FILM CAPACITORS

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Mylar Capacitors

A capacitor is a charge storage device. When two plates are separated by a specific distance in a particular medium such as mica, plastic films, oil, etc., capacitance is formed between the two plates. One plate acts anode and the other as cathode. It is measured in farad.

Capacitance is the amount of electrically charged carriers a capacitor can store per unit of voltage. Capacitance formed is directly proportional to the area of plates and inversely proportional to square of distance between them, Mathematically,

\[ C = \varepsilon_0 \varepsilon_r \frac{A}{D} \]

A capacitor has four important parameters.
- Rated Capacitance
- Rated Voltage
- Insulation Resistance
- Loss Factor(Tanδ)

**Rated Capacitance:**

The rated capacitance \( C_R \) of a capacitor is the value for which it is designed, and that is indicated on it.

**Measuring conditions:**

<table>
<thead>
<tr>
<th>Measuring conditions</th>
<th>Standard conditions</th>
<th>Referee conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>15 to 35 deg Celsius</td>
<td>(23+/-1)deg Celsius</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>45 to 75%</td>
<td>(50+/-2)%</td>
</tr>
<tr>
<td>Ambient atm. Pressure</td>
<td>86 to 106 kPa</td>
<td>86 to 106 kPa</td>
</tr>
<tr>
<td>Frequency</td>
<td>1 kHz</td>
<td>1 kHz</td>
</tr>
<tr>
<td>Voltage</td>
<td>0.03.Vr(max 5V)</td>
<td>0.03.Vr(max 5V)</td>
</tr>
</tbody>
</table>

**Rated Voltage:**

Rated DC voltage:

The rated voltage \( V_r \) is the DC voltage for which the capacitor is designed. It is defined as the maximum DC voltage that may be applied continuously to the capacitor terminals at any temperature between the lower category temperature \( T_{min} \) and the rated temperature \( T_r \).
**Rated AC Voltage:**

It is the maximum RMS voltage at specified frequency (usually 50 Hz) that may be applied continuously to the terminals of capacitor at any temperature between the lower category temperature $T_{\text{min}}$ and the rated temperature $T_r$.

**Insulation Resistance:**

It is the measure of resistivity in dc. Under a stationary dc voltage, a leakage current flows through the dielectric and over the capacitance surfaces.

Rins = $V$ (applied voltage)/$I$ (Leakage current)

<table>
<thead>
<tr>
<th>Rated voltage $V_r$ of capacitor</th>
<th>Measuring voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10V \leq V_r &lt; 100V$</td>
<td>$(10 +/- 1)V$</td>
</tr>
<tr>
<td>$100V \leq V_r &lt; 500V$</td>
<td>$(100 +/- 15)V$</td>
</tr>
<tr>
<td>$V_r \geq 500V$</td>
<td>$(500 +/- 50)V$</td>
</tr>
</tbody>
</table>

**Loss factor:**

The tangent of loss angle is the ratio of power loss of the capacitor to the reactive power of the capacitor at a sinusoidal voltage of specified frequency.

$\tan \delta = 2\pi f C ESR$

$ESR=$ Equivalent series resistance ($Rs$)

Equivalent circuit of a Capacitor:

Where $L_s$ is the inductance effect

$Rs$ is the ESR

$Rp$ is Insulation resistance

$C$ is the capacitance
Here in this type of capacitor, the film is in wound construction. As the current flows in wound it forms an EM field which gives rise Self-inductance.

Then the Series resistance is due to resistance of foil, lead wire weld contact resistance and lead wire resistance.

Parallel resistance is due to the insulating film between the two foils.

In a capacitor, Voltage lags the current by 90 degrees.

\[ \tan \delta = \frac{ESR}{Xc} \]

**Power Dissipation:**

The power dissipated by a capacitor is a function of the voltage across or the current (I) through the equivalent series resistance ESR.

\[
P = \omega x C x \tan \delta \times V^2 \\
P = 2 \pi f x C x \tan \delta \times V^2 \\
\]

Where \( f \) = frequency, \( \tan \delta \) = maximum value specified, \( V \) = rated voltage

**Material used:**

- Aluminium foil,
- Dielectric film – Polyethylene terephthalate (PET), Polypropylene (PP)
- Protective films,
- Lead wire (Tin plated copper cladded steel)

Aluminium foils are used as electrodes. It has good electrical conductivity.

PET – dielectric constant 3.2, \( \tan \delta \) : 0.0050.

PP – dielectric constant 2.2, \( \tan \delta \) : 0.0005.

**Manufacturing Process:**
Winding:

Winding is the process of rolling the foils and films in a cylindrical shape and then covering them with an insulating film. Welding of lead wire is done by spot welding. After the winding, the capacitance value is slightly less than the specified value due to the air gap in it.

Types of winding structures:

- Two film without protective
- Two film with protective
- Four film without protective
- Four film with protective
- PET Self healing using metallized film(TSH)
- Polypropylene Self healing(PSH)

The length and the width of foil determine the capacitance value. In some machines the width of foils may vary by .5 mm. This is to avoid slipping of one foil over another but the overlap area only decides the capacitance value. This structure gives more reliability and the capacitance value will not change more.

The length of dielectric is always more than the foil for sealing purpose and width of film also more than the width of the foils this is to avoid the charge jump between two layers at high voltages.

Two film without protective:
Unlike parallel plate capacitors, here in wound type the capacitance value is doubled. It can be understood from the below shown diagram.

From figure, it is clear that it forms a capacitor C1 between two foils. But when it goes in second and more wounds, there is another interaction. So it also forms a capacitance C2. Hence the capacitance value is doubled. Here the thickness of dielectric is more so that the protective layer is not needed. This structure forms two capacitors in parallel.

Here in this structure, two films and two foils are wound as shown in figure.
Two films with protective:

Generally, when the dielectric film thickness is very thin then protective film layer is used. It is placed in such a way that to cover both lead wires. So it prevents the lead wires from damaging the film (short circuit of foil).

The diagram is shown below. Here if there is no protective, the first foil lead wire can damage the dielectric and cause a short circuit. This is prevented by using protective film. The second protective film also does the same function.

Also the protective film is placed in such a position that the first protective film starts from first lead wire and also covers the second lead wire. So that the second lead wire damaging the dielectric and making short circuit is prevented.
NOTE: Protective film is wound for only one wound which is at the lead wires.

Four film without protective:

Here we use four films instead of two films because of the requirement of high rated voltage.

\[ C = \frac{Q}{V} \]

\[ C = \varepsilon_0 \varepsilon_r A/D \]

As dielectric thickness increases, capacitance value decreases and hence rated voltage across the capacitor increases. We can also use a single dielectric of thickness equal to two dielectrics here, but the factor is reliability. If only one film is used, if it is damaged at any weak point then dielectric breakdown occurs. But in the two film structure there is less possibility of both films are weak at the same point.
Four film with protective:

Here in this design the dielectric thickness is less, so the lead wires can damage and cause a short circuit with foils. To avoid that and to give protection to that dielectric we use protective films.
Polypropylene Self-healing capacitors (PSH)/ Polyethylene Terephthalate Self-healing Capacitors (TSH):

In this construction, metallized film is used. Metallized film is generally a polyester or polypropylene film that is metallized one side by vapour deposition. Metal layer thickness will be about 0.03 micron.

The process by which the electrical properties of the capacitor, after a local breakdown of the dielectric are rapidly restored to those before the breakdown. This type is mostly used in CFL and Ballasts.

Self-healing Property:

![Diagram](image)

From the figure, if a dielectric breakdown occurs in a metallized film, there is no possibility of short circuit of metal on film and foil because the metal on film vaporizes. So the capacitor regains its operational ability. This property is called as Self-healing.

PSH/TSH:

This capacitor is of internal series extended foil construction. This is special type of capacitor in which a metallized film is used for self healing property. As there is internal series construction, rated voltage of the capacitor is very much increased (doubled). Hence by using series construction (PSH/TSH) is used to get high rated voltage at a small capacitance value but the size of the capacitor increases. The construction is same for both PSH and TSH but in PSH Polypropylene dielectric film is used and in TSH, PET film is used.
From the figure shown above, it is clear that it forms two capacitors in series. One is between foil1 and metal layer on the metallized film (C1) then another one is in between metal layer on the metallized film and foil2 (C2). Where CM is centre margin between the foils. In the metallized layer, the free margin is weak point. It can be damaged by the lead wires. So the protective layer is extended to cover the free margin.
**Winding Construction:**

Because of the winding construction of sandwiched layers of films and foils, it forms another two capacitances other than C1 and C2. It is shown in the figure below.

All the film capacitors have the property that, the capacitance value is doubled due to winding structure but in this PSH/TSH construction no more capacitance can be formed other than those mentioned in the figure. The equivalent circuit of capacitance is shown in figure below.

**Pinching:**

Pinching is the process of sticking the lead wires of the wound capacitors on a PVC scale, in order to make the other manufacturing process easier and to produce the capacitors in bulk. The bowl feeder mechanism is used to feed the capacitors in an uphill
movement to the linear feeder. The bowl feeder operated by electromagnetic vibration at a constant frequency of 50 Hz. The pinching speed and pinching index should be optimum. There is a photo sensor which controls the overflow of capacitor. These sensors are controlled by a fiber optic amplifier. Finally the capacitors arranged on a down slope and then it is placed on the slots of the pinching index plate of specified. Index is the number of slots on the index plate.

Pressing:

The main objective of pressing is to remove the air gaps between the films and foils that are formed during winding process. Pinched/striped capacitors are placed in the pressing plates. By applying optimum pressure and temperature, the capacitors are pressed by moving the pneumatic cylinder upwards and kept pressed for a definite time. The temperature and pressure is maintained constant between all the plates. The temperature of 170 degrees and pressure of 5kg/cm² is maintained for PET and PSH. The pressing time depends on the size of the capacitors.

If the temperature and pressure increases slightly, the capacitance value increases and insulation resistance decreases and power dissipation increases. If the temperature and pressure is increased more, then the capacitor will be damaged.

Silicon coating:

In this process, silicon layer is formed on the lead wires of the capacitors. Silicon is diluted with xylene/styrene and applied on the lead wires. The main objective of this process is to prevent the epoxy resin sticking to the lead wires during the dipping process. The pressed capacitors scale is fed in a linear feeder and silicon is poured on the lead wires. If the silicon coating is more throughout the lead wires, it affects the solderability on PCB.

Dipping:

Under coating:

The objective of this process is to remove air gaps and to strength to the lead wires. Though the pressing is done, the air gaps are not fully removed. So in order to remove air gaps completely, the capacitors are dipped a solution of ETR-30 and ETH-30 for 30 seconds maintained at a vacuum pressure. The air gap (permittivity=1) decreases the capacitance value. In this process, air is removed and filled with resin of permittivity of 3.2. Here the vacuum level pressure is more than 700mm/Hg is applied to remove air completely.

Because of the undercoating process, the capacitance value slightly increases.

Outer coating:

The objective of this process is to protect the capacitors from humidity and bad environment. In this process, the capacitors are dipped in the epoxy resin+diluent
(ETD) +hardener for about 30 seconds maintained at a vacuum pressure. Here epoxy paint is used because of its flame retardant property. It has good electrical resistance, chemical resistance. It gives good mechanical strength. It is less adhesive and hardens strongly. After this process, capacitance value does not change.

15~20% Epoxy resin is mixed with 80-85% hardener. The mixing is done at 15 deg Celsius.

**Curing:**

It is the heating process. It is to make the epoxy coating set to the capacitors strongly. Capacitors are incubated in an oven maintained at 120 degrees for about 90 minutes after under coating process and again after the outer coating process.

**Marking:**

For marking the value of capacitor on it “Ink jet marking principle” is used. The marking code is entered on the display of the machine. The capacitor scale is rolled out; the jet gun marks the code on the capacitor and then passes through the UV-chamber. Here UV-ink is used instead of normal ink because after curing marking is done in mylar capacitors. The ultra violet ray is used to evacuate the marked code.

**Testing:**

Testing machine has a bowl feeder like pinching machine and same principle is used. Capacitors are fed in an uphill movement, finally an arm picks up the capacitors one by one and arranging it on a running chain slots and testing is done. There are various types of tests. They are,

- Out of Tolerance test (OTR)
- Capacitor Open (CO)
- Flash Over test (FO)
- Tested Voltage test (TV)
- Insulation Resistance test (IR)
- tanδ test

**Out of Tolerance test:**
If the capacitance value is within the tolerance limit it will fall in the c2 bin. If the capacitance value is less than the lower limit, it will fall in the c1 bin. If it is higher it will fall in the c3 bin.

**CO test:**
Capacitor open: The capacitance value for e.g. 0.10 microfarad, the value must be more than 0.07μF. That is the capacitance value should be more than 70% of the rated capacitance value. CO bin collects these rejects.
**Flash over test:**
In this the impact voltage of 2 times the rated voltage is applied for one minute and the process abnormalities are checked. Welding defects and sealing defects etc are checked and the rejects fall in FO bin.

**TV test:**
Tested voltage: In this the voltage two times the rated voltage is applied gradually in steps. The abnormalities are checked and rejected.
In Mylar insulation resistance and tan delta are not checked as the mylar capacitors have good insulation resistance and therefore dissipation factor is very less.

**T/F section and packing:**
In this the capacitors are formed, tapped and lead cut according to the requirement.
**Types of packing style:**
- Bulk packing
- Bulk after forming and lead cutting
- Ammo packing
- Reel packing

The observed values for capacitors of 0.005μF / 1000V / 40% tolerance are below.

<table>
<thead>
<tr>
<th>Capacitance value</th>
<th>Before pressing</th>
<th>After pressing</th>
<th>After dipping</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C value</td>
<td>Tanδ</td>
<td>C value</td>
</tr>
<tr>
<td>0.004417</td>
<td>0.0044</td>
<td>0.0054</td>
<td>0.0045</td>
</tr>
<tr>
<td>0.004883</td>
<td>0.0043</td>
<td>0.0053</td>
<td>0.0045</td>
</tr>
<tr>
<td>0.004980</td>
<td>0.0033</td>
<td>0.0052</td>
<td>0.0043</td>
</tr>
<tr>
<td>0.004600</td>
<td>0.0034</td>
<td>0.0055</td>
<td>0.0046</td>
</tr>
<tr>
<td>0.004989</td>
<td>0.0034</td>
<td>0.0053</td>
<td>0.0043</td>
</tr>
<tr>
<td>0.004989</td>
<td>0.0034</td>
<td>0.0054</td>
<td>0.0044</td>
</tr>
<tr>
<td>0.004980</td>
<td>0.0034</td>
<td>0.0056</td>
<td>0.0046</td>
</tr>
<tr>
<td>Process abnormality</td>
<td>Increase/decrease</td>
<td>capacitance</td>
<td>Rated voltage</td>
</tr>
<tr>
<td>---------------------</td>
<td>-------------------</td>
<td>-------------</td>
<td>---------------</td>
</tr>
<tr>
<td><strong>winding</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length of foil</td>
<td>Increase</td>
<td>Increase, $C \alpha L$</td>
<td>No effect</td>
</tr>
<tr>
<td>Width of foil</td>
<td>Increase</td>
<td>Increase, $C \alpha W$</td>
<td>No effect</td>
</tr>
<tr>
<td>Thickness of foil</td>
<td>The current carrying capability of foil is more. Welding is good. ESR is less, so dissipation is less.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness of dielectric</td>
<td>Increase</td>
<td>Decrease, $C \alpha 1/d$</td>
<td>Increase, $C \alpha Q/V$</td>
</tr>
</tbody>
</table>

| Pinching            | Due to operator fault the lead wire can damage the films and cause welding defects. It leads to capacitor open. |           |               |                       |                   |

<p>| <strong>Pressing</strong>        |                   |             |               |                       |                   |
| pressure            | Increase          | Increases to a limit then capacitance fails due to film damage, $C \alpha 1/d$ | Dielectric breakdown voltage decrease and then fails due to dielectric damage | Decreases then fails due to short circuit of foils | More, $\tan\delta= \omega <em>C</em>ESR$ |
| Temperature         | Increase          | Increase to a limit then dielectric breaks, fails | Fails | Decreases then fails due to short circuit of foils | More |
| Pressing time       | Increase          | Increase to a limit then dielectric breaks, fails | Fails | Decreases then fails due to short circuit of foils | More |</p>
<table>
<thead>
<tr>
<th>Pressing time</th>
<th>Decrease</th>
<th>Decrease, $C \alpha 1/d$</th>
<th>Break down voltage decrease due to air packets (corona)</th>
<th>Good insulation resistance</th>
<th>More, $\tan \delta = \omega <em>C</em>ESR$</th>
</tr>
</thead>
</table>

**Silicon coating**

If the silicon coating is more it affects the solderability on the PCBs.

**Undercoating**

<table>
<thead>
<tr>
<th>viscosity</th>
<th>Increases more</th>
<th>Charge jump from one foil to another which leads to short, fails</th>
<th>fail</th>
<th>Less and fail</th>
<th>-</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Dip time</th>
<th>increases</th>
<th>Reliability increase</th>
<th>No effect</th>
<th>High, since protection of charge jump</th>
<th>decrease</th>
</tr>
</thead>
</table>

**Final coating**

<table>
<thead>
<tr>
<th>viscosity</th>
<th>increases</th>
<th>Size of capacitor increase and coating problem arises.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Dip time</th>
<th>increase</th>
<th>Parameters not affected</th>
</tr>
</thead>
</table>

**Curing**

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Increase</th>
<th>Capacitor dielectric damage. Shrinkage at foils. Capacitor open. So IR decreases.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Curing time</th>
<th>Increase</th>
<th>Loss factor decreases.</th>
</tr>
</thead>
</table>