MULTI-STRESS AGEING AND ITS INFLUENCE ON ELECTRICAL STRENGTH

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SUMMARY

The purpose of this article is to show how electrical and thermal field exercise an influence on life-time of insulation material. Fist of all simple ageing is described. When thermal stress is analyses, the Arrhenius's law is used together with chemical kinetic reaction theory. From theses assumption thermal classes of each material applied in insulation system can be determined. Nowadays there is material with class F. It is ReMica material based on mica, epoxy resin and textile base. After thermal heating it is prepared for industry used. It is necessary to know the influence of temperature during production and service, because ageing mechanism can be change if certain boundary above thermal class is overcame. The same situation is during electrical stress. For thermoplastic materials the sufficient theory isn't present nowadays, especially for critical limits. Finally the combination of both brings their interaction. The influence from single stresses can't be cumulated without correction.

Keywords: *thermal and electrical stress, multi-stress factor, life-time, breakdown*

1. INTRODUCTION

Electrical insulation material is ageing due to multi-stress factor during its service. Combination of room temperature and electrical field is present everywhere. Reason of excursion of single stresses and their conjoint influence is their interaction. Ageing of insulation is primary changes of chemical properties as sequence of ageing reaction or diffusion phenomenon [1]. Changes of physical properties are very often used for state of degradation determination and they are depended on primary changes in very complicated form.

2. THERMAL DEGRADATION

Basic law of chemical reaction kinetic is Arrhenius's law

$$k = A.e^{-\frac{W}{R.T}} \tag{1}$$

where k - Arrhenius's accelerated constant,
R- universal gas constant,
A - frequency factor,
W - activation energy,
T - absolute temperature.

It was done that rate of thermo-oxidation ageing depends on magnitude of activation energy. As high is energy, as slow is ageing. Logarithmic calculation of equation (1)

$$\log k = \log A - \frac{E}{2,303.R}.\frac{1}{T} \tag{2}$$

If accelerated constant of ageing process is reached, result of graphic relation of

$$\log k = f(1/T) \tag{3}$$

is line with slope of a straight line –E/(2,303.R)

At some temperature that is characteristic for each material the mechanism of ageing is changed. The activation energy is changed and slope of a straight line is changed too.

Time change of concentration is according to [2]

$$\frac{\partial c}{\partial t} = -k.c^{n_r} \tag{4}$$

where c – concentration related to chemical composition of material,
n_r – degree of reaction.

For $n_r = 1$ $$\ln\frac{C}{C_0} = -k.t \tag{5}$$

then

$$t = \frac{1}{A}.\ln\frac{C}{C_0}.e^{\frac{B}{T}} \tag{6}$$

$$\ln t = \frac{B}{T} + \ln t_\infty \tag{7}$$

where $$t_\infty = \frac{1}{A}.\ln\frac{C}{C_0} \tag{8}$$

Insulation material can be shared according of slope of line from equation (5) to thermal classes. If changes in material are result of several chemical degradation processes, straight line is changed to cusped.

3. ELECTRICAL DEGRADATION

Life-time model for thermoreactive materials can be done according to [2]

$$t = H\frac{e^{-h.E}}{E - E_T} \quad (9)$$

where E - electrical stress,
E_T- primary thermal depended stress,
H - thermal depended constant,
h - thermal depended constant.

Life-time analysis for thermoplastic material is not satisfy solved. Inverse-power model is applied often

$$t = C.E^{-n} \quad (10)$$

where n - voltage endurance coefficient,
C - thermal depended constant.

As high is voltage endurance coefficient as high is quality of material.

4. MULTI - STRESS DEGRADATION

Generally life time during multi-stress ageing can be set as

$$t = f(E, \Delta T) \quad (11)$$

For $\Delta T = T - T_0 = 0$ the result is only electrical ageing, for $E = 0$ the result is thermal ageing. T_0 is room temperature.

If Arrhenius's thermal model and inverse-power model are valid, the following equations can be done for simple thermal stress

$$t_t = t_0.e^{-B.\Delta T} \quad (12)$$

where $$\Delta T = \frac{1}{T_0} - \frac{1}{T} \quad (13)$$

and simple electrical stress

$$t_e = t_0.\left(\frac{E}{E_0}\right)^{-n} \quad (14)$$

According to [3] total life time is

$$\frac{t}{t_0} = \frac{t_t}{t_0}.\frac{t_e}{t_0} \quad (15)$$

If the voltage endurance coefficient is thermal depended, then

$$n(T) = n - b.\Delta T \quad (16)$$

$$t = t_0.e^{-B.\Delta T}.\left(\frac{E}{E_0}\right)^{-(n-b.\Delta T)} \quad (17)$$

and

$$\ln t = \ln t_0 - B.\Delta T - n.\ln\left(\frac{E}{E_0}\right) + b.\Delta T \ln\left(\frac{E}{E_0}\right) \quad (18)$$

For thermoreactive material

$$t_t = t_0 \frac{e^{-B.\Delta T}}{\Delta T - \Delta T_T} \quad (19)$$

$$t_e = t_0 \frac{e^{-h.E}}{E - E_T} \quad (20)$$

where $$\Delta T_T = \frac{1}{T_0} - \frac{1}{T_T} \quad (21)$$

Temperature T_T is thermal threshold. Ageing isn't present under this temperature.

$$t = k_0.t_0.\frac{e^{-B.\Delta T - h.E + b.E.\Delta T}}{\frac{E}{E_T} + \frac{\Delta T}{\Delta T_T} - 1} \quad (22)$$

Coefficient k_0 is depended on short time feature of material.

5. INFLUENCE OF MULTI-STRESS ON ELECTRICAL STRENGTH

There are premises :

- Ageing is cumulative process
- Electrical strength is basic attribute of insulation material
- Arrhenius's law is valid
- Inverse-power model is valid

According to [3] equation of ageing is

$$1 - \left(\frac{E_s}{E_{s0}}\right)^{n+1} = \left(\frac{E}{E_{s0}}\right)^{n}.\frac{t}{t_0} \quad (23)$$

where E_{s0} - initial electrical strength,
E_s - electrical strength in time t ,
t - life-time,
t_0 - time to breakdown in time of stress with initial electrical strength.

The equation of life time is

$$t = t_0 \cdot \left(\frac{E}{E_{s0}}\right)^{-n} \tag{24}$$

Decreasing of electrical strength can be expressed as

$$F(s) = R(S).t \tag{25}$$

where F(s) - ageing,
s - quality with connection to ageing,
S - stress,
R(S)- speed of degradation.

Let stress S is thermal and electrical field and quality is electrical strength.

$$F(E_s) = R(E,T).t \tag{26}$$

Failure $F_L = F(E_s) = F(0)$ can be reached by two ways. In initial condition by stressing with E_{s0} during time t_0

$$F_L = R(E_{so},T).t_0 \tag{27}$$

After certain time t by stressing with E and then by E_s during time $t_0^{'}$

$$F_L = R(E,T).t + R(E_s,T).t_0^{'} \tag{28}$$

Voltage slope of each breakdown is the same

$$\frac{t_0^{'}}{t_0} = \frac{E_s}{E_{s0}} \tag{29}$$

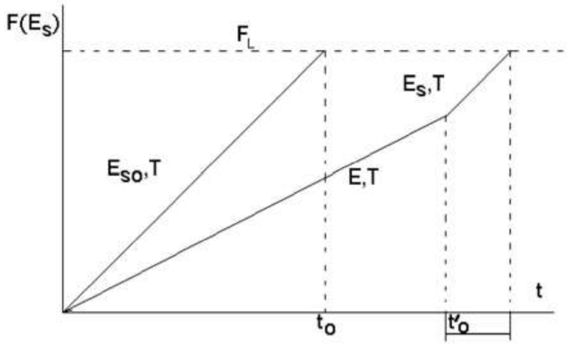

Fig. 1 Equal time slope of breakdown

$$R(E_{s0},T) - R(E_s,T).\frac{E_s}{E_{s0}} = R(E,T).\frac{t}{t_0} \tag{30}$$

Speed of ageing is opposite commensurable to life time in equation (17).

$$L = L_0.e^{-B.\Delta T}.\left(\frac{E}{E_0}\right)^{-(n-b.\Delta T)} \tag{31}$$

Then signs in equation are only changed

$$R(E,T) = R_0.e^{B.\Delta T}.\left(\frac{E}{E_0}\right)^{(n-b.\Delta T)} \tag{32}$$

In initial condition and electrical stress E_{s0} is life time

$$t_0 = L_0.e^{-B.\Delta T}.\left(\frac{E_{s0}}{E_0}\right)^{-(n-b.\Delta T)} \tag{33}$$

$$R(E_{s0},T) = R_0.e^{B.\Delta T}.\left(\frac{E_{s0}}{E_0}\right)^{(n-b.\Delta T)} \tag{34}$$

Let join equations (23), (32), (33) and (34) to (30)

$$\left(\frac{E_{s0}}{E_0}\right)^{(n-b.\Delta T)} - \left(\frac{E_s}{E_0}\right)^{(n-b.\Delta T)}.\frac{E_s}{E_{s0}} = \\ = \left(\frac{E}{E_0}\right)^{(n-b.\Delta T)}.\frac{t}{t_0}\left(\frac{E_{s0}}{E_0}\right)^{(n-b.\Delta T)}.e^{B\Delta T} \tag{35}$$

$$1 - \left(\frac{E_s}{E_{s0}}\right)^{(n-b.\Delta T)+1} = \\ = \left(\frac{E}{E_{s0}}\right)^{(n-b.\Delta T)}\left(\frac{E}{E_0}\right)^{-b\Delta T}.\frac{t}{t_0}.e^{B\Delta T} \tag{36}$$

There are four quantities – time, electrical strength, electrical stress and temperature. They can be imaged following (E, E_s ,T), (E, E_s, t) and (E_s, T, t) in figures 2, 3 and 4.

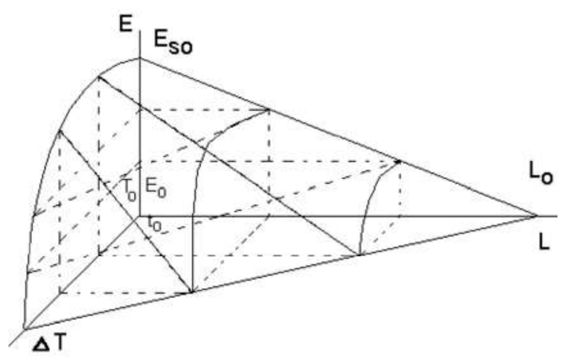

Fig. 2 Relationship of (E, E_s ,T)

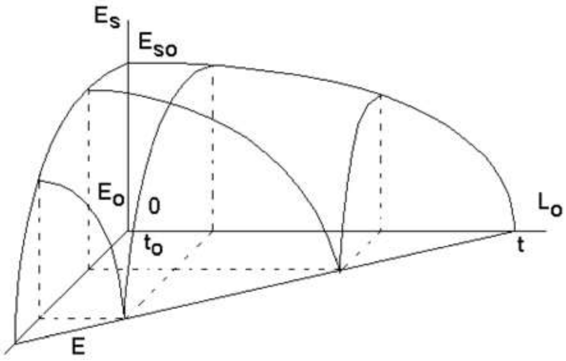

Fig. 3 Relationship of (E, E_s ,t)

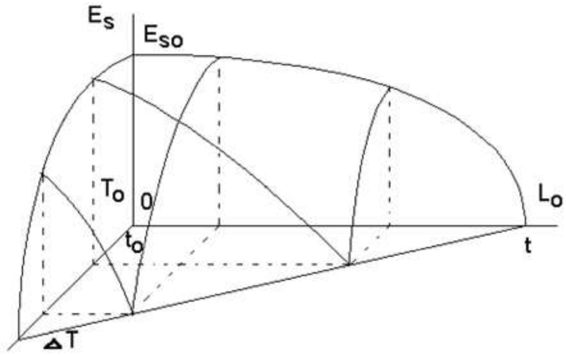

Fig. 4 Relationship of (E_s, T, t)

Life-time under defined electrical and thermal stress is shown in next figure.

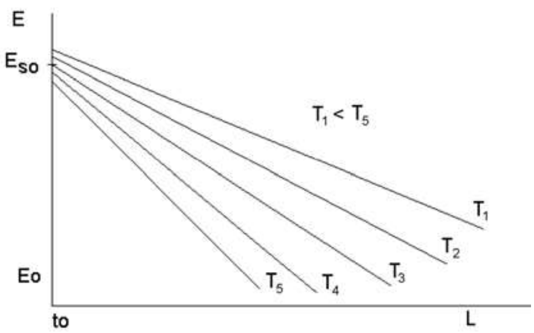

Fig. 5 Life-time during multi-stress ageing

6. CONCLUSION

The multi-stress ageing was described. The result was reached from simple thermal and electrical stress, through their combination up to its influence on electrical strength. The Arrhenius' law and inverse-power model were used to set 1-th and 2-nd Simoni's models and finally both models lead to multi-stress ageing of insulation systems.

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BIOGRAPHY

Roman Cimbala: received MSc degree in Power Engineering at Technical University of Košice in 1986. He received PhD degree in Power Engineering at Slovak Technical University Bratislava in 1994. He works on diagnostics of high voltage and ultra high voltage insulation system of power engineering equipment, especially on current and voltage response of dielectrics. He designs and constructs diagnostic system for isothermal relaxation current analysis based on electrometer and controlled by Hewlett Packard Virtual Engineering Environment.