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INTERACTION ASPECTS OF PULSE STRESS AND INSULATION SYSTEMS

WPŁYW ZASILANIA IMPULSOWEGO NA UKŁADY IZOLACYJNE MASZYN ELEKTRYCZNYCH

Abstract: In the past twenty years, industrial controls have experienced dramatic changes with advances in adjustable speed drive technology. It has been observed that voltage waveforms generated by power frequency converters may affect significantly the reliability of electric motor insulation system.
Over voltage problems in long cable drives due to step voltage pulse rise time became an important research area during the last decade. The over voltage phenomenon is usually described using the traveling wave and reflection phenomena. For better understanding of the processes in long cable drives distributed-parameter representation in simulations is used.
The problem with bearing currents is well known. Besides magnetic dissymmetries, other causes exist for bearing currents, such as voltage potential accidentally applied to the shaft, electrostatic charge accumulation, and common-mode voltages generated by unbalanced excitation of the motor windings. Any of the above could cause bearing currents and bearing failures. Recently, common-mode voltages with high frequency and high dv/dt have been a major cause of bearing currents and premature bearing failures in high-frequency inverter-fed, induction motors.
This paper deals with this topic, showing experimental evidences between electrical insulation materials life time under two different voltage conditions.

Streszczenie: W ostatnich 20 latach w dziedzinie przemysłowych układów sterowania zaobserwowano bardzo szybki rozwój w zakresie technologii napędu o regulowanej prędkości. Jednocześnie zaobserwowano, że przebiegi czasowe napięć generowanych przez przekształtniki częstotliwości mogą niekorzystnie wpłynąć na niezawodność i żywotność układów izolacyjnych w silnikach elektrycznych. Problemy związane z przepięciami występującymi w napędach z długim okablowaniem, wywołanymi krótkimi czasami narastania zboczy prostokątnych impulsów napięciowych stały się w ostatniej dekadzie istotną dziedziną badań. Ponadto znany jest również problem prądów łożyskowych. Obok asymetrii magnetycznej istnieją także inne przyczyny wywołujące prądy łożyskowe, takie jak np. niezamierzone podanie potencjału napięciowego na wał silnika, kumulowanie się ładunku elektrostatycznego czy napięcia współbieżne wytwarzane przez niesymetryczne zasilanie uzwojeń silników. Każda z wymienionych przyczyn może wywołać prądy łożyskowe i w efekcie uszkodzenie łożysk. Ostatnio główną przyczyną prądów łożyskowych i uszkodzeń łożysk stały się napięcia współbieżne o wysokiej częstotliwości i dużych przyrostach dv/dt, występujące przy zasilaniu silników indukcyjnych z przekształtników częstotliwościowych. Niniejszy artykuł dotyczy powyższych zagadnień. Przedstawiono w nim wyniki badań eksperymentalnych wpływu złożonych warunków napięciowych na żywotność wybranych materiałów izolacyjnych stosowanych w maszynach elektrycznych wirujących. Zauważono, że dla niektórych materiałów izolacyjnych przy zasilaniu z falowników PWM następuje zmniejszenie czasu zużycia izolacji nawet o 80%.

1. Introduction

Nowadays adjustable speed drives (ASD) are widely used in appliances where electrical motor speed has to be varied almost continuously. A power inverter is used to supply the AC electrical motor. In particular, modern power converters implement the pulse width modulation (PWM). This technique produces the square waveforms voltage, width modulated ac cording to sinusoidal law. Rise fronts (slew rates) have attained values of up to tens kV/μs and voltage pulse repetition frequency up to some tens of kHz. Increasing the voltage rise front and pulse repetition frequency can provide advantages in terms of switching loss reduction and improved stability of motor torque. At the same time it has been observed that the reliability of electrical machines can be significantly worsened by power inverter.
Premature failures can be attributed to accelerated degradation caused by:

- Local insulation overheating caused by increased losses.
- Over voltage phenomenon. Over voltage amplitude is dependent on supply-motor connection, especially on cable length.
- Increasing of partial discharges (PD) activity.
- Intrinsic aging due to electro-mechanical fatigue increasing with frequency.
- Bearing currents causing accelerated aging of motor bearings.

Other problems are caused by partial discharges. Partial discharges are considered to be one of the main causes of the reliability loss. New enamel insulations for magnet wires are being developed in order to withstand better stress amplification.
Some materials with improved insulation for motor winding have become recently available on the market, being designed specially for motors supplied by ASD. These materials are called corona resistant (CR) for their claimed ability to endure better partial discharges.
In order to prevent the effects of steep-fronted waveforms on winding insulations, filters can be employed. However the problem is that their cost may not be acceptable, especially for low-voltage low-power motors.
The electrical characterization of insulation materials is often carried out through aging test that may provide estimation of live under different stress levels and conditions. However, deeper investigation of aging phenomena due to supply voltage waveforms is needed, especially regarding the relation between aging factors and stress conditions.
Characterization of insulation materials and comparison of candidate materials for application in power electronic waveform environments can be carried out using the methodology proposed here. This approach can provide, therefore, a useful feedback to manufacturers.

2. Experimental Set-Up

The purpose for conducting reliability testing of the insulation materials under pulse stress is to create and compare two life time curves. One curve will show sinusoidal ageing, the other curve will show high frequency square waveform voltage ageing.

2.1 Tested Materials

Three different insulation materials were tested. The first material Remikapor 45.024 is made by Elektroisola a.s. Tábor. This material is polyester-remica based with a small amount of epoxy. This material is processed by vacuum pressure impregnation (VPI). The impregnating material is Rütapox 0162 x Härter HM. This insulation material is used to insulate systems up to 155 °C.

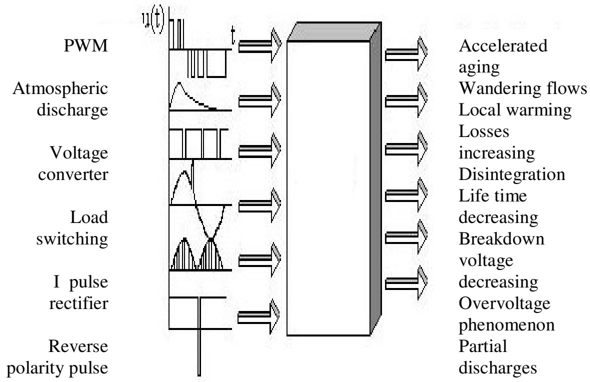

Figure 1. Pulse stress types

The second material was Poroband made by Isovolta AG. This material contains mica paper and glass fabric and is VPI impregnated with H 62C. This material is used in electrical rotary machines.
The third and the last material for testing was Porofol with H 62C which contains mica paper and polyester film with modified epoxy bond.
Samples of motor winding were created from these three materials produced by VPI technology [1].

Table 1. Insulation tapes parameters

Material	Tape Thickness /mm	Surface Density /g.m^{-2}	Bond /g.m^{-2}
Remikapor 45.024	0,11 – 0,15	191 - 240	6 – 12
Poroband + H 62C	0,15	176 – 216	10 -16
Porofol + H 62C	0,105 – 0,135	184 - 224	8 – 16

Some parameters of insulated tapes are shown in table 1. In table 2 the average values of breakdown voltages of tested samples mentioned above are shown. These values were measured before accelerated aging was started.

Table 2. Sample breakdown voltages, 50 Hz

Material of Sample	Breakdown Voltage /kV
Remikapor 45.024	17,5
Poroband + H 62C	25,91
Porofol + H 62C	11,8

2.2 Choice of the Test Waveform

Since real waveforms affecting insulation in ASD controlled motors can change with drive, motor and connecting cable characteristics, it is generally expected that simple voltage waveform (e.g., square, either bipolar and unipolar) can be used for the purpose of testing simple insulation systems and comparing their behavior.
The square waveform generator which we have used for testing of insulation materials is described in [1]. Maximum testing voltage was 5 kV by repetitive frequency 10 kHz.

2.3 Measured Quantities

During the life time testing, dissipation factor, absorption and resorption current were measured.
From particular specimen's lifetimes on tested electrical field gradient values the technical life time curve was acquired. Life times by sinusoidal and high frequency square waveform voltage were compared.
For resorption characteristic comparison the reduced resobed curves method was used.

3. Life Test Comparison

The life time curves obtained for tested materials are shown in figures 2, 3 and 4. Particular points on the curves were received from measured data using the least squares method. In figures we can see pulse voltage life time decreasing rate.

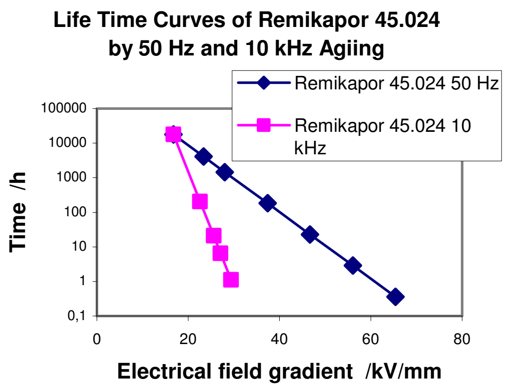

Figure 2. Life time curves of remikapor 45.024

Figure 2 shows measured and recalculated values of the life times on set value of the electrical field gradient for material Remikapor 45.024.
In figure 3 the data for material Porofol are presented and in figure 4 for material Poroband.-

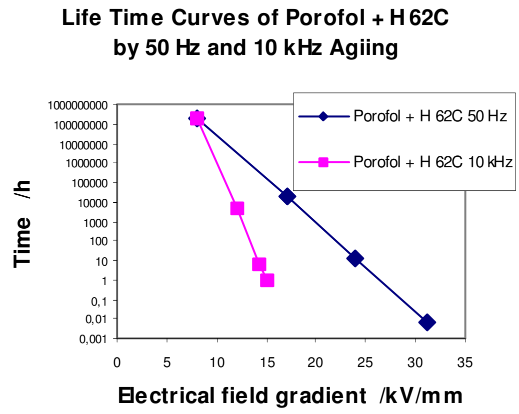

Figure 3. Life time curves of Porofol + H 62C

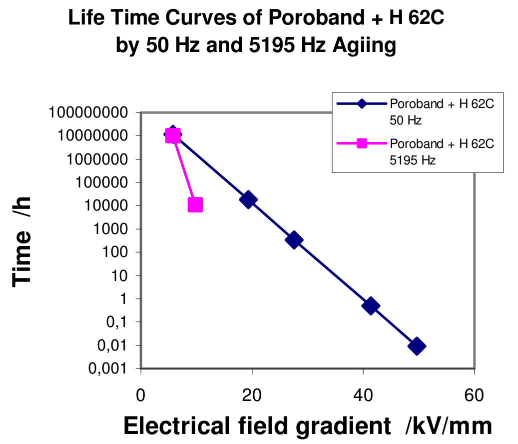

Figure 4. Life time curves of Poroband +H 62C

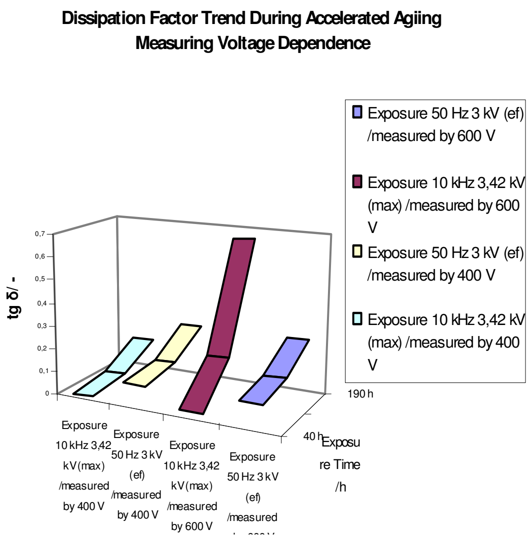

Figure 5. Dissipation factor trend during test

Figure 5 shows the measurement of voltage and exposure time dependence dissipation factors for the sampled materials. Analysis af measured data shows how dissipation factor grows in dependence on high frequency pulse voltage exposure. It is interesting that this high frequency deterioration of material parameter is observable by measuring voltage 600 V. Accelerated deterioration by 400 V is not observed.

6. Conclusions

This experiment illustrates how the reliability of electrical insulation material in rotary machines decreases under high frequency pulse voltage. The results of this experiment provide information to consider in designing materials more resistant to stresses caused by power invertors. The results of this experiment also show manufacturers how much the technical life time of insulation systems under pulse stress is decreased.

By comparison of the life time curves of insulation materials for 50 Hz sinusoidal aging and for high voltage square waveform voltage aging the life time shortening was determinate. For material Remikapor 45.024 and Porofol + H 62C more then 80 % life time shortening was deducted.

7. References

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