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Study on Metallized Polypropylene Film Capacitors and its Change in Dielectric Loss due to the Effect of End Connection Quality

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***Abstract*—This paper presents the results of the dielectric properties and zinc sprayed ends quality on electrodes of self healing metallized polypropylene capacitors. Zinc sprayed metal end connections of metallized film capacitors are the weak link for pulse power applications which involve discharge times of tens of microseconds and less. This problem will only get worse with increased capacitor energy density. The present contribution quantifies the relationship between the ‘‘quality’’ of the end connection and dielectric loss of the capacitor winding. The analysis suggests that even for very poor end connections, the effect on dielectric loss of the total capacitor is relatively small. This makes a low stress production test for end connection qualityproblematic since such tests can only show the totalcapacitor dissipation factor resulting from various factors.**

***Index Terms*— Polypropylene, dissipation factor, dielectric loss, equivalent series resistance, zinc spray, metallized film capacitor, end connection.**

I. INTRODUCTION

POLYPROPYLENEmetallized film capacitors facilitate operation of the polymeric dielectric with a relatively small margin to its dc breakdown strength, especially for the case of pulse discharge capacitors from which only a limited number of discharge cycles are expected. For such capacitors, the dielectric can be operated in the range of 70% of the film dielectric strength. As a result, this technology provides the greatest volumetric energy density among high voltage capacitor technologies. In the context of pulse discharge operation, the primary limitation of this technology is failure of the end connections at high discharge currents. The end connections of self-clearing metallized film capacitors are made by spraying metal on the ends of the capacitor winding. The metallized surfaces of the two polymer films which form the capacitor are each metallized to one edge, with an unrealized margin at the opposite edge. Thus the metallization of one film extends to one end of the cylindrical capacitor winding while the metallization of the other film extends

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to the opposite end of the winding. When the two ends are zincsprayed, one end connects to one metallized electrode, while the opposite end connects to the other metallized electrode.

Figure 1shows zinc sprayed ac capacitor connected to Impedance analyser through soldered wire. The Al/Zn metallization has a typical surface resistivity in the range of 7.5 Ω/sq, which is often decreased near the edge to the range of 2.5 Ω/sq. This implies that the metallization is of order 10 nm thick, while the polymer film is typically 5µm to 10 µm thick. The two polymer films are generally offset slightly, so that only the film to which the plasma sprayed connection will be made extends to the edge of the winding. This provides roughly 10 µm separation between the polymer layers at the end of the capacitor winding. However, the zinc spray particles are much larger than 10 µm, typically 50 µm or greater in diameter as required to maintain a surface to volume ratio which will prevent excessive cooling between particle creation and deposition [1]. Thus the particlesdo not penetrate well into the winding and, therefore, do not make a good, continuous connection to the film metallization. The minimum size of plasma spray particle is limited by the surface to volume ratio which assures that the particles are sufficiently hot at impact. In this paper, we model the zinc sprayed end connection as a periodic set of semicircular ‘‘spot’’ connections to the film metallization with a centre-to-centre separation Δx, as shown in Figure 2. Our objective is to determine the contribution of such a periodic connection to the capacitor dissipation factor as a function of the centre-to-centre separation between connection spots and the radius of the spots. The analysis suggests that even for very poor end connections, the effect on dielectric loss of the total capacitor is relatively small. This makes a low stress production test for end connection quality problematic since such tests can only show the total capacitor dissipation factor resulting from various factors. Previous authors have argued that end connection failure results from progressive electro-thermal failure of contact spots [2,3], and the present authors have quantified the temperature rise around a contact spot in another contribution [4]. The computed temperature rise is sufficient to cause failure of the sprayed end connection.

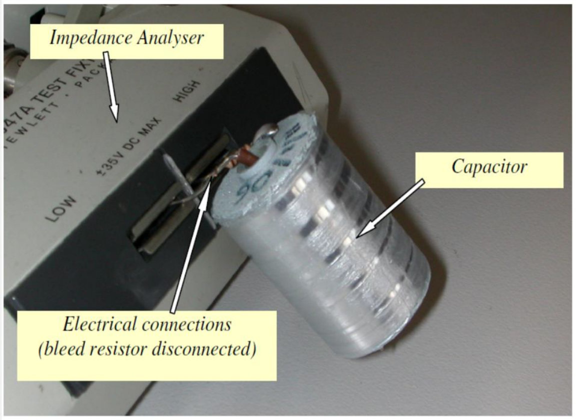

Fig. 1: Zinc sprayed ac capacitor connected to Impedance analyser through soldered wire

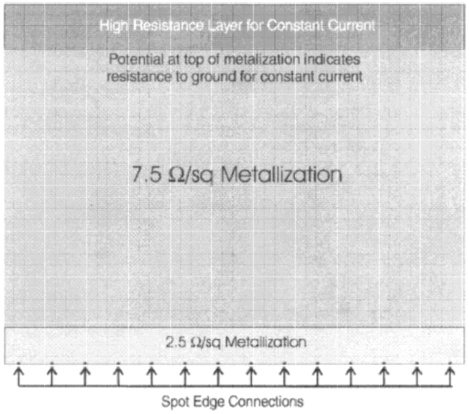

Fig. 2:Geometry used for finite element analysis. The semicircular black spots at the arrow points are the connection spots

II. DIELECTRIC LOSS AS A FUNCTION OF CONNECTION SPOT INTERVAL

The capacitance of a wound capacitor is given by

$$C = 2\frac{\varepsilon_1 \varepsilon_0 wl}{d} \quad (1)$$

where C is capacitance, d is film thickness, ε_1 is relative permittivity of the film, ε_0 is the vacuum permittivity, w is effective width of the capacitor dielectric (the width over which metallized electrodes face each other), l is effective length of the capacitor winding (the total length over which the metallized electrodes face each other), and the factor of 2 results from the capacitance from each layer to both that above and below.For a sinusoidal applied voltage, $V=V_o \sin\omega t$. The surface current density Is(A/m) as a function of positionacross the width of the capacitor dielectric is

$$I_s = \frac{\omega C V_0}{d} x \quad (2)$$

where$x$ is the distance from the edge of the capacitor film which is not connected to the sprayed end connection.Thus the current increases linearly from 0 at the ‘‘free’’ edge of the capacitor film to a maximum at the sprayed edge of the film.The total resistance from one edge of the capacitor film to the other is given by

$$R_f = R_s . \frac{W}{l} \quad (3)$$

whereR_s is the surface resistivity of the metallization in Ω/sq .Assuming a perfect edge connection to the metallization,the power dissipated by the current passing throughthis resistance is

$$P_1 = 2 \int_o^w I_s^2 . \frac{R_f}{w} dx = \frac{4 \omega^2 C V_o^2 w^2 R_s \varepsilon_1 \varepsilon_0}{3 d} \quad (4)$$

Additional power is also dissipated as a result of the need for this current to concentrate at the contact spots. We assume this effect contributes an additional resistivity of $R_c$in Ω-m along the winding length l, the magnitudeof which will be discussed below in detail. Thus the total current at the edge x=w is

$$I_{sl} = \omega C V_0 \quad (5)$$

Since these effects occur at both contacts of the capacitor, the total power dissipated from the additional edgeresistance caused by the contact spots is

$$P_2 = \frac{2 I^2_{sl} R_c}{l} = \frac{2 \omega^2 C^2 V_o^2 w^2 R_c}{l} \quad (6)$$

Thus the equivalent series resistance (ESR) caused by the metallization and edge contact effects is

$$ESR = \frac{P_1 + P_2}{I_{sl}^2} \quad (7)$$

Incorporating equations (1)-(6) into(7) , we obtain

$$ESR = \frac{4 w^2 \varepsilon_1 \varepsilon_0 R_s}{3 C d} + \frac{2 R_c}{l} \quad (8)$$

While the dissipation factor (DF). is

$$DF = ESR \ \omega C = \frac{4 w^2 \varepsilon_1 \varepsilon_0 R_s \omega}{3 d} + \frac{4 R_c \varepsilon_1 \varepsilon_0 w \omega}{d} \quad (9)$$

Of course, the measured ESR and dissipation factor also include an additional contribution from dielectric loss inthe polymer.The total measured dissipation factor will be the sum of that caused by losses in the metallization, losses from theend connection spots, and dielectric loss in the polymer. Dielectric loss of polypropylene is essentially independent of frequency up to the range of MHz. The dissipation factor caused by the metallization end edge resistanceshould be proportional to frequency, as seen from equation (9). Further, the edge resistance should be essentiallyindependent of frequency.

Careful measurements were made of the dielectric losses as function of frequency for a 25µF capacitor windingwith a film width of 70 mm, and polypropylene thickness of 7µm. Figure 3 shows the measured data (Experimental DF) along with the modelled contributions to the dissipation factor by the film metallization and polymer. The dissipation factor resulting from film metallization can be calculated with the known parameters. Analysis of the data in Figure 3 based on the fact that polypropylene dissipation factor is relatively constant which results in an edge resistivity which is essentially independent of frequency and with a value of about 0.016 Ω m of edge length, half of which would be contributed by each end of the capacitor. However, such an analysis is speculative as, for example, the surface resistivity of the film is not known

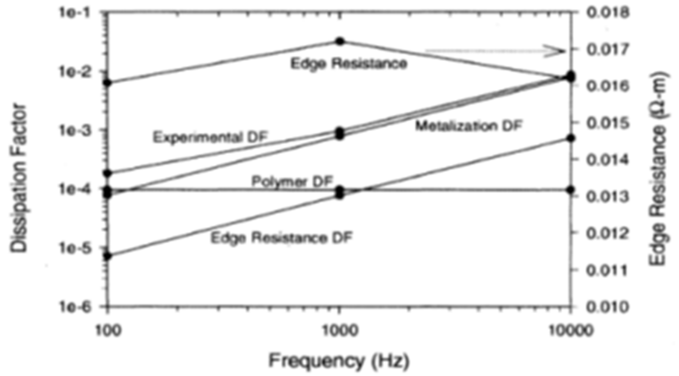

Fig.3:Dissipation factor vs. frequency. At 1 kHz, most of the dissipation factor results from the surface resistivity of the metallization. The contribution of any additional edge resistance caused by the imperfect edge connection is relatively small

precisely, and contributions of the film surface resistivity and edge resistivity are interchangeable as they are both proportional to frequency. Thus this Figure must be taken more for its presentation of the typical contributions of the polypropylene and metallization to the dissipation factor than for it's ''determination'' of a typical edge resistivity.

III. CONTACT SPOT EDGE RESISTANCE

Finite element analysis was used to evaluate the contact edge resistance as a function of contact spot centre-to centre separation. A constant current was generated by applying the voltage to a high resistance layer in serieswith the film metallization. The current through the metallization was thus independent of variations in the resistance caused by the edge connection. As a control, the voltage drop across the film was first computed with the entire edge of the film grounded. This formed the base voltage drop for a ''perfect'' edge connections.Next, aseries of semicircular contact spots of 0.3 mm radius and 5 mm centre-to-centre separation was placed along the opposite edge of the metallization, as shown in Figure 2. All of these spots could be grounded; alternate spots could be grounded, etc. to model varying contact spot centre-to-centre separation. The increase in voltage drop across the metallization to a grounded contact spot(for constant current) was measured as a function of the centre-to centre separation between grounded contact spots, from which the change in resistance from the case of a perfectconnection could be computed. This is change in resistance, as normalized to the length of edge, is the ''edgeresistivity'' as a function of contact spot centre-to-centre separation as shown in Figure 4. For an edge resistivity of0.008Ω m the contact spot centre-to-centre separation is about 10 mm for 0.3 mm radius spot contact.

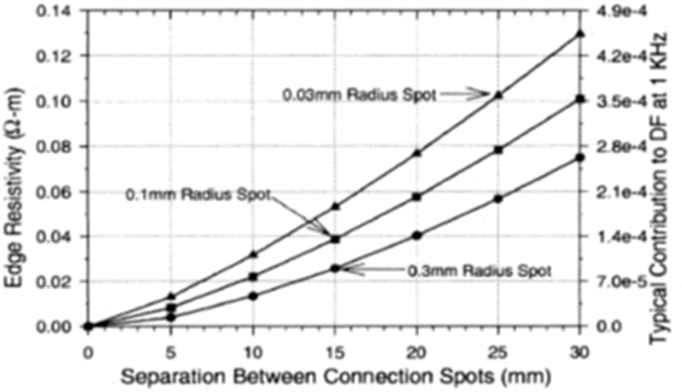

Fig.4:Computed edge resistivity vs. connection spot centre-to-centreseparation for spot with radii of 0.03 mm, 0.1mm, 0.3 mm. Forthe additional dissipation factor caused by the imperfect edge contactto be comparable to that of the polypropylene film at 1 kHz, thecontact centre-to-centre separation would have to be in the range of15 to 20 mm. For the contribution to be comparable with that of the metallization, the contact centre-to-centre separation would have tobe much greater than 30 mm. Thus even with very poor connection to the edge, the contribution of the edge contact resistance to theoverall dissipation factor is very small

IV. CURRENT DENSITY NEAR A CONTACT SPOT

Finite element analysis was employed to calculate the current density near a contact spot. The current densitywas then examined around a contact spot. As seen in Figure 5, which plots contour lines of constant current density around a contact spot in Figure 2, the current density appears to fall off as ry1 and to be constant as a function of azimuthal angle around the contact spot, as indicated by the contour lines which form semicircles which areconcentric to the spot. This analysis is confirmed in Figure 5, which plots the current density vs. radial positionfor the radial vectors indicated in Figure 5. Note that current density falls off as r^{-1} to beyond 1 mm radius andis essentially independent of angular position. These results provide a good basis for undertaking a 2-D axisymmetric analysis.

Based on the axisymmetric current density distribution around the contact spot, the change in contact spot-inducedresistance in going from spot radius r_0 to spot radius r for constant contact spot centre-to centre separation is calculated as follows: a small increment of drin r direction will result in a resistance increment of $R_{sq}dr/\pi r$for a semicircle contact spot, where $R_{sq}$is surface resistivity near the edge(2.5 Ω/sq) The total resistance $\Delta R$is the integration from $r_0$to r, which is

$$\Delta R = \int_0^r R_{sq}\frac{dr}{\pi r} = \frac{R_{sq}}{\pi}\ln\frac{r}{r_0} \qquad (10)$$

Thus given a finite element computation of the edge resistance for one contact spot radius, we can computethe edge resistivity as a function of spot radius as shown in Figure 6.

V. DISCUSSION

Figure 3 also shows the dissipation factor contributed by the edge resistance as a function of contact spot centre-to-centre separation at 1 kHz and for typical capacitor geometry. As seen from Figure 2, the dissipation factorcaused by the metallization is typically about 0.001 at 1 kHz. For the contact resistance to contribute a similardissipation factor, the centre-to-centre separation between contact spots would have to be untenably large.Thus the sprayed contact can be very ‘‘bad’’ without having a major impact on the measured capacitor dissipationfactor, which makes diagnosis after manufacturing problematic.

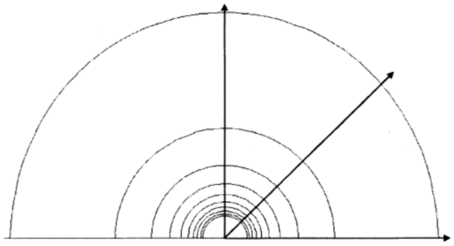

Fig.5:Contours at constant current density.The fact that the contour lines are concentric around the contact spot indicates axisymmetric symmetry

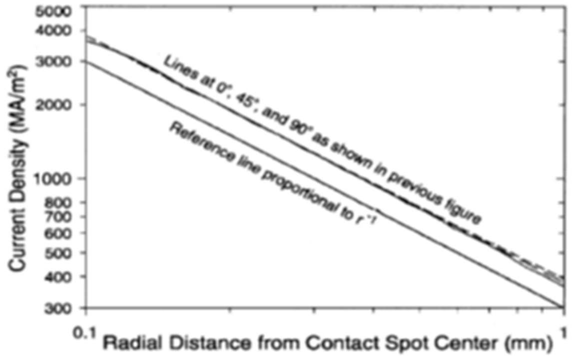

Fig.6**:** Current density vs. radial distance from contact spot centre along the three radial vectors indicated in Fig. 5. The plot indicates that the current density falls off as r^{-1} to a distance of at least 1 mm from the contact spot centre. Thus over the high current density region of interest, we can assume that the current density is axisymmetric and falls off as r^{-1}

The study on the end connection of metallized film capacitors ends shows the quality of thebonding between the film and sprayed metallization cannot be clearly detected by the regular measurement of dissipationfactor. So far there is no good way to tell it sincethe direct measurement is almost impossible.

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REFERENCES

[1] El-Husseini M.H., Venet P., Al-Majid A., Fathallah M., RojatG.,Ferreira J.A., , Manufacturing technology effect on current pulse handling performance of metallized polypropylene film capacitors. Journal of Physics D: Applied Physics, Vol. 36, 2003.

[2] Reboul, J.M., A. Cherifi and R. Carin "A new method for space charge measurements in dielectric films forpower capacitors", IEEE Trans DEI. Vol. 8. No. 5, pp. 753-759 October. 2001.

[3] S. S. Park, D. H. Park, J. H. Choi, B.W. Kim, and S. H. Kim,‘‘Characterization of Metal Contact Layer Prepared by Arc SprayMethod and Their Effects in Metallized Film Capacitor’’, Proc.5th Intern. Conf. Properties and Applications of Dielectric Materials,pp. 697_700, 1997.

[4] J. K. Nelson and Y. Hu, “Nanocomposite Dielectrics-Properties and Implications”, J. Phys. D: Appl. Phys., Vol. 38, pp. 213-222, 2005.

[5] R. W. Brown, “Linking corrosion and catastrophic failure in low powermetallised polypropylene capacitors,” *IEEE Trans. Device Mater. Rel.*,vol. 6, no. 2, pp. 326–333, Jun. 2006.

[6] L. Fuchang, D. Xin, L. Jin, Y. Zonggan, and W. Nanyan, “On thefailure mechanism of metallized polypropylene pulse capacitors,” in*Proc. Annu. Rep., Conf. Elect. Insul. Dielect. Phenom. (CEIDP)*, vol. 2, pp. 592–595. 2000.