UHV Superconducting Magnet System for Soft X-ray MCD Experiments

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Abstract. In the framework of the ESRF upgrade program, the soft X-ray beamline UPBL7 will replace the current beamline ID08. The new beamline will be installed on port ID32 and will be equipped with a superconducting magnet system dedicated to study the electronic and magnetic properties of matter using soft X-rays from 300 up to 1500 eV. The magnet system comprises two nested UHV cold bore split-coil magnets of ±9T along the X-ray beam and ±4T perpendicular to the X-ray beam and a variable temperature insert with a temperature range of 1.5 to 400 K. The VTI wiring will include possibilities to measure total electron yield, sample transport properties or the application of an electric field. The system will be further equipped with a UHV sample preparation facility allowing in-situ application of surface science techniques.

1. Introduction
The ESRF UPBL7 project foresees the replacement of ID08 by a new long beamline in the EXPH2 Belledonne extension. Two end stations to study electronic and magnetic properties of matter are planned: one for RIXS with a combined resolving power of 30,000 [1], and another one for state-of-the-art magnetic dichroism experiments at high magnetic field. The superconducting magnet system for the dichroism end station described in this paper will have higher magnetic field than most other SXMCD end stations [2-7] and higher sweep rate to allow more efficient use of beamtime. The magnet system will be further equipped with a UHV sample preparation facility allowing in-situ application of surface science techniques.

In the pre-design phase of the magnet system several key considerations concerning magnetic field, sample temperature and sample conditioning have played an important role. Production of a 2D or 3D vector magnetic field yields very high mechanical constraints on the coils which imposes a heavy support structure clamping the magnets together. The strength of the support structure limits the maximum field, and additionally the clamping parts diminish the thermal contact between the liquid Helium and coil, partially blocking the coil cooling and thus limiting the sweep rate. It was decided to trade off the vector field for a secondary field horizontally perpendicular to the beam. Design studies were done on three perpendicular horizontal accesses (split) of dimensions 30, 40 and 50mm. The choice of the split distance has a big impact on the magnetic field and size of the coil. With an increase in split, the magnet inner diameter (bore) will also have to be bigger to maintain the field homogeneity.
penalizing the maximum field. The larger coil will have more inductance, needs more voltage to reach high sweep rate and will have higher helium consumption during sweeping. It also offers a more comfortable working space around the field center and an increase in optical angle, so the choice was made in favor of the larger split. Concerning the cryogenics it was considered most important to design a system which would have optimum serviceability: the smaller magnet support structure results in a faster cooldown while a set of heaters around the coils reduces the warmup time. The possibility to remove the VTI without dismounting any other parts of the system has already led to considerable savings in beamtime on the current system and was one of the crucial options to be implemented. Although the UHV conditions are of prime importance when working in the soft X-ray range it was decided not to separate the cryogenic vacuum from the experimental vacuum as this would result in too severe space constraints. Thus the whole system had to be built to UHV specifications.

2. Magnet
The main specifications of the magnets include a very high sweep rate of 8 T/min on the main axis and 2 T/min on the perpendicular axis. The magnets are operated in exclusive OR mode: only one magnet at a time can be energised. The inner coil providing a magnetic field of 9T along the beam is wound in Nb$_3$Sn wire, the outer coil providing 4T perpendicular to the beam is wound in NbTi wire. Both magnets are running off a single power supply providing 200 A. The coils are operated in a liquid He bath at 4.2 K. Even though cooling is very efficient in the liquid bath, a 5 minute thermalisation time was respected after a 124 seconds sweep from +8T to -8 T during factory testing. The temperature of the superconducting wire cannot be measured in-situ, so the only way to learn when the coil temperature rises too much is by doing fast sweeping until a quench is provoked. On the 9 T magnet this happened once during factory testing but it is to be avoided during regular use as repeated quenching reduces the maximum field and may even completely destroy the magnet. In this respect the 4 T coil is much less critical as it is wound in NbTi wire and has a bigger temperature margin.

Figure 1a: 9T coil continuous sweeps with 4 min sweep and 4 min waiting time; Figure 1b: Hold time of 2 seconds at the zero field passage; Figure 1c: 4T coil sweeps. Magnetic field is calculated from the coil current and NMR calibrated field factor.

| Field direction | Field (T) | L (H) | UHV access (mm) | Sweep time -max to +max | Homogeneity 1cm DSV |
|-----------------|-----------|-------|-----------------|-------------------------|---------------------|
| Along the beam  | 9         | 3.1   | 60              | 140 sec                 | <1%                 |
| Perpendicular horizontal | 4         | 7.8   | 50              | 240 sec                 | <0.1%               |

Table 1: Main properties of the two magnets.
3. Variable temperature insert

Based upon previous experience the VTI was designed for optimum serviceability. There is no internal capillary for sample cooling; Helium for sample cooling is supplied to the VTI from the main bath through a short external syphon. Thus the VTI can be simply pulled out of the system once it is at room temperature. The VTI contains a 4K pot plus needle valve to bring the cold source close to the sample. The siphon evaporation losses are pumped away separately and the sample cooling benefits from a supply of liquid Helium. The base temperature depends on the radiation heat load, during factory testing 1.43 K was reached at the sample position. The maximum temperature the VTI can reach is 400K; this is conditioned by the use of an indium seal and Cernox HT thermometer which cannot be heated above this temperature. Warm-up from base temperature to room temperature is achieved in 20 minutes (see figure 2); from 300K to 400 K takes another 20 minutes. The setpoint can be chosen at any temperature between minimum and 400K; the final stability is better than 0.1 K. Cooldown from 300 to 4K is achieved in 15 minutes, thus allowing for very fast sample changing. The VTI can be rotated around the vertical axis over an angle of 360 degrees, and translated vertically over ± 25mm. The VTI rotation and translation stages were supplied by VG Scienta.

![Figure 2a: warmup and cooldown to base temperature for three different temperatures, as measured at the sample position; Figure 2b: warmup and cooldown from 300 to 400 K.](image)

4. UHV cryostat vessel

As the cryogenic vacuum is not separated from the experiment vacuum the complete system was built to UHV specifications. The cryostat has two radiation shields; the outer shield is cooled by direct contact with the liquid Nitrogen reservoir while the inner radiation shield is cooled by the Helium evaporating from the reservoir. The cylindrical top part of the cryostat contains the liquid Nitrogen (65 litres) and liquid Helium (100 litres) reservoirs. It measures 800 mm in diameter and 900 mm in height. The rectangular bottom part containing the coil measures 390 mm along the beam, 480 mm perpendicular to the beam and 430 mm in height.

As the magnets are potted in epoxy the temperature has to stay below 80 ºC during baking. A number of thermometers mounted on the magnet set allow monitoring the temperature during baking. A vacuum of 3x10^{-10} mbar has been reached with the Helium bath at 4.2K, with an RGA showing the presence of hydrogen and water but no oxygen or hydrocarbons. During testing the magnet has experienced a quench; the impact on the vacuum was minimal.

5. System control unit

The system control rack contains a purpose built magnet power supply, two Lake Shore temperature controllers (336 and 340), LHe and LN\textsubscript{2} level meters and needle valve control electronics, the bakeout unit and control computer. The magnet power supply consists of a non standard 200A power supply featuring an increased voltage of 20 V to reach the required magnet sweep rate, a magnet switching
unit to switch between the two magnets and a current direction switching unit. The latter is controlled by the power supply and achieves switching in two seconds at the zero passage without causing glitches on the output as can be seen in figure 1b.

6. Conclusions
The system has successfully passed all of the factory tests and will soon be delivered at the ESRF. After arrival at the ESRF the VTI will be wired for total electron yield and magnetoresistance measurements and installed on ID08 for testing with beam. Future plans include the possible replacement of the VTI by a $^3$He insert to achieve temperatures below 0.5 K.

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