Capacitor Testing Procedure

Revision 1.0

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Revision History

Version	Release Date	Notes
1.0	February 2025	First draft

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Definitions

Capacitance

It is the ability of a component, typically a capacitor, to store electrical charge. It is defined as the ratio of the electric charge (Q) stored on one plate of the capacitor to the voltage (V) across the plates, expressed as:

$$C = \frac{\mathrm{Q}}{\mathrm{V}}$$

Capacitance is measured in farads (F), where one farad is the capacitance of a capacitor that stores one coulomb of charge at one volt. Capacitance depends on factors such as the surface area of the plates, the distance between them, and the dielectric material between the plates. [1][2]

Dissipation Factor (D)

It is a measure of energy loss in a capacitor or other dielectric materials. It is the ratio of the real power dissipated (due to resistance) to the reactive power stored (due to the capacitor's reactance) in an AC circuit. Mathematically, it is related to the tan δ (tangent of the loss angle), where δ is the phase angle between voltage and current. A higher dissipation factor indicates greater energy loss and poorer efficiency in the capacitor.

Dissipation factor is inversely related to the quality of the dielectric material; lower values are desirable for better performance in high-frequency applications. [3][4]

Equivalent series resistance (ESR)

It refers to the internal resistance of a capacitor or other electronic components that affects its efficiency, particularly in AC circuits. It represents the combined effect of resistive losses within the component, including the resistance of the leads, electrodes, and the dielectric material. ESR is significant in power applications, as high ESR values can lead to energy losses, heat generation, and performance degradation, especially in filtering applications or in power supply systems.

In capacitors, a lower ESR is generally desirable for better performance, particularly in high-frequency or high-current applications. [5][6]

Phase Angle (Θ)

It refers to the angular difference between the voltage and current waveforms in an AC circuit. It is measured in degrees (°) or radians (rad) and indicates the time shift between the two waveforms. A phase angle of 0° means the voltage and current are in phase, while a phase angle of 90° or -90° indicates the current and voltage are completely out of phase (for example, in purely inductive or capacitive circuits).

The phase angle is critical in determining the power factor and the efficiency of AC power systems. [8][10]

Quality Factor (Q)

It is the ability of a component, typically a capacitor, to store electrical charge. It is defined as the ratio of the electric charge (Q) stored on one plate of the capacitor to the voltage (V) across the plates, expressed as:

$$C = \frac{f_0}{\Delta f}$$

where f_0 is the resonant frequency and Δf is the bandwidth (the range of frequencies where the circuit resonates effectively).

In capacitors, inductors, and other resonant systems, a higher Q means sharper resonance and less energy dissipation.[9][10]

Prologue

In today's electronics, capacitors are everywhere, playing an important role in every product's lifetime. This is why it is of imperative importance to be able to assess their quality and tolerance to abuse using scientific methods that don't require prolonged testing periods.

A capacitor is an electronic component that stores and releases electrical energy in a circuit. It consists of two conductive plates separated by an insulating material known as a dielectric. An electric field is created when voltage is applied across the plates, causing the capacitor to store energy. Capacitors are commonly used in electronic circuits for various purposes, such as smoothing power supply voltages, filtering signals, and timing applications. They are characterized by their capacitance, measured in farads (F).

Quality capacitors are essential to any electronics component, including power supplies, which are used by many electronic devices nowadays, not only PCs. Usually, high-end PSUs use Chemi-Con capacitors, while mid-level PSUs use more affordable caps from either Teapo or Elite.

The capacitor voltage rating indicates the maximum voltage a capacitor can safely withstand without breaking down. Exceeding this voltage rating can lead to the insulation breaking down, causing the capacitor to fail or even become damaged. When selecting a capacitor for a circuit, choosing one with a voltage rating higher than the maximum voltage the capacitor will experience in the application is essential. This provides a safety margin and helps ensure the capacitor operates reliably within its specified parameters.

Overvolting a capacitor or applying a voltage beyond its rated voltage can lead to several undesirable consequences:

- Breakdown and Damage: Exceeding the voltage rating can cause the dielectric material between the capacitor plates to break down. This breakdown can result in a short circuit, damaging the capacitor and potentially other components in the circuit.

- Reduced Capacitance: Overvoltage can alter the physical and electrical properties of the capacitor, leading to a decrease in capacitance. This change can affect the performance of the capacitor in the circuit.

- Leakage Current: Overvoltage stress can increase the leakage current across the capacitor. Leakage current flows through the dielectric material, and excessive leakage can negatively impact the performance of the capacitor.

- Electrical Failure: Prolonged exposure to overvoltage conditions may lead to the gradual degradation of the capacitor, eventually resulting in electrical failure.

- Safety Hazards: In extreme cases, overvoltage can cause the capacitor to fail catastrophically, leading to the release of smoke, gas, or even rupture. This poses safety risks, especially in applications where the capacitor is close to other components or in an enclosed space.

Test Equipment

- Bench Power Supply: GW INSTEK PS800-2.88 [11]
- LCR Meter: Sourcetronic ST2832 [12]

An LCR meter is a type of electronic test equipment used to measure the inductance (L), capacitance (C), and resistance (R) of an electronic component.

Voltage Treatment

Voltage treatment for capacitors, often referred to as forming or initialization, is a process where a capacitor is subjected to a controlled voltage to stabilize its characteristics before it is used in a circuit, in this case our testing rig. This treatment is especially important for electrolytic capacitors, which are prone to degradation if not properly conditioned.

It is important to treat the capacitors before testing for the following reasons:

- Establishes Proper Dielectric Layer: In electrolytic capacitors, a thin dielectric oxide layer is formed on the surface of the anode when a voltage is applied. This layer acts as an insulator, allowing the capacitor to store charge. If this dielectric layer isn’t properly formed, the capacitor may not function as intended or could even fail early. Voltage treatment helps to form this oxide layer correctly and ensures the capacitor performs reliably over time.

- Prevents Leakage: In the absence of a properly formed dielectric layer, electrolytic capacitors may experience high leakage currents, meaning they lose charge over time. Voltage treatment ensures the dielectric layer is stable and effective, reducing the chances of leakage and improving overall reliability.

- Improves Performance and Lifespan: When a capacitor is "treated," it ensures that the capacitance value remains stable and consistent over time. Proper voltage treatment helps the capacitor reach its optimal working state, thereby improving its performance (such as efficiency and capacitance stability) and extending its lifespan. Capacitors that are not voltage treated may fail prematurely or degrade faster.

- Minimizes Risks of Damage: Electrolytic capacitors that have been exposed to voltages higher than their rated value or those that have not been initialized properly can break down or even short-circuit. Voltage treatment ensures that the capacitor gradually adjusts to its rated voltage without causing stress that could lead to breakdowns.

The voltage treatment process of Cybenetics is the following:

- Controlled Application of Voltage: The capacitor is connected to a power supply set to operate at the rated voltage of the capacitor.

- Current Monitoring: The current passing through the capacitor is monitored to ensure that it is within safe limits while the capacitor is treated.
- Stabilization: The voltage is applied for 30 minutes to ensure the oxide layer stabilizes and the capacitor's properties are set.

In addition, a resistor rated at 1KOhm must be connected in series with the capacitor being tested only for the treatment period.

Capacitor Failure

Capacitors can fail in various ways, and the most common causes of failure are the following:

- Excessive Voltage: Overvoltage can break down the dielectric material.
- Overheating: High ripple current or temperature stress can degrade the capacitor.
- Age and Wear: Capacitors degrade over time, especially electrolytics.
- Improper Polarity: Reversing polarity in polarized capacitors can cause failure.

The signs of failure can depend on the type of capacitor and the nature of the failure. Here are some common indicators of capacitor failure:

1. Visual Signs
    - Bulging or Swelling: Indicates internal pressure buildup, common in electrolytic capacitors.
    - Discoloration or Leaking Fluid: Signs of electrolyte leakage, typically in electrolytic capacitors.
    - Cracked or Damaged Case: Physical damage to the capacitor housing, indicating stress or overheating.

2. Electrical Symptoms
    - Increased ESR (Equivalent Series Resistance): Higher resistance leads to reduced efficiency, heat, and potential failure.
    - Capacitance Loss: A significant drop in capacitance means the capacitor can no longer store charge properly.
    - Short Circuit: Internal short can cause excessive current flow, damaging other components.
    - Open Circuit: Capacitor becomes electrically disconnected, resulting in no function.

3. Increased Leakage Current
    - Higher Leakage Current: If current leakage increases significantly, the capacitor is failing and should be replaced.

4. Circuit Behavior Changes
    - Overheating: Caused by excessive ripple current or voltage, leading to further capacitor degradation.

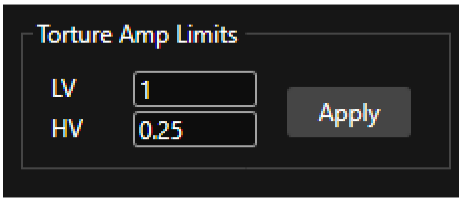
- Noise or Distortion: A failed capacitor in audio or signal circuits may cause hum, distortion, or instability.
- Circuit Failure or Malfunction: Capacitor failure can lead to power instability or complete circuit malfunction.

5. Through Testing

- ESR Testing: Measuring ESR can identify internal degradation or failure.
- Capacitance Testing: A significant decrease in capacitance indicates failure.
- Visual Inspection with Infrared Thermometer: Elevated temperatures may point to overheating or failure.

Among these various methods of detecting failure, Cybenetics monitors the current that flows through the capacitor. As the capacitor gets weaker it starts allowing more current to flow through which is a sign of degradation. As soon as the current reaches the limit we have set in the software, testing stops to avoid making a mess, as the capacitor is about to fail.

The limits Cybenetics uses are the following:



Torture Amp Limits

LV: 1

HV: 0.25

Where LV stands for Low Voltage and HV for High Voltage.

Testing Software

To use and monitor the testing equipment as well as viewing, logging and analyzing the test results, Cybenetics has developed proprietary software.

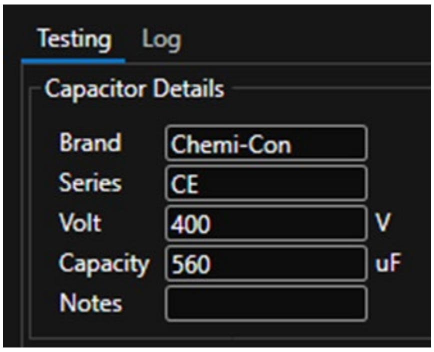
The software allows the user to input testing data, connect to the bench power supply, control it and monitor the results.

Testing Methodology

The first step is turning on the LCR meter, allowing it to operate for at least 30 minutes before we start using it, according the manufacturer's instructions. Meanwhile, the voltage treatment process can start.

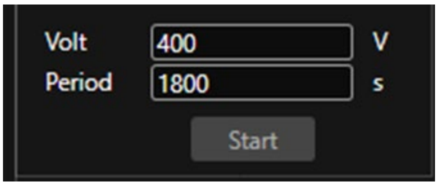
To connect the capacitor to the bench power supply we have to identify the capacitor's positive and negative terminals. If the capacitor is new and unused, then the lead length helps identify them as the longer one is the positive. Otherwise, dash and positive symbols may be printed on the housing of the capacitor.

Once the capacitor is connected and placed inside the testing box, we turn on the bench power supply and the testing software on the computer. Next, we have to input the characteristics of the capacitor, more specifically the Brand, the Series, the Voltage and the Capacity.



Brand: Chemi-Con
Series: CE
Volt: 400 V
Capacity: 560 uF
Notes:

Then, we input the voltage treatment information.



Volt: 400 V
Period: 1800 s

After connecting the capacitor and entering the information, the voltage treatment is ready to start. When we start it, we have to check that the readings on the bench power supply correspond to our input on the software.

Once the voltage treatment is completed, the LCR meter would have had enough time to warm up and be ready to take measurements.

The LCR meter is used to measure the Quality Factor (Q), the Dissipation Factor (DF) and the Equivalent Series Rating (ESR). We connect the capacitor to the LCR meter’s test fixture. We navigate through its menu to set the frequency to 120Hz, which we will use to measure Q and DF, while for ESR we will change the frequency to 1KHz.

The last phase of testing is the overvoltage or torture part. At this phase, we overvolt the capacitor to find the failure point. To do so, we have to reconnect the capacitor to the bench power supply.

For **low voltage** capacitors, start from the nominal voltage and increase it with a 20% step. The capacitor will operate for five (5) minutes at each test voltage and this procedure takes place automatically through the software.

For **high voltage** capacitors we start at 10V for one (1) minute, followed by one (1) minute at 500V, and then we keep increasing the voltage by 10V and running each test for one minute. The only exception is the 520V setting, at which we allow the capacitor to run for 30 minutes. When the capacitor fails as described before, we take note of the test duration (t_{DUT}) and the maximum voltage we were able to apply.

Results and Interpretation

After completing all tests and taking note of the results, we have to calculate the performance of the capacitor. To do so, we compare it to the best-so-far results ($Performance_{BSF}$) of the capacitors we have tested, using the following formula:

$$Performance\ _{DUT}(\%) = \frac{100\%}{Performance_{BSF}} * t_{DUT}$$

Epilogue

Capacitor testing is a critical process in ensuring the reliability and functionality of electronic circuits, as well as being able to compare the quality different manufacturers offer. Given that capacitors are used in every electronics device and are a vital part of them, affecting reliability and performance, it is crucial to have actual test data regarding their performance and tolerance to abuse.

Through our testing and our capacitor performance database we will try to bring down some myths like the “X” brand makes mediocre capacitors while “Y” brand produces good ones. First of all, each brand has different capacitor models, with different specifications affecting their performance. So, you cannot take a capacitor and compare it to another one with different specifications. Secondly, we cannot rely any more on rumors spread on the internet and on user opinions about capacitor quality, we need actual data and the easiest and best way to evaluate capacitors has been already described in this article.

We hope that our capacitor database will help manufacturers, brands and users find out the best products and hopefully it will lead to reduced production cost, since it will show that some expensive and not easy to find capacitor models can be replaced with other that cost less and are available in larger quantities. This is the final goal of our capacitor database, to help the industry move forward, since not all manufacturers and especially brands have the capability to check capacitor quality and performance, so they don’t have the complete picture in hand to select the most appropriate parts for their products.

References

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