Superconducting Octupole Magnet for Soft X-ray Scattering

Over the last decade, X-ray magnetic circular dichroism (XMCD) and X-ray magnetic linear dichroism (XMLD) measurements have become powerful element-specific techniques for studying magnetism and magnetic materials. To explore XMCD and XMLD in photon scattering experiments, the magnet assembly needs to produce a variable high magnetic field in three dimensions to magnetize the sample, especially for hard-to-magnetize materials. For this purpose we have designed and constructed a novel superconducting octupole magnet, dubbed the Dragon Ball, which produce magnetic fields above 3.5 T for X-ray magnetic dichroism experiments. The magnet was designed to be cryogen-free and very compact to allow insertion into a vacuum chamber. Eight cone-shaped superconducting coils are arranged octahedrally to form four independent dipole pairs, facilitating five 30°conic bore holes and a 210°slit opening for large angle photon-in-photon-out experiments. Fig. 1 shows a photograph of the octupole magnet with the 60 K thermal radiation shield removed. The magnet is comprised of the following main components: eight cone-shaped superconducting coils (Fig. 2), each equipped with a holmium pole piece and a steel return yoke, eight HTS current leads, a monolithic aluminum supporting block (Fig. 3), thermal interceptions, quench protection diodes, a gold plated copper cylindrical tank for 60 K thermal radiation shielding, a G-M type 1.5 W cryocooler, and a liquid nitrogen reservoir. The magnet gap in the dipole pair was designed to be 1 inch, sufficient to accommodate the sample and its manipulator. Applying different excitation currents to the four-dipole pairs, a variable magnetic field can be produced in three dimensions at the center of the device. Table 1 lists the design parameters of the octupole superconducting magnet.

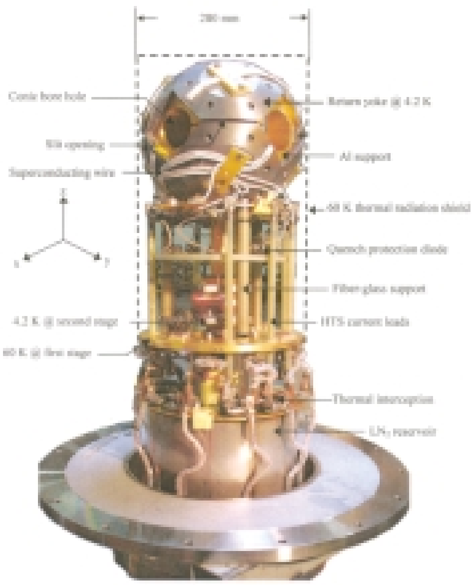

Fig. 1: Photograph of the superconducting octupole magnet with the 60 K thermal radiation shield removed.

As shown in Fig. 4, the 3D view of the maximum magnetic field created at the center of the magnet is defined by the rhombic dodecahedron surface, by using only one bi-polar power supply and a switching circuit. Near the center of the device the magnetic field is measured with one transverse-axis Hall probe in the x and y direction, and one raidal-axis Hall probe in the z direction, both inserted through the top conic bore hole. The good field region with $\triangle B/B \leq 2\%$ was larger than ± 3 mm in all three directions which will suit the needs of XMCD, XMLD, and photon scattering experiments.

The heat load on the 4 K assembly is 1.1 W and the cooling capacity of the second stage of the cryocooler at 4 K is 1.5 W. Therefore, this magnet has achieved the cryogen-free operation without LHe. However, the heat loads on 60 K come

Table 1: Design and construction specification of superconducting octupole magnet.

Number of poles	8
Maximum field along three main axes (T)	3.65
Gap between opposite poles (cm)	2.54
Diameter of the octopole magnet (cm)	24.7
Pole piece material	Holmium
Return yoke material	1006 steel
Inductance at 150 A (H)	3.0
Total energy (kJ)	33
Heat leak @ 60K (W)	80
Heat leak @ 4.2K (W)	1.15
Good fild region$\triangle B/B \leq 0.04$ (mm)	10
Cooling method	Conduction cooling by a 1.5 W G-M cryocooler

Superconducting wire	High field grade	Low field grade
Cu to NbTi ratio	1.35	2.0
Current density (A/mm^2)	243.2	313
Operation current (A)	150	150
Critical current @ 4.2 K (A)	195 @ B_S=8T	210 @ B_S=6T
Maximum field on wire B_S (T)	6.1	5.7
Wire cross-section (mm)	0.95×0.7	0.84×0.64

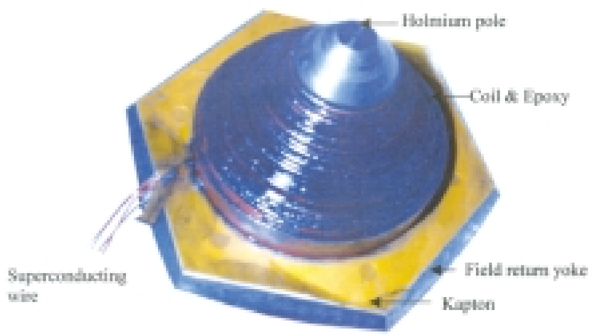

Fig. 2: Photograph of cone-shaped superconducting coil and the Holmium pole piece.

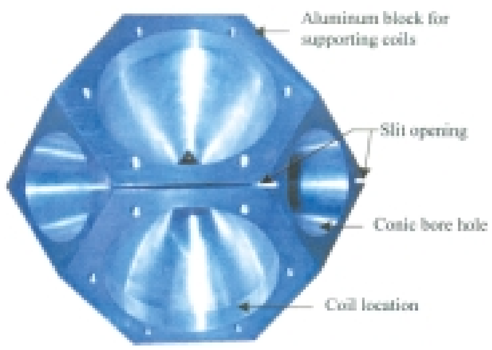

Fig. 3: Monolithic aluminum block for supporting and cooling eight cone-shape superconducting coils.

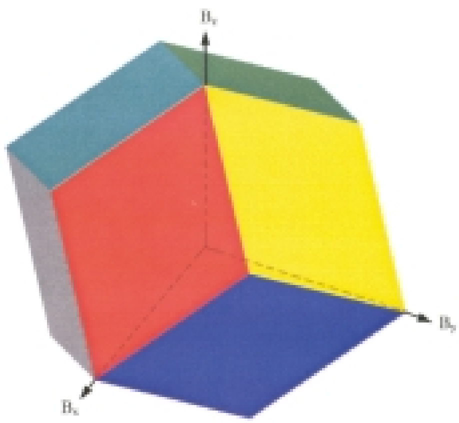

Fig. 4: 3D view of the rhombic docecahedron that defines the maximum magnetic field reachable by the octupole magnet .

primarily from the eight HTS current leads that have a cooling capacity larger than that of the first stage of cryocooler. Therefore, LN_2 is required to assist the cooling capacity of the first stage of the cryocooler. Further improvements are needed to achieve a fully cryogen-free operation. The improvements for the octupole magnet include: (1) decreasing the heat conduction to 60 K stages by reducing the number of HTS current leads to two by using an in-situ persistent current switching device that works at 4 K, (2) reducing the eddy current effect by laminating the aluminum support block to enhance the current slew rate, and (3) minimizing the Cu/SC ratio of the superconducting wire to reduce the operation current.

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Publications:

- C. S. Hwang, C. T. Chen, B. Wang, R. Wahrer, C. H. Chang, C. Y. Liu, F. Y. Lin, J. Magn. Magn. Mater. **239**, 586 (2002).