DESIGN CONSIDERATION ON SUPERCONDUCTING MAGNETS WITH HIGH CURRENT DENSITIES

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Abstract

Two important parameters of superconducting magnets, overall current density and electromagnetic force are discussed from a view point of economical magnet design. The overall current density is crucial in small magnet and the electromagnetic force is decisive in large magnet.

1. Introduction

Among the parameters of superconducting magnets, overall current density J in the coil and electromagnetic force F to the conductor are seemed to be essentially important. In the following, the overall current density J means the average current density in the coil including superconducting wire, insulator, reinforcement and cooling channel except winding bobbin and supporting structure. The overall current density is a dominant design parameter in the magnet. The higher current density gives the higher performance of magnet.

The electromagnetic force is also decisive parameter in large magnet. The wire can not stand without reinforcement. The reinforcement reduces the overall current density in the coil, therefore, the problem of making a high performance magnet is complicated. We want to consider the problem in the following paragraphs.

2. Our Experience

In order to make use of superconducting magnets for high energy accelerators and experimental facilities, we have designed and constructed various types of magnets. Some of them are listed in the Table 1. As is shown in the Table, each magnet has the coil of high current density. All coils have been wound with the partially stabilized, fine-multi,twisted solid wire or compacted strands of NbTi superconductors. No reinforcement in the coil is used. The ratio of superconductor/copper is in the range of 1/8 to 1/1.8.

Table 1. Examples of Superconducting Magnets in KEK

Type of Magnet	5T Solenoid	SD430 Dipole	8SPQ310 Quadrupole	3SD324 Dipole	TRISTAN Test Dipole
Current	1000A	3500A	730A	2200A	4400A
Field	5T	4T	15T/m	2T	4.5T
Overall Current Density	$1.9 \times 10^8 A/m^2$	$2.0 \times 10^8 A/m^2$	$1.7 \times 10^8 A/m^2$	$2.5 \times 10^8 A/m^2$	$3.1 \times 10^8 A/m^2$
Stored Energy	25kJ	620kJ	80kJ	50kJ	220kJ

We had no difficulty with the 5T solenoid. The quench current of the solenoid is 1040A at 5.2T and 4.3°K and the value is seemed to be near to the critical current at the field and temperature.

3. Solenoid

As is well known, the central field of a solenoid is given in the following equation.

$$B_o = \frac{\mu J a_1}{2\pi} F(\alpha, \beta)$$

Where μ is permeability, J is overall current density, a_1 is inner radius of solenoid and $F(\alpha,\beta)$ is shape factor dpending on α and β. The ratio of outer radius to inner radius is α and the one of a half length to inner radius is β.

In small or medium size solenoids, the overall current density often reaches the maximum value which is expected from the critical current of the wire as is shown in the previous paragraph. The maximum field point of solenoid is always in the center of inner column. The field enhancement at the point changes depending on α, β and J. The shorter and thinner solenoid has the larger field enhancement. The overall current density is limited with the critical current at the enhanced field.

Small or medium size solenoid can stand alone without any reinforcement or supporting structure and keep a considerable current density. Many excellent solenoids have been manufactured here and there.

On the other hand, large solenoid in which the electromagnetic force on the wire is superior to its mechanical strength, requires reinforcement. The electromagnetic force is roughly proportional to the product of magnetic field and radius. Combination of superconductor and reinforcement or supporting structure and selection of the overall current density are important design problems.

4. Dipole and Quadrupole

There is a quite different aspect in the dipole or quadrupole magnets. Superconducting wires in the dipole or quadrupole scarcely survive without supporting structure under the strong electromagnetic force, therefore, self-supporting coils of dipole or quadrupole could not be designed. Furthermore an accurate control of wire position is required to generate high quality magnetic field.

The electromagnetic bursting force of typical accelerator dipole reaches the value larger than 500ton/m.

Main design problems of the dipole or quadrupole are how to support the electromagnetic force and how to fix the wire in right position. High current density is required to induce a high field with small amount of wire material.

5. Stabilization and Quench Protection

One of the most important problems in operation of high current density magnets, is to install a quench protection system suitable to the stablization condition of the coil. The minimum requirement for the system is to prevent burn out of the coil.

6. Conclusion

Two important parameters, overall current density and electromagnetic force, are governing the magnet performance. The excellent superconducting magnets should be studied and constructed to save material required for the magnets.