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INFLUENCE OF THIN LAYERS ON STATIC ELECTRIFICATION PHENOMENA OF MATERIALS FOR POWER TRANSFORMERS

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Abstract

The static electrification phenomenon is investigated, using a test cell with a rotating metallic disk coated on both sides with thin layers (0,5 and 2 μm) of conducting, semiconducting and insulating materials, obtained by magnetron sputtering. The current characterising the static electrification is studied as a function of the nature of the coating material and the oil, the temperature and the rotating velocity of the disk. Modification of the surface properties has a decisive influence on the static electrification of insulating oils, the sign and the amplitude of the currents are strongly affected.

Introduction

Numerous failures of large forced-oil-cooled power transformers reported all over the world in recent years, have been attributed to the static electrification phenomena [1-3]. In order to prevent these defects, intense investigations have been undertaken to shed light on the processes involved in the static electrification of materials used in power transformers. It follows from the reported results that these processes are complex and depend upon: (i) the intrinsic properties of oils and solid materials, (ii) the external parameters such as the streaming velocity of oil, the temperature and the applied voltage [3-6].

The electrostatic charging tendency (ECT) of oil depends on the properties of the oil/solid material interface; the latter constitutes the electric charge double layer seat. The characteristics of this electric double layer can be seriously affected by the physico-chemical properties of oil (for e.g. ageing, moisture,...) and by the surface state (roughness, porosity,...) of the solid material.

The modification of the surface properties of the electrodes, by coating them with thin layers of different materials, can have a decisive effect on the static electrification phenomenon. In the presence of an electric field, fundamental mechanisms such as charge injection, electroconvection, electrification and discharge initiation also can be affected, as shown in [7,8].

This paper deals with the influence of thin layers of conducting, semiconducting and insulating materials, obtained by magnetron sputtering, on the static electrification of fresh and aged oils. The influence of the temperature and oil hydrodynamic are investigated.

Experimental

The experimental arrangement is a typical test cell known as " CIGRE test cell". It consist of a rotating disk, 150 mm in diameter and 5 mm thick, covered or not covered on its both sides with a thin layer of the solid deposit and immersed in a metallic tank 170 mm in diameter and 80 mm high (Fig.1). The disk is placed at the centre of the tank where it can be rotated by means of a little electrical motor; the rotating velocity of the disk is changed between 100 and 600 rpm. The disk is made of aluminium. A heating system with temperature regulated between 20°C and 80°C is used.

Due to the centrifugal force, the charges created by the rotating motion of the disk coated with the solid deposit material in the oil are drained towards the tank wall where they are colected. The current created by the charge concentration gradient is measured by an electrometer (Keitley 485) inserted between the tank and the earth. The CIGRE cell and the electrometer are placed in a Faraday cage.

The considered thin layers are deposits of three kinds: (i) a 2 μm thick conducting layer of pure aluminium Al (5N), (ii) a 2 μm thick semiconducting layer of silicon Si ('n'type) and (iii) a 0,5 μm thick layer of an insulating material of polytetrafluoroethylene (teflon). These deposits are obtained by magnetron sputtering with a vacuum of 10^{-2} Tr. The magnetron is of the WMK-100 type with a maximum power at the target of 7 kW.

The considered oil samples are fresh or taken from different transformers in service. Basic properties of the aged oil samples are presented in table 1.

Results and Discussion

Influence of temperature

Figures 2 to 5 show the variation of the leakage current versus the rotating velocity of the disk for different interface oil/solid couples and for different temperatures.

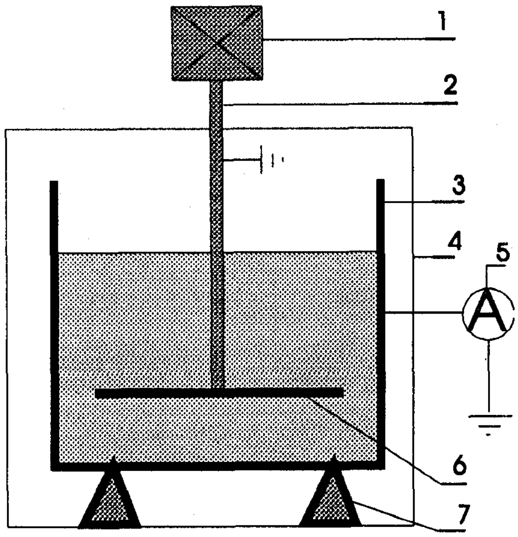

Fig. 1 Rotating disk test cell: 1 - variable speed motor, 2 - rotation axis, 3 - measuring vessel, 4 - electrostatic screen, 5 - electrometer, 6 - rotating disk, 7 - teflon isolators

Table 1. Basic properties of aged oil samples

Property	Oil Sample		
	1	2	3
Breakdown voltage (kV)	36	71	73
Volume resistivity at 50°C (Ωm)	$2,7*10^9$	$4,7*10^{11}$	$1,1*10^{10}$
Dissipation factor at 50°C, 50Hz	0,05	0,0007	0,016
Acidity (mg KOH/g)	0,2	0,02	0,06
Interfacial tension (N/m)	19	45	31
Water content (ppm)	45	19	20

It follows from the experimental results that for a new (fresh) oil and an uncoated disk, the current increases with temperature and rotating velocity. This increase is weak for temperatures of 20 and 40°C whereas it becomes more important for temperatures higher than 60°C (Fig.2). The currents measured in the case of aged oil 1 are higher than for a new oil. One can also notice that for aged oil 1, the current is more influenced by the temperature than by the rotating velocity in the considered range; the current variation shows some stabilisation when the velocity is changed. For the temperature of oil of 80°C, one observes some decrease in the current when the velocity increases (Fig.3).

Similar results have been obtained by Radwan *et al* [6] with Perspex^{Tm} and Teflon^{Tm} disk materials.

Let us consider now a disk coated with pure aluminium (5N), we remark that all the measured current are negative for a new oil (Fig.4) whereas they are all positive for aged oil 1 (Fig.5). For the new oil, the increase in the current is higher at the temperature of 80°C

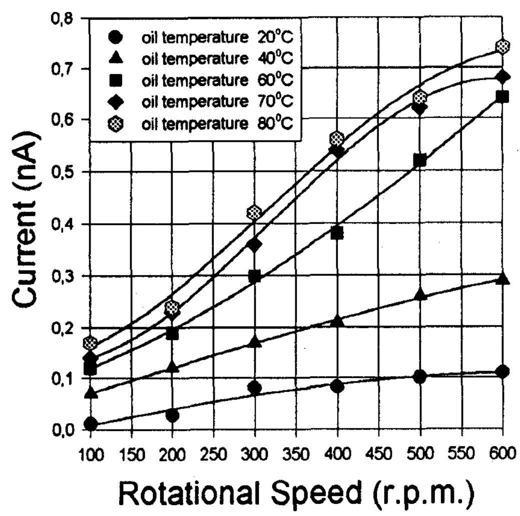

Fig.2 Current vs. rotating velocity for uncoated disk in new oil, at different temperatures.

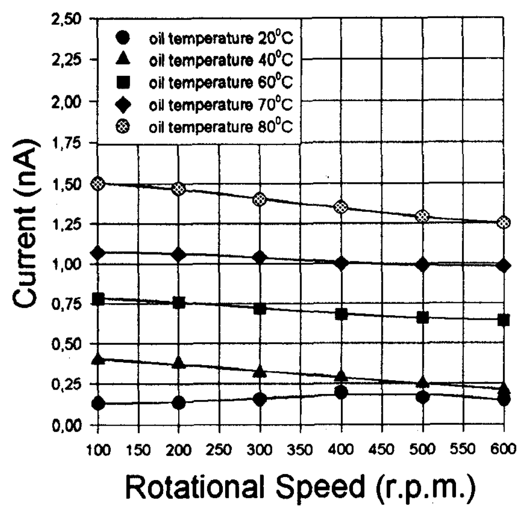

Fig.3 Current vs. rotating velocity for uncoated disk in aged oil 1, at different temperatures.

For a disk coated with silicon ('n'type) in a new oil, the currents increase with the rotating velocity and the temperature. They are highest for aged oil 1 at temperatures higher than 60°C; the measured values are negative at 20 and 40°C. In the case of a teflon deposit, the currents increase with temperature and velocity for the new oil. However, contrary to the preceding case, they are more important for the new oil than for aged oil 1, especially at temperatures higher than 20°C. The variation of the currents are weak for aged oil 1, regardless of the temperature and the velocity of the disk.

<u>Influence of oil and deposit nature</u>

The sign and the current values greatly depends on the nature of the deposit material and on the oil. At 20°C the current significantly increases with velocity for a teflon deposit in the new oil (Fig.6). For a pure aluminium layer, the current also increase but their values are negative. As concerns the silicon coating, the currents are very close to those measured for the uncoated disk.

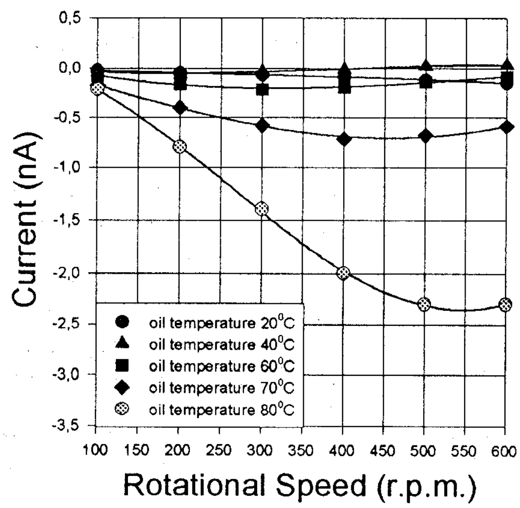

Fig.4 Current vs. rotating velocity for disk coated with pure aluminium in new oil, at different temperatures.

For aged oil 1, the variation character is in opposition with respect to that observed for the new oil. Negative currents are observed for a disk coated with silicon deposit at 20°C (Fig.7). For teflon or pure aluminium deposits, the currents are very similar; they increase with velocity.

The experimental curves obtained for aged oil 2, show the same increasing behavior for all the deposits (Fig.8). Note that no negative current was observed for the different types of deposits.

The variations of the currents measured for aged oil 3 are different (Fig.9). For an uncoated disk and a disk coated with teflon, the electrification current first increases up to

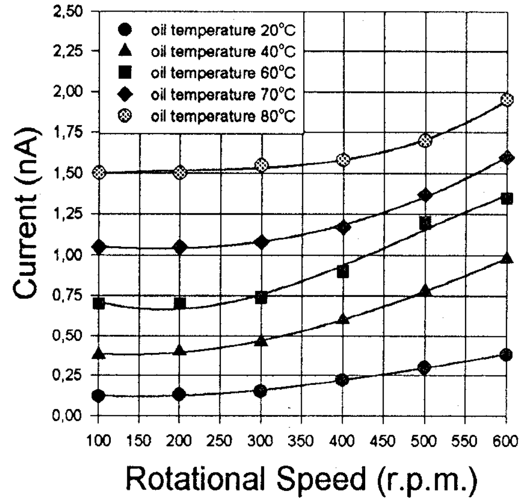

Fig.5 Current vs. rotating velocity for disk coated with pure aluminium in aged oil 1, at different temperatures.

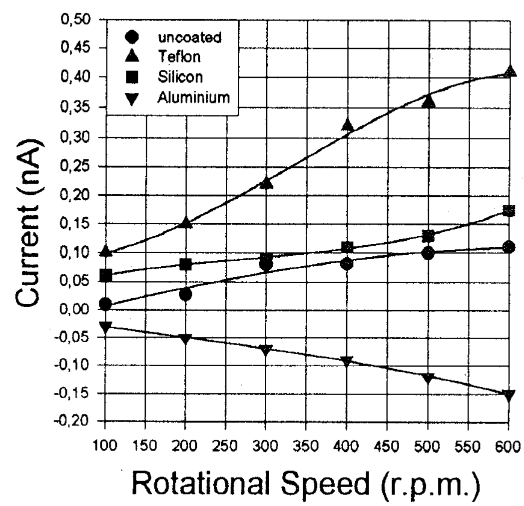

Fig.6 Influence of nature of deposit and rotating velocity on current in new oil at 20°C.

150 r. p. m. and then decreases.

For a rotating velocity in the range 200-400 r.p.m, these currents decrease and assume negative values.

For higher rotating velocities, the currents increase again and change their sign. For a pure aluminium layer, the currents continuously increase and they are positive whereas they are negative for a silicon coating.

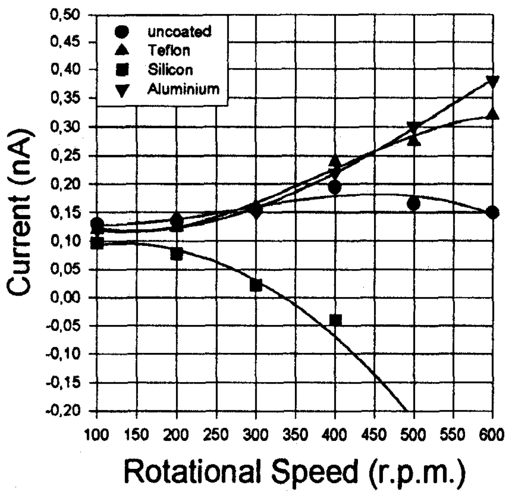

Fig.7 Influence of nature of deposit and rotating velocity on current in aged oil 1 at 20°C.

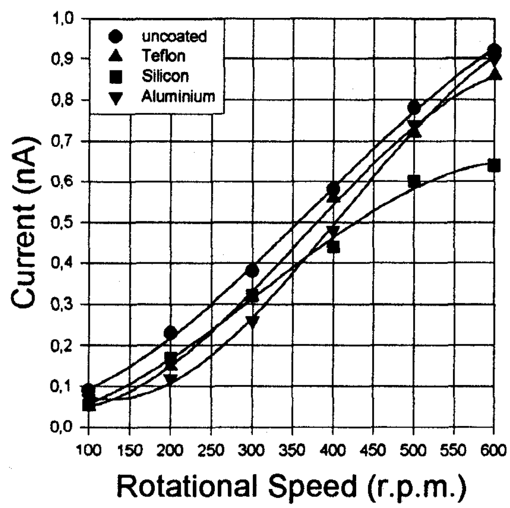

Fig.8 Influence of nature of deposit and rotating velocity on current in aged oil 2 at 20°C.

Conclusions

The study shows that the modification of an aluminium surface coated with different thin layers of materials, obtained by magnetron sputtering has a significant effect on the static electrification phenomenon. Our results confirm those reported elsewhere concerning the influence of the ageing of oils. On the other hand, the electrostatic charging tendency has to be analysed not with respect to the oil alone but also to the couple of materials, i.e. oil/solid.

Among the obtained results one should notice the one concerning the change of the sign of the static charges when thin deposits of pure aluminium (5N) are in contact with fresh oil.

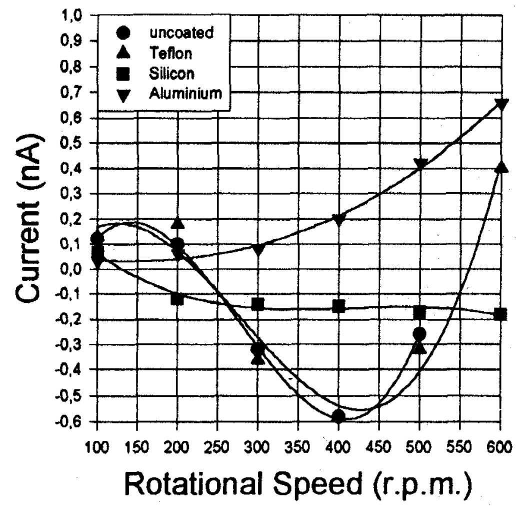

Fig.9 Influence of deposit nature and rotating velocity on current in aged oil 3 at 20°C.

References

[1] R. Tamura, Y. Miura, T. Watanabe, T. Ishi, N. Yamada, T. Nitta, "Static Electrification by Forced Oil Flow in Large Power Transformers", IEEE Trans. on Power Appar. and Syst., Vol. PAS-99, No. 1, pp. 335-343, Jan./Feb. 1980.

[2] D. W. Croft, "The Static Electrfication Phenomena in Power Transformers", IEEE Trans. on Electr. Insul., Vol.23, No. 1, pp. 137-146, 1988.

[3] S. R. Lindgren, "Progress in Control of Static Electrification in Power Transformers", Electra, No. 133, pp.51-59,1992.

[4] L. Peyraque, A. Béroual, C. Boisdon, F. Buret, "Phénomenes d'électrisation des matériaux isolants pour transformateurs de puissance", J. Phys. III France 4, pp. 1295-1304, 1994.

[5] I. A. Metwally, "Influence of Solid Insulating Phase on Streaming Electrification of Transformer Oil", IEEE Trans. on Diel. and Electr. Ins., Vol. 4, No. 3, pp.327-339, June 1997.

[6] R. M. Radwan, R.M. El-Dewienny, I.A. Metwally, "Investigation of Static Electrification Phenomenon Due to Transformer Oil Flow in Electric Power Apparatus", IEEE Trans. of Electric. Ins., Vol. 27, No. 2, pp. 278-286, April 1992.

[7] J. Fleszyński, B. Lutyński, J. Słowikowski, "Factors Affecting the Onset and Development of Electroconvection in Transformer Oil", CIGRE Session, Paper 5/33-02 Paris 1990.

[8] A. E. Vlastos, S. Rusck, "Influence of Coating on the AC Breakdown of Liquid Dielectric", Proc. Int. High Voltage Symp., pp. 741-746, Zurich 1975.