ADVANCED ADIABATIC DEMAGNETIZATION REFRIGERATORS FOR CONTINUOUS COOLING

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The research at Houston was focused on optimizing the design of superconducting magnets for advanced adiabatic demagnetization refrigerators (ADRs), assessing the feasibility of using high temperature superconducting (HTS) magnets in ADRs in the future, and developing techniques to deposit HTS thin and thick films on high strength, low thermal conductivity substrates for HTS magnet leads. Several approaches have been tested for the suggested superconducting magnets.

A. An estimate of the HTS magnet design

Preliminary designs have been done on the bases of the Bi2223 coil (using commercially available first-generation HTS tapes), the NbTi coil, and the Nb_3Sn coil. The operation temperatures will be 35 K, 4.5-6.5 K, and 8-10 K, respectively. The parameters so obtained are listed below:

Table I HTS Coil

Parameter	Value
HTS tape width (mm)	3.1
HTS tape thickness (mm)	0.17
Coil height (cm)	5.1
Coil ID (cm)	5
Coil OD (cm)	21.2
Single pancakes	16
No. of turns per pancake	300
Total length of HTS conductor (m)	1975
Central Operating B-field (T)	**2.8**
Operating Current (A)	60
Operating Temperature (K)	**35**
Operating fraction of $I=I_{op}/I_c$	0.7
Stored Energy (J)	3456
Inductance (h)	1.92
Coil mass (kg)	**12.3**

Table II LTS NbTi Coil

Parameter	4.5 K	5.5 K	6.5 K
NbTi Strand diameter (mm)	0.335	0.388	0.48
Coil height (cm)	5.1	5.1	5.1
Coil ID (cm)	5	5	5
Coil OD (cm)	9.3	10.3	12.1
No. of turns	3744	3720	3696
Copper to NbTi ratio	1.8	1.8	1.8
Operating Current (A)	60	60	60
Central Operating B-field (T)	**3.2**	**3.09**	**2.85**
Operating Fraction $I=I_{op}/I_c$	0.5	0.5	0.5
Inductance (h)	0.65	0.67	0.76
Stored Energy (J)	1170	1206	1368
Coil mass (kg)	**0.69**	**0.95**	**1.51**

Table III LTS Nb_3Sn Coil

Parameter	8 K	10 K
Nb_3Sn Strand diameter (mm)	0.52	0.68
Coil height (cm)	5.0	5.0
Coil ID (cm)	5	5
Coil OD (cm)	12.2	16.6
No. of turns	3848	3654
Copper to non-Cu ratio	1.16	1.16
Operating Current (A)	60	60
Central Operating B-field (T)	**2.9**	**2.45**
Operating Fraction $I=I_{op}/I_c$	0.5	0.5
Inductance (h)	0.83	0.91
Stored Energy (J)	1494	1638
Coil mass (kg)	**1.8**	**3.4**

It appears from the design that:

1) Using available HTS tapes (Bi2223), the magnets are far heavier than the NASA specification. The overall performance, however, depends on the weight associated with refrigeration. In such a case, the overall duration of the adiabatic demagnetization experiment is a significant factor. It should also be noted that the rapid developments in the second-generation HTS (YBCO-based) tapes may totally change this evaluation.
2) At a central B-field above 2.8 T, the weight limitation may limit the Nb_3Sn coil to operating only at 8 K.

B. Magnets based on the trapped field in large single-crystalline HTS superconductors developed through the melt-texturing procedure

The synthesis procedure for melt-textured bulk $YBa_2Cu_3O_{7-\delta}$ pellets has been systematically investigated with the aim of maximizing the trapped field. We found:

1) Using of the top-seed method, i.e. using a small piece of single-crystalline $SmBa_2Cu_3O_{7-\delta}$ imbedded into the top of the precursors, significantly improves the growth of large melt-textured pellets. As a result, disks of melt-textured $YBa_2Cu_3O_{7-\delta}$ as large as 5 cm are routinely produced.
2) The temperature profile during the slowly cooling stage, i.e. the crystal growth, of the melt-textured growth is one of the key parameters. Trapped field as high as 4 T at the surface was observed. A record shielding field greater than 19 T was detected at 4.2 K
3) The partial replacement of Y by other rare-earth elements may increase the trapped field. Especially, Nd shows rather promising results.
4) A new process developed by us shortens the processing time for melt-texturing quasi-single crystalline $YBa_2Cu_3O_{7-\delta}$ disks by ~ 40% without degrading their superconducting properties.

C. Avoidance of thermal instability by special configurations

1) We observed that the large trapped field at low temperature is determined by flux avalanche due to the intrinsic thermal instability associated with the lower thermal conductivity in HTS materials.
2) We proposed a new configuration to assemble several HTS pellets with sizes smaller than the thermal instability limit, and produced fields higher than that allowed by the thermal instability in single pellets.
3) A U.S. patent has been granted based on the work.

D. Fabrication and improvement of the performance of HTS-based tapes

1) We developed a non-vacuum two-step spray compress process for the fabrication of YBCO, BSCCO, and HBCCO thick films.
2) We achieved YBCO thick films with a J_c of $7x10^5$ A/cm^2 at 77 K in self-field and BSCCO thick films with 4.2 K J_c of $5x10^5$ A/cm^2 at zero field and $3x10^5$ A/cm^2 at 8 T.
3) We have studied the influence of a $(Y,Ca)Ba_2Cu_3O_{7-\delta}$ top layer on the critical current of YBCO films and found:
   a. a ten-fold enhancement of the critical current density at 4.2 K in polycrystalline YBCO films on MgO substrates.
   b. the Ca-doping improves the film alignment in multi-layer configurations.

E. Investigation of the effects of cation substitution and nano-particles on YBCO films

1) We found that Ho doping may relax the preparation conditions for the films.
2) We observed that Nd doping in YBCO improves the J_c at high fields and high temperatures.
3) Studies of mixed rare-earth and nano-particle doping are underway.

References

- "Top-Seed Method in Making Large Single-Grain $YBa_2Cu_3O_{7-\delta}$," R. L. Meng and C. W. Chu et al., unpublished.
- "The effects of rare-earth element doping on the critical currents of YBCO films," R. L. Meng and C. W. Chu et al., in preparation.
- "YBCO/YCBCO Multi-Layer Healing Technique for YBCO Coated Conductors," R. L. Meng and C. W. Chu et al., submitted to Proceedings of the 2004 Applied Superconductivity Conference, Jacksonville, Florida, October 3-8, 2004 (October 3, 2004); to be published in IEEE Transactions on Applied Superconductivity.
- Additional manuscripts in preparation.