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Page:	1 of 5

TECHNICAL DATA

THE COOPER POWER SYSTEMS MULTI-STRESS TEST

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BACKGROUND

One of the primary objectives of the ongoing materials development program at Cooper Power Systems is to ensure the superior performance of the insulating rubber compounds in all types of environments. Experience has shown that the most severe physical environment for molded rubber products is one that is below grade, warm and moist.

To verify that the insulating rubber compounds will perform as expected under these severe conditions, a series of tests are performed during design validation and periodically during production as an audit. All products undergo the standard ANSI/IEEE 386 tests, however, they also undergo the Multi-Stress Test. RTE developed this test to evaluate the field performance of products used in the severe environmental conditions found in below grade, warm and moist locations.

The Multi-Stress Test is so named because it measures the performance of products subjected to multiple environmental stresses (elevated voltage, temperature and moisture) simultaneously. It is designed to simulate in the laboratory warm, wet, below grade field conditions and to evaluate the wet dielectric stability of the insulating rubber compounds. The goal of the Multi-Stress Test is to verify reliable long term performance of the molded rubber products in harsh, wet field environments.

PROCEDURE

Product subjected to this test is assembled on cable with a mating device and submerged in water while an elevated voltage is applied. Test conditions were chosen to accelerate the test process based upon product and environmental constraints.

An elevated temperature of 90°C water was selected to match the maximum continuous conductor temperature specified by cable manufacturers. To ensure the connector system does not experience artificial failure due to corona, voltage is maintained at 1.5 times rated line-to-ground voltage. The minimum duration for the test, 1000 hours, has been established based on experience. Product with known insulation flaws fails the test in less time.

Periodically during testing, the assemblies are removed from the water and measurements of the insulating rubber's dielectric strength are taken. The parameter measured to determine dielectric strength is the dissipation factor.

Dissipation factor is the tangent of the loss angle (δ) of the insulating rubber and is a standard measure of dielectric strength. As measurements of the dissipation factor (tan δ) are made during the test they are charted to identify its trend. A stable or unchanging tan δ indicates that the insulating rubber is stable. An increasing tan δ indicates instability resulting from a decrease in insulation resistance, a precursor to dielectric breakdown and eventual failure.

A marked increase in tan δ over the duration of the test is an indication that the insulating rubber is susceptible to premature breakdown caused by one of the applied stresses. Unlike the standard ANSI/IEEE tests, the Multi-Stress Test does demonstrate correlation between the laboratory and the warm, wet field environments. Product that passes the Multi-Stress Test with a stable tan δ performs well in harsh environments and assures reliable long term field life.

THEORY

The construction of molded rubber products is such that insulating rubber is molded between two semi-conducting shields. When these products are placed into service the inner shield maintains a voltage potential equal to the system voltage while the outer shield is maintained at ground potential.

By definition, electrical insulation is a material which, when placed between conductors at different potentials, permits only a negligible resistive current, in phase with the applied voltage, to flow through it. The term dielectric is basically synonymous with the term electrical insulation.

A perfect dielectric will allow no resistive current and only capacitive charging current to pass between conductors. The only conditions that simulate this ideal is uncontaminated metal surfaces separated by vacuum at low stresses.

Real world dielectrics or electrical insulation materials will allow some amount of resistive current to pass between conductors. As such, an imperfect dielectric can be considered as equivalent to a circuit of capacitors and resistors in parallel. Figure 1 shows the simplest circuit representation.

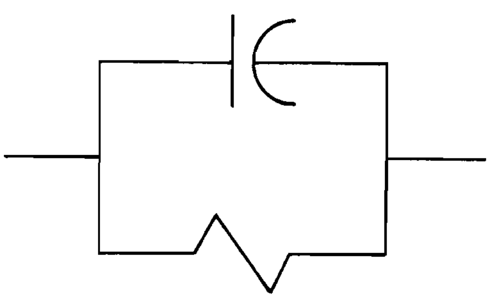

Figure 1: Representative circuit of a dielectric.

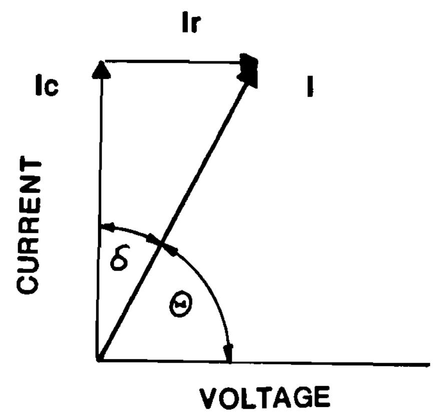

Figure 2: Current-voltage phase relation in a dielectric.

The ac dielectric behavior of the circuit in Figure 1 can be represented by the phase diagram in Figure 2. The perfect dielectric has only a capacitive charging current (Ic) which leads the voltage with a phase angle (Θ) of 90°. However, the imperfect dielectric has a resistive current component (I_r) in phase with the voltage. The resulting current flow through the dielectric still leads the voltage but with a phase angle less than 90°.

Resistive current passing through the insulating rubber is the cause of internal heating which accelerates deterioration of the rubber and leads to dielectric breakdown. The quantifying measure of internal heating is watts loss. Watts loss is the product of voltage (V) and resistive current (I_r).

$$\text{Watts loss} = VI_r \qquad [1]$$

Although voltage is an easily measurable quantity, I_r is not. Therefore, it is convenient to completely express watts loss in terms of easily measurable quantities.

A standard measure of the dielectric strength of insulating materials and an easily measurable quantity is dissipation factor. It is the ratio of resistive current to capacitive current passing through the insulating material. From Figure 2 this ratio is seen to be defined as the tangent of the angle δ, where δ is the loss angle and is equal to 90° - Θ.

It then follows that,

$$I_r = I \sin \delta$$

and by substitution into equation [1],

$$\text{Watts loss} = VI \sin \delta. \qquad [2]$$

By definition:

$$\tan \delta = \sin \delta / \cos \delta$$

or, by rearranging the terms,

$$\sin \delta = \cos \delta \tan \delta. \qquad [3]$$

Therefore, by substituting Equation 3 into Equation 2:

$$\text{Watts loss} = VI \cos \delta \tan \delta. \qquad [4]$$

The term I cos δ is the capacitive charging current (I_c) and is by definition:

$$I_c = I \cos \delta = V\omega C \qquad [5]$$

where:

$$\omega = 2\pi f$$
$$f = \text{frequency}$$
$$C = \text{capacitance}$$

Substituting Equation 5 into Equation 4:

$$\text{Watts loss} = V (V\omega C) \tan \delta$$

or,

$$\text{Watts loss} = V^2\omega C \tan \delta. \qquad [6]$$

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By analyzing the terms in equation 6, watts loss is seen to be dependent upon the factors of system voltage (V), frequency (f), capacitance of the dielectric (C) and dissipation factor (tan δ). All of these, with the exception of tan δ, are relatively constant. Therefore, tan δ can be used as a direct indicator of changing watts loss.

Tan δ is easily measured and, as previously noted, is the ratio of resistive current to capacitive current. Capacitive current, defined previously as,

$$I_c = V\omega C$$

is dependent on system voltage (V), frequency (ω) and capacitance (C) and will be relatively constant. Therefore, any change in tan δ will be the result of a change in the resistive current.

Tan δ will increase as the dielectric strength of the insulating material degrades or, simply stated, as the resistance of the insulation decreases. As measurements of tan δ are made during the test they are charted to identify its trend (Figure 3). A stable or unchanging dissipation factor indicates that the insulating rubber is maintaining its dielectric strength when subjected to the harsh conditions of this accelerated aging test and will provide reliable long term performance.

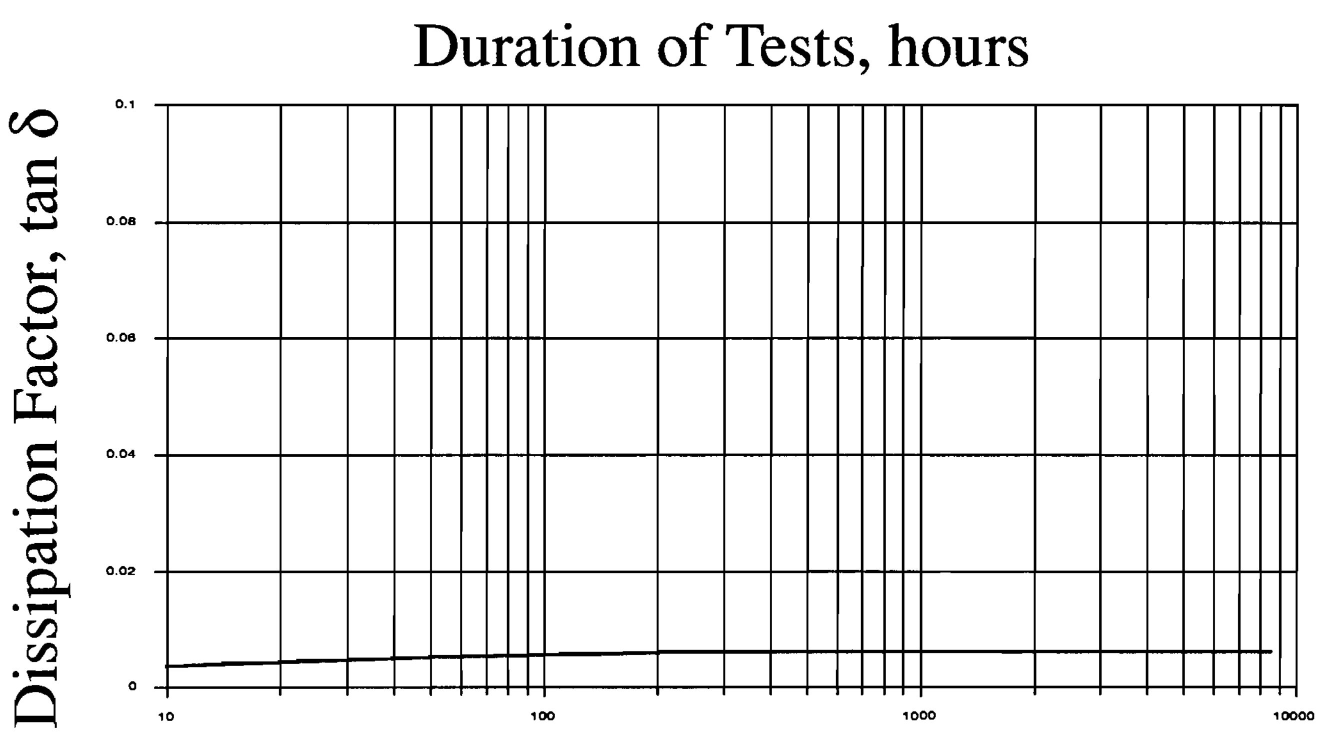

Figure 3: Typical Performance of Insulating Rubber Subjected to the Multi-Stress Test