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Fundamental Study of MgB_2 Superconducting Coil for Storage Devices

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Abstract: *The authors carried out a basic study on a power storage coil made of MgB_2 superconducting wires which was expected to require less cooling and lower manufacturing costs. First, for manufacturing the storage coil, the basic characteristics of MgB_2 superconducting wire were evaluated. The characteristics at 20 K under 1.5 T were a critical current of 170 A for the in-situ MgB_2 wire and 200 A for the ex-situ MgB_2 wire. Based on these results, MgB_2 conductors and prototype storage coils were produced and their performance was evaluated. The prototype was successfully energized to 600 A under 1.5 T at less than 25 K, which are the basic requirements for several 10 kJ class coils, and there was no significant deterioration through conductor and coil processing.*

Keywords: superconducting wire, superconducting coil, power storage device, characteristic evaluation, manufacturing technology.

I. Introduction

Superconductivity is a phenomenon whereby certain materials have exactly zero electrical resistance when they are cooled below a certain temperature, and these materials are called superconductors. Figure 1 shows supercon- ducting material divided into "superconducting bulk" and superconducting wire," depending on the form it takes, and active research and development is underway on these materials, to find new ways to use them.

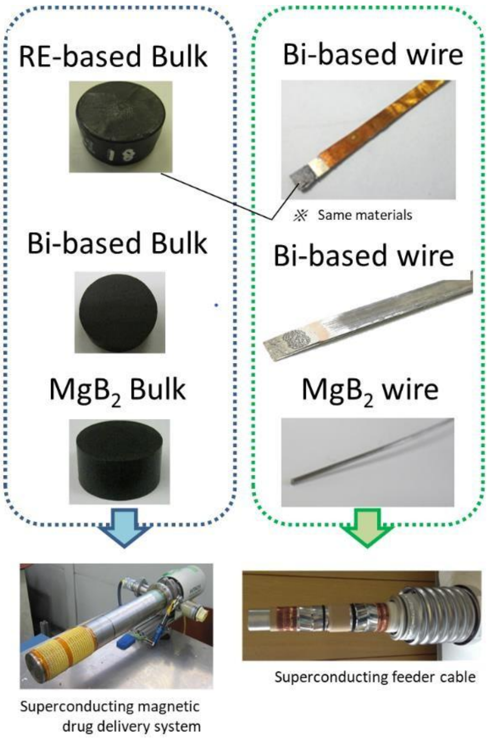


Fig. 1 Superconducting materials and Applications

The superconducting bulk used as a block is expected to significantly improve the performance of various devices by applying it to magnetic field sources of analyzers, magnetic transport of medicines, current leads, magnetic bearings, etc. The magnetic strength of a typical permanent magnet is less than 1 Tesla (T), while that of superconducting bulk reaches over 17 T [1, 2]. On the other hand, the superconducting wire used in a state where it is thinly stretched can be energized with zero electrical resistance, and no heat is generated by the energization, so a large current can be energized. In an attempt to make the most of such properties, research and development is being con- ducted in power application fields, for products such as superconducting magnets, superconducting coils, and superconducting cables [3].

RTRI is currently engaged in research and development on a wide range of areas, from producing superconducting materials to their various applications. Research centers not only on using standard superconducting materials in equipment, but also increasing superconducting performance, by improving manufacturing processes and

Currently NbTi and Nb_3Sn are used for superconducting magnetic energy storage devices (SMES) which are power storage devices. Although NbTi and Nb_3Sn are highly stable and reliable, running costs are high when using them, because liquid helium which is employed as the refrigerant is expensive. Fundamental studies were conducted on MgB_2 superconducting coils for storage, and power storage devices for power systems and railways were developed.

1.1 Magnesium Diboride (MgB_2) Superconductor

The MgB_2 superconductor is a relatively new discovery made in 2001[4]. It has the highest critical temperature of 39 K in metal-based superconductors, and operates at higher temperatures which reduces cooling costs. Further- more, MgB_2 is light weight and inexpensive, as it is com- posed of only light elements such as boron (Ba) and magnesium (Mg). As such, research into practical applications of this material is actively underway.

Conventional superconducting bulks are made using rare earth (RE)-based superconducting bulks consisting mainly of RE oxides, barium(B) and copper(Cu). However, since crystal growth from a seed crystal is required in the manufacturing process, it is difficult to manufacture large samples and poor yields are a problem. MgB_2 superconducting bulk can be used at lower temperatures than RE- based superconducting bulk, and can be manufactured by sintering the materials under uniform pressure, making it possible to manufacture large bulks of ϕ100 mm. Furthermore, MgB_2 superconducting bulk can easily be manufactured into any shape, making it suitable for precision instruments such as NMR and MRI.

In the case of superconducting wires, metal-based superconductors such as NbTi and Nb_3Sn are generally employed to make superconducting coils and magnets, which require liquid helium to cool them. Recent research, however, has brought progress for high-temperature superconducting materials such as RE-based superconducting materials and superconducting bulks. These materials are available at liquid nitrogen temperatures and are very promising in their applications. The key drawback, however, with these materials is that REs are expensive, and manufacturing is complex, generating higher costs. To minimize material cost therefore, work was launched to develop and commercialize MgB_2 wire. Development of MgB_2 wire has just started, and in the next 10 years, the goal is to raise the existing critical current characteristics of the material at 20 K of 3 T, to five times this level, and cut costs to 1/20 [5]. RTRI has therefore been working on the production of a storage coil using the MgB_2 wire, which is expected to reduce manufacturing and cooling costs [6].

1.2 Development of a Prototype Storage Coil

With a view to developing a 33 kJ class storage coil, a small prototype storage coil was produced for a basic study to evaluate the superconducting characteristics that would be required for manufacture. Table 1 shows the specifications required for a 33 kJ class coil, which indicates that achieving the target energy storage should be possible through energization at 600 A. 600 A was therefore sup- plied to the prototype coil, and its performance was evaluated at 1.5 T. The current capacity of a single strand of MgB_2 wire, however, is small. Therefore, multiple strands of wire need to twisted together to achieve the current capacity required for the storage coil. Following this, the MgB_2 wire characteristics were evaluated in a magnetic field. Prototypes of multiple strand MgB_2 conductors were prepared, that could be energized to over 600 A at 20 K under 1.5 T, and then storage coils using these different wire configurations were also produced.

Table 1 Specifications of 33 kJ class storage coil

Stored energy [kJ]	33
Inductance [H]	0.18
Operational current [A]	600
Maximum B field [T]	1.5
Inner diameter [mm]	450
Outer diameter [mm]	660
Height [mm]	77.4
Items [-]	8 DP
Num. of turns [-]	500

1.3 Specifications of MgB_2 wires

MgB_2 wires need to heat-treated before it can be used as a superconductor. Heat treatment however weakens the material to bending strain and causes deterioration. Nevertheless, in order to produce a large coil, heat treatment must be applied before coiling because it is impossible to heat-treat the wire after coiling unless there is an available furnace large enough to house the coil. This paper compares the characteristics of both heat-treated MgB_2 wire (performed by Columbus Superconductors SPA) and non-heat-treated MgB_2 wire (30-NM made by HyperTech Research Inc.).

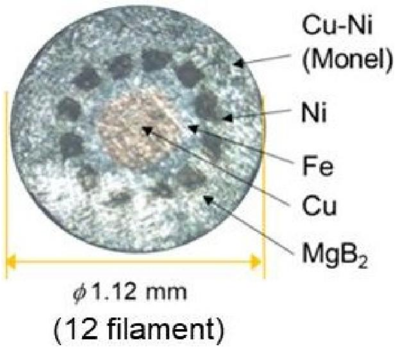
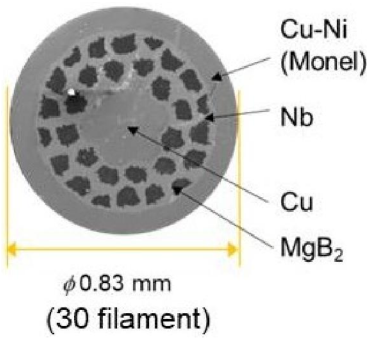


Fig. 2: Cross section of MgB_2 wire made by Columbus Superconductors SPA

The heat-treated MgB_2 wire made by Columbus Su- perconductors SPA was heat-treated before shipment, andan external magnetic field was applied using a 10 T super- conducting magnet, and electricity was supplied using a DC power supply (Fig. 4).

As a result, it was found that the wire manufactured by Columbus had a critical current value of over 200 A un- der 1.5 T at 20 K (Fig. 5). The magnetic field dependence of the critical current at 2 K intervals from 20 K to 30 K is shown in Fig. 6. This method made it possible to acquire the data, such as temperature range, and magnetic field 3.0



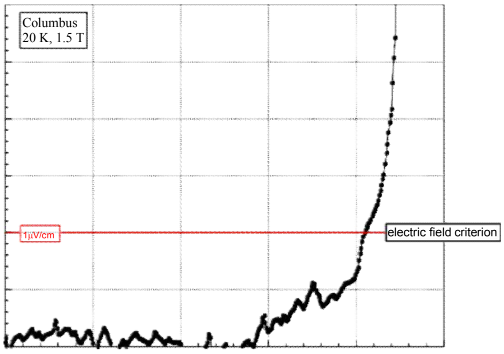


Fig. 3: Cross section of MgB_2 wire made by HyperTech Research Inc

II. CONCLUSION

consisted of a copper core, an iron layer and 12 MgB_2 filaments covered with nickel arrayed from the centre, as seen in Fig. 2 showing a cross section of the wire. The non-heat- treated MgB_2 wire made by HyperTech Research Inc. was not heat-treated before shipment, so heat treatment was performed at 650 for 1 hour in an argon atmosphere. Figure 3 showing its cross section therefore illustrates copper core 30 MgB_2 filaments covered with niobium and monels

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