

**NORME
INTERNATIONALE
INTERNATIONAL
STANDARD**

**CEI
IEC
60851-3**

Edition 2.1

1997-12

Edition 2:1996, consolidée par l'amendement 1:1997
Edition 2:1996, consolidated with amendment 1:1997

Fils de bobinage – Méthodes d'essai –

**Partie 3:
Propriétés mécaniques**

Winding wires – Test methods –

**Part 3:
Mechanical properties**



Numéro de référence
Reference number
CEI/IEC 60851-3+A1:1997

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Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

CODE PRIX
PRICE CODE

CJ

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

WINDING WIRES – TEST METHODS –**Part 3: Mechanical properties**

FOREWORD

- 1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60851-3 has been prepared by IEC technical committee 55: Winding wires.

This consolidated version of IEC 60851-3 consists of the second edition (1996) [documents 55/472A/FDIS and 55/513/RVD] and its amendment 1 (1997) [documents 55/592/FDIS and 55/612/RVD].

The technical content is therefore identical to the base edition and its amendment and has been prepared for user convenience.

It bears the edition number 2.1.

A vertical line in the margin shows where the base publication has been modified by amendment 1.

Annexes A and B are for information only.

INTRODUCTION

This part of IEC 60851 forms an element of a series of standards which deals with insulated wires used for windings in electrical equipment. The series has three groups describing:

- a) methods of test (IEC 60851);
- b) specifications (IEC 60317);
- c) packaging (IEC 60264).

WINDING WIRES – TEST METHODS –

Part 3: Mechanical properties

1 Scope

This part of IEC 60851 specifies the following methods of test:

- Test 6: Elongation;
- Test 7: Springiness;
- Test 8: Flexibility and adherence;
- Test 11: Resistance to abrasion;
- Test 18: Heat or solvent bonding.

For definitions, general notes on methods of test and the complete series of methods of test for winding wires see IEC 60851-1.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 60851. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this part of IEC 60851 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of the IEC and ISO maintain registers of currently valid International Standards.

IEC 60851-1:1996, *Winding wires – Test methods – Part 1: General*

IEC 60851-2:1996, *Winding wires – Test methods – Part 2: Determination of dimensions*

IEC 61033:1991, *Test methods for the determination of bond strength of impregnating agents to an enamelled wire substrate*

ISO 178:1993, *Plastics – Determination of flexural properties*

3 Test 6: Elongation

3.1 Elongation at fracture

Elongation is the increase in length expressed as a percentage of the original length.

A straight piece of wire shall be elongated to the point of fracture of the conductor at a rate of (5 ± 1) mm/s with an elongation tester or with a tensile testing equipment with a free measuring length of between 200 mm and 250 mm. The linear increase at fracture shall be calculated as a percentage of the free measuring length.

Three specimens shall be tested. The three single values shall be reported. The mean value represents elongation at fracture.

3.2 Tensile strength

Tensile strength is the ratio of the force at fracture to initial cross-section.

A straight piece of wire shall be elongated to the point of fracture of the conductor at a rate of (5 ± 1) mm/s with tensile testing equipment with a free measuring length of between 200 mm and 250 mm and which records the force at fracture.

Three specimens shall be tested. The initial cross-section and the three single values of the force at fracture shall be reported. The mean value of the ratio of the force at fracture and the initial cross-section represents the tensile strength.

4 Test 7: Springiness

Springiness is the recoil measured in degrees after the wire is wound in the form of a helical coil or bent through an angle.

4.1 Round wire with a nominal conductor diameter from 0,080 mm up to and including 1,600 mm

4.1.1 Principle

A straight piece of wire is wound five times around a mandrel with a diameter and under a tension applied to the wire as specified in the relevant standard. The reading of the angle by which the end of the five turns recoils is the measure of springiness.

4.1.2 Equipment

Figure 1 shows an example of the test equipment with details of the mandrel given in figure 2 and table 1. Figure 2 indicates a helical groove, which may be used to facilitate winding. The provision of this groove, however, is not mandatory. The dial is marked with 72 equally spaced divisions so that with five turns of the wire the reading corresponds to the number of degrees that each turn springs back.

Table 1 – Mandrels for springiness

Mandrel diameter ¹⁾ mm	Dimensions ²⁾ mm					
	a	b	c	d	e	f
5	6,0	7,5	32	0,30	0,05	0,13
7	6,0	9,0	34	0,40	0,07	0,18
10	6,0	9,0	34	0,60	0,10	0,25
12,5	6,0	9,0	40	0,80	0,14	0,35
19	10,0	11,0	45	1,20	0,20	0,50
25	12,5	12,5	45	2,00	0,28	0,70
37,5	12,5	14,5	47	2,40	0,40	1,00
50	12,5	17,5	50	3,00	0,80	2,00

¹⁾ At the bottom of the groove, if provided.
²⁾ See figure 2.

4.1.3 Procedure

The specified mandrel shall be mounted and locked in position with its axis horizontal and with the slot or hole for fastening the wire corresponding with the zero of the dial. The mandrel shall be dusted with powdered talc (French chalk) to prevent the wire clinging to the mandrel.

A tension shall be applied to a straight piece of wire of about 1 m in length by attaching the specified load to one end of the wire. The handle to rotate the mandrel shall be unlatched. The other end of the wire shall be inserted into the slot or hole so that sufficient wire projects on the other side of the mandrel and the wire is in firm contact with the mandrel. The weight shall be slowly lowered with the wire suspended vertically below the mandrel and with the dial zero and the slot or hole pointing downwards.

With the free end of the wire being held securely, the mandrel shall be rotated for five complete turns counter clockwise (looking at the face of the dial) and further until the zero on the dial is vertically upwards. The handle shall then be latched in this position. The load shall be removed while the wire is held in position, and the wire shall then be cut about 25 mm beyond the end of the fifth turn. This end of the wire shall be bent into a vertical position in line with the dial zero to act as a pointer.

A pencil or similar tool shall be placed to the left of this end of the wire to prevent any sudden springback. The coil shall then be allowed to unwind slowly and without jerking.

NOTE – If the wire springs back suddenly, erroneous results may be obtained.

The mandrel and the dial shall then be unlatched and rotated clockwise to bring the pointer back into a vertical position. The springback angle is equal to the reading on the dial in line with the pointer. With very springy wires, the pointer may recoil more than one complete revolution. If this is the case, 72 has to be added to the dial reading for each complete revolution of recoil.

Three specimens shall be tested. The three single values shall be reported. The mean value represents springiness.

4.2 Round wire with a nominal conductor diameter over 1,600 mm and rectangular wire

4.2.1 Principle

A straight piece of wire shall be bent through an angle of 30°. After removing the force, the reading of the angle by which the wire springs back is the measure of springiness.

4.2.2 Equipment

Figure 3 shows an example of the test equipment basically consisting of two jaws, one of which is fixed (2) and one is movable (1), and a sector graduated in degrees (5) with the 0° to 10° sector of the scale graduated in 0,5° increments. The graduated sector is an arc placed in a plane at 90° to the clamp faces. Its centre is located at the outer edge of the fixed jaw (3). The lever arm with its fulcrum placed at the centre of the arc can move over the graduated sector in the vertical plane.

The lever arm shall have a pointer or marker to provide a proper reading of the springback angle. On the lever arm with approximately 305 mm length scaled off in millimetres with the origin at the centre of the arc, is a slider (4) with a knife edge.

4.2.3 Specimen

A wire sample of at least 1 200 mm in length shall be removed from the spool with as little bending of the wire as possible. It shall be straightened by hand and cut into three pieces each of 400 mm length. Elongation by tools shall not be used. Unnecessary bending shall be avoided to minimize work hardening.

4.2.4 Procedure

The conductor diameter or thickness, multiplied by 40 determines the position of the slider on the lever arm. The specimen shall be tightened between the jaws with a force just sufficient to prevent slipping. The specimen shall be tightened in such a position as to allow bending the wire in the same direction as it was wound on the spool. The free end of the specimen shall exceed the slider knife edge by (12 ± 2) mm.

By means of the lever arm, starting at the initial position (the 30° scale mark, position 1), the wire shall be bent for 30° (the 0° scale mark, position 2). The total bending shall take between 2 s and 5 s. The specimen shall be held in this position for not more than 2 s and then returned in the reverse direction at the same angular rate at which it was bent, until the slider knife edge moves away from the wire specimen. The lever arm shall be raised again until the slider knife edge just contacts the wire specimen without bending it. In this position, the springback angle equals the reading on the scale of the graduated sector in line with the pointer on the lever arm (position 3).

Three specimens shall be tested. The single values shall be reported. The mean value represents springiness.

5 Test 8: Flexibility and adherence

Flexibility and adherence reflect the potential of the wire to withstand stretching, winding, bending or twisting without showing cracks or loss of adhesion of the insulation.

5.1 Mandrel winding test

5.1.1 Round wire

A straight piece of wire shall be wound for 10 continuous and adjacent turns around a polished mandrel of the diameter given in the relevant standard. The mandrel shall be rotated with a rate of 1 r/s to 3 r/s with a tension applied to the wire which is just sufficient to keep it in contact with the mandrel. Elongating or twisting the wire shall be avoided. Any suitable equipment shall be used.

5.1.1.1 Enamelled round wire with a nominal conductor diameter up to and including 1,600 mm

If the relevant standard calls for pre-stretching before winding, the wire shall be elongated according to clause 3 to the specified percentage. After winding, the specimen shall be examined for cracks with the magnification as given in table 2.

Table 2 – Magnification to detect cracks

Nominal conductor diameter mm		Magnification*
A partir de	Jusqu'à et y compris	
–	0,040	10 to 15 times
0,040	0,500	6 to 10 times
0,500	1,600	1 to 6 times

* One time expresses normal vision.

Three specimens shall be tested. Any cracks detected shall be reported.

5.1.1.2 Fibre covered round wire

After winding, the specimen shall be examined for exposure of the bare conductor with normal vision or with a magnification of up to six times.

Three specimens shall be tested. Exposure of the bare conductor shall be reported.

5.1.1.3 Fibre covered enamelled round wire

After winding, the specimen shall be examined for exposure of the bare conductor or underlying coating with normal vision or with a magnification of up to six times.

Three specimens shall be tested. Exposure of the bare conductor or the underlying coating shall be reported.

5.1.1.4 Tape wrapped round wire

After winding, the specimen shall be examined for exposure of the bare conductor or delamination with normal vision or with a magnification of up to six times.

Three specimens shall be tested. Exposure of the bare conductor or any delamination shall be reported.

5.1.2 Rectangular wire

A straight piece of wire approximately 400 mm in length shall be bent through 180° round a polished mandrel of the diameter given in the relevant standard in two directions to form an elongated S-shape. The straight part between the U-shape bends shall be at least 150 mm. Care should be taken to ensure that the specimen does not buckle or depart from a uniform bend. A suitable apparatus is shown in figure 4.

After bending, the insulation shall be examined for cracks in case of enamelled wire, for exposure of the bare conductor or underlying coating in case of fibre covered wire and for exposure of the bare conductor and delamination in case of tape wrapped wire under a magnification of six to ten times.

Six specimens shall be bent, three flatwise (on the thickness) and three edgewise (on the width). It shall be reported, if the wire shows cracks or delamination, exposure of the bare conductor or underlying coating, whichever is applicable.

5.1.3 Covered bunched wire

A straight piece of wire shall be wound for ten continuous turns around a polished mandrel of the diameter given in the relevant standard and under a tension given in 3.2.5.3 of IEC 60851-2. Care should be taken not to twist the specimen for each revolution.

After winding, the specimen shall be examined by normal vision for openings in the covering.

One specimen shall be tested. It shall be reported, if the wire does not show the required degree of closeness of the covering.

5.2 Stretching test (applicable to enamelled round wire with a nominal conductor diameter over 1,600 mm)

A straight piece of wire shall be elongated according to clause 3 to the percentage specified in the relevant standard. After elongation, the specimen shall be examined for cracks or loss of adhesion with normal vision or with a magnification of up to six times.

Three specimens shall be tested. It shall be reported, if the wire shows cracks and/or loss of adhesion.

5.3 Jerk test (applicable to enamelled round wire with a nominal conductor diameter up to and including 1,000 mm)

A straight piece of wire shall be rapidly stretched to the breaking point or to an elongation given in the relevant standard, with a test equipment shown in figure 5 providing a free measuring length of between 200 mm and 250 mm. After elongation, the specimen shall be examined for cracks or loss of adhesion under a magnification as given in table 2. A distance of 2 mm from the broken ends shall be disregarded.

Three specimens shall be tested. It shall be reported, if the wire shows cracks and/or loss of adhesion.

5.4 Peel test (applicable to enamelled round wire with a nominal conductor diameter over 1,000 mm)

A straight piece of wire shall be placed in the test equipment shown in figure 6 consisting of two fixing devices 500 mm apart on the same axis. One of these is free to rotate. The other is not but can be displaced axially and is loaded according to table 3 to apply a tension to the rotating wire.

Table 3 – Load for peel test

Nominal conductor diameter mm		Load N
Over	Up to and included	
1,000	1,400	25
1,400	1,800	40
1,800	2,240	60
2,240	2,800	100
2,800	3,550	160
3,550	4,500	250
4,500	5,000	400

By means of a scraper as shown in figure 7, the coating shall be removed on opposite sides of the wire and along the wire axis down to the bare conductor as shown in figure 8. The pressure on the scraper shall be sufficient to remove the coating and leave a clean smooth surface at the coating/conductor interface without scraping off a significant quantity of conductor material. The removal of the coating shall commence about 10 mm from the fixing devices. The rotating device shall be driven at a speed of between 60 r/min and 100 r/min until the number of revolutions R as specified in the relevant standard has been reached.

After peeling and rotating, the specimen shall be examined for loss of adhesion. If the coating can be removed from the wire without difficulty (for example with the thumbnail), it shall be considered to have lost its adhesion even if it has not become completely detached from the wire.

One specimen shall be tested. It shall be reported, if loss of adhesion is observed.

5.5 Adherence test

A straight piece of wire of about 300 mm length, shall be elongated in accordance with clause 3 to the percentage specified in the relevant standard.

5.5.1 Enamelled rectangular wire

Before elongation, the coating shall be cut circumferentially through to the conductor at a point approximately in the centre of the measured length. After elongation, the specimen shall be examined for loss of adhesion.

One specimen shall be tested. It shall be reported, if loss of adhesion is observed, measured longitudinally from the cut. If so, the length of loss of adhesion shall be measured in one direction from the cut. The maximum value observed shall be reported after examining all sides of the specimen.

5.5.2 Impregnated fibre covered round and rectangular wire

Before elongation, the insulation shall be removed from all but the central 100 mm of the wire piece. After elongation, the specimen shall be examined for loss of adhesion.

One specimen shall be tested. It shall be reported, if loss of adhesion is observed with the insulation sliding along the conductor in case of round wire or being detached in case of rectangular wire.

5.5.3 Fibre covered enamelled round and rectangular wire

Before elongation, the insulation shall be cut circumferentially at two places 100 mm apart in the centre of the wire piece through to the conductor. After elongation, the specimen shall be examined for loss of adhesion.

One specimen shall be tested. It shall be reported, if loss of adhesion is observed.

5.5.4 Tape wrapped round and rectangular wire

Before elongation, the insulation shall be cut circumferentially through to the conductor at a point approximately in the centre of the measured length. After elongation, the specimen shall be examined for loss of adhesion.

One specimen shall be tested. It shall be reported, if loss of adhesion is observed, measured longitudinally from the cut. If so, the length of loss of adhesion shall be measured in one direction from the cut. The maximum value observed shall be reported after examining all sides of the specimen.

6 Test 11: Resistance to abrasion (applicable to enamelled round wire)

Resistance to abrasion is determined as the maximum force which can be sustained when a needle scrapes along the wire under a progressively increasing force.

6.1 Principle

A straight piece of wire is subjected to a unidirectional scrape test, by a needle to which a progressively increasing load is applied and which scrapes along the wire surface. The load which causes an electrical contact of the needle with the conductor is called the load-to-failure.

6.2 Equipment

Test equipment as shown in figure 9 shall be used. It shall be provided with a mechanism to produce scraping action in one direction at a rate of (400 ± 40) mm/min. The scraping device shall contain a polished piano wire or a needle of $(0,23 \pm 0,01)$ mm diameter, located between two jaws which hold the piano wire or needle rigidly, without sagging or curvature and at right angles to the direction of stroke which shall be in the direction of the axis of the wire under test. For placing the specimen, the test equipment shall be provided with two clamping jaws over a supporting anvil which can be lowered while a wire is inserted into the jaws and straightened.

The test equipment shall provide a d.c. voltage of $(6,5 \pm 0,5)$ V to be applied between the conductor and the piano wire or the needle scraper. The short-circuit current shall be limited to 20 mA, for example by means of a series resistor or a relay. The circuit shall be designed to detect a short circuit and stop the equipment after the scraper is in contact with the conductor of the wire for about 3 mm.

The test equipment shall be provided with a graduated scale over the lower edge of the lever, which indicates the factor by which the initial load applied to the piano wire or to the needle has to be multiplied to determine the force-to-failure.

6.3 Procedure

A straight piece of wire shall be wiped clean, placed in the apparatus and straightened by a maximum of 1 % elongation. The specimen shall then be secured in the clamping jaws and the supporting anvil adjusted to contact the specimen. The initial force applied to the scraping device shall not exceed 90 % of the minimum force to failure specified in the relevant standard and shall lead to short circuit between scraper and conductor at a point between 200 mm and 150 mm from the fixed pivot point. The weighted scraping device shall be lowered slowly to the surface of the wire and the scraping action started.

The value at which the scraper stops shall be read on the graduated scale on the lower edge of the lever. The product of this value and the initial load applied shall be recorded.

The procedure shall be repeated twice on the same specimen, indexing around the periphery of the wire, once at 120° and once at 240° from the original position and the same information recorded.

One specimen shall be tested. The three single values shall be reported. The mean value represents the average force-to-failure.

7 Test 18: Heat or solvent bonding*

(applicable to enamelled round wire with a nominal conductor diameter over 0,050 mm up to and including 2,000 mm)

Heat or solvent bonding is the potential of the windings of a coil to bond together under the influence of heat or solvent.

7.1 Vertical bond retention of a helical coil

Vertical bond retention of a helical coil is the potential of the bonded coil to maintain its coherence when a load is applied to its lower end.

7.1.1 Nominal conductor diameter up to and including 0,050 mm

The method of test is to be agreed upon between purchaser and supplier.

7.1.2 Nominal conductor diameter over 0,050 mm up to and including 2,000 mm

7.1.2.1 Principle

The turns of a helical coil of the wire wound on a mandrel are pressed together by applying a load and then bonded by means of heat or solvent. After bonding, the specimen is removed from the mandrel and suspended in a vertical position with a load applied at the lower end to determine whether the specimen withstands a specified load or not. This procedure is repeated at an elevated temperature.

7.1.2.2 Specimen

A straight piece of wire shall be wound on a polished mandrel** of a diameter according to table 4. The coil shall have a minimum length of 20 mm. The winding rate shall be between 1 r/s and 3 r/s with an applied winding force not exceeding the values in table 4. In order to allow the coil to relax freely, the ends of the wire shall not be fastened. The coil on the mandrel shall be positioned vertically as shown in figure 10a) with a load applied as specified in table 4. The weight shall not stick to the mandrel, and there shall be a clearance between the weight and the mandrel. This arrangement shall then be placed in an oven with forced air circulation at a temperature specified in the relevant standard for a period of:

- 30 min for wires with a nominal conductor diameter up to and including 0,710 mm;
- 1 h for wires with a nominal conductor diameter over 0,710 mm up to and including 2,000 mm, unless otherwise agreed upon between purchaser and supplier.

After cooling to room temperature, the coil shall be removed from the mandrel.

7.1.2.3 Procedure at room temperature

A specimen shall be suspended by one of its ends (see figure 10b) and loaded as required in the relevant standard. The load shall be applied in a way which avoids any additional shock.

Three specimens shall be tested. It shall be reported, if turns other than the first and the last are separated. The temperature for bonding the specimen shall be reported.

* This method of test will be extended to solvent bonding at a later stage.

** A steel mandrel is satisfactory for larger diameter wires. For smaller wires, copper mandrels may assist in the removal of the coil from the mandrel by stretching the mandrel to reduce its diameter.

7.1.2.4 Procedure at elevated temperature

A specimen shall be suspended by one of its ends (see figure 10b) and loaded as specified in table 5. The load shall be applied in a way which avoids any additional shock. The specimen with its load shall be placed in an oven with forced air circulation for 15 min at a temperature as specified in the relevant standard.

Three specimens shall be tested. It shall be reported, if turns other than the first and the last are separated. The temperature for bonding the specimen shall be reported.

Table 4 – Preparation of helical coils

Nominal conductor diameter mm		Diameter of the mandrel	Maximum winding force	Load on the coil during bonding
Over	Up to and including	mm	N	N
0,050	0,071	1	0,05	0,05
0,071	0,100	1	0,05	0,05
0,100	0,160	1	0,12	0,15
0,160	0,200	1	0,30	0,25
0,200	0,315	2	0,80	0,35
0,315	0,400	3	0,80	0,50
0,400	0,500	4	2,00	0,75
0,500	0,630	5	2,00	1,25
0,630	0,710	6	5,00	1,75
0,710	0,800	7	5,00	2,00
0,800	0,900	8	5,00	2,50
0,900	1,000	9	5,00	3,25
1,000	1,120	10	12,00	4,00
1,120	1,250	11	12,00	4,50
1,250	1,400	12	12,00	5,50
1,400	1,600	14	12,00	6,50
1,600	1,800	16	30,00	8,00
1,800	2,000	18	30,00	10,00

Table 5 – Bond retention at elevated temperature

Nominal conductor diameter mm		Load N	Nominal conductor diameter mm		Load N
Over	Up to and including		Over	Up to and including	
0,050	0,071	0,04	0,800	0,900	2,60
0,071	0,100	0,06	0,900	1,000	3,20
0,100	0,160	0,09	1,000	1,120	3,80
0,160	0,200	0,19	1,120	1,250	4,40
0,200	0,315	0,25	1,250	1,400	4,90
0,315	0,400	0,55	1,400	1,600	6,40
0,400	0,500	0,80	1,600	1,800	7,90
0,500	0,630	1,20	1,800	2,000	7,90
0,630	0,710	1,70			
0,710	0,800	2,10			

7.2 Bond strength of a twisted coil

Bond strength is the maximum force required to break the twisted coil.

7.2.1 Principle

A random wound coil prepared from the wire is formed to an oval shape, twisted and then bonded by applying a d.c. current. This specimen produces a rod, which is tested in a tensile testing equipment in a horizontal position to obtain the maximum deflection force to break this rod. The test shall be repeated at elevated temperature.

NOTE – This test is similar to method A, twisted coil test, given in 2.1 of IEC 61033, and is based on the same principle. It differs from method A of IEC 61033 with respect to twisting and bonding the specimen and with respect to wire sizes. It permits the testing of different wire sizes, whereas method A of IEC 61033 specifies that a wire of a nominal conductor diameter of 0,315 mm shall be used.

7.2.2 Equipment

The following equipment shall be used:

- coil winder in accordance with figures 11a and 11b;
- coil twister in accordance with figure 13;
- tensile test equipment in accordance with ISO 178 with a support complying with figure 13;
- d.c. supply unit providing a constant current output with a capacity of minimum 50 V and 15 A;
- attached to the tensile test equipment, an oven with forced air circulation, which shall maintain the test temperature within a tolerance of ± 2 °C and which shall allow heating at least five specimens simultaneously within 5 min to 10 min to the test temperature.

7.2.3 Specimen

A random wound coil shall be prepared from the wire using a winding equipment according to figures 11a and 11b. The number of windings shall be calculated as:

$$N = \frac{100 \times 0,315^2}{d^2}$$

where d is the nominal conductor diameter of the wire under test.

NOTE – For a nominal conductor diameter of $d = 0,315$ mm, N represents 100 turns. For other values of d , the above equation will lead to a number N , which gives the same total conductor cross-section as $N = 100$ and $d = 0,315$ mm.

To prevent opening of the coil after removal from the winding equipment, each end of the wire (or short pieces of enamelled wire) shall be wrapped around the coil two or three times at opposite positions. For this purpose, the winding equipment is provided with appropriate notches (see figure 11b).

For winding the coil, the following dimensions shall apply:

- winding diameter: $(57 \pm 0,1)$ mm;
- width of slot: $(5 \pm 0,5)$ mm.

After removal from the winding equipment, the coil shall be formed to an oval shape (see figure 12) and then twisted in a twisting device around its longitudinal axis according to figure 13. This device allows application of a mechanical load to be applied to the coil while it is twisted and subsequently bonded. This load shall be 100 N. The coil shall be twisted for two and a half turns and then half a turn in the reverse direction. While held under a mechanical load in the twisting device, the specimen shall be bonded by applying a constant d.c. current to the wire. A current shall be chosen that bonds the specimen within a period of 30 s to 60 s.

NOTE – Since d.c. current is used, it allows an easy approach to determine the average temperature of the specimen at the end of the heating period (see annex A).

The specimen is a rod of about 7 mm diameter and 85 mm to 90 mm in length.

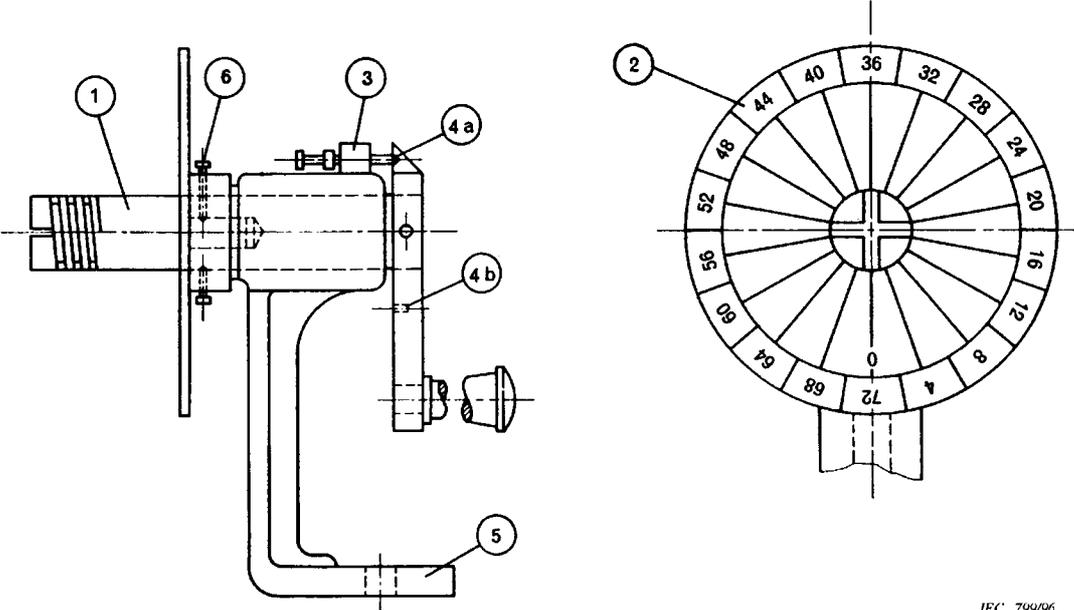
7.2.4 Procedure

With the specimen properly positioned on a support according to figure 14, the bond strength of the specimen shall be determined by adjusting the crosshead speed so that the maximum deflection force is reached in about 1 min.

For tests at elevated temperature, the specimen shall be placed in the oven preheated to the specified temperature. The specimen shall be tested after it has reached the oven temperature but not later than 15 min after being placed in the oven.

7.2.5 Result

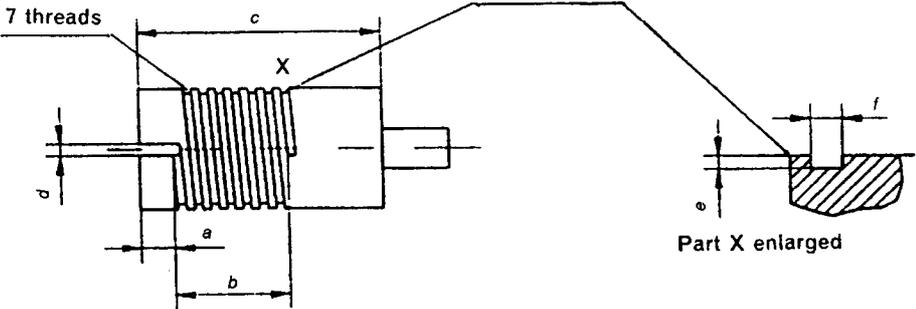
For each temperature, five specimens shall be tested. The five single values shall be reported for each test temperature. The mean value represents the bond strength. The nominal conductor diameter, the number of turns of the coil and the bonding conditions of specimens shall also be reported.



IEC 799/96

- 1 = mandrel
- 2 = dial
- 3 = locking device
- 4 = locking device
- 5 = base-plate
- 6 = mandrel-fixing screw

Figure 1 – Test equipment to determine spinginess



IEC 800/96

Figure 2 – Construction and details of the mandrel (see table 1)

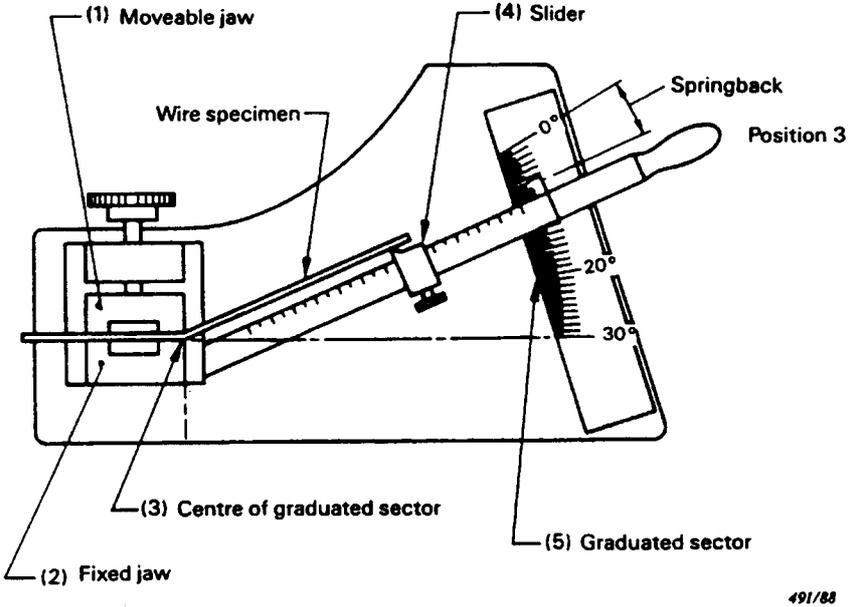
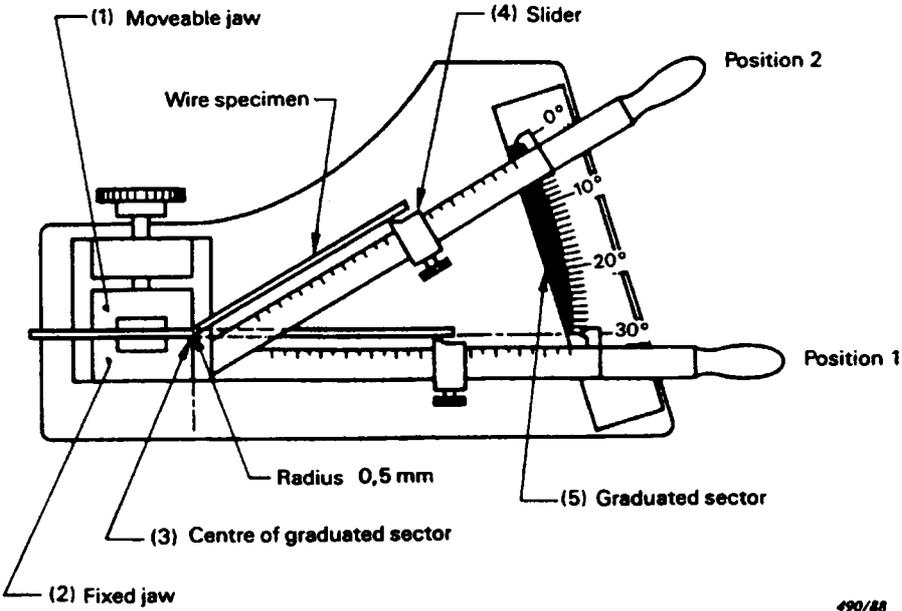
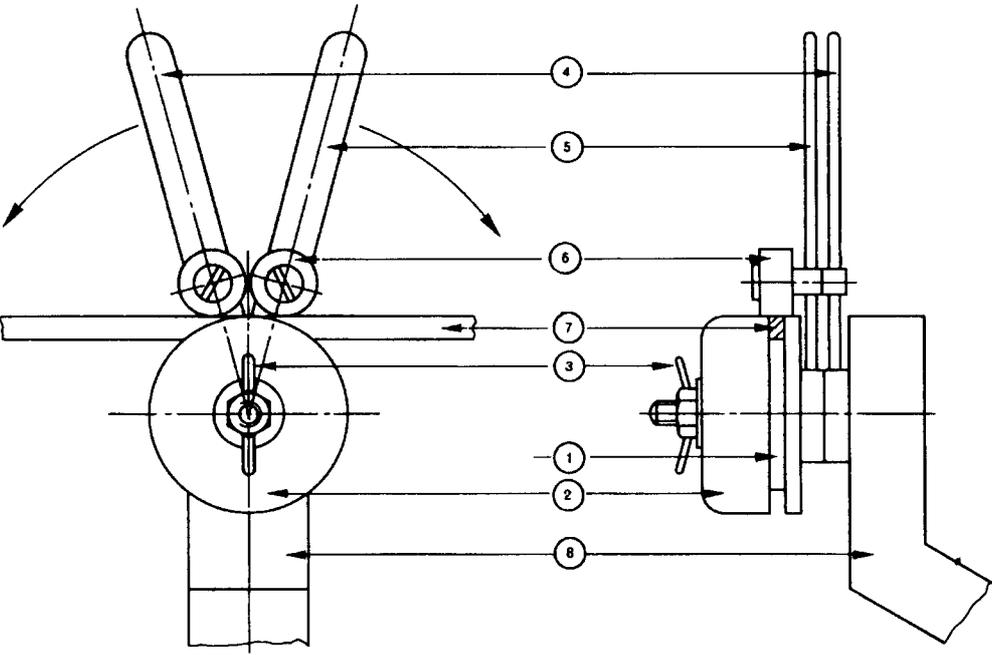


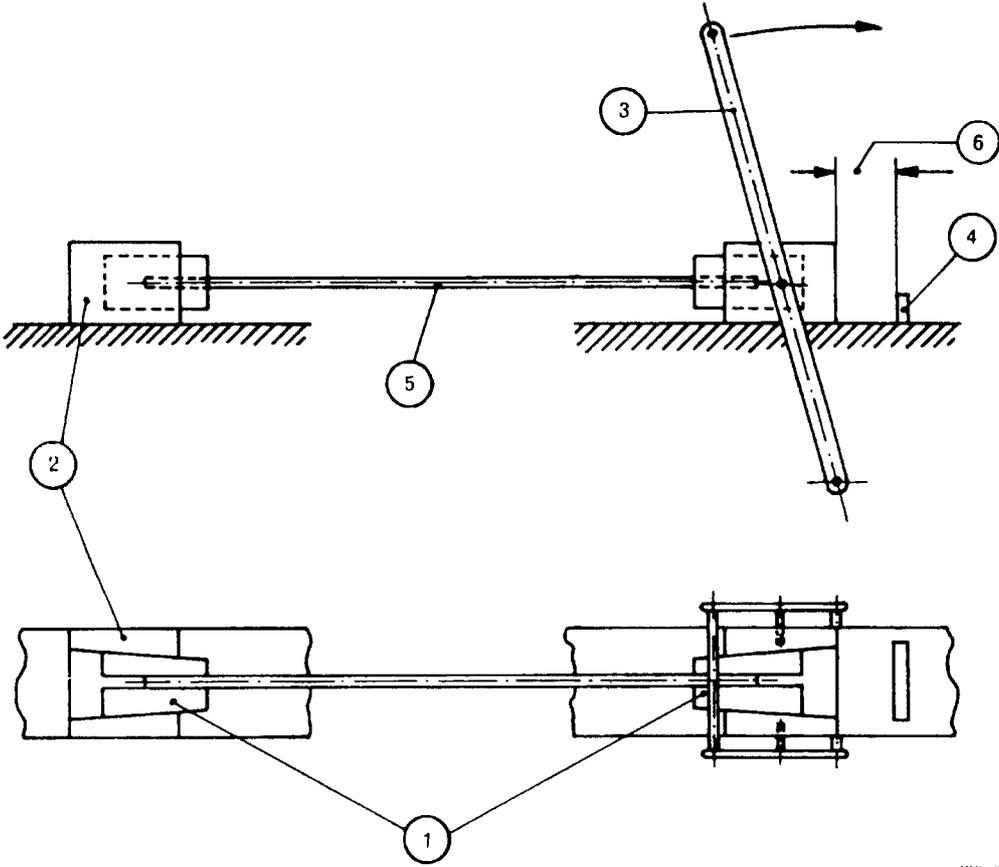
Figure 3 – Test equipment to determine springiness



IEC 801/96

- 1 = mandrel
- 2 = mandrel clamping collar
- 3 = winding nut
- 4 = lever
- 5 = lever
- 6 = ball bearing
- 7 = specimen
- 8 = support

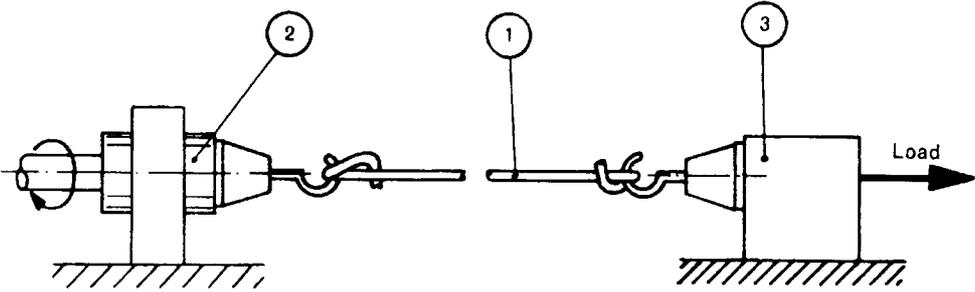
Figure 4 – Test equipment for mandrel winding test



IEC 802/96

- 1 = wedge grips (clamps)
- 2 = fixed jaw set
- 3 = lever arm
- 4 = adjustable stop
- 5 = specimen
- 6 = specified elongation

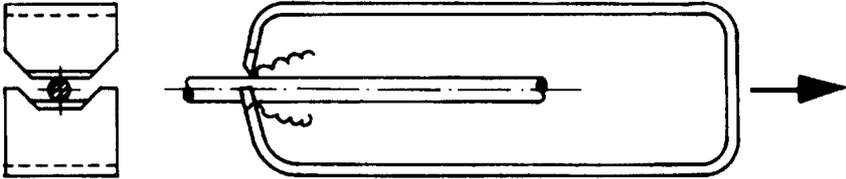
Figure 5 – Test equipment for jerk test



IEC 803/96

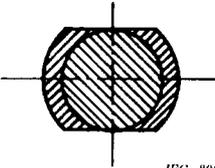
- 1 = specimen
- 2 = rotary clamp
- 3 = fixed clamp

Figure 6 – Test equipment for peel test



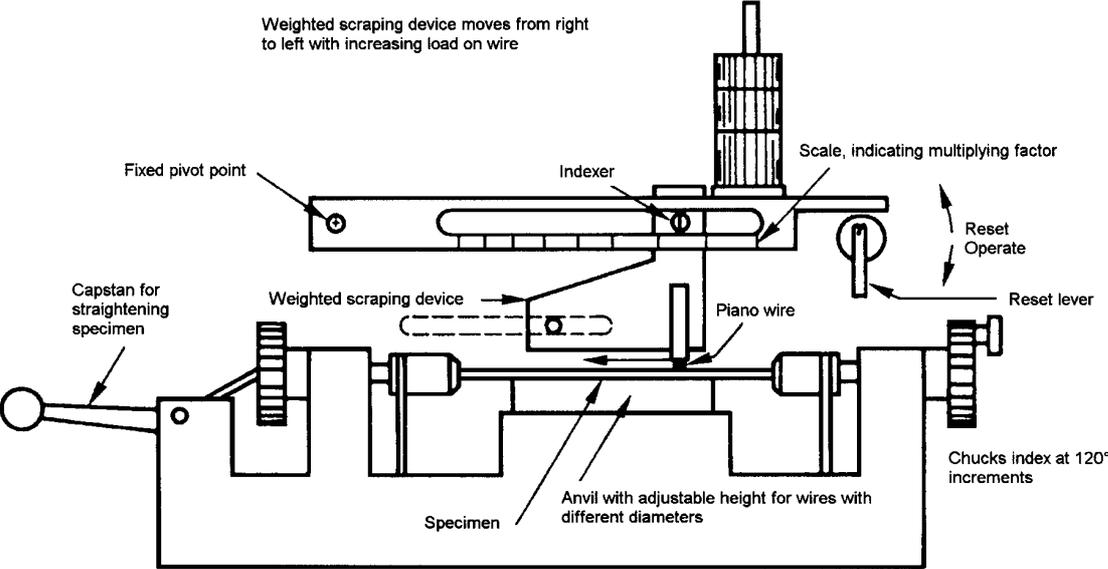
IEC 804/96

Figure 7 – Scraper



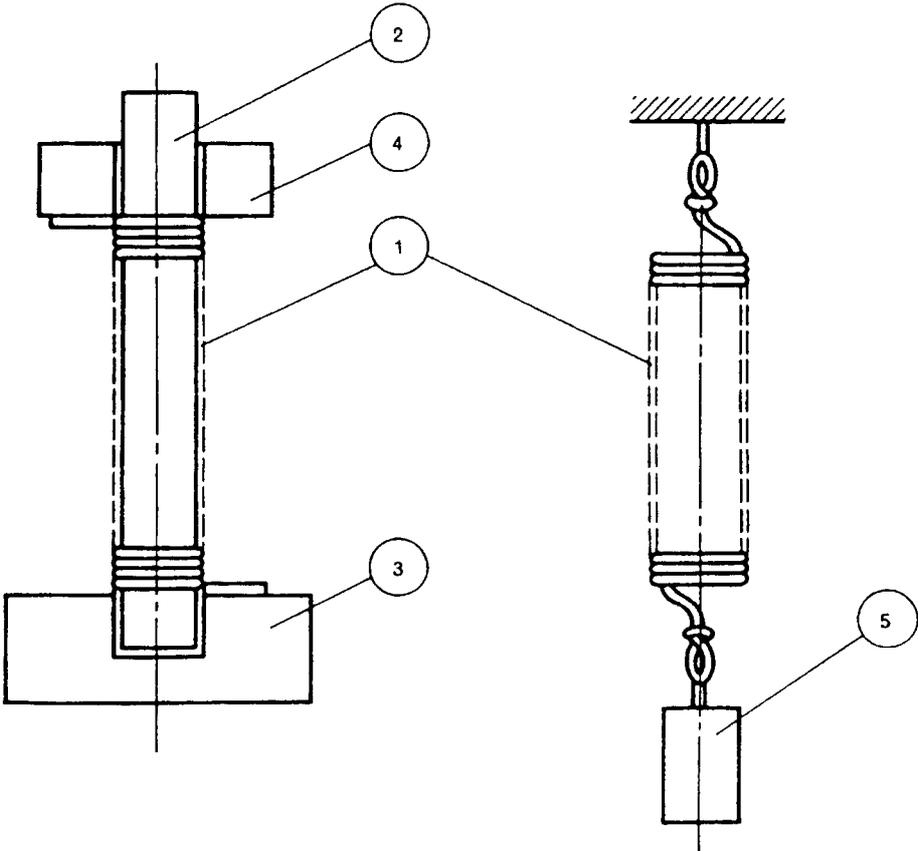
IEC 805/96

Figure 8 – Cross-section of the wire after removal of the coating



IEC 806/96

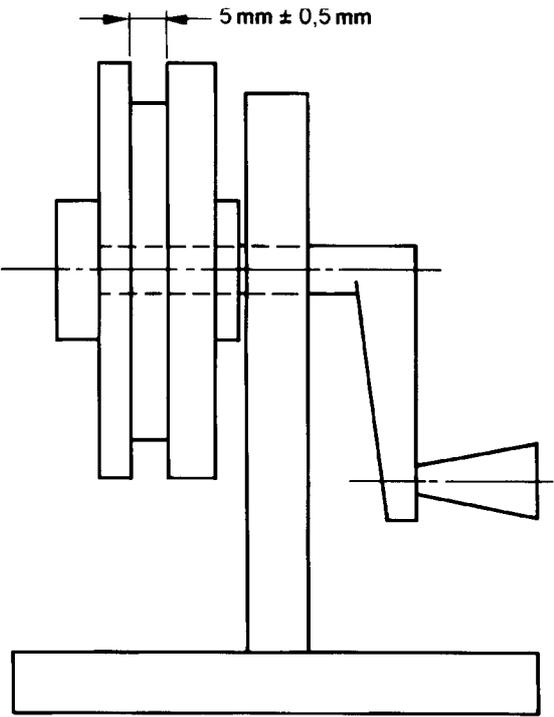
Figure 9 – Test equipment for unidirectional scrape test



IEC 80796

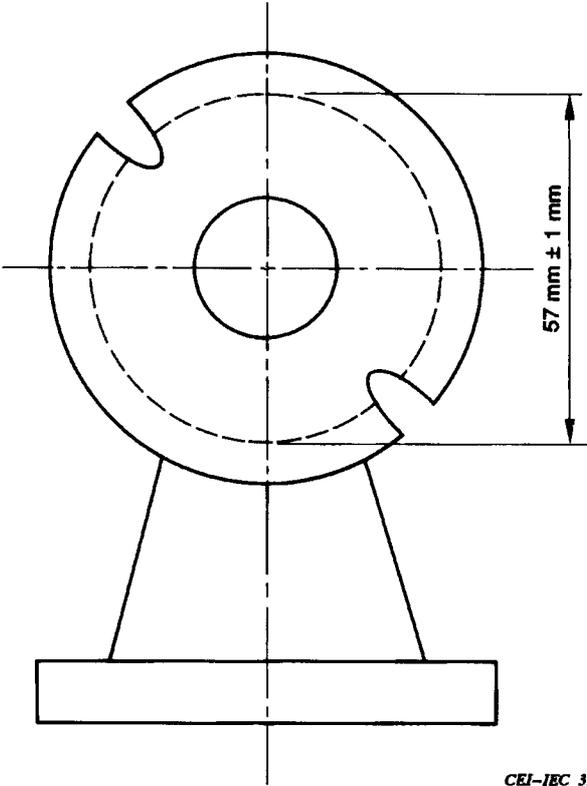
- 1 = coil
- 2 = mandrel
- 3 = mandrel-holder
- 4 = weight
- 5 = separating load

Figure 10 – Test equipment for bond retention of a helical coil



IEC 808/96

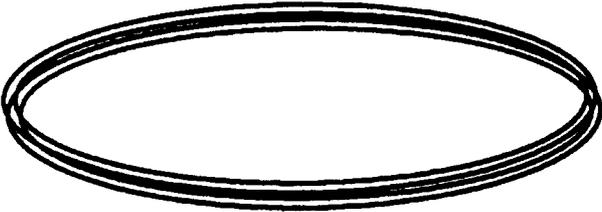
Figure 11a – Coil winder



CEI-IEC 318/91

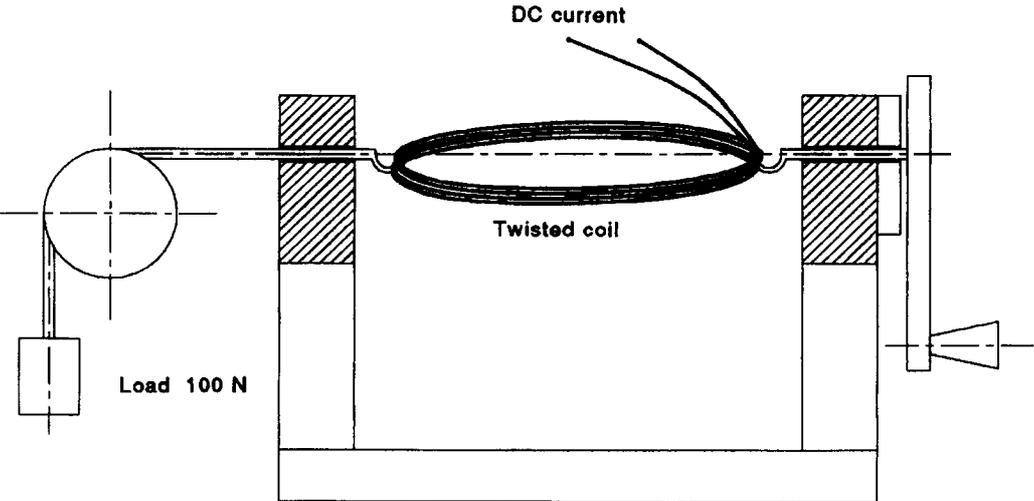
Figure 11b – Coil winder, front view

Figure 11 – Coil winder



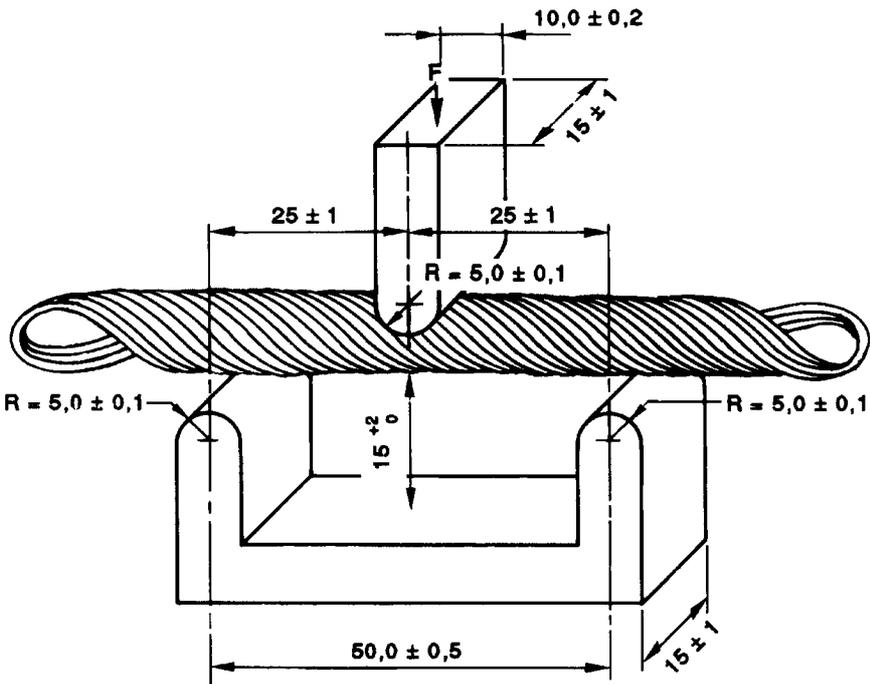
CEI-IEC 319/91

Figure 12 – Oval shape coil



CEI-IEC 680/92

Figure 13 – Twisting device with a load applied to the twisted coil specimen



CEI-IEC 321/91

Figure 14 – Arrangement of supports

Annex A (informative)

Bond strength of heat bonding wires

A.1 Calculation of the temperature of the twisted coil specimen

Method

While heating the twisted coil by means of d.c. current, the average temperature of the specimen may be derived from its d.c. resistance, which is the ratio of the voltage and the constant current applied. Such ratios can be determined at the beginning and at the end of any heating period and allow the calculation of the temperature at the end of the heating period.

Temperature coefficient

For the following calculations, a temperature coefficient of copper of $\alpha = 0,004 \text{ K}^{-1}$ is used.

Calculation

With this temperature coefficient, the resistance of the test specimen at the end of a heating period is calculated from the equation

$$R_{T_t} = R_{T_0} + \alpha R_{T_0} \times (T_t - T_0)$$

where

R_{T_0} is the resistance in the beginning (at room temperature);

T_t is the temperature at the end of the heating period;

T_0 is the temperature in the beginning of the heating period (T_0 normally is identical with room temperature, i.e. 23 °C).

The index t stands for the end of the heating period.

If the current is constant, the following equation applies:

$$\frac{R_{T_t}}{R_{T_0}} = \frac{U_t}{U_0}$$

where

U_t is the voltage at the end of the heating period;

U_0 is the voltage in the beginning of the heating period.

This results in the temperature at the end of the heating period:

$$T_t = T_0 + \left[250 \times \left(\frac{U_t}{U_0} - 1 \right) \right] \text{ in } ^\circ\text{C}$$

A.2 Determination of the heating period

Voltage-time graphs

While heating the twisted coil with a constant current, the electrical resistance increases with the temperature. To maintain the current, the voltage output of the constant current transformer increases accordingly. This allows to plot the d.c. voltage output against time. This provides information about the time t of the heating period. Different graphs may be taken for different currents all plotted on one and the same diagram.

Voltage at maximum temperature

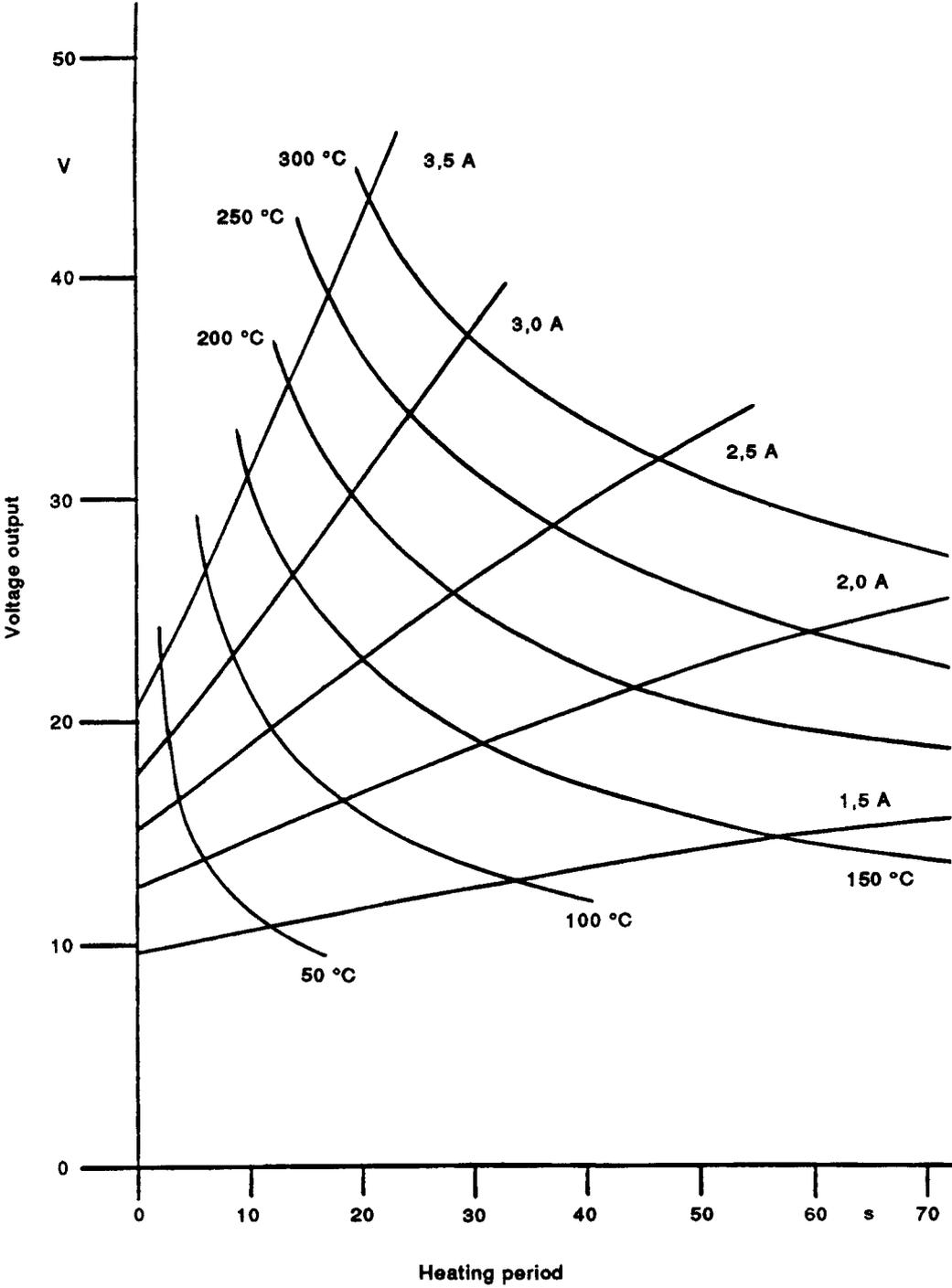
In a specific case one may wish to bond the specimen up to a certain temperature, but not to exceed this temperature. If this maximum temperature is defined, the last equation as shown in A.1 allows the calculation of the voltage required to reach that temperature with a particular heating current:

$$U_t = U_0 + 0,004 \times (T_t - T_0) U_0$$

The point of intersection of the Voltage-time graph with the Y-axis corresponds to the value of U_0 . With this reading, the last equation allows the calculation of the voltage to arrive at the temperature of the specimen at the end of the heating period. The corresponding value of the X-axis gives the time length of the heating period required to reach the temperature T_t .

If the same calculation is done with all Voltage-time graphs for one and the same temperature T_t , the corresponding entries may be used to produce an isothermic graph that intersects the Voltage-time graphs. If this is repeated with different temperatures, it results in a final diagram which is very helpful in selecting a suitable pair of values for the heating current in amperes and the time in seconds of the heating period to heat the test specimen up to the chosen temperature T_t .

Figures A.1 through A.4 show examples of such complete diagrams for easy reference, based on wire sizes 0,300 mm, 0,315 mm, 0,355 mm and 0,500 mm respectively.



CEI-IEC 681/92

Figure A.1 – Example of voltage-time graphs of twisted coil specimens with a nominal conductor diameter of 0,300 mm with isothermic graphs

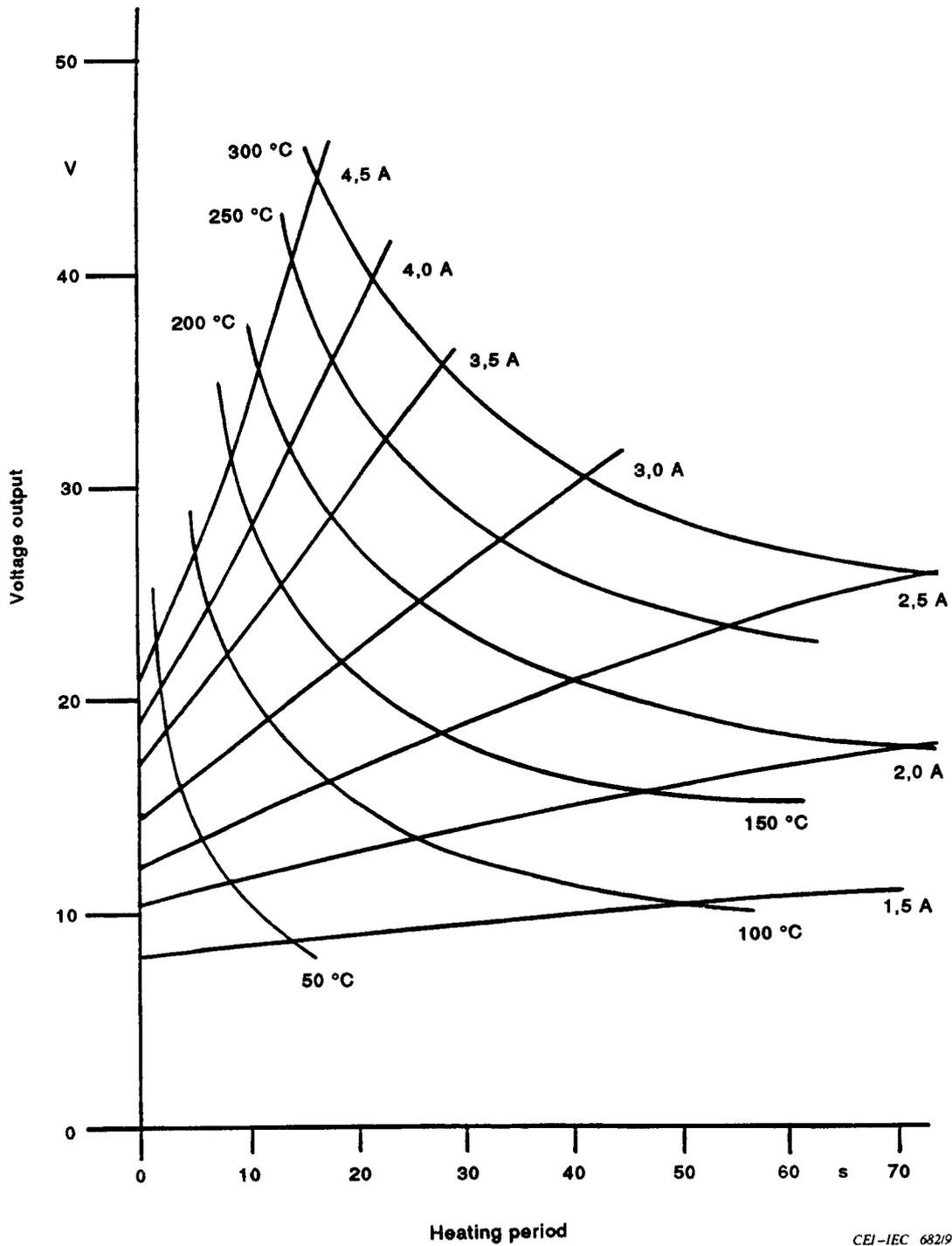
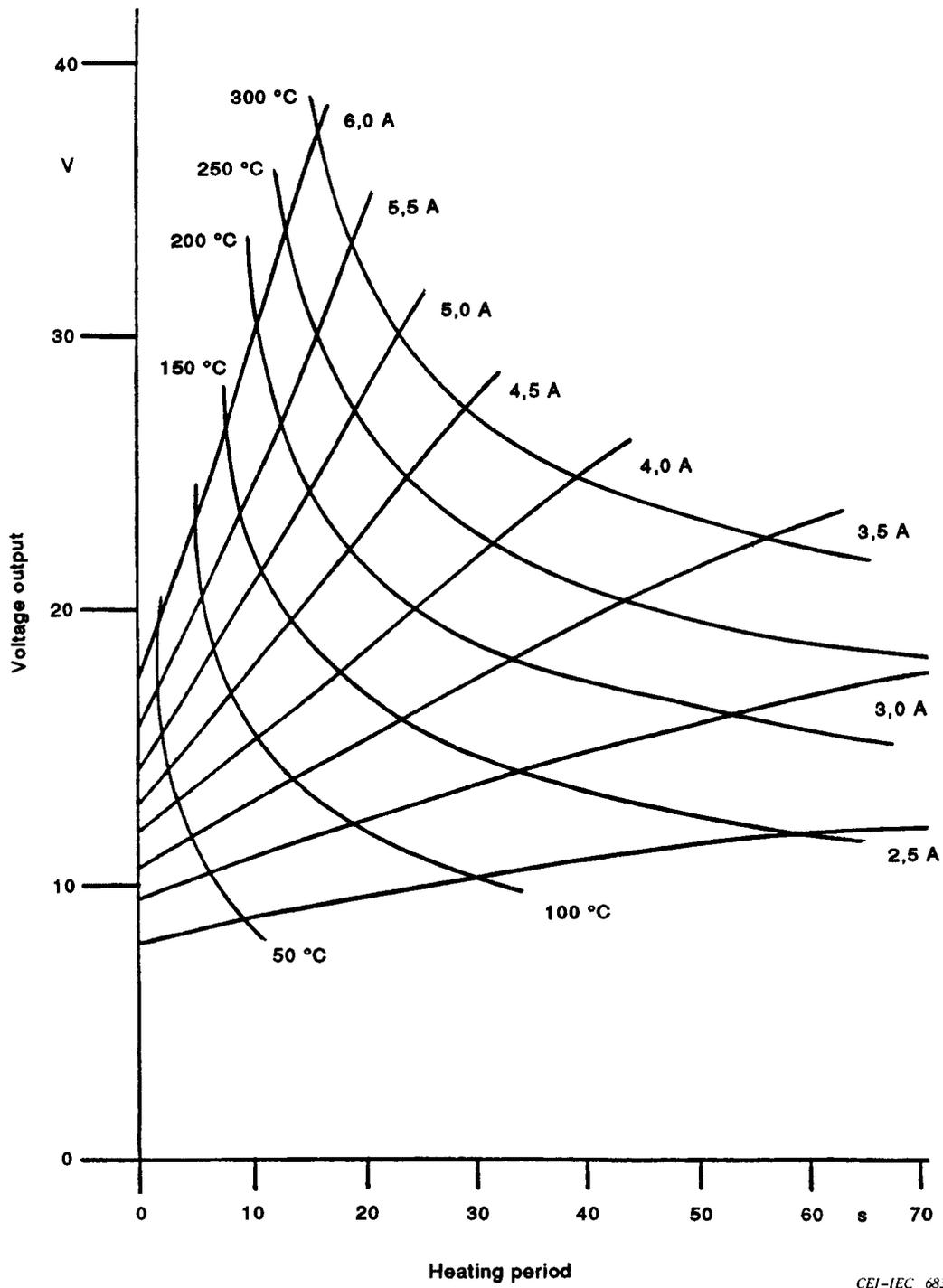
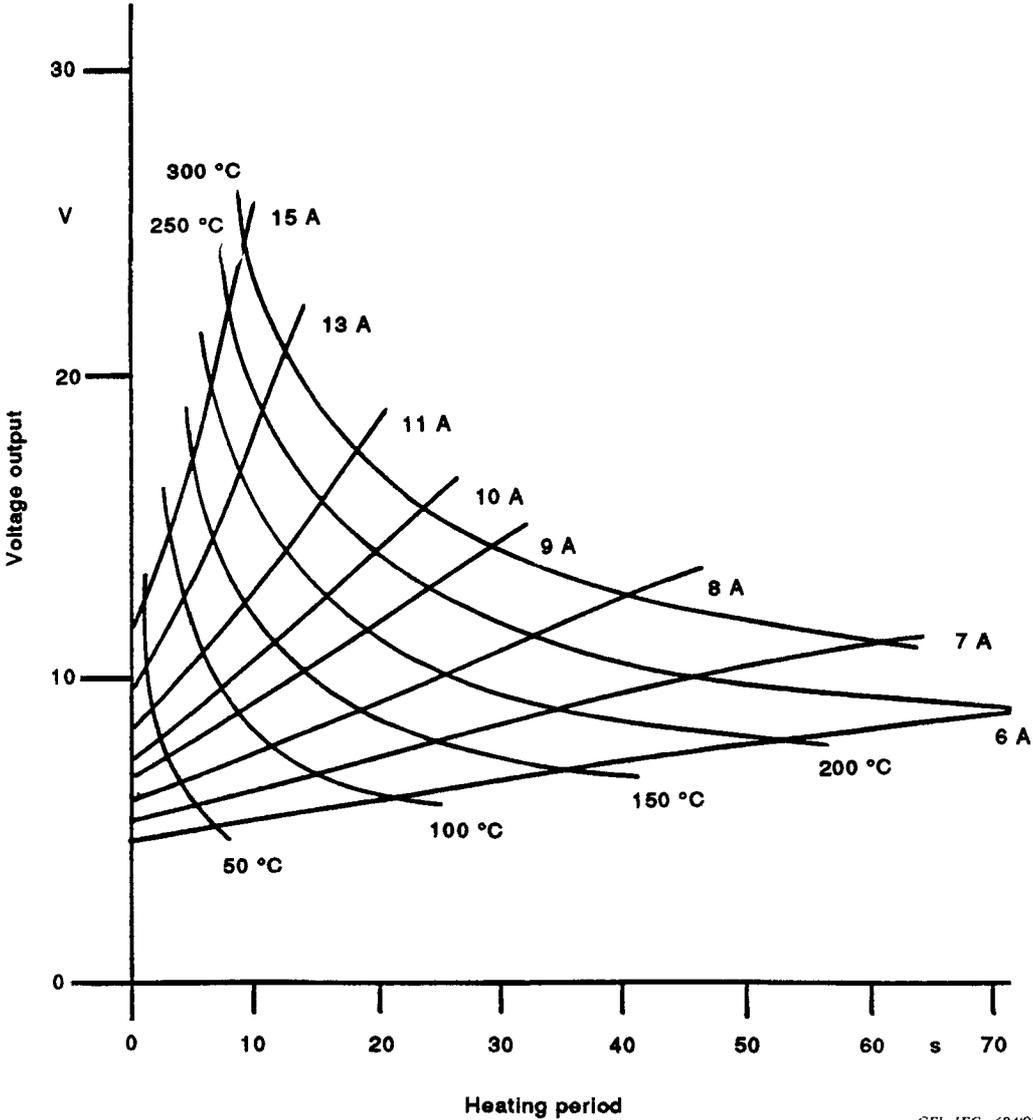


Figure A.2 – Example of voltage-time graphs of twisted coil specimens with a nominal conductor diameter of 0,315 mm with isothermic graphs



CEI-IEC 683192

Figure A.3 – Example of voltage-time graphs of twisted coil specimens with a nominal conductor diameter of 0,355 mm with isothermic graphs



CEI-IEC 68492

Figure A.4 – Example of voltage-time graphs of twisted coil specimens with a nominal conductor diameter of 0,500 mm with isothermic graphs

Annex B (informative)

Friction test methods

B.1 General

This annex provides recommendations to the purchaser and supplier of winding wires with respect to friction test methods to be used for winding wires.

B.2 Test A: Static coefficient of friction test method

B.2.1 Method of test (applicable to enamelled round wires with a nominal conductor diameter from 0,050 mm up to and including 1,600 mm)

The static coefficient of friction (μ_s) is determined by measuring the inclining angle (α) of a plane at the moment when a block begins to slip on the track made from the wire specimen. The wire test specimen shall be removed from the delivery spools by dereeling over the end flange. The top layers of the spool shall be removed before testing when the wire surface is contaminated by dirt or dust. One part of the wire specimen is straightened and then fixed on the inclining plane by means of the two posts and the two clamps constituting the sliding track. The other part of the wire specimen is mounted in a similar way on the sliding block.

The sliding block with the wire specimen is then placed on the track of the plane to be inclined in such a way that the wire on the block and the wire on the plane are crossed at right angles at the point of contact.

The plane is then slowly inclined (approximately 1 degree per second) until the block starts to slide down the track. At that moment, the angle of inclination (α) is read from the scale.

The static coefficient of friction is calculated as follows:

$$\mu_s = \tan \alpha$$

B.2.2 Test apparatus

The general arrangement of the test apparatus is shown in figure B.1.

The apparatus consists of a plane (1) which can be inclined to an angle (α) by turning the plane around the axis (8). The support (9) carries a scale (7) marked with the inclination angle (α) or the coefficient of friction ($\tan \alpha$).

The plane has means for fixing the wire specimen (3), for example the two posts (5) and the two clamps (6). The parallel parts of the wire shall be 110 mm apart. They form a sliding track running from the scale end to the axis on the plane.

On the block (2) clamps and posts are provided to fix the second wire specimen (4). The parallel parts of the specimen shall be 60 mm apart. The size of the block must allow the clamps and posts to stay clear of the plane (1) to avoid additional friction forces. The block shall have:

- a mass of about 50 g for a wire with a nominal conductor diameter up to and including 0,150 mm;
- a mass of about 500 g for a wire with a nominal conductor diameter over 0,150 mm.

The mass is not critical as it is anyway changed by the mass of the second wire specimen.

The angle of inclination shall be changed slowly by means of a motor-operated block and tackle.

B.3 Test B: First dynamic coefficient of friction test method

B.3.1 Principle

The coefficient of friction, μ_d , is determined by measuring the frictional force, C, applied on the wire when moving under the pressure of a known mass, E:

$$\mu_d = \frac{C}{9,81 \times E}$$

B.3.2 Method of test

The general arrangement of the test apparatus is shown in figure B.2.

The enamelled wire runs via a guide wheel and a brake (D) over a metal plate (B). Via another guide wheel, the wire is lead below this plate (B) and runs back, parallel with the first passage, over this plate again (see figure B.2). By means of a capstan (A), the wire is drawn with a speed of 0,25 m/s. A mass (E) is placed on the running wire over the plate (B) which is coupled to a force indication meter (C).

The force indication meter can be coupled to a linear recorder (measuring range 1 mV – 250 mV). This linear recorder shows the spread of the smoothness and the level of the wire smoothness over a long distance.

B.4 Test C: Second dynamic coefficient of friction test method

B.4.1 Method of test (applicable to enamelled round wires with a nominal conductor diameter from 0,050 mm up to and including 1,600 mm)

The wire specimen is pulled under a test load. The force is developed between the wire surface and the load contact surface and transferred to an appropriate measuring device. The reading in N is divided by the load in N for determination of the dynamic coefficient of friction (μ_d).

The wire test specimen shall be removed from the delivery spools by dereeling over the end flange or from the pail or drum. The top wire specimen layer of the spool shall be removed before testing if the wire specimen has been contaminated by dirt or dust.

Referring to figure B.4, level the smooth surface (6) using the levelling leg screws (2) and float level (8).

Adjust the electronic force transducer (5) (figure B.4) sensitivity to the appropriate range, and set chart recorder to full-scale setting for the wire size being tested using a calibrating weight (9) (figure B.3). The calibrating weight should be removed after the transducer and chart recorder are adjusted.

If a mechanical dynamometer (5) (figure B.4) is used, adjust the correct range for the wire size being tested.

- Nominal conductor diameters from 0,050 mm up to and including 0,125 mm: 0 – 0,49 N.
- Nominal conductor diameters over 0,125 mm up to and including 1,600 mm: 0 – 1,96 N.

Clean the sapphire surfaces located on the load block (3) (figure B.4) in contact with the wire with an appropriate cleaning solvent and allow time to dry thoroughly.

Lower the dampening paddle (4) (figure B.4) into the oil.

- Completely immerse for sizes over 0,224 mm up to and including 1,600 mm.
- Immerse one-half paddle for sizes from 0,050 mm up to and including 0,224 mm.

Thread the wire over appropriate guide pulleys (figures B.3 (4) and B.4 (9)) so that the wire is in contact with the two sapphires.

Apply the appropriate test load (7) (figure B.4):

- for sizes over 0,050 mm up to and including 0,071 mm: 0,98 N;
- for sizes over 0,071 mm up to and including 0,125 mm: 1,96 N;
- for sizes over 0,125 mm up to and including 0,450 mm: 5,88 N;
- for sizes over 0,450 mm up to and including 1,600 mm: 9,87 N.

The test load (7) (figure B.4) should be positioned on the test bed (6) (figure B.4) where no reading is indicated on the force transducer or dynamometer. If the mechanical dynamometer is used, it should be zeroed.

Adjust the calibrated dial (1) (figure B.4) to make the test load parallel with the test bed surface. Turn tester on and start the test wire moving.

Slight tension (1) (figure B.3) should be applied to keep the wire travelling smoothly.

To allow time for the start-up variations to cease, the average dynamometer reading to the nearest newton should be recorded at least 15 s after start-up.

Calculate the average coefficient of friction (μ_d) as follows:

$$\mu_d = \frac{F}{L}$$

where

F is the average dynamometer force reading, in newtons;

L is the test load, in newtons.

B.4.2 Test apparatus

The general arrangement of the test apparatus is shown in figures B.3, B.4 and B.5.

A motor (3) (figure B.3) shall pull the wire specimen at 15 m/min across a smooth surface (10) (figure B.3) using a motor take-up (6) (figure B.3).

Various load weights (7) (figure B.4) should be available which will provide 0,98 N – 9,81 N force. The load surface shall be synthetic sapphire and have a surface roughness of not more than 0,5 µm. The sapphires are described and shall be mounted as shown in figure B.5.

There shall be a means to guide the wire (figure B.3 (4) and figure B.4 (9)) and a means to maintain a slight tension (figure B.3, (1) (5)) if needed.

B.4.3 Measuring device

The measuring device consists of:

- Electronic force measuring devices or transducers (2) (figure B.3) incorporated with a chart recorder for measuring the force due to friction. The electronic force measuring device will provide a record indicating the peak variation along the surface of the wire. A force transducer with a range of 0 – 4,9 N, and a chart recorder with a 0 – 5 V range and a 0,5 s full-scale response time are satisfactory.
- Figure B.4 illustrates the use of a mechanical dynamometer (5) in place of an electronic force transducer and chart recorder. Two dynamometer ranges, 0 – 0,49 N and 0 – 1,96 N, are satisfactory.
- A dampening system (4) (figure B.4) consisting of a paddle and a container filled to a depth of 5 mm with oil having a viscosity of approximately 10 200 mPa × s at 25 °C.
- An appropriate cleaning solvent for the lubricant being tested.

B.5 Test D: Force of friction by the twisted pair method.

B.5.1 Enamelled round wires with a nominal conductor diameter from 0,1 mm up to and including 1,500 mm

From an enamelled wire specimen a twist is made similar to the one used for test 13 (breakdown voltage) in 4.3 of IEC 60851-5. The end of the first twist strand is attached to a fixed jaw, and a force is applied to the opposite end of the second strand that has been kept free to slide by traction and without rotating, using for example a dynamometer. The force to separate the two strands is the sliding force.

B.5.2 Method of test

A specimen approximately of 400 mm in length shall be twisted back on itself for a distance of 125 mm on an apparatus as shown in figure B.6. The force (weight) applied to the wire pair while being twisted and the number of twists are given in table B.1.

At the twisted end, the loop is cut in two separate places to obtain a maximum separation between these cut ends.

Any bending of the wires, at the cut end or at the other untwisted end, to ensure adequate separation between the wires, shall avoid sharp bends or damage to the insulation.

One end of one wire shall be attached firmly to a jaw, while at the opposite end of the other wire a force (weight) is applied to let that wire slide without any rotation. Three specimens shall be tested.

B.6 Reference document

IEC 60851-5:1996, *Methods of test for winding wires – Part 5: Electrical properties.*

Table B.1 – Twisted pair method

Nominal conductor diameter mm		Force applied to wire pairs N	Number of twists per 125 mm
Over	Up to and including		
0,10	0,25	0,85	17
0,25	0,315	1,40	15
0,315	0,40	2,40	13
0,40	0,50	3,40	12
0,50	0,71	6,00	11
0,71	0,80	8,50	10
0,80	0,90	10,00	9
0,90	1,00	12,50	8
1,00	1,12	15,00	7
1,12	1,25	20,00	6
1,25	1,50	27,00	5

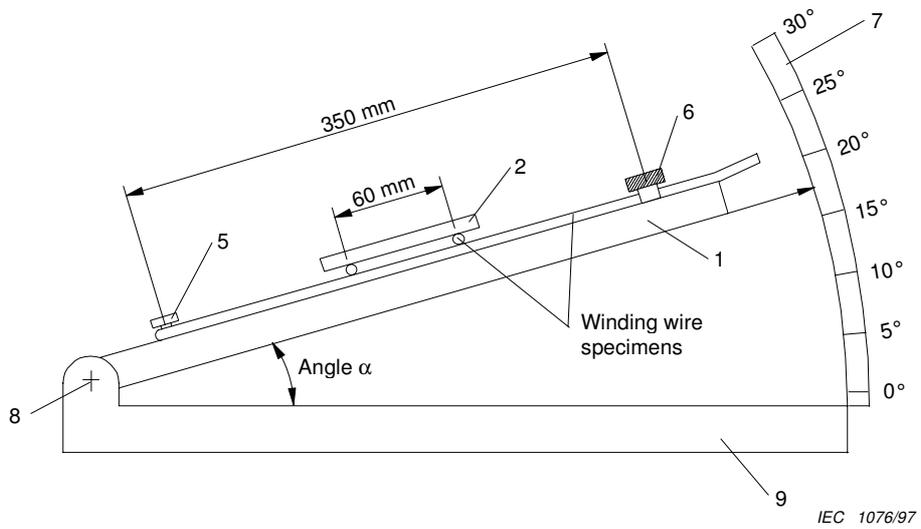


Figure B.1a – Side view

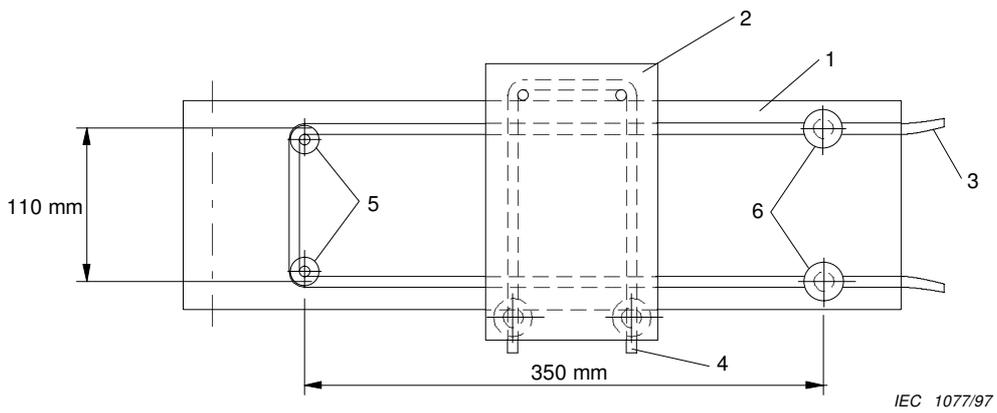


Figure B.1b – Top view

- | | |
|-------------------|-------------|
| 1 = plane | 6 = clamps |
| 2 = block | 7 = scale |
| 3 = wire specimen | 8 = axis |
| 4 = wire | 9 = support |
| 5 = posts | |

Figure B.1 – Static coefficient of friction test apparatus

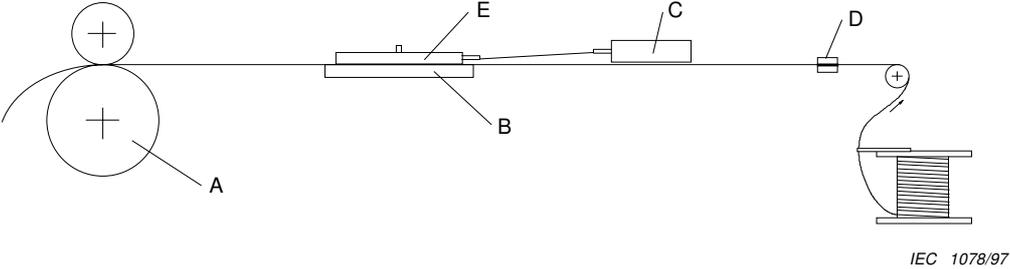


Figure B.2a – Side view

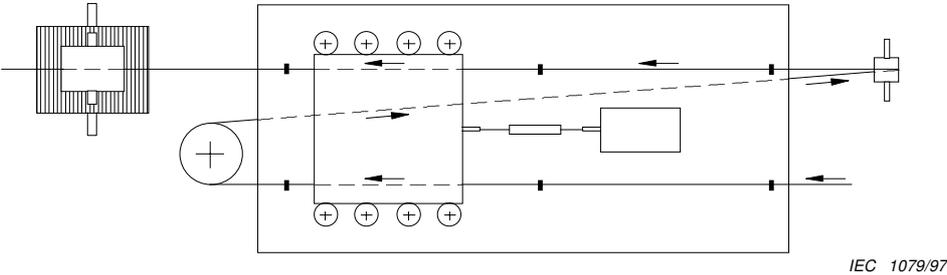


Figure B.2b – Top view

- A = capstan
- B = plate
- C = force indication meter
- D = brake
- E = mass

Figure B.2 – Dynamic coefficient of friction test apparatus

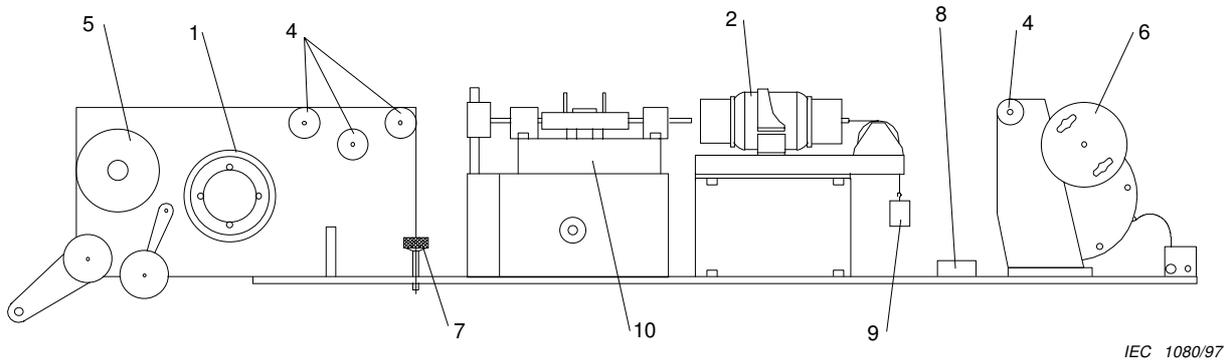


Figure B.3a – Side view

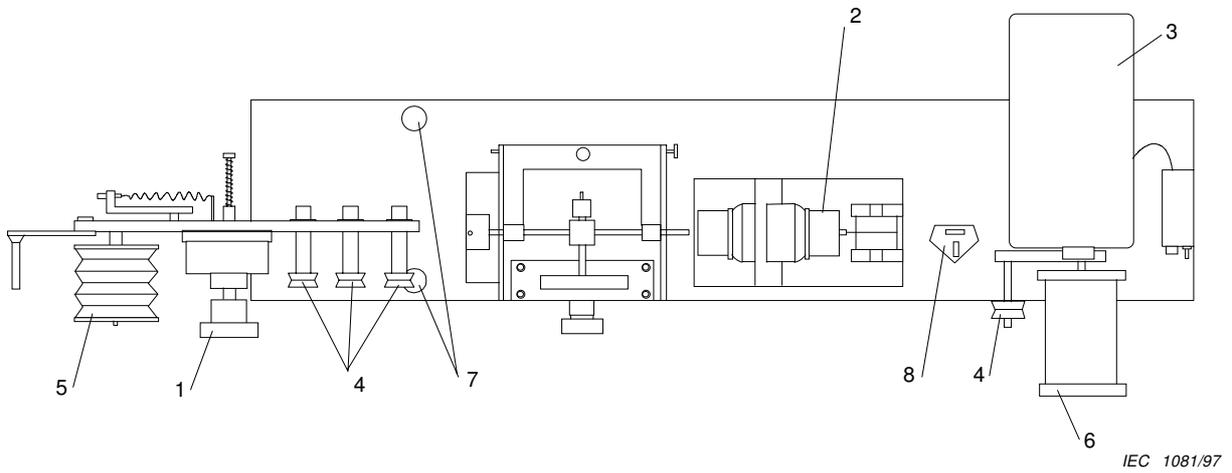
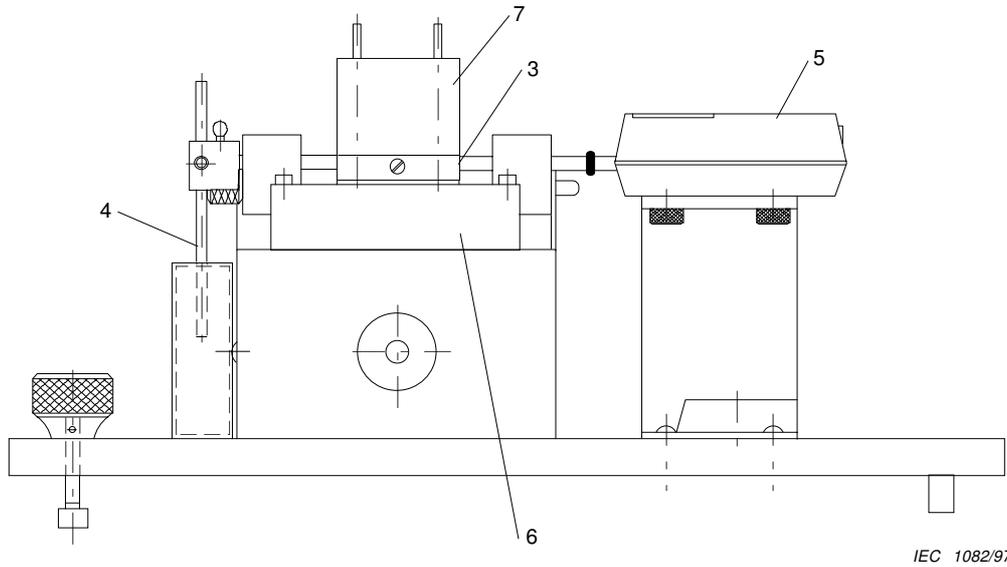


Figure B.3b – Top view

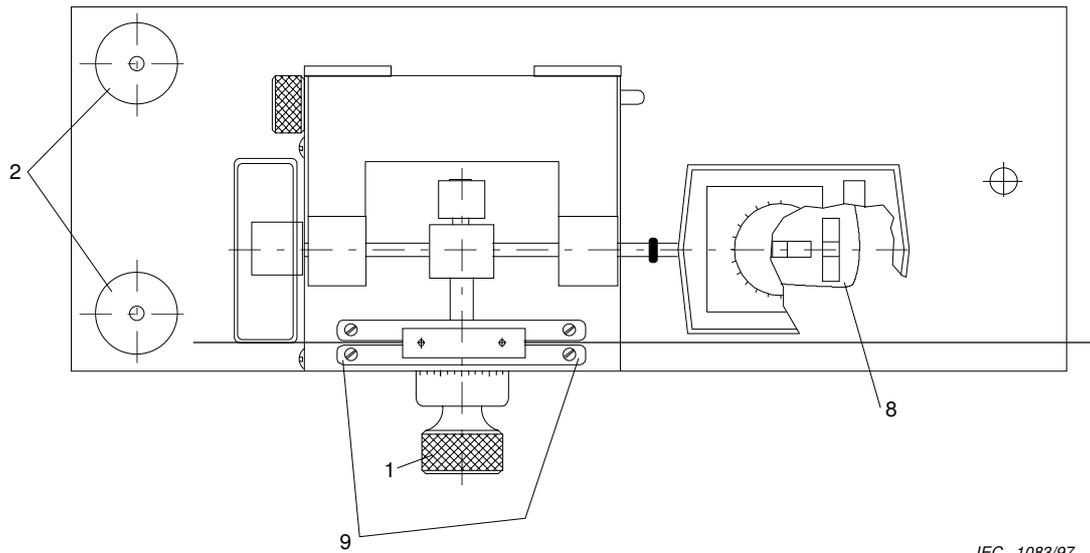
- | | |
|-----------------------|---|
| 1 = tension capstan | 6 = wire take-up |
| 2 = transducer | 7 = leg levellers |
| 3 = motor | 8 = float level |
| 4 = wire guide pulley | 9 = calibration weight |
| 5 = pay-off pulley | 10 = test bed (consisting of 2 positions
depending on wire diameter) |

Figure B.3 – Dynamic coefficient of friction test apparatus



IEC 1082/97

Figure B.4a – Side view



IEC 1083/97

Figure B.4b – Top view

- 1 = calibrated adjustment for parallelism between the test load and test bed surfaces
- 2 = leg levellers
- 3 = load block (see figure B.5)
- 4 = dampening system
- 5 = dynamometer
- 6 = test bed
- 7 = test weights
- 8 = float level
- 9 = test guides

Figure B.4 – Detail drawing of friction head assembly with mechanical dynamometer

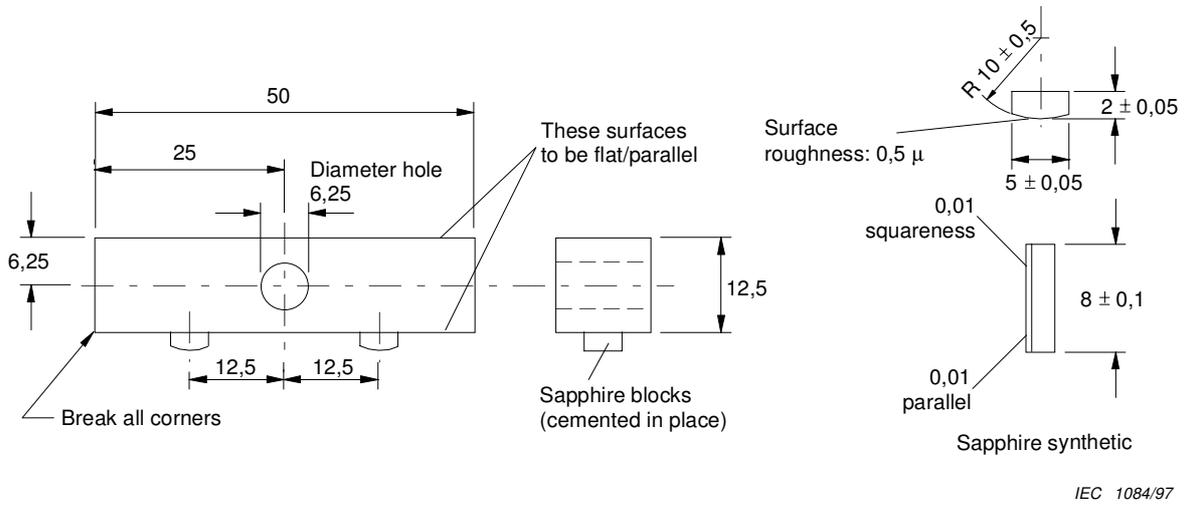
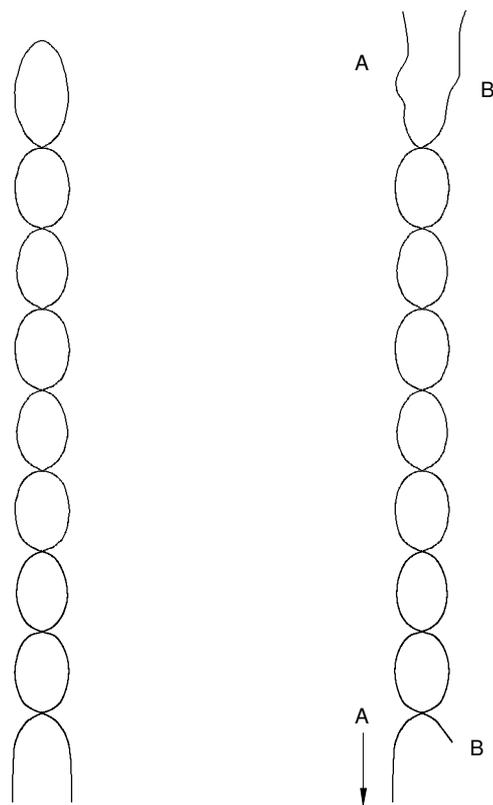


Figure B.5 – Load block with sapphires



IEC 1085/97

Figure B.6 – Twisted specimen