POWER SUPPLY AND COOLING SYSTEM FOR HIGH-POWER WATER-COOLED MAGNETS AT TOHOKU UNIVERSITY

T. Fujioka, Y. Sato, M. Tanabe, A. Hoshi, S. Miura, Y. Nakagawa

JOURNAL DE PHYSIQUE
Colloque C1, supplément au n° 1, Tome 45, janvier 1984

POWER SUPPLY AND COOLING SYSTEM FOR HIGH-POWER WATER-COOLED MAGNETS AT TOHOKU UNIVERSITY

T. Fujioka, Y. Sato, M. Tanabe, A. Hoshi*, S. Miura* and Y. Nakagawa*

Fusion Technology Development Dept., Toshiba, 13-12 Mita 3-chome, Minato-ku, Tokyo, Japan
**The Research Institute for Iron, Steel and Other Metals, Tohoku University, Sendai, Japan*

Résumé - Cet article rapporte les essais d'une alimentation de puissance à courant continu et d'un système de refroidissement pour des aimants de haute puissance à refroidissement par eau.

Abstract - The design and test results of a DC power supply and a cooling system for high-power water cooled magnets at Tohoku university are reported.

1. Introduction

At the Research Institute for Ion, Steel and Other metals, Tohoku University, a hybrid magnet project has been under way since 1981. Toshiba corporation has been contributing to this project with the manufacture of hybrid magnets and relevant principal facilities. This paper describes the design and the test of a DC power supply and a cooling system for high-power water-cooled magnets. Details of this project are reported in a separate paper[1].

2. DC Power Supply

The DC power supply consists of two identical 4 MW (350^{O}V-11.5 kA) units which may be operated either in parallel or separately depending on the load. One of them was already manufactured and tested successfully to energize a 3.6 MW water-cooled magnet. Another unit is scheduled to be tested at the beginning of 1984 linked with the unit already installed. Principal specifications and a circuit diagram of the system are shown in Table 1 and Fig. 1, respectively.

2.1 Circuit Diagram

As shown in Fig. 1, each unit is fed independently from an AC 6.6 kV power line through a transformer which is followed by a 3-phase rectifier bridge with 60 thyristers (SCR), resulting in a fundamental ripple frequency of 300 Hz. To reduce the ripple, both a passive filter and a two-staged active filter are equipped, as described in the next section.
At the 6.6 kV power line, a harmonic filter bank is installed in order to reduce the harmonics produced by SCR. The bank consists of 5th and 7th filters, and a highpass filter resonant in 11th. It is to be noticed that 5th and 7th harmonics are nullified in the case of the parallel operation of two units because the connection of transformer is Δ-Δ at one unit and 人 -Δ at the other unit so as to generate the 12-phase AC. This allows for the relatively small capacities of both the 5th and 7th filters.
The polarity of the magnet field can be reversed by means of a reversing switch installed at a main busbar, and also a disconnector is installed at each branch busbar for the magnet. Aluminum was chosen as the material of the main busbar from the viewpoint of cost and easy handling for the installation. The power supply can be manipulated by using a remote control panel located at the control room. In addition, an automatic sweep and modulation of the magnet current can be done by means of a computer control.

2.2 DC Filter Design

In the designing of the power supply, the most difficult problem was how to reduce the ripple to such a small value as 1×10^{-4} rms, while the inductance of the magnet is very small as shown in Table 1. The conventional passive filter with LC circuit is advantageous to reduce relatively high frequency ripples. But it is not suitable to reduce the ripple with such low frequency as 50 Hz, 100 Hz and so on because LC capacity becomes excessively large. Usually these ripples are caused by phase unbalance and/or unbalanced firing timing of SCR. To cope with this difficulty, we used the so-called active filter. There are two types of the active filters: one of them[2)] connects many transistors in series with the load, and the other[3)] is to control the ripple at a main circuit by a transister bank of a small capacity at a secondary circuit through a reactor-transformer. The latter was chosen for the present power supply.

As shown in Fig. 1, the transistor bank amplifies alternate components of the voltage as measured at point A_1 or A2 which are fed into the main circuit with opposite phase via a reactor-transformer L_1 or L_2, compensating any deviations up to 1×10^{-4} rms. The gain required for this active filter is designed to be about 30 dB being too large to be attained by a one-staged active filter without the occurrence of hunting due to detection errors. Then a two-staged active filter is designed. It is to be emphasized that not a 12-pulse, but only a 6-pulse SCR is designed, because the ripples with higher frequency than 300 Hz are not so dominating factors in the DC filter design as compared with the low frequency ripples mentioned above.

Table 1 Specifications of DC Power Supply

Primary voltage	AC 6.6KV	
Secondary voltage	DC 0 – 350V	
Secondary current	DC 0 –23 KA	(two units in parallel)
Secondary power	8 MW	(two units in parellel)
Current stability	$\leq 1 \times 10^{-4}$/3hr	(at full power)
Current ripple	$\leq 1 \times 10^{-4}$ rms	(at full power)
Linearity of sweep	$\leq 1 \times 10^{-2}$	(at current of 5% ~ 95%)
Magnet parameter	R = 15 ~ 35 mΩ	
	L = 0.3 ~ 1.3mH	

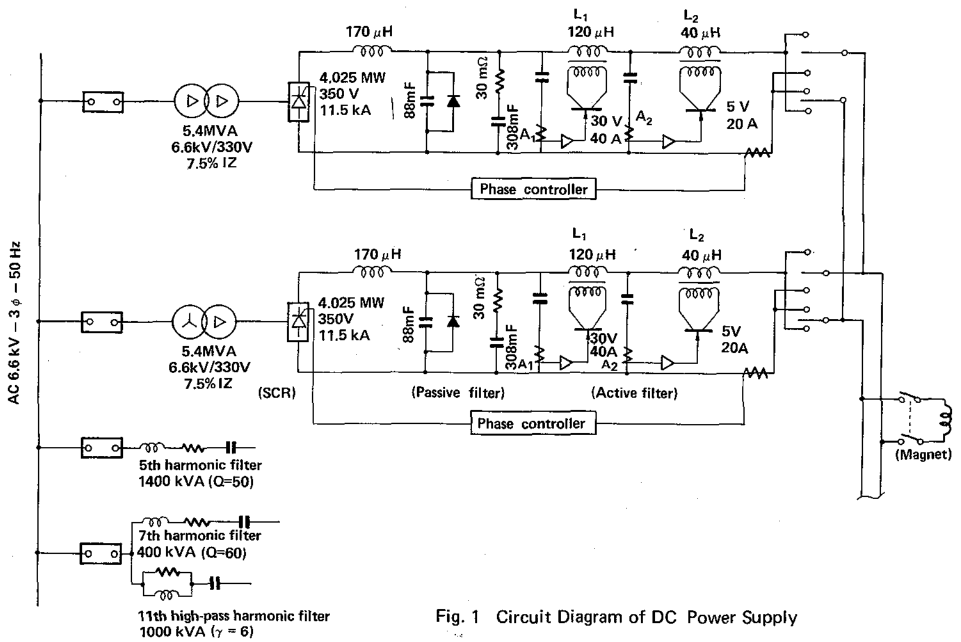

Fig. 1 Circuit Diagram of DC Power Supply

2.3 Tests Results

The test results satisfied the specifications listed in Table 1. The ripples with higher frequency than 50 Hz were small enough. In some case, however, rather large ripples of low frequency (5 ∿ 7 Hz) were observed as shown in Fig. 2. Such low frequency ripples were considered to be caused by external noise in the AC power line because it always appears whenever and only when the same low frequency components were found at the primary voltage. On the other hand, harmonics of

5th, 7th, 11th, 13th and so on produced in the AC line by the SCR were measured and confirmed to be within permitted values.

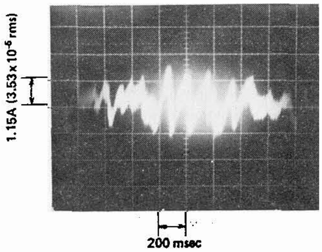

Fig. 2 Photo of Ripple at 11.5 KA

3. Cooling System

The purpose of the cooling system is to remove a vast amount of Joule loss dissipated in the magnet and also to cool all of the DC power supplies used for the hybrid magnets. The total cooling capacity of 6MW is obtained by two identical sets consisting of a turbo-refrigerator, a cooling tower and relevant pumps. One set was already manufactured and tested successfully to cool the magnet. Like the DC power supply, another set now being manufactured in scheduled to be tested soon. Principal specifications and a circuit diagram of the system are shown in Table 2 and Fig. 3, respectively. It is to be noticed that this system differs from that of MIT or Grenoble where the Joule loss is finally transferred into the river water. In the present system, the cooling capacity of 6 MW can be maintained with water temperature of about 6°C even in summer.

3.1 Circuit Diagram

The system is composed of a primary circuit with deionized water which cools the magnets after being chilled by refrigerators, and a secondary circuit with city water which cools as a condensing circuit of the refrigerators.

3.1.1 Primary Circuit

The deionized water is directly chilled below 10°C by the refrigerators R_1 and R_2, and stored in a 200 m^3 tank DT. Then it is pressurized by four circulation pumps $P_1 \sim P_4$ (75 kW each) up to the pressure of about 20 kg/cm^2, and supplied to the magnets WM1 $\sim$ WM7. The resistivity of water is kept over 1MΩ.cm by an ion-exchanger IE. The DC power supplies $PS_1 \sim PS_5$ are cooled indirectly by this chilled water through a heat exchanger HE to avoid dew condensing in them especially during the wet and cold season.

3.1.2 Secondary Circuit

The cooling towers CT_1 and CT_2 of so-called open type are to cool the city water which is once stored in a tank WT and circulates through the condensors of the refrigerators. The Joule loss of the magnet is once converted thermodynamically into the enthalpy of Freon in the refrigerators and finally dissipated as the evaporation heat of water in the cooling towers.

3.2 Characteristics of the System

Refrigerators: They can chill the deionized water directly so as to improve the cooling efficiency of the system. Each refrigerator has two compressors in parallel, and their capacities are automatically controlled to keep the water temperature between 6°C $\sim$ 10°C without frequent start/stop operations.

Deionized water tank: Its capacity of 200 m^3 enables us to energize the magnet with the power over 6 MW (rated cooling capacity) for a short time. It is to be noted that rated DC power is 8 MW.

Cooling towers: They are designed to be low-noise type and moreover a sound proof barrier of about 11 m height was constructed around them. To reduce the noise further at night, their fans' speed is changed from 1000 rpm to 750 rpm by means of pole-change of the motor; the cooling capacity at night is not so different from that of daytime, because of lower temperature at night. Also they are designed to suppress the fog to be produced in the air.

Circulation pump: One of four pumps is speed-controlled by transistor inverter in order to adjust the flow rate continuously and also to make an air-venting operation of the primary circuit smoothly.

Table 2 Specification of Cooling System

Primary circuit		**Secondary circuit**	
Flow rate for magnet	350 m^3/hr	Cooling capacity of cooling tower	
Delivery pressure of pump for magnet	20 kg/cm^2	at wet bulb temperature of 25°C	7.4 MW
Inlet temperature for magnet	6°C ~ 10°C	Capacity of city water tank	100 m^3
Resistivity of cooling water	> 1MΩ·cm	Flow rate of supplied water	12 m^3/hr
Cooling capacity of turbo-refrigerators	6MW		
Capacity of deionized water tank	200 m^3		
Flow rate for DC power supplies	36 m^2/hr		
Inlet temperature for DC power supplies	25°C		

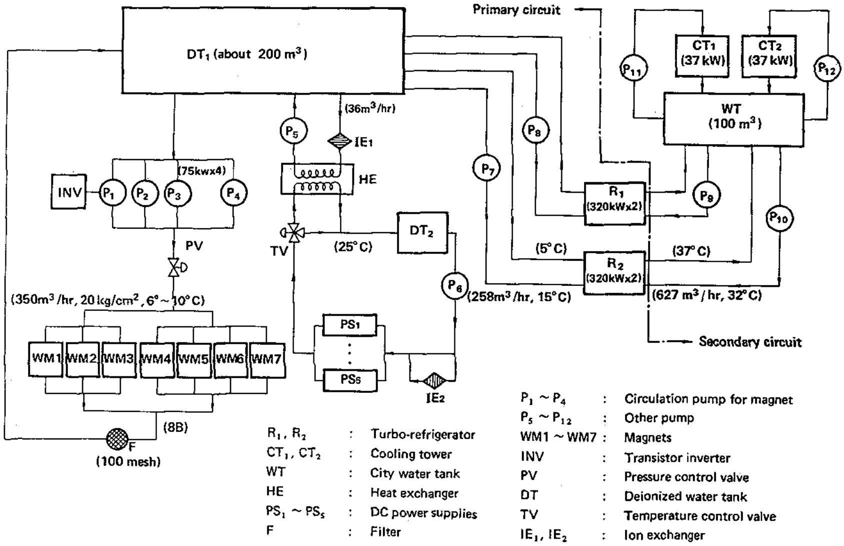

Fig. 3 Diagram of Cooling System

3.3 Test Results

The cooling capacity of the refrigerator and the cooling tower were confirmed to satisfy specifications in the test where the magnet was energized with 3 MW continuously for a sufficiently long time. Also they could be controlled to start/stop periodically in several ten minutes, maintaining the temperature of the inlet water to the magnet between 6°C and 10°C. The noise produced by the cooling tower was confirmed to be much less than the permitted value.

Acknowledgements

The authors express their thanks to Professor Y. Muto, Dr. K. Noto and Mr. K. Watanabe of Tohoku University for their cooperation in the present project. Thanks are also due to Dr. J. Nagamura and Mr. S. Ichikawa of Toshiba.

References

1) Y. Nakagawa, K. Noto, A. Hoshi, S. Miura, K. Watanabe and Y. Muto: This Conference 4E2-01.
2) K. van Hulst, C.J.M. AARTS, A.R. de Vroomen and P. Wyder: J. Magn. Magn. Mater. 11 (1979) 317
3) J.C. Picoche, P. Rub, J.C. Vallier and H.J. Schneider-Muntau: J. Magn. Magn. Mater. 11 (1979) 308