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REDESIGNING THE COIL END INSULATION OF ELECTRICAL MOTOR

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VAASAN AMMATTIKORKEAKOULU
Kone- ja Tuotantotekniikan koulutusohjelma

TIIVISTELMÄ

Tekijä	Joonas Kauppinen
Opinnäytetyön nimi	Redesigning the Coil End Insulation of Electrical Motor
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Ohjaaja	Mika Billing

Tutkimus tehtiin ABB Motors & Generators Vaasan yksikölle. Tutkimus pohjautuu kesällä 2013 tapahtuneeseen koneiden yllättävään hajoamiseen. Tutkimuksessa todettiin eristeiden tarvitsevan uutta suunnittelua.

Tutkimus suoritettiin tutkimalla eristeille vaadittavia ominaisuuksia. Eristeille tehtiin testejä ja parhaista vaihtoehdoista tehtiin prototyyppi, jolloin uusia eristyksiä pystyttiin vertailemaan vanhaan eristykseen.

Tutkimuksissa todettiin, että alkuperäinen eristeryhmä oli aivan liian paksu ja sähköiset ominaisuudet ylittivät vaaditun rajan. Eristeisiin tehtiin optimointia ja materiaalimuutoksia.

Avainsanat eristys, tuotekehitys, sähkömoottori

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ABSTRACT

Author	Joonas Kauppinen
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The thesis was made for ABB Motors & Generators in Vaasa. The thesis is based on a case in June 2013 when a few same type of electric motors suddenly broke down. In the investigations it was noticed that the insulations in the electric motor need to be redesigned.

The thesis was made by searching the old and the new insulations properties. Different tests were conducted to the insulations and prototypes were manufactured of the best ones.

The thesis shows that the old insulations were too thick and the electrical properties were much higher than the limit. The impregnation level insulations was decreased because of multilayer insulation.

Keywords Insulation, product development, electric motor

TABLE OF CONTENTS

TABLE OF FIGURES

Electric motor = Converts electrical energy to mechanical energy

Stator = Electric motors solid part which produces magnet field to rotate rotor

Coil = Copper thread is placed inside of the stator in a way that when electricity is fed to them, they produce magnetic field.

Insulation = Substance which insulate electricity.

Resin = Substance that is used in stators impregnation. Increase the properties of insulation system.

VPI = Vacuum pressure impregnation.

VSD = Variable speed drive. Frequence converter drive motor.(Multi-speed)

NEMA= National Electrical Manufactures Associative

1 INTRODUCTION

The subject of the thesis was redesigning the insulation of VSD motors H-class. The insulation in the electric motor is one of the most important structures in the electric motor. The insulation is the substance that separates phases from each other's. Motors that run in different temperatures have their own insulation classes. The H-class insulation must withstand the temperature of 180 Celsius degrees.

This thesis was made for ABB Motors & Generators Vaasa. The objective of the thesis was to redesign the H-class stators in VSD motors. The object of the redesigning was to create a new insulation group that impregnates better. The redesigning includes the investigation of the old and the new insulations and creating a new insulation group for stator. The thesis also deals with the investigation of resins properties and different ways to impregnate the stator.

The goal of thesis was to increase the impregnation level of the stators. By increasing the impregnation level the lifetime of the motors was also increased.

2 ABB OY, INTRODUCTION

ABB Oy is one of the leading electrical and automation technology companies, founded in 1988. ABB was founded when Swedish Asea and Swiss Brown Bover merged. The ABB name comes directly from the initials of Asea and Brown Bover. ABB has got approximately 150 000 employees in 100 different countries. In Finland ABB has 6600 employees. ABB's major factories in Finland are located in Vaasa and in Helsinki. ABB has also few minor maintenance and product development units all around Finland. /1/

ABB Finland's turnover in 2012 was 2.4 billion euros. According to ABB's president Tauno Heinola, ABB is building the future by investing strongly in the product research and development. In 2012 ABB pronounced spending 184 milion euros on the product development which is 7,4 percent of the turnover. ABB's turnover in total in 2012 was 39,336 billion US dollars which is approximately 28, 66 billion euro's. /2/, /3/

ABB Motors and Generators Vaasa produce electric motors and generators. The Vaasa's unit is specialized in producing explosion safe low voltage motors but also producing other specialized motors.

3 ELECTRIC MOTORS

Electric motors convert electrical energy to mechanical energy. For this conversion the electric motor uses electrical magnetic field. Electricity is fed to a copper coil which produces magnetic field. Inside the motor a rotor is magnetised. Because of the rotors magnetic field the rotor revolves to the same position with stators magnet field. By feeding electricity to differed coils the rotor starts to revolve. If there is need to convert mechanical energy to electrical energy it is also possible. These machines are called generators. Generators work just the opposite than motors. When the magnetised rotor is revolving it inducts electricity to coils by changing the magnetic field. /9/

There are many varieties of electric motors. Electric motors can be built for alternating current or to direct current. Direct current motors are used for example in battery used power tools like electric screwdrivers. Usually alternative current motors are more powerful than direct current motors. Alternative current motors are used in factories for many purposes. /9/

The main components of an electric motor are the stator and the rotor. The electric motor also includes a frame. The structure of the electric motor has been developing since 1740. The first electric motor which contained the stator and rotor was developed in 1832. A picture of an electric motor with components is presented in figure 1.

The stator core is compressed of several electrical plates. Each electrical plate has got slots for coils which are made by using the punch. The stator is wound, insulated and impregnated before the stator is compress fitted inside to the frame.

The core of the rotor is compressed of electrical plates. Also in every electrical plates there is a slot for rotor poles. Rotor pole are manufactured of melted aluminium. To the both end of the poles a short circuit ring is attached. The shaft is attached inside of the rotor to convey the energy to mechanical. At the end of the shaft there is a cooler fan which revolves by the power of the motor and helps the motor to cool down.

The frame is the outer part of the motor. The frame positions every other part to their right positions by using compress fit and bearings. The stator is compress fitted to the frame and rotor lies on frames bearings. The surface of the frame is usually made wing shaped. This form conducts heat out of the motor easier. The connection box is also a part of frame. The electricity is fed through the connection box to the stator. The connection box includes connections for several attachments. Every motor has got a rating plate, which shows the model and other information of the specific motor. The rating plate is also a part of the frame.

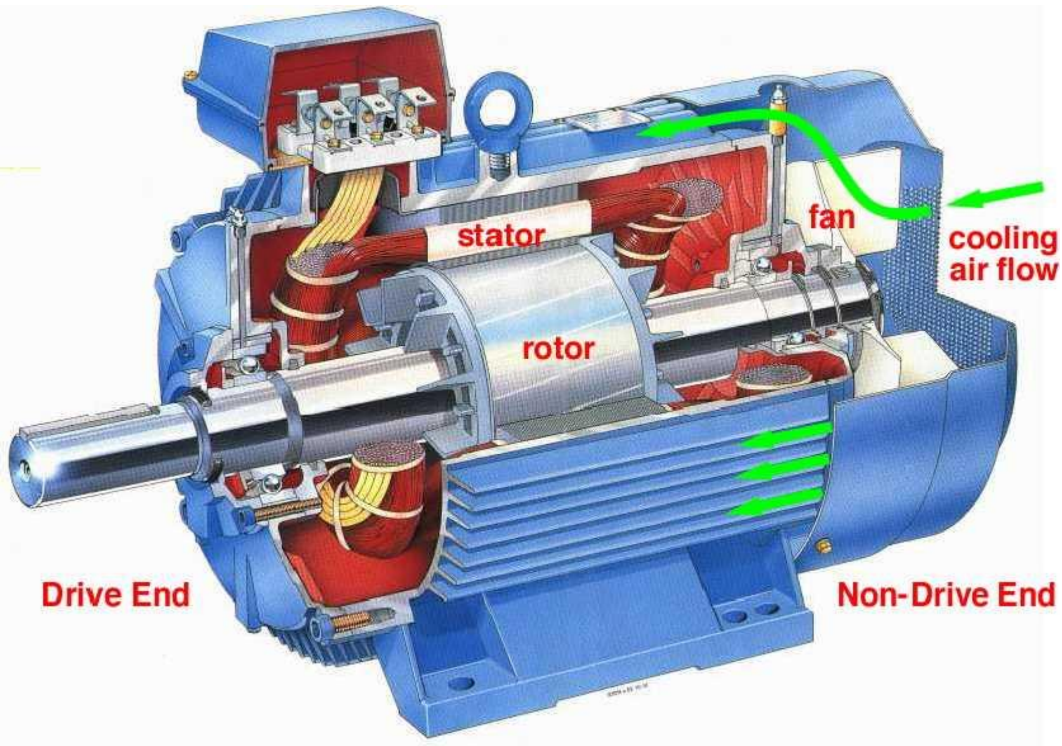


Figure 1. The cross section of the Electric motor

4 STATOR PRODUCTION AND WINDING STYLES

The manufacturing of the stator begins from the stator core. The stator core is piled of electric plates and compressed together. When the plates are compressed, finger plates are attached to the core. The finger plates keep plates tightly compressed. The winding begins, after the stator core is ready, as shown in figure 2.

Figure 2. Stator core ready for winding.

The winding begins with placing the slot insulation. The slot insulation prevents ground contacts and protects copper coils from mechanical stress. After placing the slot insulation copper coils will be added to the slots. The coils are in groups and can be placed in different ways in to the slots. Depending on the winding style, the position of coils changes. While the coils are placed to the slots the ends of coils are shaped at the same time. They must be shaped in the way that the coils cannot touch the rotor, frame or end shield. If the end coils touch the end shield or the frame, it creates a short circuit or ground contact. That is why they have a shape tolerance. The ends of coils must be insulated at least from phase to phase. Different phases cannot touch each other because it will cause short a circuit and burning of the motor. When the coil insulation is placed, the ends of coils are tied with lacing and simultaneously coils are hammered so that the lacing will be tight. This ensures that the insulations will stay in place and copper wires stay close to each other, as shown in figure 3. /8/

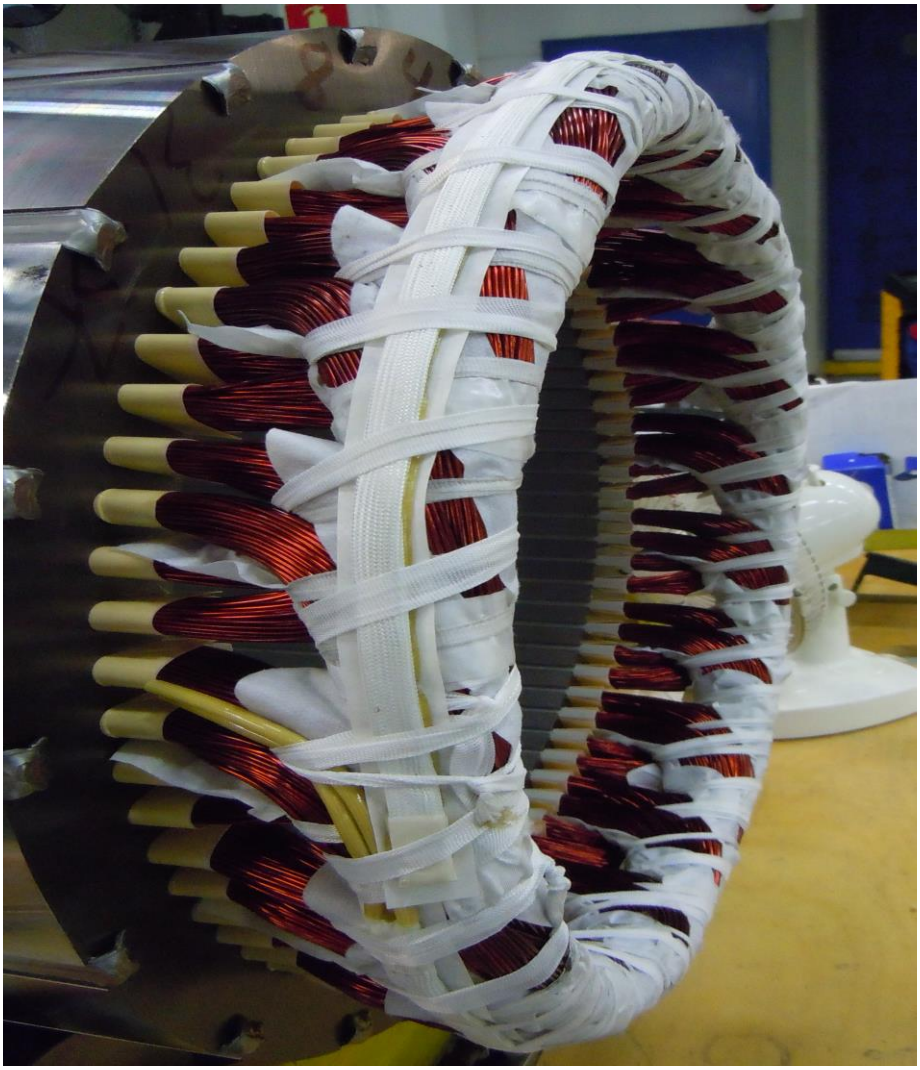


Figure 3. The end coil tied with lacing.

Finally the stator is impregnated with resin. The impregnation depends on the size and the insulation level that is required. It can be trickle, dip or vacuum impregnated, the resin can be polyester or epoxy.

4.1 Overlap Winding

In overlap winding all copper coils run to the same direction. The winding has been made as double level overlap winding, as seen in figure 2. The outer coils go to one direction and the inner coils go to the other. The overlap winding has regular torque because it has regular wounds. Normally the overlap windings are used with a frequency converter. With the frequency converter the frequency that is fed to the motor can be modified. This affects the rotation speed of the rotor and this enables adjusting the revolving of the motor in variable speeds.

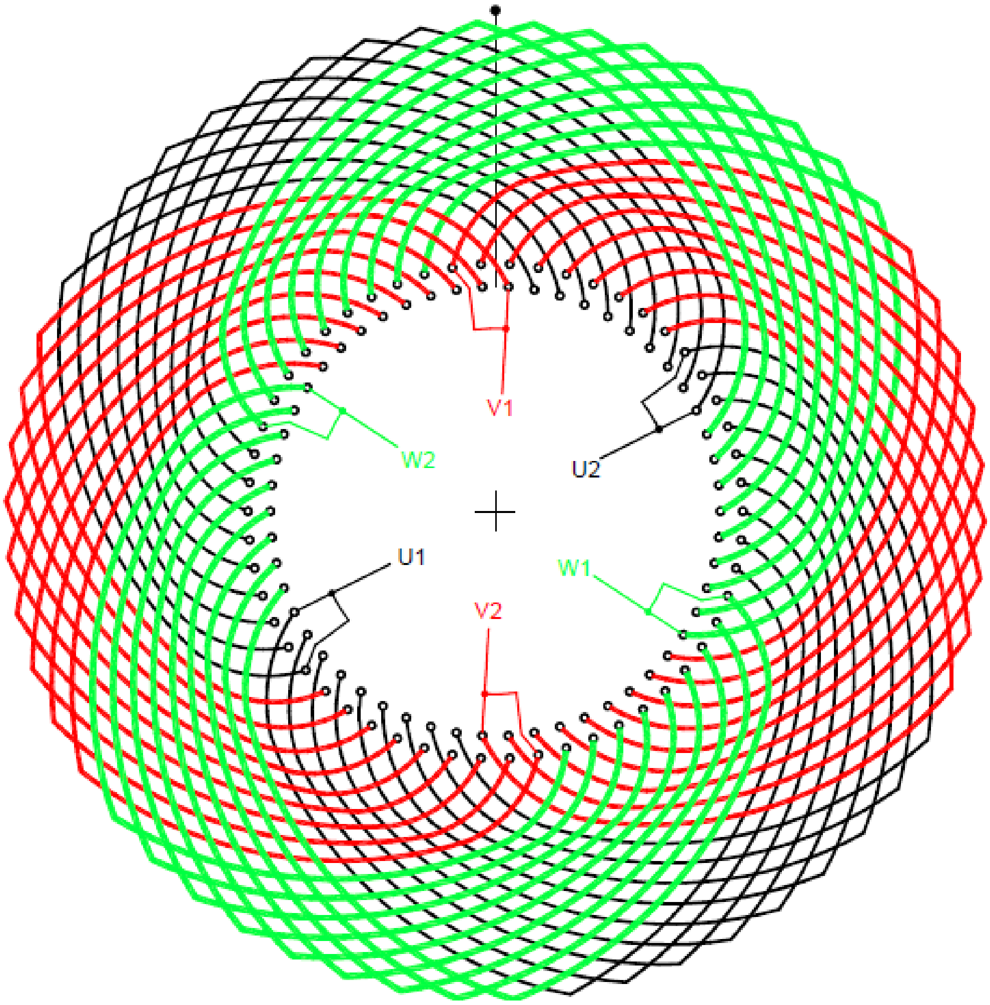


Figure 4. Double label overlap winding.

4.2 Cross Winding

In cross winding the copper coils are placed to go across each other, as shown in figure 3. Cross winding motors do not have as regular torque than overlap winding but cross winding is much easier and faster to manufacture.

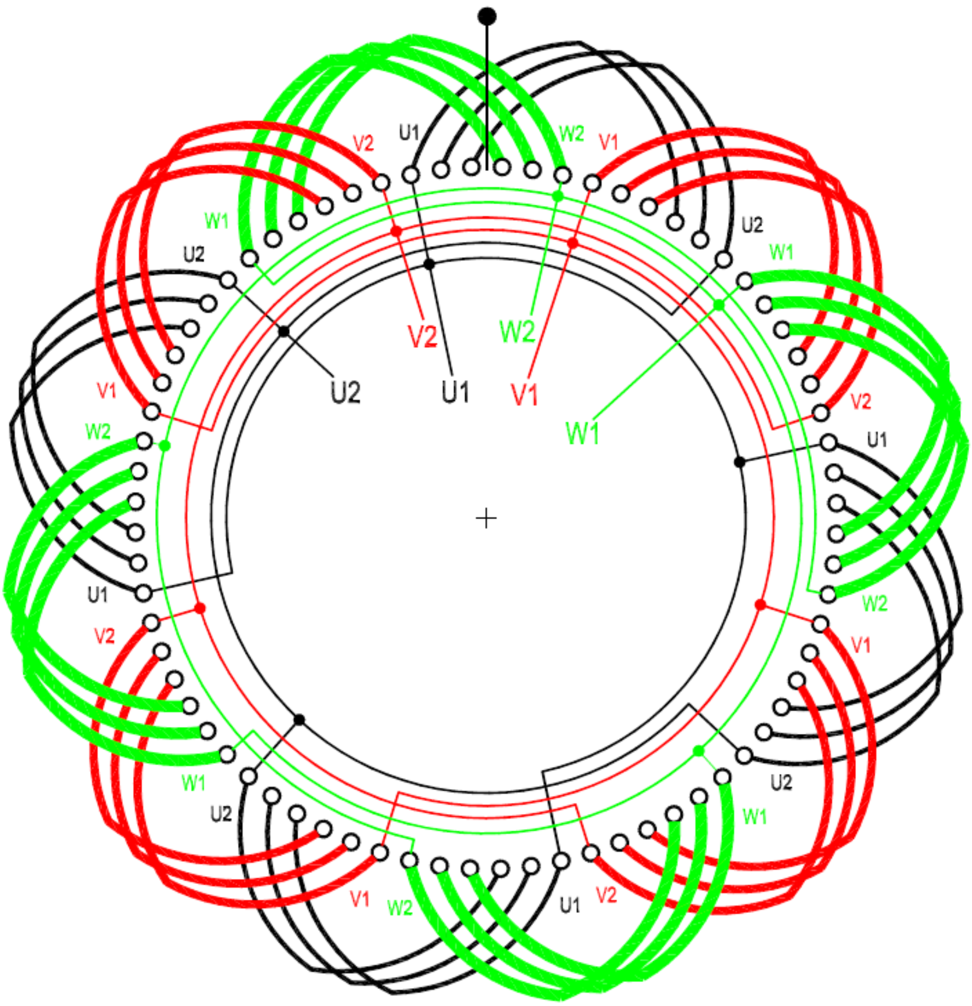


Figure 5. 8-pole cross winding.

4.3 Concentric Winding

The advantage of concentric winding is that the voltage between the phases is lower. This enables using less electric insulation than in other winding styles. The problem in concentric winding is that concentric winding can’t be done to bigger motor sizes. Concentric winding is suitable for 355 and smaller motors. Some of the concentric windings can be wound with machines which makes winding easier and faster.

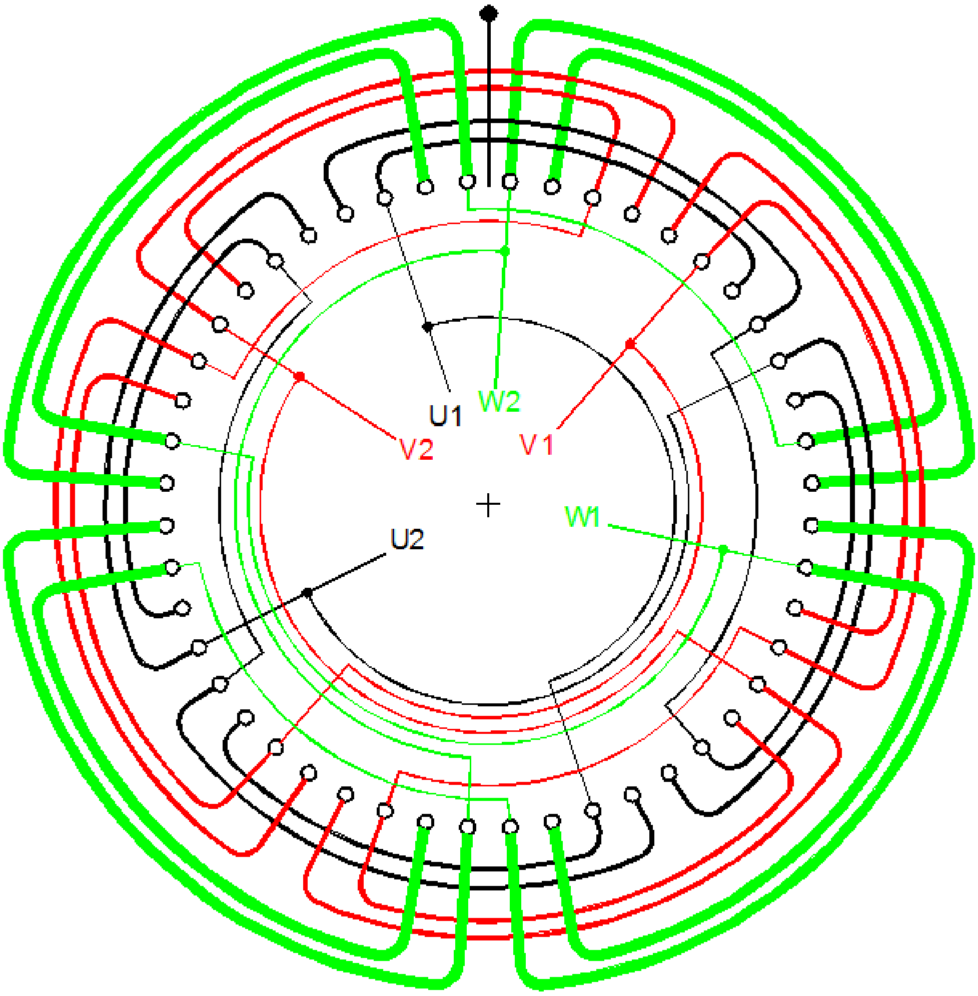


Figure 6. 4-Pole concentric winding.

5 STATOR INSULATION AND TESTING

The purpose of the insulation in electric motor is to insulate electric phases from each other and from the stator core. In the case of an insulation failure the electric motor goes to short circuit which might lead the motor to burn. In the end coils, the insulations are strips which are placed between phases or between the coil groups. To get the insulation to stay in the right place, the stator is impregnated with resin. Electric motors have two different insulation groups, phase insulation and slot insulation. The phase insulations are in end coils and slot insulations are in the slots. /13/

5.1 Required Properties of Insulation

The insulations must withstand several different stresses such as mechanical, high temperatures, temperature changes and electrical stress. The insulations must stand the winding process where it gets twisted and hammered with a rubber hammer. In the final wiring the insulations usually bend tightly which might tear the insulation. The most important property of the insulation is electrical insulation. Insulation must be chosen depending on the motor properties. /10/

Electric motors have different classes for different running temperature. NEMA has defined temperature classes such as B-class, F-class and H-class. The F-class must stand 155 °C and H-class 180 °C. The thermal class consist of the maximum ambient temperature, the rise of permissible temperature and the hotspot margin. ABB uses the F-class insulation when making a B-class motor. This gives longer life to motor insulation and a much higher marginal. The temperature class affects always when choosing insulation for the stator. If temperatures are higher the insulation in the stator must have better properties. Usually when higher temperatures and partial discharge resistance are required, the mica is used in insulation. /4/

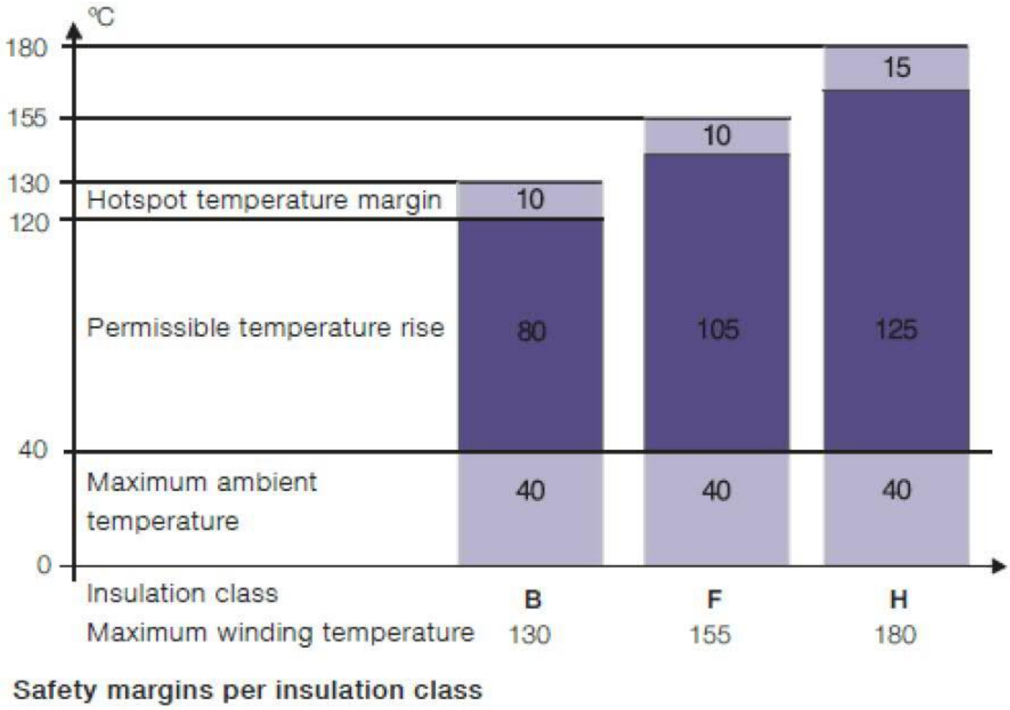


Figure 7. Thermal class figure

The difference in insulation between the VSD-motor and the DOL-motor is that the VSD-motor needs insulation that can stand higher electrical stress. In VSD-motors the fed voltage may change much more than in DOL-motors, because of the frequency converter. For example if in VSD-motors the rated voltage is 500 V, the highest voltage spike may be 1,3 kV. If the insulations breakdown voltage in VSD-motor is not high enough, the motor will go into short circuit. ABB informs that if the rated voltage of the VSD-motors is under 600 V, special insulation is not necessarily needed. In DOL-motors the voltage remains stable and that is why DOL-motors are produced with non-mica materials. /5/

5.2 Insulations Testing

To ensure the quality of the insulations the insulation must be tested. To test the insulation there are many different methods, such as thickness, electrical strength test, grammage measurement, elongation test, loss of mass test and hammer test.

If the insulation is not as thick as it should be, its electrical strength is not as good as is stated. The test is made by using a micrometre. In the test several measurements must be taken in different places around the insulation piece, picture 6. Every insulation has its own tolerance, how thin or thick the insulation can be. /12/

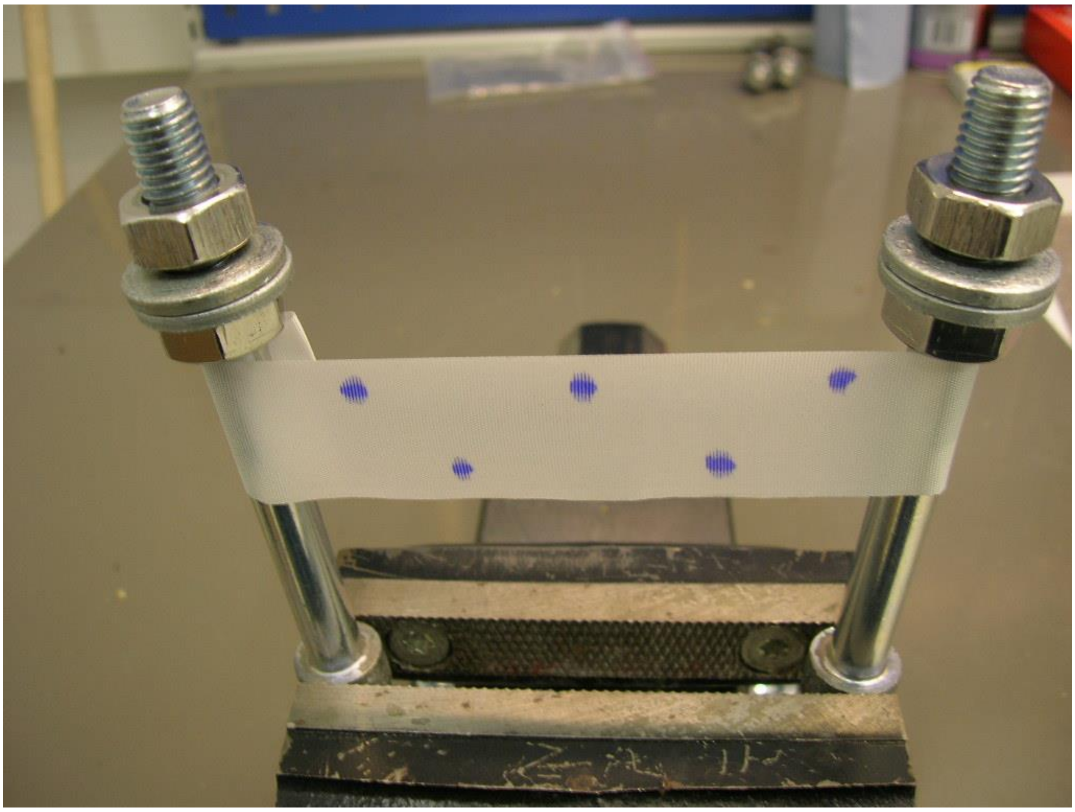
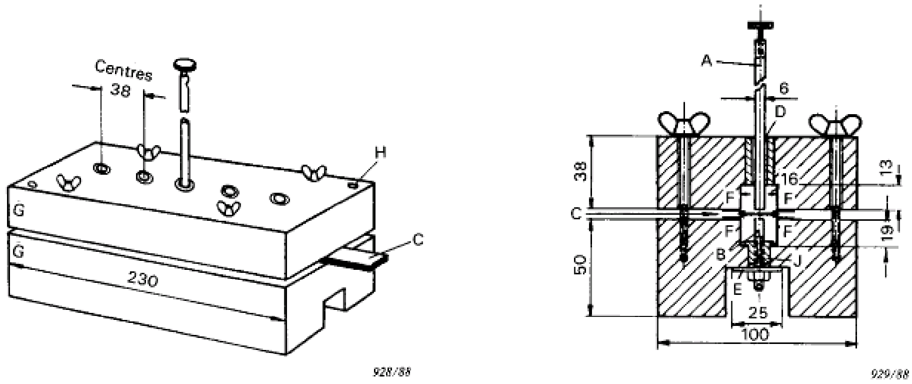


Figure 8. Thickness measurement

In the electrical strength test the insulation is set between electrodes. Electrodes are charged and voltage raised to 500 Volts per second. When the voltage is high enough the insulation will break down and lets the current go through. This information helps to know which insulation has enough electrical strenght for different motor types. Electrical stress test is also made to insulations which are impregnated. When the insulation is impregnated its electrical properties usually get better, but it will be tested to be sure of the breakdown voltage in the manufactured motor. /12/



Dimensions in millimetres

A = upper electrode to be an easy fit in bush D
B = lower electrode
C = specimen under test
D = brass bush with inside diameter just sufficient to clear 6 mm rod
E = brass strip 25 mm wide connecting all lower electrodes
F = pieces of film overlapping edges or specimen
G = blocks of suitable insulating material, for example a paper filled laminate
H = dowel hole
J = brass bushing with internal thread

Figureure 9. Apparatus of electrical strength test

In the grammage test the test pieces are of equal sizes. First the insulations are cut into pieces. Then the insulations are placed to oven in 105 °C for 30 to 60 minutes depending on the size of the test pieces. The test piece is put to oven to decrease the moisture of the test piece. After oven the insulations are weighed and calculated how much insulation weighs per square meter. /12/

In the elongation test the test piece is attached to a clamping device which extends the insulation. The distance between the clamps must be 200 mm. The test continues until the test piece ruptures. The results of the extensions are reported. /12/

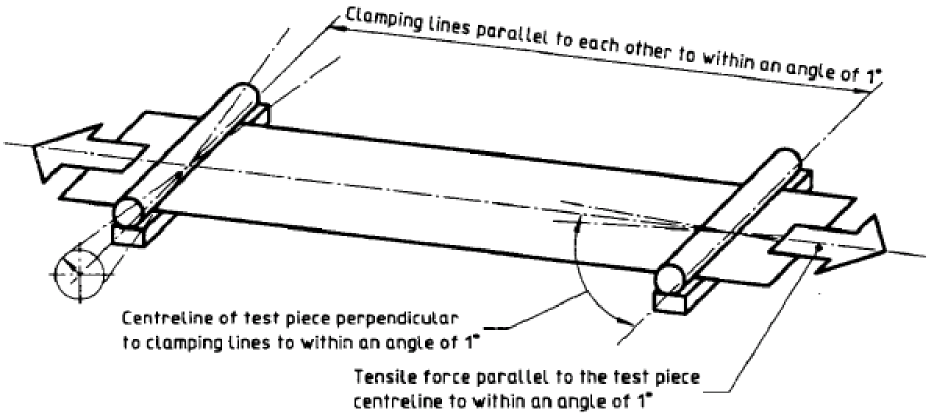


Figure 10. Apparatus of elongation test

In the loss of mass test the preferred size of the piece is 100x25 mm. Test pieces are weighed with a highly sensitive scale which detects the change of mass in 0,2 % units. The test pieces are placed into the oven in different temperatures for a certain duration. The test pieces are in the oven for example in 140 °C for 14 days.

The loss of mass is calculated. /12/

$$\textbf{LOSS OF MASS} = \frac{\textit{INITIAL MASS} - \textit{MASS AFTER AGEING}}{\textit{INITIAL MASS}} \times 100\%$$

One way to test mechanical stress endurance is the hammer test. In the hammer test the insulation is placed in side of the coil and the insulation is turned into a tight corner. After placing the insulation inside of the coil, the coil is beaten with rubber hammer for ten times, as shown in figure 11. After hammering the insulation piece is removed of the coil. The test piece is checked if there are any cracks. The test simulates the mechanical stress in a real winding situation. This test helps to make sure that insulation can stand the winding process. /12/

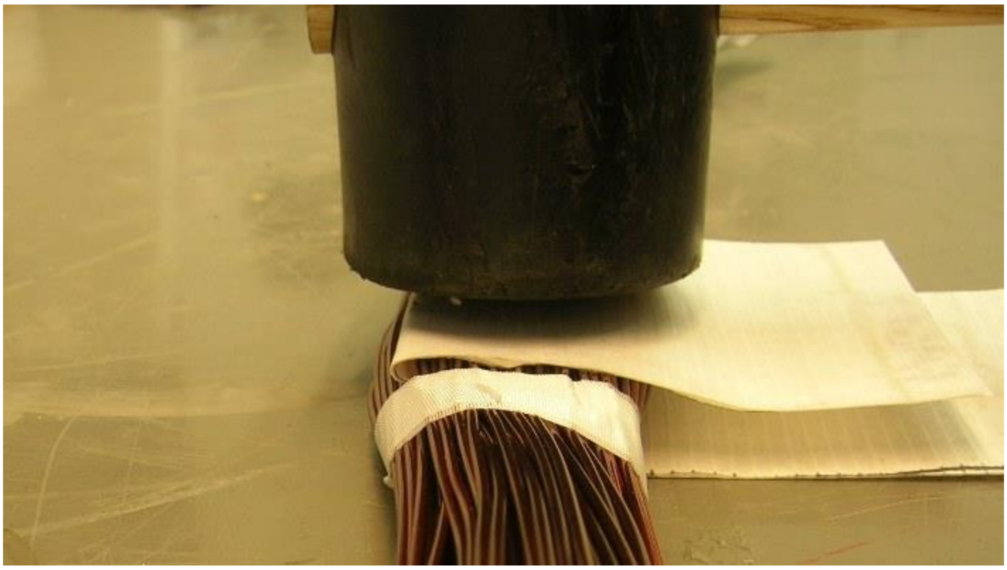


Figure 11. Insulation hammer test.

5.3 Resin

The purpose of the resin in the stator is to fill all air pockets in coils and impregnate the insulation. When the insulation is impregnated with resin, the breakdown voltage strength of the insulation material increases, as shown in Table 1. Resin also act as insulation in coils. If the impregnation fails and air pockets remain in coil, it may lead to a partial discharge and the motor to lose power and length of age. If the impregnation is well made, resin forms a thermal conductor and solid structure which prevents tremble when the motor is running. /11/

Table 1. Average of breakdown voltages

	Unimpregnated, aged in oven for 4 hours in 160 °C				Polyester resin				epoxy resin			
	aver-er-age [kV]	stdev [kV]	stdev [%]	kV/mm	aver-er-age [kV]	stdev [kV]	stdev [%]	kV/mm	aver-er-age [kV]	stdev [kV]	stdev [%]	kV/mm
AOMF	1.3	0.2	15.6 %	11.5	11.6	0.9	7.7 %	44.1	8.8	2.5	27.9 %	31.5
APGNH	4.4	0.3	5.8 %	24.5	5.9	0.1	1.7 %	20.8	4.4	1.0	22.4 %	15.1

Resins can be single or multi-component resins. This means how many different substances are blended before the resin is able to react. If the resin is single-component it does not need any other substance to react. Multi-component resins need one or more substances to start reacting. Viscosity is very important measurement in resins and it may vary in resins. Viscosity is a detector of ageing, mixing ration and reacting. If the resin has started to react and the mixing ratio is right the viscosity is much higher than normally.

Viscosity is the inner friction of substances. Friction is measured with a Din-cup. The Din-cup is a cup that has got a small hole on the bottom. Viscosity can be calculated from the time that resin takes when it runs through the cup. Temperature has a major impact to viscosity. As can be seen in figures 12 and 13, if the temperature is high, the viscosity is low and if the temperature is low, the viscosity is high. To ensure that the resin is good, the results must be compared to result shown in picture. If the time and temperatures result is between maximum and minimum lines it means that the viscosity is correct. /6/

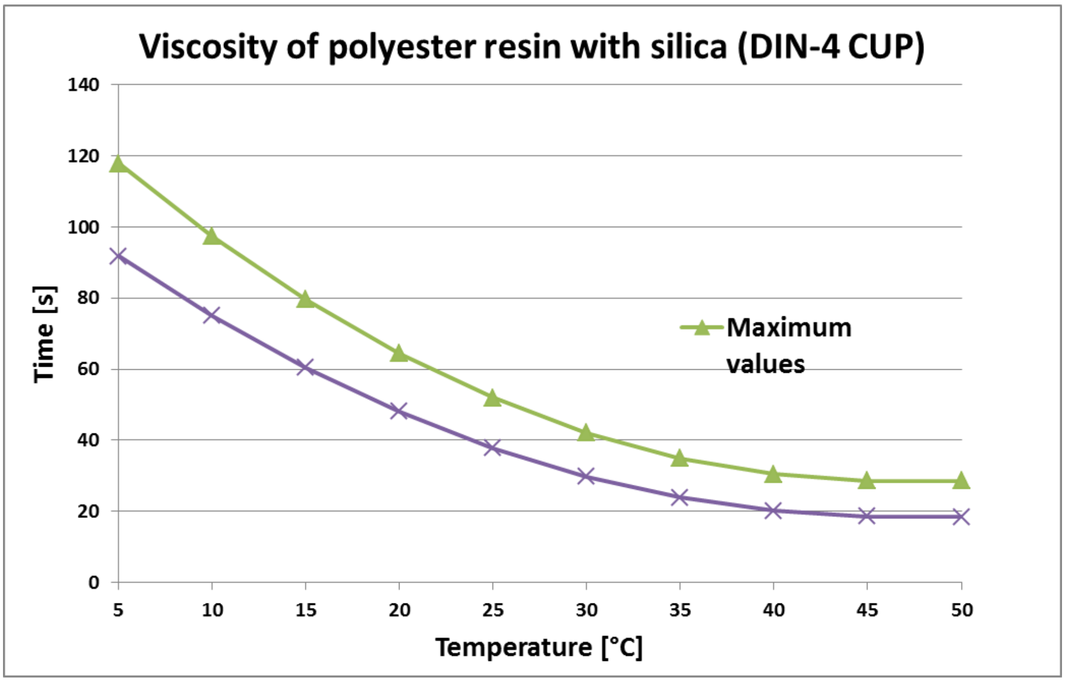


Figure 12. Minimum and maximum values of polyester resin viscosity as a function of a temperature.

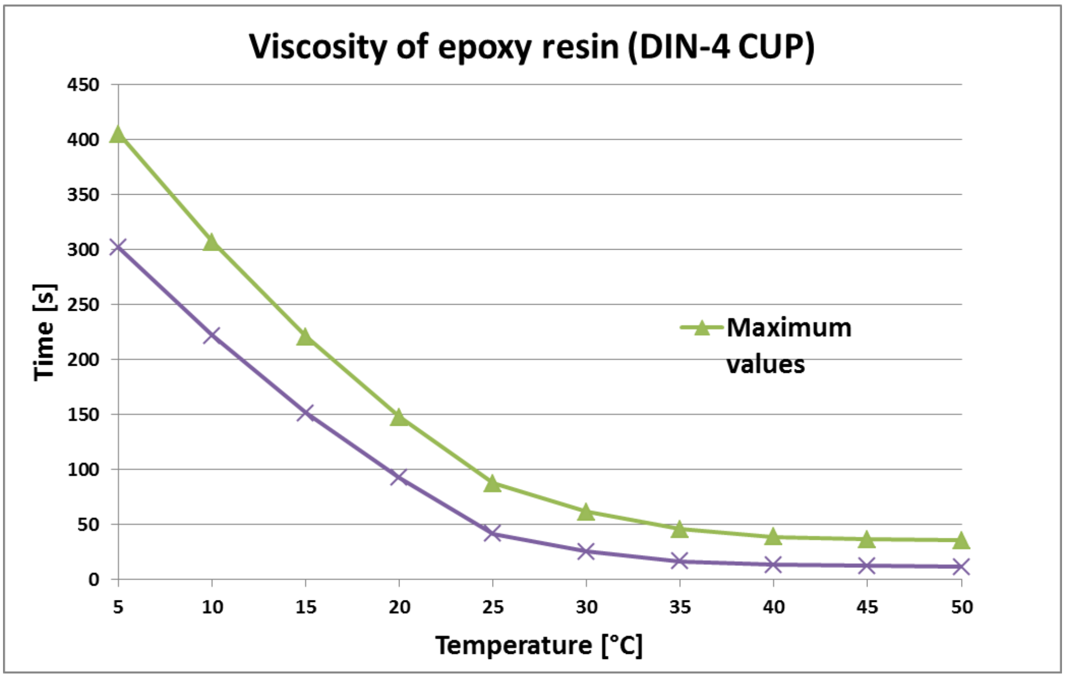


Figure 13. Minimum and maximum values of epoxy resin viscosity as a function of a temperature.

Resin components can be harmful to human health. This is the main reason why protection gear must be worn while handling resin. When the resin has hardened it is not so dangerous to human or nature anymore. /6/

Stators can be impregnated with a few different techniques. ABB Vaasa factory uses vacuum pressure impregnation (VPI) and trickle impregnation. The trickle impregnation is used at ABB for bigger stator sizes and vacuum impregnation for smaller sizes. /6/

At the moment ABB uses three different resin types. Double-componential polyester resin and double-componential epoxy resin are used in trickle impregnation. In the vacuum impregnation single componential polyester resin is used. /6/

In trickle impregnation stators coils are heated to the starting temperature which decreases the viscosity of the resin. This ensures that the resin spreads more easily to everywhere in the stator. When the resin is all over coils and inside of the slots, resin gelling begins. When the temperature is raised to around 95-125° C, the resin starts to react and it starts to turn from liquid to solid. The gelling temperature depends on the resin. Usually polyester resin starts to react at about 90 °C and epoxy at about 125 °C. At the end the resin is hardened in a higher temperature. Similar to gelling temperatures also hardening temperatures depend on the resin. Usually the temperatures are around 135-160 °C. Finally the stator is put into the oven for a few hours in 160 °C. The impregnation phases can be seen in figure 14. /6/

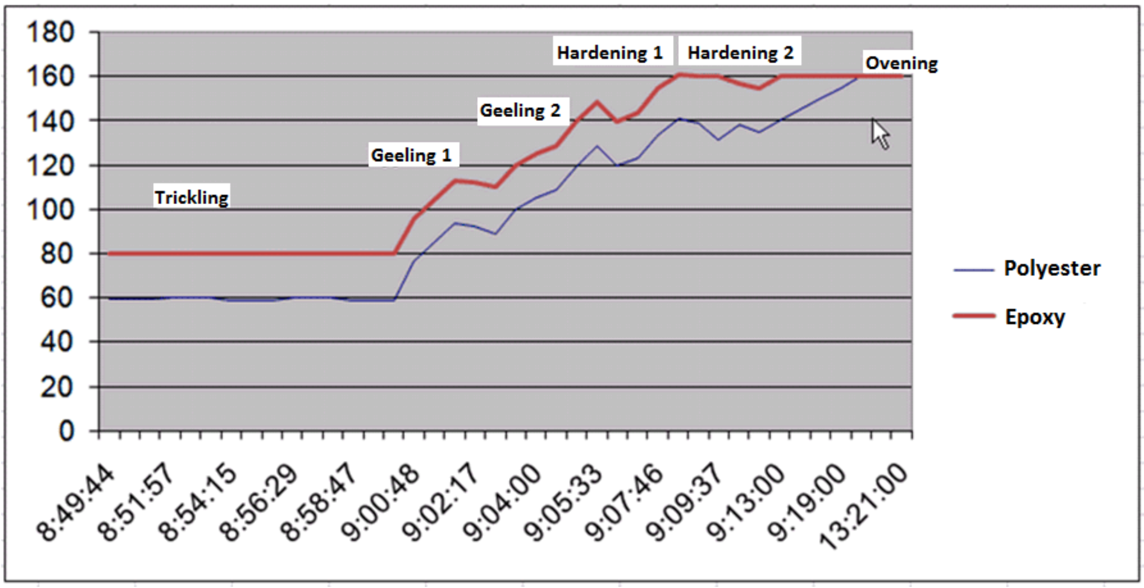


Figure 14. Table of trickle impregnations temperature phases

In the vacuum impregnation the stator is placed into a tank. When the stator is in the tank, a vacuum is created into the tank. This way there cannot remain any air pockets inside the stator. After the tank is totally vacuumed the resin is released and it runs all over the stator including inside the stator. If the vacuum is not properly maid, air pocket remains inside of the stator and the resin cannot invade properly. /7/

According to ABB's precept it would be good if resin - copper ratio is 9 %. To ensure this, the stator is weighed before the impregnation and after the impregnation. The start weight and the end weights are fed into the system, which registers the weights, the specific stator and the model. The system tells how much resin remained inside the stator. The measurement tool can be seen in Figure 15. In the long run it is good to see how impregnation quality develop has gone. If the resin to copper ratio starts to drop, it can be investigated. Without the system no one knows if there is a problem. Now ABB can also tell the client how much resin their motor contains. /6/

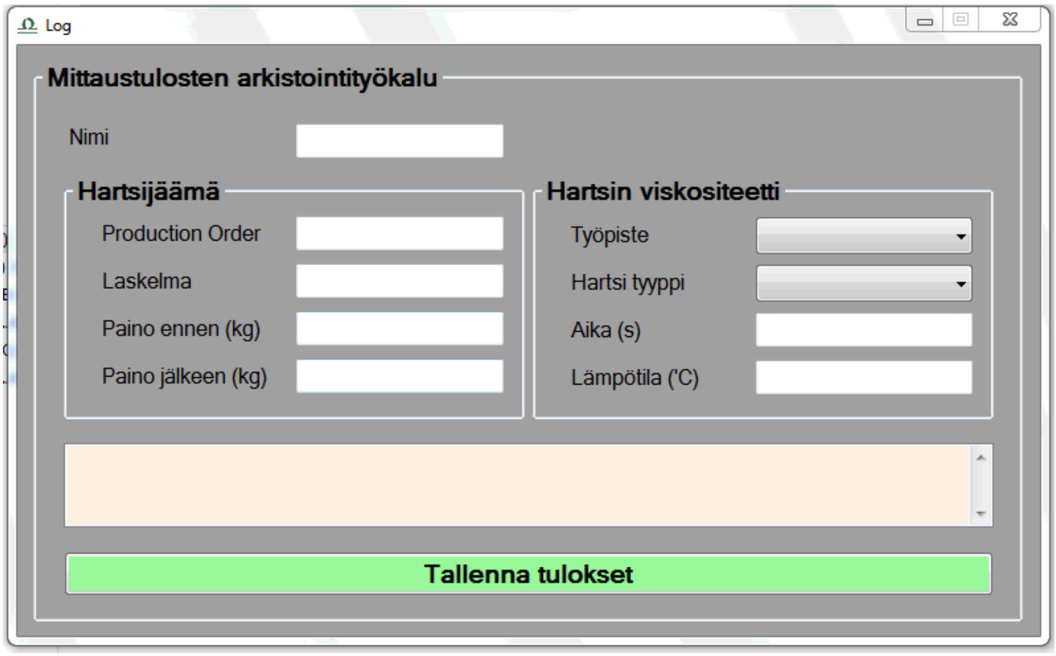


Figure 15. Tool for archiving measurement result

Polyester resin is mainly used in the vacuum impregnation because it has got low viscosity without heating. This helps the resin to penetrate inside of coils and into the slots. Polyester resin in the vacuum impregnation is mainly single-componential resin. Polyester resin is also used in the trickle impregnation in single- and multi-componential.

The viscosity of epoxy resins is a bit higher than that of polyester resin. After heating epoxy resin its viscosity turns very low and the resin gets very liquid. That is why epoxy needs a high temperature to jellify. When epoxy resin is hardened, it withstands high temperatures easily. Impregnated stator shown in figure 16.

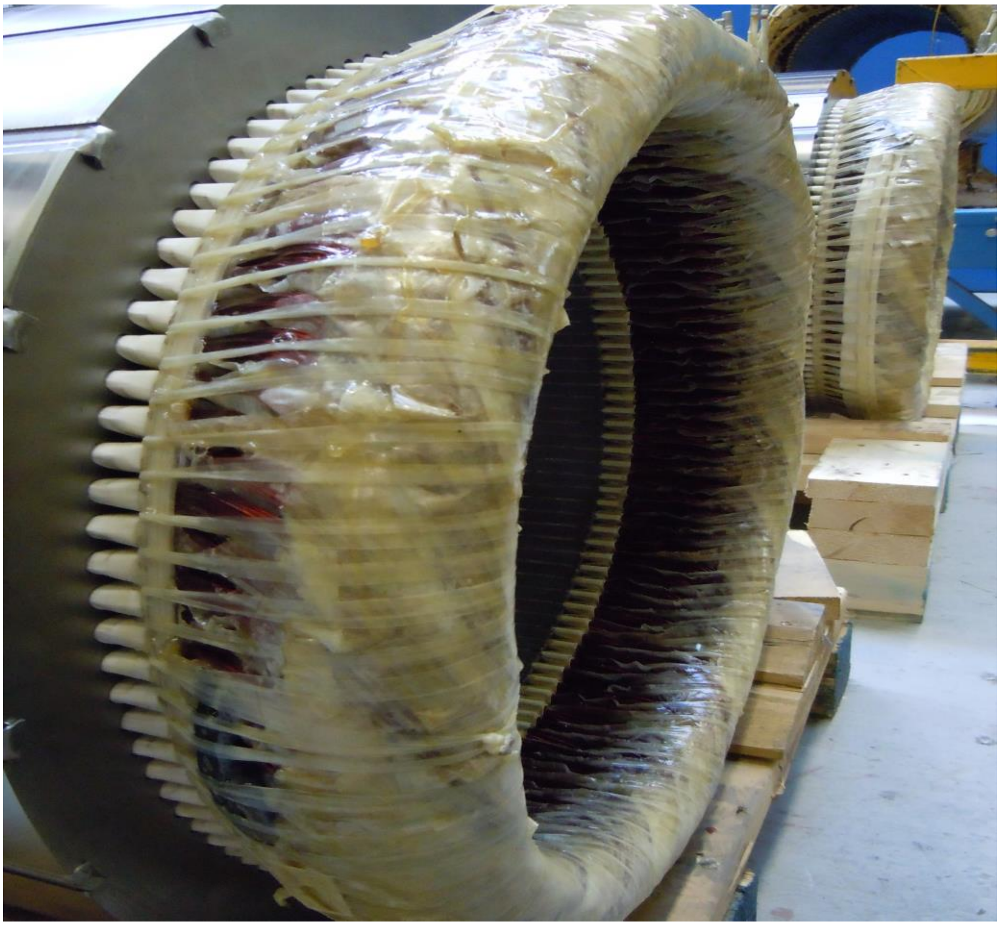


Figure 16. Impregnated stator.

6 PROBLEMS

Main problem is that the stators have too much insulation. It leads to that resin cannot spread all over the stator coils, which means that air pockets remain in coils, which might result in partial discharge. One target stator has got the H-class VSD structure and in the end coils two different insulation groups are used. Coils are insulated with three insulation stripes which are PET-fleece (AOMF 0.15), glass-mica laminate (APGNH 0.18) and PET-fleece (AOMF 0.15). The phases are insulated with four insulation stripes which are PET-fleece (AOMF 0.15), glass-mica laminate (APGNH 0.18), mica-insulation (APGNH 0.18), PET-fleece (AOMF 0.15). APGNH contains mica in silicone which has got great short circuit resistance. The PET-fleece is papery insulation that protects mica-insulation from mechanical stress and impregnates with resin extremely well.

At the moment the target stator is impregnated with double-componential epoxy resin. The impregnation is performed in accordance with ABB instruction Fimot 0249. After the impregnation the stator is put into oven in 160 °C for two hours.

As an example ABB produced a stator which was a H class VSD structure motor. The stator did not have resin enough to fill all the air pockets and resin did not penetrate all over coils, as can be seen in figure 13. The stator had enough insulation but not enough resin. Several dry spots were found from the stators insulation. These dry spots are a bad sign of the quality of the impregnations.

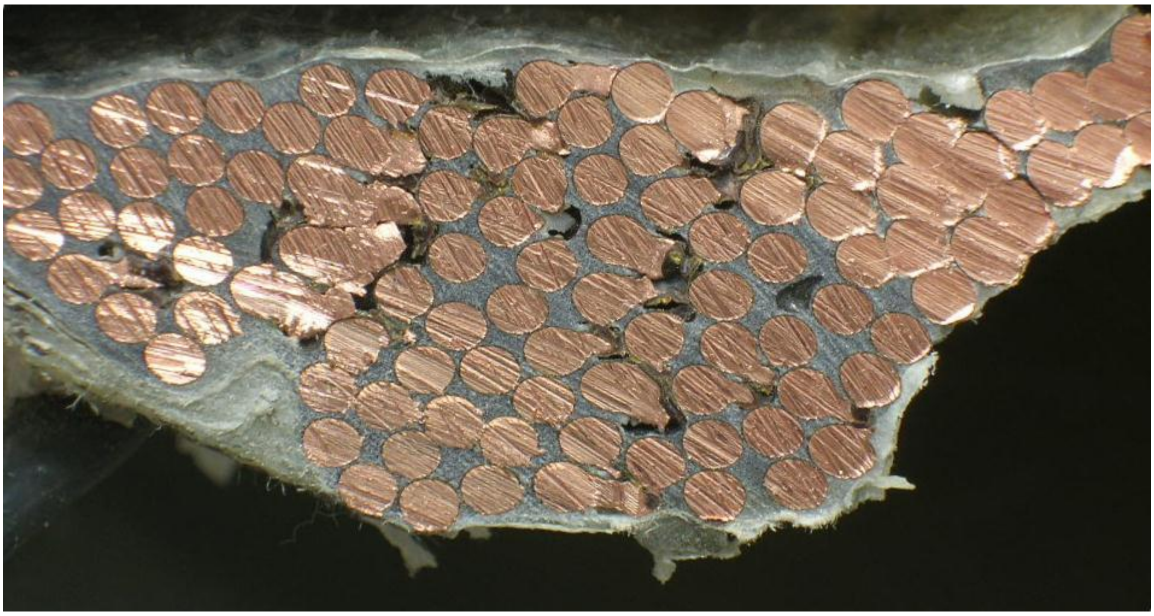


Figure 17. Air pockets in end coil.

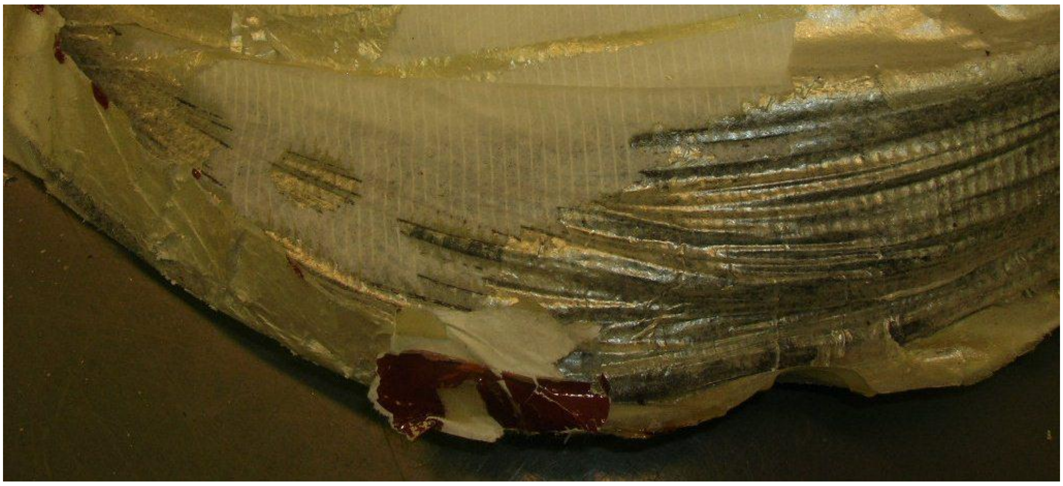


Figure 18. Dry spot in coil

Dry spots are seen as light areas in the insulations which can be seen in figure 17. The insulation on top was removed to see how coils were impregnated as can be seen in figure 18. The result was extremely bad, copper wires were loose from each other because there was not any resin to bind the copper wires together. In these cases copper wires were exposed to tremble which can cause in the long run copper wires abrasion and it causes partial-discharges or severance of the copper wires.

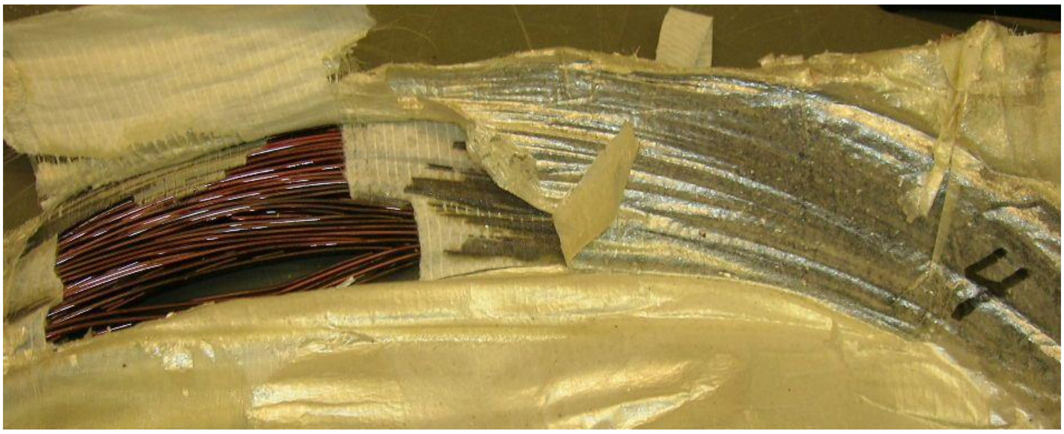


Figure 19. Dry spot after removing the insulation

The main reason for the motors failure was the phase insulation in slot. The insulation group were NKN2525 and two APGNH, as can be seen in figure 20.

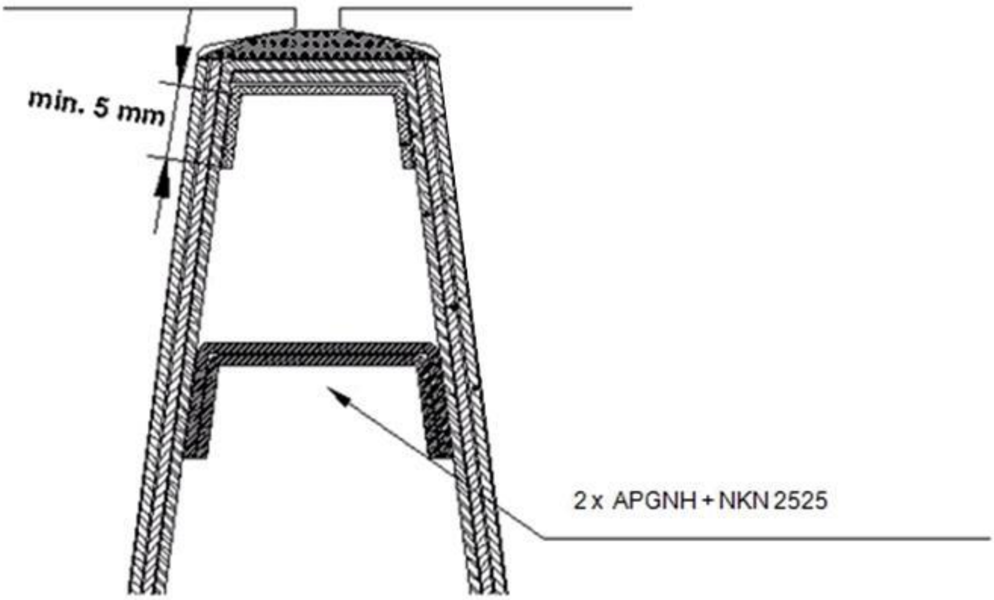


Figure 20. The correct phase insulation in slot.

In large motors the phase insulation in slot is very long and it easily turns away from the middle of the phases, where it should be, as shown in figure 21. The flabbiness of the APGNH is the main reason why insulation was not in the correct position. When watching the phase insulation in slot from the end coil, it seems to be in the correct position, but in the middle of slot the insulation might not be in the correct position. When the phase insulation in slot was not between the phases the motor was in short circuit which resulted the motor to burn, figure 21. In the picture it can be seen how the phase insulation turns away from the middle of the phases.

Figure 21. Slot insulation failure.

7 INVESTIGATING SOLUTIONS

The three biggest insulation manufacturers that produce insulation for ABB were investigated for new insulation solution. At the beginning all the required properties were listed with the help of ABB's database and the insulation team so that requires were easy to recognise. First thing required from the insulation group was that it must contain mica bonded with silicone and it also must contain some kind of insulation that increases the mechanical strength of the mica insulation. Electrical breakdown must withstand over 10 kV. In the insulation group the F-class insulation can be used if the insulation is used with the H-class insulation.

From every of the three biggest insulation manufacturers data sheets were searched that meets all the requirements. When searching for the optimal insulation for the stator, only few were found. Most of the insulations were good for slot insulation. Sample pieces of insulation were ordered for tests.

The combinations of insulations were made, with help of the ABB's insulation team. For replacing the old insulation, a few new insulation groups were designed, as can be seen below, in table 3 and table 4. In the tables the differences of the new and the old insulations are compared. Every insulator has own task when insulating the stator. Some insulation protects motor from partial discharge and others from breakdown. Mica gives the content to the insulations, which protect the motor from a partial discharge. Thickness has also an impact on the winding of the motor. If the insulations are thick there will not be so much space for coils. If the slot is tight, placing the coil is much more difficult

Table 2. Old insulation in VSD, H-class motor

	Current insulations (temperature class)	thickness mm	Mica content g/m^2
Slot insulation	NKN 2525 (H), Nomex-Kapton-Nomex	0,25	
	APGNS (F), Glass cloth-mica laminate bonded with resin	0,18	120
	APGUH (H), Glass cloth-mica laminate bonded with silicone-glass cloth	0,25	400
	Total	**0,68**	**520**
Slot phase insulation	APGNH (H), Glass cloth-mica laminate bonded with silicone	0,18	120
	APGNH (H), Glass cloth-mica laminate bonded with silicone	0,18	120
	NKN 2525 (H), Nomex-Kapton-Nomex	0,25	
	Total	**0,61**	**240**
Phase insulaton in end coil	AOMF (F), Polyester paper with reinforcement with threads	0,15	
	APGNH (H), Glass cloth-mica laminate bonded with silicone	0,18	120
	APGNH (H), Glass cloth-mica laminate bonded with silicone	0,18	120
	AOMF (F), Polyester paper with reinforcement with threads	0,15	
	Total	**0,66**	**240**
Coil group insulation	AOMF (F), Polyester paper with reinforcement with threads	0,15	
	APGNH (H), Glass cloth-mica laminate bonded with silicone	0,18	120
	AOMF (F), Polyester paper with reinforcement with threads	0,15	
	Total	**0,48**	**120**

The old insulation group contained a few insulations that were over rated when compared to the insulation level that is needed. Some of the insulations are wanted to get rid of, because they are very expensive and sometimes hard to get, for example APGUH. In the old insulation group were used several different insulations. When using same insulation in many places, the storage of the insulations is easier to manage.

Table 3. New insulation (solution 1).

	New insulation (temperature class)	thickness mm	Mica content g/m^2
Slot insulation	NKN 2525 (H), Nomex-Kapton-Nomex APGNF (F), Class Cloth-mica laminate-polyester pa-per	0,25 0,2	 160
	Total	**0,45**	**160**
Slot phase insulation	NKN 2525 (H), Nomex-Kapton-Nomex APGNF (F), Class Cloth-mica laminate-polyester pa-per	0,25 0,2	 160
	Total	**0,45**	**160**
Phase insulaton in end coil	APGNH (H), Glass cloth-mica laminate bonded with silicone AOMF (F), Polyester paper with reinforcement with threads	0,18 0,15	120
	Total	0,32	**120**
Coil group insulation	APGNH (H), Glass cloth-mica laminate bonded with silicone AOMF (F), Polyester paper with reinforcement with threads	0,18 0,15	120
	Total	**0,32**	**120**

In the solution 1 were used NKN2525, which has high breakdown voltage and APGNF which contained mica, which protects motor from partial discharge. The properties of combination NKN2525 and APGNF are so good, that those can be used in both the slot and the slots phase insulation, as can be seen in table 3. The phase insulation is lightened. AOMF can withstand the breakdown voltage and one APGNH is enough in phase insulation in end coil.

Table 4. New insulation in VSD, H-class motor (solution 2).

	New insulation (temperature class)	thickness mm	Mica content g/m^2
Slot insulation	NKN 2525 (H), Nomex-Kapton-Nomex	0,25	
	NMIN 3209 (H), Nomex-mica bonded with epoxy resin-nomex	0,24	120
	Total	**0,49**	**120**
Slot phase insulation	NKN 2525 (H), Nomex-Kapton-Nomex	0,25	
	NMIN 3209 (H), Nomex-mica bonded with epoxy resin-nomex	0,24	120
	Total	**0,49**	**120**
Phase insulaton in end coil	APGNH (H), Glass cloth-mica laminate bonded with silicone	0,18	120
	AOMF (F), Polyester paper with reinforcement with threads	0,15	
	Total	**0,33**	**120**
Coil group insulation	APGNH (H), Glass cloth-mica laminate bonded with silicone	0,18	120
	AOMF (F), Polyester paper with reinforcement with threads	0,15	
	Total	**0,33**	**120**

Insulation group 2 is almost the same than insulation group 1. Only difference is that instead of using APGNF in the slot, NMIN 3209 replaced it. NMIN 3209 is also very good insulation. NMIN contains mica and it also has high breakdown voltage. NKN2525 is used mainly to protect NMIN from the stators frame.

Table 5.New insulation in VSD, H-class motor (solution 3).

	New insulation (temperature class)	thickness mm	Mica content g/m^2
Slot insulation	NKN 2525 (H), Nomex-Kapton-Nomex	0,25	
	APGNF (F), Class Cloth-mica laminate-polyester paper	0,2	160
	Total	**0,45**	**160**
Slot phase insulation	NKN 2525 (H), Nomex-Kapton-Nomex	0,25	
	APGNF (F), Class Cloth-mica laminate-polyester paper	0,2	160
	Total	**0,45**	**160**
Phase insulaton in end coil	APGNH (H), Glass cloth-mica laminate bonded with silicone	0,18	120
	AOMF (F), Polyester paper with reinforcement with threads	0,15	
	Total	**0,33**	**120**
Coil group insulation	AOMF (F), Polyester paper with reinforcement with threads	0,15	
	Total	**0,15**	

Insulation group 3 is also almost the same than group 1 but in the coil group insulation APGNH is removed. APGNH were removed because in the thermal class F is used only one AOMF between coil groups. AOMF is Thermal class F but when it is impregnated with H-class resin AOMF can with stand the H-class thermal stress.

Table 6. New insulation in VSD, H-class motor (solution 4).

	New insulation (temperature class)	thickness mm	Mica content g/m^2
Slot insulation	NKN 2525 (H), Nomex-Kapton-Nomex	0,25	
	NMIN 3209 (H), Nomex-mica bonded with epoxy resin-nomex	0,24	120
	Total	**0,49**	**120**
Slot phase insulation	NKN 2525 (H), Nomex-Kapton-Nomex	0,25	
	NMIN 3209 (H), Nomex-mica bonded with epoxy resin-nomex	0,24	120
	Total	**0,49**	**120**
Phase insulaton in end coil	APGNH (H), Glass cloth-mica laminate bonded with silicone	0,18	120
	AOMF (F), Polyester paper with reinforcement with threads	0,15	
	Total	0,33	**120**
Coil group insulation	AOMF (F), Polyester paper with reinforcement with threads	0,15	
	Total	**0,15**	

Insulation group 4 is almost the same than insulation group 2. Same as in insulation group 3 the APGNH is removed from the coil group insulation.

All insulation groups were looked over in a meeting with insulation team and production chiefs. Two new insulation groups were designed in meeting. The new groups are combinations of the four first ones.

Table 7. New insulation in VSD, H-class motor (solution 5).

	Current insulations (temperature class)	thickness mm	Mica content g/m^2
Slot insulation	NMiN 3209 (Nomex-mica laminate-nomex)	0,25	120
	APGNF (Polyester fleece-mica laminate-polyester fleece)	0,2	160
	Total	**0,45**	**280**
Slot phase insulation	NMiN 3209 (Nomex-mica laminate-nomex)	0,25	120
	APGNF (Polyester fleece-mica laminate-polyester fleece)	0,2	160
	Total	**0,45**	**280**
Phase insulation in end coil	AOMF (F), Polyester paper with reinforcement with threads	0,15	
	APGNH (H), Glass cloth-mica laminate bonded with silicone	0,18	120
	Total	**0,33**	**120**
Coil group insulation	AOMF (F), Polyester paper with reinforcement with threads	0,15	
	Total	**0,15**	

The group 5 consists of same coil group and phase insulation in end coil than in groups 3 and 4. The changes are made in slot insulations. The NKN2525 is replaced with APGNF which is much cheaper than NKN2525. The NKN2525 did not consist Mica but the APGNF does consist Mica which increase the withstand of partial discharge.

Table 8. New insulation in VSD, H-class motor (solution 6).

	Current insulations (temperature class)	thickness mm	Mica content g/m^2
Slot insulation	NMiN 3209 (Nomex-mica laminate-nomex) NMN (Nomex-polyester film-nomex)	0,25 0,22	120
	Total	**0,47**	**120**
Slot phase insulati-on	NMiN 3209 (Nomex-mica laminate-nomex) NMN (Nomex-polyester film-nomex)	0,25 0,22	120
	Total	**0,47**	**120**
Phase insulaton in end coil	APGNW (Class cloth-mica laminate-polyester paper)	0,18	160
	Total	**0,18**	**160**
Coil group insulati-on	AOMF (F), Polyester paper with reinforcement with threads	0,15	
	Total	**0,15**	

A few new insulations are added to the list in group 6 insulation. The NMN is very cheap and it has high break down voltage withstand property. APGNW is the also a new insulation in the list. APGNW has got Mica and withstand to break-down voltage which is required from phase insulation in end coil.

The first combination of insulation in end coil was AOMF+APGNH. These mate-rials were already in use in ABB, in different combinations. The first insulation group to be tested were almost the same as the end coil phase insulation before. The only change made was that other AOMF and APGNH were removed. The first test was the hammer test, because of the mechanical weakness of the glass-mica laminate. The hammer test was made both with and without the second AOMF.

Figture 22. Insulation group AOMF+APGNH+AOMF

When using the AOMF on the both sides, the mechanical strength is very good, as shows above figure 19. Hammer test was made to five insulation pieces and all of them were acceptable. No ruptures were found. This combination is the present H-class insulation in VSD motors in the coil group insulation.

Figure 23. Insulation group AOMF+APGNH after hammer test

With AOMF+APGNH insulation combinations success in tests were varied. Two tests of five did not show any kind of rupture or crack in the structure, but three test pieces were partially cracked. The cracks and ruptures were from1mm to 6mm in size, as above in figure 20. In a closer look the ruptures stopped always into filament of the AOMF. This means that if the insulation pieces are large enough they will not rupture in the way that phases can contact. the insulation filaments must be placed normally to coils. Better solutions can be achieved if the APGNH has a glass cloth on both sides. This increases the mechanical strength of the APGNH.

As for their electrical properties AOMF and APGNH are excellent for the H-class VSD motors. AOMF can withstand a 8.8 kV breakdown voltage when impregnated with epoxy resin and APGNH withstands the partial discharge. These properties were already tested.

The second insulation that need for test is APGNW. Only information that is not known is how it withstands mechanical stress. In the hammer test the APGNW had few ruptures as can be seen in figure 21.

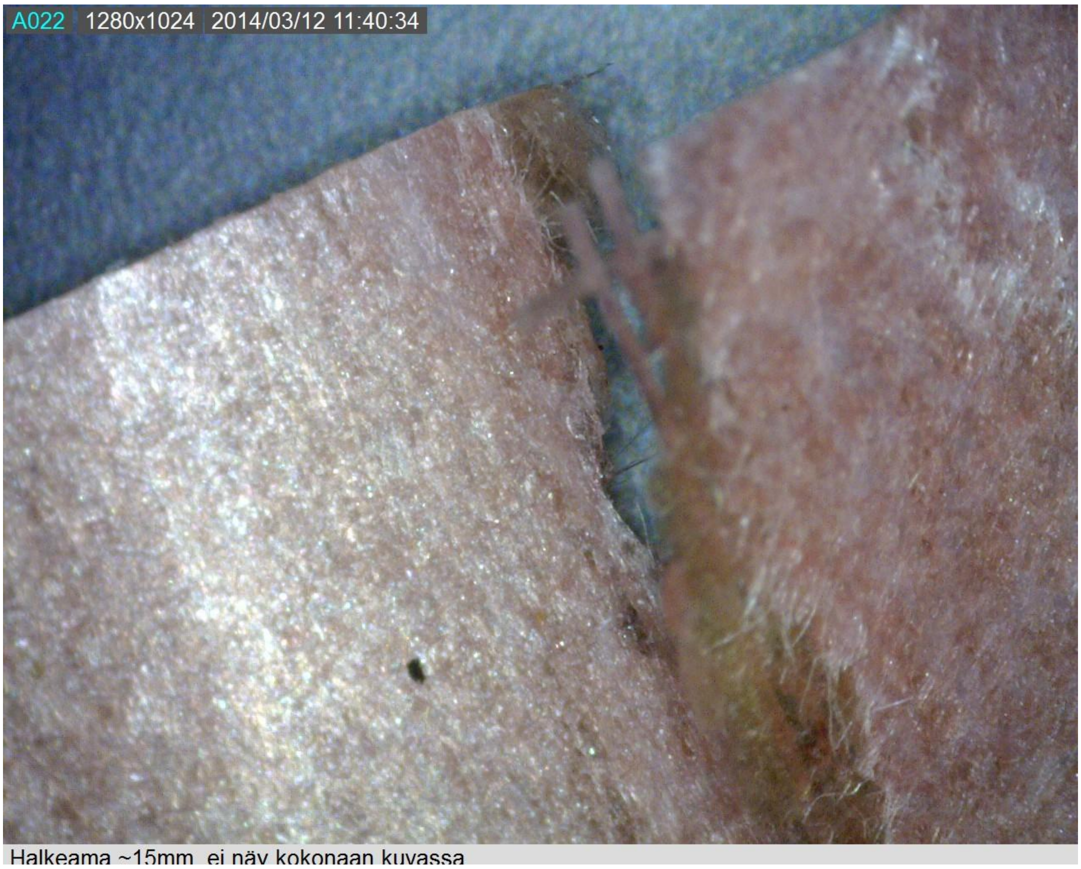


Figure 24. Hammer test result of APGNW

Because of the results of the hammer tests, test winding was made to 450 size stator. In this way the real mechanical strength of the insulation can be measured. The stator was insulated with three insulations. Every third part of the stator was insulated with the old and the two new insulation group, group 5 and 6. The stator was winded normally and after that the stator was disassembled in the way that the insulation could be investigated. The results showed that the old insulation group worked well. The shapes of the slot insulations were good and in the phase insulations did not had any ruptures. The first new insulation group had problems with the slot insulation. The Insulation (APGNF+NMiN) ruptured from the end to the frame, as shown in figure 25. This showed that this insulation in the slot does not have enough mechanical strength. One of the main doubt was the phase insulation in end coil (APGNH+AOMF) which had problems in hammer test. Test winding showed that the phase insulation did not have any problems with the mechanical strength. The second insulation group had problems with the phase insulation. The phase insulation (APGNW) started to rupture and to delaminate in winding, as shown in figure 26.

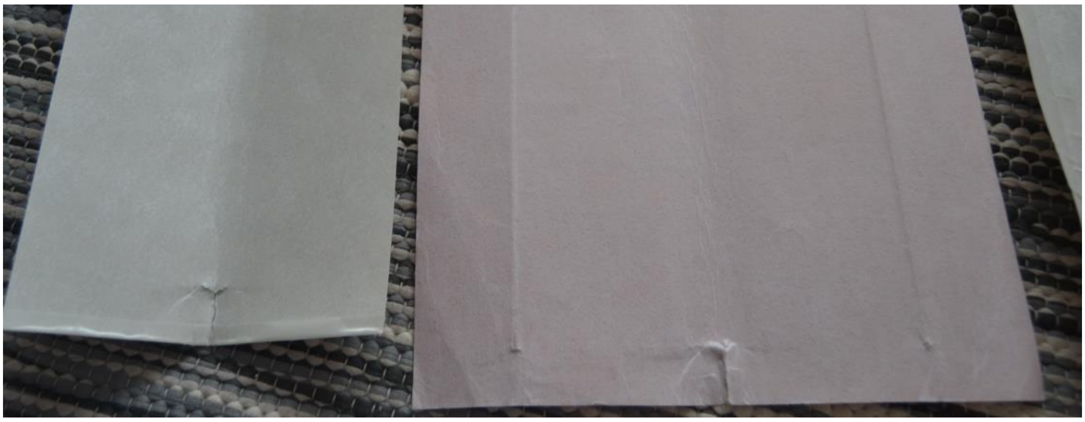


Figure 25. Rupture in NMiN+APGNF

Figure 26. Rupture in APGNW

No tests except test winding were made for the slot insulation, because of the information that was received from the insulation manufacturer. The real properties of the slot insulations are seen in the prototype.

When investigating the coil group insulation, if the voltage difference in the same phases is over 350V then all same phase coil groups must be insulated of each other, in accordance with FIMOT0345. The most important thing is to think which insulation is used in the coil group insulation to maintain the good impregnation level. It is not useful to use too thick insulation, if there are thinner insulations that can stand the stresses. The calculation works mainly for the F-thermal class insulation because in accordance with the H-thermal class instruction all VSD motors that use more than 500 V D or 660 V Y as rated voltage, every coil group must be insulated. All the other motors are calculated individuality, as shown below.

$$\mathrm{U1} = \frac{3 \times NR \times UN \times b}{Q \times k} \qquad (1)$$

After this coil pair voltage U2 can be calculated

$$U2 = 2 \times U1 \qquad (2)$$

Notes:

NR = The number of parallel branches for example when the connection is 3Y, NR is 3

UN = The effective value of the phase to phase voltage

b = Coefficient. In one-layer winding **b** is **2**. In two-layer winding **b** is **1**.

Note! For two-speed motors, where two windings with different number of poles form a two-layer structure, **b=2** works for both windings.

Information about the impregnation of the resins in the H-class VSD motors was collected with measurement tool of impregnation. The results were collected since the beginning of year 2012. The result seems to be good when all of the frame sizes are over 10 %. Information from frame sizes 35 were fed 17 times, frame size 40 for 99 times and frame sizes 45 for 29 times, as seen in figure 27. When investigating the impregnation it must be noticed that resin might not be inside of the stator. In trickle impregnation, the resin is also impregnated to the surface of the stator and in the vacuum pressure impregnation the surface part is very small.

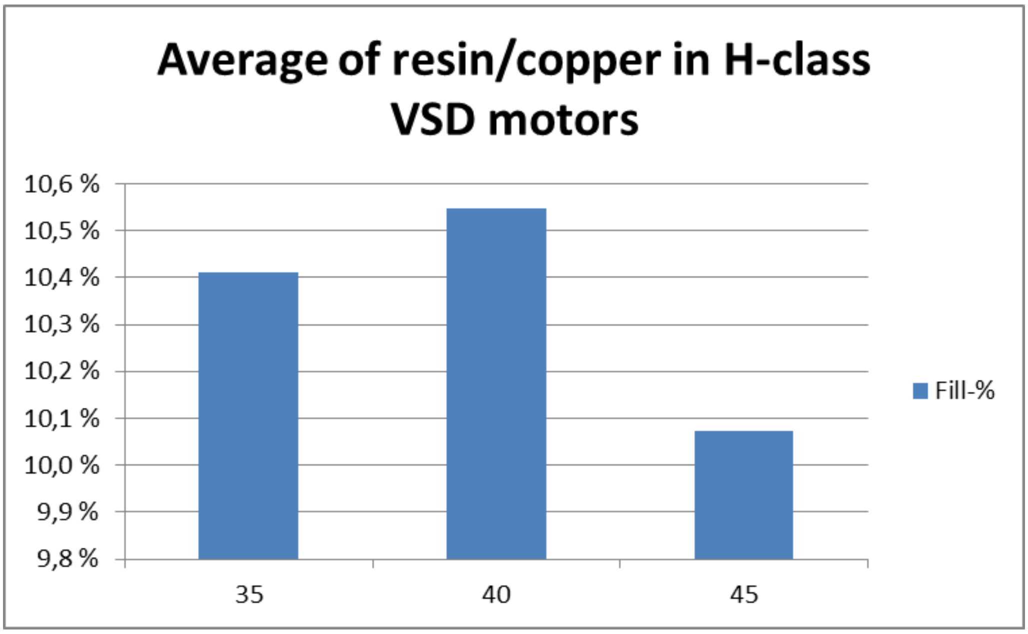


Figure 27. Impregnation level in old H-class VSD motors

8 SOLUTION

The objective in thesis was to reach a good impregnation level and at the same time maintain good winding properties. All the new solutions are based on the investigation of the insulation datasheets and the prototype. The costs of the insulation were also added to observe.

8.1 Insulation

The new insulation had all the requirements that were wanted. The chosen insulation group for prototypes was modification of table 8 and table 7. The slot insulation is NMiN and NMN. The phase insulation in slot is also NMiN and NMN to decrease the insulation materials in storage. The phase insulation in the end coil is AOMF and APGNH. The coil cap insulation is AOMF. This group was chosen from the hammer test which showed the best mechanical withstand insulations.

8.2 Impregnation level

Because of the lack of time the impregnation test were not made. According to the measure that was made in 2012 showed that the impregnation level was quite good and when the insulation is reduced it is very likely that the impregnation level will increase.

8.3 Cost comparison

Insulation is quite expensive material. The old insulation was made of very expensive materials and materials were used too much. The new insulation group was 66,7 % cheaper than the old insulation group. The savings that are made with changing insulations is magnificent. By decreasing the price of the insulation the motors are more competitive on the markets.

9 THE CONCLUSION OF THE WORK

To reach the goal about how insulations work in a real motor, prototypes must be made. Two prototypes should be ordered. Both prototypes should include the old winding style and frame but a new insulation group. The stator size could be 315 and it should have 4 poles and the winding style should be double stage overlap. Both prototypes groups should be trickle impregnated. In the trickle impregnation, epoxy resin in accordance with FIMOT0345 must be used and in the other stator polyester resin accordance with FIMOT0345. The prototypes give real information how the new insulation and impregnation ways affects to resins impregnation to stator. To make sure that the insulations will work, the prototypes must be tested. The first test should be a partial discharge test, where electricity is fed to stator and the stator is observed in the case of the partial discharge and to it must be ensure that the insulation can withstand it. The second test is to cut the stator to pieces and see how well the stator is impregnated.

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