



Dielectric-Loss Measurements Problems

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Abstract:

The measurement of dielectric loss in high-voltage cables presents many problems that are not obvious until such measurements have actually been attempted and the results checked and analyzed. Some of these problems are not simple, and their solution is obtained only after considerable effort and research. This paper presents some of the problems that the authors have encountered in this type of work, together with the methods used for their solution. The bridge method, which is used for the measurement of dielectric loss, is described in some detail. Details of the auxiliary equipment, such as galvanometer, amplifiers, air condenser, shielding, and special methods of bringing the shielding to the proper potential are also given. If accurate results are to be had in dielectric loss measurements, the entire bridge, including cable, air condenser, and leads, must be properly shielded and the capacitance between leads and shielding should be made small. Errors of large magnitude may be introduced in the results if these precautions are not taken. It is entirely insufficient to shield the bridge and ground the shielding directly. At times shielding cables may increase the measured losses. In measuring the capacitance of the air condenser, all stray capacitance to its guard rings and to surroundings must be eliminated. The paper gives a method of accomplishing this. The voltage across the voltmeter coil of a high-voltage transformer is frequently taken as a measure of the voltage across its secondary.

I. INTRODUCTION

What is a dielectric material...?:

A dielectric material is a poor conductor of electricity but an efficient supporter of electrostatic fields. It can store electrical charges, have a high specific resistance and a negative temperature coefficient of resistance.

Problems in dielectric –loss measurement

Dielectric materials play a vital role in modern technology, from electronic devices and energy storage systems to medical equipment and aerospace applications. Characterizing the electrical properties of these materials is essential to ensure their reliability, efficiency, and safety. Dielectric-loss measurements are a crucial tool for material characterization, as they provide valuable information on the material's ability to store electrical energy, dissipate heat, and withstand electrical stress.

Dielectric loss, typically represented by the loss tangent ($\tan \delta$), is a measure of the energy dissipated by a dielectric material when subjected to an alternating electric field. Accurate measurement of dielectric loss is critical in various industries, including:

1. **Electrical engineering:** to design and optimize electrical systems, such as transformers, capacitors, and insulation materials.
2. **Electronics:** to develop high-performance electronic devices, such as semiconductors, memory devices, and display screens.

3. **Energy storage:** to improve the efficiency and reliability of batteries, supercapacitors, and fuel cells.
4. **Medical applications:** to ensure the safety and efficacy of medical devices, such as implantable devices, imaging equipment, and radiation therapy machines.
5. **Aerospace:** to develop lightweight, high-performance materials for aircraft and spacecraft applications.

Despite its importance, dielectric-loss measurement is a complex task, prone to various errors and challenges. These problems can lead to inaccurate measurements, misinterpretation of results, and unreliable material characterization, ultimately affecting the performance, safety, and reliability of devices and systems.

In this context, understanding the problems in dielectric-loss measurements is essential to develop accurate and reliable material characterization techniques, ensuring the optimal performance of various technologies and devices. In the context of dielectric-loss measurements, detectors are used to measure the small changes in voltage or current that occur due to the dielectric properties of the material under test. The detectors are essentially sensors that convert the physical parameters of the material into electrical signals, which are then processed to determine the dielectric loss.

Common types of detectors used in dielectric-loss measurements include:

1. **Voltage detectors:** Measure the voltage across the material under test, typically using a high-impedance voltage divider or a voltage transformer.
2. **Current detectors:** Measure the current flowing through the material under test, often using a current transformer or a shunt resistor.
3. **Capacitive detectors:** Measure the capacitance changes in the material under test, typically using a capacitive bridge or a capacitance sensor.
4. **Inductive detectors:** Measure the inductance changes in the material under test, often using an inductive bridge or an inductance sensor.
5. **Piezoelectric detectors:** Use piezoelectric materials to detect changes in the material under test, converting mechanical stress into electrical signals.
6. **Thermal detectors:** Measure the temperature changes in the material under test, often using thermocouples or thermistors.

These detectors are used in various measurement techniques, including:

- Bridge circuits
- Resonant circuits
- Impedance analyzers
- Dielectric spectroscopy

By selecting the appropriate detector and measurement technique, researchers and engineers can accurately measure the dielectric loss of materials and characterize their electrical properties.

Dielectric materials are used to store electric charge and maintain an electric field. However, they can experience losses due to various factors. Here are some common losses associated with dielectric materials:

1. **Dielectric Hysteresis Loss:** Energy lost due to the rearrangement of dipoles in the material as the electric field changes.
2. **Conduction Loss:** Loss due to the flow of current through the material, often caused by impurities or defects.
3. **Relaxation Loss:** Energy lost as the material's polarization lags behind the changing electric field.
4. **Leakage Loss:** Loss due to the flow of current through the material, often caused by defects or contaminants.

5. Thermal Loss: Energy lost as heat due to dielectric losses, which can lead to material degradation.

6. Radiation Loss: Energy lost as electromagnetic radiation, often at high frequencies.

Bridge method technique in dielectric-loss measurement

The bridge method is a widely used technique in dielectric-loss measurements to determine the dielectric properties of materials. It's called a "bridge" because it balances the unknown impedance of the material under test against a known impedance, creating a "bridge" between the two.

Here's a simplified overview of the bridge method:

1. Wheatstone Bridge: The basic circuit consists of a Wheatstone bridge, which has four arms: two known resistors (R_1 and R_2), a capacitor (C_x) representing the material under test, and a fourth arm (R_3) that completes the bridge.

2. Balancing the Bridge: An AC voltage source is applied across the bridge, and the voltage across the material under test (C_x) is compared to the voltage across the known resistor (R_3). The bridge is balanced by adjusting R_3 until the voltages are equal.

3. Measuring Dielectric Loss: When the bridge is balanced, the dielectric loss ($\tan \delta$) of the material under test can be calculated from the known values of R_1 , R_2 , and R_3 .

4. Advantages: The bridge method offers high accuracy, sensitivity, and resolution, making it suitable for measuring small changes in dielectric loss.

The bridge method is commonly used in various applications, including:

- Material characterization
- Quality control
- Research and development
- Dielectric spectroscopy

By using the bridge method, researchers and engineers can accurately measure dielectric loss and characterize the electrical properties of materials, enabling advancements in various fields.

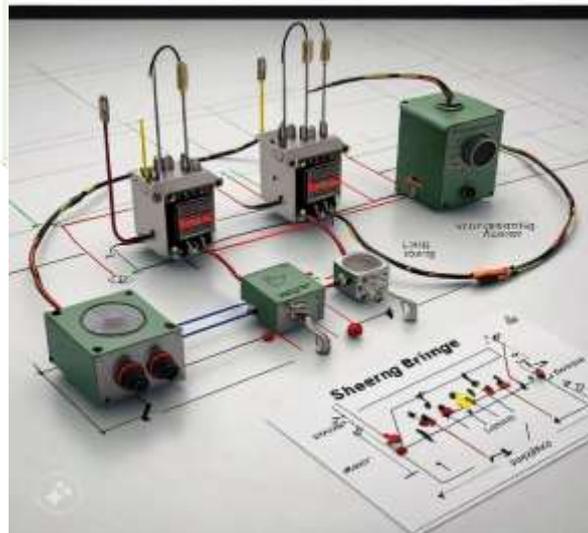


Fig.1:Schering bridge

The Schering Bridge consists of four arms:

1. Unknown arm (Z_x): Contains the sample capacitor (C_x) with unknown dielectric loss ($\tan \delta$).
2. Standard arm (Z_s): Contains a standard capacitor (C_s) with known capacitance and negligible dielectric loss.
3. Resistor arm (R_1): A variable resistor used to balance the bridge.
4. Resistor arm (R_2): A fixed resistor used to complete the bridge circuit.

Bridge Circuit:

The bridge circuit is connected as follows:

- Z_x and Z_s are connected in parallel across the bridge.
- R_1 and R_2 are connected in series across the bridge.
- An AC voltage source is applied across the bridge.
- A null detector (e.g., a galvanometer) is connected across the bridge to detect balance.

Measurement Principle:

1. Adjust R_1 to balance the bridge, i.e., when the null detector shows zero deflection.
2. Measure the values of R_1 , R_2 , C_s , and the frequency (f) of the AC voltage source.
3. Calculate the dielectric loss ($\tan \delta$) and capacitance (C_x) of the unknown sample using the following equations:

$$\tan \delta = (R_1/R_2) * (C_s/C_x)$$

$$C_x = C_s * (R_2/R_1)$$

Advantages:

- High accuracy and sensitivity
- Wide range of measurement capabilities
- Simple and robust circuit design

What is shielding...?

Shielding a cable means wrapping a conductive material (like copper or aluminum) around the cable to block electromagnetic interference (EMI) and radio-frequency interference (RFI). This helps:

1. Reduce electrical noise: Prevents external interference from affecting the signal inside the cable.
2. Prevent signal leakage: Keeps the signal within the cable from radiating out and interfering with other devices.

Shielding is commonly used in:

1. Coaxial cables (e.g., TV and internet cables)
2. Data cables (e.g., USB and Ethernet cables)
3. Power cables (e.g., those used in medical equipment and industrial applications)

The shielding material can be:

1. Braided (a woven mesh)
2. Foiled (a thin, flexible sheet)
3. Spiral-wrapped (a helical wrap)

Proper shielding ensures reliable data transmission, reduces electromagnetic radiation, and improves overall system performance.

Conclusion:

In conclusion, dielectric-loss measurements are a crucial tool for characterizing the electrical properties of insulating materials, but they are susceptible to various errors and challenges. The problems encountered in dielectric-loss measurements, including instrumental limitations, sample preparation issues, frequency and temperature dependence, interfacial polarization, non-linear effects, and environmental factors, can lead to inaccurate measurements and misinterpretation of results.

To overcome these challenges, it is essential to:

1. Understand the underlying physics of dielectric-loss phenomena
2. Select appropriate measurement techniques and instruments
3. Ensure proper sample preparation and handling
4. Control environmental factors and experimental conditions
5. Apply correction methods and data analysis techniques

By acknowledging and addressing these problems, researchers and engineers can develop accurate and reliable material characterization techniques, enabling the development of high-performance materials and devices for various applications. Ultimately, this knowledge will contribute to advancements in fields like electrical engineering, electronics, energy storage, medical technology, and aerospace, driving innovation and technological progress.

Future research in dielectric-loss measurements should focus on:

1. Developing new measurement techniques and instruments
2. Improving data analysis and correction methods
3. Investigating new materials and applications
4. Establishing standardized measurement protocols
5. Encouraging interdisciplinary collaboration and knowledge sharing

By working together to overcome the challenges in dielectric-loss measurements, we can unlock the full potential of insulating materials and drive technological advancements that benefit society as a whole.

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