CLS Magnet Measurement Facility

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TABLE OF CONTENTS

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1.0 INTRODUCTION

1.1 PURPOSE

This document describes the requirements for the CLS Magnet Measurement Facility (MMF). The MMF has two purposes:

- To allow the assembly, measurement and adjustment of the magnetic structures used in insertion devices.
- To allow the measurement and calibration of other CLS electromagnets.

1.2 SCOPE

This document provides the necessary specifications for the design of the CLS Magnet Measurement Facility. Also included are layouts of different components indicating how they are placed relative to each other and how they might be placed in a room. The room dimensions are preliminary; final dimensions can be determined when the size of the Hall probe bench is known.

1.3 BACKGROUND

The first round of beam lines for the CLS requires five insertion devices. At least four of these will have their magnetic structures assembled, measured and adjusted at the CLS. The fifth (a super-conducting wiggler) will likely be assembled and tested elsewhere.

1.4 DEFINITIONS

The central component in the Magnet Measurement Facility is the Hall probe bench, the other components are aligned relative to this bench. We use a co-ordinate system with the x-axis horizontal and perpendicular to the Hall probe bench, the y-axis vertical and the z-axis horizontal and parallel to the Hall probe bench.

The x- and y-axes of the flip coil bench are parallel to the corresponding Hall probe bench axes.

2.0 REQUIREMENTS

2.1 FUNCTION

The MMF will be used in the assembly, measurement and adjustment of arrays of permanent magnets to be used in CLS insertion devices. This puts a number of constraints on the design of the facility.

First, the room must be large enough to house the measurement equipment. The main equipment needed for this room includes:

- A nuclear magnetic resonance probe and rack mounted electronics. The NMR unit should be able to measure fields from about 0.05 T to 3 T.
- Four sets of three axis Hall effect probes.
- A calibration dipole and power supply. The dipole shall reach a maximum flux density of 2.1 T with a gap large enough that the Hall effect probes and the appropriate NMR unit can be simultaneously inserted in the homogenous field region.

- A flip coil bench and the appropriate massive pedestals to allow it to be operated in a stable manner.
- A laser interferometer and pedestal to allow accurate measurement of Hall Probe position; includes an XY table. This must move synchronized with the Hall Probe.
- Four high precision rack mounted digital voltmeters (one for each Hall effect Probe and one for the flip coil).
- A precision current source for the Hall probes.
- Two PT100 thermometers for recording the ambient and the Hall probe temperatures.
- A Hall probe bench. The measurement length shall be 4.5 m to allow measurements on full-length insertion device for CLS. The bench is estimated to be 5.5 m long and 0.5 m wide.
- Two 19” standard height racks.
- Industrial PC (need ISA slots). Interface cards as needed for control and read out of the measurement equipment.
- Analysis PC (1 GB of RAM, large local hard drive, high performance CPU). This computer will also serve as the main computer for running RADIA.
- High-level software to control the measurements, possibly modeled on ESRF solution using IGOR Pro.
- Standard double pedestal desk.
- Wood table for assembly of magnet structures. The table must be completely non-magnetic and only non-magnetic nails and screws can be used.
- Wall mounted shelves.

2.2 PERFORMANCE

This section briefly discusses issues relevant to the effective operation of the equipment listed above.

2.2.1 NMR Probe

The NMR Probe needs to be able to span the range from about 0.05 T to 3 T. This means that several probes (probably about 4, depending on manufacturer) will be needed in order to cover this range. NMR field measurement is an absolute measurement and the frequency of the resonance signal can be measured with part per million accuracy.

The top end of the range of field capacity is needed in order to be able to measure the strongest fields that are likely to be used at the CLS insertion devices (about 2 T).

We will not be able to calibrate the Hall probes in the interval from –0.05 T to 0.05 T except for the point 0 T, which we can reach by using a mu-metal box. However, the Bell Hall elements used are quite linear at low fields.

2.2.2 Hall effect probes

The facility should be capable of simultaneously measuring all three components of the magnetic field. Four sets of three dimensional probes are required so that there will be spares available. Probes can be obtained from France.

2.2.3 Calibration dipole

A calibration dipole (and a power supply) should be available. This dipole should be capable of reaching 2.1 T. There seems to be a spare power supply available, and we must compare the cost of designing and manufacturing a calibration magnet that fits this power supply and the cost of buying a combination of laboratory magnet and power supply from a vendor. We also need support to hold the Hall probe and the NMR probes during calibration. The Hall probe must be able to rotate 90^o and to be inclined for calibration of the x- and z-elements.

In the calibration we will not only determine the coefficients in the polynomial converting the Hall voltage to magnetic field, but also the coefficients for the planar Hall effect and the miss-alignment for the different Hall elements.

2.2.4 Length of the Hall Probe Bench [1]

The available room in a CLS straight section is 4.97 m. At each end there is a vacuum valve, a bellow, an SLS-type absorber and an APS-type connection box for the vacuum chamber. Normal policy on straight sections is that they shall house two insertion devices. In some cases, these two insertion devices may point down the same beam line, but they would normally be the sources for separate beam lines. In the case we have two insertion devices in the same straight, the typical length of the insertion devices will not exceed about 1.7 m, as we must fit a chicane magnet between the two devices. If an insertion device is constructed to fill the entire free length, the total length will not exceed about 3.6 m. We need about 0.5 m before and after the insertion device to include the fringe field, and the longitudinal measurement length shall be 4.5 m. In the layout of the room we assume the granite block supporting the bench will be about 5.5 m long and about 0.5 m wide.

2.2.5 Measurement volume for the Hall Probe Bench

The photon beam height at the CLS is 1.4 m. The Hall probe shall be able to measure anywhere in a volume measuring 300 mm horizontally, 300 mm vertically and 4500 mm longitudinally. In the vertical plane the volume is centered at 1.4 m. In the horizontal plane the center position is determined by the length of the Hall probe holder.

2.2.6 Measurement of the longitudinal position of the Hall probes

The longitudinal position of the Hall probe must be measured very accurately due to the large gradients in the flux density. We therefore intend to use a laser interferometer and a retro-reflector mounted as close to the Hall elements as possible to be independent of small errors in the granite bench and guides. The interferometer head must be mounted on a (x,y) table to follow the Hall probe.

2.2.7 The Flip Coil Bench [2]

The flip coil bench consists of two (x,y,z) tables mounted on heavy concrete blocks. The y-tables carry a rotating stage, and the coil is stretched between bobbins mounted on the rotating stages and connected to an integrator. The z-stage is used to stretch the coil, the x- and y-stages to position the coil for measurement. The length of the coil is changed by moving the concrete blocks. The coil shall be able to measure anywhere in a volume measuring 300 mm horizontally, 300 mm vertically and the length of the coil longitudinally. In the vertical plane the volume is centered at 1.4 m, the centering in the horizontal plane is determined by the position of the concrete blocks.

2.2.8 Electronics

The Hall probe requires a precision current source feeding all three Hall elements in series. Each Hall element is connected to a digital voltmeter, for example Keithley 2000 6½-digit multimeter. The flip coil bench can use the same type Keithley multimeter, used as an integrator.

To change the insertion device gap and phase, we need access to a channel of the CLS undulator control system for helical devices with control also of the undulator phase.

The motors in the slides and the encoders might require special electronics. This depends on the manufacturer of the equipment.

2.3 TYPICAL SHIMMING PROCEDURE

Here we describe a typical shimming procedure for an insertion device. Before the assembly starts, each block has been measured with the flip coil, and a database is established which contains the flip coil measurements for each block.

The insertion device gap is set to maximum (about 300 mm) and the magnet assembly is mounted on the girders. We use the Hall probe bench with a micrometer to place each block at the right position longitudinally. Each time we have an even number of poles we measure the first integrals with the flip coil, and we choose the next blocks from the database in such a way that the integrated multipoles are minimized. The large gap allows us to measure the integrals for each girder without disturbance from the other.

When the assembly is finished, we use the Hall probe to measure the magnetic flux density for each girder on the centerline. Immediately after each Hall probe measurement we make a flip coil measurement at the same position. The flip coil measurement is used to eliminate the influence of drift and variations in the zero offset for the Hall elements.

In the Hall probe measurements the Hall probe moves with constant speed along the bench. Either an external clock or the laser interferometer is used to trigger the read out of the voltage from the Hall elements and the longitudinal position from the laser interferometer. The distance between measurement points is typically 1 mm, 0.5 mm for short period insertion devices. After the measurement the measurement data are re-binned with a constant step length if necessary, we will make extensive use of fast Fourier transform. The data are converted from V to T using a calibration polynomial and corrected for miss-alignment and planar and tensor Hall effects. Finally the Hall probe data are normalized using the flip coil measurement.

The vertical and transverse flux density data are then integrated and averaged over one period to show the size and position of the angular kicks. The block positions are adjusted vertically and horizontally to eliminate the kicks on both girders.

The gap is then closed to minimum gap, and the position of the magnetic mid plane is measured for each pole pair and corrected if necessary. The remaining angular kicks are eliminated, and the integrated multipoles measured with the flip coil and eliminated by applying small magnet blocks at the entrance and exit of the insertion device. Flip coil measurements are made for a number of gaps to make sure the integrated multipoles stay within specified valued. The multipole shimming is now finished, and the spectrum shimming starts.

The bulk of the spectrum shimming is done at minimum gap. Hall probe and flip coil measurements are done on the centerline and the phase angle error calculated for each pole. First any remaining taper is removed, and then the variation in the phase angle error is reduced by moving horizontally polarized blocks. When the RMS value for the phase angle error is within the specified range at minimum gap, measurements are made at a number of gaps to check how the RMS phase angle error behaves as function of gap. If necessary, correction coils can be used to correct the phase angle error in a given gap range.

After control and final correction of the integrated multipoles the shimming process is finished.

The work we do in the magnet measurement area is very different from what is done elsewhere at CLS; the magnet measurement area is self-contained and uses specially developed software to make and interpret the measurements. The only thing in common with the rest of CLS is the insertion device gap and phase control.

2.4 LAYOUT

Three figures are included. Figure 1 shows the arrangement of the Hall probe bench, the flip coil bench, laser interferometer and a 1.7 m long insertion device. We need a walk space behind the insertion device as the bolts and shims on the back of the girders are easier to reach from the back.

Figure 2 shows the measurement area to be covered by the Hall probe bench and the flip coil bench. The important thing is that we have coverage vertically from $y = 1.35$ m to $y = 1.55$ m. The exact position in x we can control by the length of the Hall probe holder and the placement of the flip coil pedestals.

Figure 3 shows a proposed layout of the magnet measurement room. The dimensions are dependent on the exact size of the Hall probe bench. As laid out in Figure 3 the room is 8 m x 5.5 m. The room shall have two windows or doors that can be opened so we can use transits outside the room to place Taylor-Hobson balls and brass plates showing the position of the magnetic center line on the insertion device. Of course, the more windows the better, but we must be able to open these two. The free floor space is needed during assembly.

The main door shall be wide enough to allow a standard pallet to enter the room.

The power supply for the calibration magnet can be placed outside the room.

The room shall be placed in the area between the storage ring and the booster with the long dimension parallel to the storage ring.

It is important to have very good light in the room.

The part of the roof covering the Hall probe bench, flip coil bench and laser interferometer pedestal shall be removable to allow the use of the overhead crane to move insertion devices in and out of the room and to move the pedestals. Some ventilation with filters is probably also necessary to keep the temperature in the closed room to $(22 +/- 1)^{o}$C when in-vacuum undulators are being shimmed.

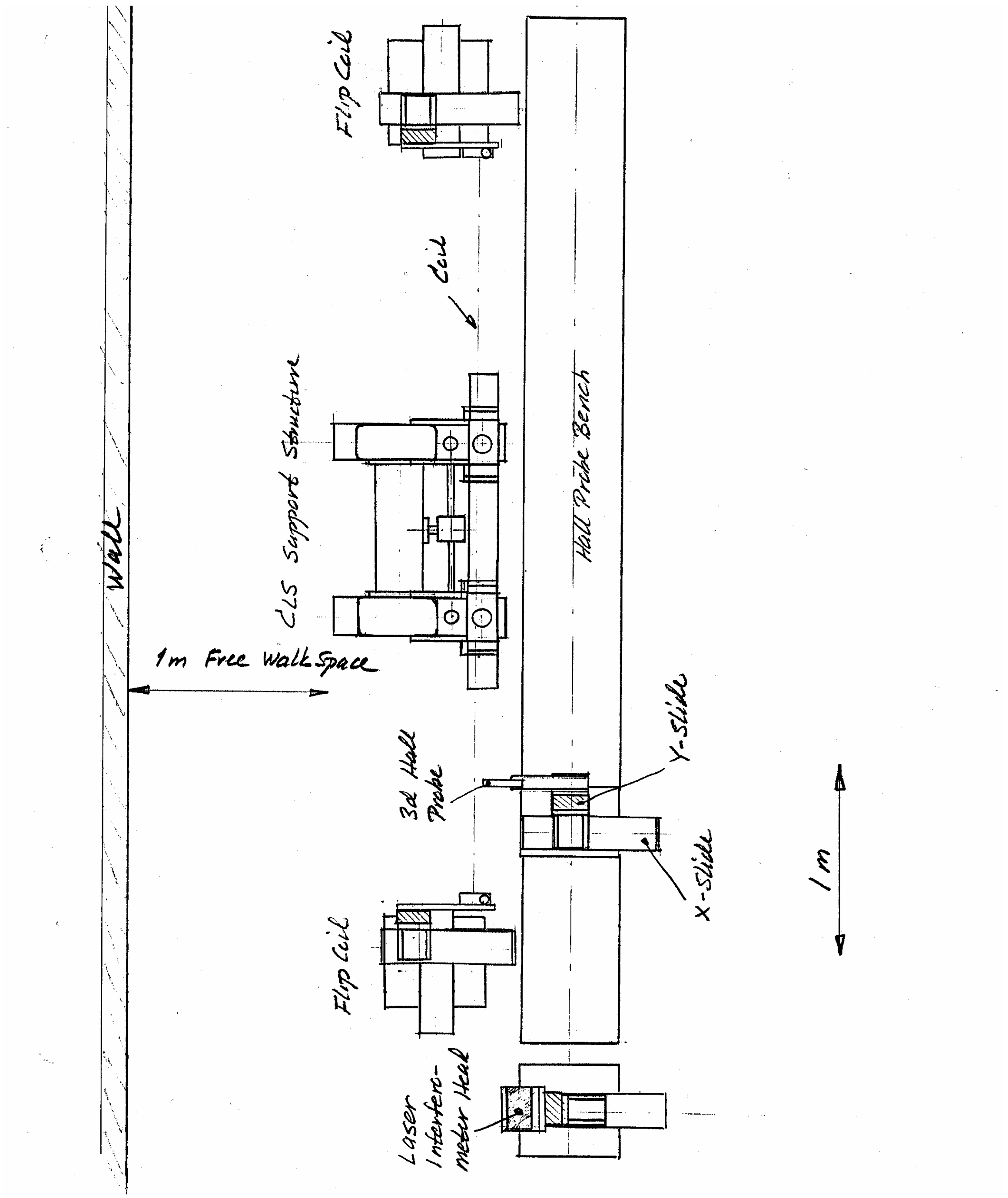

Figure 1. Relative positions of the Hall probe bench, the flip coil bench, the insertion device support and the laser interferometer support.

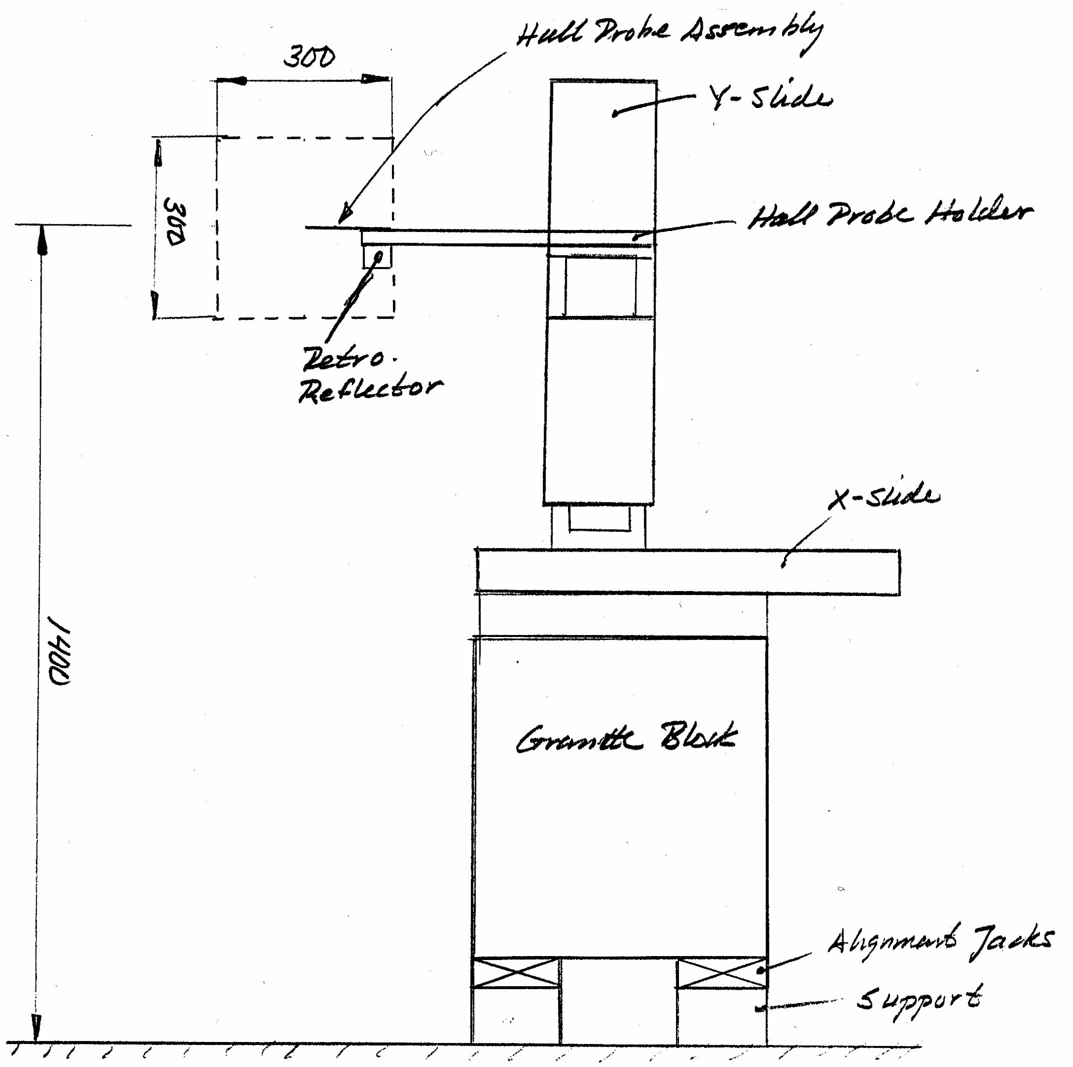

Figure 2. The area covered by the Hall probe bench in the (x,y) plane.

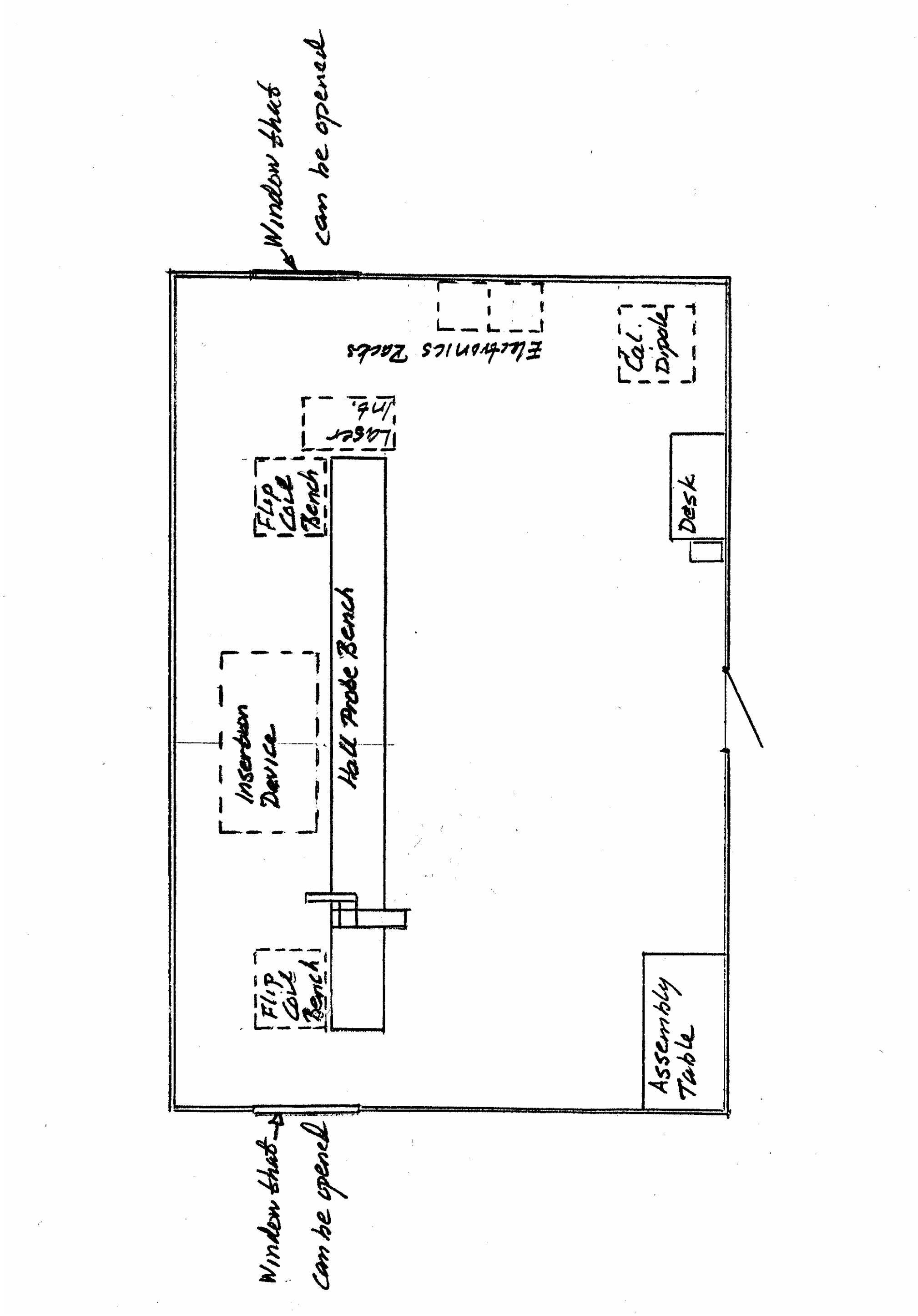

Figure 3. Layout of the Magnet Measurement Facility room.

2.5 VIBRATION AND ACOUSTIC NOISE

The granite block and its support structure should dampen most vibration frequencies that would be transmitted through the cement pad on which it sits.

2.6 SERVICES

The MMF needs to have a controlled environment in order to limit the amount of ferromagnetic dust that can be unintentionally introduced. No special temperature control should be required, provided that the hall in which the MMF is located is controlled to within +/- 1°C, and provided that the variation in temperature in the hall is slow.

However, with the room closed and the electronics running we probably need ventilation to keep the temperature in the room under control. Air filters are needed to keep out dust etc. This is especially important when shimming in-vacuum devices.

The calibration magnet and power supply needs cooling water. A typical laboratory magnet requires a flow of 30-40 l/min.

If the Hall probe bench uses air cushion we also need dry pressurized air.

2.7 OTHER REQUIREMENTS AND CONSTRAINTS

The half of the roof over the Hall probe bench, ID support and the flip coil and laser interferometer pedestals should be removable to allow the overhead crane to be used in manipulating the insertion devices and the pedestals.

3.0 REFERENCES

[1] I. Blomqvist, Canadian Light Source, Saskatoon, SK. CLS Design Note 8.4.43.1, Hall Probe Bench Specification.

[2] I. Blomqvist, Canadian Light Source, Saskatoon, SK. CLS Design Note 6.4.25.1, Specification for Flip Coil Bench Parts.