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# Rubber, vulcanized or thermoplastic — Determination of rebound resilience

*Caoutchouc vulcanisé ou thermoplastique — Détermination de la résilience de rebondissement*

Reference number
ISO 4662:2017(E)

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# Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 45, *Rubber and rubber products*, Subcommittee SC 2, *Testing and analysis*.

This fourth edition cancels and replaces the third edition (ISO 4662:2009), which has been technically revised to add the calculation of the impact velocity for tripsometer method (Annex E). It also incorporates the Technical Corrigendum ISO 4662:2009/Cor.1:2010.

# Introduction

When rubber is deformed, an energy input is involved; part of which is returned when the rubber returns to its original shape. That part of the energy which is not returned as mechanical energy is dissipated as heat in the rubber.

The ratio of the energy returned to the energy applied is termed the resilience. When the deformation is an indentation due to a single impact, this ratio is termed the rebound resilience.

The value of the rebound resilience for a given material is not a fixed quantity, but varies with temperature, strain distribution (determined by the type of indentor and test piece and by their dimensions), strain rate (determined by the velocity of the indentor), strain energy (determined by the mass and velocity of the indentor) and strain history. Strain history is particularly important in the case of filler-loaded polymers, where the stress-softening effect necessitates a mechanical conditioning.

This variation of resilience with conditions is an inherent property of polymers, which can therefore only be fully evaluated if tests are carried out over a wide range of conditions. The factors described can have a different quantitative influence on resilience. While temperature can critically affect resilience near transition regions of the material tested, factors connected with time and amplitude of indentation have only moderate effects, and fairly wide tolerances may be admissible for them.

Ideally, rebound resilience should be measured on a test piece the back surface of which is bonded to a rigid support in order to avoid friction losses due to slippage during the impact. Since the use of bonded test pieces is impractical in many applications, unbonded test pieces are used. Frictional losses are avoided by secure clamping of the test piece.

To approach these ideal conditions in a practical apparatus, limitations are put upon the hardness (see ISO 48) of the rubber that can be tested: on the hard side to avoid unusual requirements of rigidity in the apparatus; on the soft side to avoid difficulties in clamping.

If a defined set of mechanical conditions and an appropriate apparatus are selected, a standard value of rebound resilience at any temperature can be obtained with a satisfactory degree of reproducibility.

# Rubber, vulcanized or thermoplastic — Determination of rebound resilience

**WARNING 1 — Persons using this document should be familiar with normal laboratory practice. This document does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and to ensure compliance with any national regulatory conditions.**

**WARNING 2 — Certain procedures specified in this document might involve the use or generation of substances, or the generation of waste, that could constitute a local environmental hazard. Reference should be made to appropriate documentation on safe handling and disposal after use.**

## 1 Scope

This document specifies two methods for determining the rebound resilience of rubber the hardness of which lies between 30 IRHD and 85 IRHD. They are the pendulum method and the tripsometer method.

With the pendulum method, a mass with a spherical end impacts a flat test piece, firmly held but free to bulge. The kinetic energy of the impacting mass is measured immediately before and after impact.

With the tripsometer method, a flat test piece is impacted by a hemisphere mounted on the periphery of a disc which is supported on an axle and caused to rotate by an off-axis mass. The kinetic energy of the impacting mass is measured immediately before and after impact.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 23529, *Rubber — General procedures for preparing and conditioning test pieces for physical test methods*

## 3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

**3.1**
**rebound resilience**
ratio between the returned and the applied energy of a moving mass which impacts a test piece

Note 1 to entry: It is usually expressed as a percentage.

# 4 Principle

A test piece with plane, parallel surfaces is impacted on one surface by a linearly or circularly oscillating body, the impacting surface of which is spherical. The rebound resilience is determined by measurement of the energy of the impacting mass immediately before and after impact.

NOTE Conventionally, the input and output energies of the moving mass have been determined by observing the potential energy of the mass when at rest before moving to impact the test piece and on reaching zero velocity after rebound. The detailed descriptions of the apparatus described in this document follow this convention. However, it is equally acceptable to measure the input and output energies of the moving mass by observing its velocity immediately before and after impact and calculating the kinetic energies.

# 5 Pendulum method

## 5.1 Apparatus

### 5.1.1 General

The rebound resilience shall be measured by means of an apparatus consisting of a pendulum-like one-degree-of-freedom mechanical oscillatory device and a heavy and secure test piece holder.

The two items shall be suitably fixed together for rebound resilience measurements, and either item can be removed for purposes of adjustment or checking of the oscillatory device.

Means shall be provided for measuring the rebound of the pendulum, either using a calibrated scale or an electrical signal.

Various practical designs of apparatus which conform to these specifications are available (see Annex B and Annex C).

NOTE 1 The various types of apparatus designed to operate within the ranges specified for the various parameters (see below) and correctly calibrated give substantially the same values of rebound resilience.

The apparatus and impacted test piece characteristics shall be such as to fall within the following specified ranges:

— indentor diameter ($D$): 12,45 mm to 15,05 mm;

— test piece thickness ($d$): (12,5 ± 0,5) mm;

— impacting mass ($m$): 0,25 kg to 0,35 kg;

— impact velocity ($v$): 1,4 m/s to 2,0 m/s;

— apparent strain energy density ($mv^2/Dd^2$): 324 kJ/m$^3$ to 463 kJ/m$^3$.

NOTE 2 The conditions and apparatus specified in this document involve the selection of a spherical indentor and of a flat test piece and are assumed to be essentially dependent on the fundamental parameters $D$, $d$, $m$ and $v$ listed above. In addition, the ratio of impact energy to an equivalent volume or "apparent strain energy density" ($mv^2/Dd^2$), which under simplifying assumptions is related to impact strain, has to be maintained within the narrow range specified.

NOTE 3 The ranges are such that they embrace the requirements for the Lüpke pendulum method (12,5 mm, 12,5 mm, 0,35 kg, 1,4 m/s, 351 kJ/m$^3$) and the modified Schob pendulum method (15,0 mm, 12,5 mm, 0,25 kg, 2 m/s, 427 kJ/m$^3$).

In addition, allowance has been made for

a) a small tolerance (±0,05 mm) to allow for mechanical imperfections of spheres of 12,5 mm and 15 mm nominal diameter;

b) an additional tolerance ($^{+112}_{-27}$ kJ/m$^3$) on $mv^2/Dd^2$ to allow for the effect of variation in test piece thickness (±0,5 mm).

### 5.1.2 Oscillatory device

The oscillatory device shall consist of a rigid body or hammer terminating in an indenting spherical surface, supported so as to oscillate linearly or circularly under the action of a restoring force which can be due to gravity or produced by the elastic reaction of springs or by a wire in torsion. The velocity of the indenting spherical surface at the point of impact shall be in the horizontal direction and perpendicular to the surface of the test piece.

### 5.1.3 System for following the motion of the hammer

The motion of the hammer shall be followed either by means of a system comprising a pointer and a fixed scale or by a system which measures the position or velocity of the hammer to furnish electrical signals.

For pendulums in which the restoring force is due to gravity, the rebound resilience, $R$, is given by Formula (1):

$$R = \frac{h}{H} \tag{1}$$

where

$h$ is the height of rebound;

$H$ is the drop height.

It is usually convenient for the scale to measure either the horizontal rebound distance or, for rigid-arm pendulums in particular, the angle of rebound. For pendulums in which the restoring force is due to a torsion wire or to the elastic reaction of springs, the rebound resilience is given by Formula (2):

$$R = \frac{\alpha_{\mathrm{R}}^2}{\alpha_{\mathrm{I}}^2} \tag{2}$$

where

$\alpha_{\mathrm{R}}$ is the angle of rebound;

$\alpha_{\mathrm{I}}$ is the angle of impact.

For this form of apparatus, it is convenient for the scale to be used to measure the angle of rebound.

The scale can be graduated uniformly or be calibrated directly in units of resilience. For uniformly graduated scales, conversion equations, charts or tables to allow the determination of the resilience are also necessary.

### 5.1.4 Test piece holder

The disc-shaped test piece shall be securely held during mechanical conditioning and rebound measurement.

The surface against which the back of the test piece is applied shall be metallic, flat and smoothly finished, vertical and perpendicular to the impact velocity direction.

This backplate is part of an anvil which shall either be free (in which case, it shall have a mass of at least 200 times the impacting mass) or shall be rigidly fastened to a very rigid system, such as a masonry structure.

Any type of suitable holding device can be used provided that it gives rebound resilience values that deviate by not more than 0,02 (absolute rebound resilience) from those obtained with test pieces bonded to a rigid backplate. This shall be checked using one compound of high rebound resilience (approximately 0,90) and one of high hardness (approximately 85 IRHD).

No lateral restraint shall be applied to the test piece. A clearance of at least 2 mm shall be left around it in order to allow it to bulge freely when impacted.

Examples of suitable holding devices include suction holding devices (by vacuum), mechanical clamping devices and combinations of the two. In any of these cases, the holding device shall not cause excess deformation of the surface to be impacted and shall not allow shuffling or slipping. A recommended mechanical clamping device consists of a metal ring (see Figure 1) with a 20 mm internal diameter and 35 mm external diameter and able to exert on the front of the test piece a force of (200 ± 20) N given, for example, by springs. In this case, the indenting sphere shall enter, at its rest position, the centre of the retaining ring. Another recommended method of holding is by suction on the back of the test piece. This can be applied through a circular groove, 25 mm in diameter and 2 mm in width, evacuated by a pump which maintains an absolute pressure not greater than 10 kPa. In this case, the force exerted by the retaining ring can be reduced to (150 ± 15) N.

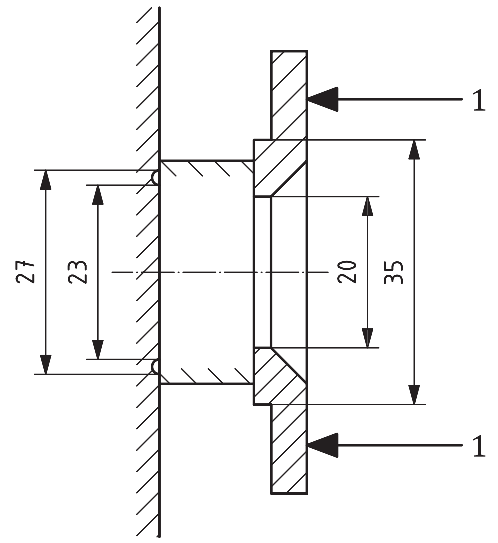
### 5.1.5 Temperature control

If measurements are to be carried out at a series of temperatures different from standard laboratory temperature, the pendulum can be placed and operated in a suitable oven or cold chamber operating in accordance with ISO 23529. In this case, the apparatus shall be checked for correct operation (see 5.1.6) over the range of temperatures used.

Alternatively, suitable provisions shall be made for heating or cooling the test piece holder by means of circulating fluids (see Figure 2). A heated or cooled gas curtain over the front opening of the holder is recommended in order to ensure that the test piece is completely surrounded by a temperature-controlled medium.

Thermocouples or other instruments shall be provided for measuring the temperature of the holder at a position as close as possible to the test piece.

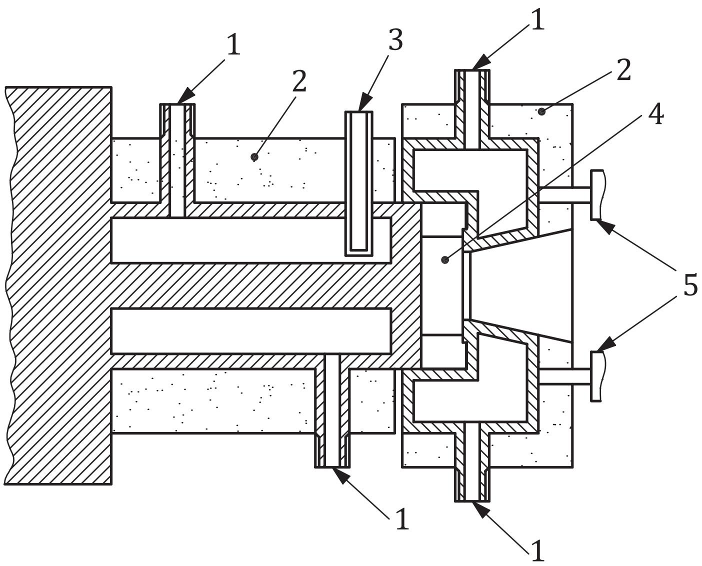
Dimensions in millimetres




**Key**

1 holding force: (150 ± 15) N with suction or (200 ± 20) N without suction

**Figure 1 — Mechanical clamping device (optional)**




**Key**

1 inlet/outlet for fluid

2 insulation

3 thermometer pocket

4 test piece

5 spring-loaded levers

**Figure 2 — Example of temperature-controlled test piece holder**

### 5.1.6 Adjustment of oscillatory device

The complete apparatus shall be repeatedly operated, impacting test pieces of rubber at the extreme ranges of hardness (30 IRHD and 85 IRHD). Its motion shall be smooth and no form of spurious oscillation mode, such as whip or vibration, shall be caused by the impact because of insufficient stiffness of rigid parts or a defective system of guidance.

For the purpose of initial adjustment or periodic checking, the test piece holder shall be removed from the oscillatory device and the following procedure carried out (measurement of the logarithmic decrement of the Lüpke pendulum may be omitted because it is clear that its logarithmic decrement is less than 0,01).

Weigh and measure the dimensions of the moving hammer and measure its distances from the guiding pivots or suspensions in order to carry out inertial-parameter calculations. From these, verify that the equivalent impacting mass conforms to the specifications in 5.1.1 and that its line of impact is such as not to cause significant reactions on pivots or suspensions.

Ensure that the diameter of the spherical indenting surface conforms to the specification in 5.1.1 and that the area of the spherical surface of the indentor in all cases exceeds the area of the indented surface of the rubber during impact. It is preferable that the impacting surface be a complete half-sphere.

Leave the complete oscillatory device free to attain its rest position. If using a pointer and fixed scale (see 5.1.3), check that this is at the zero point of the scale and that this is the position at which impact takes place. At this point, the indenting sphere shall be moving horizontally.

The following procedure shall be carried out where necessary to correct for frictional losses. It is not necessary where a method of observing impact and rebound velocities is used or the logarithmic decrement can be shown to be less than 0,01.

To correct for frictional losses, determine logarithmic decrements and corresponding damping corrections as follows. Set the oscillatory device in motion. Time its periods of oscillation and measure the amplitudes of successive oscillations (on the same side). Calculate the corresponding logarithmic decrement $\Lambda$ by Formula (3):

$$\begin{aligned}\Lambda &= \frac{1}{n}\log_e \frac{l_x}{l_{x+n}} \\ &= \frac{1}{2n}\log_e \frac{R_x}{R_{x+n}}\end{aligned} \quad (3)$$

where

| | |
|---|---|
| $n$ | is the number of full oscillations considered; |
| $l_x$ and $l_{x+n}$ | are amplitudes read on a uniform scale; |
| $R_x$ and $R_{x+n}$ | are amplitudes read on a quadratic scale. |

For the present purposes, it is immaterial whether the scale has or has not already been corrected for small nonlinearity.

If the operation of the instrument involves different damping conditions during the forward and backward impact strokes, due for example to a pawl engaging the pointer, then the measurements described shall be carried out under both conditions and their readings averaged.

Calculate the full period of oscillation, $T$, and logarithmic decrement, $\Lambda$, as the averages of five oscillations for different amplitudes, as follows:

— full scale $T_1$ $\Lambda_1$

— one-half scale $T_2$ $\Lambda_2$

— one-quarter scale $T_4$ $\Lambda_4$

None of the values $\Lambda_1$, $\Lambda_2$ and $\Lambda_4$ shall differ from their average by more than 0,01 and none of them shall exceed 0,03. While a value under 0,01 can be neglected, for values between 0,01 and 0,03 a correction shall be applied to the rebound results, preferably by displacing the starting point of the moving mass beyond the unity resilience point by a corresponding amount.

Calculate the damping correction, $\Delta H$, in millimetres, to the drop height by Formula (4):

$$\Delta H = H\left(1 - \frac{1}{e^{2\Lambda_i}}\right) \times \frac{1}{4} \quad (4)$$

where

| | |
|---|---|
| $H$ | is the drop height (mm); |
| $\Lambda_i$ | is the appropriate logarithmic decrement measured for the drop height. |

A more refined evaluation of the correction is in most cases unnecessary, but may be made if a detailed analysis of energy losses is available.

## 5.2 Test pieces

### 5.2.1 Preparation

The test pieces shall have flat, smooth and parallel surfaces. They shall be prepared either by moulding or by cutting and buffing. If test pieces are prepared by cutting and buffing, this shall be carried out in accordance with ISO 23529. They shall be free from fabric and any other reinforcing support.

### 5.2.2 Dimensions

The standard test piece is a disc with a thickness of (12,5 ± 0,5) mm and a diameter of (29 ± 0,5) mm. Other test pieces having non-standard dimensions may be used for comparative measurements with special provisions (see Annex A).

### 5.2.3 Measurement of dimensions

Check that the test pieces meet the requirements in 5.2.2, using the appropriate method of measurement described in ISO 23529.

### 5.2.4 Number of test pieces

For each material, two test pieces shall be tested.

### 5.2.5 Time-interval between forming and testing

Samples and test pieces shall be protected from light and heat as much as possible during the interval between forming (vulcanization or moulding) and testing.

For normal test purposes, the minimum time between forming and testing shall be 16 h. In cases of arbitration, the minimum time shall be 72 h.

For non-product tests, the maximum time between forming and testing shall be four weeks and, for evaluations intended to be comparable, the tests shall, as far as possible, be carried out after the same time interval.

For product tests, whenever possible, the time between forming and testing shall not exceed three months. In other cases, tests shall be made within two months of the date of receipt of the product by the purchaser (see ISO 23529).

If the preparation of the test piece involves buffing, the interval between buffing and testing shall be not less than 3 h and not greater than 72 h.

### 5.2.6 Conditioning

Prepared test pieces shall be conditioned immediately before testing for a minimum period of 3 h at one of the standard laboratory temperatures specified in ISO 23529. The same temperature shall be used throughout any one test or series of tests intended to be comparable.

## 5.3 Temperature of test

The temperature or temperature range of the test shall be chosen according to the material being tested and the information required. Preference shall be given to the temperatures listed in ISO 23529. The tolerance limits on the temperature shall be not more than ±1 °C. When no temperature is specified, a standard laboratory temperature shall be chosen.

Where the resilience changes quickly with temperature, the use of more temperatures at closer intervals is recommended.

## 5.4 Procedure

### 5.4.1 Thermal conditioning and mounting of test piece

If stickiness is noted on the impacted surface, its effect shall be avoided by dusting the surface lightly, for example, with talc.

If the test temperature differs from the standard laboratory temperature chosen (see 5.3), first bring the complete test apparatus, or the special heated or cooled holder (see 5.1.5), to the test temperature.

Mount the test piece in the holder and allow sufficient time for the test piece to reach a uniform temperature within the prescribed tolerance limits (see ISO 23529). Alternatively, test pieces may be heated or cooled separately from the holder in an oven or cold chamber in accordance with ISO 23529 and then quickly inserted in the heated or cooled holder. In this case, the time in the holder before testing shall preferably be reduced to 3 min.

In tests at low temperatures, provision shall be made to prevent frost from forming on the test piece.

#### 5.4.2 Mechanical conditioning of test piece

After applying the prescribed thermal conditioning and mounting the test piece in the holder, carry out a mechanical conditioning by subjecting the test piece to a number of successive impacts between three minimum and seven as maximum, so as to reach a practically constant rebound amplitude.

#### 5.4.3 Measurement of rebound resilience

Immediately after the impacts for mechanical conditioning, carry out three more impacts on the test piece and note the three rebound readings.

#### 5.4.4 Calculation and expression of results

Where no corrections are necessary, calculate the rebound resilience using the appropriate formula in 5.1.3.

Where correction of drop height and rebound height is necessary, the rebound resilience is calculated by Formula (5):

$$R_L = \frac{h + \Delta h}{H - \Delta H} \times 100 \tag{5}$$

where

$R_L$ is the rebound resilience (%);

$h$ is the rebound height (mm);

$H$ is the drop height (mm);

$\Delta h$ is the damping correction to the rebound height (mm);

$\Delta H$ is the damping correction to the drop height (mm).

Take the median of the resilience values calculated for each of the three impacts on the test piece as the rebound resilience of the test piece.

Calculate the mean of the median values for the two test pieces.

### 5.5 Precision

Precision data for this method are given in Annex D.

### 5.6 Test report

The test report shall include the following particulars:

a) sample details:

 1) a full description of the sample and its origin;

2) the method of preparation of the test pieces from the sample, for example moulded or cut;

b) test method:

1) a full reference to the test method used, i.e. the number of this document and “pendulum method”;

2) the type of apparatus used and the indentor diameter, mass and velocity;

3) if the standard test piece was not used, details of the test piece;

4) the method used to hold the test piece;

c) test details:

1) the time and temperature of conditioning of the test pieces prior to testing;

2) the temperature of the test, and the relative humidity if necessary;

3) details of any procedures not specified in this document;

d) test results:

1) the number of test pieces tested;

2) the individual test results;

3) the mean result;

e) the date of the test.

# 6 Tripsometer method

## 6.1 Apparatus

### 6.1.1 General

The apparatus shall consist of a rotary pendulum consisting of an axle-mounted disc with an off-centre mass and an indentor attached to the periphery, a heavy and secure test piece holder and a means of measuring the height of drop and rebound of the off-centre mass (see Figure 3). The pendulum and holder shall be removable for purposes of adjustment or checking of the oscillatory device. The apparatus and test piece shall meet the following requirements:

— indentor diameter ($D$): (4,00 ± 0,04) mm;

— thickness of type 1 test piece ($d_1$): (7,0 ± 0,1) mm;

— thickness of type 2 test piece ($d_2$): (4,0 ± 0,1) mm;

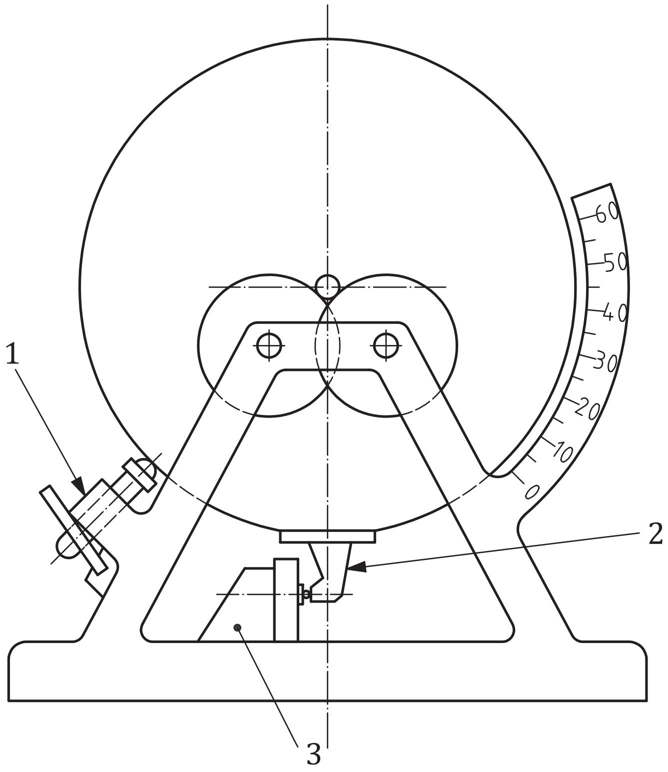
— impacting mass ($m$): (60,0 ± 0,2) g;

— impact velocity ($v$): (0,125 ± 0,006) m/s;

— apparent strain energy density for type 1 test piece ($mv^2/Dd_1{}^2$): 3,3 kJ/m$^3$ to 7,2 kJ/m$^3$;

— apparent strain energy density for type 2 test piece ($mv^2/Dd_2{}^2$): 12,6 kJ/m$^3$ to 16,9 kJ/m$^3$.

NOTE The example of the calculation procedure for the impact velocity is given in Annex E.




**Key**

1 release mechanism

2 striker

3 test piece holder

**Figure 3 — Example of a tripsometer**

### 6.1.2 Pendulum

The pendulum shall consist of a solid steel disc (420 ± 2,5) mm in diameter and with a mass of (16,5 ± 0,05) kg. The disc shall carry on its periphery a bracket holding a steel ball or hemispherical striker (4 ± 0,04) mm in diameter, with its centre (260 ± 0,5) mm from the centre of the disc. The ball and bracket together shall add an unbalanced mass of (60 ± 0,2) g. The unbalanced mass shall be in such a position that the time for one complete oscillation (amplitude about 45°) of the disc plus unbalanced mass is (10 ± 0,5) s.

The disc shall be mounted on bearings designed to impart a minimum of friction to the system. It shall be provided with a mechanism permitting it to be held, displaced 45° from the impact position, until released. The release mechanism shall not impart any impulse to the disc (see Figure 3).

NOTE 1 Details of the determination of the logarithmic decrement of the oscillating device and the maximum permissible value are given in 6.1.6.

NOTE 2 A design using air bearings to minimize friction is described in Annex C.

### 6.1.3 System for following the motion of the disc

The motion of the disc shall be followed either by means of a system comprising a pointer or vernier rigidly fixed to the disc, travelling along a scale carried on the frame of the machine, thus measuring the angular displacement of the disc, or by a system which determines the angular velocity of the disc immediately before and immediately after impact. If a scale is used, it shall be graduated either in degrees of arc or directly in percentage rebound resilience. The spacing of the graduation marks shall be such that the percentage rebound resilience can be determined to an accuracy of ±1.

For pendulums in which the restoring force is due to gravity, the rebound resilience, $R$, is given by Formula (6):

$$R = \frac{1 - \cos\theta}{1 - \cos\phi} \tag{6}$$

where

$\theta$ is the rebound angle;

$\phi$ is the angle of drop (45°).

#### 6.1.4 Test piece holder

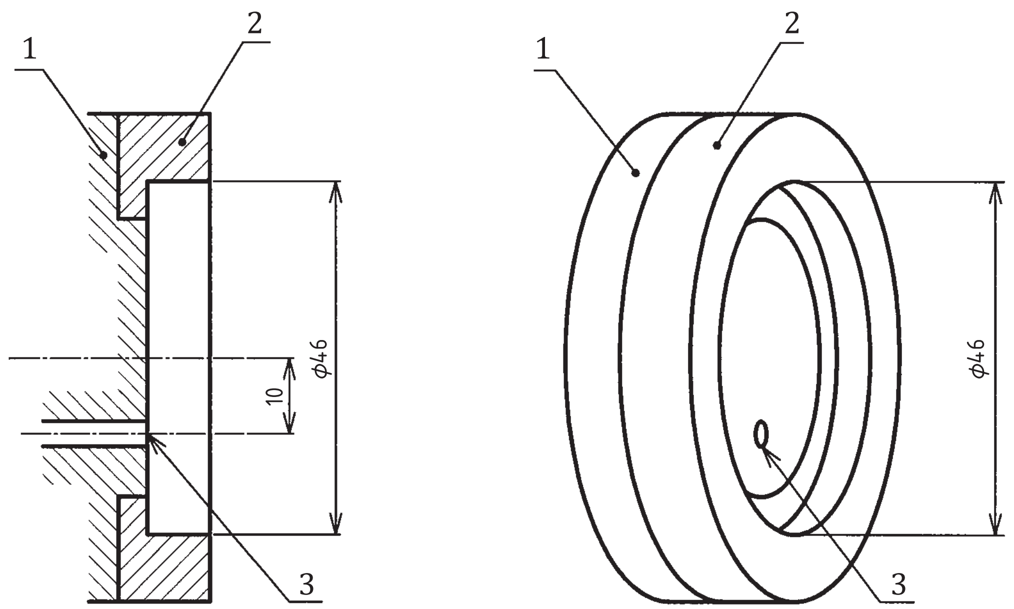
The test piece holder shall hold the test piece firmly against a rigid anvil. The test piece shall be so held that, when the pendulum is in its position of equilibrium, the striker just touches the centre of the test surface of the test piece.

The test piece shall be held by the following means according to the type of test piece (see 6.2.2).

a) Type 1 test piece shall be held by suction acting through holes in the anvil near the periphery of the test piece. A recommended method of holding is by applying suction to the back of the test piece by a pump which maintains an absolute pressure not greater than 10 kPa (see Figure 4).

b) Type 2 test piece shall be held by a cover plate acting on the front surface of the test piece. A recommended device consists of a cover plate (see Figure 5) which clamps the edge of the test piece and exerting, on the front of the test piece, a force of (2 ± 0,1) N produced, for example, by springs.

Dimensions in millimetres




**Key**

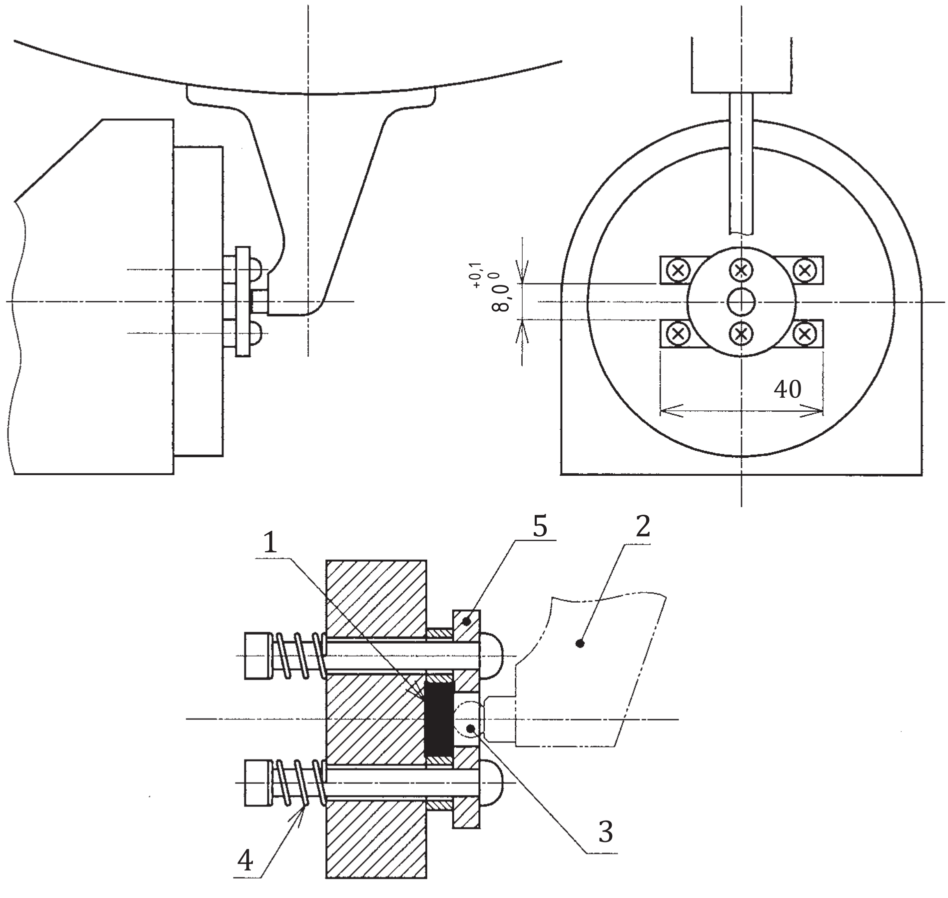
1 backplate

2 test piece holder

3 vacuum connection

**Figure 4 — Example of a holder for type 1 test pieces**

Dimensions in millimetres




**Key**

1 test piece

2 striker

3 indenter

4 spring

5 cover plate

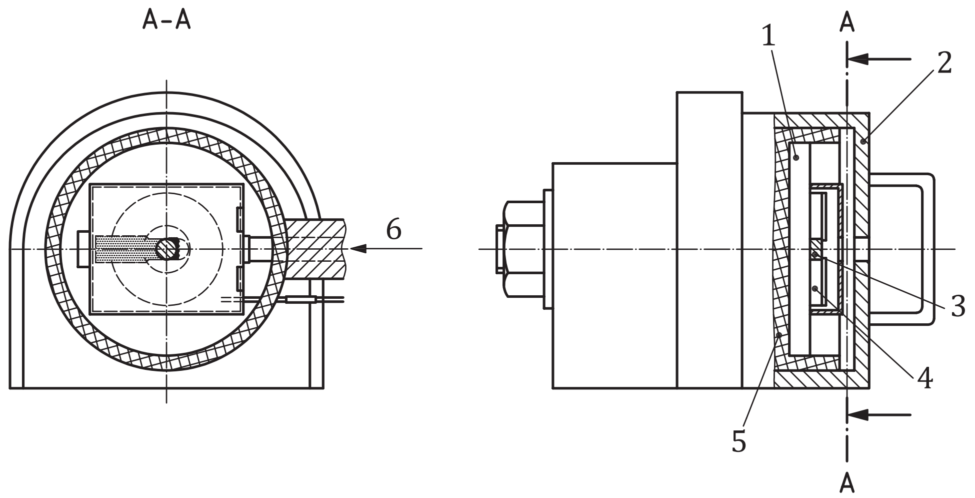
**Figure 5 — Example of a holder for type 2 test pieces**

### 6.1.5 Temperature control

If measurements are to be carried out at a series of temperatures different from the ambient temperature, the pendulum can be placed and operated in a suitable oven or cold chamber operating in accordance with ISO 23529. In this case, the apparatus shall be checked for correct operation (see 6.1.6) in the range of temperatures used. Alternatively, suitable provisions shall be made for heating or cooling the test piece holder by means of circulating fluids (see Figure 6). A heated or cooled gas curtain over the front opening of the holder is recommended in order to ensure that the test piece is completely surrounded by a temperature-controlled medium.

Thermocouples or other instruments shall be provided for measuring the temperature of the holder in a position as close as possible to the test piece.




**Key**

1 backplate
2 heat shield cover
3 test piece
4 test piece holder
5 insulation
6 inlet/outlet for fluid

**Figure 6 — Example of test piece holder with temperature control system**

### 6.1.6 Adjustment of oscillatory device

The complete apparatus shall be repeatedly operated, impacting test pieces of rubber at the extreme ranges of hardness (30 IRHD and 85 IRHD). Its motion shall be smooth and no form of spurious oscillation mode, such as whip or vibration, shall be caused by the impact because of insufficient stiffness of rigid parts or a defective system of guidance.

For the purpose of initial adjustment or periodic checking, the test piece holder shall be removed from the oscillatory device and the following procedure carried out.

Weigh and measure the dimensions of the moving striker and bracket and measure their distances from the axis of rotation of the disc in order to carry out inertial-parameter calculations. From these, verify that the machine parameters conform to the specifications in 6.1.1 and that the line of impact is such as not to cause significant reactions on pivots or suspensions.

Ensure that the diameter of the spherical indenting surface conforms to the specification in 6.1.1 and that only the spherical surface of the indentor will contact the test piece during impact. It is preferable that the impacting surface be a complete half-sphere.

Allow the complete oscillatory device to attain its rest position. Check that this is at the zero point of the scale and that this is the position at which impact takes place. At this point, the indenting sphere shall be moving horizontally.

The following procedure shall be carried out where necessary to correct for frictional losses. It is not necessary where a method of observing impact and rebound velocities is used or the logarithmic decrement can be shown to be less than 0,01.

Set the oscillatory device in motion, time its periods of oscillation and measure the successive amplitudes (on the same side). Calculate the corresponding logarithmic decrement $\Lambda$ by Formula (7):

$$\Lambda = \frac{1}{n}\log_{e}\frac{\theta_x}{\theta_{x+n}} \tag{7}$$

where

$n$ is the number of full oscillations considered;

$\theta_x$ and $\theta_{x+n}$ are angles read on a uniform scale.

For the present purposes, it is immaterial whether the scale has or has not already been corrected for small nonlinearity.

If the operation of the instrument involves different damping conditions during the forward and backward impact strokes, due for example to a pawl engaging the pointer, then the measurements described shall be carried out under both conditions and their readings averaged.

Calculate the full period of oscillation, $T$, and logarithmic decrement, $\Lambda$, as the averages of five oscillations for different amplitudes, as follows:

— full scale $T_1$ $\Lambda_1$

— one-half scale $T_2$ $\Lambda_2$

— one-quarter scale $T_4$ $\Lambda_4$

None of the values $T_1$, $T_2$ and $T_4$ shall differ from their average by more than 10 %. While a difference of under 1 % can be neglected, a difference between 1 % and 10 % shall be taken into account by applying suitable nonlinearity corrections. These shall be made by correcting the energy of the pendulum at the corresponding point on the scale.

None of the values $\Lambda_1$, $\Lambda_2$ and $\Lambda_4$ shall differ from their average by more than 0,01 and none of them shall exceed 0,03. While a value under 0,01 can be neglected, for values between 0,01 and 0,03 a correction shall be applied to the rebound results, preferably by displacing the starting point of the moving mass beyond the unity resilience point by a corresponding amount.

Calculate the damping correction $\delta_1$ to the angle of drop by Formula (8):

$$\delta_1 = \phi\left(1 - \frac{1}{e^{2\Lambda_i}}\right)\times\frac{1}{4} \tag{8}$$

where

$\Lambda_i$ is the logarithmic decrement measured close to the angle of drop;

$\phi$ is the angle of drop (45°).

Calculate the damping correction $\delta_2$ to the rebound angle by Formula (9):

$$\delta_2 = \theta\left(1 - \frac{1}{e^{2\Lambda_i}}\right)\times\frac{1}{4} \tag{9}$$

where

$\theta$ is the rebound angle;

$\Lambda_i$ is the logarithmic decrement measured close to the rebound angle.

A more refined evaluation of the correction is in most cases unnecessary, but may be made if a detailed analysis of energy losses is available.

## 6.2 Test pieces

### 6.2.1 Preparation

The test pieces shall have flat, smooth and parallel surfaces. They shall be prepared either by moulding or by cutting and buffing. If test pieces are prepared by cutting and buffing, this shall be carried out in accordance with ISO 23529. They shall be free from fabric and any other reinforcing support.

### 6.2.2 Dimensions

The test piece shall either be

— a disc with a diameter of (44,6 ± 0,5) mm and a thickness of (7 ± 1,0) mm (type 1);

— a cuboid measuring (8 ± 0,5) mm by (8 ± 0,5) mm by (4 ± 0,1) mm (type 2).

The latter test piece is particularly suitable when a number of tests are being conducted at a series of temperatures, as thermal equilibrium is achieved in a shorter time per test than when the larger and thicker disc-shaped test pieces are used.

### 6.2.3 Measurement of dimensions

Check that the test pieces meet the requirements in 6.2.2, using the appropriate method of measurement described in ISO 23529.

### 6.2.4 Number of test pieces

For each material, two test pieces shall be tested.

### 6.2.5 Time-interval between forming and testing

Samples and test pieces shall be protected from light and heat as much as possible during the interval between forming (vulcanization or moulding) and testing.

For normal test purposes, the minimum time between forming and testing shall be 16 h. In cases of arbitration, the minimum time shall be 72 h.

For non-product tests, the maximum time between forming and testing shall be four weeks and, for evaluations intended to be comparable, the tests shall, as far as possible, be carried out after the same time interval.

For product tests, whenever possible, the time between forming and testing shall not exceed three months. In other cases, tests shall be made within two months of the date of receipt of the product by the purchaser (see ISO 23529).

If the preparation of the test piece involves buffing, the interval between buffing and testing shall be not less than 3 h and not greater than 72 h.

### 6.2.6 Conditioning

Prepared test pieces shall be conditioned immediately before testing for a minimum period of 3 h at one of the standard laboratory temperatures specified in ISO 23529. The same temperature shall be used throughout any one test or series of tests intended to be comparable.

## 6.3 Temperature of test

The preferred temperature of test is one of the standard laboratory temperatures specified in ISO 23529. When other temperatures are required, these shall be selected from the list of preferred temperatures given in ISO 23529. The tolerance limits on the temperature shall be not more than ±1 °C.

Where the resilience changes quickly with temperature, the use of more temperatures at closer intervals is recommended.

## 6.4 Procedure

### 6.4.1 Thermal conditioning and mounting of test piece

If stickiness is shown on the impacted surface, its effect shall be avoided by lightly dusting the front surface only, for example, with talc.

Ensure that the test piece and test piece holder are thoroughly clean. Wipe the rear surface of the test piece with solvent to reduce shuffle (slight movement of the test piece during impact). Bring the test piece holder to the test temperature, insert the test piece and leave it in position for a sufficient time for it to reach the test temperature (see ISO 23529). A period of at least 15 min is required for 7 mm-thick test pieces. This period can, however, be shortened by first bringing the test piece to the test temperature in a chamber separate from the test piece holder.

In tests at low temperatures, provision shall be made to prevent frost from forming on the test piece.

Errors can arise if the test piece temperature is assumed to be that of the test piece holder. It is therefore recommended that the temperature of the test piece be measured by means of a fine-wire thermocouple inserted into the rubber in such a way that it does not interfere with the pendulum.

### 6.4.2 Mechanical conditioning of test piece

After applying the prescribed thermal conditioning and mounting the test piece in the holder, carry out a mechanical conditioning by subjecting the test piece to a number of successive impacts of the pendulum from its release position of 45° between three minimum and seven as maximum, so as to reach a practically constant rebound amplitude.

### 6.4.3 Measurement

Immediately after the impacts for mechanical conditioning, apply three more impacts to the test piece and note the three rebound readings.

NOTE When using the thin type 2 test piece, it has been found useful to release the pendulum at 25° to the vertical to reduce the energy of impact, particularly when softer rubbers are being tested. If this is done, the results will not necessarily equate with those obtained using a type 1 test piece.

### 6.4.4 Calculation and expression of results

Where a calibrated scale of rebound resilience is not provided, calculate the percentage rebound resilience, $R_T$, for each test using either Formula (10) or Formula (11):

$$R_T = \left(\frac{V_a}{V_b}\right)^2 \times 100 \quad (10)$$

$$R_T = \frac{1-\cos(\theta+\delta_2)}{1-\cos(\phi-\delta_1)} \times 100 \quad (11)$$

where

$V_a$ is the velocity after impact;

$V_b$ is the velocity before impact;

$\theta$ is the rebound angle;

$\phi$ is the angle of drop (45°);

$\delta_1$ is the damping correction for angle $\phi$;

$\delta_2$ is the damping correction for angle $\theta$.

Express the final percentage rebound resilience as the mean of the two individual results.

## 6.5 Precision

Precision data for this method are given in Annex D.

## 6.6 Test report

The test report shall include the following particulars:

a) sample details:

   1) a full description of the sample and its origin;

   2) compound details and cure details, where appropriate;

   3) the method of preparation of the test pieces from the sample, for example moulded or cut;

b) test method:

   1) a full reference to the test method used, i.e. the number of this document and “tripsometer method”;

   2) the type of apparatus used and the indentor diameter, mass and velocity;

   3) the type of test piece used;

   4) the method used to hold the test piece;

c) test details:

   1) the laboratory temperature;

   2) the time and temperature of conditioning of the test pieces prior to testing;

   3) the temperature of the test, and the relative humidity if necessary;

   4) details of any procedures not specified in this document;

d) test results:

   1) the number of test pieces tested;

   2) the individual test results;

   3) the mean result;

e) the date of the test.

# Annex A
(informative)

# Use of non-standard test pieces

## A.1 Non-standard diameter

Test pieces of standard thickness but having a diameter larger than standard, up to a maximum of 53 mm, may be tested. They will give results close to those obtained with the standard procedure and apparatus, provided an increased holding force is used (see Table A.1).

## A.2 Non-standard thickness

### A.2.1 General

The rebound resilience may be measured with test pieces having a thickness differing from, and in general lower than, (12,5 ± 0,5) mm. Such test pieces will give results close to those obtained with the standard procedure, provided either the adjustments described in A.2.2 or those described in A.2.3 are made. Both are based on the principle of maintaining the apparent strain energy density $mv^2/Dd^2$ at a constant value of 351 kJ/m$^3$. Test pieces may also be stacked (see A.2.4).

### A.2.2 Adjustment of the impact velocity

The impact velocity, *v*, is reduced proportionally to the test piece thickness. This reduction in velocity can easily be obtained by changing the starting point and initial deviation of the hammer while keeping the indentor diameter and impacting mass at their standard values (see 5.1.1).

In order to be able to hold thinner test pieces with the standard clamping ring, the clamping action of the latter should be supplemented by the use of suction (see 5.1.4).

While these adjustments give results which may show some discrepancies from standard rebound resilience, because of different strain distribution and poorer test piece holding, it has the advantage of simplicity because a single type of apparatus with minor adjustments may accommodate different thicknesses.

### A.2.3 Adjustment of the indentor diameter, indentor mass and impact velocity

The indentor diameter, *D*, the indentor mass, *m*, and the impact velocity, *v*, are all changed proportionally to the test piece thickness (see Table A.1). It is also necessary to change the test piece diameter, the holding ring diameter and the holding force to suit the new thickness (see Table A.1 and Figure A.1).

These adjustments obviously require different sizes of apparatus to be used and, unless only a single non-standard thickness is to be tested, are therefore more expensive. They have the important advantage, however, of giving results very close to the standard rebound resilience.

### A.2.4 Stacked test pieces

A stack, of no more than three thin test pieces of the same material, may be used to obtain a greater test piece thickness. It is necessary that the surfaces of the test pieces be very smooth, and lateral suction may help in ensuring their close contact.

Stacking of test pieces can introduce additional errors and should therefore be used only for comparative measurements.

## A.3 Thermal conditioning of non-standard test pieces

The thermal conditioning of non-standard test pieces may be carried out as for the standard ones (see 5.4.1), but taking into account the changed dimensions (see ISO 23529).

## A.4 Test report

In addition to the data already required (see 5.6), the dimensions of the test piece and the method and apparatus used to accommodate the non-standard dimensions should be reported.

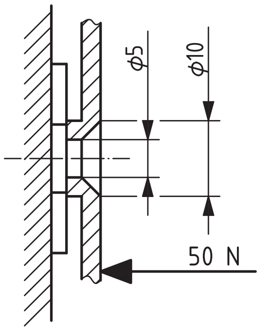
**Table A.1 — Recommended fundamental parameters when using test pieces of non-standard dimensions in the way described in A.2.3**

| | Size I | Size II | Size III | Size IV | Size V |
|---|---|---|---|---|---|
| **Fundamental parameters** | | | | | |
| Test piece thickness (*d*), mm | 2 ± 0,1 | 4 ± 0,2 | 6,3 ± 0,3 | 12,5 ± 0,5 | 25 ± 1 |
| Indenting sphere diameter (*D*), mm | 2 ± 0,05 | 4 ± 0,1 | 6,3 ± 0,1 | 12,5 ± 0,1 | 25 ± 0,2 |
| Impacting mass (*m*), kg | 0,056 ± 0,001 | 0,112 ± 0,002 | 0,176 ± 0,005 | 0,35 ± 0,01 | 0,70 ± 0,01 |
| Impact velocity (*v*), m/s | 0,222 ± 0,005 | 0,45 ± 0,005 | 0,71 ± 0,01 | 1,40 ± 0,01 | 2,8 ± 0,02 |
| **Recommended clamping arrangement** | | | | | |
| Test piece diameter, mm | | | | | |
| minimum | 9 | 15 | 20 | 29 | 50 |
| maximum | 25 | 45 | 53 | 53 | 70 |
| Clamping ring diameter (see Figure 4), mm | | | | | |
| inner | 5 | 8 | 12 | 20 | 36 |
| outer | 10 | 16 | 22 | 35 | 55 |
| Force on test piece, N | 50 | 100 | 150 | 300 | 600 |

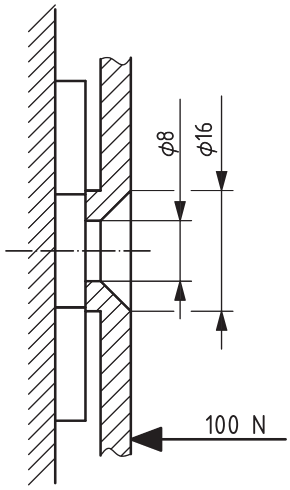
NOTE The holding force of 300 N for size IV applies to a maximum diameter of 53 mm, while the force of 200 N given in 5.1.4 applies to a maximum diameter of 35 mm. The holding force necessary to obtain consistent values of rebound resilience is contained within a widely varying range, depending on the test piece dimensions and properties, the finish of the holding surfaces and previous contact history. Its maximum value is limited by the possibility of excessive deformation of soft vulcanizates, while its minimum value is limited by the possibility of shuffle or slip.

The values indicated here are considered to be safe values for most ranges of the dimensions and properties involved.

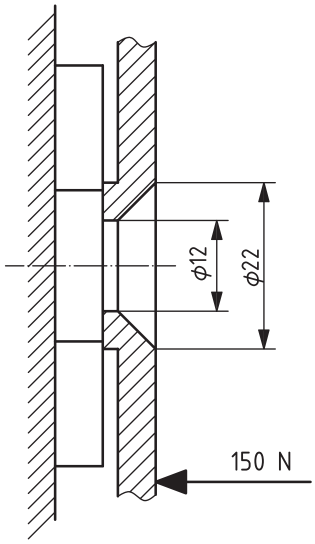
Dimensions in millimetres



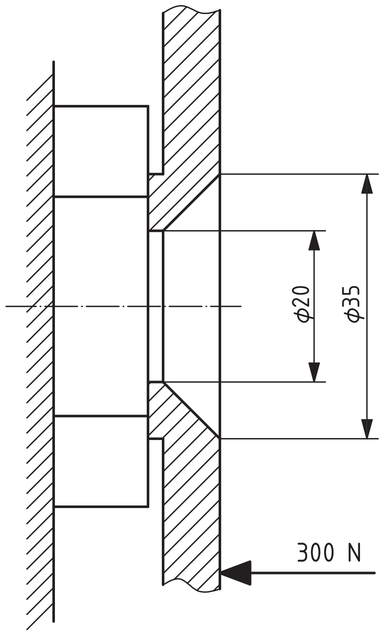

**a) Size I**



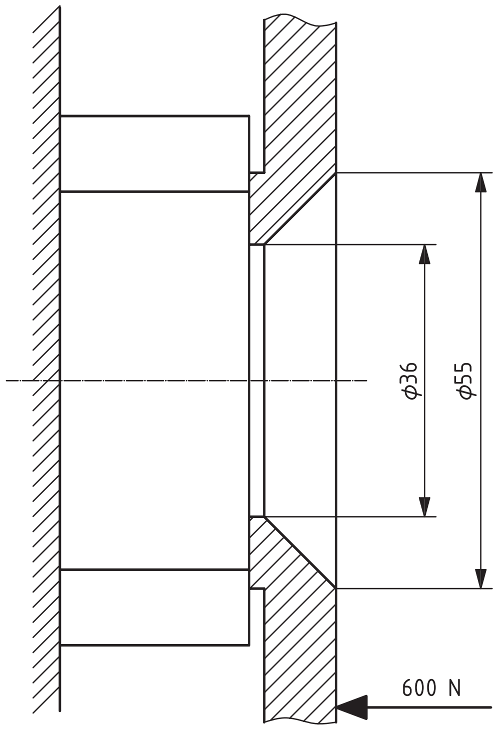

**b) Size II**




**c) Size III**




**d) Size IV**




**e) Size V**

**Figure A.1 — Retaining rings for test pieces of non-standard dimensions**

# Annex B
(informative)

# Apparatus designs

## B.1 General

References are given here to designs of apparatus which, suitably dimensioned and constructed, will conform to this document.

## B.2 Lüpke pendulum

The moving hammer of the Lüpke pendulum is essentially a cylindrical bar ending in a spherical surface and supported by a quadrifilar suspension. This system oscillates under the action of gravity.

The hammer has a mass of 0,35 kg and the spherical surface has a diameter of 12,5 mm. The length of the wire suspension is 2 m and the initial angle is such that the mass is raised by 0,1 m.

Details of the apparatus are given in Reference [4].

## B.3 Schob pendulum

This is a rigid pendulum consisting of a hammer, terminating in a spherical indenting surface 15 mm in diameter, and a rod about 200 mm in length connecting the hammer to a pivot.

The dimensions and masses should be such that, when the pendulum is lifted through a right angle from its rest position and released, the hammer impacts the test piece with a velocity of 2 m/s and an energy of 0,5 J.

The original Schob pendulum, described in Reference [5], involves the use of a 6 mm-thick test piece and is therefore outside the range of specifications given in this document. However, a modified version, which uses a 12,5-mm-thick test piece, comes within the range of specifications in this document.

## B.4 Zerbini pendulum

This pendulum consists of a bar having a spherical indentor fixed transversely to one end and rotating under the action of a taut torsion wire which is suitably connected, at its centre-point, to the bar and at its ends to fixed points.

This design, which can be constructed with a wide range of fundamental parameters, is described in Reference [6].

# Annex C
(informative)

# Mounting system for the disc of the tripsometer

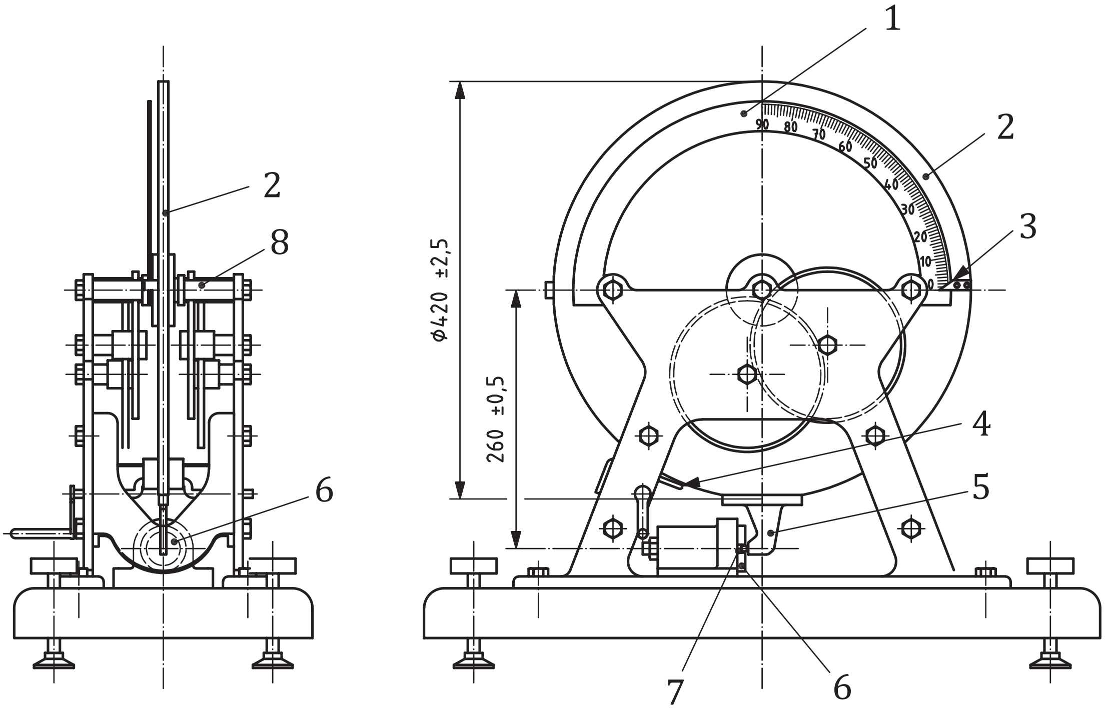
## C.1 General

This annex discusses the bearings supporting the disc in a typical tripsometer design. It is important that the bearings are of low, constant friction to ensure that the specified parameters for the operation of the instrument are met.

## C.2 Conventional mounting system

Figure C.1 shows a typical tripsometer design. The disc is mounted on an axle, which rests on pairs of rollers on each side of the disc. This system requires constant attention to avoid increasing frictional losses due to contamination or lubrication, which would lead to changes in logarithmic decrement. Such changes require recalibration, or maintenance.

Dimensions in millimetres



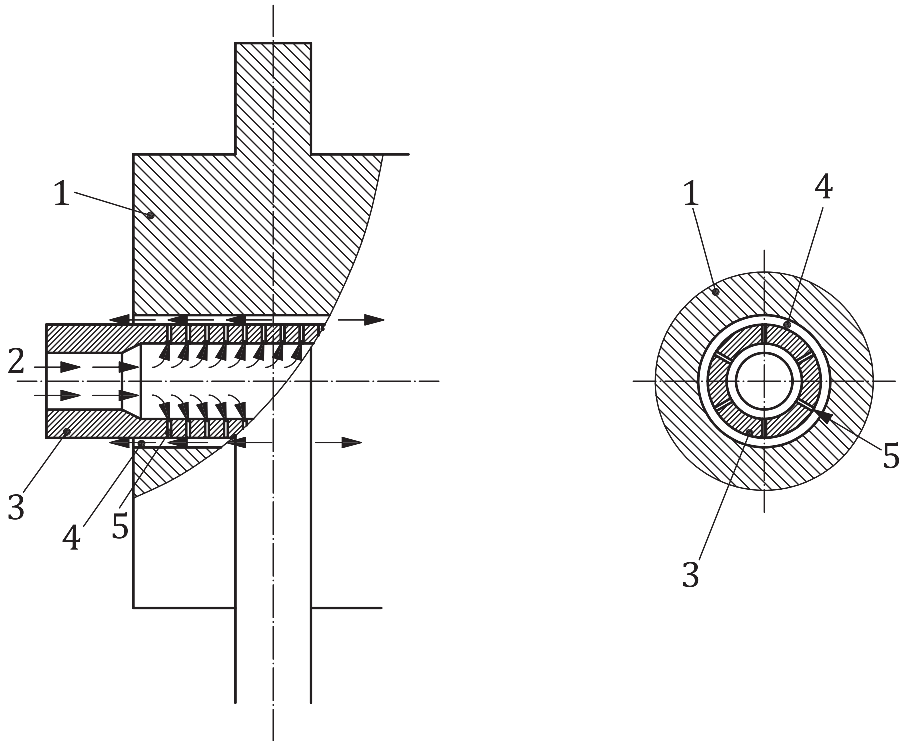

**Key**

1 scale
2 disc
3 pointer
4 release mechanism
5 mounting bracket for striker
6 test piece holder
7 test piece
8 axle

**Figure C.1 — Example of a conventional mounting system for a tripsometer**

## C.3 Use of air bearings

The air-bearing system was developed to allow the construction of low-maintenance instruments. Two arrangements have been used. Either the disc is mounted on a fixed shaft with an air bearing between the shaft and the hub of the steel disc (see Figure C.2) or the disc is rigidly mounted on a rotating axle, which is then mounted on a pair of air bearings, one at each end.




**Key**

1 shaft holder

2 compressed air

3 disc shaft

4 thin air layer between shaft and holder

5 nozzle

**Figure C.2 — Air-bearing system for steel disc**

# Annex D
(informative)

# Precision

## D.1 Background

An interlaboratory test programme (ITP) to determine the precision of the methods specified in this document was conducted in 2007, using the procedures and guidelines described in ISO/TR 9272. Refer to ISO/TR 9272 for details of, and terminology on, precision determination.

Since the test methods involve rather detailed and complex operations to conduct a measurement effectively, a number of these details are outlined in D.2. Refer to this for important information on the ITP. A “test result” is the mean of the rebound resilience values measured (for the specified number of impacts) for two test pieces. The precision analysis was based on test result data, i.e. two test result values per laboratory per material or compound for each of two test days one week apart. The numbers of participating laboratories are given in Table D.3.

The precision results as determined from this ITP may not be applied to acceptance or rejection testing for any group of materials or products without documentation that the results of this precision determination actually apply to the materials or products tested.

For the general procedure for using precision results, see ISO 19983.

## D.2 Details of the ITP

### D.2.1 Precision type

A type 1 precision was determined.

### D.2.2 Test method

Testing was carried out with Lüpke and Schob pendulums and with tripsometers having conventional and air bearings.

### D.2.3 Test pieces

The dimensions of the test pieces used are given Table D.1. For the details of the compounding of the materials, see Table D.2.

**Table D.1 — Test method and test piece size**

| Test method | Test piece shape (Test piece No.) | Test piece dimensions mm | | | | Test piece compounds |
|---|---|---|---|---|---|---|
| | | Thickness | Diameter | Width | Length | |
| Lüpke | Disc (test piece 1) | 12,5 ± 0,5 | 29 ± 0,5 | — | — | Compounds A, B and C[a] |
| Schob | Disc (test piece 1) | 12,5 ± 0,5 | 29 ± 0,5 | — | — | |
| Tripsometer with conventional bearings[b] | Disc (test piece 2) | 7,0 ± 1,0 | 44,6 ± 0,5 | — | — | |
| | Cuboid (test piece 3) | 4,0 ± 0,1 | — | 8,0 | approximately 8,0 | |
| Tripsometer with air bearings[b] | Cuboid (test piece 3) | 4,0 ± 0,1 | — | 8,0 | approximately 8,0 | |

a See Table D.2. All three compounds were used for each kind of test piece.

b Details of the disc shaft bearings in a particular instrument can be found in the instrument supplier's maintenance manual.

**Table D.2 — Compounding**

| Ingredient | Number of parts by mass | | |
|---|---|---|---|
| | Compound A (NR 1) | Compound B (NR 2) | Compound C (SBR) |
| NR (RSS3) | 100,0 | 100,0 | — |
| SBR (1712) | — | — | 137,5 |
| HAF carbon black (N330) | 45,0 | 60,0 | 60,0 |
| Zinc oxide | 5,0 | 5,0 | 5,0 |
| Stearic acid | 2,0 | 2,0 | 1,5 |
| Process oil (naphthenic) | 5,0 | 15,0 | 5,0 |
| Antioxidant (6PPD)[a] | 1,0 | 1,0 | 1,5 |
| Antioxidant (TMQ)[b] | 1,5 | 1,5 | 1,5 |
| Accelerator (TBBS)[c] | 0,6 | 0,6 | 1,0 |
| Sulfur | 2,5 | 2,0 | 2,0 |
| Total | 162,6 | 187,1 | 215,0 |
| Press cure | 150 °C<br>30 min | 150 °C<br>30 min | 150 °C<br>65 min |

NOTE Any adjustments made to the vulcanization conditions due to differences in sample thickness are not indicated.

a *N*-(1,3-dimethylbutyl)-*N'*-phenyl-*p*-phenylenediamine.

b Polymerized 2,2,4-trimethyl-1,2-dihydroquinoline.

c *N*-tert-butyl-2-benzothiazole sulfenamide.

## D.3 Precision results

### D.3.1 General

The precision results for all the test instruments and for the test pieces selected for each test instrument are given in Table D.3 for all three compounds. General statements concerning the use of the precision results are made below. These are given in terms of both the absolute precision, $r$ and $R$ (in measurement units), and relative precision, $(r)$ and $(R)$ (as a percentage).

### D.3.2 Repeatability

The repeatability, or local domain precision, for each of the rebound resilience methods has been established for each material as the values given in Table D.3.

### D.3.3 Reproducibility

The reproducibility, or global domain precision, for each of the rebound resilience methods has been established for each material as the values given in Table D.3.

### D.3.4 Comments on the precision

The precision with the Lüpke and Schob pendulums appears to be very similar. The mean rebound resilience is the same, the repeatability with the Schob pendulum is slightly higher than with the Lüpke, but the reproducibility is the same with both. The tripsometer gives, for both test pieces, rebound resilience values which are higher than those obtained with the Lüpke and Schob pendulums, but there appears to be no substantial difference in either repeatability or reproducibility. Tripsometer test piece 2 (disc) gives higher rebound resilience values than test piece 3 (cuboid).

### D.3.5 Bias

Bias is the difference between a measured average test result and a reference or true value for the measurement in question. Reference values do not exist for this test method, and therefore bias cannot be determined.

**Table D.3 — Precision (type 1) for Lüpke, Schob and tripsometer rebound resilience testing**

| Test method | Compound | Mean value | Within-laboratory | | | Between laboratories | | | No. of laboratories[c] |
|---|---|---|---|---|---|---|---|---|---|
| | | | $s_r$ | $r$ | $(r)$ | $s_R$ | $R$ | $(R)$ | |
| Lüpke (test piece 1)[a] | Compound A | 59,56 | 0,53 | 1,49 | 2,50 | 1,60 | 4,54 | 7,62 | 6 |
| | Compound B | 50,75 | 0,54 | 1,53 | 3,01 | 1,90 | 5,37 | 10,57 | 6 |
| | Compound C | 39,75 | 0,44 | 1,26 | 3,17 | 1,23 | 3,49 | 8,77 | 6 |
| | Average[b] | 50,02 | 0,50 | 1,42 | 2,89 | 1,58 | 4,46 | 8,99 | 6 |
| Schob (test piece 1)[a] | Compound A | 59,18 | 1,10 | 3,12 | 5,27 | 1,59 | 4,50 | 7,60 | 10 → 9 |
| | Compound B | 50,75 | 0,69 | 1,95 | 3,84 | 1,80 | 5,11 | 10,06 | 10 → 9 |
| | Compound C | 39,38 | 0,51 | 1,44 | 3,65 | 1,32 | 3,75 | 9,52 | 10 → 9 |
| | Average[b] | 49,77 | 0,77 | 2,17 | 4,25 | 1,57 | 4,45 | 9,06 | 9 |
| Tripsometer (test piece 2)[a] | Compound A | 70,48 | 0,43 | 1,22 | 1,73 | 1,79 | 5,08 | 7,20 | 2 |
| | Compound B | 60,69 | 0,91 | 2,58 | 4,24 | 2,64 | 7,48 | 12,32 | 2 |
| | Compound C | 47,33 | 0,30 | 0,85 | 1,79 | 0,64 | 1,80 | 3,81 | 2 |
| | Average[b] | 59,50 | 0,55 | 1,55 | 2,59 | 1,69 | 4,79 | 7,78 | 2 |

$s_r$ = within-laboratory standard deviation (in measurement units)

$r$ = repeatability (in measurement units)

$(r)$ = repeatability (in percent of mean value)

$s_R$ = between-laboratory standard deviation (for total between-laboratory variation in measurement units)

$R$ = reproducibility (in measurement units)

$(R)$ = reproducibility (in percent of mean value)

[a] See Table D.1.

[b] Simple averages are given for quick comparison of the results.

[c] First number = number of laboratories in the ITP; second number = number of laboratories remaining after deletion of outliers.

**Table D.3** *(continued)*

| Test method | Compound | Mean value | Within-laboratory | | | Between laboratories | | | No. of laboratories[c] |
|---|---|---|---|---|---|---|---|---|---|
| | | | $s_r$ | $r$ | $(r)$ | $s_R$ | $R$ | $(R)$ | |
| Tripsometer (test piece 3)[a] | Compound A | 63,03 | 0,57 | 1,62 | 2,57 | 1,68 | 4,76 | 7,56 | 5 → 4 |
| | Compound B | 54,54 | 1,58 | 4,47 | 8,20 | 1,14 | 3,21 | 5,89 | 5 → 4 |
| | Compound C | 42,85 | 0,47 | 1,34 | 3,14 | 1,60 | 4,54 | 10,58 | 5 → 4 |
| | Average[b] | 53,48 | 0,88 | 2,48 | 4,64 | 1,47 | 4,17 | 8,01 | 4 |

$s_r$ = within-laboratory standard deviation (in measurement units)

$r$ = repeatability (in measurement units)

$(r)$ = repeatability (in percent of mean value)

$s_R$ = between-laboratory standard deviation (for total between-laboratory variation in measurement units)

$R$ = reproducibility (in measurement units)

$(R)$ = reproducibility (in percent of mean value)

a See Table D.1.

b Simple averages are given for quick comparison of the results.

c First number = number of laboratories in the ITP; second number = number of laboratories remaining after deletion of outliers.

# Annex E
(informative)

# Calculation method for the tripsometer's impact velocity

## E.1 General

This annex specifies the calculation procedure of the impact velocity for the tripsometer method.

## E.2 Calculation method of the impact velocity for tripsometer

### E.2.1 Procedure

#### E.2.1.1 Simple model of a pendulum's movement

When the rotary pendulum's movement is converted to a simple pendulum's movement, the length from the simple pendulum's supporting point to the centre of mass ($l_p$ in meters; see Figure E.1) is calculated from the oscillating period of the rotary pendulum ($T$) with Formula (E.1).

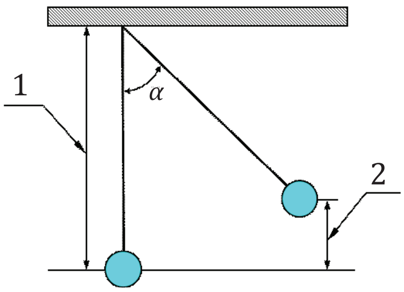
$$T = 2\pi\sqrt{l_p / g}$$

$$l_p = gT^2 / 4\pi^2 = 0{,}248T^2 \tag{E.1}$$

where

$T$ is the oscillating period of the pendulum (s);

$g$ is the acceleration of gravity (m/s$^2$).




**Key**

1 length from the simple pendulum's supporting point to the centre of mass ($l_p$)

2 drop height ($H$)

**Figure E.1 — Example of a simple pendulum**

Then, the impact velocity of the simple pendulum ($V_p$, in m/s) can be determined by Formula (E.2), using the $l_p$ value from Formula (E.1):

$$\frac{1}{2} m V_p^2 = mgH = mg\, l_p\, (1 - \cos\alpha)$$

$$V_p = [2g\ l_p\ (1 - \cos\alpha)]^{\frac{1}{2}} = 4{,}43 \times \left[l_p (1 - \cos\alpha)\right]^{\frac{1}{2}} \quad \text{(E.2)}$$

where

$\alpha$ is the angle of drop;

$H$ is the drop height (m).

#### E.2.1.2 Determination of the rotary pendulum's impact velocity

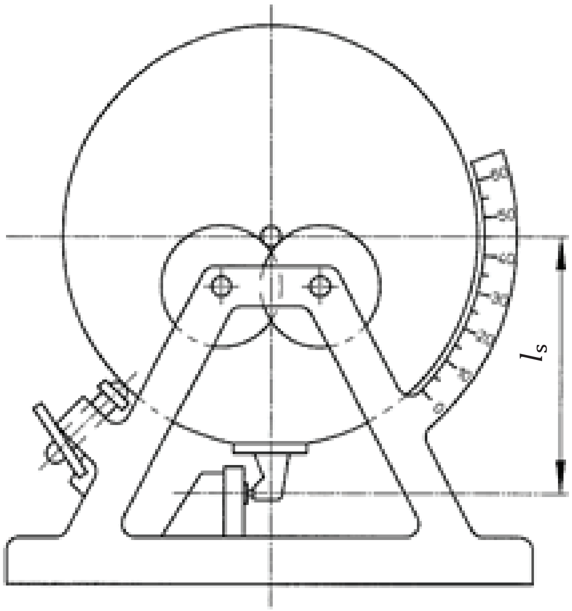



**Figure E.2 — Example of a rotary pendulum**

Lastly, determine the rotary pendulum's impact velocity ($V_s$, in m/s) by Formula (E.3), using the $l_p$ value from Formula (E.1) and the $V_p$ value from Formula (E.2):

$$V_s = V_p \times l_s / l_p \quad \text{(E.3)}$$

where

$l_s$ is the length from the rotation centre to the striking point (m) shown in Figure E.2.

### E.2.2 Proof example

When the length from the rotation centre to the striking point of a tripsometer ($l_s$) is 0,26 m, with 10 s of period $T_1$ and 45° of angle of drop, $\alpha$, $l_p$ and $V_p$ are:

$$l_p = gT^2 / 4\pi^2 = 0{,}248T^2 = 24{,}82\ \text{(m)}$$

$$V_{\mathrm{p}} = \left[2g\ l_{\mathrm{p}}\left(1 - \cos\alpha\right)\right]^{\frac{1}{2}} = 4{,}43 \times \left[24{,}82\ \left(1 - \cos\ \alpha\right)\right]^{\frac{1}{2}} = 11{,}94\ \ (\mathrm{m/s})$$

Accordingly, $V_{\mathrm{s}} = 11{,}94 \times 0{,}26/24{,}82 = 0{,}125\ 07\ \ (\mathrm{m/s})$, and it is confirmed that this tripsometer's impact velocity meets the specification in 6.1.1.

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