Study on the Influence of Ultra - low Temperature (Liquid Nitrogen) on Resistance of Insulating Materials

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Keywords: liquid nitrogen environment; insulating materials; breakdown property; surface flashover performance

Abstract. The electrical characteristics of insulating materials play a key role on the working performance and operation reliability of power equipment. With the rapid development of superconducting technology in recent years, the working temperature of high temperature superconducting power equipment can be controlled around the liquid nitrogen temperature. Therefore, the study on the breakdown property and surface flashover performance of insulating materials at the cryogenic temperatures is of great significance. This paper cites and summarizes the results got by domestic and foreign researchers on this subject.

1. Introduction

Beginning with the discovery of low-temperature superconductivity at the beginning of the twentieth century, people tried to apply it to engineering, and the discovery of high-temperature superconducting materials in the 1980s accelerated the process. With the deepening of the application of superconductivity, low-temperature electrical equipment is gradually close to the level of industrialization [1]. The practical application of superconducting power technology has the effect of greatly reducing the power loss and improving the stability and reliability of power system operation [2].

The insulating properties of low-temperature dielectrics have become an important factor affecting the performance and reliability of superconducting devices [3,4], which is one of the key technologies in the practical process of low temperature electrical equipment.

In the following study, the breakdown characteristics of the insulating material under normal temperature and low temperature environment are compared with the surface flashover characteristics.

2. Effect of Ultra-low Temperature on Electrical Resistance of Insulating Materials

2.1 Study on Breakdown Characteristics

The breakdown strength of the insulating material is calculated as follows:

$$E = U_b / d \tag{1}$$

Which E is the breakdown strength; U_b for the breakdown voltage; d for the sample thickness.

In reference [7], the dielectric strength test uses a ball-plate electrode system, which allows the breakdown of the sample to occur in a uniform electric field as much as possible, thereby measuring the intrinsic dielectric strength of the material. Electrodes must have good electrical conductivity, thermal conductivity and are generally made of copper or stainless steel. The electrode surface must be smooth so that it is in good contact with the sample surface. Figure 1 is a self-designed ball-plate electrode diagram [8].

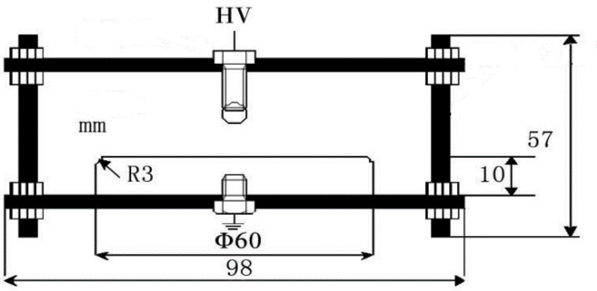
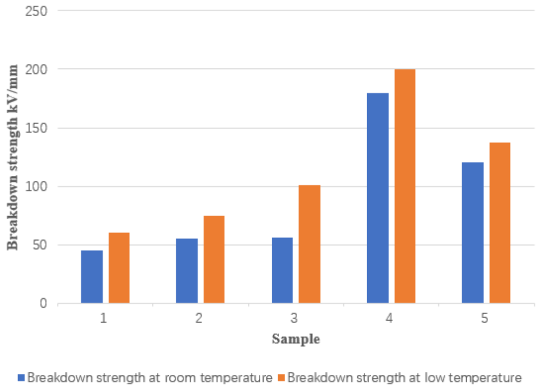


Fig. 1 Ball-plate electrode system

At the same time, four kinds of insulating materials such as cable paper, polypropylene laminated paper (PPLP), polyimide film (PI) and low density polyethylene film (LDPE) were selected as the research object. The power frequency voltage range was set as low-voltage for 0~55kV; high-voltage for 0~110kV and the current range was set for 0~100Ma. The voltage was boost every 20s. The impact test uses an impulse voltage generator, this device is used for insulation, dielectric devices and small power equipment impact strength test [4]. The histogram for the breakdown field strength of materials under power frequency voltage and impact voltage was shown in Fig.2 and Fig.3. The results exhibit that regardless of the power frequency voltage or the impact voltage, the dielectric strength of the selected material at low temperature is greater than that at the normal temperature.



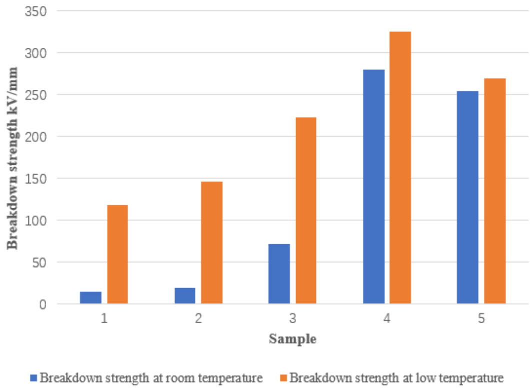


Fig. 2 Breakdown field by rated frequency voltage Fig. 3 Breakdown field by impulse voltage

The article focuses on PTFE, PI and PET insulting materials and tested its negative DC or power frequency breakdown field strength at room and low temperature. At the same time, in order to investigate the effect of different electrode systems on the breakdown field strength of insulating materials, the electrode strength test of column - column, ball - column, column - plate and ball - plate was selected. The conclusions are:

1) The power frequency breakdown field strength of PTFE and PI in low temperature was a little higher than that in room temperature, PI increased significantly higher than the degree of PTFE; PET slightly decreased.
2) The negative DC breakdown strength of the three materials at low temperature is lower than that in normal temperature, and the decreasing degree of PI is the smallest, followed by PTFE and the most serious decrease was of PET.
3) The negative DC and power frequency breakdown field strength of PI in low temperature are obviously higher than those of PTFE and PET.

In reference [6], polyimide was also selected as the research object. The column - plate electrode model was selected for breakdown tests. Shown in Fig.4, the electric field between the upper and lower electrodes of this electrode system is relatively uniform, which ensures the accuracy of the data measurement.

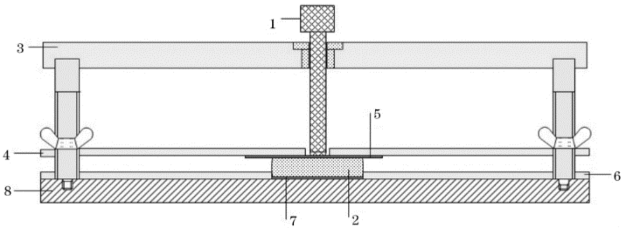


Fig. 4 Schematic illustration of electrode system for breakdown test

Temperature	Number	Breakdown strength （kV/mm）	Average breakdown strength （kV/mm）
300 K	1	327.6	329.1
	2	328.8	
	3	333.2	
	4	330.4	
	5	325.6	
78 K	1	411.2	407.8
	2	414.8	
	3	417.6	
	4	406.4	
	5	389.2	

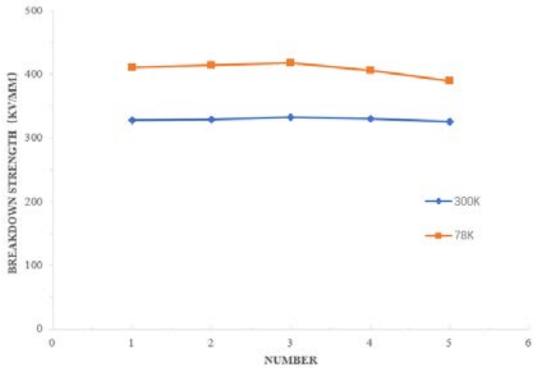


Fig.5a The Breakdown strength of polyimide film under DC voltage

Fig. 5b Variation of DC breakdown strength with temperature increasing

Fig. 5a is the DC breakdown strength of 0.025 mm polyimide material at room temperature (300 K) and liquid nitrogen temperature (78 K), the corresponding data curve is shown in Fig. 5b (kV/mm). It's obvious that the data of breakdown strength for polyimide film is less dispersed, indicating that its insulation performance is stable. As the temperature goes down, the data shows an increasing tendency. The breakdown strength of polyimide films increased significantly with the decrease of temperature, and the breakdown strength of 0.025 mm polyimide film at 78 K was about 23.9% higher than that of 300 K.

2.2 Study on the Surface Flashover Characteristics

The surface flashover field of the insulating material is calculated as follows:

$$E = U_{bt} / d \tag{2}$$

Which E is the surface flashover field strength; U_{bt} for the surface flashover voltage; d for the creepage distance.

In reference [6], the surface flashover characteristics of polyimide were studied. The plane chip crimp electrode model was selected for the surface flashover test. The electrode system was shown as Fig.6, The electric field distribution of the system is symmetrical nonuniform field, the maximum field strength is located near the part where the electrode end is in contact with the material. The field strength between the two poles is lower and the distribution is more uniform [5].

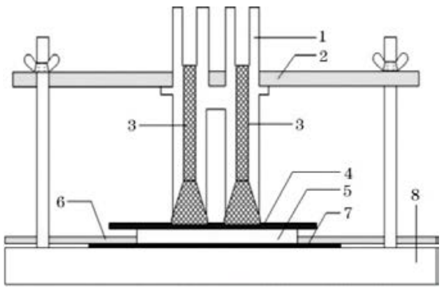


Fig. 6 Electrode system for surface flashover test

Fig.7a is the DC surface flashover strength along the surface of 0.025 mm polyimide material at room temperature (300 K) and liquid nitrogen temperature (78 K), the corresponding data curve is shown in Figure 7b (kV/mm). It's obvious that the first flashover strength of the polyimide film is the lowest, with the increase of the number of flashover, the flashover intensity increases and tends to be stable. The first two flashover belongs to the pre-discharge process of the insulating material and the flashover intensity is low. Starting from the third flashover, the flashover value tends to a steady value and the data is less dispersed. The surface flashover field strength of polyimide films decreases with the decrease of temperature. When the flashover intensity is stable, the surface flashover strength of the 0.025 mm polyimide film at 78K decreases by about 12.1% compared that at 300 K.

Temperature	Number	Surface flashover strength (kV/mm)	Average surface flashover strength when stable (kV/mm)
300 K	1	3.13	4.8
	2	4.07	
	3	4.68	
	4	4.72	
	5	4.94	
	6	4.75	
	7	4.91	
78 K	1	3.18	4.22
	2	3.82	
	3	4.19	
	4	4.13	
	5	4.32	
	6	4.23	
	7	4.23	

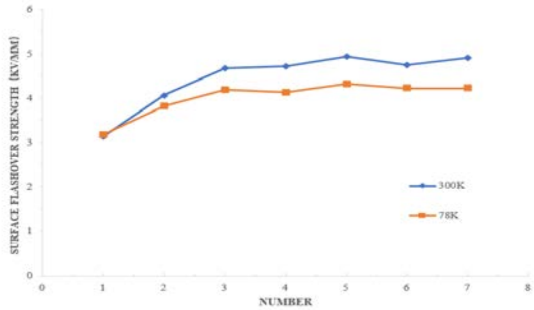


Fig.7a The Breakdown strength of polyimide film under DC voltage

Fig. 7b Variation of surface flashover strength with flashover times increasing

In reference [7], the relation curve between flashover voltage and creepage distance is fitted by MATLAB software obeying Weber distribution with 0.1% probability of flashover. And the exact formula can be obtained, shown in Equation 3 and Equation 4. The conclusion can be made that the surface flashover voltage in the liquid nitrogen environment is greatly influenced by the electrode distance and the electric field unevenness.

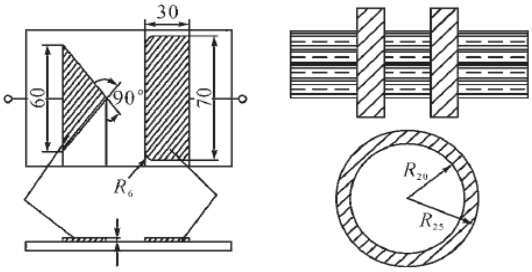


Fig. 8 Experimental electrode

$$U_{tip-plate} = 17.7033 \cdot d^{0.4513} \quad (3)$$

$$U_{ring-ring} = 8.1808 \cdot d^{0.9159} \quad (4)$$

3. Conclusion

In summary, this paper summarizes the relevant research results of corresponding scholars, and makes a comprehensive analysis of both breakdown characteristics and surface flashover characteristics for varieties of insulating materials in the ultra-low temperature (liquid nitrogen), which provides a more comprehensive guide for the interested readers.

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