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Bearing insulation' and 'Winding insulation' – new technologies for electric motors used with Converter operation

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Abstract:

In paper manufacturing industry, the integration of Variable Frequency Drives (VFDs) powering variable speed motors proves indispensable for optimizing the production process. By leveraging VFD technology to control motor speeds, paper mills can achieve enhanced energy efficiency by precisely matching power consumption with operational demands such as a variety of paper grades, variation in capacity etc.

The variable speed functionality enabled by VFDs also plays a pivotal role in adapting to the fluctuating requirements of various manufacturing stages such as pulping, refining, drying, and winding. The ability to finely adjust motor speeds ensures that each phase operates at an optimal pace, ensuring product quality and overall efficiency. For a reliable operation of a motor when operating with VFD it is essential to have good di-electric insulation strength – both for winding and bearings.

Having winding insulation of strength IVIC-C as per IEC 60034-18-41 helps a motor for partial discharge free operation and thus significantly reduces probability of winding failures due to insulation breakdown.

Bearing currents causes fluting of bearings which generally results into bearings noise, vibration and if sustained, results in premature bearing failures. Thus, a good bearing insulation is also important to prevent risk of bearing failures.

This paper gives introduction to IVIC classes as per IEC 60034-18-41 and key guidelines process and material selection which helps to reach IVIC-C class as well as information regarding the new technology used in electric motors to prevent bearing currents effectively. For converter fed motors, satisfactory operation of bearings is possible when bearing currents are minimized to the best possible extent. There are many available solutions like, insulated bearings, insulated end-shields, insulated shafts, hybrid ceramic bearings etc, and intention of this paper is to elaborate insulated shafts where a special moulding compound is used for shaft insulation which is proven for 'thermal stability', 'high impedance at high frequency' and 'sustainability against shock and vibration of grade 3M4'. The technology is not just about selection of material but also the process which helps the reliable operating life and ease of service and replacement. For bearings, this solution is currently available in frame sizes 225 to 315 where demand for VFD operation is higher as compared to smaller frame sizes. As defined by the international paper specification nr 3614-3 from May'2017 bearing insulation need to have min impedance of 25Ω at 10MHz and this criterion is fulfilled by this new shaft insulation process. For windings this solution is available in frame sizes 71 to 500.

Keywords : converter operation, bearing currents, insulation composite compounds, Surge test, Top-coat polyamide imide, PD free operation, IVIC

A. INTRODUCTION:

In order to achieve sustainability, VFD's (variable frequency drive) / VSD's drives (variable speed drive) are increasingly being used, especially with changing loads, which are controlled in a coordinated system depending on the required speed/torque.

By using frequency converters, the energy consumption of electric drive systems can be optimized.

Apart from the advantages of converter operation the designer of the system must be ready for some unwanted effects, mainly arising from DC link voltage source converters, there are side effects induced by the functional principle of these converters. The frequency variable voltage is generated by modulated switching of the DC link voltage of the converter. These are the steep rising voltages, which are required to minimize losses in the switching devices of the converter.

These steep voltages have effects on two key design components, one is rolling bearings and second is motor winding insulation.

The high frequency currents are induced into the whole drive system, comprising converter, motor and installation grounding and as a result, insulation and air gaps act as capacitances and establish a circuit, however the current will flow only if the voltage exceeds the breakdown field strength of the respective insulation material.

In case of rolling bearings, the higher voltages beyond di-electric strength of the oil film (grease), results in the arc discharges which induce currents in and across the rolling bearings of the electric motor and the attached load machine. These discharges in the lubrication gap of the affected bearings result burning of oil film within grease and loses lubrication property of the grease and increases the friction while rolling of the bearings and bearings runs hotter than permissible temperature. As a direct effect on bearings due to repeated discharge currents, the material at raceways continuously melts in a specific pattern which is also called as fluting.

Some examples of the bearing damages due to grease losing lubrication and fluting are shown below in Fig.-1.

In case of motor winding, the insulation breakdown results in flashover in the windings, primarily in the terminal coils (inter-turn) or subsequently inter-phase or ground failures.

Some examples of the winding damages are shown below in Fig.-2.

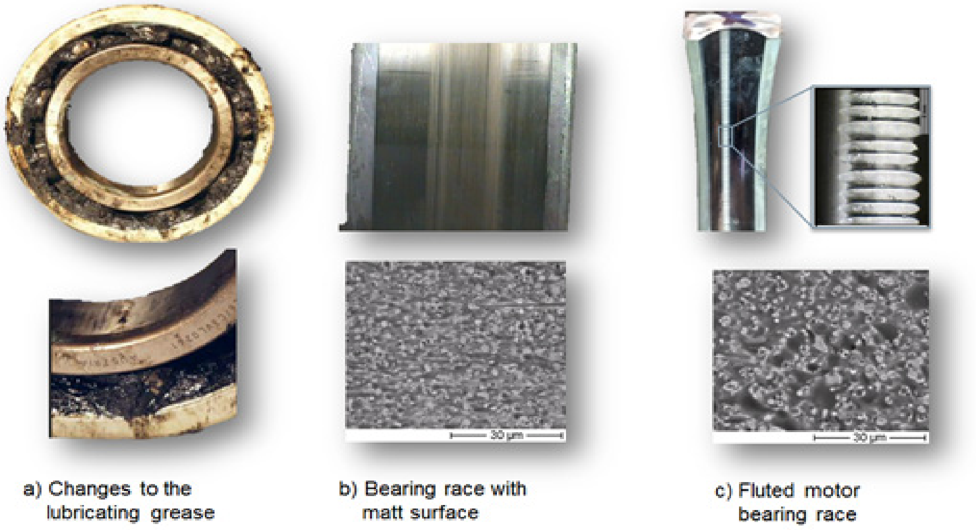


Fig.-1 Photographs of damaged motor bearings

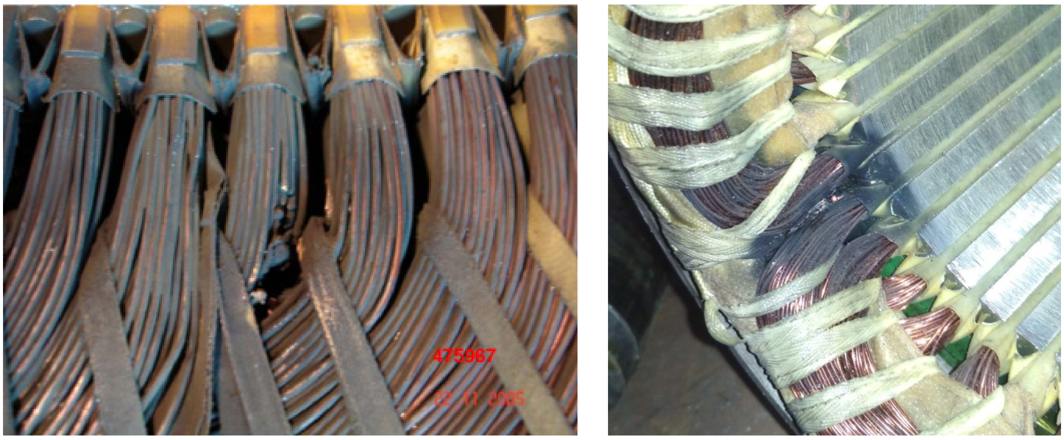


Fig.-2 Photographs of damaged motor windings

B. BEARINGS

1. BEARING CURRENTS IN CONVERTER-FED DRIVE SYSTEMS

Effectively there are three types of bearing currents with details given in text below as well as in Fig.-3

a. High frequency capacitive currents discharged through the motor bearings from rotor to the ground. To reduce rotor-ground currents is possible by the improvement of the impedance conditions in the system design e.g. HF grounding of the components, Use symmetrically shielded motor connecting cables, Potential bonding in the system, etc.

b. High frequency circulating currents which flows in a circuit through the housing, end-shields, shaft, via the rolling bearings. An effective method to reduce the circular bearing currents is to break the circuit at both or either one bearing by providing the insulation.

c. EDM (Electric Discharge Machining) currents which are flashovers in the lubrication system. Though it is not possible to eliminate EDM bearings currents, avoiding them to some extent, is possible with prevention of critical operating conditions which by prediction of flash-over activities.

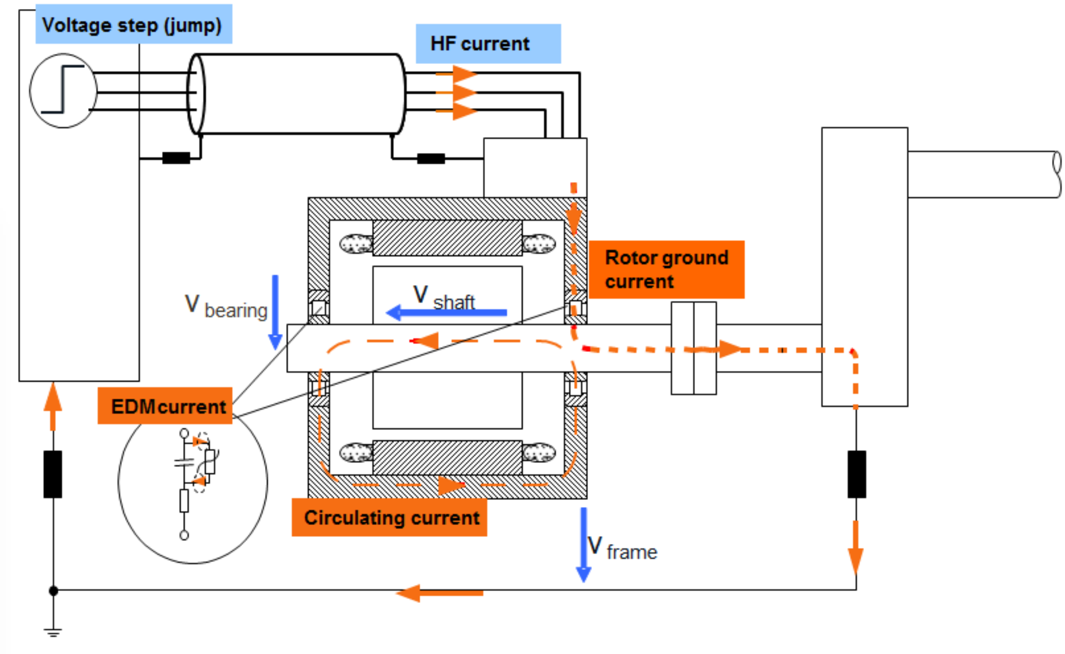
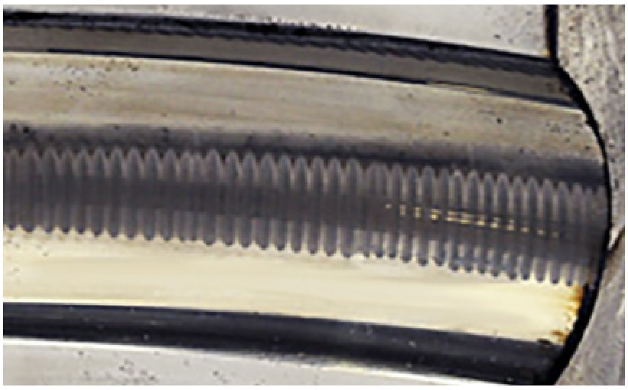


Fig.-3 Bearing current types in the drive system

2. DAMAGES IN BEARINGS DUE TO BEARING CURRENTS

The damage pattern typically seen in a discoloured raceway in the bearings and melting of material in a typical ripple pattern which is called also called as fluting of raceways as seen in image below. The ripple formation occurs at right angles to the raceway as seen in picture below.



The factors influencing the formation of bearing current are very extensive. The most important factors influencing the formation of bearing currents are,

- speed spectrum
- bearing size
- operating temperature
- grease properties
- vibrations
- bearing forces
- manufacturing tolerances

Remedial methods such as sine filters, earthing brushes, ceramic-coated bearings or conductive shaft seals offer only limited protection.

In order to control the large number of influencing factors, the use of hybrid bearings (bearings with ceramic balls) has established itself as quite safe method against bearing current. However, the hybrid bearings have limitations like very high cost, non-availability of medium and large size bearings etc, and hence this solution is available for small bearing sizes only.

For this reason, Innomotics (formerly Siemens) has developed an alternative solution. A special insulation material in the form of a shell (cover) is used to create minimum contact surface area between the inner ring of the bearing and the shaft to establish smallest possible capacitance.

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

C = Capacitance of end shield to shaft

ε_0 = Di-electric constant of the vacuum

ε_r = Di-electric constant of the insulating shells

d = Distance between the contact surfaces

A = Size of the contact surface on the inner ring

Two injection-moulded half shells made of a high-performance plastic are bonded to the shaft over the bearing seat. The material is based on a phenolic resin, which is filled with a very high proportion of short glass fibres.

The oversized half-shells are then ground (machining process) to the appropriate fitting dimensions for use with coolant. The half-shells are also provided with a shoulder for an axial stop.

3. NEW TECHNOLOGY - STRUCTURE OF INSULATION TECHNIC WITH TWO HALF SHELLS ON THE SHAFT

Target:

The purpose is significant improvement of bearing current protection by fulfillment of International Paper specification number 3614-3 May'2017 for bearing insulation requirements clause 6.5.1.

Design:

The desired results are achieved by using of composite compound which has excellent dimensional stability, high electrical insulation properties, UL listed, dimensionally stabilized for 150 °C with maximal curing temperature up to 240 °C. Phenolic moulding compound, filled with a high proportion of glass fibres, suitable for injection moulding is used. The design schematic is as shown in Fig.-4

Material properties:

Temperature resistance under compressive stress up to 200°C according to ISO 75 Af

Compressive strength up to 360 MPa according to ISO 604

Insulation 25 KV/mm according to IEC60243-1

UL V0 according to UL94

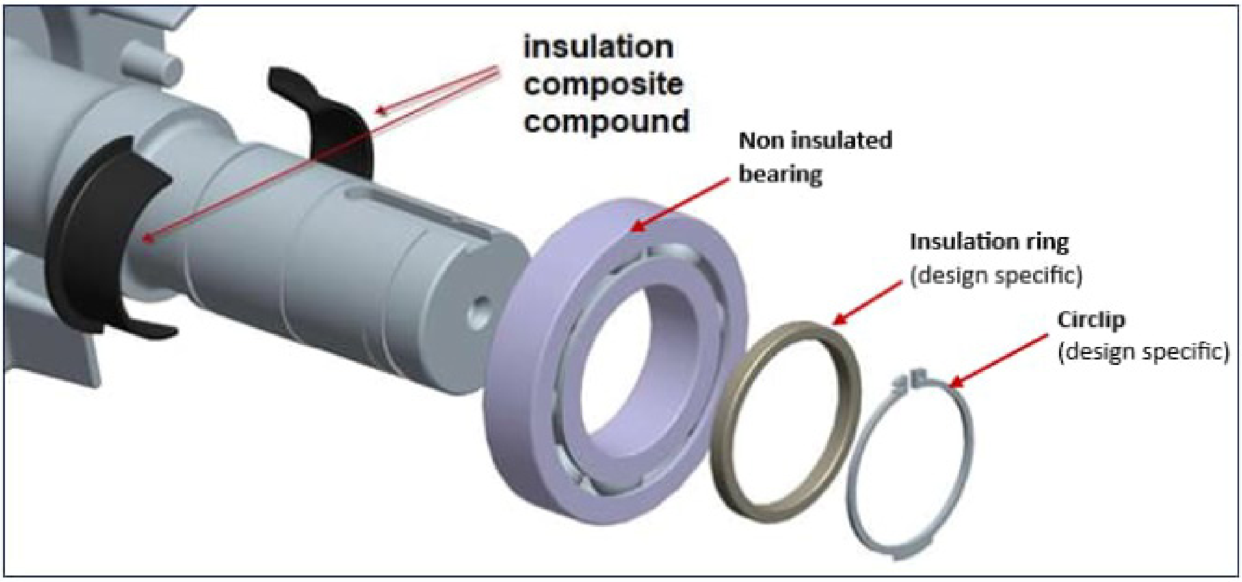


Fig.-4 Schematic of bearing insulation technic with two half shells

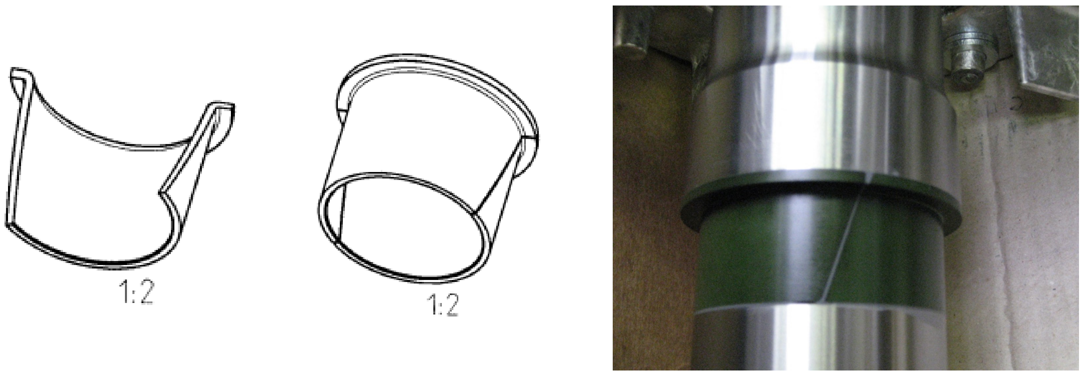


Fig.-5 Representative drawing and actual assembly

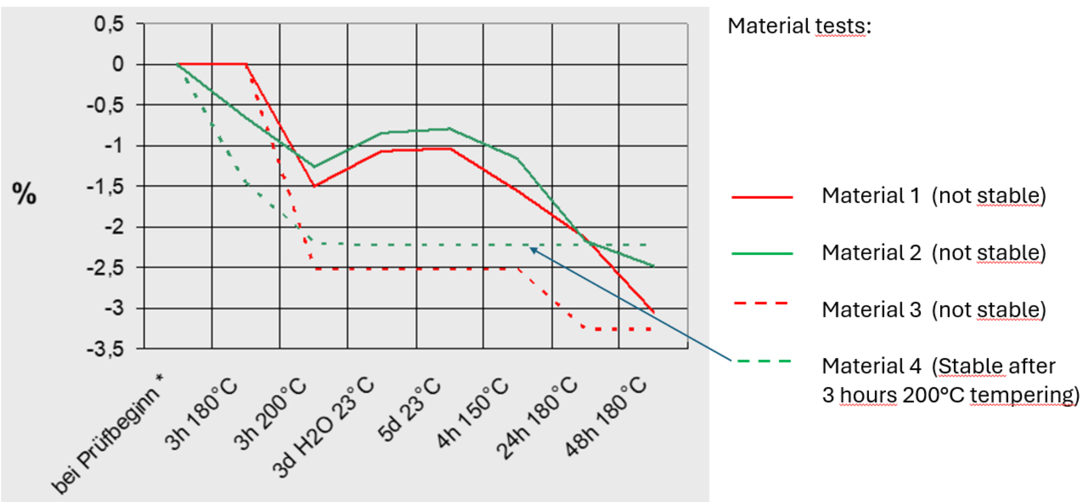


Fig.-6 Achieving dimensional stability through tempering

Tempering of the half-shells to stabilize the shrinkage:

In an upstream thermal process at the supplier, the half-shells are tempered at very high temperatures as seen in Fig.-6. The dimension stability is achieved after curing the composite mould for 3 hrs at 200°C

Function of electrical insulation:

The aim of this development is to achieve electrical insulation with a dielectric strength for at least 1000 V and a minimum impedance of 25Ω at 10 MHz as per International Paper specification number 3614-3 May'2017 clause 6.5.1. The impedance is calculated as

$Z = 1 / (2 \times \pi \times f \times c)$, Impedance requirement is minimum 25Ω.

Bearing insulation methods discussed in this paper are:

1) New Technology - Composite compounds half shells (Fig.-7)
2) Conventional Al_2O_3 coated outer race (Fig.-8)
3) Conventional Al_2O_3 coated shaft seat (Fig.-9)
4) New Technology - Hybrid bearings having ceramic balls (Fig.-10)

For comparison between these 4x methods, impedance was measured for a 6319-size bearing.

6319 axially floating bearing - radial insulation composite compound

Measuring	Capacity	Calculated impedance for 10MHz
1)	0,422 nF	37,7 Ω
2)	0,434 nF	36,7 Ω
3)	0,462 nF	34,4 Ω

All measurements result into calculated impedance higher than 25Ω

Fig.-7 New Technology - Composite compounds half shells

6319 axially floating bearing - Al_2O_3 insulated outer ring

Measuring	Capacity	Calculated impedance for 10MHz
1)	7,26 nF	2,2 Ω
2)	7,24 nF	2,2 Ω
3)	7,31 nF	2,2 Ω

All measurements result into calculated impedance lower than 25Ω

Fig.-8 Conventional Al2O3 coated outer race

6319 axially floating bearing - Al_2O_3 insulated shaft

Measuring	Capacity	Calculated impedance for 10MHz
1)	6,95 nF	2,3 Ω
2)	7,88 nF	2,0 Ω
3)	7,92 nF	2,0 Ω

All measurements result into calculated impedance lower than 25Ω

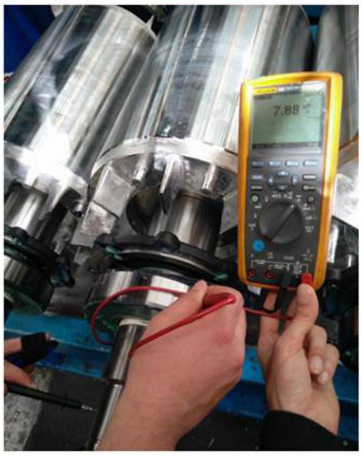


Fig.-9 Conventional Al2O3 coated shaft seat

6319 axially floating hybrid bearing using ceramic balls

Measuring	Capacity	Calculated impedance for 10MHz
1)	0,187 nF	85,1 Ω
2)	0,222 nF	71,7 Ω
3)	0,22 nF	72,3 Ω

All measurements result into calculated impedance higher than 25Ω

Fig.-10 New Technology - Hybrid bearings having ceramic balls

6319 axially floating bearing - comparison

Design	Measuring	Capacity nF	Calculated impedance for 10MHz		Result with respect to International Paper requirement 25 Ohm at 10MHz
Composite compound - NEW	1)	0,422	37,7	Ω	O.K.
	2)	0,434	36,7	Ω	O.K.
	3)	0,462	34,4	Ω	O.K.
Al2O3 insulated outer ring ONGOING	1)	7,26	2,2	Ω	N.O.K.
	2)	7,24	2,2	Ω	N.O.K.
	3)	7,31	2,2	Ω	N.O.K.
Al2O3 insulated shaft - ONGOING	1)	6,95	2,3	Ω	N.O.K.
	2)	7,88	2,0	Ω	N.O.K.
	3)	7,92	2,0	Ω	N.O.K.
Hybrid bearing using ceramic balls - ONGOING	1)	0,187	85,1	Ω	O.K.
	2)	0,222	71,7	Ω	O.K.
	3)	0,22	72,3	Ω	O.K.

6319 size bearing assembly with composite moulds	Measured capacitance value	Calculated impedance value at 10MHz Z = 1 / (2 x pi x f x c)
	nF	Ω
Sample motor 1	0.325	49
Sample motor 2	0.294	54
Sample motor 3	0.292	54

Fig.-11 New Technology - Hybrid bearings having ceramic balls

As we can see in Fig.-11 above the insulation with two half shells of composite compounds is found meeting the requirement of 25Ω comfortably whereas the typical Al2O3 coated bearings/shafts are having very low impedance and thus less reliable as compared to composite compounds or hybrid bearings. As already explained in section 3, hybrid bearings is not optimum solution except for small bearing sizes.

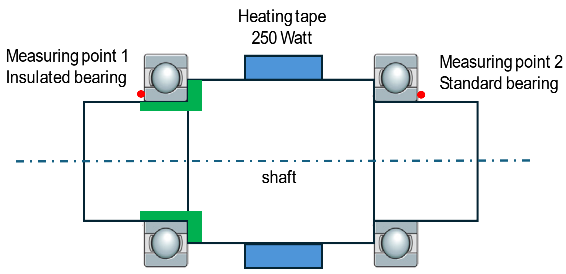
The mechanical conditions must also be considered, as the bearing seat is subjected to pressure and thermal loads. Plastics generally have the negative property of shrinking under pressure and temperature and changing shape. These negative properties are not suitable for a bearing seat; hence the new material selection must be done after verifying various materials and curing processes. To increase the compressive strength of the half-shells, a plastic with a very high glass fibre content was considered, further a properly selected tempering process helps optimizing the shrinkage behaviour and thus a dimensional stability is achieved.

Function of thermal insulation:

The use of half shells has an additional positive effect due to their thermal insulation properties. With asynchronous motors in particular, heat flows from the rotor stack towards the bearing seat and bearing inner ring. This heat flow is blocked by the insulation using plastic, so that the temperature on the bearing inner ring is reduced by 10-20 K. This benefits the service life of the grease as, typically, a reduction in the grease temperature by approx. 15 K means a doubling of the grease service life.

By reducing the temperature on the bearing inner ring, the delta of the inner ring temperature to the outer ring temperature is also reduced, which makes it possible to use standard C3 clearance bearings instead of non-std requirement of C4 clearance bearings.

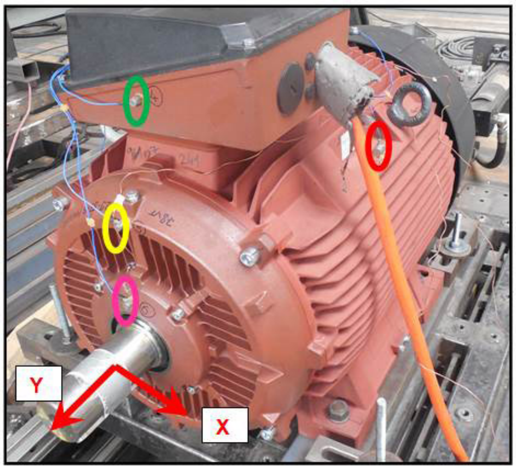
In a simplified test with a heater tape mounted on a rotor between a standard bearing and an insulated bearing, a temperature drop of approx. 20 K was observed which confirms the same.



Measuring point		Temperature
1	Insulated bearing	139 °C
2	Standard bearing	162 °C

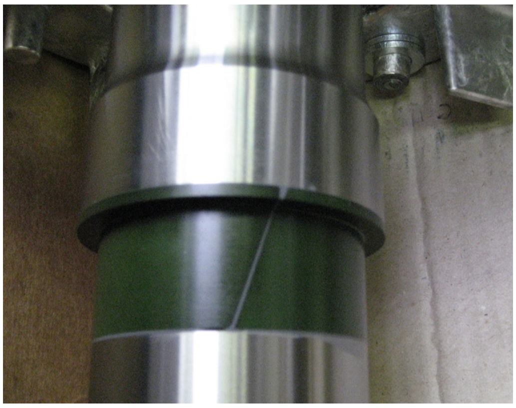
Laboratory Test - Vibrations and Shock:

The laboratory tests for 3M4 requirement was carried out for vibration according to IEC 60068-2-6 and shock according to IEC 60038-2-27 on a motor provided this bearing insulation technique using composite compound half shells and then impedance was measured. The impedance was still >25Ω and no damage or settling behaviour was detected on the bearing seat which proved electric breakdown was reliably prevented. This assures good service life. As an elevated test condition motor was tested also for 3M6 and it passed.



Mounting the half-shells on the shaft:

The half-shells are glued to the shaft using a heat-resistant, high-viscosity special purpose adhesive. The half-shells are pressed on with a clamping tool to prevent a cavity under the half-shells. After the adhesive has hardened, the bearing seat is ground over using coolant to produce a suitable fit dimensions for bearing assembly. The incline on the half-shells is used to create a smooth transition at the joint in the tangential direction.



Dismantling of bearings from the shaft:

For ball bearings the dismantling is like standard process by using puller.

Dismantling of glued roller bearing inner ring is possible with combined use of bearing puller and hot air gun (maximum temperature allowed is 250°C). The surface of composite shells must be protected against direct hot air stream. Activator Loctite 7240 need to be applied on the surface of the composite shells before the bearing installation. The new inner ring of roller bearing need to be then fixed by Loctite 640.

Use of an open flame is to be prohibited.

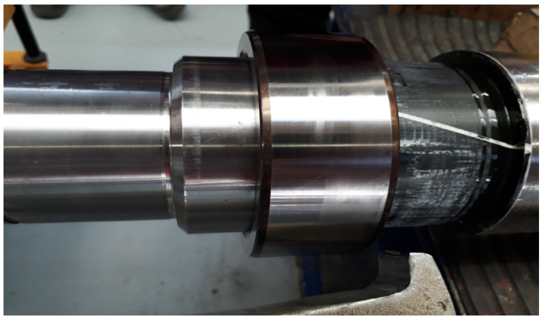
A rare case but if at all there is a situation of damaged composite compound half shells, then this is to be repaired at manufacturer or authorized service centre only.

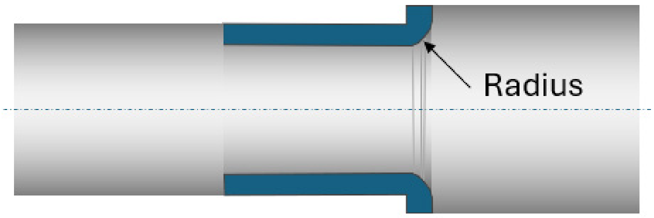
Mechanical stability of the shaft:

The wall thickness of the half shells is in the range of 2 - 2.5 mm. Accordingly, the shaft is turned to a smaller diameter at bearing seat.

Regarding bending strength and safety against shaft breakage the shoulder radius is designed optimum to avoid any stress concentration.

To avoid a weakening of the bending strength, this radius on the shaft is increased to a maximum possible dimension. In the example of a motor with shaft height 225, the radius is increased from 0.6 to 3 mm.





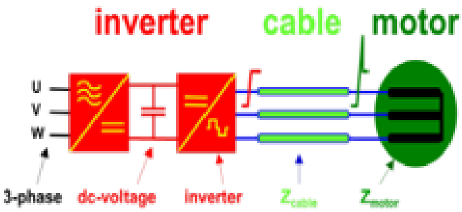
C. WINDING

1. STRESS ON WINDING INSULATION DUE TO VFD

Electrical stress on the winding insulation is much higher in VFD operation than in grid operation. Following are the main causes which are stressing the winding insulation when operated with VFD.

- Non-uniform voltage distribution in the winding
- Increased voltage at the motor terminals
- Random wound windings, which results in a probability that two wires with a high potential difference may be close to eachother .

The voltages influencing the electrical stress on the winding insulation due to AFE-inverters i.e. VFDs is calculated as follows:



Effective upp = 500 V x 1.35 x a x b x 2.0

1.35 - DC link voltage factor

a - Supply variation 0% to 10% (i.e. 1.0 to 1.1), assume 1.0

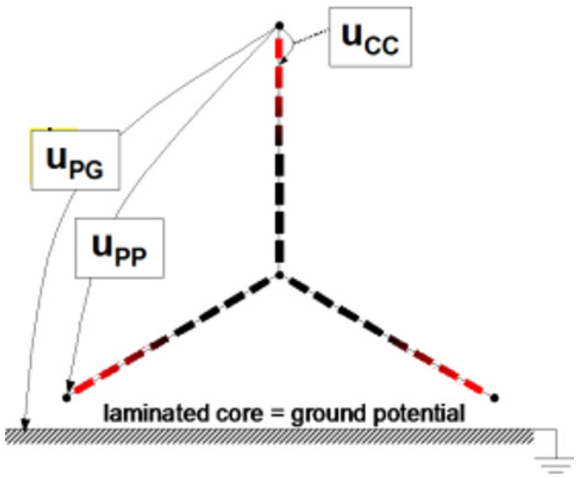
b - Safety factor 1.0 to 1.25, assume 1.0

2.0 – peak to peak values

upp = 500 x 1.35 x 1.0 x 1.0 x 2.0 = 1350 V

However, due to surge effect ~80% of voltage appears across the first coil from terminal, which is pictorially shown in image below.

hence, ucc = 1350 x 80% = 1080 V



Different from VFD, in Grid operation the voltage is equally distributed across the coils connected in series per phase and thus, the voltage stress on winding when fed through VFD is significantly higher as compared to connected to Grid.

Higher amplitude of voltage than the partial discharge inception voltage (PDIV), results in the partial discharges in the insulation and if sustained for longer duration results in flashover in that section of the winding (refer fig.-2). To check the insulation strength of the terminal coils as well as the complete insulation, typically 'partial discharge' test at impulse wave (or surge) and at sine wave supply is useful.

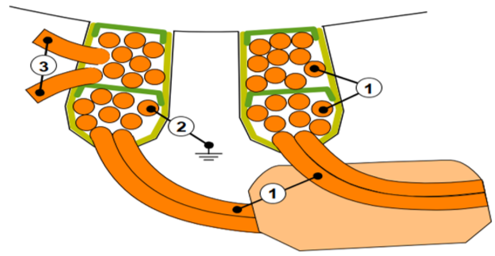
2.HOW TO ACHIEVE HIGHER STRENGTH OF INSULATION REQUIRED FOR VFD OPERATION

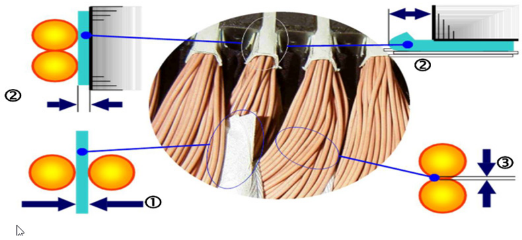
It is possible to achieve partial discharge free operation by optimized selection of 'Materials', 'Processes', and 'Qualification tests.

Each component and process play an important role, but for the purpose of this technical paper only key topics are explained.

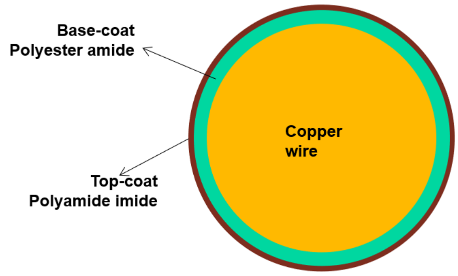
Material – Winding wires

As it can be seen in images below, the winding wires is the first component to face the voltage stress. The insulated wires need to provide protection against 1) 'phase-to-phase' 2) 'phase-to-ground' and 3) 'turn-to-turn' voltage stress.

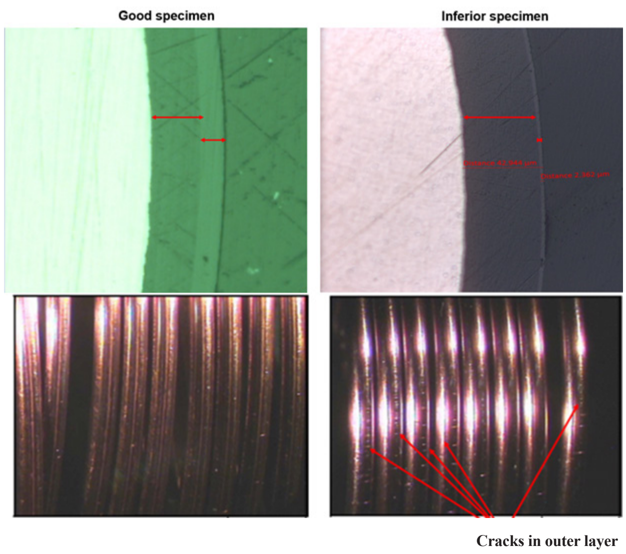




Typically, dual coat class 200 wires according to IEC 60317-13 are used for motors operated with VFD.



'Base-coat' has strong electrical properties whereas 'Top-coat' has strong thermal & mechanical properties. The thickness of these coats plays crucial role. The 'Top-coat' provides endurance against service life conditions like higher temperatures, vibrations etc and thus electrical endurance is also sustained. However, if 'Top-coat' is thin, the probability of failure increases.



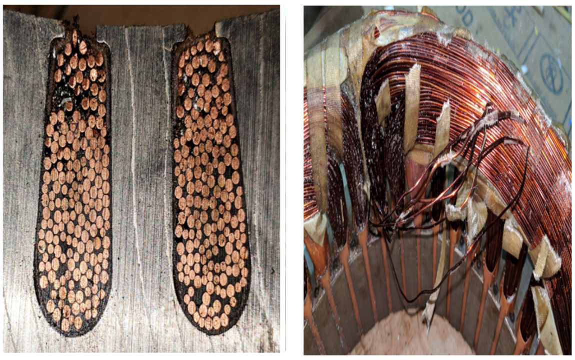
Above image shows difference between two specimens. The one on left side has 'Top-coat' >25% of total insulation and the other one at right has just 5% 'Top-coat'. When tested against specific styrene chemical, the specimen with lower thickness of 'Top-coat' failed as multiple cracks were observed. As the cost of 'Top-coat (polyamide imide)' is higher as compared to 'Base-coat (polyester amide)' it is necessary to perform quality inspection to ensure the thermal, mechanical, electrical endurance is not compromised.

Process – Impregnation

Many a times there is unclarity for use of ‘Resin’ v/s ‘Varnish’ and ‘Dip impregnation’ v/s ‘VPI’. This technical paper attempts to clarify this FAQ.

Similar to a medicine, where one specific treatment is not always best for different patients, in case of impregnation also we need to consider size of winding and core length to get optimum quality.

Typically, small windings give optimum results with Varnish with dip impregnation and for bigger size windings Resin is required with VPI. Every manufacturer has their own experience based on which the optimum process and chemistry is finalized with internal qualification. The quality of impregnation is also verified using cut through test to see the penetration of resin/varnish and adhesion between wires as seen in next picture.



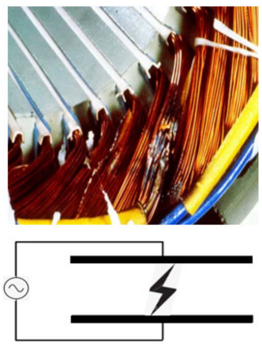
(i) resin penetration *(ii) bonding between wires*

Qualification tests – IVIC as per IEC 60034-18-41

This test is introduced to specify requirements of partial discharge free operation for motors when operated with VFD. More details are given in next section.

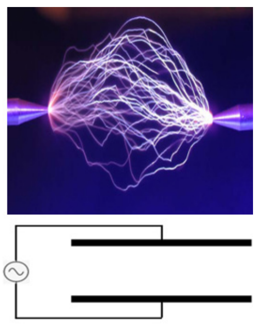
3. ELECTRIC BREAKDOWN, CORONA DISCHARGE AND PARTIAL DISCHARGE

Before we understand ‘partial discharge’, let’s briefly recap ‘complete electric breakdown’, and ‘corona discharge’.



Complete electric breakdown

As seen in picture here there is complete short circuit between insulation medium. Obviously, this is destructive phenomenon as winding is already damaged.



Corona discharge

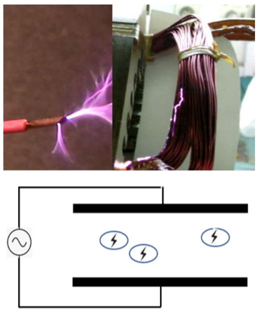
A corona discharge is an electrical discharge caused by the ionization of a medium such as air surrounding a conductor carrying a high voltage.

Dielectric strength of dry air = 3kV/mm

where the air (or other medium) undergoes electrical breakdown and become conducive allowing electrons to continuously leak off the conductor into the air towards other positive potential.

It is often seen as a bluish glow in the air adjacent to pointed metal conductors carrying high voltages.

This is also a destructive phenomenon and though the winding is not damaged but longer duration results is reduction in insulation life expectancy.



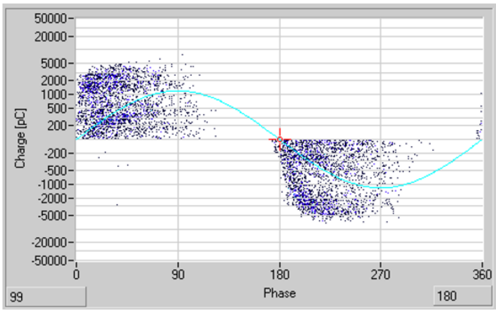
Partial discharge

In electrical engineering, partial discharge (PD) is a localized dielectric breakdown of a tiny sections of a solid or fluid electrical insulation system under the high voltage stress.

This breakdown does not completely bridge the two electrodes like in a permeant breakdown.

Whenever partial discharge is initiated, high frequency transient current pulses appear and persist for few nanoseconds to a microsecond, then disappear and reappear repeatedly as the voltage is a sinewave.

PD pulses are measured using the high frequency current transducer (HFCT) method. It is also measured in units of pico-coulombs, pC or nano-coulombs, nC.



4. PARTIAL DISCHARGE AND IVIC CLASSES

Movement of electrons from -ve potential to +ve potential is called as current, however when this movement is through un-intended path i.e. via insulation then it is undesirable.

In case of initial stage of partial discharge as seen in above picture movement from -ve electrode of insulator to +ve electrode is not taking place but the partial discharge within voids increases the kinetic energy of electrons in exponential form and if the partial discharges are sustained, then eventually results in overall heating of insulation medium and reducing its breakdown limit. Depending upon the amplitude of the partial discharge the life expectance of the insulation medium changes.

Low voltage machines winding design is predominantly based on organic materials. Organic materials by their chemical structure are not suitable for operating with continuous partial discharge and hence for low voltage machines it is necessary to design and manufacture insulation system which will work as free from partial discharge (also called as ‘PD free’).

Voltage appearing at motor terminals depends upon following parameters e.g.,

a) DC link voltage

b) Motor cable type and length

c) Rise time of voltage waveform

d) Motor winding coil length & impedance

At various installations of motor connected with VFD, the above parameters vary, and thus effective amplitude of voltage can be different.

This amplitude is generally denoted as Vp-p i.e. voltage amplitude peak to peak.

Hence to specify PD free operation it became necessary to classify amplitudes. This classification is done for 'Impulse Voltage Insulation class i.e. IVIC which is defined in IEC 60034-18-41 as follows,

Maximum allowable peak to peak operating voltage (VPP) in units of UN

Impulse insulation class (A-D)	Maximum allowable peak/peak operating voltages in units of U_N	
	Phase/phase	Phase/ground
A (Benign)	3,3	2,3
B (Moderate)	4,5	3,1
C (Severe)	5,9	4,2
D (Extreme)	7,4	5,2

For typical rated voltages 415V and 690V the calculated maximum allowable operating voltages are given below.

IVIC class Impulse Voltage Insulation Class For U_N = 415V	Max allowed peak-peak operating voltage (Volts)	
	Phase to Phase	Phase to Earth
A (Benign)	1370	955
B (Moderate)	1868	1287
C (Severe)	2449	1743
D (Extreme)	3071	2158

IVIC class Impulse Voltage Insulation Class For U_N = 690V	Max allowed peak-peak operating voltage (Volts)	
	Phase to Phase	Phase to Earth
A (Benign)	2277	1587
B (Moderate)	3105	2139
C (Severe)	4071	2898
D (Extreme)	5106	3588

For a selected class it is necessary to have a PD free operation at respective ph-ph and ph-E terminal voltage.

5. PARTIAL DISCHARGE TEST

For high voltage machines partial discharge is common phenomenon and in fact HV machines are designed to operate with limited continuous partial discharge of typically 10 nano-coulombs. PD measurement equipments for HV machines are available in market for long time.

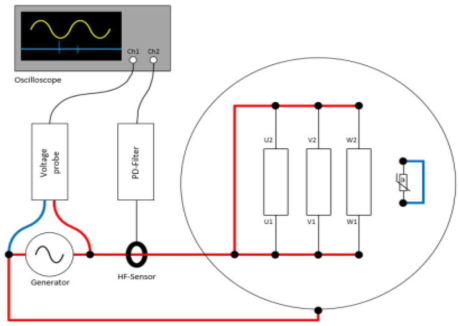
For sine wave test, partial discharge is measured as charge in in terms of nano-coulombs, whereas for impulse wave test, partial discharge is measured in terms of pulse in mV. In completely noise-free supply condition to the tester, a PD free operation is considered for discharges typically <0.1 nano-coulombs or <20mV.

Since LV motors are expected to work PD free the testing equipment required is of high precision and considering this new technological requirement of high-precision these testers are available at significantly high investment cost.

Connections during test are as follows.

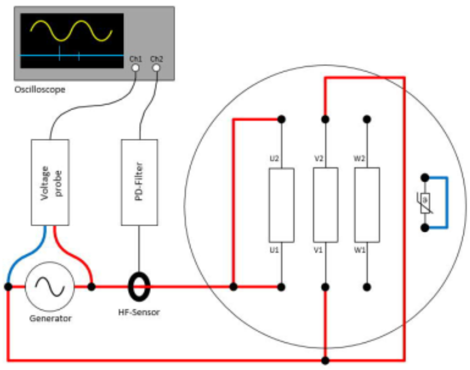
Sine wave test

Phase to Earth:

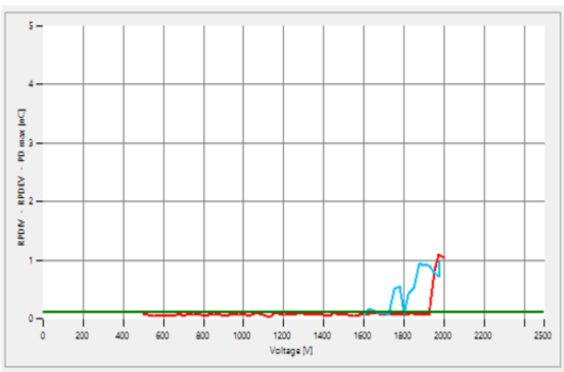


Sine Phase-Ground

Phase to phase:



Typical measurement results are graphically available as follows.



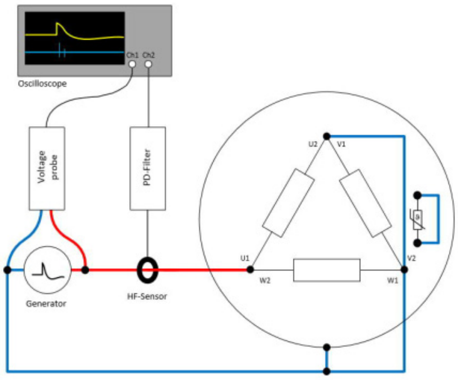
Green line indicates set threshold limit for PD free operation i.e. 0.1 nano-coulombs.

Red colour pattern indicates PD measurements done when terminal voltage is gradually increased. When the red pattern crosses the threshold limit in upward direction, its corresponding value at x-axis is called as PDIV i.e. partial discharge inception voltage. PDIV value shall be higher than the respective IVIC class to fulfil the requirement of PD free operation.

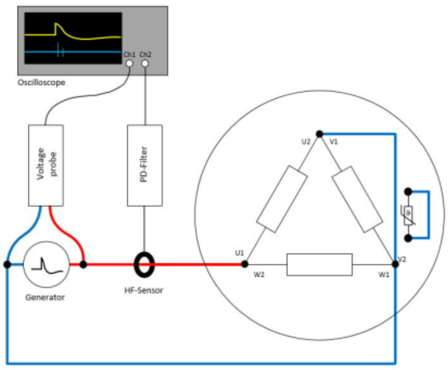
After crossing the PDIV stage when voltage is gradually reduced the pattern of PD measurement is indicated by blue colour and when the blue pattern crosses the threshold limit in downward direction, its corresponding value at x-axis is called as PDEV i.e. partial discharge extinction voltage.

Impulse/Surge wave test

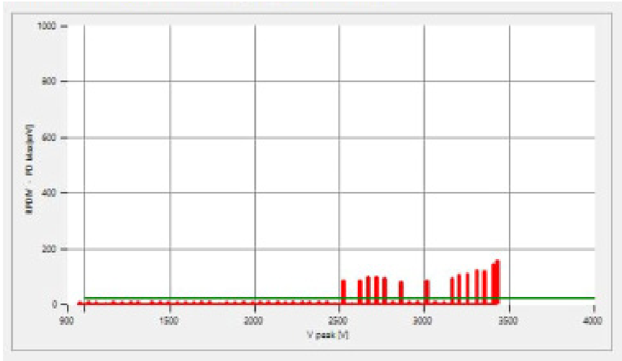
Phase to Earth:



Phase to phase:



Typical measurement results are graphically available as follows.



Green line indicates set threshold limit for PD free operation i.e. 20mV.

Red colour pattern indicates PD measurements done when terminal voltage is gradually increased. When the red pattern crosses the threshold limit in upward direction, its corresponding value at x-axis is called as PDIV i.e. partial discharge inception voltage. PDIV value shall be higher than the respective IVIC class to fulfil the requirement of PD free operation.

Considering the typical details from installations and calculating the expected voltage appearing at terminals it is highly recommended to use motors qualified with winding insulation of IVIC class C for reliable operation.

D. REFERENCES

[1] H. Tischmacher, Innomotics GmbH, Technical paper - Bearing wear in electric motors and rotating equipment under the aspect of VSD converter operation

[2] K. Bauer, Innomotics GmbH, Technical paper – Insulation coordination for converters/motors for low voltage machines with round/random wire wound windings

[3] IEC 60034-18-41 (2019-06)