Ac Metallized Polypropylene Film Capacitors (MKP) Dependent Values with Equivalent Circuit

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Abstract **- The dominant capacitor type used in a wide range of power and electronic circuit applications capacitors are Metallised polypropylene (MKP) capacitors . MKP capacitors offer high volumetric capacitor density, low cost, excellent frequency characteristics and a unique ability to recover from point failures in the dielectric film. These properties and especially the self healing capability make the MKP capacitor the capacitor of choice around the world for low power applications. Equivalent series resistance and capacitance of the traditional capacitor equivalent circuit, to frequency and the physical parameters of a capacitor are demonstrated. Spiral-wound cylindrical capacitors without schooping end spray connections were used to model metalized film disconnected from direct connection to the schooping in corroded capacitors are formulated relatedly.**

The simple formulae for equivalent series resistance and capacitance, derived empirically from the diffusion equation modelling, were found to accurately reproduce experimental results for model experimental capacitors. Source or connection impedance was found to accurately model a rise in dissipation factor at higher frequencies. The paper presents a best fit values for external inductance and source resistance were used in this modeling. Inclusion in the discrete model of a series resistance inversely proportional to frequency effectively modeled the flat low frequency dissipation factor of the commercial polypropylene capacitor.

***Keywords*— Metallised polypropylene (MKP); Dissipation factor; Capacitor equivalent circuit.**

1. INTRODUCTION

The capacitor type used almost exclusively for low power ac application is the The metalized polypropylene (MKP) capacitor.Typical applications are in snubber circuits, general filtering, and split phase low power electric motors and power factor correction circuits. The main development stages of MKP capacitor is shown in Fig.1. The first stage is the coiled cylindrical element, the second stage is the element with the sprayed ends, the third stage is the element with the two connection wires, and the fourth stage is the complete capacitor. A clear1.5mm to 3mm wide border on one edge of each ensures electrical connection is not made to the schoopingg metallization on that edge. Schooping metallization refers to plasma-arc-Typical examples of cylindrical MKP capacitors are shown in Fig. 2. The configuration of the normal connection of an MKP capacitor is shown in Fig. 3.Two polypropylene strips, typically between 6 and 12 micrometers in thickness, are co-wound on an insulating mandrel.

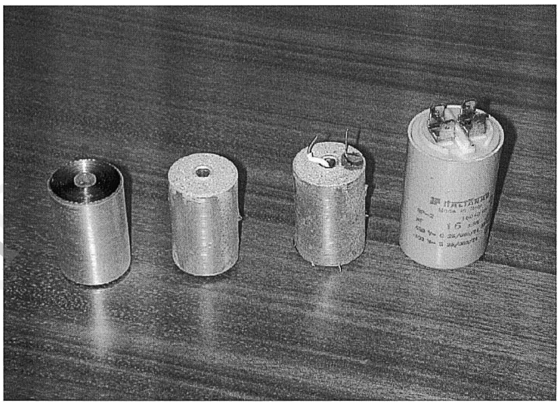

Fig.1: From left: the coiled cylindrical element: the element with the sprayed ends; the element with the two connection wires; and the complete capacitor.

The two spiral wound strips has metallization covering most but not all of their width. sprayed zinc particles which form a metallic cap on each end of the cylinder to which wires are later attached.

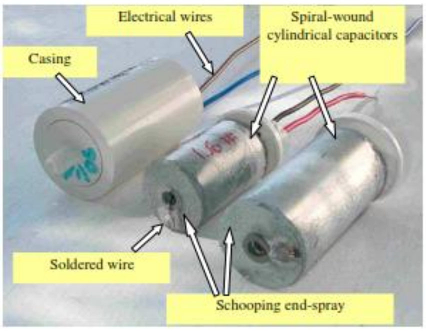

Fig. 2: Typical cylindrical low power MKP capacitors. The two removed from their cases are degraded through use.

Corrosion can breach the direct connection between the schooping end spray and the film metallization by forming a gap between the metallization and schooping. Such corrosion advances axially into the capacitor from each end cap. Commonly linked to the ingress of atmospheric moisture, the resultant loss of metallization adjacent to the schooping tends to advance progressively from the outer turns of the spiral winding into the inner turns since the outer turns are looser and allow easier ingress of moisture.

The result is a central area of metallization isolated from direct connection to the schooping but still connected somewhere deeper into the Winding where corrosion has not yet breached the margin. The extra electrical path length results in increased power loss and raised *DF* (dissipation factor).

2. DERIVED FORMULAE FOR DISSIPATION FACTOR (DF)

Derived formulae for *DF*, R_{ES} (equivalent series resistance of capacitor equivalent circuit), C_{ES} (equivalent shunt capacitance of capacitor series equivalent circuit), have been empirically developed to closely fit the results obtained from distributed circuit (diffusion) analysis ,of capacitors based on a model with both electrical connections at the same end. These formulae, reproduced in this report, show that breakpoints between upper and lower frequency regions are inversely proportional to the per–square capacitance, the per–square area resistance of the metal film and the square of the concatenated length (n) of the capacitor strip in number of squares. In the case of "disconnected" strip, n is the total length of the metalized strips in units of width of the metalized strips.

The formulae provide a link between the values of the components of the traditional capacitor equivalent circuit and capacitor build parameters and frequency. A resistance inversely proportional to frequency may be added in series with R_{ES} to model the typical constant dissipation factor at low frequency exhibited by polypropylene capacitors. Capacitors with partial edge disconnection can be viewed as a hybrid of two capacitors in parallel, one being a normal edge–connected capacitor with good characteristics, the other being an edge–disconnected low frequency capacitor with greatly increased loss. As little as 5% disconnections can increase the dissipation factor by factors exceeding one to two orders of magnitude. The composite simplified equivalent circuit model used in this study is shown in Fig. 3. Rs and Ls representing unavoidable external circuit (connection) series impedance are essential for upper frequency modelling.

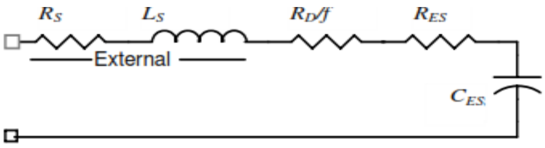

Fig.3: Modified capacitor equivalent circuit.

2.1 Partial disconnection in Modelling of Capacitors

Modelling of capacitors with partial disconnection and its effects on overall capacitor performance are not reported in the literature prior to the current study. In addition, the traditional capacitor equivalent circuit has components invariant with frequency. More accurate modelling may be achieved using diffusion equations based on distributed circuit equivalents of metalized thin film power capacitors. Long edge–disconnected strips of capacitor metallization maybe conveniently modelled using two spiral wound strips as shown in Fig. 2, but without the schooping edge connection. Electrical connections are made at the outer ends of the filmstrips as shown by the elliptical dots on the metallization.

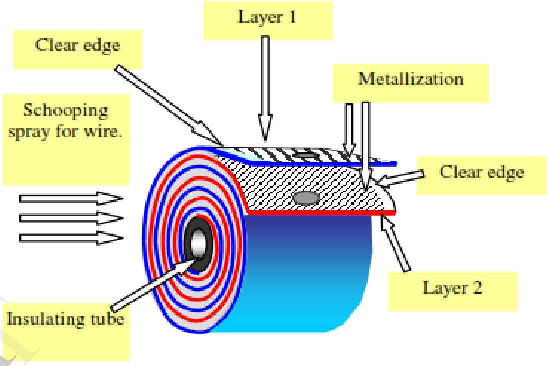

Fig.4: Normal spiral wound construction of cylindrical low power MKP capacitor using two vacuum metalized polypropylene strips.

2. 2 . Modeling Formula Related to the Metal Film Layer

Previously derived curve-fitting formulae for *RES* and *C ES* are:

$$R_{ES} = \left| \frac{2k\sqrt{\frac{R}{C}}}{\left(f + \frac{9k^2}{RCn^2}\right)^{0.5}} \right| \qquad (1)$$

and

$$C_{ES} = \left| \frac{2k\sqrt{\frac{C}{R}}}{\left(f + \frac{4k^2}{RCn^2}\right)^{0.5}} \right| \qquad (2)$$

where:

C is the effective capacitance per square area in the roll;f is the complex frequency (*Hz*); k=0.19947n is the number of concatenated squares – equal to the width of the strip in this example.R is the metalized strip spreading resistance (ohms/square) .

Breakpoint (*BP*) frequencies are:

$$f_{BP}(C_{ES}) = \frac{4k^2}{RCn^2} \qquad \textbf{(3)}$$

And

$$f_{BP}(R_{ES}) = \frac{9k^2}{RCn^2} \qquad \textbf{(4)}$$

Dissipation factor (*DF*) by definition is:

$$DF = 2\pi f R_{ES} C_{ES} \qquad \textbf{(5)}$$

Equations (1) and (2) can be substituted into (5) to produce an equation for *DF*:

$$DF =| 2\pi f \,\|[\frac{4k^2}{|[(f+\frac{9k^2}{RCn^2})^{0.5}]\,\|\,[(f+\frac{4k^2}{RCn^2})^{0.5}]|}] \qquad \textbf{(6)}$$

The frequency dependent modelling resistor for dielectric loss is *RD/f* and this becomes in effect, a part of *R*.

Assuming dielectric loss predominantly determines *R* at the region of constant *DF* for the capacitor, (5) can be used to determine the value of *R* for any given *DF*. Typically this value is 0.0002 for polypropylene capacitors.

$$DF =| 2\pi f \,\|(R_D / f)| C_{ES} \qquad \textbf{(7)}$$

Re-arranging:

$$R_D = \frac{DF}{2\pi C_{ES}} \qquad \textbf{(8)}$$

R_D is the dielectric loss modelling resistance.

3 EVALUATION RESULTS

A commercial cylindrical polypropylene capacitor without schooping end-spray was used to model a section of a capacitor without direct edge connection. Metallization width was 35 mm (corresponding to a square of length) and the strip length was 39.2 m or 1121 squares. Resistivity was 2.92 Ω/square and total nominal initial capacitance was 8.02 µF.

After measurements were taken at one particular length, the capacitor was progressively unwound and further readings taken at various lengths.

The connection from the capacitor body to the HP 4192A Impedance Analyzer incurred an unavoidable length of metalized film representing up to 20 Ω or more of resistance that was not part of the distributed capacitance. Shown in Fig. 4 is an overlay of experimental and formula predicted results For DF. The general correspondence was excellent except at very low frequency in the 33-square trace where the actual *DF* is higher than predicted. Connection resistance caused the rising inflexion of the graphs above 10 kHz, the formula (6) predicting a flat *DF* asymptote of 1.0 in this region. With metal film resistance of 2.92 Ω per 35mm, the connection resistance (Rs) were 18 Ω, 23 Ω and 13 Ω respectively for the 33, 121 and 721 square lengths. Corresponding values of *RD* were 135 Ω, 36.9 Ω and 6.19 Ω.

3.1 New Commercial Capacitor Testing

A new 8µF, 415V commercial polypropylene capacitor had estimated values, derived from physical dimensions and measurement, of a total length "*n*" of 829 squares and a metal film resistivity of 2.8646 Ω/square. The metalized strip was 35 mm in width and 29 m long. *C* was 9.67 nF/square.

The two theoretical breakpoint frequencies affecting D_F were 5.8 MHz and 13 MHz as determined using (3) and (4) respectively. These were well above the typical self resonance frequency of around 100 kHz to 200 kHz for a capacitor of this size and type.

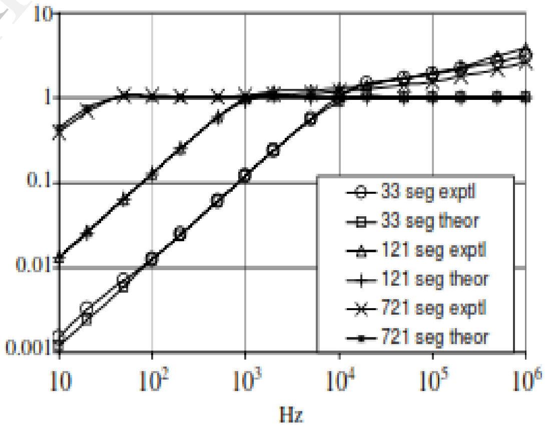

Fig.5: Formula derived and measured DF for single end connected capacitors.

The R_D term determined by (8) to model dielectric loss, was 3.97 Ω. Best fit values for *Rs and Ls* were 0.004 Ω and 40 nH respectively. Theoretical and measured results are shown in Fig. 5

4. CONCLUSION

Diffusion equation modelling based on distributed *R–C* capacitor topology gave accurate measures of the fundamental frequency characteristics of a power capacitor. High frequency peaking of the dissipation factor of single-end-connected capacitor was effectively modelled with the addition of an external resistance representing connection resistance to the measuring circuit.

Simple formulae for equivalent series resistance and equivalent series capacitance approximating the results of more complex diffusion equation modelling were found to accurately model measured dissipation factors for capacitors not only for single–end connected capacitor strips, but for the normal double–end connected capacitor configuration. Inclusion in the capacitor equivalent circuit of a series resistance element inversely proportional to frequency was found to approximate the typical low frequency dissipation factor determined by dielectric loss in a normal double-end connected power capacitor. Addition of lumped external inductance effectively modelled the self-resonance peak.

5. REFERENCES

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