Whitepaper

Accelerated lifetime-test for metallized film capacitors

1. ABSTRACT

The expected life cycles of industrial products are continuously increasing, so that today life cycles of at least 10, 15 or 20 years are expected.

Each electronic component used in such an industrial product with a life cycle of that length should, of course, have at least the same expected life cycle.

This means that film capacitors in such applications must continue to function for up to 20 years and longer. However, due to market pressure for miniaturization and cost-savings, film capacitors are being produced with increasingly thinner dielectric films and metallisation layers. The result of this tendency is greater sensitivity of the capacitors to environmental conditions. Throughout their life cycles, film capacitors must cope with a range of temperature and humidity stresses while under applied voltage. If they are no longer able to fulfil their specified functions under such conditions, they must be considered to have failed.

This Whitepaper discusses film capacitors intended for use in environments with various temperature- and humidity- cycles.

The goal of this white paper is to present an accelerated life cycle test (Accelerated Life Test (ALT)) for metallised film capacitors to be used under such environmental conditions. The test demonstrates the film capacitor ageing processes to be anticipated over the entire life cycle of the application. This test is designed to consider all relevant factors which may influence the ageing of film capacitors.

In contrast to aluminium electrolytic capacitors, which are divided into life cycle classes (e.g. 85°C/2,000 hours, 105°C/10,000 hours), there is no such categorisation of film capacitors in terms of their minimum expected life cycles. This can lead to the same film capacitors being used in low-cost consumer electronics as well as in significantly more demanding performance electronics.

It is recommended that the ALT test (described below) be included as a part of the component qualification process to ensure that the film capacitor to be used does in fact possess sufficient robustness for the application.

2. THE STRUCTURE OF A METALLIZED FILM CAPACITOR

Wound metallised film capacitors usually consist of two plastic films as dielectric and metallization applied to the plastic films as electrodes.

In production, the two metallized films for one capacitor are wound slightly offset from each other, so that, as a result of the offset arrangement of the electrodes, one edge of the metallization in each electrode protrudes from one of the two faces (end faces) of the winding.

The protruding electrodes are metallized with tin, zinc or aluminium using a process named after Max Schoop (*schoopage* = wound end face contacting with sprayed metal particles), and thereby made into electrical contacts. In this process, the contact metal is liquefied and immediately sprayed onto the corresponding end face of the capacitor as a finely distributed mist using compressed air.

The contacts are soldered or welded onto the contact layer of the winding end faces. This connection is called endspray-contacts.

This capacitor cell is then placed in a boc and sheathed with an epoxy sealing compound for improved protection against environmental effects.

Finally, each capacitor is electrically tested during final electrical inspection for 100% compliance with the specified capacitance value, the loss factor tan Delta and the impedance.

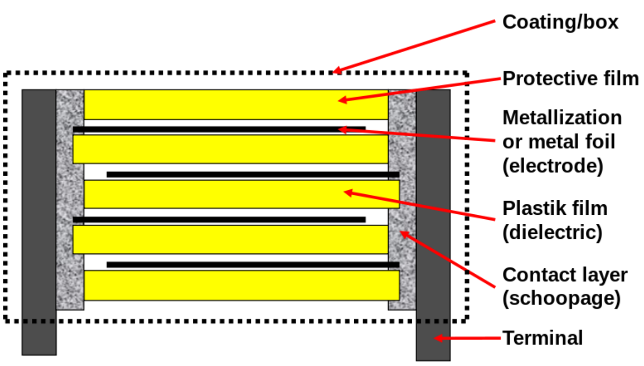


Fig. 1: Schematic diagram of the structure of a metallised film capacitor

(Source: http://en.wikipedia.org/wiki/Film_capacitor)

3. METALLIZED FILM CAPACITORS IN ENVIRONMENTS WITH UNSTABLE TEMEPERATURE- AND HUMIDITY- CONDITIONS

3.A. DIFFERENCES IN THE REQUIREMENTS FOR FILM CAPACITORS FOR USE IN PV INVERTERS INSTEAD OF CONSUMER ELECTRONICS

In industrial products like e.g. inverters or electronic controlled motors and drives, metallized film capacitors are used on the AC and the DC side, primarily as filter, impulse and DC-link capacitors.

Use in such applications is significantly different from applications in consumer electronics. Film capacitors in such applications are expected to have a life cycle of up to 20 years or more, compared to approx. 5-7 years in consumer electronics. Furthermore, significantly higher component temperatures may occur depending on the installation location of the product.

Owing to the major differences in the expected life cycles of consumer electronics and industrial electronics as well as the different demands, it is clear that the design of film capacitors for industrial applications must be more robust so that they can reach up 4 times the life cycle under, in part, more difficult conditions. At the same time, the design of the film capacitors must take into account the fact that customers require high capacitances and voltages in as small a configuration as possible.

3.B. FACTORS INFLUENCING THE LIFE CYCLE OF METALLIZED FILM CAPACITORS AND THE RESULTING REQUIREMENTS FOR A LIFE CYCLE TEST.

The ageing of metallized film capacitors is fundamentally determined by the ageing of the dielectric, the electrodes and the endspray contacts.

The speed of this ageing process is accelerated by temperature, voltage and humidity. All three influence factors are relevant for film capacitors in industrial applications.

Once the industrial product has been sent out into the field, it is expected to operate for up to 20 years or more. It is therefore important that a suitable life cycle test be used to detect beforehand any potential weaknesses in a film capacitor which might lead to ageing and associated degradation of the capacitor’s specified values. This test should be designed, at the same time, to take into account the simultaneous influence factors of temperature, voltage and humidity. Successful completion of the test should confirm the long-term stability of the tested film capacitor.

4. END OF LIFE CRITERIA FOR A METALLIZED FILM CAPACITOR AND THEIR RELEVANCE FOR RELIABLE OPERATION OF THE FINAL GOOD

4.A. END OF LIFE CRITERIA

The following end of life criteria apply to metallized film capacitors in high-performance electronics, for practical considerations:

- $\Delta C/C$: ≤ 10%
- Δ tan δ/tan δ (at 1kHz and 10kHz): ≤ 200%

If a metallized film capacitor fails to fulfil one of these two criteria either during actual use or in an accelerated life cycle test, it has reached its end of life. The end of life is defined as the point in time from which onwards the capacitors does not fulfil its speficied values any more.

Depending on the application, it is possible to define a higher loss of capacitance or greater increase of tan δ during the intended period of use. It is necessary to take into account the fact that the increase of tan δ is directly proportional to the increase in the power loss and the temperature increase of the capacitor, as explained further under 4.3.. If the permissible criteria are set too high, the permissible, more intense ageing process may assume uncontrollable dynamic proportions.

4.B. EFFECTS OF A LOSS OF CAPACITANCE

Depending on the use of the film capacitor, a loss of capacitance exceeding its specified tolerance can have knock-on effects on the EMC characteristics or on the functioning of the final good.

In LCR- or LC- circuits in oscillator circuit applications, it is important that the capacitance tolerance of the film capacitor is designed to be particularly narrow (e.g. +/- 2%) and remains consistently stable throughout the entire life cycle, as the tolerances of the inductance and the capacitor in this application must remain constant.

4.C. EFFECTS OF AN INCREASE IN TAN δ

An increase in tan δ leads to an increase in the power loss of the film capacitor and to a corresponding increase in capacitor temperature.

The selected end of life criterion states that tan δ may only increase by a factor of 3 over the life cycle of the film capacitor.

Rationale:

Assuming a constant frequency f and capacitance C, the increase of tan δ is caused by an increase of the ESR (equivalent series resistance):

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

Not only can an uncontrolled loss of capacitance have fatal consequences in the application, it is also important to keep tan δ (ESR) within an acceptable value during the life cycle to limit power loss and the self-heating of the film capacitor.

An increase in the ESR leads to an increase in the power loss as well as corresponding heating of the film capacitor:

Temperature increase of the capacitor (ΔT):

$$\Delta T = P_V/G$$

- $\Delta T = T_{housing} - T_{ambient}$
  Increase in the housing temperature of the capacitor (°C), maximum 15°C above rated temperature
- $P_V = Irms^2 \times ESR$
  Power loss of the film capacitor (mW)
- $G =$ Thermal conductivity (mW/°C)

The maximum permissible values for both the leakage current I_{rms} (depending on the maximum permissible surrounding temperature) and the thermal conductivity G must be specified by the manufacturer of the capacitor.

Following these formulas, it is clear that both the power loss P_V and the increase in the housing temperature of the film capacitor increase by the same factor by which the ESR increases.

The leakage current I_{rms} of the circuit – assuming the maximum permissible increase of the ESR (tan δ)) – must be limited so that, by limiting the power loss P_V, the increase in temperature ΔT of the film capacitor is limited to a maximum of 15°C above the capacitor's rated temperature.

Hotspot temperature:

The hotspot temperature at the warmest spot on the interior of the film capacitor must not exceed the specified maximum operating temperature. The difference in the temperature between the environment and the hotspot (ΔT_{HS}) is approximately twice the temperature difference Δ T between the environment and the housing.

$\Delta T_{HS} \sim 2 \times \Delta T$

4.D. EFFECTS ON THE FINAL GOOD IF AN INSTALLED FILM CAPACITOR EXCEEDS ITS SPECIFIED VALUES.

The following effects may occur if, during its operation, an installed film capacitor exceeds its specified values:

For X- and Y- film capacitors on the AC side:
- Increase in the emission potential to interfere with other electronics.
- Reduction in immunity to interference.
- If the loss of capacitance is very large (e.g. > 50%), inverter regulation can become unstable with the possible consequence of malfunction of the inverter.

For pulse capacitors for applications with high dV/dt's, parallel with IBGT, MOSFET, etc.:
- Worsening of EMC emissions.
- In rare cases, the circuit may be destroyed if overshoots in the circuit can no longer be prevented.

For filter capacitors at the DC input:
- EMC limit values are no longer met.
- EMC interference can disrupt other devices.

The limit values of the EN 55011-22 might not be respected anymore and the end product loose its CE-compliance.

For DC-link capacitors:
- Malfunction of the end product.

These possible effects resulting from prematurely exceeding the end of life criteria highlight the importance of carrying out a suitable accelerated life cycle test on metallized film capacitors as part of component qualification.

5. CAUSE OF CAPACITANCE LOSSES AND AN INCREASE IN TAN DELTA

5.A. CAUSES OF CAPACITANCE LOSSES

Capacitance losses in a film capacitor are caused by self-healing effects and/or by corrosion of the electrode metallization.

If a voltage flashover occurs between the electrodes in a film capacitor, the metallic coating around the flashover point vaporises and insulates the damaged dielectric locally to avoid a short circuit between the electrodes. This is called self-healing. The self-healing results in a loss of electrode surface area. Capacitance losses which occur due to self healing are relatively limited and generally less than 10% of the initial capacitance.

A further reason for capacitance loss can be corrosion of the film metallization due to the presence of undesired moisture. When corrosion occurs in the film metallization, the metallization coating breaks down, which results in a thinning of the metal layer and ultimately loss of electrode surface area with corresponding loss of capacitance. If the film metallization is heavily influenced by humidity, this may lead to a correspondingly high loss of electrode surface area and therefore to major loss of capacitance and increase of the ESR (tan δ).

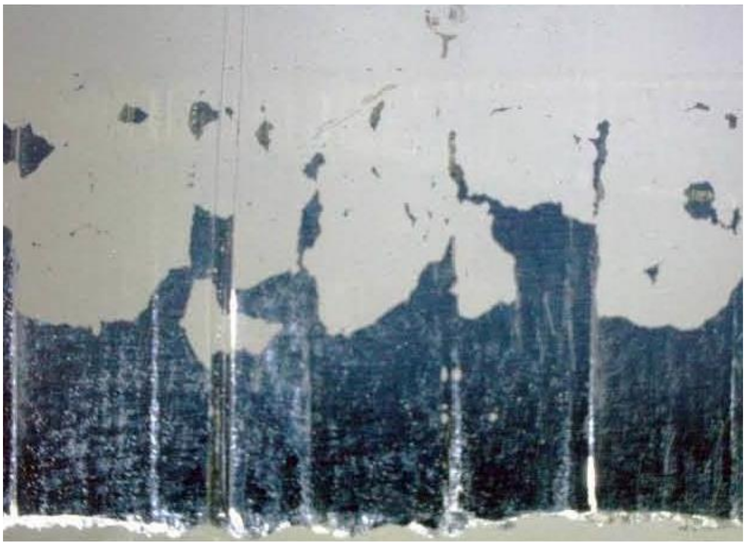


Figure 2: Film metallization displaying significant corrosion.

The danger of a loss of electrode surface due to corrosion increases the thinner (or higher in resistance) the metallization layer is. The electrodes have less material with which to counter the corrosion process.

However, metallization that is too thick hinders the self-healing process, as the self healing process has to expend more energy if more metallization is to be locally insulated (burned). Excessive heat caused by a large expenditure of energy can damage the plastic dielectric and thereby reduce the dielectric strength of the capacitor.

To increase the expected life cycle of a metallized film capacitor, it is therefore important that an optimal combination of maximum dielectric strength and maximum resistance to humidity is selected for the dielectric and electrodes.

5.B. CAUSES OF AN INCREASE IN TAN δ

An increase in tan δ during the life cycle may be caused by the following:

- climatic ageing of the dielectric. Undesired humidity causes ion migration through the dielectric. This leads to an increase in dielectric losses and is demonstrated by the change in tan δ in the low frequency range (e.g. 50 Hz).
- corrosion in the electrodes, demonstrated by a change in tan δ in the range from 1 – 100 kHz.
- corrosion in the endspray-contacts, demonstrated by the change in tan δ in the higher frequency range (e.g. 10kHz or 100kHz).
- a break of the endspray-contacts due to excessive stress from voltage and current.

6. LIFETIME-EXPECTATION

The expected lifetime of a metallized film capacitor in operation can be obtained by measurements and calculations, in which all relevant factors of influence are respected: Temperature (e.g. Arrhenius-law), Voltage (Exponential-law) and Humidity (e.g Hallberg-Peck model).

The specification of lifetime-curves just in function of temperature and voltage, but without humidity, seems not to be appropriate for the application in PV-inverters.

The lifetime of a capacitor is the time required to fail. The failure is defined as the lack of ability of a component to fulfill its specified function. One of its characteristics will be out of the specification. For example the capacitance will be below its specified limit value, or the series resistance will be above its specified value, the component will be leaking, or will be opened. The lifetime is a statistical value which gives the best estimate for the service life based on the Weibull theory.

The Survivor function F(t) is the number of elements of the statistical sample

$$F(t) = \exp^{-(\lambda_o t)^p}$$

which have not failed or lost their function at time t and are still working.

The capacitor aging is usually determined by the capacitor manufacturers by performing accelerated tests, increasing the temperature or/and the voltage or/and the humidity, in steady state or in accelerated cycling. The cycling experiments have the disadvantage to require a lot of power and complex equipment which consequently limits the sample number which can be tested.

The general specified limit values, 90% for the capacitance and 200% for the series resistance increase may be adapted to particular application requirements which may be different. This is an important point which must be kept in mind when comparing data-sheets from different manufacturers.

To get an estimation of the time required to reach 10% of electrode capacitance loss, the coefficient λ_o and p of the Weibull law must be determined for all the operating temperatures T and for all the operating voltages V. They are determined experimentally, with the Weibull fits, for a set of discrete values defined in the plan of experiment, and then, the coefficient λ_o and and p for the

$$\frac{t_1}{t_2} = \left(\frac{V_2}{V_1}\right)^{n1} \left(\frac{RH_2}{RH_1}\right)^{n2} \exp\left[\frac{E_a}{k}\left(\frac{1}{T_{1_{abs}}} - \frac{1}{T_{2_{abs}}}\right)\right]$$

other temperatures and voltages may be calculated using the following solicitation ratio:

In this relation t1 is the lifetime at the temperature T1, humidity RH1 and voltage V1 ; t2 is the lifetime at the temperature T2 , humidity RH2 and voltage V2, Ea is the temperature activation energy determined by the experimental data, k is the Boltzmann constant 1.38 10-23 [J/K]] and n1, n2 are “constants” which depend on temperature, which are determined experimentally.

An Arrhenius law is used for the temperature dependency, while an inverse power law is used for the voltage dependency.

Some authors are also using the exponential law, as for the temperature dependence, for the voltage dependance:

$$\frac{t_1}{t_2} = \exp\left[\frac{E_u}{e}\left(\frac{1}{V_1} - \frac{1}{V_2}\right)\right]\left(\frac{RH_2}{RH_1}\right)^{n2} \exp\left[\frac{E_a}{k}\left(\frac{1}{T_{1_{abs}}} - \frac{1}{T_{2_{abs}}}\right)\right]$$

where e is the electrical charge and Eu is a voltage activation energy.

7. CURRENT IEC NORMS FOR THE USE OF METALLIZED FILM CAPACITORS IN PV INVERTERS

7.A. ANALYSIS OF THE CURRENT IEC NORMS FOR A TEST COMBINING TEMPERATURE, VOLTAGE AND HUMIDITY

The current IEC norms for film capacitors do not include a test which simultaneously takes into account temperature, voltage and air humidity.

The IEC norm does provide a test intended to verify the humidity resistance of a film capacitor. This test does not, however, correspond to the conditions prevalent during operation, as its parameters only include temperature and air humidity, not voltage.

Current IEC norms regarding humidity resistance:

X- and Y- capacitors:

IEC 60384-14 4.12 (Damp heat)

→ 40°C, 90-95% humidity, 56 days (→ without voltage!)

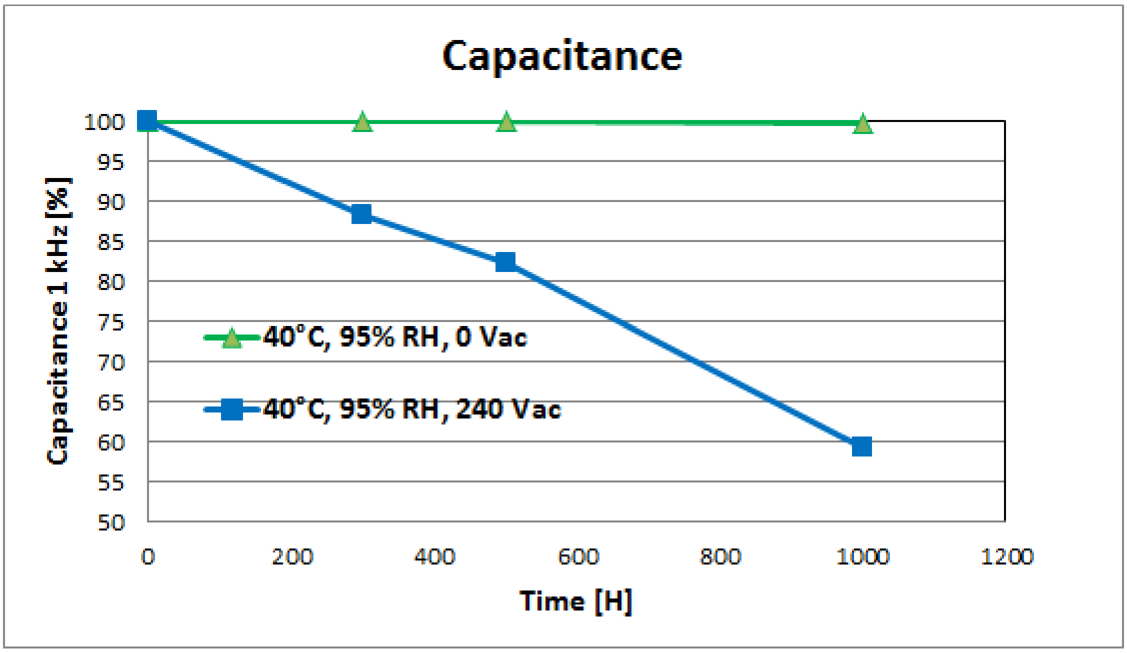
DC capacitors:

IEC 60068-2-78 (Damp heat)

→ 40°C, ~ 95% air humidity, 56 days (→ without voltage!)

These test conditions turns out to be insufficient to prove a long-term stability of the specified values in the application under temperature, humidity and voltage. However, the chemical process of corrosion in the metallization occurs faster when humidity and voltage are present at the same time.

So it can be determined that a humidity resistance of metallized film capacitors cannot be satisfactorily proven using the damp heat test of the Standard IEC, since the test is performed without voltage.



Picture 8: Mean values of the capacitance-loss over the time

<u>Green curve:</u> Standard X2-capacitors from HJC in accordance with the latest issue of IEC 60384-14, testet with the conditions of point 4.12 of the IEC-norm (40°C/95% RH).
<u>Blue curve</u>: Standard X2-capacitors from HJC in accordance with the latest issue of IEC 60384-14, testet with the conditions of point 4.12 of the IEC-Norm plus voltage (40°C/95% RH, 240Vac).

All X2-capacitors shown in picture 8 are specified with a capacitance-tolerance of +/-10%. The test-result shows that a conventional X2-capacitor can pass the test 4.2 (damp heat test) from the latest issue of the standard IEC 60384-14 with very good results (green curve). However, the same capacitor may exceed his specified capacitance-value already after about 250 hours (blue curve), if in addition to the temperature of 40°C and Humidity of 95% there will be also applied the mains-voltage.

HJC has made the same testings with numerous equivalent series from the competition. All of them are specified according to the latest issue of the IEC 60384-14. The strong difference in the capacitance-drift when a capacitor is tested with 40°C/90% RH without voltage and when it is tested with 40°C/90% RH with voltage can be recognized.

This means that a truly conclusive life cycle test for the use of film capacitors in applications with simultaneously stress from temperatue, humidity and voltage must also be carried out with voltage applied, in addition to the high temperatures and high air humidity which occur in practice.

An explanation of why the current standards provide a humidity resistance test without voltage may be that these standards were originally created many years ago. The standards may not have been adapted specifically to the use of thinner metallized films ("miniaturization") alongside the simultaneous trend towards higher expected life cycles for industrial applications.

From a legal point of view, the standard is merely a recommendation. Manufacturers of final goods are therefore not guaranteed sufficient protection if a film capacitor supplier delivers his products according to the current applicable standards. It is therefore recommended that manufacturers of PV inverters carry out their own appropriate life cycle test which verifies whether consistent quality can be expected of the selected film capacitors throughout the entire life cycle of the final good.

7.B. LIFE CYCLE TEST PUT INTO PRACTICE IN OTHER APPLICATIONS WITH COMPARABLE EXPECTED LIFE CYCLES

Experience with other industrial applications with long expected life cycles can be used to identify the conditions of a suitable life cycle test for metallized film capacitors installed in other industrial applications.

For example, smart meters (electronic electricity meters) are specified with an expected life cycle of 20 years. In this application, the current IEC norm has proven itself to be insufficient in practice in terms of ruling out any malfunctions in the field of metallized film capacitors as the result of humidity.

The manufacturers of smart meters have therefore switched over to an additional qualification test for film capacitors beyond the current IEC norm. This test, which is currently carried out by almost all leading manufacturers of smart meters as part of component qualification, has the following conditions for metallized film capacitors:

- **85°C, 85% air humidity, 240VAC, 1000 hours**

This test is referred to as the 85/85 test or the THB (Temperature, Humidity, Bias) test.

In this test, high temperature, high air humidity and voltage are applied simultaneously to the capacitor for 1000 hours. Successfully passing this test demonstrates that the design of the tested film capacitor is sufficiently robust that, in this application, no undesired climatic ageing resulting from air humidity will take place for up to 20 years.

Whether a test with air humidity, temperature and voltage is fundamentally relevant to metallized film capacitors can be determined by carrying out the test with different types of capacitors (aluminium electrolytic capacitors, ceramic capacitors, tantalum capacitors, film capacitors) and comparing the results.

Furthermore, it can also verify whether the combination of "temperature, air humidity and voltage" in metallized film capacitors leads to a faster ageing process than the combination of only "temperature and air humidity" or only "temperature and voltage", both to film capacitors used in AC- and in DC- voltage.

All film capacitors which failed in smart meters due to corrosion of the film metallisation as a result of undesired air humidity fulfilled the current IEC norm, i.e. the air humidity resistance requirements contained in the standard.

This means that, for long-term applications, the current IEC norm does not offer sufficient protection against this type of failure. Following the discovery of this correlation as the result of failures in the field, smart meter manufacturers introduced the THB test (85/85 test) for qualification of film capacitors.

8. ACCELERATED LIFE CYCLE TEST FOR METALLIZED FILM CAPACITORS SUGGESTED BY HJC: THB TEST (85/85 TEST)

HJC has found evidence that the ambient air humidity negatively influences the ability of metallized film capacitors to fulfil their function continuously over a long period of time in operation. Also the market has seen quality defects in metallized film capacitors mounted on PCBs, where the problems which have occurred are related to the ambient air humidity.

Following the lessons learnt from recent years, HJC has introduced two important measures to increase the robustness and therefore the expected life cycle of PCB-mounted metallized film capacitors:

- a new design for metallized film capacitors using materials with a lower water diffusion rate, associated with the increase of the steam diffusion path and increased diffusion barriers.

- stricter test conditions to verify the ability of the capacitor to remain unaffected by a humid environment.

The investigations carried out by HJC in the test laboratory have demonstrated that the three influence factors of temperature, humidity and voltage must be combined to determine the long-term robustness of the capacitor design against climatic ageing.

Whether a sufficiently robust film capacitor design has been found for applications with a long expected life cycle can be demonstrated using an accelerated life cycle test with the following parameters:

- **85°C, 85% air humidity, nominal voltage U_N, 1000 hours.**

The nominal voltage is either AC or DC, depending on the type of film capacitor.

Whereby the following criteria apply:

1.) $\Delta C/C \leq 10\%$
2.) $\Delta \tan \delta / \tan \delta \leq 200\%$ at 1 kHz, and at 10 kHz or 100 kHz.
the loss factor may increase by a maximum factor of 3

To verify the ability of the endspray-contacts to withstand corrosion, the tan δ at higher frequencies must be measured, e.g. at 10 kHz or 100 kHz.

THB tests at 85°C, 85% air humidity and under voltage for 1,000 hours are already used in the qualification processes for semiconductors.

In the meantime this test is also used from leading manufacturers of Smart Meters as an integral part of the qualification process for film capacitors.

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9. TEST RESULTS

9.A. 85°C, 85% RELATIVE HUMIDITY AND $U_{NOMINAL}$

A total of 3 capacitors (HJC standard version EPB606K700VDC) and 3 corresponding HJC THB versions (THB-EPB606K700VDC) were compared with 3 samples from competitor A and 3 capacitors from competitor B. All capacitors were tested in the same test under the same conditions, i.e. at a constant temperature of 85°C, a constant air humidity of 85% (RH) and a constant voltage of 700 VDC. The capacitance values and the values of tan δ were measured at room temperature following a recovery time of 24 hours.

The results are summarised in the following graphs and tables:

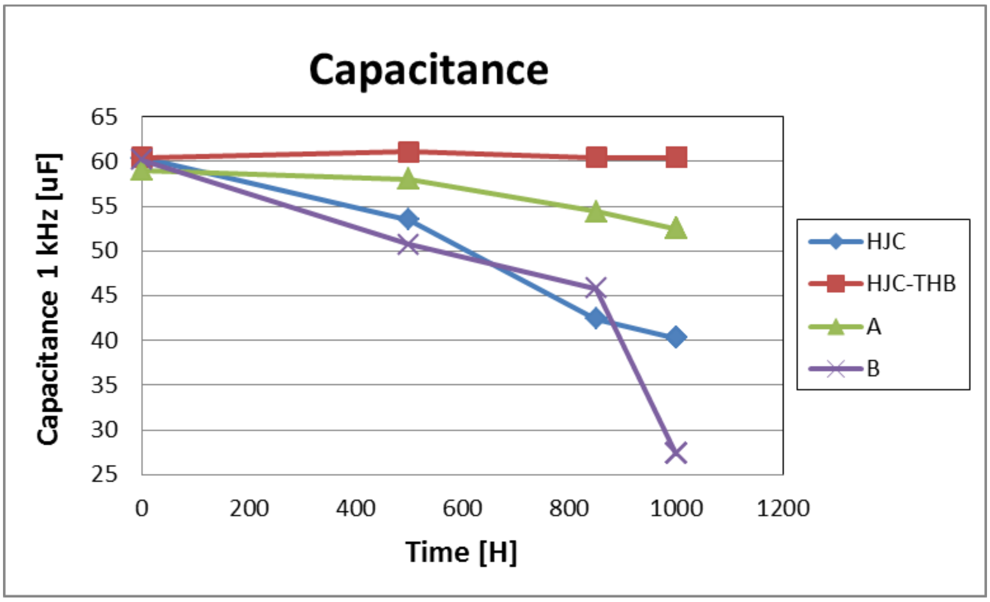
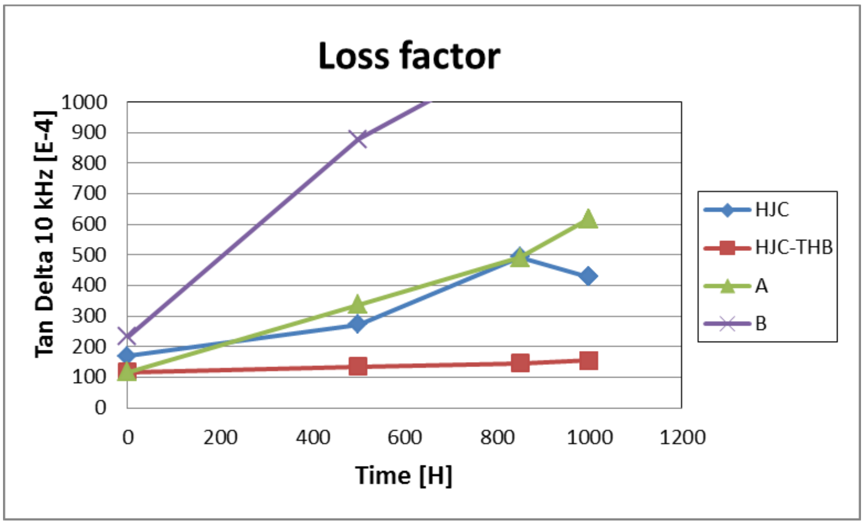


Fig. 3: Capacitance loss during a THB test (700 VDC, 85°C and 85% RH) for 4 capacitor types (HJC = HJC standard version EPB606K700VDC, HJC-THB = HJC strengthened version THB-EPB606K700VDC, A = competitor A, B = competitor B).

In this test, HJC's THB version clearly achieved the best result.

The following graph shows the mean values of the loss factor of the 3 capacitors in this test.



Fig, 4: Loss factor increase during a THB test (700 VDC, 85°C and 85% RH) for 4 capacitor types (HJC = HJC standard version EPB606K700VDC, HJC-THB = HJC strengthened version THB-EPB606K700VDC, A = competitor A, B = competitor B). The loss factor tan δ of the capacitors was measured at 10 kHz.

Only the THB version capacitors from HJC fulfilled the test criteria of a maximum acceptable increase in tan δ by a factor of 3.

These two graphs demonstrate the need for a particularly robust metallised film capacitor design if the capacitors are to be used in long-term applications in demanding environmental conditions.

Example of a test record:

Nr	1	KHz Cs		tan δ	10 KHz		IR	
	Initial (μF)	After Test (μF)	△C / C	Initial (10^{-4})	After Test (10^{-4})	△tan δ /tan δ	Initial (GΩ)	After Test (GΩ)
1	60.36	60.83	0.78 %	117.0	162.0	38.5 %	1.25	0.64
2	60.58	60.74	0.26 %	117.0	149.0	27.4 %	1.25	0.22
3	60.38	59.66	-1.19%	120.0	154.0	28.3 %	1.32	0.54
$\bar{X}$	60.44	60.41	0.05 %	118.0	155.0	31.4 %	1.273	0.47
MAX	60.58	60.83	-0.41%	120.0	162.0	35.0 %	1.320	0.64
MIN	60.36	59.66	1.16 %	117.0	149.0	27.4 %	1.250	0.22
R	0.12	0.65	-435.18%	1.73	2.56	47.8 %	0.04	0.22

Table 1: Test record for the THB version THB-EPB606K700VDC from HJC after 1000 hours under continuous 85°C temperature, 85% RH humidity and 700 VDC voltage

It is recommended that a value for tan δ is given in [E-4] to be able to clearly interpret the changes in tan δ. As per the end of life criteria, a triplication of tan δ is the maximum permitted during the test. If the value is given in [E-4], in contrast to a value in [1] or in [%], it is easy to understand whether this criterion has been fulfilled.

Since tan δ is already a ratio (imaginary over real impedance), the best way to make the difference is to use:

a) tan δ: [10-4]
b) Δ tan δ / tan δ: [%]
c) Δ tan δ: [10-4]

9.B. 85°C AND 85% HUMIDITY WITH VARIOUS VOLTAGES

A total of 3 HJC THB-EPB606K700VDC capacitors were tested at 4 different voltages. The nominal voltage of this capacitor is 700 VDC and its capacitance is 60µF. The test was carried out in a climate chamber at 85°C and air humidity of 85% RH.

Figures 5 and 6 demonstrate the necessity of considering both voltage and humidity in order to analyse the potential for degradation in the quality of metallized film capacitors over their life cycle. Tests only looking at humidity, without applied voltage, do not demonstrate any risks of degradation.

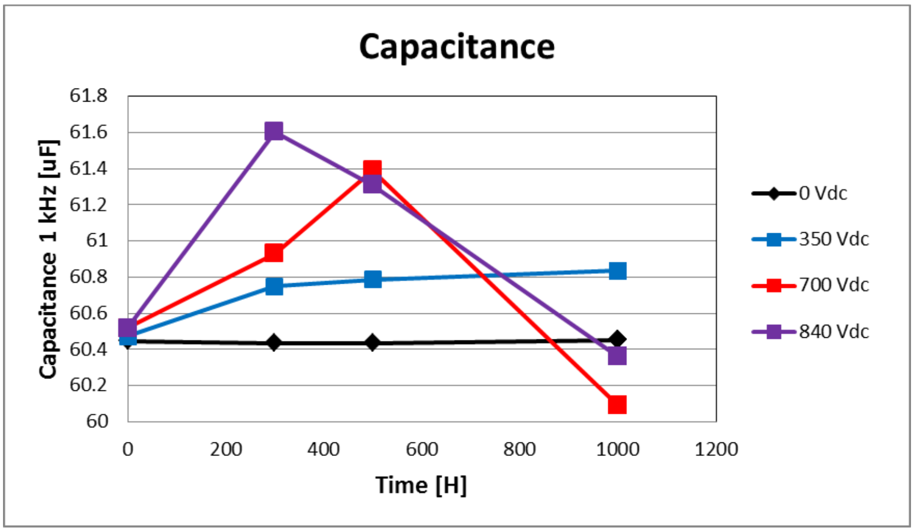


Fig. 5: **Capacitor type THB-EPB606K700VDC (THB version at 60µF/700VDC). Capacitance change in a THB test with continuous conditions of 85°C temperature and 85% RH humidity. The test was carried out simultaneously for different voltages (0, 0.5, 1 and 1.2 U_n)**

The graph first shows an increase in the capacitance average of each of the 3 tested capacitors. This increase is a result of electrostatic compression on the dielectric film from the voltage. The higher the voltage, the higher the compression and the increase in capacitance.

The following graph shows the mean value of the loss factor of 3 capacitors at 10kHz at 4 different voltages in a test carried out at 85°C and 85% RH:

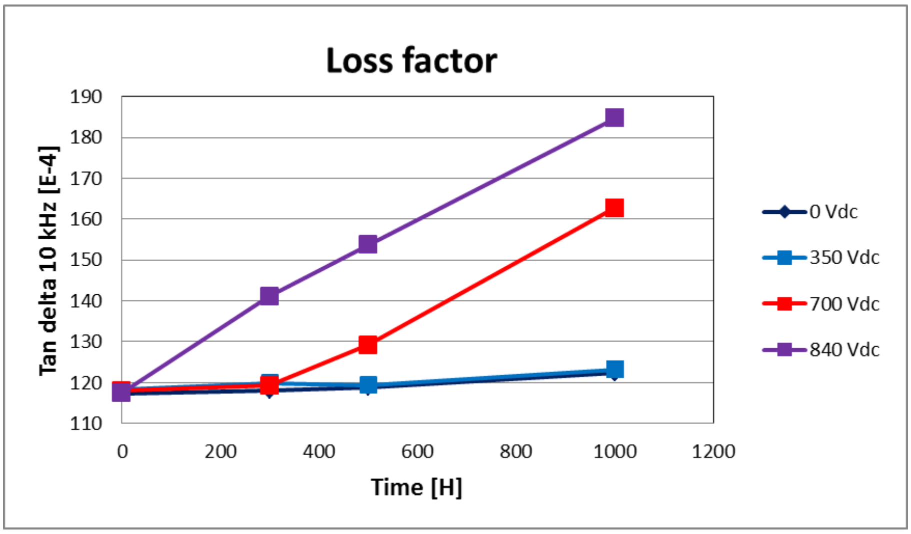


Fig. 6: **Capacitor type THB-EPB606K700VDC (60µF/700VDC). Loss factor change, measured at 10 kHz, in a THB test at 85°C temperature and 85% RH humidity. The test was carried out simultaneously at different voltages (0, 0.5, 1 and 1.2 Un).**

The combination of voltage and air humidity leads to a clear result: at higher voltages, the loss factor increases much more quickly. This is caused by the corrosion of the film metallisation and the corresponding increase in the ESR. Owing to the reduction in metallization caused by the corrosion process, the resistance of the metallization increases, whereby the loss factor increases more quickly. Even at a voltage > 0.5 U_{nom}, intruding air humidity causes a more rapid increase in the loss factor. A further reason for the increase of the loss factor tan δ can be found in a corrosion of the endspray-contacts.

These 2 graphs demonstrate that a corrosion test without any applied voltage does not observe the potential problems which can occur in metallized film capacitors in applications with high ambient air humidity.

9.C. TEST WITH 85°C, 85% RH AND NOMINAL VOLTAGE WITH FILM CAPACITORS FOR PULSE APPLICATIONS

The following THB test was conducted with film capacitors for pulse applications with high dV/dt's. The capacitors electrodes are double-sided metallized Polyester film, the dielectric is a Polypropylene film.

Such type of film capacitors often are also being used in In LCR- or LC- circuits in oscillator circuit applications.

A total of 10 pieces from the THB-version of the MP3S-series from,HJC with 10nF/1000Vdc has been measured, as well as 10 samples of the corresponding standard version of a competitor with 10nF/1000Vdc. In the THB test with 85°C, 85% RH and 1000Vdc, the capacitance and the loss-factor have been measured

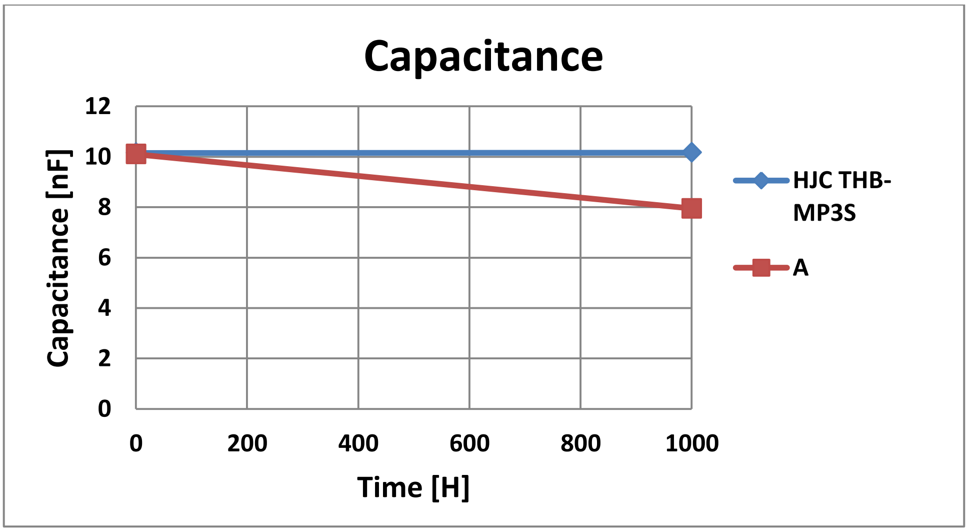


Fig. 7: Capacitance-change in a THB-test with 1000V VDC, 85°C and 85 % for two different versions of pulse capacitors (HJC-THB MP3S= HJC strengthened version THB-MP3S 10nF/1000VDC. A = Competitor A, correspoding type Iin standard version 10nF/1000VDC).

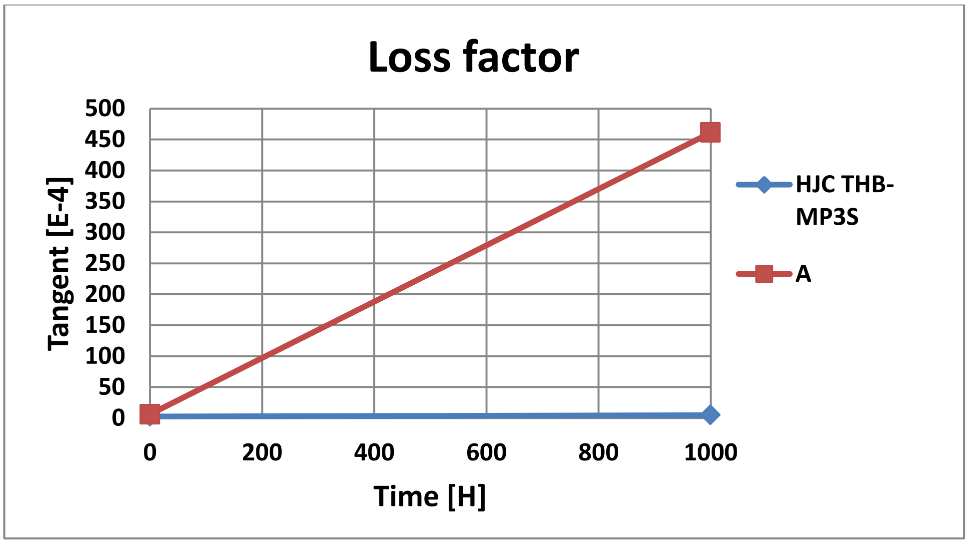


Fig 8: Loss factor –increase measured at 100 kHz in a THB-test with 1000V VDC, 85°C and 85 % for two different versions of pulse capacitors (HJC-THB MP3S= HJC strengthened version THB-MP3S 10nF/ 1000VDC. A = Competitor A, correspoding type Iin standard version 10nF/1000VDC).

Fig.7 shows that this type of film capacitors with electrodes by double-sided metallized plastic film have a good robustness against a capacitance-change caused by climatic ageing. This can be observed for the standard version and the strengthened THB-version.

However, the standard version shows a high susceptibility to a corrosion of the endspray-contacts, verified by the strong increase of the loss factor at 100 kHz. This could become a major problem for pulse applications with high dV/dt's. Ins ich application, solid endspray-contacts are essential.

The THB-version of the MP3S-series from HJC for pulse applications proves a high robustness against climatic ageing both for the electrodes as well as for the endspray-contacts.

9.D. TEST WITH 85°C, 85% RH AND 240VAC WITH X2- AND Y2- INTERFERENCE SUPPRESSION CAPACITORS

Standard versions of X- and Y- film capacitors shows a high susceptibility to climatic ageing. Next to related failures in the field, this characteristic can be observed by the following test-results.

It has been tested a total of 10 pieces from HJC's THB-version THB-X2 with 0.68µF and 305Vac, together with 10 pieces each from the corresponding standard versions from two manufacturers. The applied test-conditions are 85°C, 85% RH and 240Vac for 1000 hours.

The same test-conditions have been applied to 10 Y2-capacitors from HJC's THB-version THB-Y2 with 0,001µF and 300Vac, together with the corresponding standard Y2-capacitors.

The mean value of the capacitance-changes are shown on following figures:

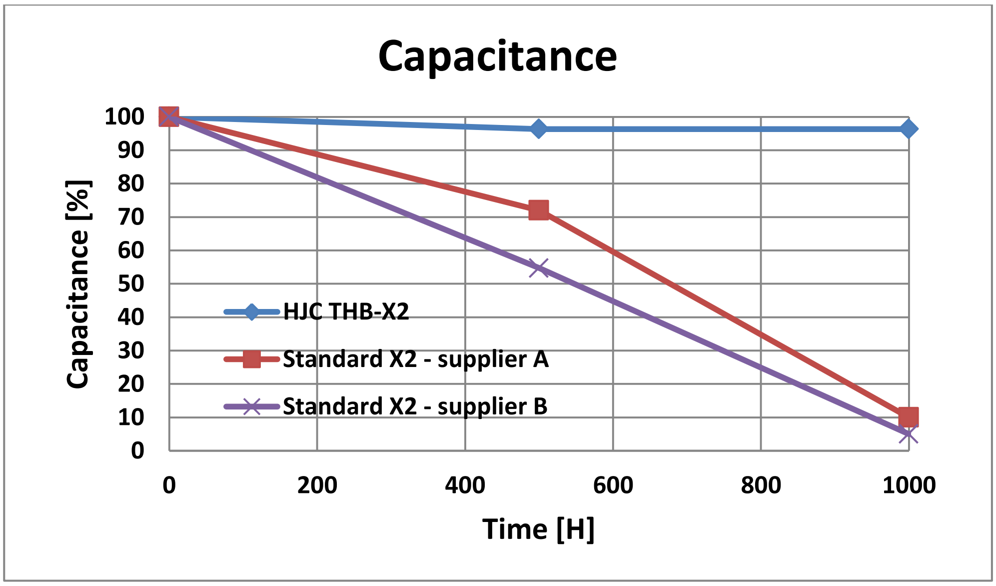


Fig. 9: THB-X2 MKP-684K0305AB1221U from HJC (X2, 0,68µF/305Vac in HJC strengthened version) and the corresponding standard X2 versions of two competitors. Capacitance-change in a THB-test with 85°C, 85% RH and 240Vac.

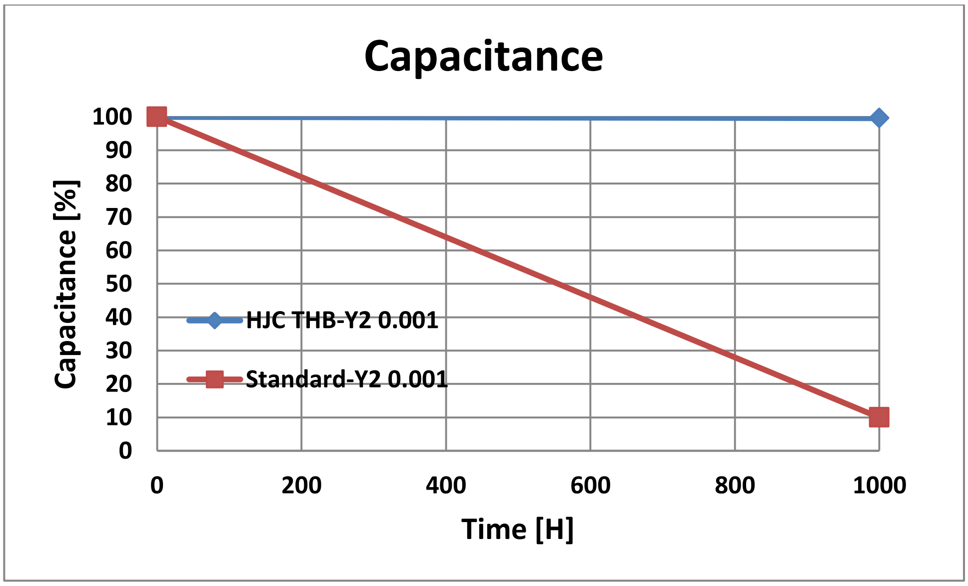


Fig. 10: THB-Y2 Y2X1102K0300AB1101U from HJC (Y2, 0,001µF/300Vac in HJC strengthened version) and the corresponding standard Y2 version. Capacitance-change in a THB-test with 85°C, 85% RH and 240Vac.

The results proves a high risc that standard version of X- and Y- film capacitors shows significant capacitance-losses in the application due to a climatic ageing.

However, under this tests the THB-versions of HJC's X2- and Y2- capacitors demonstrates their high stability of the initial capacitance.

The very bad test-results as well as the related failures in the field only can be explained that based on the current IEC-norm with the insufficient criteria for humidity resistance, manufactures have exaggerated their activities for miniaturization and cost-down. Obviously this trend for smaller dimensions and cheaper costs is at the expense of the lifetime expectation of standard X- and Y- film capacitors.

Failures in capacitive power supplies have shown that standard versions of X2 film capacitors may reach their end of life already within just 3 years.

In inverters, the inverter regulation can become unstable if the loss of capacitance is very large (e.g. > 50%). This can lead to a malfunction of the inverter.

Moreover, the capacitance-losses of X- and Y- capacitors always have consequences for the electromagnetic compatibility of the end product. This might cause the situation in the field that the interference limit values of the EMC norm EN 55011_22 are not satisfied anymore and the end product loose its CE conformity.

9.E. FAILURE PATTERNS DURING THE TEST

During the THB test, if a film capacitor shows a failure such as a significant swelling or first signs of melting off, this demonstrates that the capacitor's design is not sufficiently robust for a long expected life cycle. One cause is to be found in not properly working self-healing processes. If the film is too thin, the dielectric strength may not be sufficient when the capacitors heats.

Image 7: Image of a film capacitor which began to burn during an 85/85 test (THB test).

On the other hand, if a film capacitor successfully passes a THB test at 85°C and 85% RH and applied voltage for 1000 hours while fulfilling the criteria described, it has demonstrated its design is sufficiently robust and healthy for long-term applications.

Humidity can destabilize the whole capacitor-sytem:

The presence of undesired humidity inside the capacitor can destabilize the whole system of a metallized Filmcapacitor. Major implications of such a humidity inside the capacitor can be:

Loss of capacitance:

- Selfhealings around dielectric breakdown (Humidity may accelerate the effect).

- Humidity-corrosion of the electrodes.

- Corona-discharges (Humidity promote it for lower electrical field).

I

ncrease of loss-factor tan δ:

- (climatic) aging of the dielectric (U,T).

- humidity-corrosion in the metallization.

- humidity-corrosion in the endspray-contacts.

- complete break-off of the endspray-contacts (Humidity can be involved).

Undesired humidity may be implicated into the film capacitor already during its manufacturing-process. Furthermore, humidity can ingress into the capacitor during the application if the encapsulation (housing and potting) of the capacitor is not sufficiently tight.

As descripted, the presence of humidiy inside the capacitor can have severe consequences to the reliability of metallized Filmcapacitors. However, the current IEC-standard specifies an insufficient damp heat test. In order to assure that the same rules are valid for all market-participants, the IEC-norms should be updated in the point 4.12 according to the latest findings as soon as possible.

10. CONCLUSION

Film capacitors are increasingly being used in industrial applications, not least due to the increase in voltage after the rectifier or the rise in switching frequencies. However, in terms of the humidity resistance of metallized film capacitors in the field, the current IEC norms have shown themselves to be insufficient, as they do not take into account the simultaneous combination of temperature, air humidity and voltage. There is not yet sufficient field experience with the current designs of metallized film capacitors in applications with long lifetime-expectancies.

For film capacitors to be used, however, it should be possible to exclude from the outset the quality defects which have occurred in metallized film capacitors in other applications due to insufficient humidity resistance.

It is therefore recommended that, as part of the component qualification process, an accelerated life cycle test (ALT test) be carried out on the film capacitors intended for use. The test should take into account all relevant factors that influence the ageing of film capacitors and should verify the long-term robustness of the selected types. Experience gained in the smart meter sector is useful for defining suitable test conditions. This test has been described in this Whitepaper.

This test takes into consideration the fact that a metallized film capacitor is not a static component, but is subject to ageing processes. In metallized film capacitors, these ageing processes are determined by the operational parameters of temperature, voltage and air humidity. In use in industrial applications, these parameters may be subject to significantly more extreme fluctuations and be more pronounced than, for example, in consumer electronics. If an unacceptable ageing process begins in a metallized film capacitor, i.e. it exceeds its end-of-life criteria, the speed of ageing can increase dynamically. In this case, any loss of capacitance and/or increase in the ESR can become uncontrolled. This should under no circumstances occur during the life cycle of the final good, as this has may lead to serious consequences for the functioning, which have also been described in this Whitepaper.

Metallized film capacitors demonstrate numerous technical advantages compared to aluminium electrolytic capacitors if it is ensured that their expected life cycles correspond to those of the end product. The accelerated life cycle test presented in this Whitepaper can be used as part of component qualification to determine whether the film capacitors intended for use remain within their specified values throughout the life cycle of the end product. In this way they assure to continuously support the reliable and optimal functioning of the end product.

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Note:

All shown test results are based on tests which have been conducted in the laboratory of HJC. The results prove the relevance of the discussed topic, but don’t claim an universal validity for all film capacitors in the market. Everyone who doubts the results may conduct his own tests. In this case, HJC recommends to apply the same test- conditions and – criteria. Thus, the results will be commonly comparable. Furthermore, it will be avoided that there will be various different testing methods in the market. In fact, this will contribute to the creation of one common standard for all market participants for an accelerated lifetime-test of metallized film capacitors.