액체질소에서의 열적 기포에 의한 절연파괴기구

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Thermal Bubble-Initiated Breakdown Mechanism of LN_2

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ABSTRACT

Ac, dc and impulse dielectric strengths of LN_2 at 0.1MPa were investigated experimentally, referring to the behavior of thermally induced bubble, which might be generated at quenching condition of immersed-cooling superconducting devices. The experimental results show that the bubble shape under electric field stress depends significantly on the applied voltage waveform. With ac voltage, the breakdown voltage of LN_2 falls suddenly near to one of the saturated gas at the threshold heater power of boiling onset. In contrast to this, the reduction of impulse breakdown voltage with heater power is gradual and the time to breakdown depends on the existence of thermal bubble. These breakdown characteristics can be explained satisfactorily by the bubble behavior under electric fields.

INTRODUCTION

In any practical superconducting system, thermally induced bubbles appear during the process of quenching or cryogenic stabilization. Under these conditions, a high voltage is produced. It is therefore necessary to evaluated the dielectric strength of a coolant in the presence of thermally induced bubbles. Unfortunately, there are very few studies[1,2] on breakdown phenomena under thermal bubble conditions, and expecially direct observation of boiling phenomena at a hot spot and clarifica-

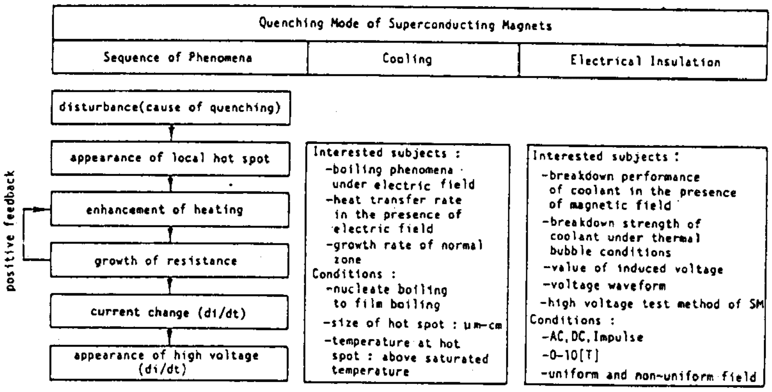


Fig.1 Phenomena in quenching mode of superconducting magnets from the viewpoint of electrical insulation.

tion of the relationship between bubble behavior and breakdown voltage characteristics have not been performed. Here, this paper reports the results of an experimental study on the breakdown characteristics of liquid nitrogen under the condition of thermal bubbling.

QUENCHING MODE IN SUPERCONDUCTING MAGNETS

The boiling phenomena in a quenching mode occur under electric stresses while electrical breakdown occurs in a cooling channel filled with a composite medium of a coolant liquid and thermal bubbles. In Fig.1, the phenomena elicited in the quenching mode of superconducting magnets are summarized from the viewpoint of electrical insulation. The heat transfer rate from the conductor to the coolant at the start of quenching is nearly equal to that at the onset of transition boiling, i.e., ~ $1 W/cm^2$ for helium and ~ $20 W/cm^2$ for nitrogen.

EXPERIMENTAL SETUP AND PROCEDURE

The schematic diagram of experimental setup is shown in Fig.2. An electric heater was mounted on one of two parallel plane electrodes and the heater power, H, was changed in the region of 10^{-3} to 1 W which elicited the heat transfer rate, q, on the conductor under quenching. The q in the present electrode system is approximately given by $q=2.5H\times10^{2}$ [W/cm^2].

The ac test voltage used was 60Hz and the standard impulse was 1/40μs.

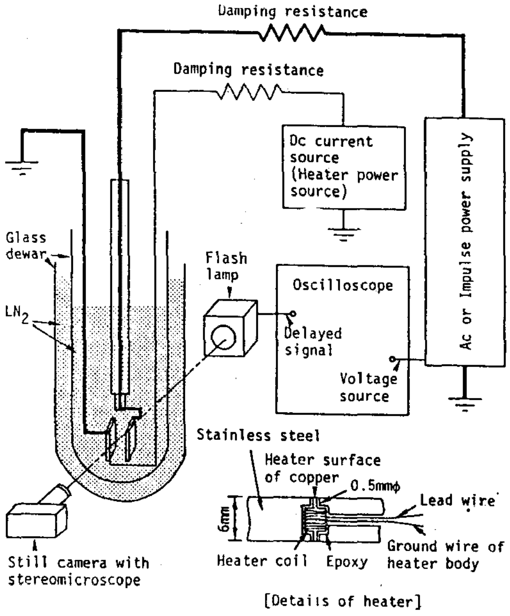


Fig.2. Experimental Setup

BUBBLE BEHAVIOR

When an ac voltage is applied across a gap, boiling phenomena are affected by the electric stress. As compared with dc stable bubbles, ac bubbles are unstable and vibrate synchronously with the variation of the electric field. This vibration motion is observed more clearly in longer gaps. If the heater power is set as an appropriate value to generate weak nucleate boiling in a gap as long as 3mm, the main bubble will float near the heater surface and become heated at this surface during the period of the voltage increase. This main bubble will emit small bubbles from the other side in the subsequent period, as shown in Fig.3. It should be noticed from the figure that the ac bubble at the moment of a zero voltage is very large compared with the dc bubble under no applied voltage. When the heater power is higher than that for the initiation of boiling H_{c1}, electrical breakdown occurs through bridged vapor.

No deformation of bubble is observed under impulse stress up to breakdown strength of liquid

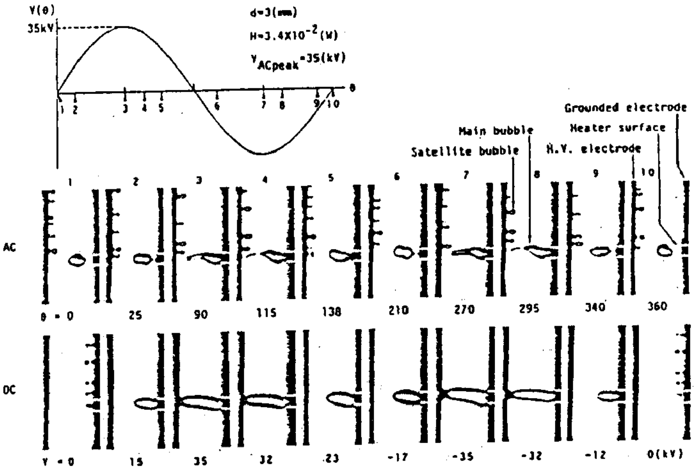


Fig.3. Comparison of bubble shapes under ac and dc electric fields

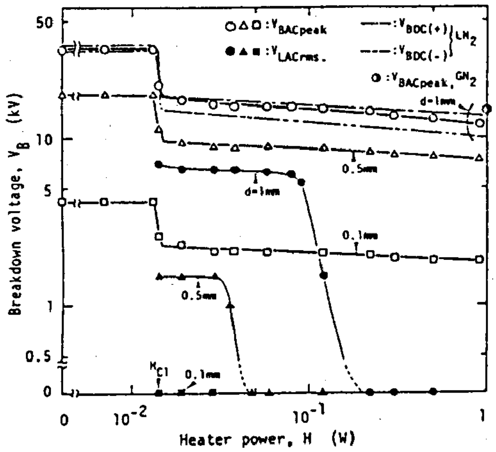


Fig.4. Static bubble behavior subjected to impulse stress with various time delays

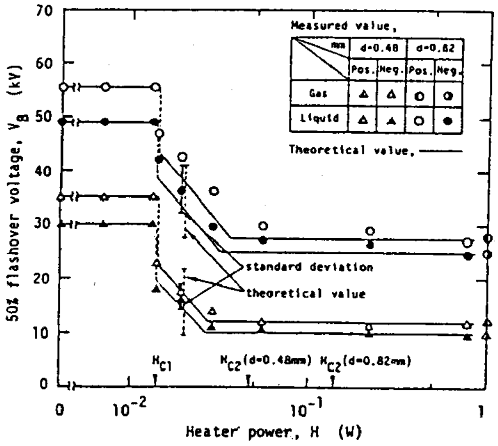
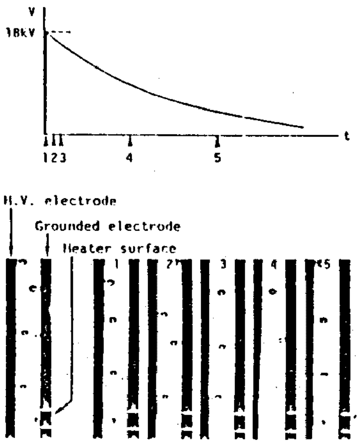
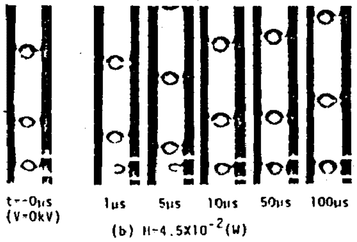


Fig.5. V_B - H characteristic



(a) H=1.9X10^{-2}(W)



(b) H=4.5X10^{-2}(W)

Fig.6. Calculated and measured impulse flashover voltage characteristics

nitrogen as shown in Fig.4. Therefore, the breakdown occurs through a serial composite of a rounded bubble and liquid beyond the H_{C1}.

BREAKDOWN CHARACTERISTICS AND DISCUSSION

Figure.5 shows the ac measured results of V_B and the onset voltage of vapor bridging, V_L. As the heater power increases, boiling begins at H_{C1} and V_L is almost constant until it reaches a critical power of heater. It then decreases with decreasing gap length and drops abruptly down to zero beyond the critical power. The breakdown voltage is higher than V_L at any gap length, it decreases sharply from the liquid breakdown voltage to that for saturated gas and decreases very slowly with the heating power. The ac breakdown voltage is comparable to that of the dc voltage. In the heater power region at which the bubble size reaches the gap length under a zero applied voltage, i.e. $V_L=0$, V_B becomes considerably lower than that in saturated gas.

The 50% impulse breakdown voltage, V_{50}, was measured by the up and down method of 30 voltage applications, and the result is shown in Fig.6. The relationship between V_{50} and H shows the same tendency as that for ac case but the decreasing rate of V_{50} against H greater than H_{c1} is smaller than that for the ac voltage stress. These characteristics are related to the bubble behavior under impulse voltage. As seen from Fig.4, rising bubbles take any place in the gap. Therfore, the medium along the breakdown path is modeled as a serial composite of a gas phase with the length of the bubble size and remaining liquid phase in the gap. The measured bubble radii show a wide scatter region and their mean value increases with the heater power, as shown in Fig.7. Assuming that the impulse breakdown occurs if the required conditions for breakdown of two phases are satisfied, the estimated V_{50} resembles the solid lines shown in Fig.6 which are in good agreement with the measured result.

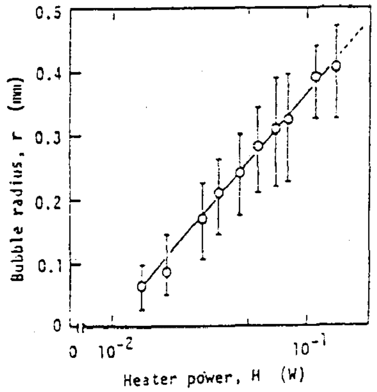


Fig.7. Measured values of bubble radii under various heater power

CONCLUSIONS

It should be mentioned that ac bubble vibrates violently with the variation of an ambient electric field but no deformation of bubble shape occurs under impulse electric stress. Breakdown voltage characteristics under thermal bubble conditions can be explained by the bubble behavior under electric fields.

REFERENCES

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2. D.J.Kwak, et al : Proc. Asian Confer. on Elec. Discharge, 25 p-2-4 (1988).