Study On Mechanism of Dielectric Breakdown in Polyimide Film

Laisheng Tong, Xueqing Zhang, Guangning Wu
School of Electrical Engineering, Southwest Jiaotong University
Chengdu, 610031,P.R. China.

Abstract The Pulse Width Modulation (PWM) inverter plays an important role in express locomotive. Especially after traction motors are fed by fast switching inverters, the interturn insulation is destroyed more heavily. However, a new type of polyimide corona resistant film is developed and used in insulation of traction motors. In order to investigate the service life of this kind of traction motor, the mechanism and characteristics of dielectric breakdown of polyimide corona resistant are studied in the paper. Experiments have been carried out on specimen according to the condition of traction motor. The breakdown point of tested sample film is analyzed through energy spectrum analysis and electron microscopic photograph. At last, it is presented that the characteristics and mechanism of breakdown of p olyimide corona resistance film.

Key word: insulation, breakdown, traction motor

1. Introduction

As it is known that AC traction motors did an important effect to the reliability of express locomotive. But there is a serious problem that the insulation of motor is destroyed heavily. Premature failure occurred in the winding insulation, especially the interturn insulation of low voltage motor fed by fast switching inverter [1]. The failure of insulation isn't the result of one single factor but is attributed to the combined effects, including partial discharge, dielectric heating and space charge [2]. In order to guarantee insulation reliability of traction motors, a new type of polyimide corona resistant film is developed and used as the interturn insulation of traction motors. Polyimide corona resistant film has several advantages [3]. The filled polyimide is a higher temperature class material that allow for overload conditions. And with filled polyimide the pulse endurance life was drastically improved.

However, high-speed railway has got a fast development since AC traction motor was fed by fast switching inverters. The problem of insulation a ttracted m ost c oncentration a gain, that interturn insulation is heavily suffered by high frequency continuous impulse than fed by sine wave. In order to make it certain that the serve life of traction motor, failure mechanism of polyimide corona resistant film is studied.

In this paper, experiments focused on the mechanism analysis of breakdown. Several types of dielectric breakdown had been tested. For analyzing the characters of breakdown point, texture of the breakdown point is experimented through energy spectrum analysis and electron microscopic photograph. At last, breakdown characteristics and mechanism of polyimide corona resistance film are presented.

2. Experiments

The test condition is processed on the condition of traction motor. In order to match the test condition, all the samples are made with the same material and bend in the same shape according to the standard IEC60851-5, as showed in Figure 1. The test sample is made by magnetic wire, which is wrapped around with polyimide corona resistant film.

The inner metal conductor is copper to connect the high voltage. It is insulated with a triple layer with a 2/3 surmounting of polyimide corona resistant film whose thickness was 25 μ m. The specimen is placed in a container filled with 2 mm of stainless steel shots to be the ground electrode. The height of stainless steel shots in container is 90 mm, and surrounded the film symmetrically. Furthermore, the wire must be at least 5 mm away from the near wall of the container, and the ends of the specimen are sufficiently long to avoid flashover.

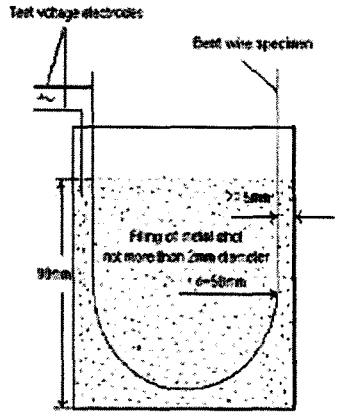

Fig .1 Rectangular wire sample

To analysis the failure mechanism under different condition, the temperature and electrical stress can be adjusted. Through measurement and analysis with the breakdown point of film, it is found that thermal, electrical and electrical tree are the main causes to destroy the film, which would be discussed below.

In addition, during test period, the result is related greatly to the condition of specimens. Because of that, specimen pretreatment is carried out. Because ambient humidity is high in Chengdu, before each experiment, specimens should be dried in oven at 80℃ for two hours.

3. Results and Discuss

3.1Thermal Breakdown

Thermal breakdown in polyimide film often occurs when the balance between heating and cooling is broken. It is related to the test temperature, the thermal change of sample shape and resistance and cooling condition.

It could be express by the basic energy balance equation, as shown below,[4]

$$C_v \frac{\partial T}{\partial t} - div(KgradT) = \sigma E^2 \quad (1)$$

Where K is the thermal conductivity, C_v is the thermal capacity of the dielectric and σ is the electrical conductivity. According to the equation, due to nano filled material is with good heat conductivity, breakdown strength of thermal breakdown may be increased.

After 47 minutes under 130℃ and 2300 volts condition, the thermal breakdown took place, the breakdown point of which can be shown in Fig.2. Its diameter is approximately 1.5mm with black powder surrounding. As mentioned above, not only electrical conduction but also dielectric loss would result in unbalance of heat inside the polyimide film [5]. When the local temperature is up to critical temperature, the rate of heating exceeding the cooling, thermal breakdown occurs. Therefore, black powder is generated as the result of decomposition and carbonization of polyimide. Its width of black power is approximately 0.3μm. Through energy spectrum analysis, as shown in Fig.3, a mass of carbon is found in powder. It proved adequately that powder is the result of polyimide carbonization. Al may be the element of nano filled materials in polyimide corona resistant film. And F is the element of Fluorinated Ethylene Propylene, a kind of bond. The granule showed in Fig. 4 is rooted of nano filled materials wrapped by melting polyimide.

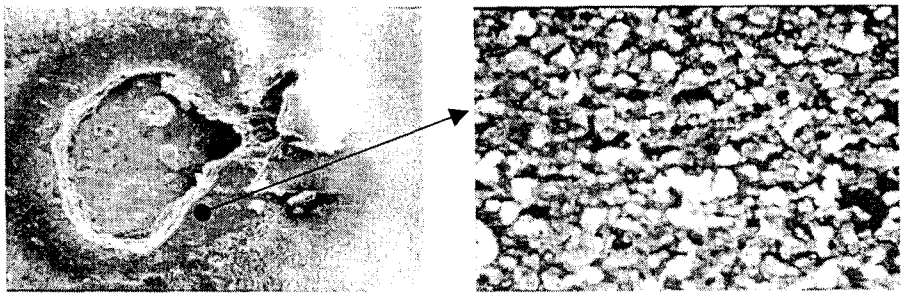

Fig 2. Thermal breakdown point and partial enlarged photograph

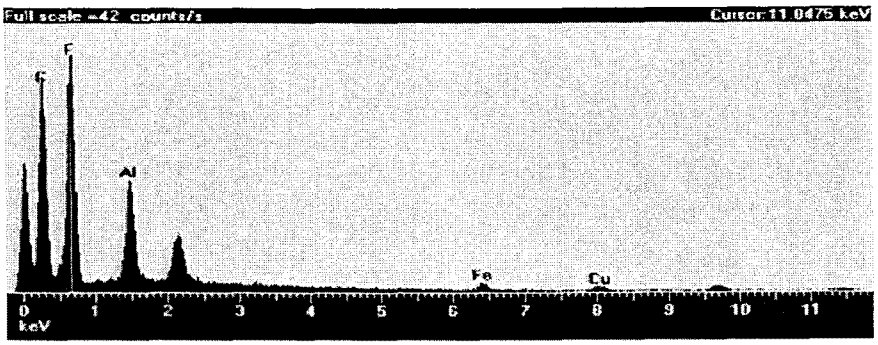

Fig 3. Energy spectrum analysis of powder

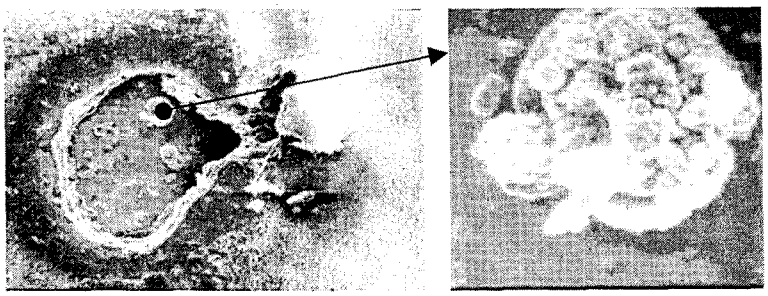

Fig 4. Inorganic filler wrapped by melting polyimide

3.2 Electrical Breakdown

Polymer dielectric is composed of unordered big molecule. So mechanism of electrical breakdown is different from order solid dielectric. Experimental results indicated that process of electrical breakdown results from breakdown of molecular bond of polymer dielectric which lead to strength of local field increasing heavily. Submicroscopic conductive crack comes into being at the same time. More and more submicroscopic conductive cracks form macroscopy conductive crack. Macroscopy conductive crack broke in very short time under high field strength. Then, electrical life τ is calculated by[6]

$$\tau = \left[E^2 L_0 \left(\frac{\omega}{2\pi} \right) \left(\frac{\alpha\omega\varepsilon}{kT} \right) \right]^{-1} \exp\left(\frac{U_0 - \alpha\pi\varepsilon E^2 C_0}{kT} \right) \quad (2)$$

where, L_0 is unit increment in submicroscopic conductive crack, ω is angular frequency of atom vibration, k is the Boltzmann constant ,T is the absolute temperature, C_0 is the size of the submicroscopic void, U_0 is the activation energy of the breakdown process in physics, ε is the dielectric permittivity and E is electrical field strength. The parameter α is a

property of the material, which physically represents the activation are in the direction of applied electric field.

Electrical breakdown point and its partial enlarged photograph are shown in Fig 5. The breakdown occurs when voltage is 7.03kV and temperature is 26℃. It is found that there are dense and distributed granules in the breakdown point. Energy spectrum analysis of granule displays that polyimide carbonized heavily. Au is smeared on sample when doing the experiment of electron microscopic photograph. Although nano filled materials could enhance the resistance corona characteristic of polyimide film, breakdown strength of electrical breakdown decrease fewer [3].

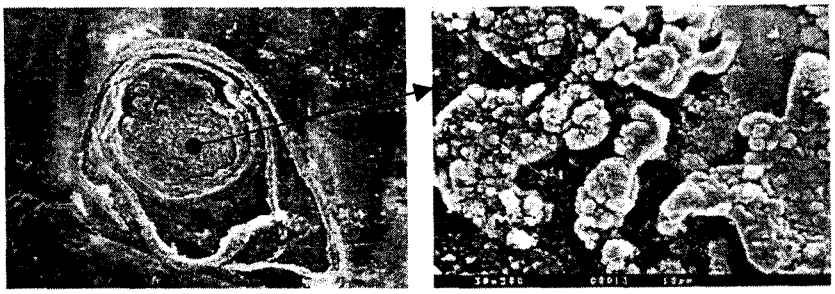

Fig 5. Electrical breakdown point and partial enlarged photograph

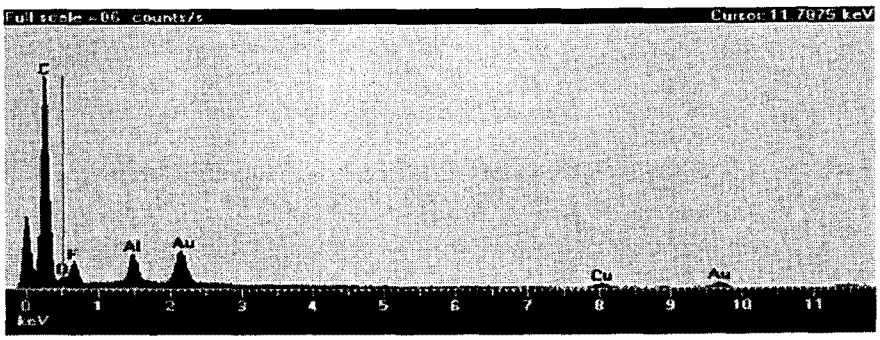

Fig 6. Energy spectrum analysis of granule

3.3 Breakdown due to Electrical Three

Electrical tree occurs almost in all high voltage polymeric insulation, because it is a principal aging process which would lead directly to breakdown failure. To understand the propagation of tree structures of polymeric insulation, much improvement is made in the physical mechanism research.

The electrical tree growth can be described by fractal growth model [7],

$$L = L_b \left\{ \frac{kT}{h} \exp\left(\frac{\alpha\pi\varepsilon E^2 C_0 - U_0}{kT} \right) \right\}^{1/d_f} t^{1/d_f} \quad (3)$$

where, L is electrical tree length,

L_b is unit increment in electrical tree length due to the joining of a secondary tree,

d_f is the fractal dimension of the electrical tree,

h is the Planck constants,

The time of electrical tree growth to failure, t_g, can be calculated by [7],

$$t_g = \left(\frac{L_c}{L_b} \right)^{d_f} \frac{h}{kT} \exp\left(\frac{U_0 - \alpha\pi\varepsilon E^2 C_0}{kT} \right) \quad (4)$$

Higher test temperature is, shorter the insulation is. Large fractal dimension of an electrical tree does good to insulation life.

Electrical tree can be shown clearly in Fig 7. PD occurs in cavities, impact from ion to wall of the cavity, and strain force, all would generate the minute discharge channels which full of gas. Both continuous chemical decomposition and gasification of the insulation material caused by electron bombardment in high electrical field and the increment of temperature, would lead to expanding of these channels. In an electrical tree tip, degradation domain can turn into a secondary submicroscopic tree that leads to the appearance of new tree channel. Electrical tree propagation is caused by the interaction between the main tree and degradation domains ahead of the main tree tip [7]. At the meantime, the growth of electrical tree is also influenced by space charges.

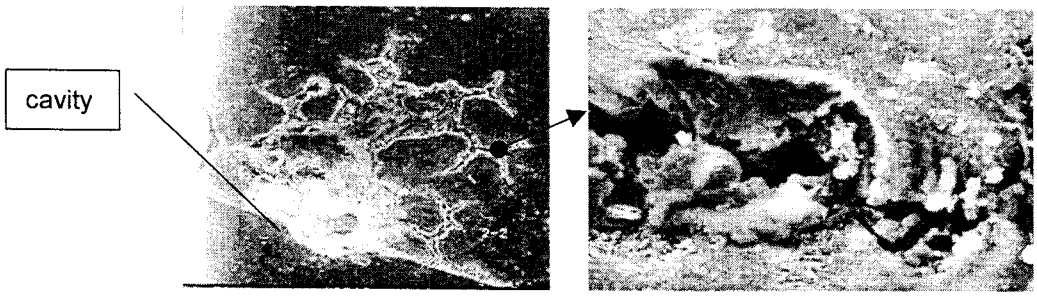

Fig 7. Electrical Three and partial enlarged photograph

4 Conclusion

An experimental activity has been carried out on magnetic wires used in traction motor of express locomotive. Different types of breakdown are analyzed by energy spectrum analysis and electron microscopic photograph.

Due to influence of good heat conductivity of nano filled materials, thermal breakdown strength of polyimide resistance corona film may be higher than general polyimide film. Electrical breakdown strength of polyimide corona resistance film decreased fewer. Cavities in magnet wire would lead to electrical tree. The growth of electrical tree can be described by a fractal growth model.

Acknowledge

The author would to acknowledge National Science Fund of China (NSFC project number 50377035), Fok Ying Tung Education Fund (project number 91060) and NSFC-KOSEF (National Natural Science Foundation of China–Korea Science and Engineering Foundation) for their financial support.

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