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Polyesterimide Resins for Rotating High Voltage Machines

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1. Introduction

An increasing number of manufacturers and repair shops for rotating high voltage machines are applying the VPI technology in their coil shop (Figure 1). The VPI process is a well established technology and has proven to give a high level of performance and reliability if the insulating materials are selected carefully to fit the type of machine and if they are applied properly. Many different types and qualities of insulating materials – VPI resins, mica tapes, anti-corona products and slot insulations – are available to meet different requirements at varying price levels. However the VPI resin is the key component determining electrical, thermal and mechanical properties of the final insulation. Most of the VPI resins used today are epoxy resins. They are available as "pure" epoxies, as mixtures with acid anhydrides or as hybrid systems which also contain polyester resins and a reactive diluent. In addition an important share of the VPI resin market is covered by polyester and polyesterimide resins. We estimate that this share is about one third of the global market of VPI resins.

Figure 1: VPI equipment for global impregnation of medium-sized high voltage stators (Von Roll Isola – Meier GmbH).

There is an ongoing trend to reduce manufacturing cost and to increase the efficiency of rotating machines. There are several solutions to follow this trend, one of it being the increase of the operating temperature of the machine. This means that the thermal endurance of the insulating system has to be improved corresponding to a change from traditional class F systems to class H. The fact is that the typical Bisphenol-A-epoxy VPI systems - although giving excellent performance at 155°C – fail in endurance tests performed at 180°C. Silicone resins are known to have excellent thermal properties but are rather expensive; therefore their application is mostly restricted to class C traction motors. We observe an increasing demand for polyesterimide resins filling the gap between epoxy and silicone resins for high voltage application.

This paper presents a range of polyesterimide resins for rotating machines which meet requirements for class H systems. The range comprises four different single component resins which cover practically all applications, see table 2. They are available in different viscosities to be used as dipping, trickle or VPI resin. They contain styrene or vinyltoluene as diluent depending on the need of the motor manufacturer. What they have in common is an excellent tank stability at room temperature, a fast gel time at 120°C and therefore a short curing time and excellent dielectric properties in the cured state. They can also be used for class H traction motors.

2. Requirements for VPI resins

Requirements for VPI resins are manifold. They do not only depend on the type and size of the machine to be manufactured but also on the manufacturing process and equipment and the other materials used for electrical insulation. Last but not least they may vary according to health, safety and environmental regulations being valid for the site.

In general a low resin viscosity is favourable for high voltage application to ease impregnation of the mica insulation and to reduce the VPI cycle time. Furthermore storage and impregnation temperature of the resin should be the same and preferably be room temperature to avoid any heating and cooling processes and to save energy and time. The shelf life of the resin is usually defined by the time during which the viscosity increase at storage temperature does not exceed a certain value. The tolerated maximum viscosity increase depends on the application but – as a guide line – it should be ≤ 50 % of the initial value. The duration of use depends also on the consumption rate or the amount of fresh resin added periodically. Ideally the duration of use is ∞ which means that the amount of fresh resin added to replace the liquid used is sufficient to keep the viscosity below the tolerated limit.

Other preferable handling properties of the resin are little or no sensitivity to moisture, small environmental and health hazards and a low toxicity.

The gel time of a VPI resin should be reasonably short to avoid losses of resin during the curing cycle. On the other hand too short gel times will reduce the shelf life of the resin. Also a short cure time is desirable to reduce the VPI cycle time.

Table 1 gives an overview on the desirable features of VPI resins.

	Requirements
Liquid resin:	
Viscosity (for high voltage)	≤ 300 mPas at RT
Storage Temp.	15 - 25°C
Shelf life at storage temp.	6 – 12 months
Duration of use (see text)	∞
Sensitivity to moisture	Low or none
Flash point	> 30°C
Gel time 120°C	2 - 6 min.
Cure time 150°C	2 – 8 h
Cured resin:	
Thermal class	F - H
Tan δ (measured on mica laminates)	$\tan\delta_{RT} \le 2$ % $\tan\delta_{155°C} \le 8$ % $\tan\delta_{180°C} \le 16$ %

Table 1: Desired properties of VPI resins

3. Test results

The range of Von Roll Isola polyesterimide resins for rotating machines comprises four products. Their properties are listed in table 2.

These resins were exposed to a large number of ageing tests to determine electrical, thermal and mechanical properties and to verify their usefulness in insulating systems for rotating machines.

Thermal endurance:

IEC 60216 gives guidelines for the determination of the temperature index of electrical insulating materials. Measurements of weight loss and flexural strength were done with laminates of a mica insulation impregnated with polyesterimide resin 3308. Results are shown in figure 2. They show a temperature index of 188°C for weight loss of organic matter and 190°C for flexural strength which means that the material meets class H requirements.

Voltage endurance:

Methods for the determination of the voltage endurance of electrical insulating systems are given by IEC 60034. Measurements of different VPI insulating systems are shown in figure 3.

	Resin type			
	3032	**3340**	**3308**	**3309**
Liquid resin:				
Viscosity	200/300 mPas	300/500 mPas	150 mPas	170 mPas
Diluent	Styrene	Vinyl Toluene	Styrene	Vinyl Toluene
Storage temp.	RT	RT	RT	RT
Shelf life at storage temp.	6 months	6 months	18 months	12 months
Sensitivity to moisture	none	none	none	none
Flash point	> 32°C	> 52°C	> 32°C	> 54°C
Gel time 120°C	1.5 – 2 min.	2 – 4 min.	2 – 3 min.	2 – 4 min.
Cure time	8h/140°C	8h/150°C	8h/130°C	8h/150°C
Cured resin:				
Thermal class	H	H	H	H
Tan δ	See figure 4			
Application:				
Dry type transformers	✓	✓	✓	✓
LV machines ≤ 1 kV	✓ (300 mPas)	✓	o	o
HV machines ≤ 6.6 kV	✓	✓	✓	✓
HV machines ≤ 15.75 kV	o	o	✓	✓
Traction motors	✓	✓	✓	✓

Table 2: Properties of Von Roll Isola polyesterimide resins for rotating machines and fields of application.

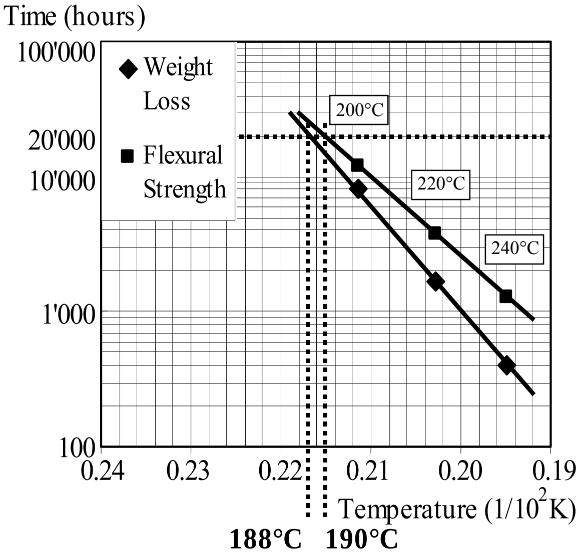

Figure 2: Determination of the temperature index of a mica insulating system with polyesterimide resin 3308 for weight loss and flexural strength according to IEC 60216.

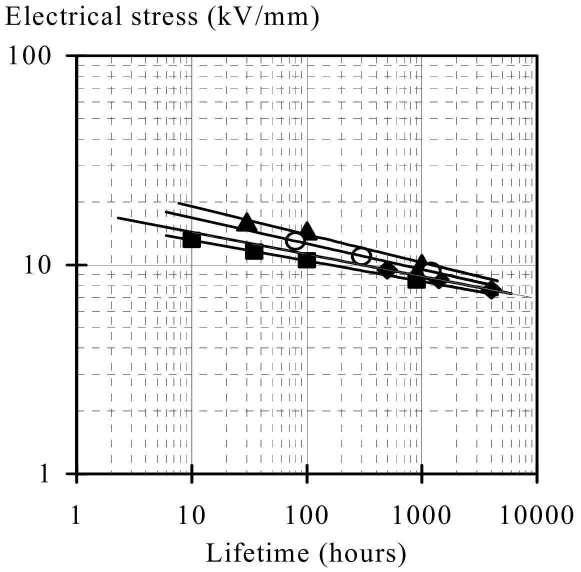

Figure 3: Voltage endurance of different VPI insulating systems according to IEC 60034. The circles represent the system with polyesterimide resin 3308.

Although IEC 60034 is the standard method used to approve insulating systems for rotating high voltage machines, it is generally assumed that electrical stress is not the dominating ageing factor in the electrical insulation of large machines. It is rather believed that the ageing mechanism is dominated by thermal degradation of the binder resin, mechanical stress caused by vibration and switching pulses and stress caused by the different thermal expansion coefficients of the materials involved [1].

Combined thermal/electrical ageing:

Therefore a combined thermal/electrical ageing test was done to determine the characteristics of poyesterimide insulating systems under electrical and thermal stress. In this ageing test model bars consisting of copper conductors of 0.8 m length and a main wall insulation thickness of 2 mm were exposed to 14 kV / 50 Hz (7 kV/mm) at 180°C for 44 weeks. Every 2 to 4 weeks the bars were removed from the oven and tan ó as a function of voltage was measured at room temperature, at 155°C and at 180°C. This corresponds to about 40 thermal cycles within 44 weeks. The test included also measurement of breakdown voltage at the beginning and the end of ageing. Results are given in figure 4. They show that tan ó drops in the first 4 weeks due to a postcuring effect and then slowly increases due to thermal degradation. After 44 weeks tan ó values are 1% / 3% / 8% measured at RT / 155°C / 180°C respectively which means that they are still considerably low.

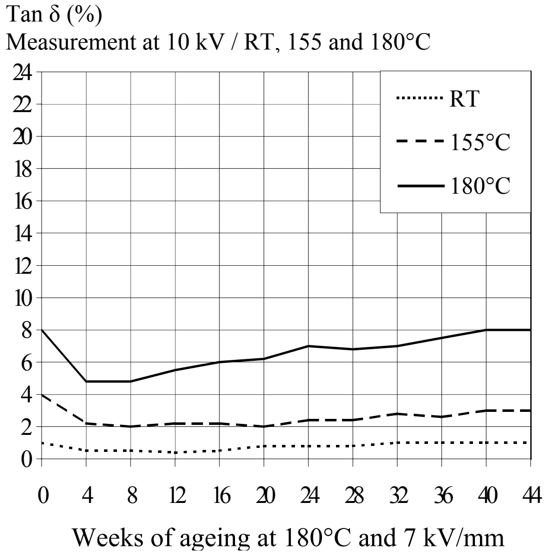

Figure 4: Tan δ (%) of test bars during combined thermal/electrical ageing (See text for further details).

No	Conductor insulation	Main wall insulation	Impregnating resin
1	Kapton 100 H	Glassbacked mica tape (Resin rich tape) + Kapton 100 H	Cyclo-aliphatic epoxy
2	Kapton 100 H	Kapton 100 H backed mica tape + Kapton 100 H	UPI resin 3340
3	Kapton 100 H	Kapton 100 H backed mica tape + Kapton 100 H	UPI resin 3309
4	Enamelled + glass / polyester lapped	Kapton 100 H backed mica tape + Kapton 100 H	UPI resin 3309
5	Enamelled + glass lapped	Glassbacked mica tape + Kapton 100 H	UPI resin 3309
6	Enamelled + glass lapped	Kapton 100 H backed mica tape + Kapton 100 H	UPI resin 3309
7	Kapton 100 H	Glassbacked mica tape + Kapton 100 H	Silicone resin 3551
8	Kapton 100 H	Glassbacked mica tape + Kapton 100 H	Silicone resin 3551
9	Kapton 100 H	Glassbacked mica tape + Kapton 100 H	Silicone resin 3551

Table 3: Insulating sytems for traction motors used in the thermal cycling test. Insulation thickness applied on the test bars was 0.35 – 0.40 mm.

It has been shown earlier [2] that insulating systems based on Bisphenol-A-epoxy resins fail after a few weeks ageing time in this combined thermal/electrical ageing test at 180°C although they have proven to give excellent results at 155°C.

Ageing tests for traction motors:

In order to evaluate the performance of polyesterimide VPI resins for traction motors some additional ageing tests were done: Electrical breakdown and weight loss of organic matter were measured as a function of thermal cycling.

Test specimen used for thermal cycling were copper conductors with a cross-section of 10 x 4 mm. The different insulating systems used are compiled in table 3. Insulation thickness was 0.35 – 0.40 mm for all systems. System no. 1 was taken as reference system; it is a resin rich mica tape with a cycloaliphatic epoxy binder resin combined with Kapton 100 H. This insulating system is used for traction motors in high speed trains.

One thermal cycle included heating for 96 h at 260°C and cooling for 48 h at 40°C and 95 % relative humidity. After each cycle a high voltage test of 2 minutes at 3.5 kV/50 Hz was done. 40 bars were tested for each insulating system. The number of cycles was registered after which 50 % of the bars had failed. Results are given in figure 5. The reference system no. 1 based on cycloaliphatic epoxy resin shows the lowest, the silicon systems no. 7 – 9 the highest number of cycles needed for the 50 % failure rate. The insulating systems no. 2 – 6 with polyesterimide VPI resin range in between.

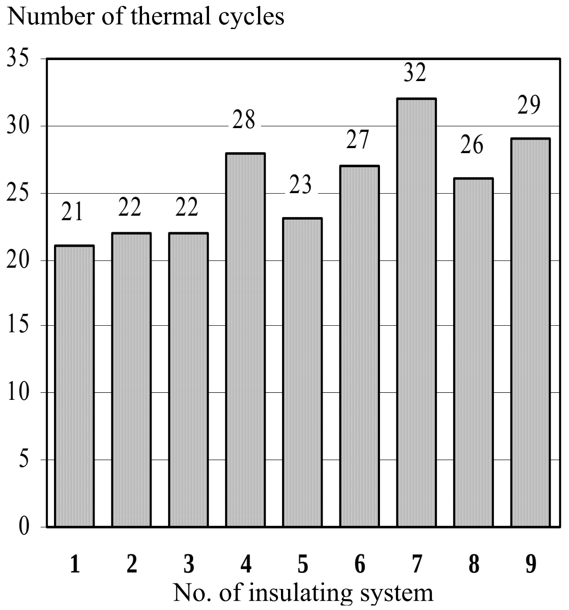

Figure 5: Thermal cycling test of different insulating systems for traction motors. Shown is the number of cycles after which 50 % of 40 test bars failed. The numbers 1 – 9 refer to the insulating systems listed in table 3.

Weight loss of organic matter of the different insulating systems was determined using the same thermal cycling test. Weight loss was measured till 50 % of the bars had failed. Weight loss curves are shown in figure 6. The figure shows that the insulating systems no. 2, 3 and 4 with polyesterimide VPI resin again range between the reference system no. 1 (based on cycloaliphatic epoxy resin) – which gives the highest weight loss – and the silicone systems no. 7 – 9 having the lowest weight loss.

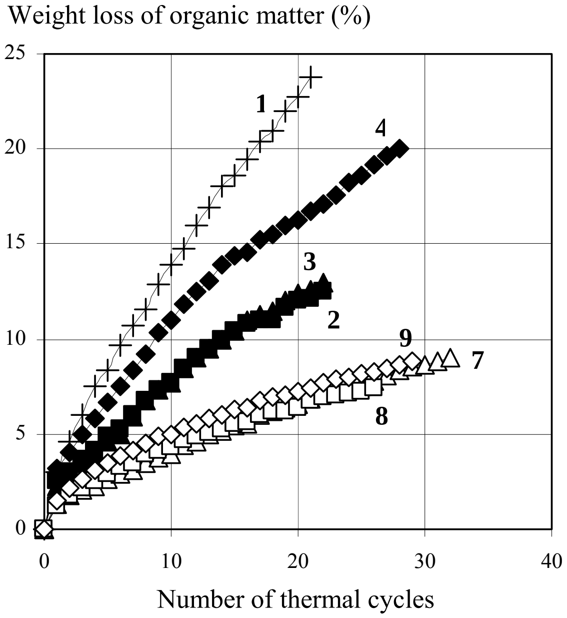

Figure 6: Weight loss curves of different insulating systems for traction motors as function of the number of thermal cycles applied. One thermal cycle included ageing for 96 h at 260°C and 48 h at 40°C. The numbers indicated in the graph refer to the insulating systems listed in table 3.

4. Conclusions

The performance of insulating systems for rotating machines is determined to a great extent by the characteristics of the impregnating resin used. Whereas polyester and epoxy systems are established in the field of class F machines polyesterimide resins offer the possibilty to extend the thermal range to class H and thus to bridge the gap to class C silicone systems. The main features of the polyesterimide resins described in this paper are their excellent dielectric properties, long shelf life, short gel time and low viscosity which make them suitable for the impregnation of machines up to 15.75 kV. They also show excellent results in class H traction motors and offer a very reasonable alternative to the expensive silicon systems.

References

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