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A 25 kA, 0.5 kW THERMALLY SWITCHED SUPERCONDUCTING RECTIFIER*

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Résumé - Le succès de l'expérience d'un redresseur supraconducteur à 25 kA est rapporté. Ce redresseur est une composante très importante d'un système électrique et cryogénique complet pour charger des bobines à courants très intenses.

Abstract - The successful test of a 25 kA superconducting rectifier is reported. This rectifier is an important component of a complete cryogenic power system to energise high current superconducting magnets.

INTRODUCTION

The introduction of high currents by current leads to a cryogenic region in order to energise a superconducting magnet causes considerable losses of about 2W/kA /1/. These losses are avoided if the conversion of the electric power to low voltage and high current is moved from roomtemperature to the temperature of liquid helium. The thermally switched superconducting rectifier-fluxpump has the best prospects to be applied as a highly efficient cryogenic power converter to energise s.c. magnets. Since 1979 we study all aspects of fluxpumps /2,3/ and have a research and development program to investigate the feasibility of superconducting rectifiers for several applications. Therefore, a number of four s.c. rectifiers for currents between 50 A and 9 kA have been built and tested /4,5/. The present activities concern a 25 kA, 0.5 kW thermally switched full wave superconducting rectifier, which is a prototype for a future 25 kA, 1.5 kW rectifier system /6/.

THE 25 kA CRYOGENIC POWER SYSTEM

The cryogenic power system (Fig. 1) can be divided into the rectifier itself (transformer M and two switches S1 and S2), its power input, a protective system (protection switch SPr and a dumpresistor Rd) as the intermediate circuit between the rectifier and the load-magnet /8/, and the control and protection electronics. The necessary operation of the protective system has been described elsewhere /9/. The maximum current and the average power that the s.c. rectifier can supply is determined by the frequency of operation (0.05-0.1 Hz), the magnetudes of the inductances

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Fig. 1 - Circuit of a s.c. magnet with its cryogenic power supply consisting of the input, control and protection units, the s.c. rectifier and a protective circuit.

(I_p, L, M) in the circuit and the amplitude of the primary current. These design data for this rectifier are explained in /6/. With an amplitude of the primary current of 25 A flowing through a primary inductance of 10.5 H with a repetition rate of 0.1 Hz, the rectifier can easily charge a 25 kA magnet with a power of 500 W. The several components of the powersystem have been connected to each other with removable soldered joints in order to allow for future experiments with a more extended rectifier system /7/.

The complete fluxpump and its load-magnet are shown in Figure 2. In this apparatus space has been reserved for two extra rectifiers (two transformers and four switches). The three rectifiers together will have an average power of 1.5 kW or 5.4 MJ/hr at 25 kA.

THE 25 kA RECTIFIER

The circuit formed by the secondary of the transformer and both thermally controlled s.c. rectifier switches S1 and S2 have been tested. As both switches are closed, the maximum current in the secondary circuit has been measured to be 26.4 kA. The secondary current alternates then between zero and its peak value with a current rate of about 15 kA/s and a cycle frequency of 0.1 Hz. The same value was found during a separate test of the shortcircuited transformer /7/. The maximum current is still limited by the conductor in the secondary of the transformer. The d.c. critical current of this 24 strand Cu/NbTi Rutherford cable /7/ is 26 kA at 3T. This value is nearly approximated by the testresult at 0.1 Hz since the peak field at the windings of the transformer is 0.1 T/kA. The maximum current of the 720 strand braided CuNi/NbTi switch-conductor will be about 55 kA at 2T.

THE COMPLETE FLUXPUMP AND LOAD

The s.c. rectifier cannot be connected directly to a load-magnet. The rectifier switches will be damaged when a quench occurs and the coil energy is dumped totally in these rectifier switches. A protective circuit being for example a protection switch and a dump resistor, has to ensure a quick decrease of the current in the open switches and a safe dissipation of the energy in the resistor located outside the helium bath. The thermally activated protection switch has to open very fast by a huge heating power. The entire protective system should operate very reliable before the energy content of the load-coil is brought to its maximum.

At the moment the protective system for this 25 kA rectifier is studied. For this reason the current in the load coil cannot exceed 10 kA. In spite of this a typical load curve is shown in Fig. 3. The current in the load-coil increases or decreases step by step depending on the phase relation between the state of the rectifier.
switches and the primary current. The current rate or the power of the rectifier can be manipulated by the amplitude of the primary current or the frequency. The first run in Fig. 3 shows an increase of the current in the load magnet \( (L_L = 250 \times 10^{-6} \text{ H}) \) from zero to 8.2 kA within 80 seconds. The average power is then 105 W at 8.2 kA. The d.c. resistance of the circuit during the persistent mode when the input
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Fig. 3 - Typical shape of the current $I_L$ in the s.c. magnet. The magnet can be charged and discharged.

is turned off, is measured to be 2.5 m$\Omega$ at 10 kA. This resistance is caused by the six soldered joints between the high current conductors in the secondary circuit.

FINAL REMARKS

There is evidence that the results mentioned above are preliminary results. The described fluxpump can be brought to full power when the protective system has been approved. Moreover, a lot of details about the experimental behaviour have to be studied in order to present a complete picture of the feasibility of high current superconducting rectifiers. Though, the successful test of the 25 kA rectifier inspires confidences in the application of s.c. rectifiers to energise s.c. magnets.

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