CDÉ CORNELL DUBILIER
ENERGIZING IDEAS

Technical Note

Motor-Run Capacitors

ABSTRACT

This technical paper discusses the larger motor-run capacitors (330 Vac to 440Vac and 20 to 50 µF) for 1/4- to 1-Hp motors. This article covers some of the evolving liquid-filled polymeric film capacitor technology advances which are continuing to improve motor-run capacitor efficiency. The article discusses the materials and construction techniques as well as the technical history of these materials and construction techniques highlighting the present day metalized film technologies. The article also discusses the electrical characteristics including loss data (watts/KVA) and how the different technologies compare.

INTRODUCTION

Motor-run capacitors for appliance applications are, and will continue to be, important to appliance OEMs.

While electronic controllers such as variable speed drives (PWM inverter power source), brushless permanent magnet motors with electronic drives, and switched-reluctance motors are replacing some motor-run capacitors, these technologies are still expensive and limited to premium-priced appliances. In addition, competing lower cost technologies such as microprocessor-controlled triac switching on permanent-split-capacitor induction motors and adjustable AC capacitors on single-phase induction motors are providing lower cost alternatives to the complete electronic control approaches and still use motor-run capacitors.

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As power components, motor-run capacitors are exposed to large amounts of reactive power for the complete operating life of the motor. Unlike DC filtering capacitors or electronic control capacitors, motor-run capacitor energy losses are measurable and contribute to the total energy loss within the motor circuit.

At the same time, efficiency and environmental issues continue to drive the appliance industry to improve efficiency rates with seasonal energy efficiency ratio (SEER) being driven up yearly. Motor-run capacitor losses are a small but measurable contributor to SEERs.

MATERIAL

For many years, polymeric film construction has been the most widely used motor-run capacitor technology in the appliance Indus try. Ceramic and tantalum capacitors are not practical for typical motor-run capacitor ratings (220 to 440 Vac, 5 to 7µF) because they are large and expensive. The capacitor energy losses for aluminum electrolytic capacitors are too large for continuous reactive power applications. While polymeric film capacitors are very efficient, they do have meaningful measurable losses. Typical loss ratings are 0.4 Watts/KVA reactive power rating of the capacitor with 1.0 Watt/KVA being a limit per EIA Standards.

This is a small number that has come down by a factor of two during the last ten years (0.6 to 0.3 Watts/KVA) and will continue to come down in a very gradual, evolutionary mode. Polymeric dielectric film motor-run capacitors are available in both a dry potted construction as well as a dielectric liquid-filled construction packaged in a metal or a plastic case. Liquid-filled construction is used for all voltages, especially voltages above 330 Vac. The appliance industry also uses dry construction for voltages at and below 300 Vac.

Discussion in this article will be limited to larger motor-run capacitors (330 Vac to 440 Vac and 20 to 50 µF) for 1/4- to 1-Hp motors. This article covers some of the evolving liquid-filled polymeric film capacitor technology advances which are continuing to improve motor-run capacitor efficiency.

FILM CAPACITOR CONSTRUCTION

A typical polymeric film capacitor section is shown in Figures 2A &. 2B. The capacitor consists of a thin dielectric grade polypropylene film with a very thin vacuum

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metallized electrode layer which is wound into either a round or an oval cylindrical section. Other dielectric films such as polyester, polycarbonate and polyphenylene sulfide, are available but have lower temperature ratings than polypropylene film and cannot be used for motor-run capacitor applications.

A typical 40 µF capacitor contains over 200 meters of film to achieve the surface area that will provide the required capacitance. The capacitor section consists of right- and left-hand metallized film as shown in Figures 1A & 1B. The margins are unmetallized strips on alternating right- and left-hand sides of the films. In addition to the margins, the film layers are offset, producing a stepped surface at each end of the film section.

Electrical connection is made to the alternating film layers through a porous metallized end spray applied to both ends of the section. The stepped end surface produced by the film offset provides some of the mechanical strength which holds the metal end spray to the ends of the section. The liquid dielectric fluid provides a diffusion barrier against moisture and air which contribute to long term aging of the capacitor. The diffusion barrier eliminates corona in the stepped surface region and provides insulation between the leads corning out of the section.

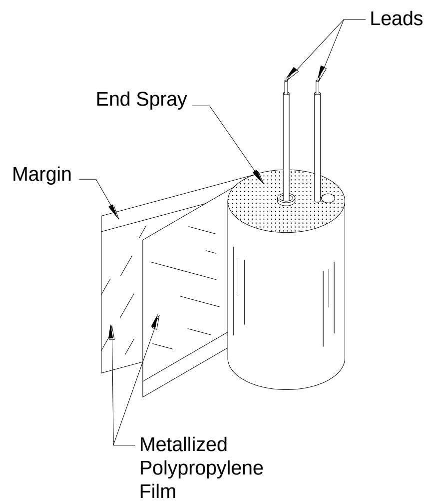

Fig. 1A – Metallized polypropylene film capacitor section with leads attached for notched interrupter capacitor assembly.

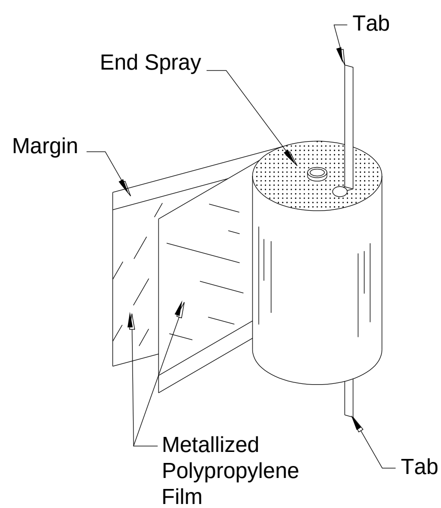

Fig. 1B – Metallized polypropylene film capacitor section with tabs and a spot welded interrupter for the metal capacitor assembly.

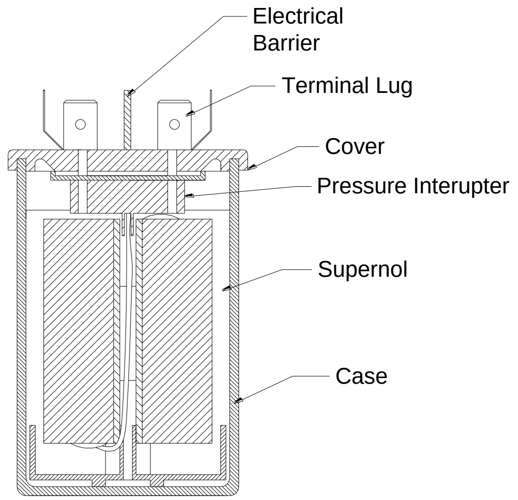

Fig. 2A – Plastic case, liquid filled, notched pressure interrupter capacitor assembly.

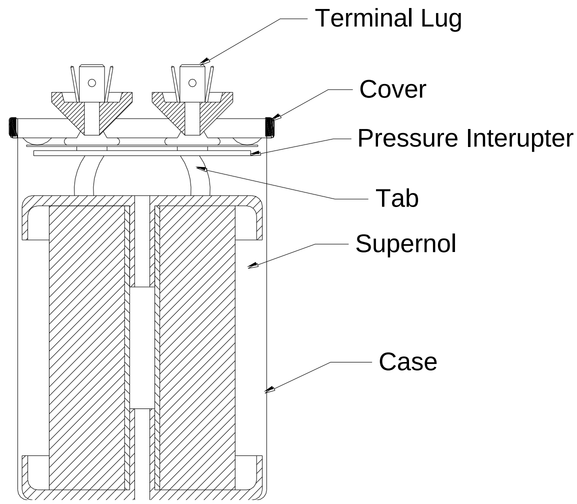

Fig. 2B – Metal case, liquid filled, tab spot welded pressure interrupter capacitor assembly.

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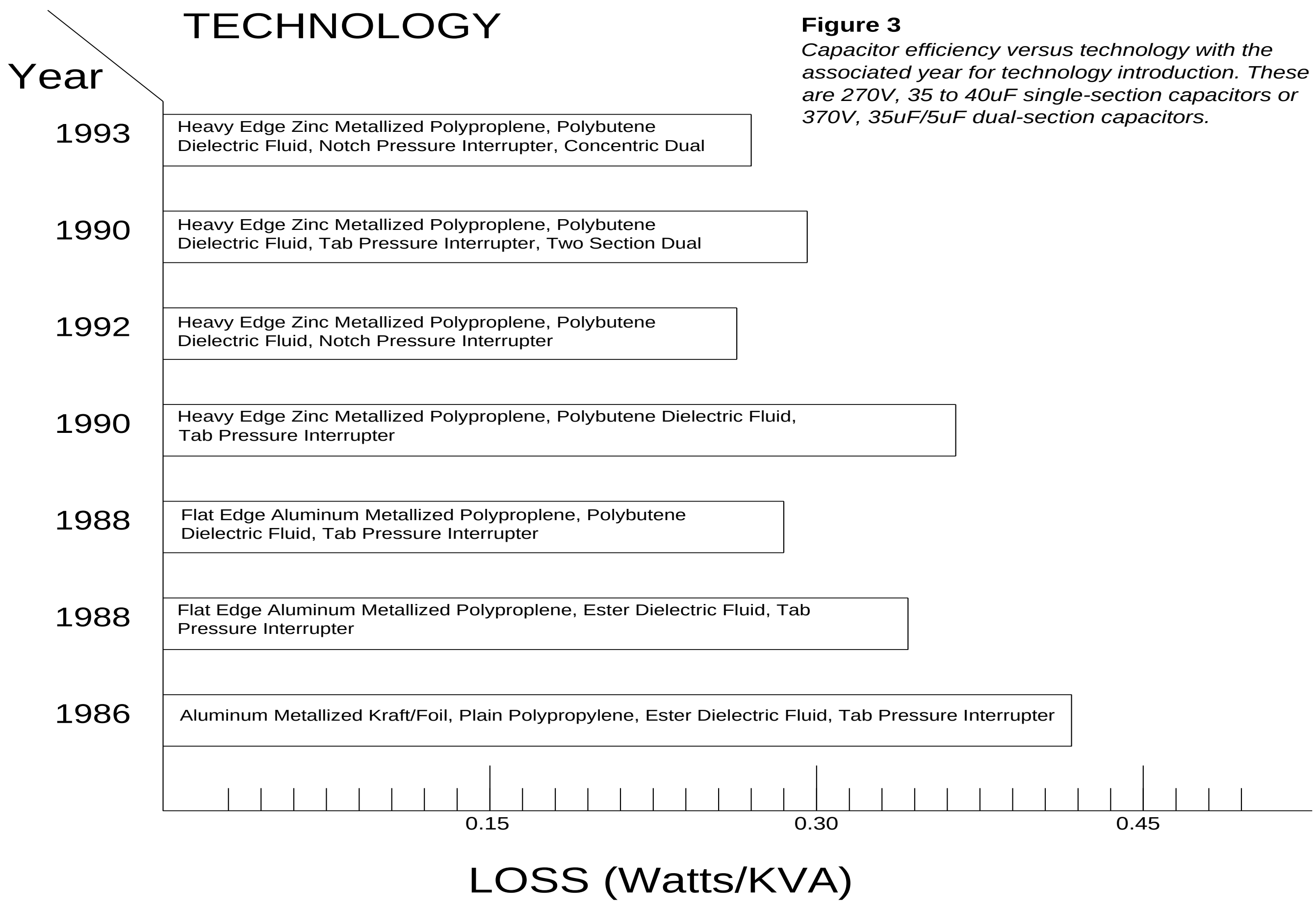

Figure 3
Capacitor efficiency versus technology with the associated year for technology introduction. These are 270V, 35 to 40uF single-section capacitors or 370V, 35uF/5uF dual-section capacitors.

The film capacitor can be modeled electrically. Rs is the series resistance and is made up of all the resistive losses in the capacitor: lug to section lead resistance, section lead to section end spray resistance including the lead resistance itself, end spray to metallized electrode resistance, and metallized electrode resistance itself.

The dielectric film also has some losses referred to as Rp. These losses consist of dipole dielectric losses (both stretching and rotation), leakage current losses through the polymeric film, clearing losses in the metallized layer and corona losses if Corona exists.

The capacitor construction has a small magnetic coupling flux between the two leads which appears as inductance labeled as Ls. For 60 Hz applications (motor-run capacitors), Ls is not a factor and can be neglected. The resonant frequency is typically above 10 KHz. For metallized polypropylene film capacitors for 60 Hz applications, the losses from Rs are much larger than the losses from Rp, and normally Rp is neglected.

This is not the case for motor-run capacitors where the metallized electrode is vacuum deposited on thin Kraft paper and the polypropylene film uses the metallized kraft paper as the electrodes. Today, capacitor ratings with voltages above 525 volts often use metallized kraft electrodes, and dielectric fluid that both seals the section and impregnates the kraft paper. When the dielectric fluid impregnates the capacitor section, it becomes part of the dielectric and contributes to the film losses or Rp. For metallized kraft paper electrode construction, losses from Rp are a factor that must be included, and results in losses more typically in the 0.6 Watt/KVA range. (These capacitors are not covered by ANSI/EIA RS456A).

EVOLVING TECHNOLOGY

Since 1977, when the liquid-filled metallized polypropylene film electrode motor run capacitors technology was introduced, improvements in the technology have reduced capacitor energy losses by a small, but real amount.
The first significant change is the profile of the metallized electrode from flat edge to heavy edge, providing an improved connection to the end spray resulting in less contact resistance. The heavy edge profile has a higher body surface resistance compared to the original technology and a slightly lower edge surface resistance. Though this higher body resistance increases the electrode resistance and the clearing loss (Rp), these two increases are offset by the decrease in the contact resistance (Rs).

The second change, aluminum metallization to zinc metallization, lowers the clearing loss. This change requires a very dry sealed section, improves the clearing performance of the metallized film and, therefore, allows the polypropylene film to operate at a higher electric stress, in a smaller and lower cost capacitor. This change contributes to a slight increase in capacitor-energy losses.

The third change is a move from low-molecular weight, low-viscosity Ester type dielectric fluids (D1 (2-ethylhexyl) phthalate, Dioctyl phthalate) to high molecular weight with higher viscosity type hydrocarbon dielectric fluids (polybutene, polypropylene glycol). The impact of this dielectric fluid change on short-term losses is small, as the fluid does not impregnate the wound section.
However, it does lower the leakage current from the section to the case and

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consequently have a small impact on energy losses. Over a longer time period, the fluid impact is significant. The low molecular weight, low viscosity Ester dielectric fluid is slowly absorbed by the polypropylene film causing the film to swell. The absorption is in the 5-percent to 10-percent range by weight, compared to 2.5 percent for the high molecular weight, high viscosity hydrocarbon dielectric like polybutene.

This absorption of the dielectric fluid by the polypropylene dielectric film leads to reduced dielectric strength, which can cause dielectric problems at the higher temperatures. It also leads to cracks in the metallized layer which increase the resistance and the losses within the film capacitor.

Most liquid-filled motor-run capacitors are self-protected through the use of a pressure interrupter within the capacitor. This pressure interrupter functions like a fuse in series with one of the leads between the capacitor section and the terminal of the capacitor. The pressure interrupter and the connection to the terminal lug contribute to the total losses of the capacitor.

There are two basic types of pressure interrupters used in motor-run capacitors. For capacitors packaged in metal cases, the thin metal strip called a tab connected from the section is spot welded to the bottom of the lug mounted to a panel held to the underside of the cover. (See Figure 1B and 2B) The second pressure interrupter is a notch in a round lead which connects the section to the terminal lug. The notch in the round wire has a smaller resistance than the thin metal tab spot welded to the terminal. (See Figure 1 A and 2A). Though the impact of this improvement is small, it is measurable.

The final advancement is the movement from two single-section capacitors packaged as a dual capacitor in an oval case to concentric sections packaged in a round case. Dual capacitors are used in appliances which have a compressor and fan, such as air conditioners, and they are also used in high-intensity lighting fixtures which are moving from single- to dual-rated output devices. A dual capacitor has three terminals with a common terminal between the two concentric sections within the capacitor. The total losses of dual capacitors wound as concentric sections is slightly less than the losses of dual capacitors wound as two separate sections and combined into a dual oval package.

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ACTUAL DATA

Capacitor losses are measured using an AC bridge and are reported as dissipation factor. To get data with sufficient resolution to differentiate small differences in the dissipation factor requires measurements using a four-terminal connection and full-rated AC voltage. As a final confirmation of the dissipation factor data, an energy balance is done wherein the temperature rise in the capacitor is measured and used to calculate the dissipation factor based on heat loss from the capacitor through connections to the air. One-hundred percent end-of-line quantity measurements are done in the capacitor industry using a two-terminal bridge with low voltage at 1,000-Hz. Although this data lacks high resolution, it does have sufficient accuracy to demonstrate the improvement trend in energy loss reduction. The data shown in Figure 3 is quality data taken from CDE records dating back to 1986.

Figure 3 presents data for the watts loss for the evolving metallized capacitor technology from metallized kraft electrode to current metallized polypropylene film technology. The year shown on the left-hand axis corresponds to the date when the technology was manufactured in large quantities at CDE.

The bottom five technologies refer to single-section capacitors while the two top technologies refer to dual-section capacitors. The transition from aluminum metallized kraft/foil electrodes with plain polypropylene and Ester dielectric plus a tab spot weld pressure interrupter can be seen.

Heavy-edge zinc-metallized polypropylene with polybutene dielectric and a notched pressure interrupter resulted in a 50-percent reduction in the losses. The transition from a two-section dual capacitor with a tab spot weld pressure interrupter to a concentric dual capacitor with a notched pressure interrupter resulted in a 15-percent reduction in the losses.

The change to the zinc heavy-edge metallized polypropylene film did not result in an energy loss reduction in 1990. However, later improvements in the capacitor design did result in energy-loss reductions. The notched wire interrupter design in 1992 is an example of one change that did result in reduced energy losses.

LOSS MAGNITUDE

For a typical 1/2-Hp, single-phase induction motor operated at 115 Vac, the auxiliary

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winding would use a motor-run capacitor with a rating in the range of 30 – 50 µf and 370 Vac (16). Using these ratings plus a motor efficiency of 70-percent, the table below summarizes the power and the losses within both the motor and the capacitor:

Motor apparent power:	532 Watts
Motor losses:	160 Watts
Capacitor apparent power:	2064 Watts
Capacitor losses:	0.6 Watts
(Using 0.3 Watts/KVA)	

This table is based on very typical application performance. In reality, the speed and the load of the motor influence the auxiliary impedance which changes the current through the capacitor. In addition, the current through the auxiliary winding can be distorted leading to some harmonic current content. Under realistic conditions, the capacitor losses are larger and can be as high as 2 Watts.

Though it is very simplistic, the table does provide a set of numbers for discussion. The numbers in the table can range by a factor of two to three, depending on the motor and capacitor efficiencies, plus the speed and load of the motor. As can be seen, the difference between a very efficient (0.3 Watts/KVA) and a moderately efficient motor run capacitor (0.6 Watts/KVA) can be 0.5 to 1 Watt for the 1/2-Hp example. Though the difference is not large, it is measurable. As a percentage of the total motor loss, the motor-run capacitor loss will range from 0.5-percent to 5-percent.

SUMMARY

Motor-run capacitors are highly efficient, but losses do exist and must be included when reviewing appliance efficiency. Motor-run capacitors continue to provide measurable improvement in efficiency. Technology has increased the efficiency of the motor-run capacitor by over 50-percent and this trend is projected to continue. -AM-

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