Keeping Cool Under Pressure: Dielectric Strength of Sheet Insulation in Boiling Liquid Nitrogen

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Introduction

The dielectric strength in liquid nitrogen of sheet insulation samples from three different kinds of paper have been investigated under a turn-to-turn electrode system (Fig.1). The samples were tested under static conditions with no boiling introduced. In addition, their dynamic dielectric characteristics under different levels of electric field have also been tested by introducing transient thermal stress. The experiment has been conducted in the open bath liquid nitrogen (77 K) and also in sub-cooled liquid nitrogen (67 K).

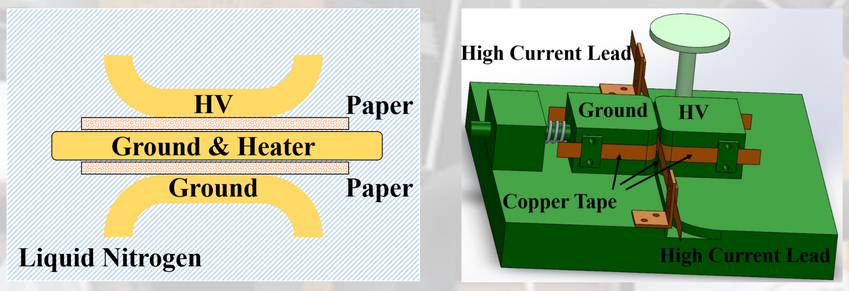


Fig. 1. The turn-to-turn electrode system

Sample	Thickness, mm
THERNOMID 14.20 laminated paper (NMN)	0.25, 0.20
DuPont Nomex T410 (N)	0.25, 0.18, 0.13, 0.05
DuPont Non-adhesive Kapton Type HN	0.025

Experiment Platform

The experiment platform is capable of injecting a current of up to 800 A maximum into the electrode system, introducing different boiling situations between the electrodes. A sub-cooling system has been also designed and built into this platform. It features a coil of copper tube half an inch in diameter and 18m in length filled with liquid nitrogen, sealed by a needle valve at one end and connected to a regulating valve at the other end, as shown in Fig. 2.

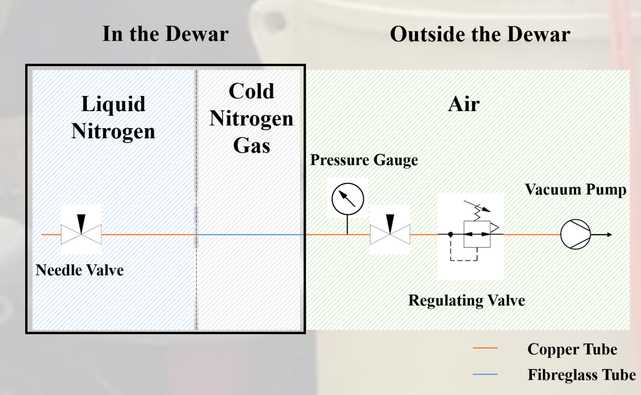


Fig. 2. The diagram of sub-cooling system

The sub-cooling copper coil is set on the G10 frame (Fig.3), which is immersed in the liquid nitrogen during the experiment. The electrode system is placed on the bottom plate of the G10 frame.

Fig. 3. Details of the experiment platform

Test Procedure

a. **Static Test:**
   1 kV/s until breakdown.
b. **Dynamic Test:**
   Constant electric stress is kept between electrodes for 5 mins.
   The transient thermal stress will be introduced after the first 1 min.

Conclusions

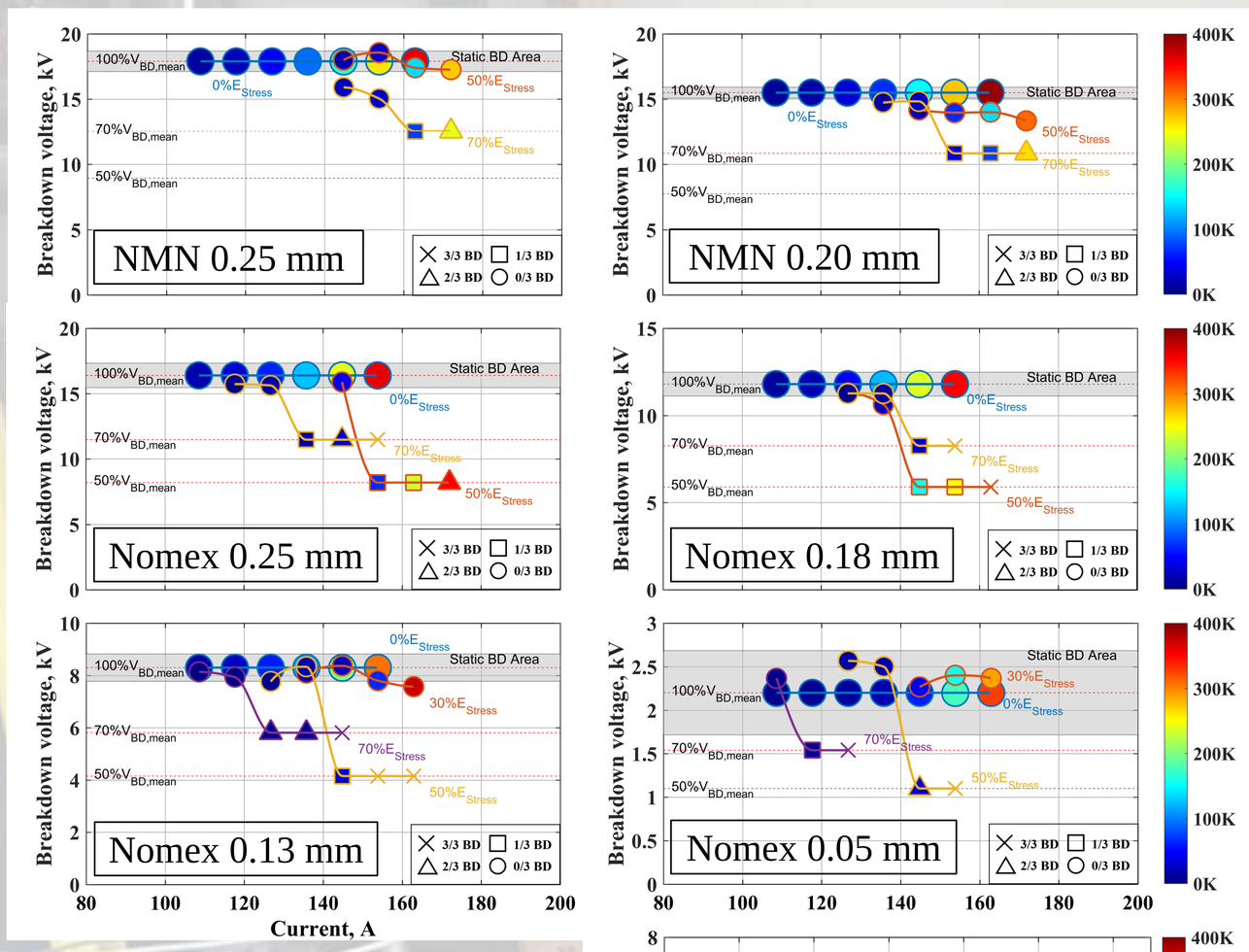
- The Kapton film has the best dielectric performance, in both liquid nitrogen at 77 K or 67 K. But its poor impregnation of liquid nitrogen largely affects its dielectric strength, especially at 77 K.
- The laminated NMN paper provides a good impregnation of the polyester film in it. When compared with the Nomex paper with the similar thickness, the NMN paper is always better possibly due to its non-porous structure.
- The static dielectric strength of Nomex paper seems to be independent from its thickness. However, it is not true for the 0.05N, due to its loss of mechanical strength during the paper feeding process. The thicker Nomex paper is able to survive greater thermal stress during the dynamic test.
- All samples have enhanced dielectric performance when immersed in the sub-cooled liquid nitrogen.

Results - Open Bath Liquid Nitrogen, 77 K

Static Test

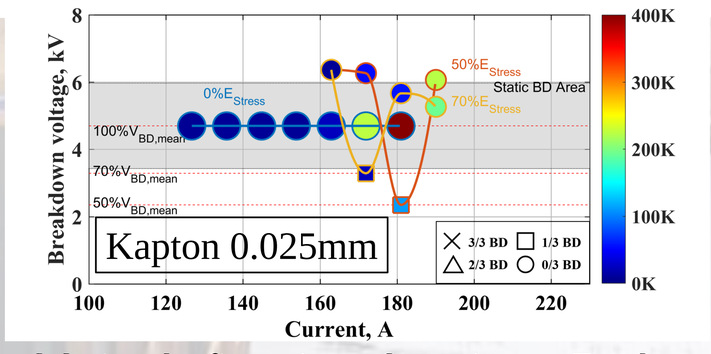
	NMN		NOMEX				Kapton
Nominal Thickness, mm	**0.25**	**0.20**	**0.25**	**0.18**	**0.13**	**0.05**	**0.025**
Mean Value of Breakdown Voltage, kV	17.9	15.5	16.4	11.8	8.3	2.2	4.7
Coefficient of Variation, %	4.4	2.7	5.7	5.8	6.3	22	27
Breakdown Voltage at 63.2% Probability, kV	18.2	15.6	16.8	12.1	8.5	2.4	5.2
Dielectric Strength*, kV/mm	72.8	78	67.2	67.2	65.5	48.4	207

*Calculated from dividing the value of breakdown voltage at 63.2% probability by the nominal thickness.



Dynamic Test

The electric stress is based on the static breakdown strength of each sample. The maximum temperature difference recorded on the heated copper tape from the surrounding liquid nitrogen is illustrated by the colour filled inside the markers when not all three samples are compromised during the five-minute dynamic test. For those when none of the three samples fail during the test, the breakdown voltage shown is the mean value of the breakdown voltage results by ramping voltage of 1 kV/s afterwards.



Results - Sub-cooled Liquid Nitrogen, 67 K

Static Test

The mean value of static breakdown voltage has increased by 9%, 18% and 32% after being immersed in subcooled liquid nitrogen for the paper of 0.25NMN, 0.25N and Kapton, respectively. The 0.25N paper has less difference in the breakdown voltage from 0.25NMN paper when compared to the results in the open bath liquid nitrogen. There is a significant decrease of the coefficient of variation of the breakdown results for Kapton film, from 27% to 5%. These enhancements might result from the suppression of the generation of nitrogen bubbles when under high electric field in the sub-cooled liquid nitrogen.

Dynamic Test

The electric stress applied is based on the corresponding static breakdown strength for each sample at 77 K. All samples tested have enhanced dielectric performance when immersed in the sub-cooled liquid nitrogen. The Kapton film is likely to be able to survive greater thermal stress, due to no obvious degradation after the test at 195 A and the slight temperature increase.