Requirements For The Construction Of The LCLS Magnetic Measurements Laboratory

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Abstract

A magnetic measurements laboratory will be built at SLAC for the LCLS. This note documents requirements for the construction of the laboratory.

1 Introduction

The LCLS will require very demanding magnetic measurements. At present, SLAC does not have a magnetic measurements laboratory capable of performing the LCLS measurements. Therefore, a new magnetic measurement facility will be built at SLAC. Final tuning of the undulators and all fiducializations will be done right before installation. Having the facility at SLAC also allows rapid checks of any components which are not operating properly. In addition, periodic checks of components can be made to look for ageing. This note gives specifications for constructing the new laboratory so that all magnetic measurement accuracy requirements can be met.

2 Contents Of The Laboratory

The laboratory must perform several test functions. The LCLS undulators must be tuned and they must be fiducialized. The LCLS quadrupoles must be measured and fiducialized. (The LCLS correctors can probably be measured in our conventional magnetic measurements laboratory.) In addition to the LCLS production measurements, we would like to be able to measure undulators in general in the new laboratory, whether they are for future LCLS work or for related projects such as the SPPS.

Because of the different functions the laboratory must perform, it must contain several test areas. To aid in visualizing the test areas, a possible layout of the laboratory is shown in figure 1. This figure is meant to assist in determining the requirements for the laboratory and is not a detailed proposal for the layout of the laboratory. In the bottom test area of the figure, the undulators will be fiducialized. This will require a large coordinate measuring machine. Near the coordinate measuring machine, we will measure and fiducialize the LCLS quadrupoles. This will be done on the granite tables in the figure. We will move the quadrupole fiducialization stand onto the large coordinate measuring machine to do the fiducialization. Moving up the figure, past the wall, there is a large lab where we will tune the LCLS undulators. This requires a specialized test stand set up specifically for the LCLS undulator geometry. During production measurements, no alterations to the test stand can be permitted. Near the LCLS test stand, we would like to include a general purpose undulator measurement stand. Its purpose is to test future undulators of various sizes for the LCLS and other SLAC projects such as the SPPS and SPEAR III. This test stand can be configured to meet the needs of each individual job. Near the general purpose test stand, we include a storage area for new LCLS undulators so they can come to thermal equilibrium at the temperature of the lab. At the top of the figure, we include an air lock which also gives another storage space for undulators entering and leaving the lab. We use this double door system because of the extreme temperature stability requirements of the lab as will be discussed below. The lab is accessed through two double doors. The two large doors are to bring in large objects. Space must be made available outside the lab for access.

Undulator Fiducialization The undulator fiducialization area will contain a large coordinate measuring machine. A desk with a computer and a work area must be nearby. This area will also require storage cabinets. The temperature in this part of the lab must be constant or the calibration of the coordinate measuring machine will change. We wish to change the temperature in the undulator tuning area, however, to test temperature effects on the undulators. This necessitates housing the coordinate measuring machine in its own room. This room will then need its own overhead crane to place and remove the undulators from the coordinate measuring machine. The room will require a large door and some type of wagon to bring in the undulators.

Quadrupole Fiducialization The quadrupoles for the LCLS have very tight alignment requirements. A coordinate measuring machine will be required for their fiducialization. In view of the cost of these machines, it is likely that the large coordinate measuring machine used for the undulators will also need to be used for the quadrupoles. In this case, the quadrupole fiducialization area must be next to the coordinate measuring machine. The fiducialization test stand will need to be moveable, so that it can be placed on the coordinate measuring machine and removed. The system will require a rack of electronics, a work area, and a computer.

Quadrupole Field Measurements Next to the quadrupole fiducialization area will be another test stand where we measure the strength and field quality of the quadrupoles. This system will also require a rack of electronics, a work area, and a computer.

Undulator Tuning The LCLS undulator tuning area will contain a large granite test bench, roughly 7 meters long and one meter wide. A special cradle with precision movers will hold the undulator next to the granite table. Near the granite table will be a large electromagnet used for calibrating Hall probes. Near the electromagnet (or possibly outside the lab for thermal reasons) we will require a high current power supply. The granite table will require at least two electronics racks, several tables, storage cabinets, and a work area with one or more computers. The calibration area will require several electronics racks and a desk with a computer. This area of the lab will require an indoor overhead crane to place and remove the undulators from the test stand. The temperature in this part of the lab will need to be adjustable and stable once the set point is reached.

Undulator Test Stand The general purpose undulator test stand will have about the same space requirements as the LCLS test stand. It will also have a granite test bench and require a rack of electronics and a work area with a computer. The Hall probe calibration system can be shared.

3 Ambient Condition Requirements

The most stringent ambient condition requirements for the laboratory come from the undulator tuning requirements. The most important ambient conditions for undulator tuning are temperature accuracy and temperature stability. The LCLS undulators will have some temperature compensation built in. It will be necessary, however, to test temperature compensation schemes. This requires temperature stability in the laboratory good enough to test an uncompensated undulator. The requirements discussed below are based on testing an uncompensated undulator.

The undulator strength is very sensitive to temperature. Typically the remanence of NdFeB magnets changes by about 0.1% per degree Celsius[1]. The on-axis undulator field strength of uncompensated LCLS undulators is expected to change by about 0.054% per degree Celsius[2]. We must measure the undulator strength to 0.015%[3]. Thus, a temperature deviation of $\pm 0.28°$C uses up our entire 0.015% measurement accuracy budget. In order not to use our entire measurement accuracy budget on temperature variations, we require the laboratory temperature to remain stable to $\pm 0.1°$C. The nominal operating temperature of the undulators is expected to be between 20°C and 25°C. The exact value has not been decided, but we will assume it to be 20°C for this discussion. The laboratory must meet two conditions in order to meet the measurement accuracy requirements. We must be able to set the temperature of the laboratory to the operating temperature of the undulators, 20°C, to within $\pm 0.1°$C for every undulator. The laboratory must remain stable at this temperature to $\pm 0.1°$C for the entire length of the measurements on an undulator. All undulators must be measured at the same temperature so the system must be capable of maintaining $20° \pm 0.1°$C for years at a time.

When specifying that the temperature of the laboratory must be $20° \pm 0.1°$C, we are referring to the average temperature of the laboratory over some period of time. What is important is that the undulator maintains this temperature. The undulator has heat capacity and finite thermal conductivity, so the undulator temperature changes at a slower rate than the air temperature. This is illustrated in figure 2. Note that a temperature fluctuation of around 0.3°C for about one hour is barely seen by the undulator. In order to take this into account, we specify that the climate control system must be able to maintain the average temperature of the laboratory

[1] LCLS Conceptual Design Report, SLAC-R-593.
[2] *ibid.*
[3] *ibid.*

at $20° \pm 0.1°C$ for years at a time, and that fluctuations in the air temperature must be below $\pm 0.3°C$ and for less than one hour. We take the definition of "average" temperature to be the temperature averaged over 2 hours.

In addition to building the lab to accommodate the chosen operating temperature of the undulators, it is necessary to test the performance of the undulators at different temperatures. In order to do this, we must be able to set the temperature to a desired value and have it remain stable on average at the set value to within $\pm 0.1°C$. In order to test the temperature dependence of an undulator, we need to be able to vary the temperature over a 5°C temperature range. The average temperature must remain constant at the desired set value to within 0.1°C. Because of this, it will be necessary to be able to set the average temperature of the lab to any value between 20°C and 25°C. The average temperature must stay at the set point to within $\pm 0.1°C$. Fluctuations in the air temperature must be below $\pm 0.3°C$ and for less than one hour.

As previously noted, the undulators will be fiducialized on a coordinate measuring machine. Such machines are sensitive to temperature changes. To preserve the machine's calibration, the temperature must remain constant to 0.5°C. The relative humidity must also remain constant. Since the temperature in the undulator tuning area must be adjustable and the temperature of the coordinate measuring machine cannot vary, this necessitates a separate room in the laboratory for the coordinate measuring machine. The temperature in the room must be selectable between 20°C and 25°C and must vary by less than $\pm 0.5°C$ from the set point. If the temperature goes much beyond this limit, the coordinate measuring machine requires a costly re-calibration. This warrants having a backup climate control system. For example, if the climate control system uses SLAC LCW for heat exchange, the coordinate measuring machine room might have a standby general consumer air conditioner for times when the LCW system is under repair.

The laboratory as a whole will have items which are sensitive to humidity, such as precision granite surfaces. Because of this, we must limit humidity variations in the laboratory. We require the relative humidity in the laboratory to stay between 40% and 50%. From experience with the climate control system in the SLAC Metrology Laboratory, we have learned that it is important to interlock the humidity control system with the air conditioning system. Should the air conditioning system fail, the interlock will turn off the heater in the humidity control system, preventing the room from being overheated. The interlock at the same time will activate the back-up air conditioner.

The speed of the air from the climate control system can also cause problems. Some devices such as Hall probes and stretched wires must be positioned accurately at the micron level and high air speeds could cause them to vibrate. We require air speeds to be below 0.25 m/s and the flow to be laminar.

The requirements listed here are the most severe. The quadrupole fiducialization will not be impacted if the above ambient conditions are met.

The air lock at the entrance to the lab helps maintain temperature stability in the lab. The temperature in the air lock should remain constant to $\pm 1°C$. Thus, the temperature in the air lock must be selectable between 20°C and 25°C and must vary by less than $\pm 1°C$ from the set point.

In addition to temperature and humidity, several other ambient conditions can affect the measurements. Vibrations are an issue for undulator tuning. Ideally, each magnetic field measurement should be accurate to better than 1.5×10^{-4} of the peak field in order to measure the effective undulator field to the required accuracy of 1.5×10^{-4}. The magnetic field in the undulator varies very rapidly. Errors of $0.5\mu m$ in the measurement probe position cause relative field errors of up to 10^{-4} of the peak field[4]. Because of this, and in order not to use our entire error budget on vibrations, we impose two requirements on the maximum vibration of the laboratory. We require long term, continuous vibrations of the ground in the measurement lab to be less than $0.5\mu m$. The measurements can tolerate short, isolated vibrations larger than this, but the exact amount is hard to quantify. Based on experts' recommendations[5], we require short vibrations to occur less than once every 20 seconds, to last less than 0.5 second, and to have an amplitude of less than $3.0\mu m$. When discussing vibration, what is of utmost importance is the relative position of the undulator to the test stand. The undulator and the test stand should to be tied together mechanically, such as being on the same slab of concrete, so they don't move relative to each other. Both the undulator and measurement bench mounts must be massive so that the ground vibrations are not amplified through a lever arm.

The Earth's magnetic field is important for undulator tuning. Fields at the level of the Earth's field cause significant deflections of the electron beam trajectory. The vertical component of the Earth's field will have the same orientation no matter how the undulator is placed. The horizontal field, however, changes relative to the undulator as the undulator is placed in different orientations, i.e. north-south vs. east-west. The magnetic poles of the undulator will provide some shielding of the horizontal field in the gap, but the exact effect is unknown. In planning the layout of the laboratory, it is possible to choose the orientation of the measurement bench. We thus require that the undulator be measured in the lab in the same orientation that it will have in operation. This is illustrated in figure 3. At present, the orientation of the undulators in the LCLS has not been finalized. We know they will be oriented along the linac, but the side of the back of the "C" has not been finalized. Thus, we require the granite bench to be parallel to the linac, and we require the flexibility to put the undulator supports on either side of the granite bench. A further requirement is that no other man-made magnetic fields at or above the level of the Earth's field can be present.

4 Facilities Requirements

Each test area will require power for instruments, motors, computers, etc. The coordinate measuring machine will require slightly under 20 A[6]. In a new laboratory we should be conservative and give each test area at least two 20 Amp circuit breakers

[4] Assuming a sinusoidal field variation in the z direction along the undulator, $\left(\frac{\Delta B}{B}\right)_{\max} = \frac{2\pi}{\lambda_u}\Delta z$. For $\lambda_u = 0.03$m and $\left(\frac{\Delta B}{B}\right)_{\max} = 10^{-4}$, $\Delta z = 0.5 \times 10^{-6}$m.

[5] Isaac Vasserman, Argonne National Laboratory, and Joachim Pflueger, DESY.

[6] Based on specifications for the Zeiss model Prismo 12/42/10 Super ACC coordinate measuring machine.

for 120 V power. We thus require at least eight 20 A, 120 V circuits. In addition, the calibration magnet power supply will require 480 V, 3 phase, and 40 A[7]. This should be the only device requiring 480 V. No devices are presently planned that require 208 V, however, we should have the capability to add one 208 V, 3 phase, 50 A circuit for unforeseen devices. The overhead crane will require power, as will lighting. These requirements should be counted separately.

The calibration magnet will require low conductivity water. We should plan on 130 psi supply water pressure, 15 psi return pressure, and 10 gallon per minute flow.

Both the two granite benches for the undulators and the coordinate measuring machine will require compressed air. Each granite test bench will require filtered air with at least 90 psi pressure and a flow rate of 0.44 cfm[8]. The coordinate measuring machine requires 87 to 145 psi, filtered air at a flow rate of 0.7 cfm[9].

The laboratory will require two overhead cranes, one for the undulator tuning area, and one for the coordinate measuring machine area. The undulator sections are expected to weigh 1.2 tons. Two 2 ton overhead cranes will be sufficient. We must realize, however, that these cranes can not pick up a typical undulator. A typical undulator at SLAC weighs around 7 tons. A rigging crew will need to bring in such an undulator on rollers. The air lock will also require a small crane, such as a jib crane, to lift undulators off storage racks and onto carts to bring them into the laboratory.

5 Space Requirements

In order to estimate the space requirements for the laboratory, the following algorithm was used. We started with the contents of the laboratory discussed above. We then required at least 5 feet of clear space around each large test stand. Each work area was given a table 3 feet by 5 feet, with 5 feet free for the operator. Each cabinet was given a width of 5 feet and a depth of 3 feet, with 5 feet of clearance in front to permit easy access. The granite tables for the quadrupoles were 4 feet by 6 feet, with 5 feet of free space to work. In addition, a clear walkway, at least 6 feet wide was made available through the length of the lab to handle the undulators. The sample lab layout in figure 1 resulted. The overall dimensions of the laboratory turned out to be 78 feet by 36 feet. The coordinate measuring machine room was 23 feet by 36 feet. The undulator tuning room was 45 feet by 36 feet. The air lock and storage area was 10 feet by 36 feet. A loading area in front of the air lock door of 20 feet by 20 feet is necessary. This is the typical size lab that should be built.

The height of the laboratory is determined by the height of the coordinate measuring machine. The coordinate measuring machine will be around 12 feet high and will need an additional 0.7 feet clearance above it[10]. We then require that the overhead crane in the lab be high enough so that its hook can reach 12.7 feet, above the floor.

[7] Based on model 3474 laboratory electromagnet from GMW Associates.

[8] Based on a 4 meter granite test bench specification from Argonne National Laboratory.

[9] Based on specifications for the Zeiss model Prismo 12/42/10 Super ACC coordinate measuring machine.

[10] *ibid.*

6 Conclusion

In order to meet all the measurement requirements, the LCLS magnetic measurements lab should be built according to the following specifications.

Summary of Ambient Condition Requirements:

1. The laboratory must be divided into two rooms. In the undulator tuning room the average temperature must be selectable between 20°C and 25°C. We take average temperature to be the temperature averaged over 2 hours. The average temperature must go to the desired set point to ±0.1°C. The average temperature must be stable at the desired set point to ±0.1°C. Fluctuations in the air temperature must be below ±0.3°C and for less than one hour. In the room containing the coordinate measuring machine the temperature must be selectable between 20°C and 25°C and must vary from the set point by less than ±0.5°C. The air lock temperature must be selectable between 20°C and 25°C and must vary from the set point by less than ±1°C. The relative humidity in all parts of the laboratory must stay between 40% and 50%. Air speeds must be below 0.25 m/s and the air flow must be laminar.

2. Continuous vibrations in the laboratory must have an amplitude below $0.5\mu m$. Short vibrations must occur less than once every 20 seconds, last less than 0.5 second, and have an amplitude less than $3.0\mu m$.

3. The undulator tuning test stand must be placed so the undulator has the same orientation as it will have when installed. Stray, man-made magnetic fields must be below 0.2 Gauss.

Summary of Facilities Requirements:

1. The electrical power requirements for the equipment inside the laboratory are at least 8 circuits of 20 A, 120 V power; one circuit of 50 A, 208 V, 3 phase power; and one circuit of 40 A, 480 V, 3 phase power. This does not include the overhead crane or the lights.

2. The lab will require low conductivity water with at least 130 psi supply pressure and at most 15 psi return pressure. The maximum flow rate will be 10 gpm.

3. The lab will require compressed air. The air must be filtered and clean. The pressure must be somewhere between 90 and 145 psi. The flow rate will be at most 2 cfm.

4. The laboratory will require two 2 ton overhead cranes, one for the coordinate measuring machine area and one for the undulator tuning area.

Summary of Space Requirements:

1. The size of the laboratory should be at least 78 feet by 36 feet. A clear space of 20 feet by 20 feet must be left at the entrance to the laboratory for undulator loading and unloading.

2. The laboratory must be high enough so that the overhead crane can reach 12.7 feet above the floor.

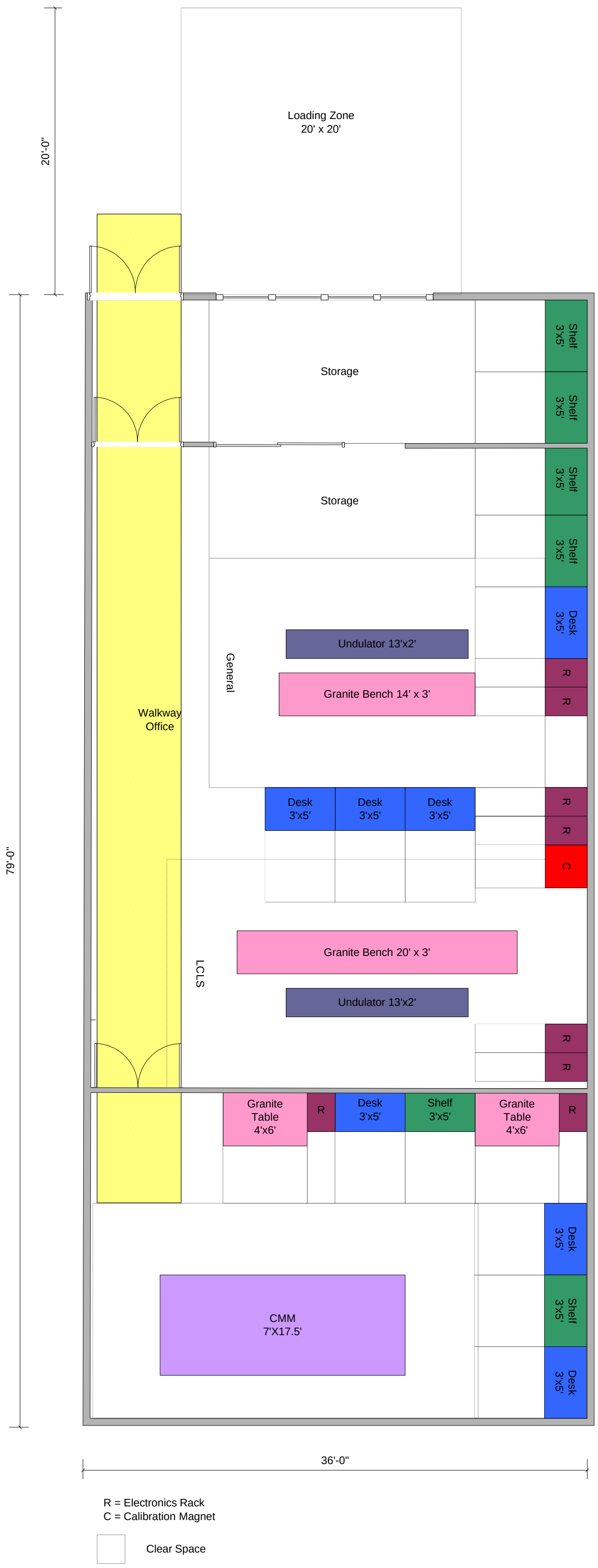

Figure 1: Possible layout of the LCLS magnetic measurement laboratory.

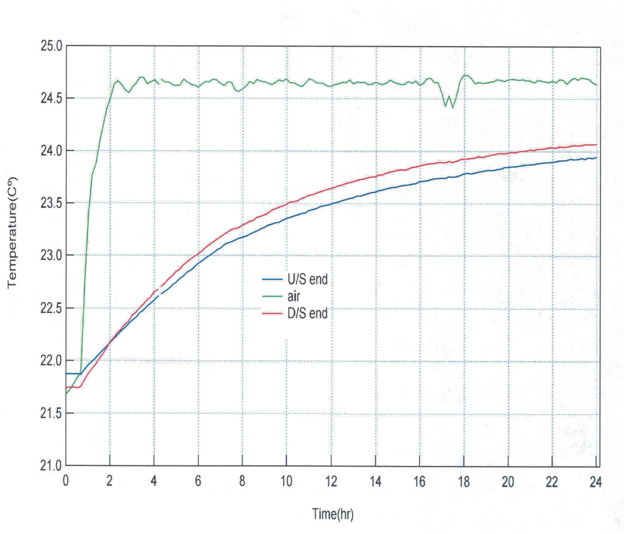

Figure 2: The undulator temperature changes at a slower rate than the air temperature. Rapid fluctuations in the air temperature do not affect the undulator temperature. This plot is courtesy of Isaac Vasserman at Argonne National Laboratory. The undulator is the first LCLS prototype.

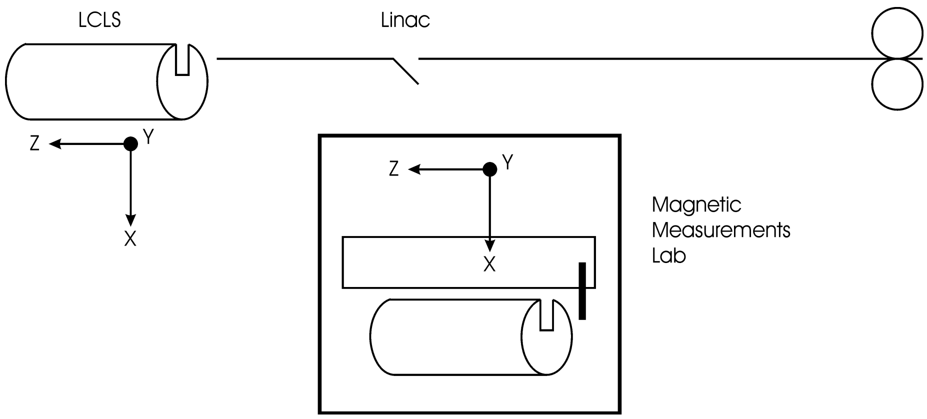

Figure 3: The undulators must be measured with the same orientation in the magnetic measurements lab as when used in the LCLS.