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DEVELOPMENT OF PROTOTYPE HTS COMPONENTS FOR MAGNETIC SUSPENSION APPLICATIONS

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ABSTRACT

We have concentrated on developing prototype lengths of bismuth and thallium based silver sheathed superconductors by the powder-in-tube approach to fabricate high temperature superconducting (HTS) components for magnetic suspension applications. Long lengths of mono and multi filament tapes are presently being fabricated with critical current densities useful for maglev and many other applications. We have recently demonstrated the prototype manufacture of lengths exceeding 1 km of Bi-2223 multi filament conductor. Long lengths of thallium based multi-filament conductor have also been fabricated with practical levels of critical current density and improved field dependence behavior.

Test coils and magnets have been built from these lengths and characterized over a range of temperatures and background fields to determine their performance. Work is in progress to develop, fabricate and test HTS windings that will be suitable for magnetic suspension, levitation and other electric power related applications.

INTRODUCTION

Significant effort has been made over the past few years in the development of superconducting wires and tapes, through use of the powder-in-tube technique for possible electric power and high field magnet applications. Several research groups have demonstrated high critical current density (J_c) in short length Ag-clad BSCCO tapes fabricated by the powder-in-tube (PIT) technique [1-7]. The tapes were fabricated in a series of uniaxial pressing and heat treatment schedules. Because this technique cannot be adopted for fabricating high quality long-length conductors a modified processing technique was required. Using a more practical approach such as rolling, Intermagnetics General Corporation has fabricated mono- and multi-filament BSCCO conductors in lengths of up to several hundred meters [4,8-9]. These conductors have been co-wound into prototype pancake coils. Currently, research is underway to improve superconducting performance and to reduce the cost of HTS tapes [10-13]. Details of high field magnets, coils, conductor fabrication and the development of the next generation thallium based HTS conductors will be discussed in the present paper.

To fabricate the Bi-2223 HTS tapes, partially reacted precursor powder for the PIT process was prepared by a solid-state reaction of high-purity oxides and carbonates of Bi, Pb, Sr, Ca, and Cu. The powder was then packed into Ag tubes, swaged, drawn through a series of dies, and then rolled to a thickness of ~0.1 mm. Multi filament conductors containing 37 and 61 filaments were fabricated by stacking mono-filament wires in a larger Ag tube and then drawing and rolling to final size.

Short lengths of tapes were cut and heat treated at ~850°C in air with a repeated thermo-mechanical routine. After each thermo-mechanical step, the tapes were characterized by X-ray diffraction (XRD), scanning electron microscopy, and critical current measurements. Transport properties of the resulting tapes were measured by the four probe technique, with a 1 μV/cm criterion. Long-length mono- and multi filament conductors were fabricated by implementing a carefully designed two-step rolling and heat treatment schedule. Figure 1 shows winding of a long length of conductor (about 1,260 meters) onto a spool during the mechanical deformation operation. After final reaction these conductors were co-wound in parallel to form pancake coils. HTS magnets were fabricated by stacking together and connecting in series a set of such coils. The magnets were characterized at various temperatures and applied magnetic fields.

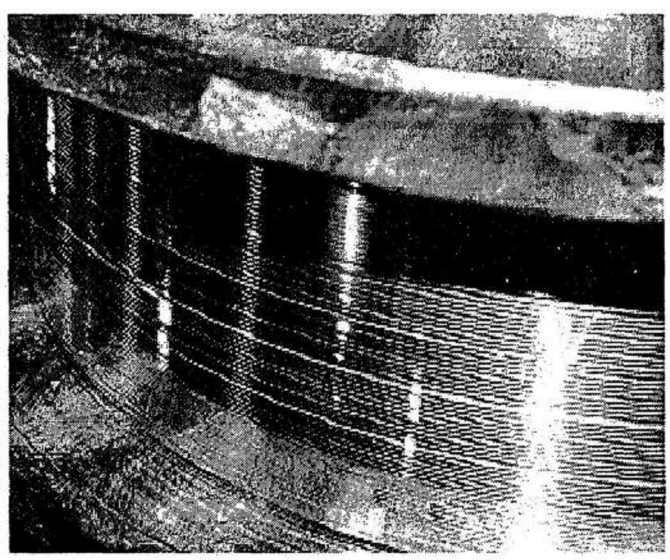

Fig. 1. Fabrication of a 1,260 m length of Bi-2223 conductor.

RESULTS AND DISCUSSION

High critical current (I_c) values in short samples of Bi-2223 tapes have been achieved by a combination of uniaxial pressing and heat treatments. I_c values above 40 A were typically attained at 77 K, with the highest being 51 A (corresponding to a J_c of 45,000 A/cm^2), in short mono filament samples subjected to three or four cycles of uniaxial pressing and heat treatment. For fabricating long length conductors, however a more practical approach such as rolling has been adopted. More recent multi-filament tapes with 61 filaments have been processed and measured in short samples to carry 58 Amps of current at 77 K, zero field. Table 1 summarizes the transport current properties, at 77 K, of both short and long mono- and multi-filament conductors. At 77 K, core J_c values of approaching 2 x 10^4 A/cm^2 have been achieved in a 90 m long multi-filament conductor.

	Length (meters)	Ic (A)	Core Jc (A/cm^2)	Overall Jc (A/cm^2)	SC %
MONOFILAMENT					
Short Pressed	0.03	51	~45,000	9,000	20
Short Rolled	0.03	51	~29,000	7,800	27
Long Length	70	23	~15,000	3,500	24
Long Length	114	20	~12,000	3,200	27
MULTIFILAMENT (37)					
Long Length	20	42	~21,000	6,800	32
Long Length	90	35	~17,500	5,600	32
Long Length	850	16	~10,500	2,500	24
Long Length	1,260	18	~12,000	3,500	30

Table 1. Summary of transport current properties of short and long mono- and multi-filament Ag-clad BSCCO conductors

Figure 2 shows the critical current density along the length of a 1,260 m long multi filament conductor containing 37 filaments. This tape was mechanically processed in a single piece length. To measure its current carrying properties small samples from the long length were sectioned and heat treated. The results of the tests of these samples are shown in Figure 2. The average I_c was 18A, corresponding to a J_c of =1.2 x 10^4 A/cm^2. These results indicate that considerable progress has been made in the development of Ag-clad BSCCO superconductors by the PIT technique. Pancake coils were fabricated from long Ag-clad BSCCO conductors. HTS magnets were fabricated by stacking the pancake coils and connecting them in series.

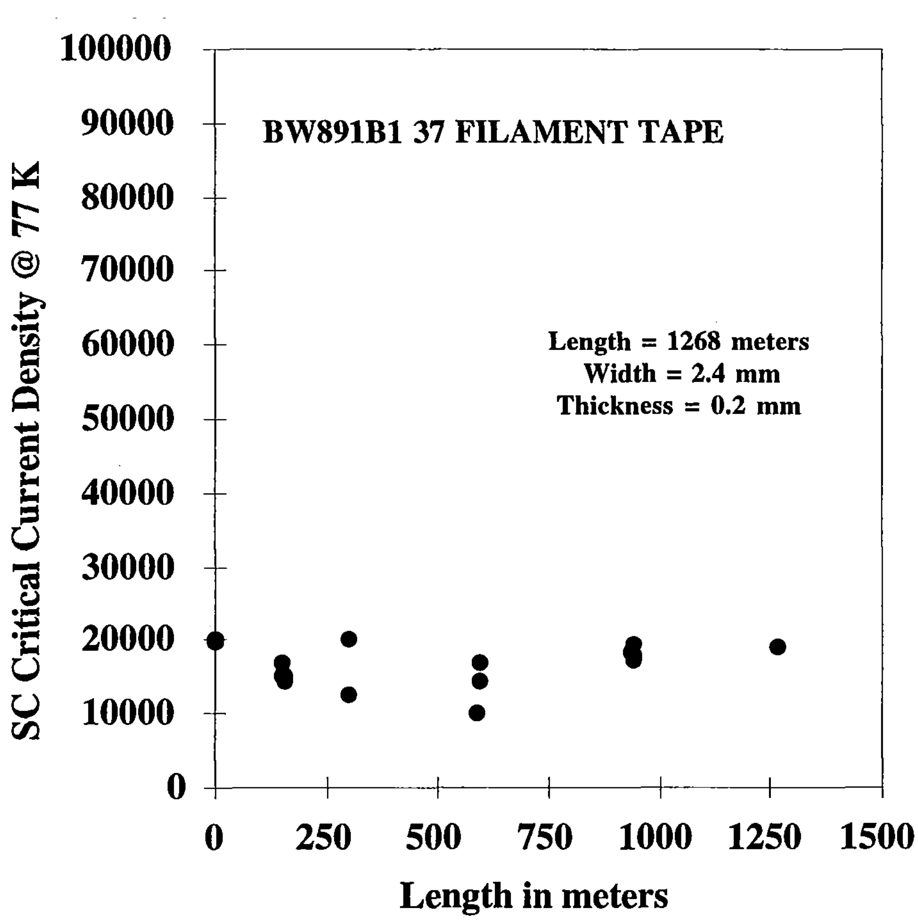

Fig. 2. J_c vs. length at 77K of multi filament conductor containing 37 filaments. Average J_c of ~1,260 m long conductor was ~1.2×10^4 A/cm^2.

A test magnet (Fig. 3) fabricated by stacking 20 pancake coils generated a self-field of ~3.2 T at 4.2 K and zero applied field. Total length of the conductor in the magnet was 2,400 m. The outer and inner winding diameters of the coil were 0.203 and 0.040 m, respectively. Ampere turns at 4.2K were >250,000. Another test magnet fabricated with a 40 mm room temperature bore was designed, fabricated and assembled for use in a dry or liquid cryogen free mode. Using the wind and react approach the coils were fabricated and assembled using copper supporting flanges and a copper base block. A schematic of this setup is shown in Figure 4. This magnet was able to generate a field of 0.8 T when cooled with a cryocooler down to 20 K.

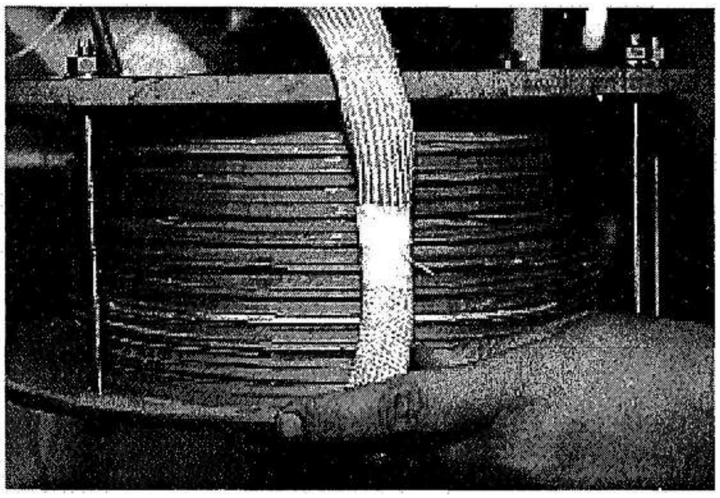

Fig. 3. Test magnet that generated a field of ~3.2T at 4.2K and zero applied field

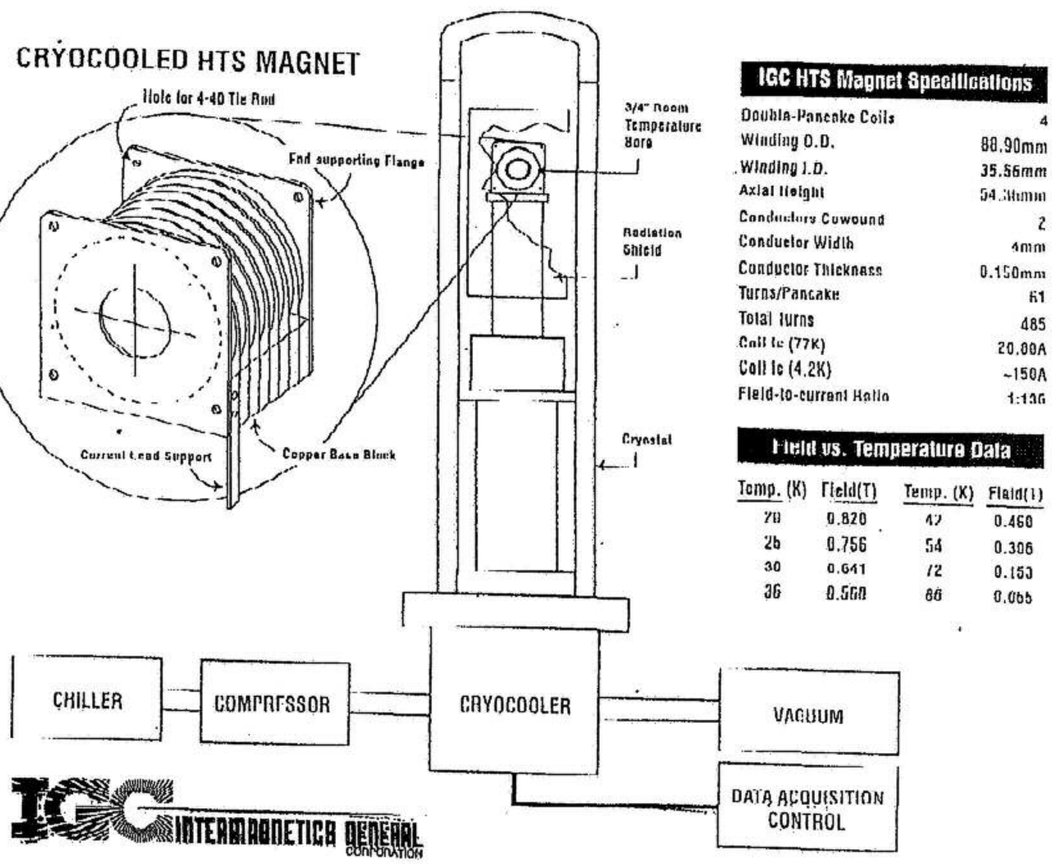

Fig 4. Schematic of a pancake magnet installed in a cryocooler assembly.

Another important advance that has recently been achieved is in the area of active magnetic bearing technology [4]. Using HTS coils fabricated by Intermagnetics, NASA Lewis Research Center has completed a proof-of-feasibility demonstration that showed the use of HTS coils in high load, active magnetic bearings operating at liquid nitrogen temperature. A homopolar radial bearing wound with Bi-2223 four control coils (about 1,000 Amp-turns each) produced over 890 N (200 lb.) radial load capacity and supported a shaft at 14,000 rpm. It was shown that HTS coils could operate stably with ferromagnetic cores in a feedback controlled system at a current density that was superior to that for Cu in liquid nitrogen. A photograph of the parts that were used to fabricate the system is shown in Figure 5.

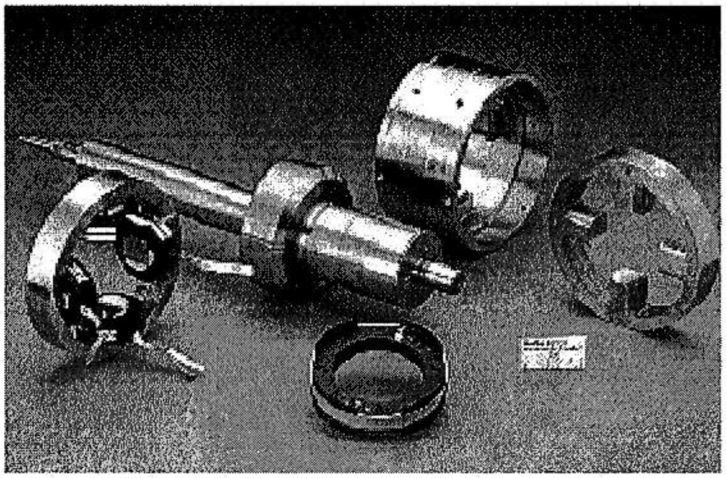

Fig 5. Parts of an active magnetic bearing using HTS control coils and developed by NASA.

The next generation of thallium based HTS conductors is being developed at Intermagnetics [15] for high field, high temperature operation. Both powder-in-tube and thick film approaches are being developed. We have concentrated on single thallium layer compounds mainly the Tl-1223 which is sometimes doped with Pb, Bi or Sr. Table 2 summarizes the performance levels of PIT Tl-1223 mono and multi filament tapes that have been fabricated at Intermagnetics. The highest critical current densities were achieved in tapes fabricated using unreacted precursors. An I_c in excess of 25 A has been achieved in zero field at 77 K in these tapes that correspond to Jc's of over 20,000 A/cm^2. Figure 6 shows the magnetic field dependence of the J_c of a PIT tape that is compared to a dip-coated tape. The Jc of the PIT tapes tend to drop rapidly at low fields but remain constant up to fields of 5 T at 77 K. Work is continuing to improve the characteristics of these materials further.

	Length (m)	I_c (A)	Core J_c (A/cm²)	Overall J_c (A/cm²)
Monofilament				
Pressed	0.04	25	20000	4500
Rolled	0.14	8	8400	1600
Rolled	1.5	6	6300	1200
Multifilament (19)				
Pressed	0.04	16	11000	2500
Pressed (sequential)	0.14	12	12000	2400
Pressed (sequential)	1.0	9.2	9200	1800
Rolled	1.5	8	8000	1600
Rolled	7.2	6.2	6200	1300
Multifilament (37)				
Rolled	1.5	13	13000	2600

Table 2. Summary of transport current properties of short and long mono- and multi- filament Ag-clad TBCCO conductors

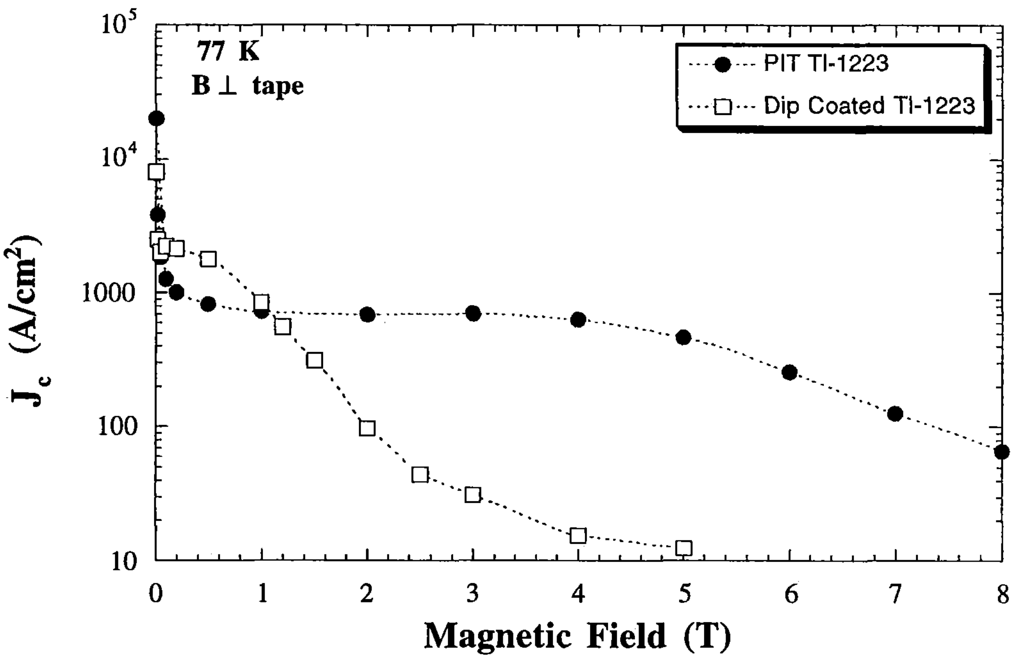

Fig 6. Magnetic field dependence of the current density of Tl-1223 tapes fabricated by the PIT and dip coating approaches.

SUMMARY

High quality mono- and multi filament conductors up to several hundred meters in length have been successfully fabricated by the PIT technique in both the Bi-2223 and Tl-1223 systems.

These conductors have been used to develop HTS superconducting magnets suitable for use in maglev applications. A long length of 1,260 meters of Bi-2223 tape was fabricated and an HTS magnet containing 20 pancake coils generated a self-field of =3.2 T at 4.2 K. A liquid cryogen free HTS magnet has been demonstrated to work effectively and produce a field of 0.8 T at 20 K. Small control coils have been fabricated and used by NASA to develop an active magnetic bearing with ferromagnetic cores that was used to support a 200 lb. radial load rotating at 14000 rpm. Work in developing the next generation HTS conductor based on thallium for higher temperature operation is showing considerable promise. Significant progress has been made in improving the superconducting properties of HTS materials that can potentially be used in a wide variety of maglev and electric power applications.

ACKNOWLEDGMENTS

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