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Soft X-Ray Scattering End Station

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Abstract. This end station has been specially engineered to solve the problem of the limited optical access typically associated with magnetic fields and synchrotron radiation measurement stations. An octupole magnet provides a fully variable direction vector field. A cryogenically cooled manipulation transfer system is provides the necessary flexibility to address a wide variety of magnetic samples. The whole system is ultra high vacuum compatible with a base pressure of 5 x 10^{-10} mbar. The eight water-cooled magnets, spaced equidistantly over the surface of a sphere, allow the application of the field in any direction. These high current magnets generate a field in the area of the sample of 1T. A photodiode detector travels along a +/- 90 [deg] arc perpendicular to the beam axis. This motion, coupled with the entire system rotation of +/- 90 [deg] and incoming light polarization allows for the diode to be placed anywhere on a hemisphere perpendicular to the beam for any light polarization. The system also has provisions for cooling the sample with LHe and sample positioning in X, Y, Z, and rotation about the Z axis with micron resolution.

Keywords: Octupole, End Station, Soft X-ray Scattering
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INTRODUCTION

Advanced Design Consulting USA, Inc. (ADC) in collaboration with MAX-lab has developed a new instrument for soft x-ray scattering. This device forms the basis of a highly adaptable end station for soft x-ray scattering experiments with the emphasis on investigating magnetism and related phenomena. Eight electromagnets, equidistantly spaced about the surface of a sphere, create an omnidirectional field vector with a magnitude of 1 [T] and uniformity over the sample space of +/- 3%. The magnets protrude into an ultra high vacuum chamber with a base pressure of 5E-10 [mbar] that houses both the sample and detector apparatus. The entire system is then capable of rotation about the beam axis.

DESIGN PRICIPALS

Building on earlier instrumentation in this field[1], each magnet uses a tapered, partially hollowed iron core with a geometry optimized to cause saturation at the pole face. The windings use approximately 100 [m] and 200 turns of polyurethane insulated 12 AWG magnet wire. Power supplies capable of 100 [A] current drive each magnet. Water is injected through the hollow in the iron core then travels out into the magnet cavity through a series of radial holes and channels. The compartment containing the windings is flooded to dissipate the 4 [kW] heat load.

The LHe cooled sample is manipulated in four axes (x,y,z,theta) with a custom manipulator attached to the exterior of the chamber allowing +/- 5 [mm] in the x and y directions, +- 50 [mm] in the z direction, and continuous rotation about the y axis. The manipulator has been designed to allow it to be rotated from the vertical to horizontal position without requiring an external support and with a minimal effect on the sample position.

A detector diode sweeps a 180 [deg] arc within the vacuum chamber about the y-axis. When coupled with the 90 [deg] rotation of the chamber and magnet system, one may examine the effect of various light polarizations without modifying the upstream optics.

Support Structure

The support structure is constructed of 304SS to minimize its effect on the magnetic field within the chamber. A magnetically permeable would shunt the field relative to the sample differently at different orientations of the chamber or with a different field vector.

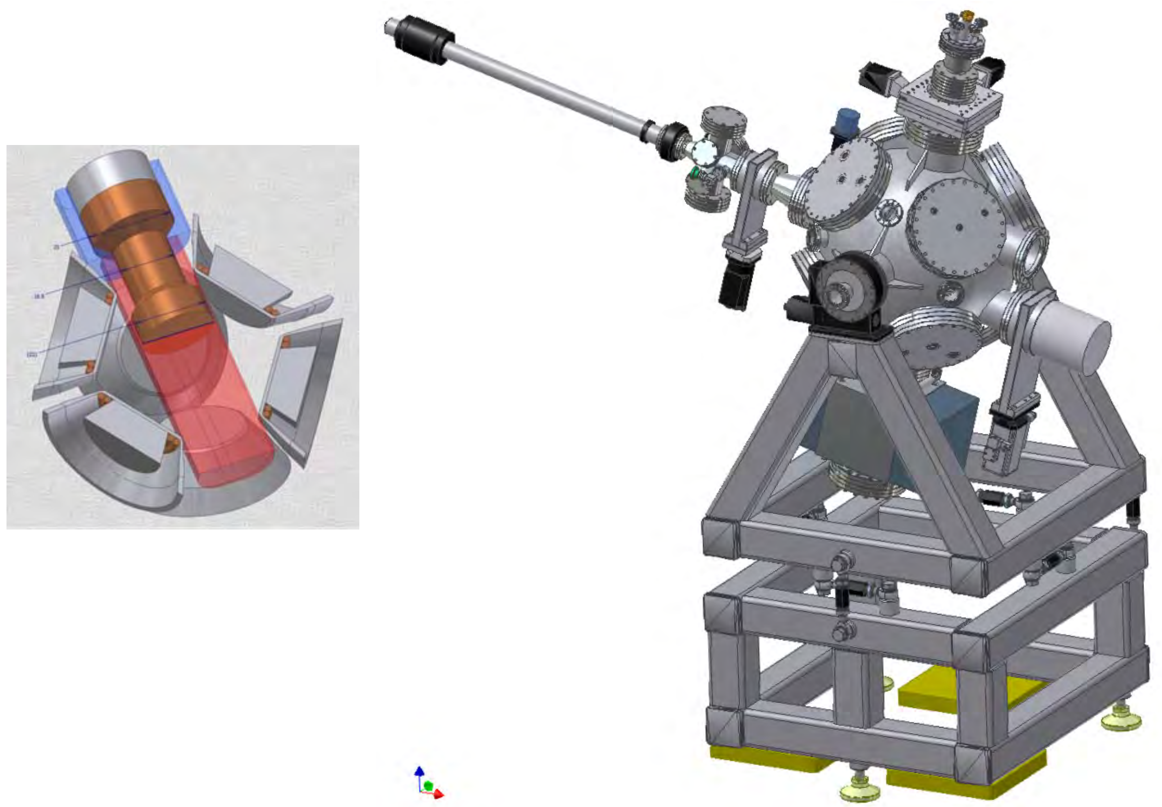

FIGURE 1. Soft X-ray Scattering Octupole End Station

Preliminary Test Results

The purpose of this test was to verify our modeling (Radia and FEMLAB) of the field both for magnitude and homogeneity as well as evaluating the cooling concept.

In addition, further optimization work was carried out on the final pole piece and winding configuration to match affordable power supplies. Primarily this meant maximising the saturation of the pole face while minimising the total length of conductor, and secondarily considering field homogeneity etc. In practice this meant using a maximum current of 100 A with a maximum 50 V or ca. 0.5 Ohms resistance in the conductor. (MAX-lab specified Detla power supplies (http://www.delta-elektronika.nl/) based on longstanding experience with their products. Specifically the 100 A - 60 V model, SM60-100.)

The biggest challenge was actually winding multi-layers of the conductor around the conical pole. We spent much time on this and learned quite a lot in a short space of time! I am happy to report that the results were very positive. First of all, the measured field agreed with the models to within, at most 7%, typically within 3%. There was a slight increase over the model at lower currents and a slight decrease at higher currents. We suspect that this deviation may be a result of the accuracy of the power supply display.

For the cooling tests, the prototype was driven up to 150 A using a Hewlet-Packard supply provided by ADC for the purpose of the tests. Two K type thermocouples were embedded in the windings: one between the layers and one on the outer winding surface. At most we observed a 10°C difference in temperature between the two thermocouples at an operating temperature of ca. 70 °C. The flow rate was varied from between 0.5 and 3.0 l/minute. (See plot below.) With the current limited to the specified 100 A we waited until a steady state was reached before recording the operating temperature. An interesting transition in the cooling efficiency is clearly visible which we believe is related to a transition from the cooling being limited by the volume flow rate under laminar conditions and the onset of turbulent flow within the winding interstices. The pressure drop in the cooling water was also measured and found to be well below the specified limits.

Summary.

Assumptions and limitations:
Voltage and current limits of 50 V and 100 A were assumed so that a low-cost PSU, rated at 60 V and 100 A, could be used. With a wire diameter of 2.05 and a resistance of 5.2 ohms/km wire length should be < 96.2 m.
At least 8mm clearance must be provided between adjacent poles.
25 mm is required between the pole-face and the sample's centre.
A maximum base diameter of 160mm can be used to fit the chosen flange size.
Peak field with 1 pair must be >0.5 T to achieve the 1.0 T specification with all poles energized.
Field strength variation over ± 5mm must be <5%.

Findings:
Larger diameter tip provides more uniform field.
With a core length of 150mm and tip radius of 10.5 mm it is possible to reach saturation with an 160mm base diameter.
Four layers of wire must be used to saturate the tip.
Total length = 96.6 m, just exceeding the 96.2 m limit.
Resistance = 0.502 Ohms.
Field at all points within 10mm cube centred on sample varies by <5%.
B(0,0) = 0.522 T (point at sample centre)
B(0,5) = 0.511 T (point at r = 5mm from sample centre)
B(5,0) = 0.543 T (point at z = 5mm from sample centre)
B(5,5) = 0.532 T (point at r = z = 5mm from sample centre)

Findings from cooling experiment:

Cooling is limited by volume flow at low flow rate (< 1 l/minute)

Cooling is limited by conduction of water in coil interstices at high flow rate (> 1 l/minute)

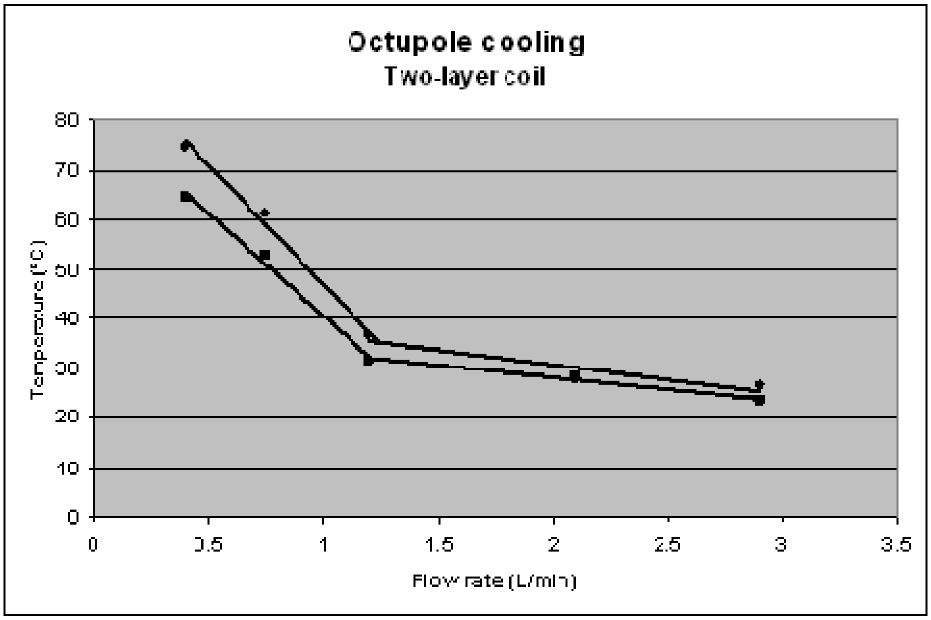

FIGURE 2. Temperature readings from thermocouples 1 and 2. (The higher temperatures are from the thermocouple embedded between the windings, the lower temperatures from the thermocouple on the outer surface of the windings.)

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