भारतीय मानक **IS 19059 : 2024**

Indian Standard

निरंतर ट्रांसपोज़्ड कंडक्टर (सीटीसी) कॉपर वाइंडिंग तार

Continuously Transposed Conductor (CTC) Copper Winding Wires

ICS 29.060.10

भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानक भवन, 9 बहादुर शाह ज़फर मार्ग, नई दिल्ली - 110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI - 110002
www.bis.gov.in www.standardsbis.in

November 2024 **Price Group X**

Winding Wire Sectional Committee, ETD 33

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Winding Wires Sectional Committee and has been approved by the Electrotechnical Division Council.

This standard has been prepared to cover the requirements of continuously transposed conductor (CTC) copper winding wires which are growing in popularity in India due to their ability to reduce eddy current loss. They are increasingly being used in transformer winding of the power and locomotive transformers. Tests to ascertain conformity in this regard have also been stipulated in the standard.

Continuously transposed conductor (CTC) copper winding wires are a specialized type of conductor used primarily in power transformers, consisting of multiple thin, rectangular copper strips stacked and twisted together along their length. This continuous transposition ensures each strip occupies every position within the conductor cross-section, offering several advantages:

a) Reduced eddy current losses — Transposition minimizes circulating currents induced by alternating magnetic fields, leading to lower energy losses and improved transformer efficiency;

b) Even current distribution — Each strip carries its share of current, preventing hot spots and improving conductor utilization;

c) Enhanced heat dissipation — The arrangement promotes better heat transfer, aiding cooling efficiency and potentially reducing transformer size;

d) Increased mechanical strength — CTCs, especially self-bonding types, offer improved mechanical strength to withstand operational stresses;

e) Easier winding — They're generally easier to wind than traditional conductors, saving production time and cost; and

f) Space efficiency — Their compact structure and thin insulation enable more efficient use of space within the transformer.

The composition of the Committee responsible for the formulation of this standard is given in Annex C.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of a test, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

CONTINUOUSLY TRANSPOSED CONDUCTORS (CTC) COPPER WINDING WIRES

1 SCOPE

1.1 This standard specifies the requirement of the continuously transposed conductors with type, product variety structure, technical requirements, acceptance rules and packaging marking.

1.2 Continuously transposed conductors are generally used in the electrical windings of a variety of transformers including oil-immersed, dry-type, and reactors etc.

2 REFERENCES

The standards listed in Annex A contain provisions, which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards.

3 TERMINOLOGY

For the purpose of this standard the following definitions, in addition to those given shall comply.

3.1 Bonding Layer — Material (generally epoxy or any other bond coat) that is deposited on an enamelled wire in which has the specific function of bonding wire together.

3.2 Butt Lapping — It refers to the lapping form that the edges of the adjacent paper lap of the same lapping layer are lapped edge to edge with overlap up to 0.5 mm or gap up to 2 mm. Illustrated in Fig. 1.

3.3 Class — Thermal performance of a wire expressed by the temperature index and the heat shock temperature.

3.4 Coating — Material which is deposited on the conductor by a suitable means and then dried and/or cured.

3.5 Coincidence of Butt Gaps — It refers to the coincidence of the adjacent lapping layer gaps during open lapping. This shall not be applicable in case of change of taping head from one layer to another.

3.6 Conductor — Bare metal after removal of insulation.

3.7 Conductor/Material Code — The following are relevant:

a) Continuously transposed conductor (CTC);
b) 0 - annealed-copper conductor; and
c) CPR - Controlled proof-stress copper conductor (recommended for CTC).

3.8 Continuously Transposed Conductor — It refers to the winding conductors formed by two rows of a certain number of enamelled copper rectangular wires mutually contacted at wide surfaces, transposed in same direction along the narrow surface of the top and bottom of the two rows of enamelled rectangular wires, and lapped continuously by electrical insulated paper, netting tape etc.

3.9 Controlled Proof-Stress Copper Conductor — It refers to the copper conductors for which the specified non-proportional elongation strength $R_{p0.2}$ is between (80 to 220) N/mm^2.

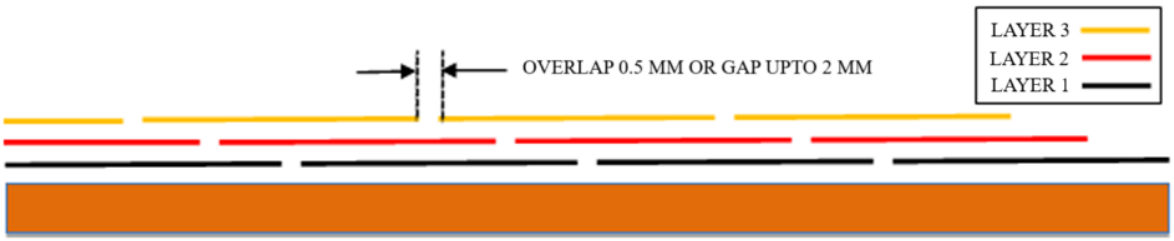

FIG. 1 BUTT LAPPING

3.10 Enamelled Rectangular Wire — Rectangular wire coated with an insulation of cured resin such as the following:

a) 105/120 class, polyvinyl acetal (PVA) enamelled copper rectangular wire;

b) 180 class, polyester imide enamel enamelled (PEI) copper rectangular wire;

c) 200 class, polyester imide over coated with polyamide-imide enamelled (PEI + PAI) copper rectangular wire;

d) 220 class, polyamide-imide enamelled (PAI) copper rectangular wire and

e) 105/120/180/200 class, enamelled copper rectangular wire overcoated with epoxy or another suitable bond coat.

3.11 Enamelled Wire — Wire coated with insulation of cured resins (for example, PVA, PEI and PAI).

3.12 Factory Acceptance Test — Tests carried out on samples taken from a lot for the purpose of factory acceptance of the lot before dispatch in presence of purchaser or third-party inspection agency as agreed between CTC manufacturer and purchaser.

3.13 Half Overlapping — It refers to the lapping form with the width of overlapping in 40 percent to 60 percent. Illustrated in Fig. 2.

3.14 Insulation Paper Tape and Binding Rope (Tape) Material — Referred to IS 9335 (Part 3/Sec 5)/IEC 60554-3-5 Specification for cellulosic papers for electrical purposes.

a) Special papers — General purpose electrical grade kraft paper winding wire and conductor wrapping.

NOTE — It is referred to all the temperature class;

b) Crepe paper — As per relevant standards IS 9335 (Part 3/Sec 3)/IEC 60554-3-3 and as per agreement between CTC manufacturer and purchaser; and

c) Netting tape — As per agreement between CTC manufacturer and purchaser.

3.15 Interlocked Lapping — It refers to the lapping form that the two layers of paper tapes which are mutually overlapped (40 to 60) percent are subjected to half overlapping along the same direction. Illustrated in Fig. 3.

3.16 One Third Overlapping — It refers to the lapping form with the width of overlapping in 25 percent to 35 percent. Illustrated in Fig. 4.

3.17 Open Lapping (Gap Lapping) — It refers to the lapping form that the edges of the adjacent paper lap of the same lapping layer are not mutually overlapped but have a gap up to 2 mm. Illustrated in Fig. 5.

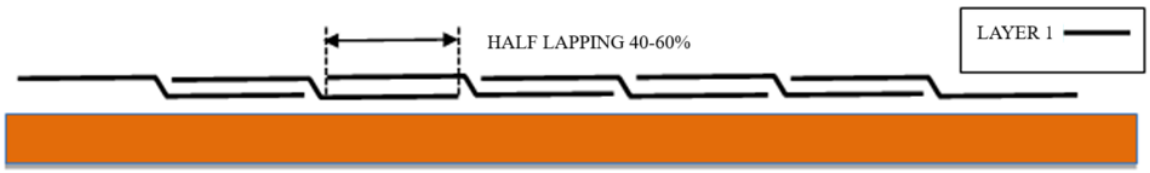

FIG. 2 HALF OVERLAPPING

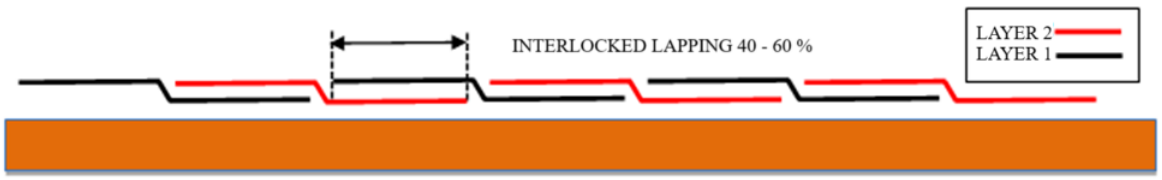

FIG. 3 INTERLOCKED LAPPING

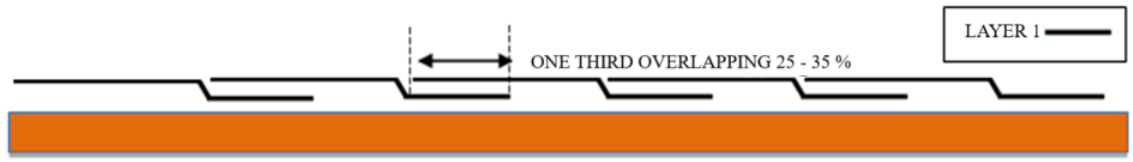

FIG. 4 ONE THIRD OVERLAPPING

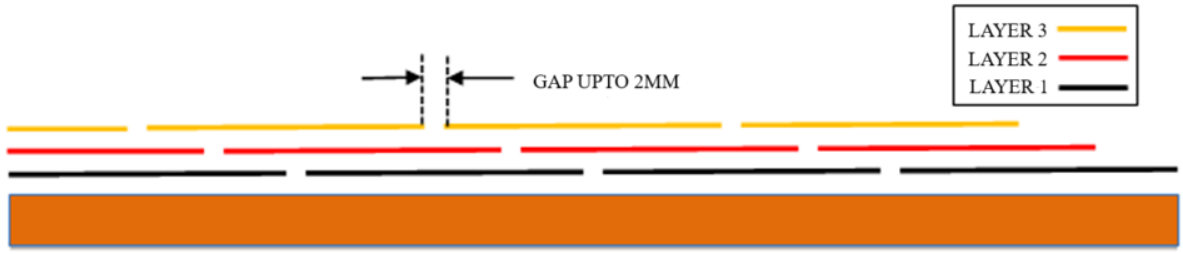

FIG. 5 GAP LAPPING

3.18 Optional Tests — Special tests to be carried out, when required, by agreement between CTC manufacturer and purchaser.

3.19 Overlapping — It refers to the lapping form that the edges of the adjacent paper tape of the same lapping layer are mutually overlapped.

3.20 Routine Test — Tests performed by the CTC manufacturer on the CTC, during manufacturing of the given product to demonstrate integrity and quality control.

3.21 Staggering in Lapping — It refers to the distance between the edges of the adjacent paper tapes. The distance shall be approx 25 percent to 40 percent of the width of the tape. This range shall not be applicable in case of change of taping head from one layer to another. Illustrated in Fig. 6.

3.22 Symbols — The dimensional symbols of the continuously transposed conductor are as shown in Fig. 7,

where

A_{Max} : Maximum dimension of the narrow edge (thickness), in mm, of enamelled rectangular wire;

a : Nominal dimension of the narrow edge (thickness), in mm, of bare rectangular wire;

B : Wide edge nominal dimension (width), in mm, of enamelled rectangular wire;

B_{Max} : Maximum dimension of the wide edge (width), in mm, of enamelled rectangular wire;

b : Nominal dimension of the wide edge (width), in mm, of bare rectangular wire;

C_k : Inter leaving/inter column paper width, in mm;

C_z : Inter leaving/inter column paper thickness, in mm;

H_2 : Nominal height, in mm, of continuously transposed conductor;

H_{2Max} : Maximum height, in mm, of continuously transposed conductor;

K_h : Tolerance in height, in mm, of continuously transposed conductor;

K_w : Tolerance in width of continuously transposed conductor, in mm;

k_1 : Height correction factor of continuously transposed conductor.

n : Number of transposed enamelled rectangular wire;

S : Transposition pitch; and

Tape : Narrow edge nominal dimension (thickness), in mm, of enamelled rectangular wire;

W_2 : Nominal width, in mm, of continuously transposed conductor;

W_{2Max} : Maximum width, in mm, of continuously transposed conductor;

Δ : Nominal thickness, in mm, of paper insulation layer (both sides) of continuously transposed conductor (or bundle and paper thickness);

δ : Enamel film thickness (both sides), in mm, of enamelled rectangular wire;

δ_n : Self-adhesive epoxy layer thickness (both sides), in mm, of enamelled rectangular wire;

ε : Allowable tolerance, in mm, of bare rectangular wire conductor dimension;

3.23 Transposed Core — It refers to the combination of the enamelled rectangular wire after transposition.

3.24 Transposition Pitch — It refers to the axial length of a certain enamelled rectangular wire in the continuously transposed conductor after subjected to a complete transposition cycle divided by the number of enamelled rectangular wires of the continuously transposed conductor, that is, the axial length between two adjacent transpositions.

3.25 Type Test — In case any type tests are required, the same may be as per mutual agreement between the CTC manufacturer and purchaser.

3.26 Width of Overlapping — It refers to the width of the paper tape edge overlapped portion during overlapping.

3.27 Winding Wire — Wire used for construction/winding of a coil in electrical/electronic components that generate the component's electro-magnetic field.

4 TECHNICAL REQUIREMENTS

4.1 Copper for Manufacturing CTC Conductor

Copper shall comply as per IS 191, IS 12444.

4.2 Enamelled Rectangular Wire for CTC Copper Winding Wires

4.2.1 Copper conductor specified non-proportional extension strength (proof strength). $Rp_{0.2}$ of the semi-hard enamelled rectangular wire conductor is divided in Table 1.

The recommended dimensions in millimetres (width × thickness) for the enamelled rectangular wire of the CTC copper winding wires are:

a) Width from 3.00 mm up to and including 12.00 mm;
b) Thickness from 1.20 mm up to and including 2.50 mm; and
c) Ratio of width to thickness shall be greater than or equal to 2.5 : 1 and shall not exceed 7 : 1.

4.2.2 Dimensions tolerance in enamelled rectangular wire conductor is given in Table 2.

4.2.3 *Corner Radii*

The arc shall merge smoothly into the flat surfaces of the conductor and the strip shall be free from sharp, rough and projecting edges. The conductor shall have radius corner complying with below Table 3. The specified radii shall be maintained within ± 25 percent.

4.2.4 *Increase in Dimensions Due to the Enamel Insulation*

The increase in width or thickness due to the enamel insulation shall be as given in Table 3A.

4.2.5 *Increase in Dimensions Over Enamel Insulation Wire with Bonding Layer Epoxy*

Bonding layer epoxy film thickness for Grade 1 or 2 enamelled wire which is determined by the CTC Manufacturer and the purchaser during ordering. The recommended self-adhesive layer of epoxy film thickness and tolerance of 0.040 mm +/- 0.010 mm. In case of any other self-adhesive layer, the thickness and tolerance shall be mutually agreed between CTC Manufacturer and purchaser.

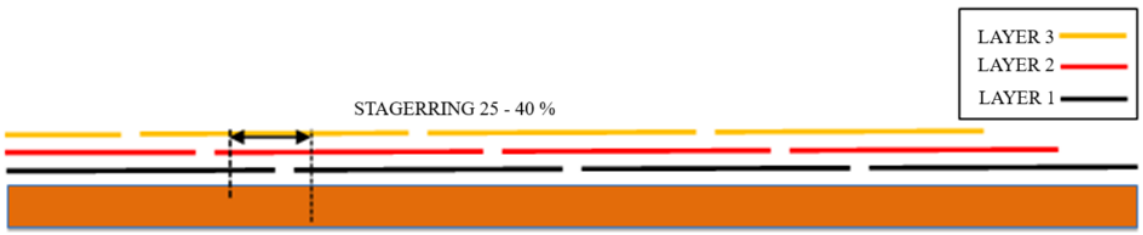

FIG. 6 STAGGERING IN LAPPING

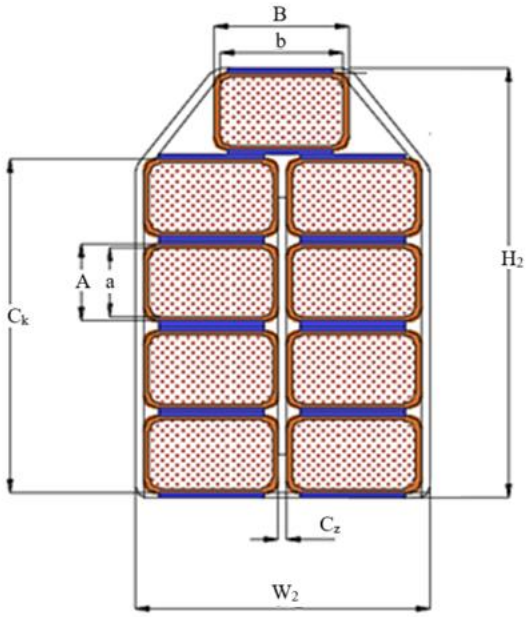

FIG.7 DIMENSIONAL SYMBOLS OF THE CONTINUOUSLY TRANSPOSED CONDUCTOR

Table 1 Proof Strength

(*Clause* 4.2.1)

Sl No.	Type	Proof Strength $R_{p0.2}$ Nominal	Tolerance
(1)	(2)	(3)	(4)
i)	Soft/Annealed	80	- 0/+ 40
ii)	Semi-hard-1	120	- 0/+ 30
iii)	Semi-hard-2	150	- 0/+ 30
iv)	Semi-hard-3	180	- 0/+ 40
v)	Semi-hard-4	220	- 0/+ 44

NOTE — Other than the above, if any nominal values are provided, a tolerance of 30 MPa or 20 percent of nominal whichever is higher shall apply, or higher if applicable, as agreed between CTC manufacturer and purchaser.

Table 2 Tolerance

(*Clause* 4.2.2)

Sl No.	Nominal Width or Thickness of the Conductor (mm)		Tolerance ± mm
	Over	Up to and including	
(1)	(2)	(3)	(4)
i)	-	3.15	0.030
ii)	3.15	6.30	0.050
iii)	6.30	12.50	0.070

Table 3 Corner Radii

(*Clause* 4.2.3)

Sl No.	Nominal Thickness of Conductor, in mm		Corner Radius, in mm
	Over	Up to and including	
(1)	(2)	(3)	(4)
i)	-	1.00	0.5 × Nominal thickness
ii)	1.00	1.60	0.50 *
iii)	1.60	2.24	0.65 **
iv)	2.24	3.55	0.80

NOTES
1 If agreed between CTC manufacturer and purchase. The corner radii for the wire with a width greater than 4.8 mm may be.
2 * 0.5 mm × t, where t is the nominal thickness of the conductor.
3 ** 0.80 mm.

Table 3A Increase in Dimensions Due to the Enamel Insulation

(*Clause* 4.2.4)

Sl No.	Grade	Increase in Dimensions, in mm		
		Minimum	Nominal	Maximum
(1)	(2)	(3)	(4)	(5)
i)	1	0.06	0.085	0.11
ii)	2	0.12	0.145	0.17

4.3 Transposed Core Structure

4.3.1 *Number of Transposed Core*

The number of transposed core is as follows:

a) Odd column: 5 to 83; and
b) Even column: in consideration.

4.3.2 *Transposed Core Dimension Range*

The dimension range of the transposed core is as follows:

a) $W_2 - \Delta \leq 26$ mm;
b) $H_2 - \Delta \leq 76$ mm; and
c) Height to width ratio $H/W \leq 6$.

When it is needed to exceed the above range, it shall be as specified by the CTC manufacturer and the purchaser through negotiation.

4.3.3 *Inter leaving/Inter Column Paper*

Inter leaving/inter column paper nominal thickness C_z. As for the inter leaving/inter column paper for the acetal enamelled continuously transposed conductor, it is recommended to use the nominal thickness 0.10 mm special paper for cellulosic papers for electrical purposes insulation paper (press paper or kraft paper).

As for the Inter leaving/inter column paper for the 180 class polyester imide enamelled continuously transposed conductor and the 200 class polyester imide/polyamide imide composite enamelled continuously transposed conductor, it is recommended to use the nominal thickness 0.05 mm aromatic polyamide paper. It may also use the inter leaving/inter column paper of other types and thicknesses as negotiated by the CTC manufacturer and the purchaser.

4.3.4 *Inter Leaving/Inter Column Paper Width C_k*

The inter leaving/inter column paper width C_k is calculated using the below equation, taking the even integer value downwards and with the deviation of - 1 mm.

$$C_k = \frac{1}{2}(n-3)A$$

When $C_k \geq 10$ mm, it shall add one layer of Inter leaving/inter column paper between the two rows of enamelled rectangular wires; when $C_k < 10$ mm, it may not be necessary to add inter leaving/inter column paper.

4.3.5 *Transposition Pitch S*

The transposition pitch S shall not exceed π/n times the minimum diameter D_{Min} of the coil winding.

$$S \leq \pi \frac{D_{Min}}{n}$$

Generally: 6b ≤ S ≤ 18b.

The user (CTC manufacturer) shall propose the S value and the allowable deviation when ordering.

4.4 Insulation Paper

Insulation paper for paper insulated continuously transposed conductors has the following types:

a) Special papers, general purpose electrical grade kraft paper shall comply with the mutual agreement of CTC manufacturer supplier and purchaser with relevant reference standard IS 9335 (Part 3/Sec 5)/IEC 60554-3-5;

b) The specifications, thickness and technical requirements for special papers, general purpose electrical grade kraft paper shall comply with the mutual agreement of CTC manufacturer and purchaser with relevant standard reference;

c) The technical requirements for other high density crepe paper shall be specified by the CTC manufacturer and the purchaser through negotiation with relevant reference standard IS 9335-3-3/IEC 60554-3-3; and

d) Other insulation paper as agreed by the CTC manufacturer and the purchaser.

4.5 Binding Rope or Tape

The technical requirements for netting tape shall be specified by the CTC manufacturer and the purchaser through negotiation.

4.6 Lapping of Insulation Layer

The nominal thickness and allowable tolerance of the paper insulation layer of the continuously transposed conductor shall comply with the requirements of Table 4. If the dimension of the continuously transposed conductor is within the specified range, it is allowed for the insulation thickness to exceed the values as specified in Table 4.

The paper insulation layer of the continuously transposed conductor shall be composed of three or more than three layers of paper tape through lapping, and the structural composition and lapping method of the paper tape are generally determined by the manufacturer. For example, the insulation paper layer of the paper-insulated acetal enamelled continuously transposed conductor has the following structures:

a) All the insulation paper is electrical grade insulation paper;

b) The innermost layer or the outermost layer and the middle layer insulation paper grade shall be agreed between purchaser and CTC manufacturer and

c) When users make other requests for paper varieties, the number of lapping layers and the thickness of each layer, it is allowed for the CTC manufacturer and the purchaser to determine through negotiation the insulation layer thickness deviation and the maximum dimension.

The paper tape shall be of appropriate density and evenly and smoothly lapped around the transposed core and the paper tape shall be free from such defects as missing layer, wrinkles or cracking.

For paperless binding type continuously transposed conductor, the CTC manufacturer and the purchaser shall define the protection paper thickness and its location.

Paper lapping method can be as per **3.2**, **3.13**, **3.15**, **3.16**, **3.17**, **3.21** and **3.26**.

Generally, all lapping layers will be in same direction. In case of specific requirement, lapping direction may be changed after group of maximum 8 layers. While lapping staggering within the group to be maintained as per **3.5**.

It is allowed for paper tape joint or repairing, but the joints shall be staggered from each other.

4.7 Maximum Dimensions of Continuously Transposed Conductors

The maximum dimensions of continuously transposed conductors H_{2max} and W_{2max} shall not be greater than the value as calculated from the below equations

Nominal CTC covered height $H_2 = ½\ k_1\ (n+1)\ (a + \delta + \delta_n) + \Delta$

$= ½\ k1\ (n+1)\ A + \Delta$ --- (1)

Nominal CTC covered width $W_2 = 2(b + \delta + \delta_n) + \Delta + C_z$

$= 2\ (B + \Delta) + C_z$ ---(2)

where

K_w, K_h and k_1 are depending on the structure of the transposed core, including semi-hard wires, various papers and other factors, with the specific value as specified in the product standards.

k_1 shall conform to the provisions of Table 5; K_w shall conform to the provisions of Table 6.

In case of specific designs which are critical to produce, the CTC manufacturer may propose higher tolerances which can be mutually agreed with the customer.

When the maximum dimension of the continuously transposed conductor does not exceed H_{2Max} and W_{2Max}, the positive tolerance of the insulation thickness is allowed to exceed the requirements of enamel, epoxy and paper insulation mention in **4.2.4**, **4.2.5** and **4.7**.

Table 4 Lapping of Insulation Layer

(*Clause* 4.6)

Sl No.	Increase in Diameters Due to Lapping Insulation Layer (Paper Covering)		Allowable Tolerance, in percent
	Over	Up to and Including	
(1)	(2)	(3)	(4)
i)	-	0.50	- 10.0/+ 0
ii)	0.50	1.25	- 7.5/+ 0
iii)	1.25	-	- 5.0/+ 0

Table 5 Factor k_1

(*Clause* 4.7)

Sl No.	Conductor Thickness	Proof Stress < 220 MPa		Proof Stress ≥ 220 MPa	
		s/b ≥ 7	s/b < 7	s/b ≥ 7	s/b < 7
(1)	(2)	(3)	(4)	(5)	(6)
i)	a ≤ 1.60	1.01	1.02	1.01	1.02
ii)	1.60 < a < 1.90	1.02	1.025	1.02	1.025
iii)	1.90 < a < 2.20	1.025	1.035	1.03	1.035
iv)	a > 2.20	1.03	1.035	1.03	1.035

Factor k_1: Table 5.
K_h and K_w as per Table 6.

Table 6 Factor K_h and K_w

(*Clause* 4.7)

Sl No.	Number of Conductors in CTC Stack	Tolerance on Radial Height (mm)	Tolerance on Axial Width (mm)
(1)	(2)	(3)	(4)
i)	≥ 5 to ≤ 21	+ 0.30 /- 0.30	+ 0.10 / - 0.15
ii)	≥ 23 to ≤ 37	+ 0.70 /- 0.30	+ 0.15 / - 0.10
iii)	≥ 39 to ≤ 55	+ 0.90 /- 0.30	+ 0.20 / - 0.10
iv)	≥ 57	+ 1.20 /- 0.30	+ 0.20 / - 0.10

4.8 Welding

It is allowed to weld the enamelled rectangular wires in the continuously transposed conductor, and the welding points shall be solid and reliable. The distance between the welding points of the two adjacent enamelled rectangular wires shall be not less than 500 mm. The weld shall be covered with heat-resistant self-adhesive electrical insulation tape (polyester or polyamide tape) compatible with transformer oil. Alternatively, or as an additional insulation based on customer specific need, one layer of 0.075 mm of crepe paper can also be applied with overlap of 40 percent to 60 percent width of the paper. The welding can be a butt weld or overlap weld. The dimension of weld should not be more than 1.5 times of 'a' and 'b' as defined in **3.22** Symbols above. Welds shall be so clearly identified as not effect onto the performance. If the user needs products without welding, it shall be mutually agreed between CTC manufacturer and purchaser at the time of ordering the CTC.

4.9 Bond Strength

a) The thermal bond strength of the enamelled rectangular wire in the self-adhesive continuously transposed conductors shall not be less than 7 N/mm² at room temperature.

b) The self-adhesive enamelled continuously transposed conductors shall, after thermal bonding, be able to withstand the specified bending test, with the bending force and bending deformation under consideration.

4.10 Delivery Length

Delivery shall be made using the delivery wire coil and delivery length as agreed between the CTC manufacturer and the purchaser, and the length error shall not exceed the followings unless otherwise the user has special requirements which need to be agreed between the CTC manufacturer and the purchaser:

a) + 0.5 percent if the delivery length ≥ 400 m; and

b) + 1.0 percent if the delivery length < 400 m.

Nominal cross-sectional areas (informative only) for preferred and intermediate sizes of rectangular copper bare conductors, from which the user may select intermediate sizes only for technical reasons is given in Annex B.

5 TEST METHODS

5.1 General

Unless otherwise specified, all tests shall be conducted at the temperature of 15 °C to 40 °C and the relative humidity of 30 percent to 75 percent. Before measurement, the specimen shall be pre-conditioned under these atmospheric conditions for a sufficient period to make the sample reach stable state.

When the tested sample is removed from the package, it shall not be subjected to tension or unnecessary bending. Prior to each test, it shall remove sufficient sample to ensure that the sample under test has no damage.

5.2 Dimensional Measurements

5.2.1 *Continuously Transposed Conductor Insulation Thickness Measurement*

Take a sample with a length of not less than 100 mm; use a sharp blade to cut the insulation layer of the sample, remove the transposed core under the conditions of not affecting the inter-layer mutual positions of the insulation layers, press the

insulation sleeve flat, use the measurement tool of the least count shall not be more than 0.01 mm, measurement pressure of (8 to 14) N, and measurement rod and measurement seat diameter of (5 to 8) mm to measure the insulation layer thickness Δ; measure three points, and take the average value as the measurement result.

5.2.2 *Continuously Transposed Conductor Dimension Measurement*

Take a straight sample of length about 300 mm to 400 mm use a suitable instrument for measurement, having precision of at least 0.02 mm, measurement pressure of about 100 N/cm^2, and measurement range of (0 to 300) mm to measure at least three points and take the average value as the measurement result.

5.2.3 *Transposition Pitch Measurement*

From one end of a whole coil of continuously transposed conductor, remove the insulation layer of sufficient length; use the steel ruler of a precision 1 mm to continuously measure five transposition pitches; and take the average value, accurate to 1 mm.

5.2.4 Measurement of width of open (gap) lapping, width of overlapping and lapping pitch.

Take a sample of about 500 mm length; use the steel ruler of a precision not less than 0.5 mm to directly measure the width of gap lapping, width of overlapping, and lapping pitch, one measurement at each layer, accurate to 1 mm.

5.3 Electrical Resistance

The copper rod being used shall comply with at least one of IS 12444, IS 2378 or ISO 1190-1.

Resistivity of a material is the resistance of a wire of that material of unit length and unit cross- sectional area. The standard value of resistivity of high conductivity annealed copper wire which shall be used for calculation is to be considered as 0.017 24 Ω.mm^2/m at 20 °C. The measurement accuracy shall be within 0.5 percent. The resistivity of the finished product (CTC) shall be as per Table 7.

5.4 Elongation

The percentage elongation after fracture shall be measured according to **20** of IS 1608 (Part 1)/ ISO 6892-1 and IS 13730 (Part 0/Sec 2)/ IEC 60317-0-2 proof strength $R_{p0.2}$. when the nominal proof strength, plastic extension is not specified or a nominal proof strength, plastic extension of 80 N/mm^2 is required. The limit of Table 8 applies otherwise, the measurement is performed for reference only. The test method shall be as per IS 13778 (Part 3)/IEC 60851-3.

5.5 Breakdown Voltage

When tested at room temperature, at least four of the five specimens tested shall not break down at a voltage less than or equal to that of given Table 9 and fifth shall not break down at less than 50 percent of the valued specified. The test shall be carried out as per IS 13778 (Part 5)/IEC 60851-5.

Table 7 Electrical Resistance

(*Clause* 5.3)

Sl No.	Type	Nominal Proof Strength	Tolerance	*Max* Resistivity (Ω.mm^{2}m^{-1})
(1)	(2)	(3)	(4)	(5)
i)	Soft/Annealed	80	-0/+40	1/58
ii)	Semi-hard-1	120	-0/+30	1/58
iii)	Semi-hard-2	150	-0/+30	1/58
iv)	Semi-hard-3	180	-0/+40	1/57.5
v)	Semi-hard-4	220	-0/+44	1/56.5

Table 8 Percentage Elongation after Fracture

(*Clause* 5.4)

Sl No.	Nominal Thickness of the Conductor mm		Minimum Elongation Percent
	Over	Up to and Including	
(1)	(2)	(3)	(4)
i)	-	2.50	30

Table 9 Breakdown Voltage

(*Clause* 5.5)

Sl No.	Grade	Minimum Breakdown Voltage (RMS) V			
		Without Bonding Layer		With Bonding Layer	
		Room Temperature	Elevated Temperature	Room Temperature	Elevated Temperature
(1)	(2)	(3)	(4)	(5)	(6)
i)	1	1 000	750	1 500	1 000
ii)	2	2 000	1 500	2 500	2 000

5.6 Interstrand Continuity/Short Circuit Test

Interstrand continuity/short circuit test should be carried out from one strand to all other strands at a minimum voltage of 300 V d.c. and there should not be any short.

5.7 Flexibility and Adherence

5.7.1 *Mandrel Winding Test*

The coating shall not crack after the wire has been bent flat wise and edgewise on a mandrel. The test shall be carried out as stated in IS 13730 (Part 0/Sec 2)/IEC 60317-0-2 and IS 13778 (Part 3)/IEC 60851-3.

5.7.2 *Adherence Test*

The wire shall be stretched and the distance of loss of adherence shall be measured. The test shall be carried out as stated in IS 13730 (Part 0/Sec 2)/ IEC 60317-0-2 and IS 13778 (Part 3)/IEC 60851-3.

5.8 Conductor Path (Continuity)

Use a multimeter to measure each enamelled rectangular wire of the continuously transposed conductors, and there shall be no open circuit.

5.9 Bond Strength Test

The thermal bond strength of the enamelled rectangular wire in the self-adhesive continuously transposed conductors shall not be less than 7 N/mm².

From the continuously transposed conductor sample, take two straight enamelled rectangular wires of length about 110 mm, 5 groups in total; as shown in Fig. 8, overlap the wide edges of the samples, with the bonding length (that is, length of overlapping) of 25 mm and the bonding area pressure of 1 MPa. Place the pressed sample in the oven of (120 ± 3) °C for treatment for 24 h; cool it to room temperature to conduct tensile test, and the tensile speed shall be not greater than 20 mm/min and the bond strength shall be not less than 7 N/mm². Conduct five tests in total and take the average value as the test result.

5.10 Resistance to Solvent

Using a pencil of hardness ‘H’ and standard solvent, coating shall not be removed. The test shall be carried out as stated in IS 13730 (Part 0/Sec 2)/ IEC 60317-0-2 and IS 13778 (Part 4)/IEC 60851-4.

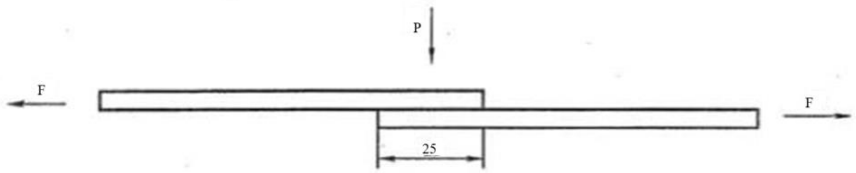

FIG. 8 BOND STRENGTH TEST

5.11 Temperature Index

The test shall be carried out on a rectangular wire in accordance with IS 5825/IEC 60172, unless otherwise agreed between CTC Manufacturer and purchaser.

When required by a purchaser, CTC manufacturer of the enamelled wire shall supply evidence that the wire meets the requirement for the temperature index.

NOTES

1 The temperature index requirement based on an extrapolated life of 20 000 h related to enamelled wire tested unvarnished and not as part of an insulation system.

2 Temperature in degree celsius corresponding to the temperature index is not necessarily that at which it is recommended that the wire be operated and this will depend on many factors including the type of equipment involved.

5.12 Test of Specified Non-Proportional Extension Strength $R_{p0.2}$

It shall follow the provisions of IS 1608 (Part 1)/ ISO 6892-1 to conduct the tests.

6 PACKAGING

The CTC copper winding wire shall be delivered in packaged coil, the finished products shall be tightly, uniformly and neatly around the wire coil, layers shall be separated by the application of protective paper, and the distance from the outermost layer to the cable coil edge shall be not less than 30 mm.

The wire coil with finished products shall be wrapped by moisture-proof and anti-bump material, and both ends of the continuously transposed conductors shall be fastened to the wire coil.

7 MARKING

Each coil of finished product shall have label, indicating:

a) Manufacturer name, trademark or certification mark;
b) Product model, specifications, number, nominal thickness of insulation layer, product dimensions;
c) Customer reference number/job number;
d) Length, in metres;
e) Net weight and gross weight, in kg; and
f) Drum number.

8 STORAGE

The finished product shall be stored in a clean, dry, and well-ventilated covered warehouse with a temperature of (15 to 40) °C away from direct sunlight and moisture.

The mechanical properties of this product such as electrical performance and bond strength etc, are related to the surroundings, and all the products shall from the date of exit-factory have a storage period of six months.

ANNEX A

(*Clause* 2)

LIST OF REFERRED STANDARDS

IS No.	*Title*
IS 191 : 2007	Copper — Specification (*fourth revision*)
ISO 1190-1:1982	Copper and copper alloys — Code of designation Part 1: Designation of materials
IS 2378 : 1974	Code for designation of copper and copper alloys
IS 1608 (Part 1) : 2022/ISO 6892-1 : 2019	Metallic materials — Tensile testing: Part 1 Method of test at room temperature (*fifth revision*)
IS 5825 : 2024/IEC 60172 : 2020	Test procedure for the determination of the temperature index of enamelled and tape wrapped winding wires (*third revision*)
IS 9335	Specification for cellulosic papers for electrical purposes:
(Part 3)	Part 3 specifications for individual materials,
(Sec 3) : 1984/ IEC 60554-3-3 : 1980	Crepe paper
(Sec 5) : 1985/ IEC 60554-3-5 : 1984	Special papers
IS 12444 : 2020	Copper wire rods for electrical applications — Specification (*first revision*)
IS 13730 (Part 0/ Sec 2) : 2024/ IEC 60317-0-2 : 2020	Specifications for particular types of winding wires: Part 0 General requirements, Section 2 Enamelled rectangular copper wire
IS 13778	Winding wires — Test methods:
(Part 3) : 2012/ IEC 60851-3 : 2009	Mechanical properties (*first revision*)
(Part 4) : 2018/ IEC 60851-4 : 2016	Chemical properties (*Second revision*)
(Part 5) : 2012/ IEC 60851-5 : 2008	Electrical properties (*first revision*)

ANNEX B

(*Clause* 4.10)

NOMINAL CROSS-SECTIONAL AREAS FOR PREFERRED AND INTERMEDIATE SIZES

B-1 Table 10 provides nominal cross-sectional areas for preferred and intermediate sizes of rectangular copper bare conductors, from which the user may select intermediate sizes only for technical reasons.

Table 10 Nominal Cross-Sectional Areas

(*Clause* B-1)

Sl No.	Nominal Width	Nominal Thickness	Corner Radius	Nominal Cross-Section Area
	(mm)	(mm)	(mm)	(mm^2)
(1)	(2)	(3)	(4)	(5)
i)	3.00	1.20	0.50	3.385
		1.25	0.50	3.535
		1.40	0.50	3.985
		1.60	0.50	4.585
		1.80	0.65	5.037
		2.00	0.65	5.637
ii)	3.15	1.20	0.50	3.565
		1.25	0.50	3.723
		1.32	0.50	3.943
		1.40	0.50	4.195
		1.50	0.50	4.510
		1.60	0.50	4.825
		1.70	0.65	4.992
		1.80	0.65	5.307
		1.90	0.65	5.622
		2.00	0.65	5.937
		2.12	0.65	6.315
		2.24	0.65	6.693
iii)	3.35	1.20	0.50	3.805
		1.25	0.50	3.973
		1.40	0.50	4.475
		1.60	0.50	5.145
		1.80	0.65	5.667
		2.00	0.65	6.337
		2.24	0.65	7.141

Table 10 (*Continued*)

iv)	3.55	1.20	0.50	4.045
		1.25	0.50	4.223
		1.32	0.50	4.471
		1.40	0.50	4.755
		1.50	0.50	5.110
		1.60	0.50	5.465
		1.70	0.65	5.672
		1.80	0.65	6.027
		1.90	0.65	6.382
		2.00	0.65	6.737
		2.12	0.65	7.163
		2.24	0.65	7.589
		2.36	0.80	7.828
		2.50	0.80	8.325
v)	3.75	1.20	0.50	4.285
		1.25	0.50	4.473
		1.32	0.50	4.735
		1.40	0.50	5.035
		1.60	0.50	5.785
		1.80	0.65	6.387
		2.00	0.65	7.137
		2.24	0.65	8.037
		2.50	0.80	8.825
vi)	4.00	1.20	0.50	4.585
		1.25	0.50	4.785
		1.32	0.50	5.065
		1.40	0.50	5.385
		1.50	0.50	5.785
		1.60	0.50	6.185
		1.70	0.65	6.437
		1.80	0.65	6.837
		1.90	0.65	7.237
		2.00	0.65	7.637
		2.12	0.65	8.117
		2.24	0.65	8.597
		2.36	0.80	8.890
		2.50	0.80	9.450
vii)	4.25	1.20	0.50	4.885
		1.25	0.50	5.098
		1.40	0.50	5.735
		1.60	0.50	6.585
		1.80	0.65	7.287
		2.00	0.65	8.137
		2.24	0.65	9.157
		2.50	0.80	10.075

Table 10 (*Continued*)

viii)	4.50	1.20	0.50	5.185
		1.25	0.50	5.410
		1.32	0.50	5.725
		1.40	0.50	6.085
		1.50	0.50	6.535
		1.60	0.50	6.985
		1.70	0.65	7.287
		1.80	0.65	7.737
		1.90	0.65	8.187
		2.00	0.65	8.637
		2.12	0.65	9.177
		2.24	0.65	9.717
		2.36	0.80	10.070
		2.50	0.80	10.700
ix)	4.75	1.20	0.50	5.485
		1.25	0.50	5.723
		1.32	0.50	6.055
		1.40	0.50	6.435
		1.50	0.50	6.910
		1.60	0.50	7.385
		1.70	0.65	7.712
		1.80	0.65	8.187
		1.90	0.65	8.662
		2.00	0.65	9.137
		2.12	0.65	9.707
		2.24	0.65	10.277
		2.36	0.80	10.660
		2.50	0.80	11.325
x)	5.00	1.20	0.50	5.785
		1.25	0.50	6.035
		1.32	0.50	6.385
		1.40	0.50	6.785
		1.50	0.50	7.285
		1.60	0.50	7.785
		1.70	0.65	8.137
		1.80	0.65	8.637
		1.90	0.65	9.137
		2.00	0.65	9.637
		2.12	0.65	10.237
		2.24	0.65	10.837
		2.36	0.80	11.250
		2.50	0.80	11.950

Table 10 (*Continued*)

xi)	5.30	1.20	0.50	6.145
		1.25	0.50	6.410
		1.32	0.50	6.781
		1.40	0.50	7.205
		1.50	0.50	7.735
		1.60	0.50	8.265
		1.70	0.65	8.647
		1.80	0.65	9.177
		1.90	0.65	9.707
		2.00	0.65	10.237
		2.12	0.65	10.873
		2.24	0.65	11.509
		2.36	0.80	11.958
		2.50	0.80	12.700
xii)	5.60	1.20	0.50	6.505
		1.25	0.50	6.785
		1.32	0.50	7.177
		1.40	0.50	7.625
		1.50	0.50	8.185
		1.60	0.50	8.745
		1.70	0.65	9.157
		1.80	0.65	9.717
		1.90	0.65	10.277
		2.00	0.65	10.837
		2.12	0.65	11.509
		2.24	0.65	12.181
		2.36	0.80	12.666
		2.50	0.80	13.450
xiii)	6.00	1.20	0.50	6.985
		1.25	0.50	7.285
		1.32	0.50	7.705
		1.40	0.50	8.185
xiv)	6.00	1.50	0.50	8.785
		1.60	0.50	9.385
		1.70	0.65	9.837
		1.80	0.65	10.437
		1.90	0.65	11.037
		2.00	0.65	11.637
		2.12	0.65	12.357
		2.24	0.65	13.077
		2.36	0.80	13.610
		2.50	0.80	14.450

Table 10 (*Continued*)

xv)	6.30	1.20	0.50	7.345
		1.25	0.50	7.660
		1.32	0.50	8.101
		1.40	0.50	8.605
		1.50	0.50	9.235
		1.60	0.50	9.865
		1.70	0.65	10.347
		1.80	0.65	10.977
		1.90	0.65	11.607
		2.00	0.65	12.237
		2.12	0.65	12.993
		2.24	0.65	13.749
		2.36	0.80	14.318
		2.50	0.80	15.200
xvi)	6.70	1.20	0.50	7.825
		1.25	0.50	8.160
		1.32	0.50	8.629
		1.40	0.50	9.165
		1.50	0.50	9.835
		1.60	0.50	10.505
		1.70	0.65	11.027
		1.80	0.65	11.697
		1.90	0.65	12.367
		2.00	0.65	13.037
		2.12	0.65	13.841
		2.24	0.65	14.645
		2.36	0.80	15.262
		2.50	0.80	16.200
xvii)	7.10	1.20	0.50	8.305
		1.25	0.50	8.660
		1.32	0.50	9.157
		1.40	0.50	9.725
		1.50	0.50	10.435
		1.60	0.50	11.145
		1.70	0.65	11.707
		1.80	0.65	12.417
xviii)	7.10	1.90	0.65	13.127
		2.00	0.65	13.837
		2.12	0.65	14.689
		2.24	0.65	15.541
		2.36	0.80	16.206
		2.50	0.80	17.200

Table 10 (*Continued*)

xix)	7.50	1.20	0.50	8.785
		1.25	0.50	9.160
		1.32	0.50	9.685
		1.40	0.50	10.285
		1.50	0.50	11.035
		1.60	0.50	11.785
		1.70	0.65	12.387
		1.80	0.65	13.137
		1.90	0.65	13.887
		2.00	0.65	14.637
		2.12	0.65	15.537
		2.24	0.65	16.437
		2.36	0.80	17.150
		2.50	0.80	18.200
xx)	8.00	1.20	0.50	9.385
		1.25	0.50	9.785
		1.32	0.50	10.345
		1.40	0.50	10.985
		1.50	0.50	11.785
		1.60	0.50	12.585
		1.70	0.65	13.237
		1.80	0.65	14.037
		1.90	0.65	14.837
		2.00	0.65	15.637
		2.12	0.65	16.597
		2.24	0.65	17.557
		2.36	0.80	18.330
		2.50	0.80	19.450
xxi)	8.50	1.20	0.50	9.985
		1.25	0.50	10.410
		1.32	0.50	11.005
		1.40	0.50	11.685
		1.50	0.50	12.535
		1.60	0.50	13.385
		1.70	0.65	14.087
		1.80	0.65	14.937
		1.90	0.65	15.787
		2.00	0.65	16.637
		2.12	0.65	17.657
		2.24	0.65	18.677
		2.36	0.80	19.510
		2.50	0.80	20.700

Table 10 (*Continued*)

xxii)	9.00	1.20	0.50	10.585
		1.25	0.50	11.035
		1.32	0.50	11.665
		1.40	0.50	12.385
		1.50	0.50	13.285
		1.60	0.50	14.185
		1.70	0.65	14.937
		1.80	0.65	15.837
		1.90	0.65	16.737
		2.00	0.65	17.637
		2.12	0.65	18.717
		2.24	0.65	19.797
		2.36	0.80	20.690
		2.50	0.80	21.950
xxiii)	9.50	1.20	0.50	11.185
		1.25	0.50	11.660
		1.32	0.50	12.325
		1.40	0.50	13.085
		1.50	0.50	14.035
		1.60	0.50	14.985
		1.70	0.65	15.787
		1.80	0.65	16.737
		1.90	0.65	17.687
		2.00	0.65	18.637
		2.12	0.65	19.777
		2.24	0.65	20.917
		2.36	0.80	21.870
		2.50	0.80	23.200
xxiv)	10.00	1.25	0.50	12.285
		1.32	0.50	12.985
		1.40	0.50	13.785
		1.50	0.50	14.785
		1.60	0.50	15.785
		1.70	0.65	16.637
		1.80	0.65	17.637
		1.90	0.65	18.637
		2.00	0.65	19.637
		2.12	0.65	20.837
		2.24	0.65	22.037
		2.36	0.80	23.050
		2.50	0.80	24.450

Table 10 (*Concluded*)

xxv)	10.60	1.40	0.50	14.625
		1.50	0.50	15.685
		1.60	0.50	16.745
		1.70	0.65	17.657
		1.80	0.65	18.717
		1.90	0.65	19.777
		2.00	0.65	20.837
		2.12	0.65	22.109
		2.24	0.65	23.381
		2.36	0.80	24.466
		2.50	0.80	25.950
xxvi)	11.20	1.40	0.50	15.465
		1.50	0.50	16.585
		1.60	0.50	17.705
		1.70	0.65	18.677
		1.80	0.65	19.797
		1.90	0.65	20.917
		2.00	0.65	22.037
		2.12	0.65	23.381
		2.24	0.65	24.725
		2.36	0.80	25.882
		2.50	0.80	27.450
xxvii)	11.80	1.60	0.50	18.665
		1.70	0.65	19.697
		1.80	0.65	20.877
		1.90	0.65	22.057
		2.00	0.65	23.237
		2.12	0.65	24.653
		2.24	0.65	26.069
		2.36	0.80	27.298
		2.50	0.80	28.950
xxviii)	12.00	1.60	0.50	18.985
		1.70	0.65	20.037
		1.80	0.65	21.237
		1.90	0.65	22.437
		2.00	0.65	23.637
		2.12	0.65	25.077
		2.24	0.65	26.517
		2.36	0.80	27.770
		2.50	0.80	29.450

ANNEX C

(*Foreword*)

COMMITTEE COMPOSITION

Winding Wire Sectional Committee, ETD 33

Organization	*Representative(s)*
Bharat Heavy Electricals Limited, New Delhi	SHRI RATNANAV ACHARYA **(*Chairperson*)**
Apar Industries Limited, Silvassa	SHRI YOGESH KHARAT SHRI SIDDHARTHA SANKAR MAITI (*Alternate*)
BEICO Industries Private Limited, Mumbai	SHRI SUHRID SINGHVI
Bharat Heavy Electrical Limited, New Delhi	SHRI LAXMI RAJAM M.
Bharat Insulation Company India Private Limited, Thane	SHRI DHIREN MEHTA
Central Electricity Authority, New Delhi	SHRI ABHISHEK KUMAR SHRI FARAZ (*Alternate*)
Central Power Research Institute, Bengaluru	DR MOUMITA NASKAR
Development Commissioner Micro-Small and Medium Enterprises	DR S. K. SAHOO SHRI S. DHARMASELVAN (*Alternate*)
Elantas Beck India Limited, New Delhi	SHRI BAPU GAWADE MISS RAKHEE TELKAR (*Alternate*)
Electrical Research and Development Association, Vadodara	SHRI SHAILESH PATEL SHRIMATI SHEETAL PANCHAL (*Alternate*)
Indian Electrical and Electronics Manufacturers Association, New Delhi	SHRI ASHUTOSH VASISHT SHRI NAVDEEP SINGH (*Alternate*)
International Copper Association India, Mumbai	SHRI K. N. HEMANTH KUMAR SHRI JYOTISH PANDE (*Alternate*)
Precision Wires India Limited, Mumbai	SHRI MILAN M. MEHTA SHRI NIRBHAY MEHTA (*Alternate*)
Siemens Limited, Mumbai	SHRI NAGABHUSHAN BHAT SHRI ASHISH SHERE (*Alternate*)
Slimlites Electricals Private Limited, Mumbai	SHRI VIMAL JALAN
Southern India Engineering Manufacturers Association, Coimbatore	SHRI KESHAVARAJULU R. G. SHRI G. RAJENDRAN (*Alternate*)
Steel Authority of India Limited (SAIL), New Delhi	SHRI GULSHAN KUMAR
Vidya Wires Private Limited, Anand	SHRI SHAILESH RATHI
Winding Wires Manufacturers' Association of India, Greater Noida	SHRI SUDHIR AGARWAL SHRI ANANT LOYA (*Alternate*)

Organization	*Representative(s)*
BIS Directorate General	SHRI ASIT KUMAR MAHARANA SCIENTIST 'E'/ DIRECTOR AND HEAD (ELECTROTECHNICAL) [REPRESENTING DIRECTOR GENERAL (*Ex-officio*)]

Member Secretary
JATIN TIWARI
SCIENTIST 'C'/DEPUTY DIRECTOR
(ELECTROTECHNICAL), BIS

Bureau of Indian Standards

BIS is a statutory institution established under the *Bureau of Indian Standards Act*, 2016 to promote harmonious development of the activities of standardization, marking and quality certification of goods and attending to connected matters in the country.

Review of Indian Standards

Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the website-www.bis.gov.in or www.standardsbis.in.

This Indian Standard has been developed from Doc No.: ETD 33 (25311).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones: 2323 0131, 2323 3375, 2323 9402 *Website*: www.bis.gov.in

Regional Offices:		*Telephones*
Central	: 601/A, Konnectus Tower -1, 6th Floor, DMRC Building, Bhavbhuti Marg, New Delhi 110002	2323 7617
Eastern	: 8th Floor, Plot No 7/7 & 7/8, CP Block, Sector V, Salt Lake, Kolkata, West Bengal 700091	2367 0012 2320 9474
Northern	: Plot No. 4-A, Sector 27-B, Madhya Marg, Chandigarh 160019	265 9930
Southern	: C.I.T. Campus, IV Cross Road, Taramani, Chennai 600113	2254 1442 2254 1216
Western	: 5th Floor/MTNL CETTM, Technology Street, Hiranandani Gardens, Powai Mumbai 400076	25700030 25702715

Branches : AHMEDABAD, BENGALURU, BHOPAL, BHUBANESHWAR, CHANDIGARH, CHENNAI, COIMBATORE, DEHRADUN, DELHI, FARIDABAD, GHAZIABAD, GUWAHATI, HARYANA (CHANDIGARH), HUBLI, HYDERABAD, JAIPUR, JAMMU, JAMSHEDPUR, KOCHI, KOLKATA, LUCKNOW, MADURAI, MUMBAI, NAGPUR, NOIDA, PARWANOO, PATNA, PUNE, RAIPUR, RAJKOT, SURAT, VIJAYAWADA.

Published by BIS, New Delhi