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Dielectric Characteristics of PPLP according to PP ratio and Electric Field Uniformity for a Superconducting Apparatus

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Introduction

- ✓ The application of high voltage superconducting apparatuses is considered as one of the most promising countermeasures against increasing power consumption.
- ✓ In order to ensure the electrical safety of high voltage superconducting apparatuses such as a superconducting power transformer and a superconducting power cable, the electrical insulation design should be conducted considering aging characteristics.
- ✓ This study deals with dielectric characteristics (electrical breakdown and V-t) of polypropylene laminated paper (PPLP) known as the most proper solid insulation material for a high voltage superconducting apparatus.
- ✓ Dielectric characteristics of PPLP according to the uniformity of electric field intensity and polypropylene (PP) contents of PPLP are experimented and analyzed to ensure the reliability of a long-term operation.

Experimental Set-up

- ✓ All dielectric experiments are conducted by using sphere-plane electrode systems in saturated liquid nitrogen of 77K in temperature.
- ✓ There are two kinds of sphere electrodes with 4 and 40mm in order to verify the effect of electric field uniformity.
- ✓ Two kinds of PPLP specimens manufactured by Tomoegawa Co., Ltd.. Table I represents the specifications of dielectric experiments.
- ✓ Table II shows PP and Kraft ratio of specimens and The thicknesses of A type and B type are 117.5mm and 120.5mm, respectively.

Table. I. Specifications of Experiments.

Electrode system	Sphere-plane electrode system
Electrode material	Stainless steel 304 cd
Diameter of sphere [mm]	4, 40
Dimensions of plane [mm]	Diameter: 120, Thickness: 10 Curvature: 5
Applied voltage	AC (60Hz)
Environment	LN_2 (77K), Silicone oil (300K)
Specimen	A type, B type

Table. II. PP and Kraft ratio of Specimens.

	PP ratio	Kraft ratio
A type	62 %	38 %
B type	40 %	60 %

- ✓ In addition, we conduct dielectric experiments of a mini cable model manufactured with two kinds of PPLP specimens.
- ✓ PPLP is wound with three layers onto a stainless steel pipe with the diameter of 20mm.
- ✓ Fig. 1 shows the schematic drawings of dielectric experiments and Fig. 2 shows the cross sectional view of a mini cable model.

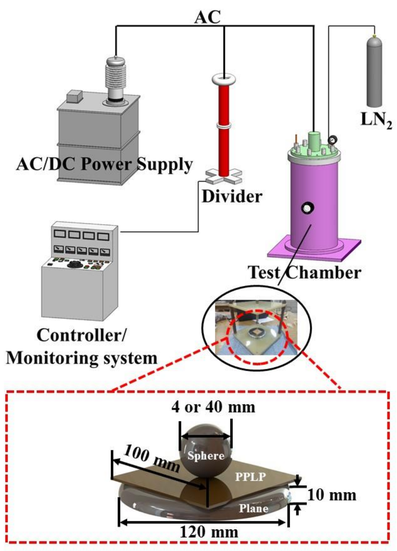

Fig. 1. Schematic drawing of dielectric experiments.

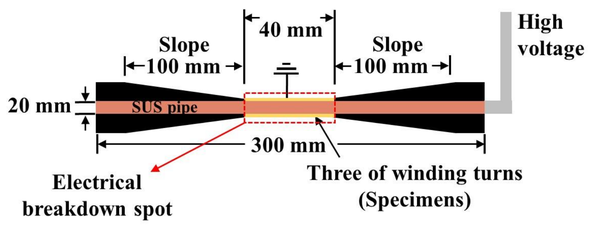

Fig. 2. Dimensions and cross sectional view of mini cable model.

$$\xi = \frac{E_{MEAN}}{E_{MAX}} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (1)$$

- ✓ The electric field uniformity (ξ) is a typical parameter indicating the degree of electric field uniformity and representing the ratio of mean electric field (E_{MEAN}) to maximum electric field (E_{MAX}) in (1).
- ✓ The electric field uniformity is determined by the shape and arrangement of an electrode system.
- ✓ The electric field of an electrode system is calculated by using a finite elements method (FEM) simulation program, COMSOL Multiphysics

Experimental Results and Analysis

- ✓ All experimental results are calculated with a cumulative probability of 63.2% through the two-parameter Weibull distribution analysis.
- ✓ Experimental electrical breakdown voltage of PPLP with different thickness are expressed as converted into electric field intensity in order to compare each other.
- ✓ Fig. 3 shows the electrical breakdown voltage of specimens with respect to the diameter of a sphere electrode and $V_{BD,63.2\%}$ represents the value of electrical breakdown voltage with a cumulative probability of 63.2 %.

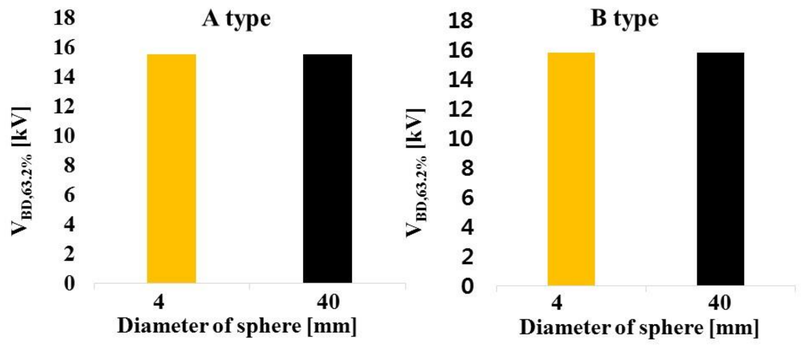

Fig. 3. Electrical breakdown voltage of PPLP specimens with respect to the diameter of a sphere electrode under cryogenic temperature

- ✓ As shown in Fig. 3, it is observed that electrical breakdown voltage is not related with the diameter of a sphere electrode.
- ✓ It accords with the facts that the electrical breakdown characteristics of a solid insulation material are determined by mean electric field intensity.
- ✓ Table III shows the analytic maximum, mean electric field and x of electrode systems, calculated by inputting 1kV into the FEM simulation.
- ✓ Maximum electric field is dependent on the diameter of a sphere electrode while mean electric field is dependent on the thickness.
- ✓ It is observed that intrinsic penetration electrical breakdown characteristics are independent on electrical field uniformity and maximum electric field intensity.

Table. III. Maximum, mean electric field and ξ of electrode systems with A type.

	Maximum electric field	Mean electrode field	ξ
4 mm	23.4 kV/mm	8.3 kV/mm	0.37
40 mm	9.9 kV/mm	8.3 kV/mm	0.86

$$E_{BD,MEAN,63.2\%} = E_{1kV,MEAN} \times V_{BD,63.2\%} \quad \cdots (2)$$

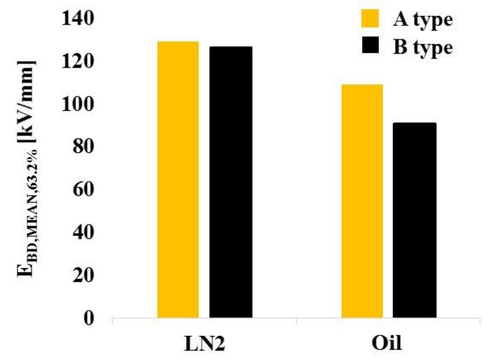

Fig. 4. Mean electric field at electrical breakdown with a cumulative probability of 63.2 % ($E_{BD,MEAN,63.2\%}$) according to temperature

- ✓ Fig. 4 shows the $E_{BD,MEAN,63.2\%}$ of specimens according to temperature.
- ✓ As shown in Fig. 4, electrical breakdown characteristics of PPLP specimens are enhanced under cryogenic temperature compared with those under room temperature.
- ✓ In saturated liquid nitrogen of 77K, difference of $E_{BD,MEAN,63.2\%}$ values between A type and B type is very small compare with that in silicone oil of 300K.
- ✓ In order to analyze the temperature dependent characteristics of PPLP according to PP ratio, electrical breakdown experiments on PP and Kraft are conducted.
- ✓ Fig. 5 shows $E_{BD,MEAN,63.2\%}$ of PP and Kraft according to the temperature of insulation medium.
- ✓ As shown in Fig. 5, electrical breakdown characteristics of PP is higher than those of Kraft regardless of medium temperature.
- ✓ It is inferred that this is due to the different variation of electrical conductivity and heat dissipation characteristics of PP and Kraft according to temperature.
- ✓ It is found that the electrical breakdown characteristics of PPLP is affected by PP ratio in silicone oil but those of PPLP is not affected by PP ratio in liquid nitrogen.

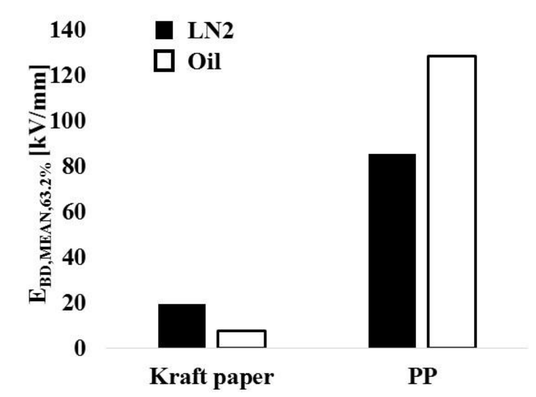

Fig. 5. Mean electric field at electrical breakdown with a cumulative probability of 63.2 %($E_{BD,MEAN,63.2\%}$) according to temperature

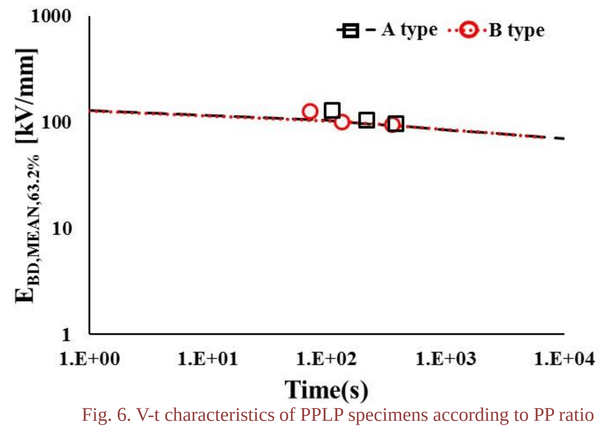

Fig. 6. V-t characteristics of PPLP specimens according to PP ratio

- ✓ The V-t characteristics are calculated and analyzed according to IEEE Std 930.
- ✓ Fig. 6 shows the V-t characteristics of PPLP specimens according to PP ratio.
- ✓ Three points on each plot in Fig. 6 indicate the cumulative probability of 63.2 % at breakdown.
- ✓ As shown in Fig. 6, n value of A type and B type is 11.73 and 13.56, respectively.
- ✓ Aging characteristics of B type which has lower PP ratio are superior to those of A type.
- ✓ Fig. 7 shows the V-t characteristics of an A type specimen according to the diameter of a sphere electrode.
- ✓ It is found that n values with the diameter of a sphere electrode of 4 mm (ξ=0.37) and 40 mm (ξ=0.86) are 11.73 and 34.66, respectively.
- ✓ It is observed that n value is dependent on electric field uniformity, ξ.

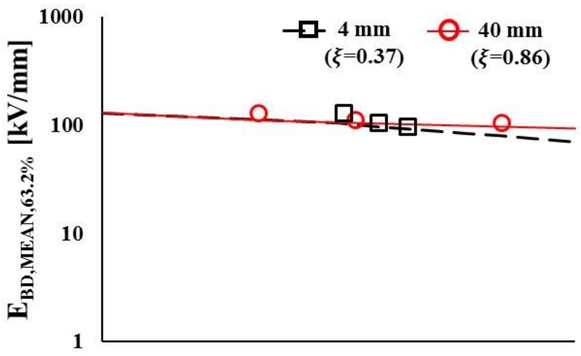

Fig. 7. V-t characteristics of A type specimen according to the diameter of a sphere electrode

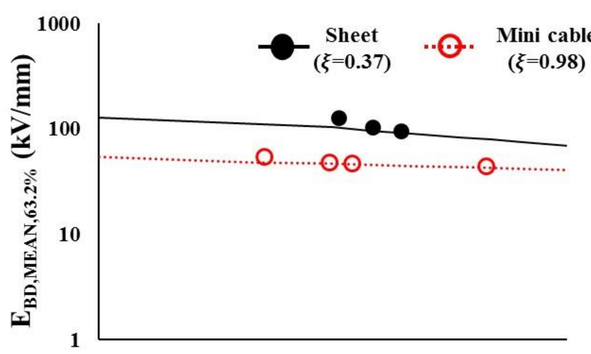

Fig. 8. V-t characteristics of A type specimen according to sheet system and mini cable system

- ✓ In addition, V-t characteristics of PPLP specimens with a sheet system are compared with those with a mini cable model.
- ✓ Fig. 8 shows the V-t characteristics of A type specimen according to structure: sheet type and mini cable model.
- ✓ As shown in Fig. 8, n value of sheet (ξ=0.37) and mini cable system (ξ=0.98) is 11.73 and 36.7, respectively.
- ✓ It is found that life time index, n value is not affected by PP ratio but by electric field uniformity.

Conclusions

- ✓ This paper deals with a study on dielectric characteristics of PPLP according to PP ratio and electric field uniformity in saturated liquid nitrogen.
- ✓ It is observed that intrinsic penetration electrical breakdown characteristics of PPLP are affected by PP ratio in silicone oil.
- ✓ However, intrinsic penetration electrical breakdown characteristics of PPLP are independent on electric field uniformity as well as PP ratio in liquid nitrogen because of electrical conductivity of PP and Kraft according to temperature.
- ✓ It is found that the life time index, n value is independent on PP ratio but dependent on electric field uniformity in liquid nitrogen.
- ✓ Also, it is revealed that electrical breakdown characteristics of PPLP with sheet type is higher than those of PPLP with mini cable type because of its butt gap structure in its overlapped layers.

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