Application Note

IEC 60851-5 Winding Wire Dielectric Tangent (tanδ) Testing

Enamel wires are used in motor windings. As part of R&D and product inspections by enamel wire manufacturers as well as acceptance inspections and material development by motor manufacturers, engineers test the performance of enamel wire by measuring its dielectric tangent (tanδ) as set forth in IEC 60851-5.

Target

Enamel wire (magnet wire) and insulated film used in motor windings
Motor R&D and acceptance inspections as part of motor production

Dielectric tangent (tan δ): An indicator of energy loss inside a material

Dielectric tangent (tanδ) indicates the extent of energy loss inside a material, with larger values signaling higher energy loss. Heat generated during energy loss accelerates the degradation of insulating materials. By using enamel wiring with a low dielectric tangent (tanδ) for motor windings, manufacturers can develop and produce motors with low energy loss and high durability. In addition, the dielectric tangent (tanδ) is dependent on temperature and frequency. Motors used in electric vehicles (EVs) are controlled by frequencies in excess of commercial power frequencies under temperatures that exceed 200°C. As a result, the ability to measure the dielectric tangent (tanδ) in the face of changing temperature and frequency is essential.

Dielectric tangent testing based on IEC 60851-5

IEC 60851-5 defines dielectric tangent (tanδ) testing as a method for evaluating performance of enamel wire insulation under specified temperature and frequency conditions. Dielectric tangent testing based on this standard uses an impedance meter. Either a metal bath or a metal block is used to maintain temperature (Fig. 1). The equivalent circuit for an enamel wire and its insulation consists of a capacitor and resistor in parallel (Fig. 2). Applying an AC voltage to this circuit results in a current I that leads the voltage E by close to 90° (Fig. 3). The loss angle δ is expressed as the triangle formed by the Y-axis component Ic and the X-axis component Ir of the current I, and the dielectric tangent (tanδ) is defined as the ratio of Ir to Ic. An enamel wire with degraded insulation will yield a large dielectric tangent (tanδ). If the temperature is increased, the dielectric tangent (tanδ) will rise starting at a certain temperature (Fig. 4). Similarly, increasing the impedance meter's measurement frequency will also cause the dielectric tangent (tanδ) to rise.

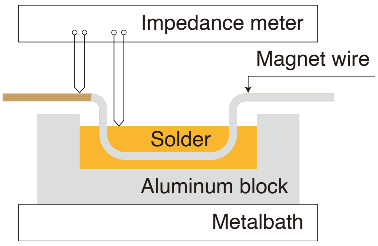


Fig. 1

Tanδ measurement of an enamel wire using a IEC 60851-5 metal bath

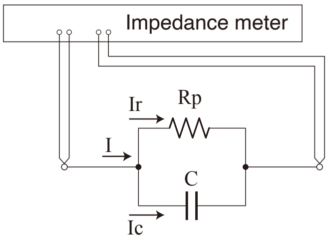


Fig. 2

Tanδ measurement of an enamel wire with an impedance meter

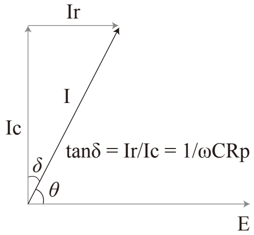


Fig. 3

Vector diagram

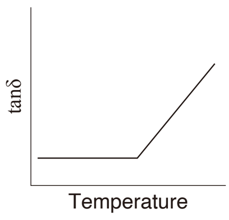
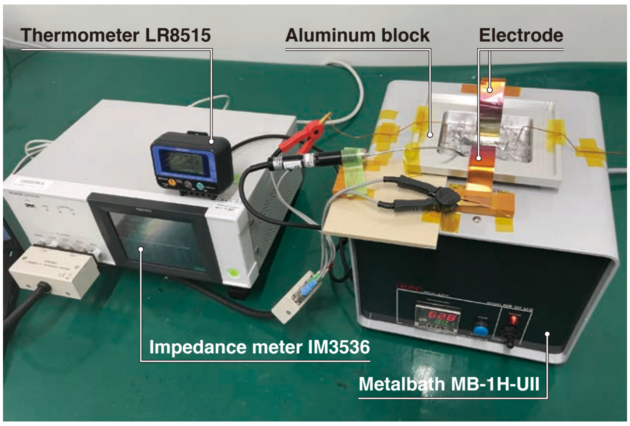


Fig. 4

Tanδ vs. temperature characteristics

Application Note

Test equipment and method



Here, an “MB-1H-U II” metal bath from Koike Precision Instruments (http://www.k-p-i.net/) is used along with a special-order rimmed aluminum block (to hold the melted solder).

Test method

- Perform open correction for the LCR meter before starting the test.
- Insert an enamel wire (with a diameter of 0.9 mm) into melted solder.
- Using a metal bath, increase the temperature of the solder from 40°C in 10°C increments.
- Using the LCR meter, measure the dielectric tangent at each temperature.
- Measure the dielectric tangent at multiple measurement frequencies.
- Perform short correction across the LCR meter’s electrodes at each temperature.
- Record the measurement data using Sequence Maker*.

*Sequence Maker is a free Excel® add-in. It can be used to control switching between measurement frequencies for an LCR meter and to collect measurement data from within Excel®. For details, please see the following minisite: https://sequencemaker.hioki.com/en/.

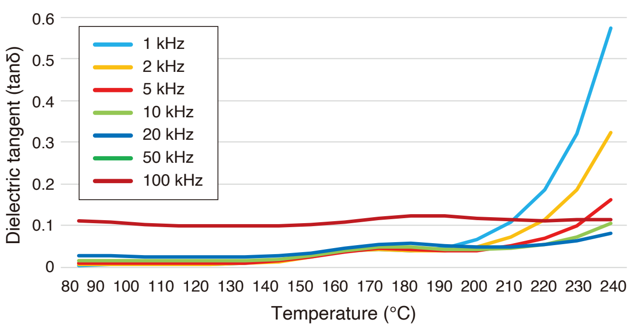
LCR meter settings	
Measurement mode	LCR mode
Measurement signal mode and level	Open voltage (V) mode, 3 V
Measurement speed	SLOW
No. of averaging iterations	20
Measurement frequencies	1 kHz, 2 kHz, 5 kHz, 10 kHz, 20 kHz, 50 kHz, 100 kHz Controlled and automatically captured using Sequence Maker*
Trigger	External trigger

Equipment used

LCR METER	IM3536	HIOKI
WIRELESS VOLTAGE/TEMP LOGGER	LR8515	HIOKI
Sheath-type K thermocouple		
Metal bath	MB-1H-UII	Koike Precision Instruments (http://www.k-p-i.net/)
Aluminum block	Special-order	With rim so that it can hold solder

Measurement data

Graph of dielectric tangent (tanδ) vs. temperature characteristics



- The tanδ value increases with the measurement frequency.
- At a measurement frequency of 1 kHz, the tanδ value switches from a stable state to rapidly increasing at a temperature of 190°C.
- Higher measurement frequencies result in higher temperatures, which increase rapidly.

- The measurement frequency and evaluation temperature range for the dielectric tangent test are determined by the specifications of the product being evaluated.
- The LCR Meter IM3536’s measurement frequency can be set from 4 Hz to 8 MHz.
- The MB-1H-U II metal bath (from Koike Precision Instruments, http://www.k-p-i.net/) can be set to a temperature of up to 300°C.
- Sequence Maker (https://sequencemaker.hioki.com/ja/) is a free Excel® add-in. It can be used to control switching between measurement frequencies for an LCR meter and to collect measurement data from within Excel®.

HIOKI

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