How to Analyze Aging Characteristics of Generator Main Insulation Based on Mechanical and Dielectric Loss

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Abstract: The main insulation (stator winding insulation) of large generator is an important component of generator and its availability and remaining lifetime depend to a large extent on the conditions of main insulation. At present, the system of epoxy mica insulation is mostly used. Against the aging problem of main insulation during the running, the epoxy mica insulation material is used to carry out the aging test under the influence of electric and thermal stress or mechanical stress; a new analysis method - dynamic mechanical analysis (DMA) is adopted to measure aging characteristics of insulation materials; dynamic mechanical parameters are compared with that of dielectric loss. The DMA should be used to describe the aging characteristics of epoxy mica insulation.

Key words: generator, dynamic mechanical analysis, dielectric loss, aging

Introduction

The main insulation (stator winding insulation) of large generator is an important component of generator and its availability and remaining lifetime depend to a large extent on the conditions of main insulation. When the generator is running, under the combined effect of electricity, heat and stress, the insulation performance will decline gradually and finally disappears. Thus the study of aging performance for stator winding insulation material has a great significance for improving safe operation of large generator.

The epoxy mica composite system is mostly adopted for main insulation of large generator. To correctly evaluate the remaining lifetime of main insulation, researches into its aging characteristics were made in many countries. But those researches are mainly based on statistics and processing of test data and fail to give convincing theoretical explanation.

Starting with the structure of epoxy mica insulation material, this paper analyzes aging characteristics of the material under the influence of thermal stress or mechanical stress respectively; a new analysis method - dynamic mechanical analysis (DMA) is introduced; dynamic mechanical parameters are compared with dielectric loss parameters; a new method of using dynamic mechanical characteristics to present the aging of epoxy mica insulation.

2. Aging Mechanism of Generator Main Insulation

Now the epoxy mica main insulation used by large generator is a thermosetting insulation system, which is based on mica and takes epoxy resin as adhesive and glassfibre fabric to reinforce. under the influence of stresses, the aging performance of epoxy resin is worse than that of mica and glassfibre fabric because epoxy resin is organic. As a result, the performance of epoxy resin reduces and interface structure is destroyed. The air gap produces, causing partial discharge, declined insulation performance and finally the failure of insulation. The diagram of aging is shown in Fig.1.

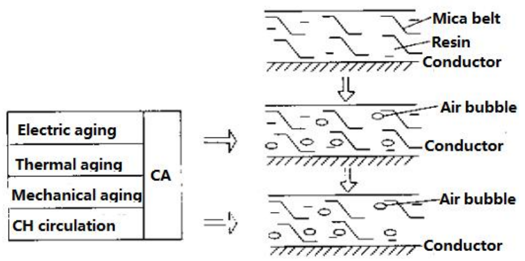

Fig.1 Diagram of aging model

3. Basic Principle of Analysis of Aging

3.1 Basic principle of dynamic mechanical analysis

The DMA measures how polymer's dynamic mechanical performances (storage modulus, mechanical loss and dynamic viscosity) vary according to temperature and frequency under the influence of stresses at an temperature controlled by the program. The dynamic mechanical performance is closely related to the structure of polymer and molecular movement. When the polymer is being affected by sine change stress, the strain lags behind the stress. The dynamic mechanical analysis is based on lagging effect.

Main parameters representing the DMA performance of polymer include: ① E' : storage modulus, the unit is GPa ② tanδ: mechanical loss factor ③ŋ: dynamic viscosity, the unit is MPa.S.

In the PMC (polymer matrix composite), the structure of interface phase is different from that of polymer matrix and filling, thus it has great effect on the performance of PMC.

3.2 Basic principle of analysis of dielectric loss

The dielectric material has the energy loss under the influence of alternating electric field, caused by conductivity or relaxation polarization. The energy consumed by the dielectric within the unit time is called dielectric loss. This feature can be represented by tanδ.

The polymer has a complex structure and multiple structure units. The Fig.3 presents the schematic diagram and vector graph of dielectric material. Generally speaking, the dielectric loss is represented by $\tan\delta_D$. In addition, the dielectric loss is only determined by material property rather than size and shape and can be directly measured by the test.

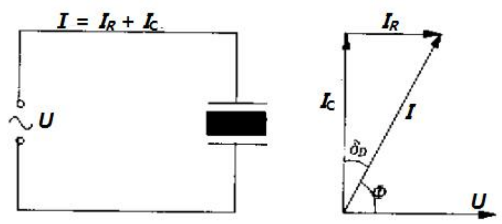

Fig.3 Current vector of electric under AC voltage

4. Test and Analysis of Results

4.1 Test method

In order to simulate aging conditions in the generator, the aging test is carried out under two conditions: ① under the influence of electric and thermal stresses, the voltage is 9.8kV and the temperature is 135; ② under the influence of mechanical stress, that is, cooling-thermocycling. Put the sample into the oven and heat to 135℃ and then use the fan to cool to room temperature. That is one circulation. Many circulations are needed.

The direction is parallel with glass belt; the temperature rises by 5℃ per minute and ranges from room temperature to 200℃; fixed frequency is 5Hz; the amplitude is 0.3m.

The dielectric loss is measured by some high-precision bridge. Test conditions meet the requirements of national standard GB1409-83; three-electrode system is used;

4.2 Result and Analysis

4.2.1 Storage modulus

How the storage modulus changes under aging conditions is shown in Fig.4. It is found that the modulus of epoxy mica insulation material falls. The decreases indicates that the interface's capability of adhering after the material aged.

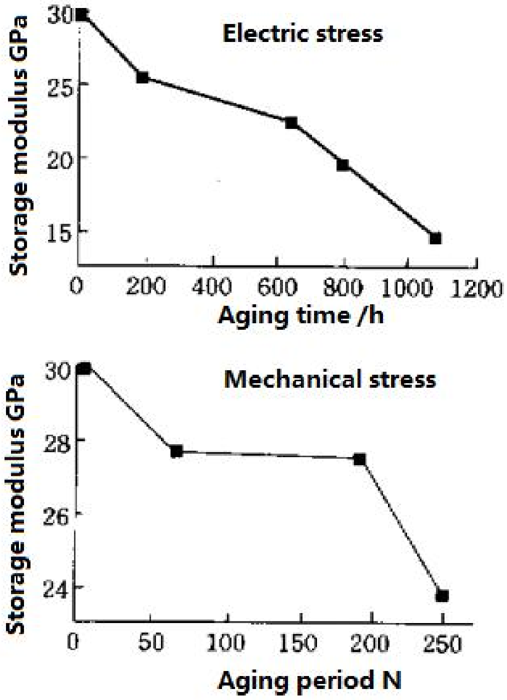

Fig.4 Storage modulus curves under aging conditions

4.2.2 Dynamic viscosity

The changes of dynamic viscosity are shown in Fig.5. From the Fig.5, it can be seen that the peak of viscosity moves to the direction of high temperature as aging time and period extend; the aging peak declines compared with non-aging initial value but the difference is not obvious; the peak appears close to 110℃ under the influence of electric stress, and the same goes for mechanical stress. However, under two aging conditions, the dynamic viscosity tends to decline at room temperature.

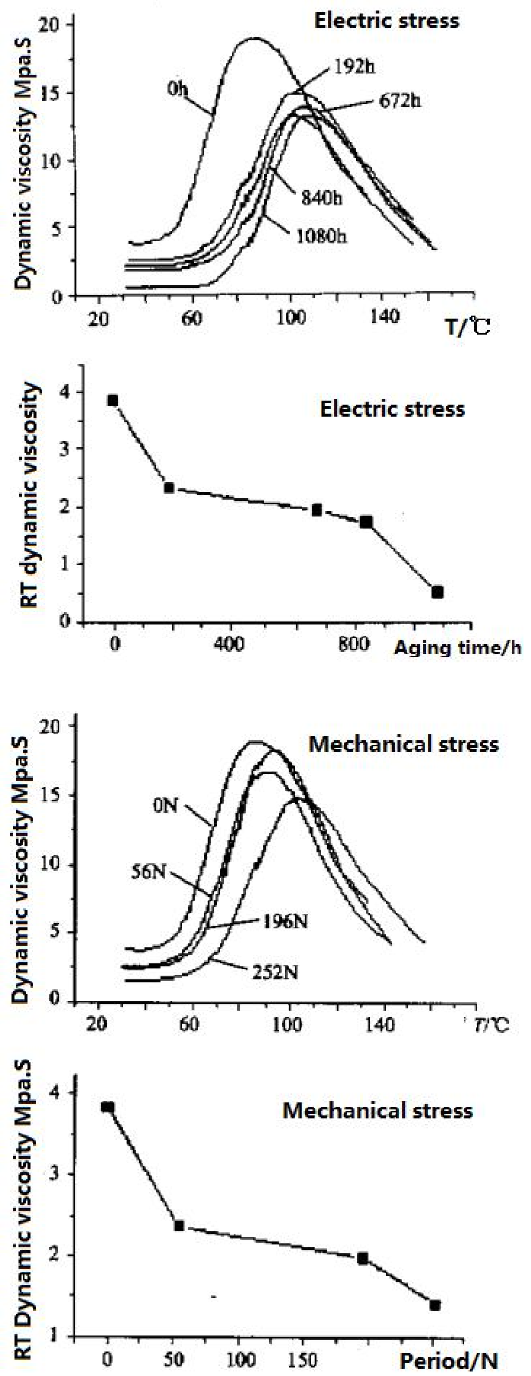

Fig.5 Dynamic viscosity curves under aging conditions

4.2.3 Mechanical loss

The changes of mechanical loss under aging conditions are shown in Fig.6. Based on Fig.6, after aging, there is no prominent characteristic for the peak change of mechanical loss. But the peak moves to the direction of high temperature as aging time and period extend. The severer the aging is, the higher the temperature is.

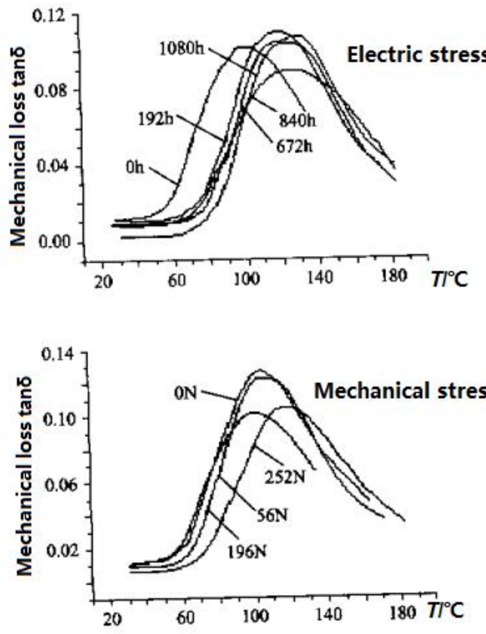

Fig.6. Mechanical loss curves under aging conditions

4.2.4 Dielectric loss

How the dielectric loss changes under aging conditions is shown in Fig.7. It is found that the dielectric loss declines compared with non-aging but the feature is not obvious; after aging, the peak of dielectric loss moves to the direction of high temperature; the severer the aging is, the higher the temperature is. The trend is similar to the peak of mechanical loss.

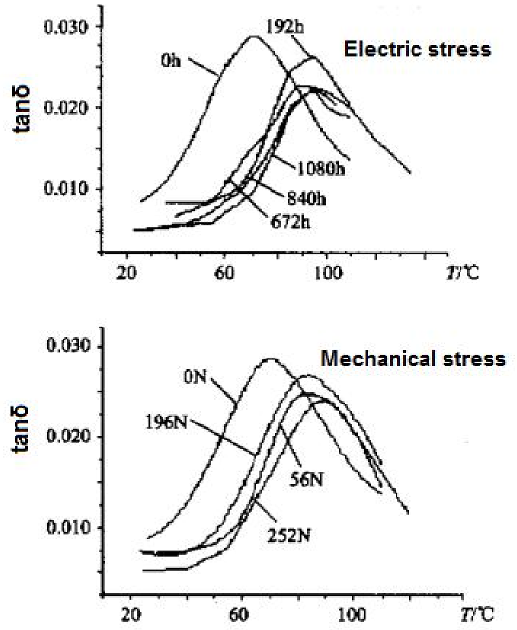

Fig.7 Dielectric loss curves under aging conditions

5. Theoretical Analysis

At the initial stage, the relation between reaction rate and DMA curve and baseline deviation is listed below:

$$\Delta \tan\delta = S_0 \times \frac{d\alpha}{dt} \qquad (1)$$

Δtanδ: distance that DMA curve deviates from baseline (mm)

S_0: mechanical effect area (mm^2)

Dα/dt: reaction rate

The formula of reaction rate:

$$\frac{d\alpha}{dt} = A_0 e^{-\Delta E/RT} f(\alpha) \qquad (2)$$

R: gas constant, 8.314J/K.mol

T: absolute temperature (K)

A_0: constant

$f(\alpha)$: reaction rate function

$f(\alpha) = (1-\alpha)^n$

Insert formula (2) into (1):

$$\ln(\Delta \tan\delta) = \ln A_0 + \ln f(\alpha) - \frac{\Delta E}{RT} + \ln S_0 \qquad (3)$$

ln A_0 and In S_0 are constants:

$$\ln(\Delta \tan\delta) = C + \ln f(\alpha) - \frac{\Delta E}{RT} \qquad (4)$$

At the initial stage, the ln$f(\alpha)$ can be neglected:

$$\ln(\Delta \tan\delta) = C - \frac{\Delta E}{RT} \qquad (5)$$

The formula (5) is linear equation and ΔE can be obtained through the slope.

tanδ: the distance that tanδ curve deviates from baseline (mm). The solution is shown in Fig.8.

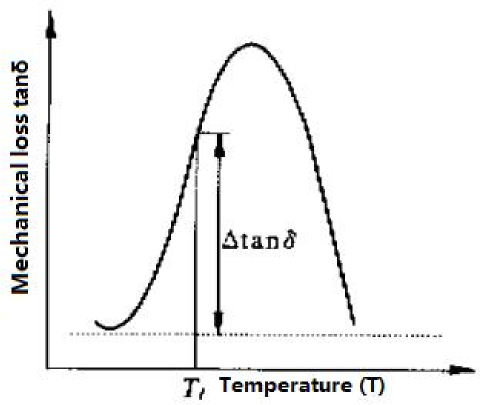

Fig.8 Calculation of glass transition apparent activation energy with mechanical loss curve

6. Conclusions

(1) The epoxy mica insulation material will age gradually under the influence of electric and mechanical

stresses. During the aging, its parameters will change and the same goes for dielectric loss parameters.

(2) Following the aging of epoxy mica insulation material, its storage modulus reduces greatly; the peak of dynamic viscosity moves to the direction of high temperature; in addition, peaks of mechanical and dielectric loss also move to the direction of high temperature.

(3) After the epoxy mica insulation material aged, its glass transition apparent activation energy increases greatly, which is consistent with test results.

(4) The dynamic mechanical parameters including storage modulus, mechanical loss and dynamic viscosity can be utilized to describe the aging characteristics of epoxy mica insulation materials.

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