BUREAU OF INDIAN STANDARDS
DRAFT FOR COMMENTS ONLY

Draft Indian Standard

Continuously Transposed Conductor (CTC) Copper Winding Wires

Power Cables Sectional Committee, ETD 33	Last date for comments- 19/07/2024

FOREWORD

This Draft is based on the need identified by the industry to request BIS to publish a Standard for Continuously Transposed Conductor (CTC) copper winding wires which are used in high voltage power and locomotive transformers.

This standard has been prepared to cover the requirements of Transformer winding to reduce eddy loss in windings of the power and locomotive transformers. Tests to ascertain conformity in this regard have also been stipulated in the standard.

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.

Draft Indian Standard

CONTINUOUSLY TRANSPOSED CONDUCTORS (CTC) COPPER WINDING WIRES

1 SCOPE

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

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 provisions in following documents become the provisions of this part through reference in this part. All standards at the time of publication the edition indicated were valid. All standards are subjected 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 indicated below:

IS No. / IEC	*Title*
IS 191 : 2007	Copper – Specification
IS 12444 : 2020	Standard Specification for CC & Rolled copper rod for Electrical purposes.
IS 13730 (Part 0/Sec 2) : 2018	Specification for particular type of winding wire, part 0: General requirement Section 2: Enamelled Rectangular Copper Wire
IS 13730 (Part 17) : 2014	Specifications for Particular Types of Winding Wires Polyvinyl Acetal Enamelled Rectangular Copper Wire, Class 105
IS 13730 (Part 27) : 2018	Specifications for Particular Types of Winding Wires, Part-27: Paper Tape Covered Rectangular Copper Wire
IS 13730 (Part 28) : 2018	Specifications for Particular Types of Winding Wires, Part-28: Polyester imide Enamelled Rectangular Copper Wire, Class 180 First Revision)
IS 13730 (Part 29) : 1996	Specifications for Particular Types of Winding Wires Part-29: polyester or polyesterimide over coated with polyamide-imide enamelled rectangular copper wire class-200.
IS 9335 (Part 1) : 2024	Specification for cellulosic paper for electrical purpose, part 1: Definition and general requirement.
IS 9335 (Part 3/Sec 3) : 1984	Specification for cellulosic paper for electrical purpose, part 3: Specification for individual materials, Section 3- Crepe paper

IS 9335 (Part 3/Sec 5) : 1985	Specification for cellulosic paper for electrical purpose, part 3: Specification for individual materials, Section 3- Special paper
IS 13778 –1 to 6	Winding wires - Test methods
IEC 60317-18	Enamelled rectangular wires, polyvinyl Acetal (PVA) enamelled rectangular copper wires class 120
IEC 60317-27-3	Paper tape covered rectangular copper wire
IEC 60317-28	Polyester Imide (PEI) enamelled rectangular copper wire, class 180)
IEC 60317-29	Enamelled rectangular wires, Polyester imide (PEI) over-coated with polyamide-imide (PAI) enamelled rectangular copper wires, class 200)
IEC 60851	Windings Wires- Test Methods (All parts)
IEC 60317-0-2	Specification for particular type of winding wire part 0: General requirements – Section 2: Enamelled rectangular copper wire.
IEC 60554-3-1	Specification for cellulosic papers for electrical purposes. Part 3: Specifications for individual materials. Sheet-1: General purpose electrical paper.
IEC 60554-3-3	Specification for cellulosic papers for electrical purposes. Part 3: Specifications for individual materials. Sheet 3: Crepe paper
IEC 60554-3-5	Specification for cellulosic papers for electrical purposes. Part 3: Specifications for individual materials. Sheet 5: Special papers
IEC 60172	Test procedure for the determination of the temperature index of enamelled and tape wrapped winding wire.
IEC 60296	Fluids for electro technical applications – Mineral insulating oils for electrical equipment
IS 335	New Insulating Oils

3 TERMINOLOGY

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

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

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

3.3 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.

3.4 Optional Tests - Special tests to be carried out, when required, by agreement between CTC Manufacturer and purchaser.

3.5 Conductor - Bare metal after removal of insulation.

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

3.7 Class - Thermal performance of a wire expressed by the temperature index and the heat shock temperature.

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 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

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

3.11 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.

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

3.13 Width of Overlapping - It refers to the width of the paper tape edge overlapped portion during overlapping

3.14 Half Overlapping - It refers to the lapping form with the width of overlapping in 40 ~ 60 %.

FIG 1 HALF OVERLAPPING

3.15 One Third Overlapping - It refers to the lapping form with the width of overlapping in 25 ~ 35 %.

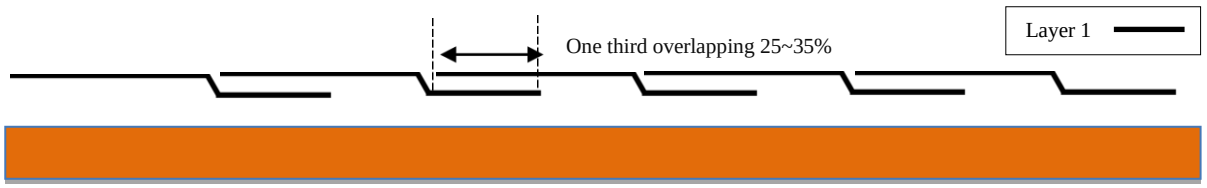

FIG 2 ONE THIRD OVERLAPPING

3.16 Interlocked Lapping - It refers to the lapping form that the two layers of paper tapes which are mutually overlapped (40 ~ 60) % are subjected to half overlapping along the same direction.

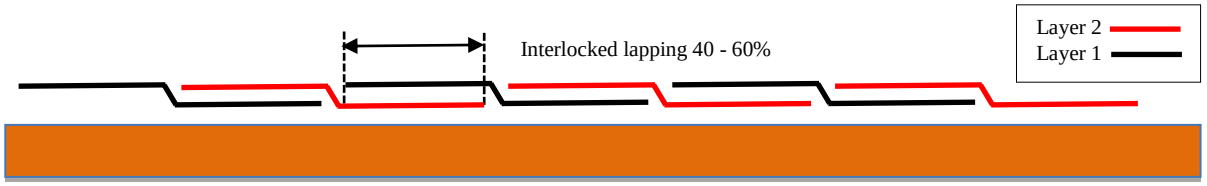

FIG 3 INTERLOCKED LAPPING

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 upto 2 mm.

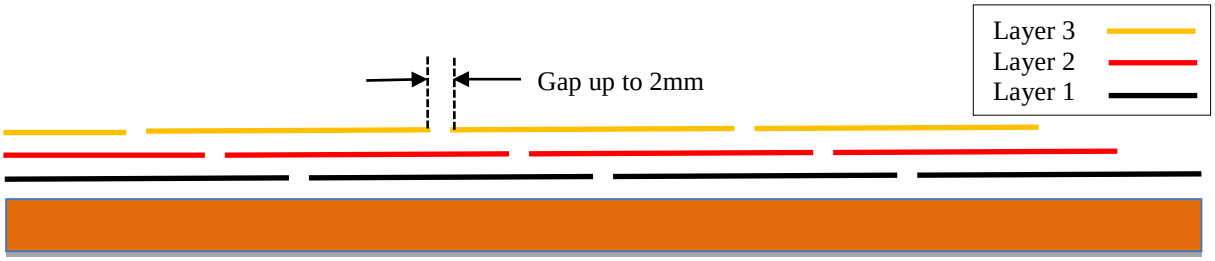

FIG 4 BUTT LAPPING

3.18 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 upto 0.5 mm or gap upto 2 mm.

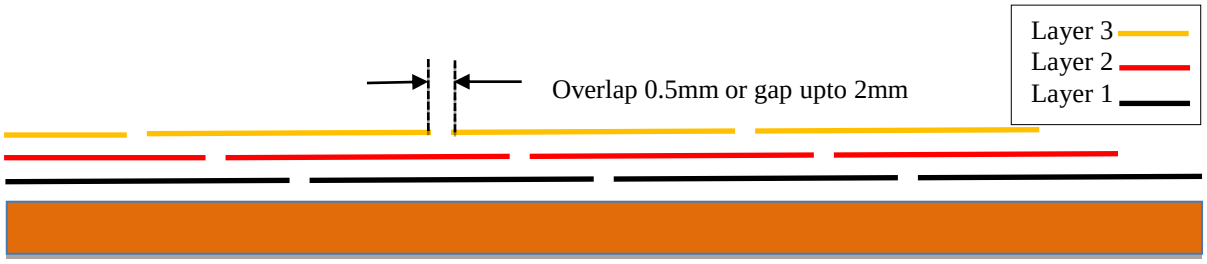

FIG 5 BUTT LAPPING

3.19 Staggering in Lapping - It refers to the distance between the edges of the adjacent paper tapes. The distance shall be approx. 25-40% of the width of the tape. This range shall not be applicable in case of change of taping head from one layer to another.

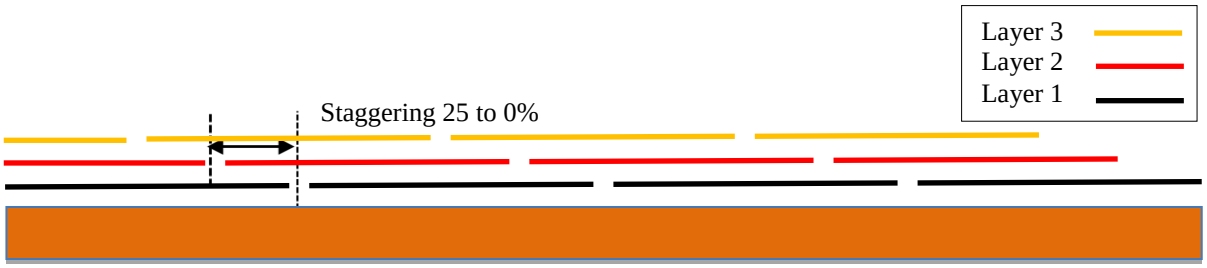

FIG 6 STAGGERING IN LAPPING

3.20 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.

3.21 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 ~ 220) N/mm^2.

3.22 Transposed Core - It refers to the combination of the enamelled rectangular wire after transposition.

3.23 Symbols - The dimensional symbols of the continuously transposed conductor are as shown in Figure 1.

where:

H_2	:	Nominal height of continuously transposed conductor, in mm;
W_2	:	Nominal width of continuously transposed conductor, in mm;
H_{2max}	:	Maximum height of continuously transposed conductor, in mm;
W_{2max}	:	Maximum width of continuously transposed conductor, in mm;
Tape	:	Narrow edge nominal dimension (thickness) of enamelled rectangular wire, in mm;
B	:	Wide edge nominal dimension (width) of enamelled rectangular wire, in mm;
A_{max}	:	Maximum dimension of the narrow edge (thickness) of enamelled rectangular wire, in mm;
B_{max}	:	Maximum dimension of the wide edge (width) of enamelled rectangular wire, in mm;
a	:	Nominal dimension of the narrow edge (thickness) of bare rectangular wire, in mm;
b	:	Nominal dimension of the wide edge (width) of bare rectangular wire, in mm;
ε	:	Allowable tolerance of bare rectangular wire conductor dimension, in mm;
δ	:	Enamel film thickness (both sides) of enamelled rectangular wire, in mm;
δ_n	:	Self-adhesive epoxy layer thickness (both sides) of enamelled rectangular wire, in mm;
Δ	:	Nominal thickness of paper insulation layer (both sides) of continuously transposed conductor (or bundle and paper thickness); in mm;
C_z	:	Inter leaving/inter column paper thickness, in mm;
C_k	:	Inter leaving/inter column paper width, in mm;
K_h	:	Tolerance in height of continuously transposed conductor, in mm;
K_w	:	Tolerance in Width of continuously transposed conductor, in mm;

n : Number of transposed enamelled rectangular wire;
S : Transposition pitch;
k_1 : Height correction factor of continuously transposed conductor;

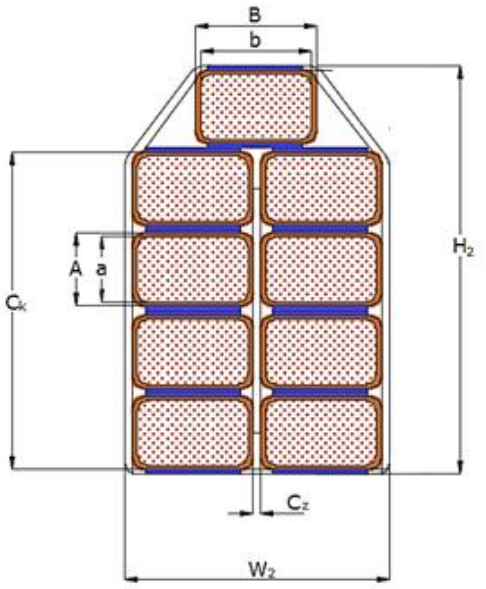

FIG 7

3.24 Conductor/Material Code- Continuously transposed conductor (CTC).

0 - Annealed- copper conductor

CPR- Controlled proof-stress copper conductor (Recommended for CTC)

3.25 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.
e) 105/120/180/200 Class, Enamelled copper rectangular wire overcoated with epoxy or another suitable bond coat.

3.26 Insulation Paper Tape and Binding Rope (Tape) Material – Referred to IEC 60554 3-5 Specification for cellulosic papers for electrical purposes

a) Special papers -General Purpose Electrical grade Kraft paper winding wire & conductor wrapping.

Note: it is referred to all the temperature class.

b) Crepe paper – As per relevant standards IEC- 60554-3-3 and as per agreement between CTC manufacturer and purchaser**.**

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

3.27 Enamelled wire - Wire Coated with Insulation of Cured Resins (**e.g**. - PVA, PEI and PAI)

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 as follows:

Table 1 Proof Strength

Sl No.	Proof strength $Rp_{0.2}$		
	Type	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
Other than the above, if any nominal values are provided, a tolerance of 30MPa or 20% of nominal whichever is higher shall apply, or higher if applicable, as agreed between CTC Manufacturer and purchaser.			

The recommended dimensions in millimetres (Width X Thickness) for the enamelled rectangular wire of the CTC copper winding wires are:

a) Width from 3.00 mm up to and including 12.00mm.
b) Thickness from 1.20 mm up to and including 2.50 mm.
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:

Table 2 Tolerance

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

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%.

Table 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 x Nominal thickness
ii)	1.00	1.60	0.50 *
iii)	1.60	2.24	0.65 **
iv)	2.24	3.55	0.80
If agreed between CTC Manufacturer and purchase. The corner radii for the wire with a width greater than 4.8 mm may be * 0.5 mm x t, where t is the nominal thickness of the conductor. ** 0.80 mm			

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-3

Table 3a

Sl No.	Grade	Increase in Dimensions 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

4.2.5 Increase in dimensions over enamel insulation wire with bonding layer epoxy.

4.2.5.1 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 0.040mm +/- 0.010mm. In case of any other self-adhesive layer, the thickness and tolerance shall be mutually agreed between CTC Manufacturer and purchaser.

4.3 Transposed Core Structure

4.3.1 *Number of Transposed Core* - The number of transposed core is as follows:

a) Odd column: 5 ~ 83. Even column: in consideration.

4.3.2 *Transposed Core Dimension Range* - The dimension range of the transposed core is as follows:

a) $W_{2-} \leq 26$ mm;
b) $H_2 \leq 76$mm;
c) Height to width ratio H/W ≤ 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.

$$C_k = ½(n-3)A$$

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.

$$S \leq \pi D_{min}/n$$
Generally: $6b \leq S \leq 18b$.

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 & purchaser with relevant reference standard 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 & 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 IEC 60554-3-3.

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.

Table 4

Sl No.	**Increase in diameters due to lapping insulation layer (paper covering)**		**Allowable tolerance in %**
	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

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 & CTC Manufacturer;

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 clause 3.13 to 3.19.

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 clause number 3.20

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.

Table-5

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 & K_w as per table 6.

Table 6

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

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 H2max and W2max, the positive tolerance of the insulation thickness is allowed to exceed the requirements of enamel, epoxy & paper insulation mention in 4.2.4, 4.2.5 and 4.7 – Recommended to add.

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 0.075mm of crepe paper can also be applied with overlap of 40 to 60% 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 3.23 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 7N/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% if the delivery length ≥ 400 metre
b) + 1.0% if the delivery length < 400 metre

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% to 75%. 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 ~ 14) N, and measurement rod and measurement seat diameter of (5 ~ 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 300-400 mm use a suitable instrument for measurement, having precision of at least 0.02 mm, measurement pressure of about 100 N/cm2, and measurement range of (0 ~ 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 and 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 0.01724 $\Omega.mm^2/m$ at 20°C. The measurement accuracy shall be within 0.5%.

The resistivity of the finished product (CTC) shall be as per Table 7 below.

Table 7

Sl No.	Type	Nominal Proof strength	Tolerance	Max. Resistivity ($\Omega.mm^2/m^{-1}$)
(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

5.4 Elongation - The percentage elongation after fracture shall be measured according to clause 20 of ISO 6892-1-2016 & IEC 60317-0-2 Proof strength Rp0.2. 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 IEC 60851-3.

Table 8 Percentage Elongation after Fracture

Sl No.	Nominal thickness of the conductor mm		Minimum elongation %
	Over	Up to and including	
(1)	(2)	(3)	(4)
i)	–	2.50	30

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% of the valued specified. The test shall be carried out as per IEC 60851-5.

Table 9

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	1000	750	1500	1000
ii)	2	2000	1500	2500	2000

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 300V DC 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 flatwise and edgewise on a mandrel. The test shall be carried out as stated in IEC 60317-0-2 and 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 IEC 60317-0-2 and IEC 60851-3.

5.7 Conductor Path (Continuity) - Use a multimeter to measure each enamelled rectangular wire of the continuously transposed conductors, and there shall be no open circuit.

5.8 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 Figure, 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 24h; 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.

5.9 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 IEC 60317-0-2 and IEC 60851-4.

5.10 Temperature index - The test shall be carried out on a rectangular wire in accordance with 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.

5.11 Test of Specified Non-Proportional Extension Strength Rp0.2 - It shall follow the provisions of IEC 60317-27 or ISO 6892-1 2016 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.

8 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.
f) Drum number

9 STORAGE

The finished product shall be stored in a clean, dry, and well-ventilated covered warehouse with a temperature of (15 ~ 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.

Annexure A

(Informative)

NOMINAL CROSS-SECTIONAL AREAS FOR PREFERRED AND INTERMEDIATE SIZES

Table A 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 A - Nominal Cross- Sectional Areas

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

Sl No.	**Nominal Width**	**Nominal Thickness**	**Corner Radius**	**Nominal Cross-Section Area**
	(mm)	(mm)	(mm)	(mm^2)
(1)	(2)	(3)	(4)	(5)
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

Sl No.	**Nominal Width**	**Nominal Thickness**	**Corner Radius**	**Nominal Cross-Section Area**
	(mm)	(mm)	(mm)	(mm^2)
(1)	(2)	(3)	(4)	(5)
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

Sl No.	**Nominal Width**	**Nominal Thickness**	**Corner Radius**	**Nominal Cross-Section Area**
	(mm)	(mm)	(mm)	(mm^2)
(1)	(2)	(3)	(4)	(5)
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

Sl No.	**Nominal Width**	**Nominal Thickness**	**Corner Radius**	**Nominal Cross-Section Area**
	(mm)	(mm)	(mm)	(mm^2)
(1)	(2)	(3)	(4)	(5)
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

Sl No.	**Nominal Width**	**Nominal Thickness**	**Corner Radius**	**Nominal Cross-Section Area**
	(mm)	(mm)	(mm)	(mm^2)
(1)	(2)	(3)	(4)	(5)
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

Sl No.	**Nominal Width**	**Nominal Thickness**	**Corner Radius**	**Nominal Cross-Section Area**
	(mm)	(mm)	(mm)	(mm^2)
(1)	(2)	(3)	(4)	(5)
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

Sl No.	**Nominal Width**	**Nominal Thickness**	**Corner Radius**	**Nominal Cross-Section Area**
	(mm)	(mm)	(mm)	(mm^2)
(1)	(2)	(3)	(4)	(5)
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