High Crystalline Segmented Polypropylene Capacitors Offer Increased Energy Density

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ABSTRACT

High crystalline segmented metallized polypropylene capacitors are the component of choice for many more DC Filter, energy storage and similar applications for the 21st century. With the introduction of higher crystalline and higher temperature dielectric, the size of segmented metallized polypropylene capacitors were reduced at least 33 percent while increasing the life expectancy and reducing the costs over previous designs. Higher temperature operation of at least 110°C is also accomplished with this material type. Capacitors are now manufactured using the combined segmented and high crystalline metallized polypropylene technology that allow denser power system packaging and lower manufacturing costs than other capacitor choices.

INTRODUCTION

Film capacitors are known to have performance traits superior to other capacitor types. These traits include lower heat dissipation and longer life. For applications requiring large capacitance values in DC applications, aluminum electrolytic capacitors were often chosen over film types because film capacitor volumetric efficiency was not sufficient. Film capacitors are now produced using high crystalline segmented polypropylene that offer energy densities acceptably close to those achieved with aluminum electrolytics.

Most of the size improvements prior to the late 1990's focused on metallization techniques with the greatest improvements in large DC film capacitor banks from segmented polypropylene. This revolution reduced volumes by over 50%. The 21st century brought high crystalline polypropylene with another volumetric improvement of 33% due to increased voltage capabilities. The additive effects of these improvements are large film capacitors in many voltage levels less then one third the size of product produced in the early 1990's.

Polypropylene has become the dominant dielectric for metallized film capacitors. This is due to the large amount of film required to justify any volume manufacturing of a dielectric film and the advantagous dielectric properties of biaxially oriented polypropylene (BOPP) film typically used in capacitors. BOPP has a higher dielectric strength than a major alternative film, PET. This is believed to be because the crystalline phase is aligned in the plane of the film. This puts the electric field in the direction of low conductivity. [1].

The advances in metallization techniques that have been previously adopted included the use of heavy edge metallization. This is where the body is made lighter in metallization to increase voltage capability while the edge remains heavier to maintain current handling capability. Segmented film was subsequently adopted with the major improvements in segmented patterns and deposition processes in the 1990's. Segmented film involves dividing the film capacitor into many smaller segments in order to reduce the potential for catastrophic failure. A self-healing in one segment is accomplished without causing additional damage to other segments preventing an "avalanche" effect of additional clearing and damage. This increases safety and allows higher voltage stresses.

High crystalline polypropylene or HCPP is a significant improvement in the base polypropylene film. The higher crystallinity leads to higher breakdown voltages and reduced film shrinkage at increased temperatures. The previous generation biaxially oriented polypropylene has had operation to 105°C with a significant de-rating from a 70°C reference, whereas HCPP has operation to 110°C or higher with less de-rating.

METALLIZED CAPACITOR PRODUCT

The biaxially oriented polypropylene is typically metallized on one side with aluminum, zinc or an alloy of zinc with a small percentage of aluminum. Higher metallization thicknesses oxidize slower and therefore have less capacitance loss in application where thinner metals cause less damage during the self-healing process. Due to segmented film reducing the damage potential during the self healing process it can allow thicker metallization leading to lower capacitance loss and lower heating in power electronic applications .

Metallized polypropylene is made into a capacitor product starting with a winding procedure. Both round windings on solid cores and flat windings on soft cores that are crushed are employed. Self-clearing characteristics are a strong function of the pressure within the layers of the winding which is more uniform with a round than a flat winding whereas flat winding technology has better volumetric efficiency. Clearly with better equipment for flat winding and proper air evacuation during thermal treatment, flat winding is preferred.

The wound capacitor elements are sprayed with metal to facilitate attachment. This sprayed metal is often called end-spray or schooping. It is essential to long term reliability of a metallized film capacitor that the bond of the sprayed metal to the metallized film remains intact. The stability of the metal bond depends on the winding design, the metal application procedure and that the film shrinkage is not too high after the application of the metal.

The metallized film windings that have been metal sprayed are then packaged to protect them from the environment and allow the user to connect to them. The packaging type depends upon whether the capacitors are oil impregnated or are potted in an insulating resin. Oil impregnation requires a sealed container that adds some cost, size and increased inductance due to connection distances. Sealing with an insulating resin such as a UL approved epoxy or polyurethane can reduce size and lower connection distances. Oil impregnation allows an increase in dielectric operating voltage with the increase dependent upon manufacturing procedures and the type of dielectric film that is used.

NEW METALLIZED HCPP CAPACITORS

Biaxially oriented polypropylene (BOPP) is polypropylene film that is stretched in two directions during the manufacturing process. Stretching is carried out at an elevated temperature below the crystalline melting point. Polypropylene is partially crystalline and there are always crystalline and amorphous phases. The degree of crystallization is typically between 50 and 60%. Higher crystalline polypropylene has an average increase in crystallinity of 3-4%.

Dielectric withstand tests of metallized film samples can be performed on sheets of film or in wound capacitor samples for comparitive purposes. Table 1 shows a comparison in dielectric withstand voltages between capacitor samples made with 6 μm thick polypropylene metallized with the same zinc process. A comparison is shown between a specific biaxially oriented polypropylene (PPTS) and HCPP. Breakdown voltage levels were recorded at three different temperatures. It was observed the dielectric withstand voltage was significantly increased with high crystalline polypropylene [2].

TABLE 1.
AC Breakdown Voltage Versus Temperature
6 μm zinc metallized PPTS and HCPP capacitors

Temperature	PPTS BDV	HCPP BDV
20°C	1200-1500	1720
85°C	1000-1300	1420
100°C	900- 1150	1300

During the manufacture of the film, heat treating is performed to relieve stresses and preshrink the film. The film will also shrink during additional heat treating performed during capacitor manufacturing. The higher temperature properties of high crystalline polypropylene allows the thermal treatment to be performed at increased temperatures. The higher temperature allows getting more air out of the capacitor winding without destroying it with the dual benefit of permitting higher temperature operation.

Studies have been performed by CDE to determine whether segmented HCPP film allows increased dielectric voltages for both capacitors impregnated with vegetable (rapeseed) oil and non-impregnated capacitors that are resin sealed. One study compared 5 micron (μm) thick metallized polypropylene that was not HCPP to an identical prepared product using

HCPP. This produced four sample groups of 8 capacitors per group that were approximately 120µF each. The groups being with and without HCPP and with and without oil. The only difference between the HCPP and the non-HCPP samples was the heat treating procedure. The HCPP samples were heat treated at higher temperatures during capacitor manufacture.

The capacitors from the four capacitor groups were all subjected to an accelerated aging study. This was performed at 1000 Vdc and 85°C. The stress on the 5 µm film was therefore 200 V/µm. Figure 1 shows the results of this testing. The non-impregnated regular polypropylene had demonstrated an average capacitance loss of 8% at 1000 hours and was discontinued. The test continued to 1500 hours with the other three groups. All three groups had capacitance values above their starting points at 1500 hours that is a desired result due to electrostatic contraction [3]. It can be observed that the HCPP in vegetable oil had a lower capacitance degradation than the dry resin sealed HCPP group. What is also important is the dry resin sealed HCPP group outperformed the oil impregnated polypropylene capacitors that were not high crystalline film.

The results of this 5µm capacitor study and other studies performed by CDE on various capacitor sizes and HCPP dielectric thicknesses provide many new opportunities in metallized film capacitors. The increase in dielectric stress as has been achieved with HCPP translates into a capacitor volumetric improvement of 30-50%. This improvement is larger with the dry resin sealed capacitor types then the oil impregnated types with respect to the previous products.

Using the segmented HCPP film, CDE has now developed new dry resin sealed packages and reduced size oil filled packages to take advantage of the new material properties. Figure 2 is an example of a dry resin sealed capacitor rated 1500 µF at 1000 Vdc with a ripple current rating of 70 Arms at 55°C. This NWL ER-Series capacitor would replace between 4 and 9 computer grade electrolytic capacitors wired in a series and parallel arrangement. The film capacitor requires no series wiring with the associated balancing resistors and additional bus-work.

The HCPP film high temperature capabilities also allows it to be used in applications where other specialty high cost films were used. These include many requirements that were previously met with polycarbonate film. HCPP film can be used continuously at 110-115°C with intermittent operation at 125°C. Polycarbonate can be used continuously up to 125°C yet often is over-specified due to self-healing characteristics that are not ideal. A segmented HCPP film capacitor operating at 110°C would typically be one half the volume of a metallized polycarbonate capacitor.

FIGURE 1.
Performance of Five Micron Segmented Film In Capacitors

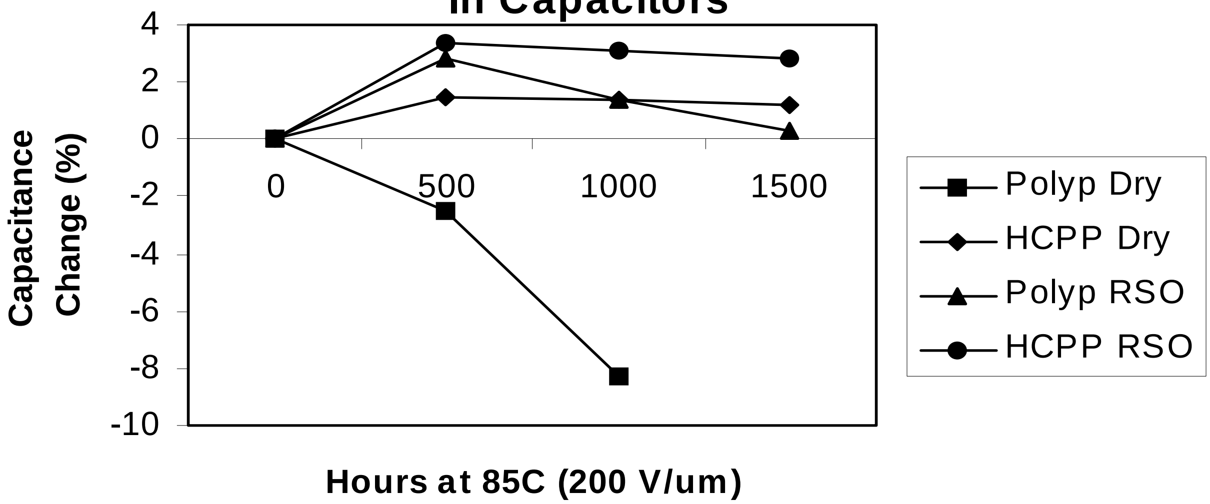

FIGURE 2. CDE ER-SERIES dry capacitor using segmented HCPP film

One of the previous limitations for metallized polypropylene was that it was only available in thicknesses such as 4μm and above. In the 1990's, 3.5 μm polypropylene was available yet not common. With the improved mechanical properties of HCPP such as greater rigidity, film in the range of 3.0 μm thick is available in industrial quantities. The applications for these thinner materials include high volume products such as hybrid electric automobiles. As the film and capacitor production procedures for these higher volume applications are refined, the comparisons between metallized film and other capacitor technologies will change again.

CONCLUSIONS

An important advancement in polymer film capacitors has been introduced. The use of high crystalline segmented polypropylene allows a film capacitor to be used in many more applications to take advantage of long life and lower power losses. These new capacitors are available in packages including oil filled and dry resin sealed. The new dry capacitors using HCPP often have higher capabilities than previous generation oil filled products. Products using high crystalline metallized polypropylene can now operate at higher temperatures with less need for cooling devices and reduced component spacing. New products are now being developed taking into account the improved properties of this film.

REFERENCES

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