DEVELOPMENT OF OXIDE SUPERCONDUCTING MAGNETS USING SILVER-SHEATHED SC WIRE

Nobuhiro Shibuta, Ken-ich Sato, Hidehito Mukai, Takato Masuda
Takeshi Hikata, Munetsugu Ueyama, Takeshi Kato and Jun Fujikami
Osaka Research Laboratories, Sumitomo Electric Industries, Ltd.
1-1-3 Shimaya, Konohana-ku, Osaka, 554 Japan

Abstract

For the purpose of investigating the practicability of high-Tc superconductors in a superconducting magnet field, several prototype magnets using silver-sheathed bismuth based wires were manufactured and evaluated.

A single pancake coil proved able to produce a field of 1,070 Gauss at 77.3 K, and a field of about 1 Tesla at 4.2 K. Two magnets were manufactured with 3 double pancake coils connected electrically in series, and were confirmed to produce a field of 3,140 Gauss in a backup super-high field as high as 23 Tesla. A prototype DC motor using a React and Wind coil was manufactured and tested successfully.

Introduction

At present, magnet applications are being considered for different fields; one is the relatively low field application of up to 1 Tesla at 77.3 K, and the other is super-high field application above 20 Tesla at 4.2 K. In this paper, we will describe the present level of development for magnet applications using silver-sheathed bismuth based superconducting wires.

Properties of bismuth/Ag superconducting wires

To put high-Tc superconductors into practical use, much reseach has been done using different high-Tc superconductors and many processing techniques. A combination of a bismuth high-Tc phase (2223 phase) and a powder-in-tube technique seems to be promising. Maximum critical current density (Jc) of short wires at 77.3 K has reached 53,700 A/cm² in a zero magnetic field, 42,300 A/cm² at 0.1 Tesla and 12,000 A/cm² 0.1 at 1 Tesla. The magnetic field dependence of Jc of this wire is shown in Figure 1.

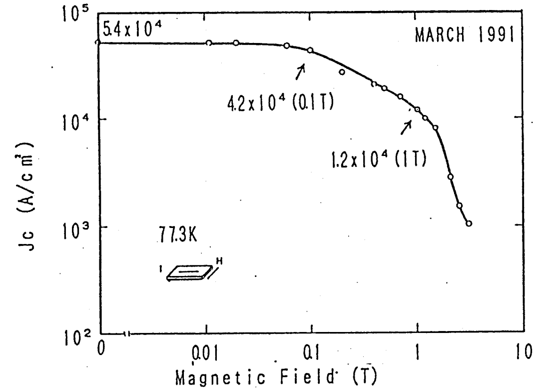

Fig. 1 Magnetic field dependence of Jc.

To investigate properties of long wires, a 100 m long wire was manufactured and evaluated using DC 4-probe method at 77.3 K. This long wire was sintered and evaluated with a single pancake coil shape having a 150 mm inner diameter and a 398mm outer diameter. Jc of this long wire was 5,250 A/cm² in a self magnetic field of 290 Gauss that produced at a critical current(Ic) of 24.3 A defined by $10^{-13}\Omega\cdot m$. Considering the reduction of Jc due to the magnetic field dependence of this wire, Jc of this 100m long wire was estimated to be 6,570 A/cm² with Ic of 30.4 A in a zero magnetic field. These properties are high enough to encourage the investigation of the practicability of superconducting magnets.

Magnet applications

To increase Ic of the current carrying conductor, a bundle conductor technique was adopted. Figure 2 shows an overview of a single pancake coil having a 18mm inner diameter and a 98mm outer diameter. This coil was formed using a Wind and React technique. Fiberglass cloth was used for the electrical insulator. This single pancake coil proved able to produce a field of 1,070 Gauss at Ic of 70 A defined by $10^{-13}\Omega\cdot m$ at 77.3 K, and a field of about 1 Tesla at 4.2 K. Figure 3 shows the load lines

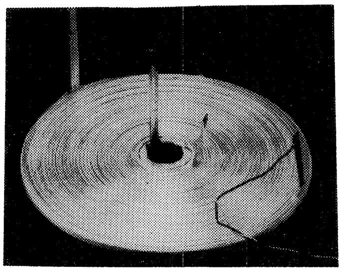

Fig. 2 An overview of a single pancake coil.

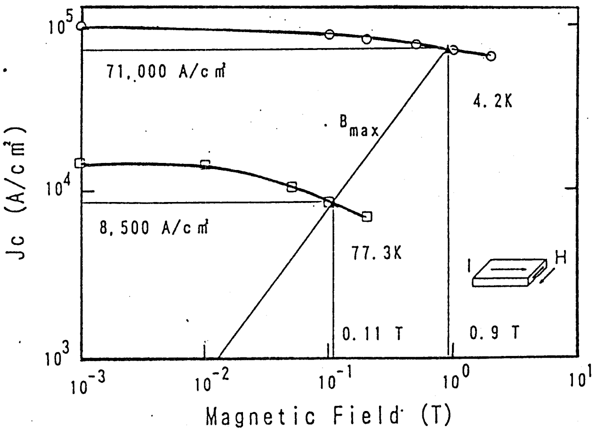

Fig. 3 The load lines of a single pancake coil.

of this coil at 77.3 K and 4.2K. Load lines were consistent with the Jc-B properties of the wires. At liquid nitrogen temperature, industrial applications could be started with magnets producing 2,000 Gauss, such as superconducting magnets for single crystal, and magnet separation.

After successful results with a single pancake coil were obtained, a double pancake coil was formed and tested at 77.3 K and 4.2 K. This coil produced a field of 876 Gauss with an Ic of 85 A at 77.3 K. Subsequently, this coil was tested in a backup field of 6 Tesla in liquid helium. The magnetic field exerts a force in proportion to both the field and current density per unit volume of current carrying conductor; in superconducting magnets, where the field and current density are both high. For a field of 6 Tesla, this force is 150 kg/cm^2. Therefore, to protect the superconductors from the electromagnetic force, two techniques for reinforcement were adopted. One was resin impregnation and the other was a stainless-steel jacket. Figure 4 shows the load line of this double pancake coil at 4.2 K. This coil produced a field of 4,120 Gauss with a critical current of 400 A in a backup field of 6 Tesla.

This coil was re-examined at 77.3 K and was confirmed to maintain the same properties, showing a critical current of 85 A, after being subjected to an electromagnetic force of 150 kg/cm^2 at 4.2 K.

For the next step in studying the feasibility of super-high field magnets, two magnets (No. 1, No. 2) were manufactured with 3 double pancake coils that were connected in series. These magnets were tested in a backup field of 23 Tesla using the Hybrid magnet at the High Field Laboratory for Superconducting Materials, Tohoku University.

Table 1 shows the dimensions of the two magnets.

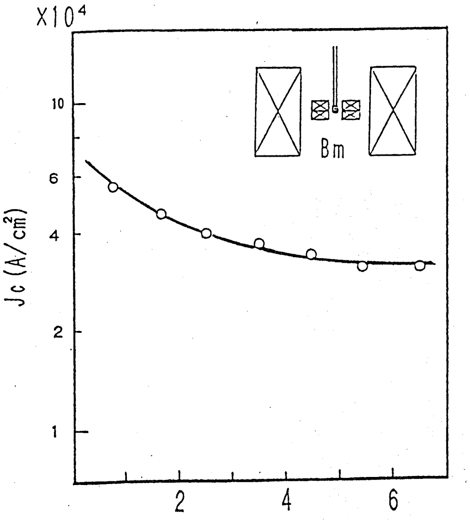

Fig. 4 Jc-B properties of a double pancake coil at 4.2 K

Figure 5 shows a computer-calculated picture of the field and the magnetic force pattern of the magnets made of 3 double pancake coils in a backup field of 23 Tesla.

Generally, the strongest component of the field is in the axial direction and produces an outward radial force on the conductors which causes circumferential hoop stress in the winding. In a super-high backup field such as 23 Tesla, the computer-calculated greatest stress is 2,000 kg/cm^2. Such forces can cause severe problems in the design and construction of superconducting magnets; they can damage the silver-sheathed bismuth based superconducting wire or insulation. Both magnets No. 1 and No. 2 were also resin-impregnated and covered with a stainless steel jacket. Figure 6 shows an overview of magnet No. 1.

Table 1 Parameter of magnets connected in series with 3 double pancake coils.

Items	Magnet No. 1	Magnet No. 2
Wire Thickness (mm)	0.90	0.56
Width (mm)	4.0	3.7
Coil I. D. (mm)	8.5	8.5
O. D. (mm)	34.0	35.0
Turns	11×2×3=66	14×2×3=84
(at4.2K,23T) Ic (A)	100 A	95 A
Bm(Gauss)	2,250	3,140

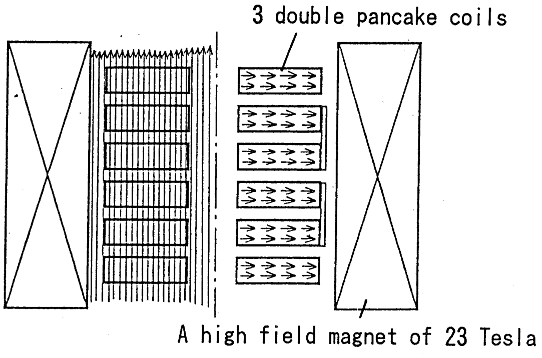

Fig.5 Computer-calculated picture for 3 double pancake coils in a backup field of 23 Tesla, showing the magnetic field line on the left-hand side and vectors of electromagnetic force per unit volume on the right.

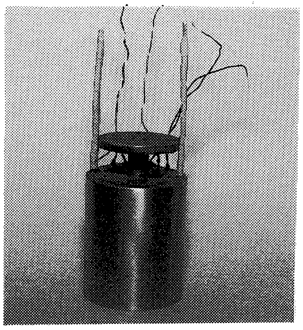

Fig.6 An over view of No. 1 magnet.

Figure 7 shows the results for the two magnets. Magnet No. 1 produced a field of 2,250 Gauss with Ic of 100 A defined by $10^{-13}\Omega\cdot m$ in a backup field of 23 Tesla at 4.2 K. But, the Ic of magnet No. 1 in a field of 23 Tesla was a half of Ic in a field of 5 Tesla. This difference was considered to be attributable to the high stress; 2,000 kg/cm^2 at 23 Tesla. For the short wire samples, Ic in a field 5 Tesla and Ic in a field of 23 Tesla differ little. In consideration of these results, an improved method was adopted for magnet No. 2, including epoxy resin impregnation and a stainless steel jacket. In magnet No. 2, the maximum self-field producing in a backup field of 23 Tesla was 3,140 Gauss with a critical current of 95 A defined by $10^{-13}\Omega\cdot m$. This magnet shows a slight reduction of Ic similar to the short wire samples, and the improved method of protecting against electromagnetic force proved to be effective.

These results are the first demonstration of the possibility of applying silver-sheathed bismuth based superconducting wires for manufacturing super-high field magnets above 20 Tesla, such as high frequency NMR magnets.

React and Wind coil

Single-core and multifilamentary wires were manufactured and wound on various-sized formers after sintering. Figure 8 shows the Jc-bending strain characteristics of single-core, 36-core, 762-core, and 1,296-core wires. Jc of the 1,296-cores wire was not reduced below a bending strain of 0.7%.

Figure 9 shows an overview of a DC motor composed of a copper rotor and a React and Wind coil made of 1,296 multifilamentary wire.

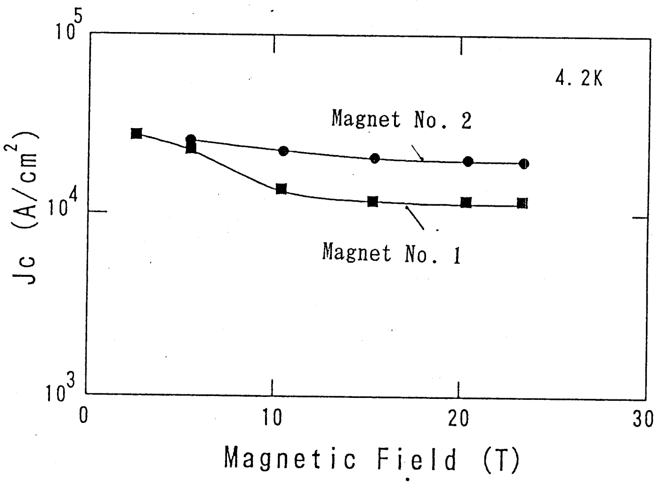

Fig. 7 Jc of three double pancake coils.

After sintering, a 4.3 m long 1,296 multifilamentary wire was covered with polyvinyl formal (PVF), and subsequently wound on a 15mm diameter steel core.
Jc of this wire was 7,800 A/cm^2 with Ic of 7.4 A. This coil produced a field of 150 Gauss within a 22mm gap of the steel core when operated at 6 A, and the copper rotor revolved smoothly. This successful result demonstrates the possibility of applying silver-sheathed bismuth based multifilamentary superconducting wire not only for motors but also superconducting transformers and other power apparatus.

Conclusion

At liquid nitrogen temperature, the application of magnets producing a field of about 1 Tesla may be possible in the near future.

At liquid helium temperature, improved method against electromagnetic forces such as at 2,000 kg/cm^2, show that it is possible to produce the characteristic expected of the wire for the super-high field magnets.

References

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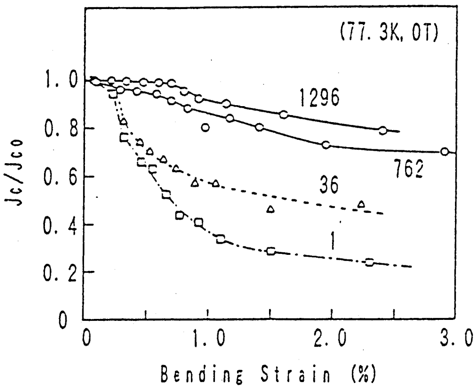

Fig. 8 Jc-strain characteristics of multifilamentary wires.

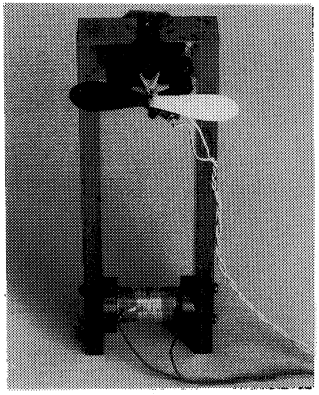

Fig. 9 An overview of a React and Wind coil.