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Density determination of slush nitrogen by the improved capacitance-type densimeter

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ABSTRACT

Slush nitrogen is considered to be a better coolant than subcooled liquid nitrogen for the high-temperature superconducting cable cooling because of its greater density and cooling capacity. The capacitance-type densimeter is utilized to determine the density of slush nitrogen in this paper. In order to improve the densimeter performance, the bulk shielding method, based on the application of the double-shielded cables, is introduced, and the influence of the frequency of the applied voltage is investigated. The parasitic capacitance of the densimeter system is significantly reduced, and the fluctuation of the capacitance is depressed within $\pm 2.0 \times 10^{-4}$ pF at a frequency of 1.0 MHz, and the typical sensitivity of the differential type densimeter is 3.718 pF and the high accuracy of within ±0.25% for density measurement is obtained. In process of producing slush nitrogen by the freeze–thaw method, the discharge rate is 4 l/s and the time of the freeze and thaw cycles is 10 s and 5 s respectively to obtain slush nitrogen with fine solid particles, and slush density is measured by the densimeter system. According to the experimental results, the rotating speed, higher than 50 rpm in this study, is necessary to homogenize slush nitrogen for the high accuracy of the density measurement.

1. Introduction

Slush nitrogen is a two-phase cryogenic fluid which contains fine solid nitrogen particles in liquid nitrogen. The cooling capacity of slush nitrogen is enhanced because the latent heat of fusion is utilized for cooling, and the temperature is kept at the triple point until solid particles melt completely, as a result, the coolant consumption and the volume of cooling system are reduced, and the stability of cooling system is improved. Therefore, slush nitrogen is expected to be a better coolant than subcooled liquid nitrogen for the high-temperature superconducting cable cooling.

There are several slush fluid production techniques, such as the freeze–thaw method [1] and the Auger method [2], and the former is commonly used in the laboratory due to its simplicity. In the freeze–thaw method, solid layers are created on the liquid/vapor interface by evacuating the vapor during the freeze cycle, then are submerged into the liquid during the thaw cycle and finally are broken into solid particles by the agitator. The thaw cycle is generally accomplished in two ways. One is by pressurizing gaseous helium. Haberbusch and McNelis [3] compared the production rate of slush hydrogen with different freeze and thaw cycle times by this method. Under certain conditions the dense solid layers, which are difficult to be broken, are probably created on the liquid/vapor interface, decreasing the production rate, and these solid layers can be eliminated by adjusting the pressure variation between the two cycles, known as pressure swing, inside the dewar. However, an extra helium system is demanded, making it not suitable for laboratories to produce small quantities of slush fluid. The other is by evaporating liquid [4], namely the self-pressurized method. While the evacuation is stopped, the pressure will be increased a little and the solid near the wall melts because of heat leakage from outside of the dewar, resulting in solid layers being submerged into the liquid. The problem that the dense solid layers hinder the liquid evaporation can be well solved by adjusting the time of the freeze and thaw cycles. Experimental apparatus of this method is simpler than that of the former, and therefore it is often used in the laboratory to produce slush fluid [5,6].

One of the most important properties which affect the flow and heat transfer characteristics of cryogenic slush fluid is solid volume fraction, which is often obtained by measuring the slush density. So far, various techniques have been developed to determine the densities of slush fluids, mainly including microwave method, gamma-ray method and capacitance method. Ellerbruch [7] used microwave instruments to measure the density of slush hydrogen and obtained the uncertainty of less than ±2%. Due to the reflection of microwave by the inner wall of dewar, the wave-absorbent material is required to improve the measurement accuracy. Carapelle and Collette [8] developed a densimeter using gamma-ray attenuation to measure the densities of cryogenic slush fluids for space

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