EXPERIMENTAL SIMULATION OF A HELIUM COOLING SYSTEM FOR A SUPERCONDUCTING GENERATOR

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Résumé: Les auteurs décrivent un système autoréglable de refroidissement à l'hélium pour un alternateur à supraconducteurs. Une installation d'essai comportant tous les éléments essentiels a été réalisée et a fonctionné avec des vitesses de rotation atteignant 3000 tr/min. La pression, le niveau de remplissage en hélium liquide ainsi que la température dans le rotor ont confirmé les prévisions théoriques.

Abstract: A self regulating helium cooling system for a superconducting generator is described. A test rig which comprises all essential elements was constructed and was operated at rotational speeds up to 3000 rpm. The pressure, the level of liquid helium and the temperature in the rotor agree with the theoretical prediction.

Introduction

The cooling system of a superconducting generator has to ensure a winding temperature lower than the transition temperature during all operating conditions, that is steady state operation, ramping, unbalanced load, sudden short circuit and hunting. Cool down must be possible within an acceptable time, and a quench should not cause any danger or damage. Further options are low helium consumption, reliable and simple helium flow regulation and a superatmospheric helium pressure at the stationary-rotating coupling to avoid pollution of the helium circuit.

Generator cooling system

The principle of the selected cooling system /1/ is shown in Fig. 1. Next to the superconducting winding (1) there are hundreds of short, radial cooling channels (2), which are connected to a rotating reservoir in the center of the rotor (3) and to supply channels at the periphery (4). Heat produced in the winding causes a buoyancy driven helium flow in the radial channels /2/.

Near the phase boundary in the central reservoir, liquid helium evaporates at subatmospheric pressure. The helium gas exhaust ducts (5) simultaneously act as a centrifugal pump and counter flow torque tube extension coolers /3/. The self-regulating refill system replenishes the evaporating helium. It consists of a non-rotating external liquid helium reservoir (6) with a liquid outlet at the bottom, a stationary-rotating transfer coupling (7), a phase separator (8) and a pressure reduction region. The end of the stationary LHe duct (10) is immersed in the rotating fluid in the phase separator. Due to gravity, LHe flows from the external reservoir into the phase separator, as long as the pressure of the rotating fluid at the orifice is lower than the pressure in the duct.

From the phase separator, liquid is conducted to the supply channels near the periphery. In the centrifugal field this geometry enables a pressure reduction from the phase separator to the subatmospheric reservoir. In the duct between the phase separator and periphery (11) the helium is warmer and less dense than in the radial winding cooling channels (2). The radius of the liquid helium level in the subatmospheric reservoir, r_2, depends on the level in the phase separator, r_1, the radius, where the duct meets the supply channel, r_3, the pressure in the phase separator and reservoir and on the rotational speed /4/.

Cooling system test rig

A test rig which comprises all essential parts of the cooling system has been constructed to study the system behavior and to verify theoretical predictions. The rotor is shown in Fig. 2. The helium temperature is measured at several points by carbon and platinum resistors. There are liquid level sensors /5/ in the phase separator and in the subatmospheric reservoir. The pressure in the reservoir is measured by a small pressure transducer /6/. Heat flow into the winding cooling channels and into the torque tube extension coolers is simulated by electrical heaters.

The rotor was balanced before it was installed in the rig. It is driven by a DC motor and rotates within a vacuum vessel. It is shielded by a liquid nitrogen cooled radiation shield. The shaft seals are of the magnetic fluid type /7/.

The sensor signals are preamplified by a rotating electronic device into analog 0 to 10 V DC voltages and transmitted by sliprings. 11 signals from the rotor and 18 other signals are scanned, converted, listed and recorded by a computer controlled scanning system. In addition, some signals are recorded by X-t recorders.

Experiments

Pressure in the rotating reservoir

To test the function of the centrifugal pump the heat load H2 in the two, symmetrically arranged outlet ducts was varied. Fig. 3 depicts the helium pressure in the rotating reservoir as a function of the temperatures behind the heater, T2 and T3. A minimum pressure of 0.48 bar was reached. The measured values agree well with the theoretical correlation, which was calculated for the geometric conditions of the test rig using the formulae given in /4/. The temperature in the winding region, T1, drops from 4.75 K without heating at H2 to 4.28 K at maximum heat load.

Level of LHe in the rotating reservoir

The self regulating refill system is designed to maintain a constant LHe level within the rotating reservoir. Using the formulae of /4/ for the geometric conditions of the test rig, the LHe level is expected to change only little with varying helium pressure p_2. The experiment showed that the radius of the LHe level fluctuated within certain limits, as indicated in Fig. 4. At p_2 = 0.48 bar the observed level, r_2 = (70 $\pm$ 15) mm, agreed well with the predicted value , 73 mm. The observed tendency to lower radial distance at higher pressure agrees also with the theory.

Conclusions

The experiments demonstrated the overall function of the cooling system. Especially the self pumping system which reduces the winding temperature and the automatic refill system operated as predicted.

Acknowledgement

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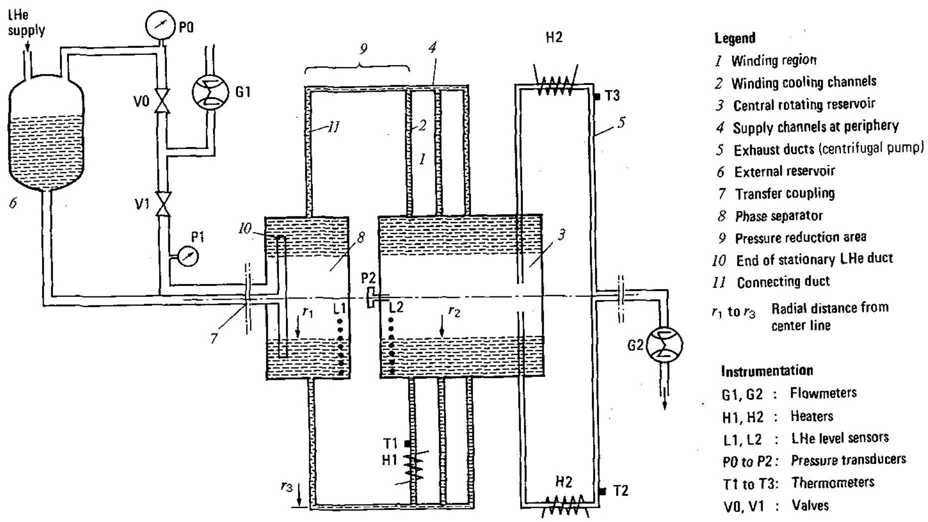

Fig. 1: Principle of SC generator cooling system and test rig

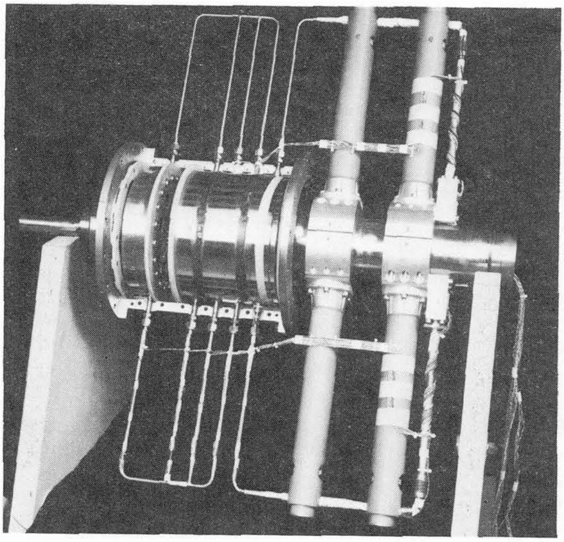

Fig. 2

Rotor of the test rig for He cooling system

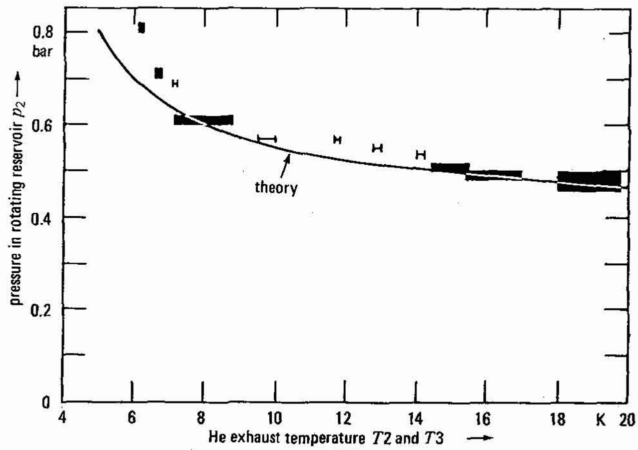

Fig. 3

Pressure in rotating reservoir as function of helium exhaust temperature

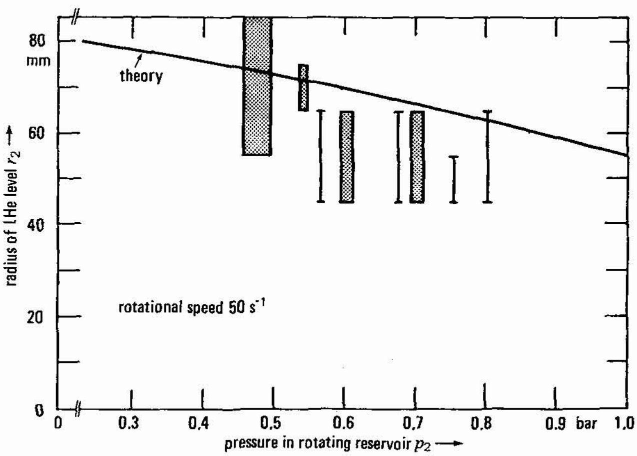

Fig. 4

Radius of LHe level as function of pressure in rotating reservoir