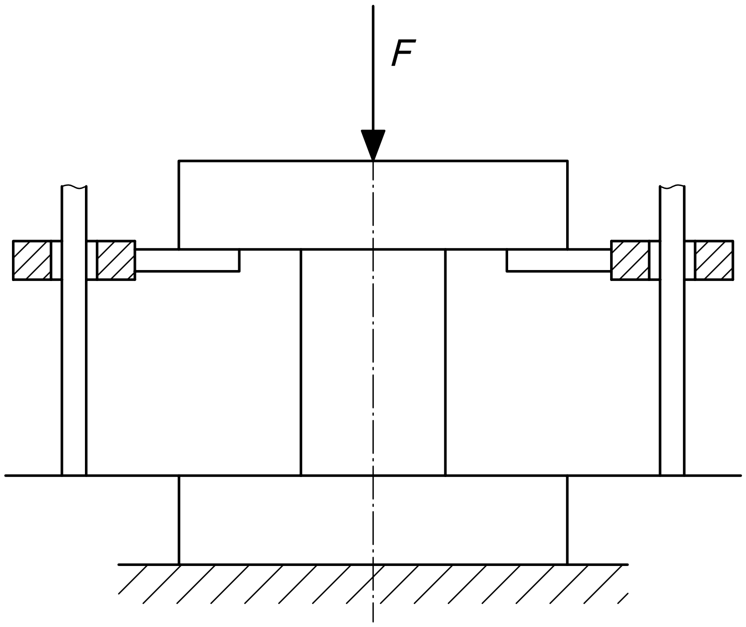


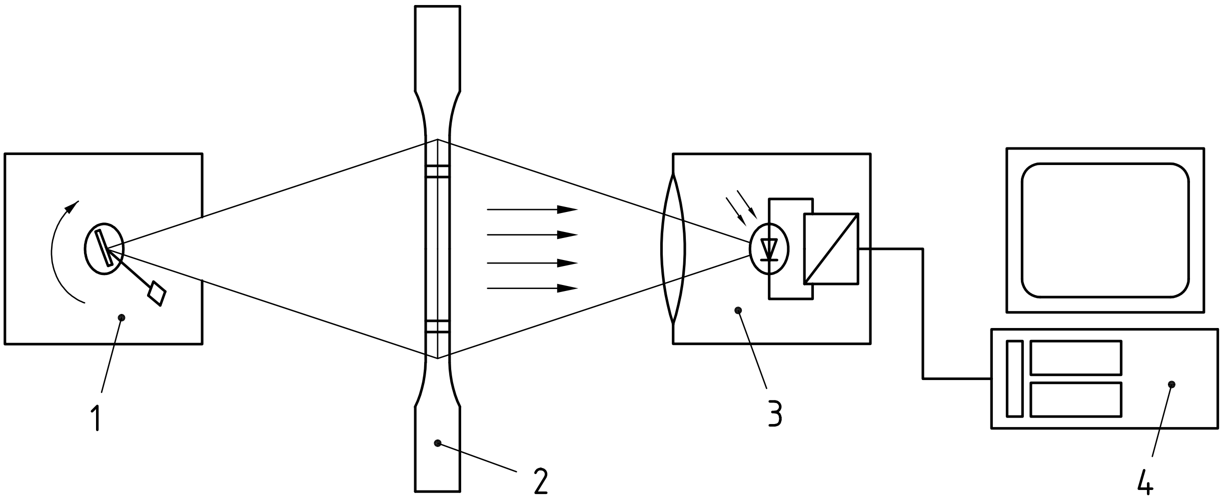
Figure D.11 — Transducer used for strain measurements between compression platens

Annex E
(informative)

Laser extensometry

E.1 Laser extensometer working principles

A set of at least two coding stripes are printed on the test sample. A laser beam driven by a rotating deflector scans continuously along the main axis of the sample. Diffuse scattering or reflection of the laser light takes place on the stripes and is detected by a photo-receiver (see Figure E.1).



Key

1 scanner

2 sample with contrasting stripes

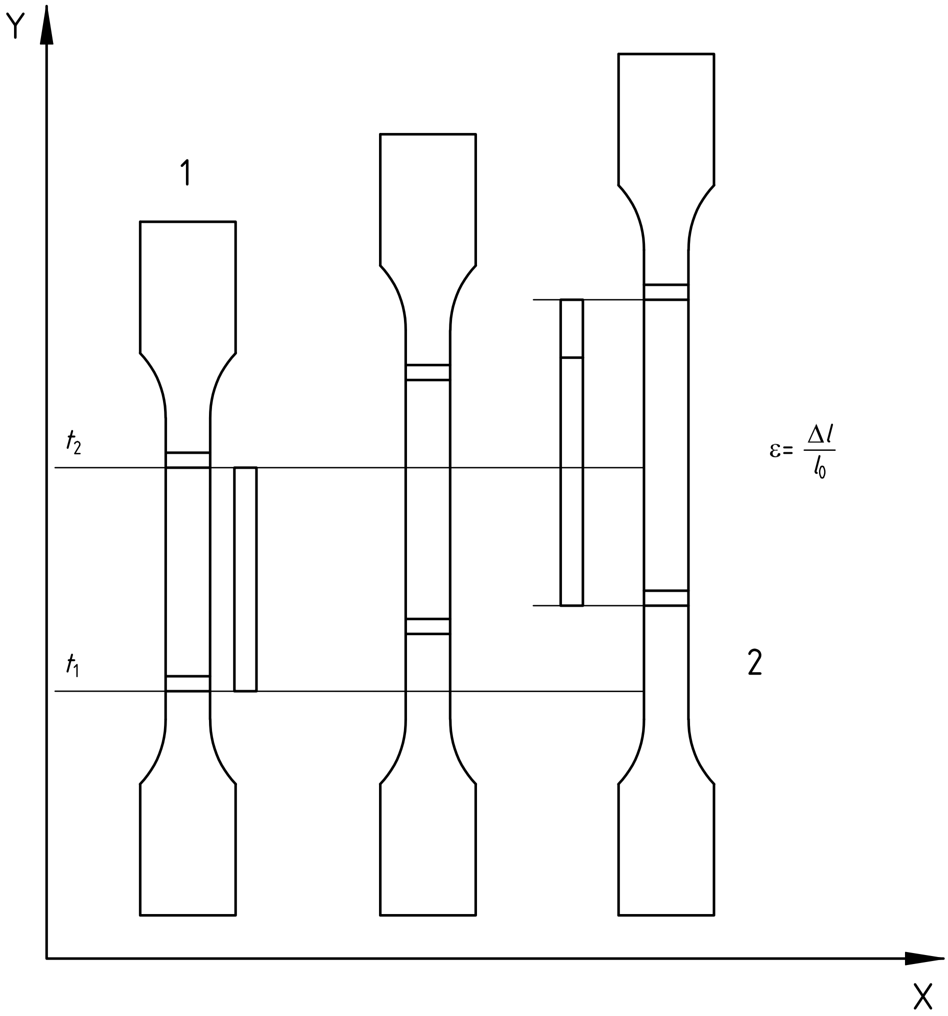
3 receiver

4 personal computer with multi-stop-counter

Figure E.1 — Working principle

In addition, the speed of the rotating deflector is measured. From the time behaviour of the detected light as it crosses the two stripes, and with the known speed of the deflector, the length of the distance between these two marks is calculated.

The reference lengths between the individual stripes (see Figure E.2) are measured at the beginning of the experiment for the unextended test piece. On the basis of changes in strain, the extension or compression between the coding stripes is measured as percentages or absolute values. These measurement results are available as analogue or digital values.



Key

1 reference

2 strain

X measurement

Y scan time

Figure E.2 — Measuring principle

Through the use of laser scanners in the visible range, the area to be scanned can be regulated with the naked eye. For coding, taped stripes contrasting to the background are applied at fixed distances, or paint or layers of powder is sprayed on using templates.

E.2 Calibration possibilities and influences on laser scanners

Basically, laser extensometer scanning can be calibrated with the usual calibration methods (gauge blocks, mechanical and optic measurement sensors, interferometric methods) as with mechanical displacement gauges. This is carried out as with the calibration of mechanical pick-ups between a fixed and a movable element or two movable ends of a calibration device, which are positioned in discrete increments. At least one coding stripe is placed on each of these fixed or movable elements. The measurement deviations are thus determined as absolute or relative deviations from the position in the scanning area.

In addition to these static errors, there are a series of further influences which are produced by the operational behaviour of scanners, receivers and their environments. These include the trigger behaviour of the electronics, the contrast of the coding marks, the influence of constant or alternating light, air turbulence and electromagnetic induction.

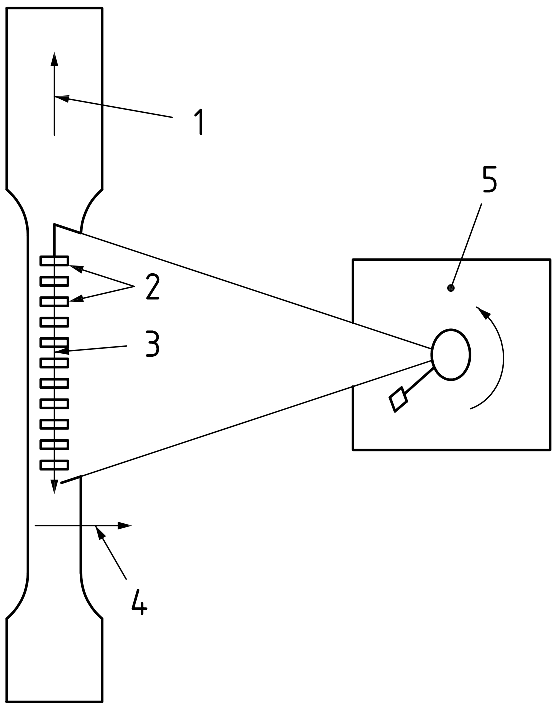
The measurement of these influences consists in measuring the behaviour of the scanner when the test piece is at rest. In this case, the statistical behaviour of the measurement of stripe positions is analysed. Under optimal conditions, the distribution for the entire measurement system should thus not be greater than a value corresponding to a deviation of ± 1 base unit of the timing device of the scanner.

A significant parameter for the scanner is the maximal scanning rate and the speed at which the laser beam travels over the surface of the test piece. Together with the frequency of the timing device and the local movement of the coding stripes in the direction of the strain, these provide the dynamic error in the measurement. These can be determined through calculations and minimized by means of compensatory functions.

Further influences are produced by the scanning principle utilized, and are described in Clauses E.3 and E.4.

E.3 Laser extensometer of the angular scanner type

E.3.1 Working principle for the angular scanner



Key

1 strain

2 contrasting stripes

3 longitudinal strain

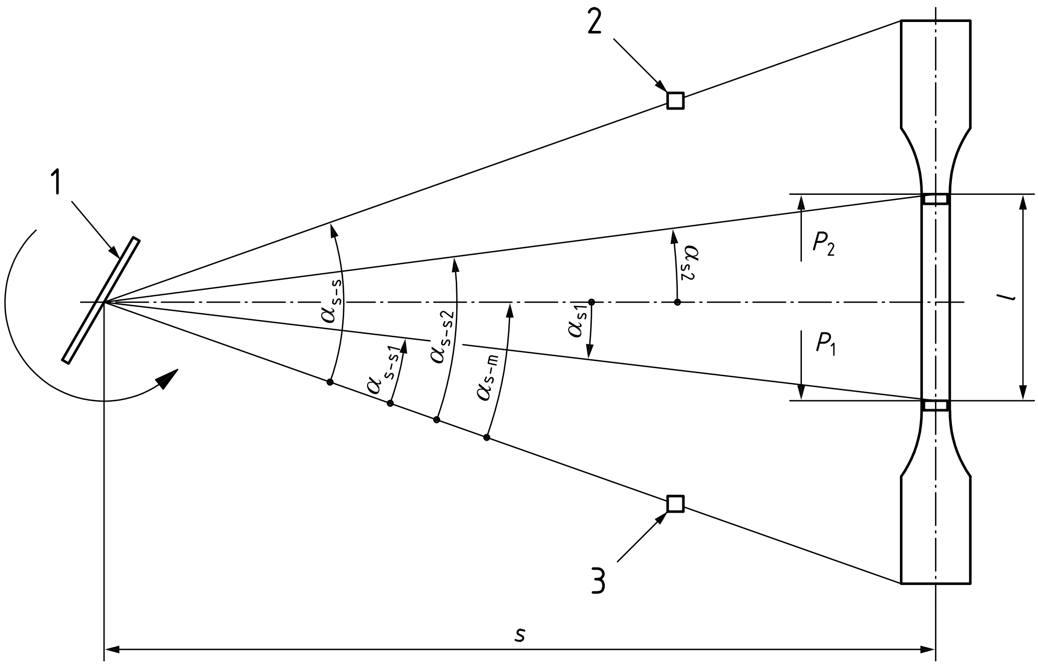
4 lateral strain

5 scanner

Figure E.3 — Working principle of the angular scanner

The laser extensometer of the angular scanner type operates as follows: at least two, or an entire set, of measurement markings are positioned on the unextended test piece. The laser beam is directed on to the central point of rotation of a rotating mirror or polygon and deflected radially from this point over the test piece. At the markings which are positioned on the test piece, the laser light is either scattered in a diffuse manner or reflected in a focused manner. The receiver analyses this light, determines die reference length(s) on the unextended test piece and then the changes in length and in the case of several markings, their distribution under the impact of the forces being tested. An additional horizontally operating scanning centre simultaneously determines the lateral expansion if required. In the case of an angular scanner, the test piece must be level and the working distance to the test piece must remain constant during the experiment.

E.3.2 Angular scanner, measurement values and influences on precision



Key

1 deflector unit

2 stop-diode

3 start-diode

Figure E.4 — Measurement values for an angular scanner

Figure E.4 shows the principal measurement values and parameters produced during a measurement between two stripes. The following values should be taken into consideration:

α_{s-s}	Start-stop-angle — Angle between the start diode and stop diode
α_{s-s1}	Start-stripe 1-angle — Angle between the start diode and stop diode and first stripe
α_{s-s2}	Start-stripe 2-angle — Angle between the start diode and second stripe
α_{s-m}	Start-middle-angle — Angle between the start diode and the middle axis of the system (the middle axis is positioned perpendicular to the axis of the test piece)
α_{s1}	Angle of stripe 1 — Angle between the middle axis and the first stripe
α_{s2}	Angle of stripe 2 — Angle between the middle axis and the second stripe
P_1	Position of stripe 1 — Position relative to the middle axis (signed)
P_2	Position of stripe 2 — Position relative to the middle axis (signed)
s	Distance between the centre of deflection and the test piece surface
l	Measurement length — Distance between the markings on the test piece

The position P_1 and P_2 of both stripes is determined by the angle and by the distance s. The angle is measured with the aid of a timing device. For the position of any stripe sk, the following applies

$$p_{sk} = s \cdot \tan\left(\alpha_{s-s} \cdot \frac{t_{sk}}{t_{ss}} - \alpha_{s-m}\right) \tag{E.1}$$

Corresponding to this equation, the following values are necessary in order to calculate the position of a stripe:

t_{s-s} start-stop-time

t_{s-s1} start-stripe-time

α_{s-s} start-stop-angle

α_{s-m} start-middle-angle

s working distance

The absolute and the relative expansion can be determined from the position of both stripes.

The testing and calibration of a laser extensometer of the angular scanner type is a procedure for determining the parameters specific to the device and the connection of the extensometer to the testing device. The parameters to be observed in this case are usually supplied by the manufacturer:

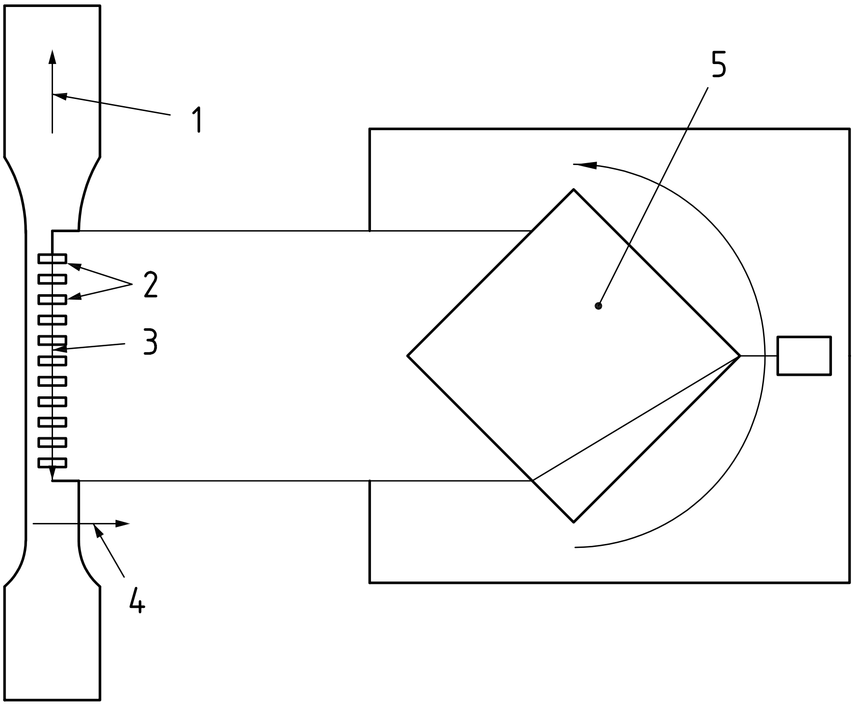
α_{s-s} the start-stop-angle

α_{s-m} the start-middle-angle

s the operating distance from the front edge of the test piece to the scanning centre

The testing, and if necessary, the readjustment and measurement of the start-stop angle, can be carried out on-site. Determining the start-middle-angle and the operating distance s from the scanning centre is done by means of a principle in which a reference test with two precisely defined contrasting stripes with a known distance is carried out parallel to these and perpendicular to the optical axis, and is measured by the angular scanner. Each measurement produces two stripe positions and a distance between stripes. On this basis, respective start-middle angles are determined and optimized for all measurements by means of a statistical procedure.

E.4 Laser extensometer parallel scanner



Key

1 strain

2 contrasting stripes

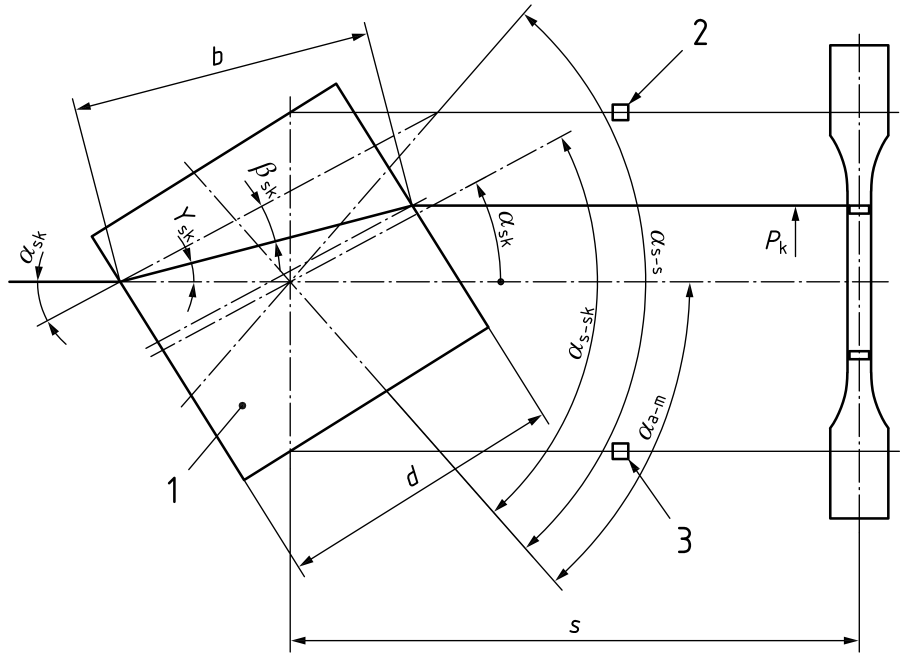
3 longitudinal strain

4 lateral strain

5 scanner

Figure E.5 — Parallel scanner, many stripes

The laser extensometer of the parallel scanner type works as follows: at least two, or an entire set, of measurement markings are positioned on the unextended test piece. The laser beam is directed onto the central point of rotation of a rotating horizontal glass flat. During entry and exit, the laser beam is refracted at two opposite planes of the optical flat, which results in respective identical refractive angles. By the rotation of the optical flat, the laser beam is deflected in parallel to itself and thus moves over the test piece. At the stripes positioned on the test piece, the laser light is either scattered in a diffuse manner or precisely reflected. The receiver analyses this light, determines die reference length(s) on the unextended test piece and then the changes in length and in the case of several markings, their distribution under the impact of the forces being tested. An additional horizontally operating scanning centre simultaneously determines, if required, the lateral expansion of the thickness.



Key

1 deflector unit

2 stop-diode

3 start-diode

Figure E.6 — Parallel scanner measurement values

Figure E.6 shows the principal measurement values and parameters produced during a measurement between two stripes.

The calculations for a parallel scanner are rather more complex than those for an angular scanner. Furthermore, the significance of the “start-stop” angle and “start stripes” are not easy to determine.

As for the angular scanner, the deflector unit is attached to a “rotating element”. This rotating element should possess a “neutral position”. This is the position in which the beam is not deflected, when it passes through the optical flat. This is in fact the case if the edges of the optical flat are positioned parallel or perpendicular to the optical axis. In the above illustration a situation is depicted, which is arrived at from a mathematically positive rotation along the angle α_{sk} from the neutral position. Through the “appropriate” rotation of the deflector unit, the laser beam can be directed onto the start diode or the stop diode. The angle which the deflector unit thus forms corresponds to the “start-stop angle” of the calibration parameters.

As for the angular scanner, time measurement begins when the laser beam reaches the start diode. ϖ_a now depicts the angular velocity of the deflector unit. This, on the other hand, remains constant.

The following parameters are required for the calculations:

α_{s-s}	start-stop-angle
α_{s-s1}	start-stripe 1-angle
α_{s-s2}	start-stripe 2-angle
α_{s-m}	start-middle-angle
α_{s1}	angle of stripe 1
α_{s2}	angle of stripe 2

p_1 position of stripe 1

p_2 position of stripe 2

s distance between the deflection centre and the test piece surface

l measurement length – distance between the markings on the test piece

ϖ_a angular velocity of the deflector unit

d length of edge of the optical flat

η refraction index of the optical flat

For calculating the position of any stripe, the following applies:

$$\alpha_{sk} = \alpha_{s-s} \cdot \frac{t_{sk}}{t_{ss}} - \alpha_{s-m} \quad \text{(E.2)}$$

$$p_{sk} = d \cdot \sin(\alpha_{sk}) \cdot \left(1 - \frac{\cos(\alpha_{sk})}{\sqrt{\eta^2 - \sin^2(\alpha_{sk})}}\right) \quad \text{(E.3)}$$

For calculating the position of any stripe, the following is necessary:

t_{s-s} start-stop-time

t_{s-sk} start-stripe-time

α_{s-s} start-stop angle of device parameters

α_{s-m} start-middle angle of the device parameters

d length of edge of the optical flat device parameters

η refraction index of the optical flat device parameters

The testing and calibration of a laser extensometer of the parallel scanner type is a procedure for determining the parameters specific to the device and the connection of the extensometer to the testing device. The parameters to be observed in this case are usually supplied by the manufacturer:

α_{s-s} start-stop-angle

α_{s-m} start-middle-angle

d length of edge of the optical flat

η refraction index of the optical flat

The length of edge, d, and the refraction index, η, are based on information supplied by the manufacturer. Here, it must be kept in mind that the refraction index depends on the wavelength of the laser which is used.

The angle positions given for the parallel scanner are not in relation to the position of the laser beam, but rather to the position of the deflector element, in which the deflected laser beam carries out the corresponding movements. The testing and, if necessary, the readjustment and measurement of the start-stop angle can be carried out on-site relatively easily.

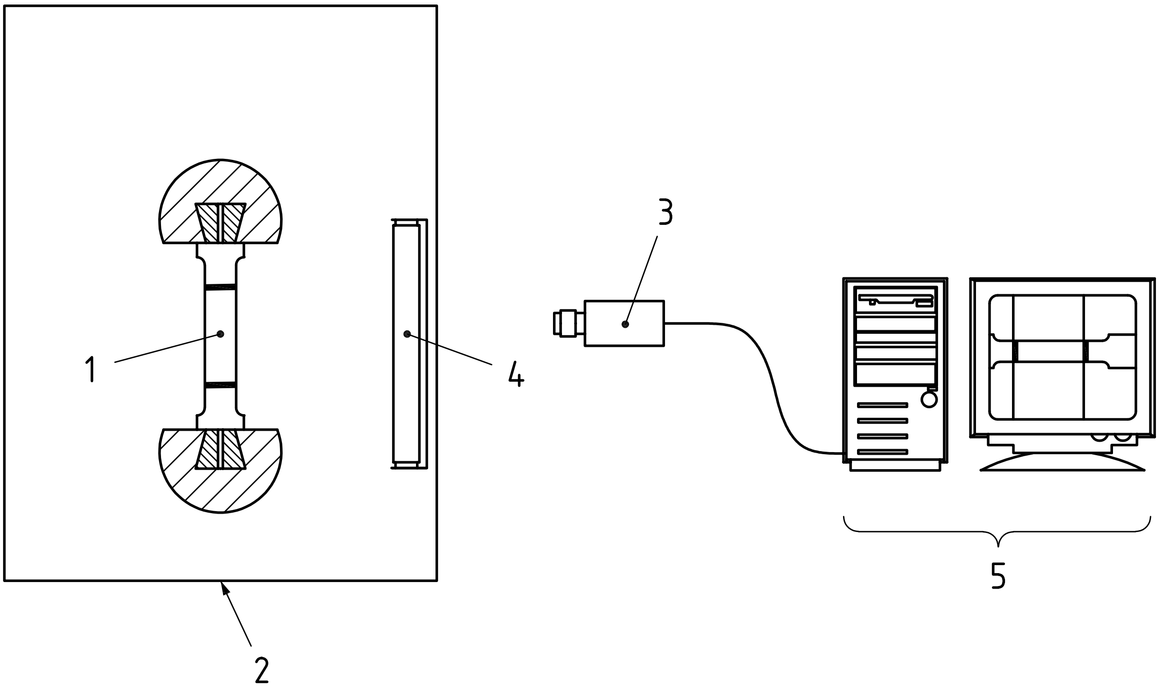
Determining the start-middle angle, the testing, and, if necessary, the adjustment of the operating distance from the scanning centre point, is done by means of a principle in which a test object with two exactly-defined contrasting stripes with a known distance is carried out parallel to these and perpendicular to the optical axis, and is measured by the parallel scanner. Each measurement produces two stripe positions and a distance between stripes. On this basis, respective start-middle angles are determined and optimized for all measurements by means of a statistical procedure.

Annex F
(informative)

Video extensometry

F.1 Video extensometer working principles

A video extensometer system consists of at least one camera with an optical system and a corresponding image processing system (see Figure F.1).



Key

1 test piece with reference marks

2 testing machine

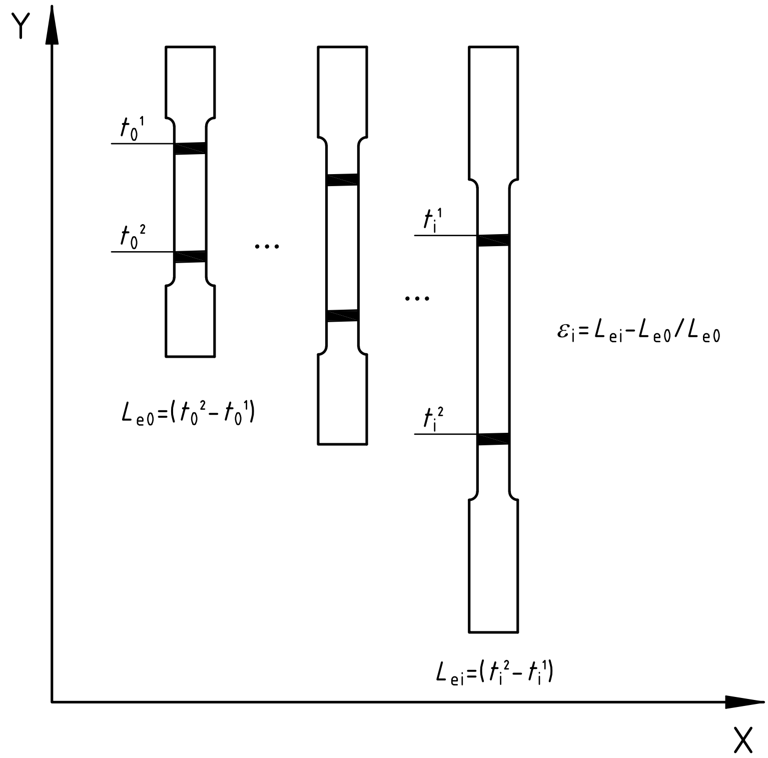
3 video camera

4 light source

5 video processor

Figure F.1 — Working principles

The surface of a test piece is marked along the load axis and sometimes also at right angles to it with at least two reference marks (see Figure F.2). These marks, which have to contrast well with the background, may be in the form of coloured marks or self-adhesive stickers. The distance between the contrasting reference edges of these marks represents the initial measuring length, which will change as a result of the strain or compression that is induced. In the video extensometer, this change is monitored by one or more cameras, and by rapid processing of the video signal it is converted into an extension or compression measurement, saved and where applicable used as the target figure for the test set-up.



Key

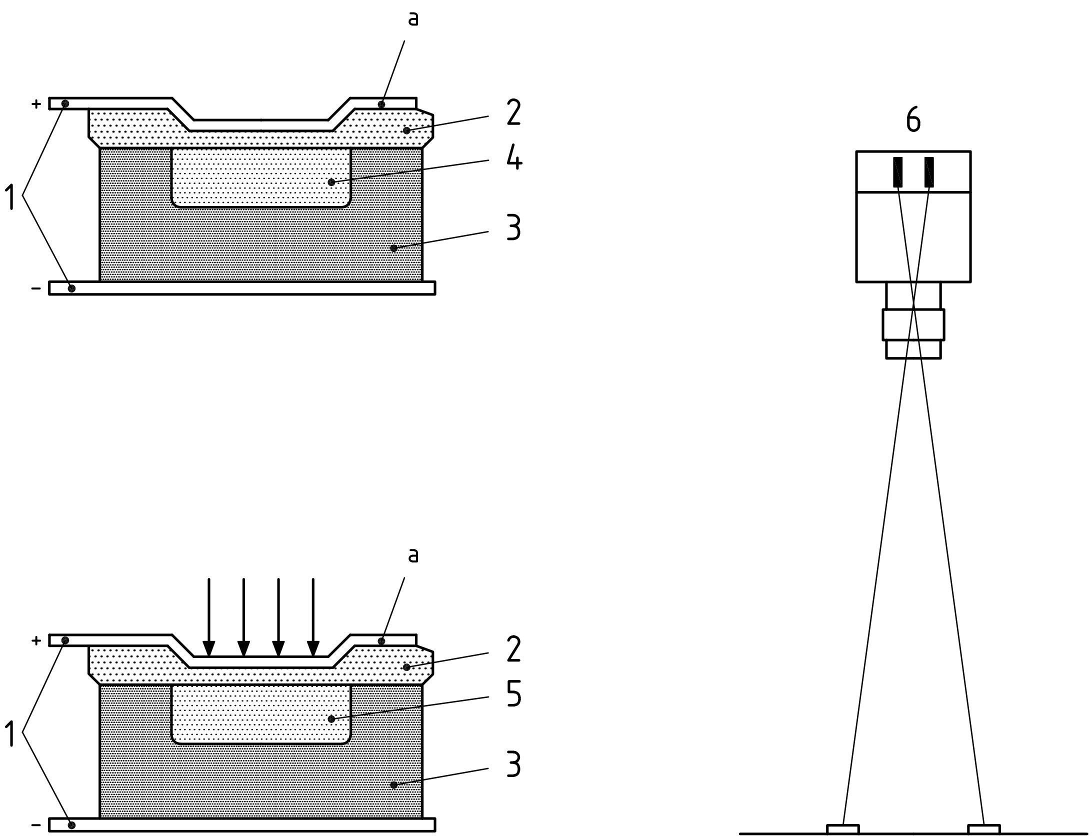
X testing time

Y change in position of the contrasting marks

Figure F.2 — Measuring principles

The way the change in position of the contrasting marks is detected is described below; see also Figure F.3.

The camera chip consists of a matrix of discrete light-sensitive elements, positioned very close together in a regular linear pattern. During an integration time which can be set externally, these elements, also called pixels, convert the incoming light into proportional electrical charges. By means of a control pulse, these charges are synchronously reloaded into a matrix of condensers and from there, via shift registers, they can be read out in either columns or lines as charge-proportional voltages. These voltages, the amplitude of which now corresponds to a grey-scale value of light, are digitized and converted into grey-scale value functions, which are thereby assigned to the individual pixel positions. From the pattern of these grey-scale value functions over the pixel addresses, it takes relatively little computer power to calculate the position and displacement of the measuring edges mapped on the CCD chip and the change in their spacing to a very high resolution.



Key

1 connections

2 SiO_2

3 P-dosed silicon

4 depleted P-layer (CCD cell not exposed to light)

5 free electrons due to light (CCD cell exposed to light)

6 camera

[a] light-permeable

Figure F.3 — Working principles

Since essentially only a few lines or columns of the chip contain information about the pattern of the position of the edges, once the starting position has been entered, the read-out can be restricted to those zones of the chip where the edge has moved. In addition to measuring the displacement of the edges along the longitudinal axis, the crossways contraction can be measured for the same time frame.

By using rapid signal processors, it is possible to measure the distortion on the main axis not only between two edges but also over a whole observation grid.

F.2 Calibration options and outside influences on video extensometers

For the purpose of calibration, the usual mechanical methods of calibration (gauge blocks, mechanical and optical measuring sensors, interferometric techniques) can be used, whereby measuring strips are set and measured in discrete positions. In addition, mechanically defined “grid elements” can be used, which are applied to the points on the test piece where the grid spacings are known.

The accuracy of the measurements can be affected by a whole range of influences which must be recognized and controlled by the user.

One influence is the field of view of the camera, which is defined by the focal length of the lens and the distance of the lens from the CCD chip and from the test piece. If the camera can resolve *n* positions in the focal plane, then the same applies to the measuring range, if the field of view and the chip plane are vertical to the optical axis. Where the field of view is small, it is important to take account of the diffraction limit of the image and remain within it.

Other influences related to the mapping principle, which are hard to detect experimentally, result from movements of the test piece in the optical axis and from a possible tilting of the image-to-object plane. The latter can lead to an error in the measurement of the absolute length or the change in length – so that these may contradict what is required by the norm – but in principle it does allow a correct relative measurement.

Another influence may come from vibrations of the camera or the lens, which, because of the mapping ratios, may have an extremely powerful effect on the focal plane, while movements of the test piece generally have a reduced effect.

In measuring the intensity of the pixel illumination amplitude, the measuring process uses so-called inter-pixel interpolation, based on defining the light intensity transfers of the reference edges between individual pixels. For this reason, the test piece shall be illuminated by artificial light that does not change in source or over time. Additional daylight, which is always subject to variations over time, must be excluded from the test piece and the camera. The test piece must be illuminated by light sources powered by direct current or high-frequency alternating current in such a way that it only scatters light diffusely in the direction of the camera and there are no direct reflections towards the camera lens.

Operators should not wear light-coloured clothing and should move about as little as possible during the experiment, to avoid optical interference in the camera system. Care must also be taken that the temperature of the camera components remains constant during the test period, since otherwise the characteristic curve of the CCD chip will shift because of changes in the quantum efficiency of the CCD chip.

Some of these outside influences can be detected quantitatively by switching on all operating elements with the test piece only fixed on one side, and observing the drift of the measuring signal.

In addition to considering the environmental influences described above, it is also important to note the dynamic behaviour of the recording system and the test piece deformation. It must be ensured that the speed of deformation and the light integration time on the chip are in proportion, guaranteeing that the deformation movement on the test piece does not become unclear in the focal plane over time.

It is particularly effective if the measuring area is passed through by a doublet of two strips at a known and fixed distance, which pass through the field of view.

Annex G
(informative)

Full field strain measurement video extensometry

G.1 Introduction

Full field strain measurement is the measurement of the “in-plane” strain fields over the surface of a test piece subject to applied stress.

G.2 General

A conventional extensometer measures a total displacement over an extended length (the gauge length), full field strain measurement methods measure multiple orthogonal and shear strain components values at multiple points across a surface.

The techniques in common use are non-contact optical; some of the techniques are capable of being extended to measure both “in-plane” strain and “out-of-plane” displacement and shape.

The amount of processing required to compute a strain field and the amount of data produced means that these systems do not produce their results in “real time”; usually, multiple images are captured during a test and these are “post-processed” to produce the strain field data.

When measuring full field strain, there is, invariably, a compromise to be made between the “spatial resolution” i.e. the density of points at which the strain values are determined, and the resolution of the strain values. Reducing the spatial resolution by averaging the strain values across a number of adjacent points will increase the resolution of the strain values.

G.3 Techniques

G.3.1 Digital image correlation (DIC)

DIC is an image analysis technique which relies upon the presence of a contrasting, random pattern over the surface of the test piece. The images are usually acquired using a CCD camera, although other image capture devices such as AFMs and SEMs can also be used.

The technique compares two images of the test piece acquired at different times, e.g. one before and one after deformation. Sub-images are chosen from the images and are then compared using cross-correlation algorithms, in order to produce a displacement map of the surface. Further processing can then produce 2D strain field data.

Digital image correlation uses non-coherent (white light) illumination. The random pattern on the surface can be produced in a number of ways. Some materials will have a natural texture which can be used directly, or random pattern which can be applied using a contrasting medium.

If multiple cameras are used, then it is possible to produce both 3D shape and deformation measurements.

G.3.2 Electronic speckle-pattern interferometry (ESPI)

ESPI uses coherent laser illumination of the test piece from two directions in order to form speckle patterns containing interference fringes on the surface of the test piece, the pattern is then recorded using a CCD camera. Analysis of the images provides full-field information about the displacement vectors. Depending on the detailed optical system used ESPI systems can, independently, sense both in plane and out of plane displacements. The displacement fields can then be processed to obtain full field strain maps.

G.3.3 Photoelasticity

Photoelastic stress analysis is based on the temporary birefringence exhibited by transparent materials subjected to strain. When such materials are viewed using polarized light, fringes are observed that are related to the direction and magnitude of the strains present. The technique can be used directly, in transmission mode, on transparent materials. More generally the technique of reflection photoelasticity can be employed; this uses a transparent polymer coating that is bonded to an opaque object and acts as a strain witness.

The photoelastic fringes can be observed using a polariscope and recorded using a digital camera for analysis using digital processing methods.

G.3.4 Geometric moiré

Geometric moiré is a white light technique (i.e. it does not require coherent illumination), which relies on the comparison between a grid attached to the test piece under load and an undeformed reference grid to determine full field strain. The moiré fringes produced by the gratings are, typically, recorded using a CDD camera. Movement of the fringes provides information about in-plane displacement on the surface of the test piece normal to the fringes. The displacement fields are then numerically differentiated in order to obtain 2D strain maps.

G.3.5 Grating (moiré) interferometry

Grating interferometry is similar, in principle, to geometric moiré, however because the gratings are much smaller in scale it is a much more sensitive technique. Grating interfereometry employs coherent laser illumination of the test piece along with a high frequency grating pattern on the surface of the test piece. Moiré fringes are formed and these are recorded with a CDD camera. Movement of the fringes provides information about in-plane displacement on the surface of the test piece normal to the fringes. It provides full-field information about in-plane displacement vectors when the test piece is illuminated from different directions. The displacement fields are numerically differentiated in order to obtain strain.

G.4 Calibration of full field strain measurement systems

The complexity of full field strain measurement systems and the large amount of data that they produce means that all aspects of these systems cannot be verified using the methods developed for conventional extensometers. It is possible, however, to process full field strain data to produce a value for the total axial strain between two points on the test piece. This value can be compared to the value that would be produced by a conventional extensometer and the methods used to calibrate a conventional extensometer can be applied.

Calibration methods for different types of full field strain measurement systems are outlined in References [13] to [20].

Annex H
(informative)

Calibration of a cross-head measurement system

The calibration of a cross-head measurement system can principally be made according to the same procedure as described in this International Standard.

The measuring of the gauge length can be omitted.

The starting point has to be documented in the calibration certificate.

Machine stiffness is the ratio between the force and the deflection of the test system. This includes the frame of the machine, the strain-application mechanism, the force-measuring device, and the grips and attachments by which the test piece is held. For a “soft” machine, the rate of traverse of the driven element is not necessarily the same as the rate of separation of the grips. Consequently, the uncorrected cross-head movement should not be used as a measure of test piece deflection. Preference should therefore be given to a machine which is stiff in comparison to the test piece so that the speeds of grip separation and, if required, their accuracy of measurement, are in accordance with the requirements of ISO 5893 [21] and ASTM E2309 [7].

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