

9 GLOBAL SUPPORT SYSTEMS

9.1 Survey and Alignment

9.1.1 Scope

This section outlines the survey and alignment requirements and the technology and tools for achieving the NSLS-II equipment positioning goals. The required alignment tolerances are defined primarily by the physics requirements of the accelerator. At this stage of preliminary design, these tolerances are not known with high precision; however, similar parameters are available for other light sources of equivalent dimension. Our preliminary design of the survey and alignment system is based on the assumption that the tolerance requirements for NSLS-II will be similar to those of the APS, for example. An assessment will be performed, however, during the preliminary engineering design phase to identify any extraordinary position requirements of the accelerator systems, and the survey and alignment system will be modified as necessary to meet them. State-of-the-art equipment and methods will be employed, but no new technology will need to be developed to meet the NSLS-II alignment requirements.

Survey and alignment provides the foundation for positioning the beam-guiding magnet structures in all 6 degrees of freedom within the required tolerances. Although the tools and instrumentation available for this task have changed over the years and faster and more accurate measurements are possible, only limited control of the environmental conditions is possible. This ultimately sets an upper limit for the achievable measurement and subsequent control network accuracy.

The scope of the survey and alignment work for NSLS-II includes the following:

- Provision of engineering staff to review the design of components having stringent alignment requirements. Engineering staff trained in state-of-the-art methods, software, and systems will be required to ensure that component designs are consistent with the survey and alignment systems that will be used to obtain the anticipated tight tolerances needed to achieve the desired emittance levels.
- Specification of alignment tolerances for each piece of equipment, and a determination of how to achieve them within the limitations of available equipment and hardware. Procedures, methods, and equipment will be specified.
- Procurement of alignment equipment, measurement equipment and instruments, targets, monuments, and hardware.
- Technical staff to achieve the precise alignment requirements during fabrication, assembly, and field installation. Technical staff trained in the use and calibration of state-of-the-art instruments and systems will be required.
- Provision of calibration equipment and facilities to maintain survey equipment within calibration tolerances.

9.1.2 Tolerances

The required positioning tolerances are an essential part of the survey and alignment design. Those tolerances dictate the instruments and methods necessary to obtain the positioning goals. Table 9.1.1 provides the required global tolerances, while Table 9.1.2 outlines the relative tolerances for the NSLS-II girder-to-girder positioning. These tolerances represent the most stringent requirements for the storage ring.

Table 9.1.1 NSLS-II Required Global Tolerances.

Global tolerances	± 3 mm
Horizontal positioning	± 3 mm
Vertical positioning	± 3 mm

Table 9.1.2 NSLS-II Girder-to-Girder Positioning Tolerances.

Relative tolerances	Girder to Girder
Horizontal positioning	± 0.15 mm
Vertical positioning	± 0.15 mm
Longitudinal	± 0.50 mm
Roll angle	± 0.5 mrad

9.1.3 Design Philosophy

9.1.3.1 Control Network Design

Depending on the size of the system to be constructed, a primary and secondary control network may be required to achieve these tolerances. NSLS-II covers an area of about one-eighth of a square kilometer with a radius of ~ 124 m and a circumference of ~ 780 m. The NSLS II construction methodology demands that separate tunnel segments be successively available and ready for installation purposes. This requires that each segment be fitted with an independent preliminary control network terminated by a primary monument at each end suitable for less demanding layout work such as the blue-line survey of the major beamline components, girder supports, and photon beamline layout in the front-end sections [9.1.1]. Only after all segments have been measured, processed by least squares, and analyzed will the final control network be ready for the positioning of the girders. Prior to construction, a calculation of the anticipated error propagation of the primary and secondary control network geometry will be needed.

9.1.3.1.1 Primary Control Network

The primary control network spans the entire accelerator facility and ties the accelerator enclosures into one reference system. It consists of a monument, M0, located at the center of the storage ring, a second similar one, M1, located at a convenient location in the infield close to the storage ring enclosure (Figure 9.1.1, left). Other monuments are distributed throughout the storage ring—for instance, at the beginning and end of each separate tunnel segment. The two monuments located in the infield should be very stable. Therefore, they require a deep foundation and a secondary outer shell for temperature stability [9.1.2], as shown in Figure 9.1.1(right). In this case a Kern centering plate is shown that will be changed for a tribrach adaptor system currently widely in use. These monuments can also be used by the construction companies for layout and construction surveys.

The central monument usually defines the origin of the local right-handed coordinate system, while the second infield monument provides the orientation of the control network. The storage ring monuments are accessible through penetrations in the roof wall shielding. One of these should be located near the linac so no additional penetrations for the linac are necessary. Depending on the instrumentation used, all of the primary control points should be inter-visible. The spacing between storage ring penetrations is normally guided by the law of error propagation and should not exceed approximately 250 m.

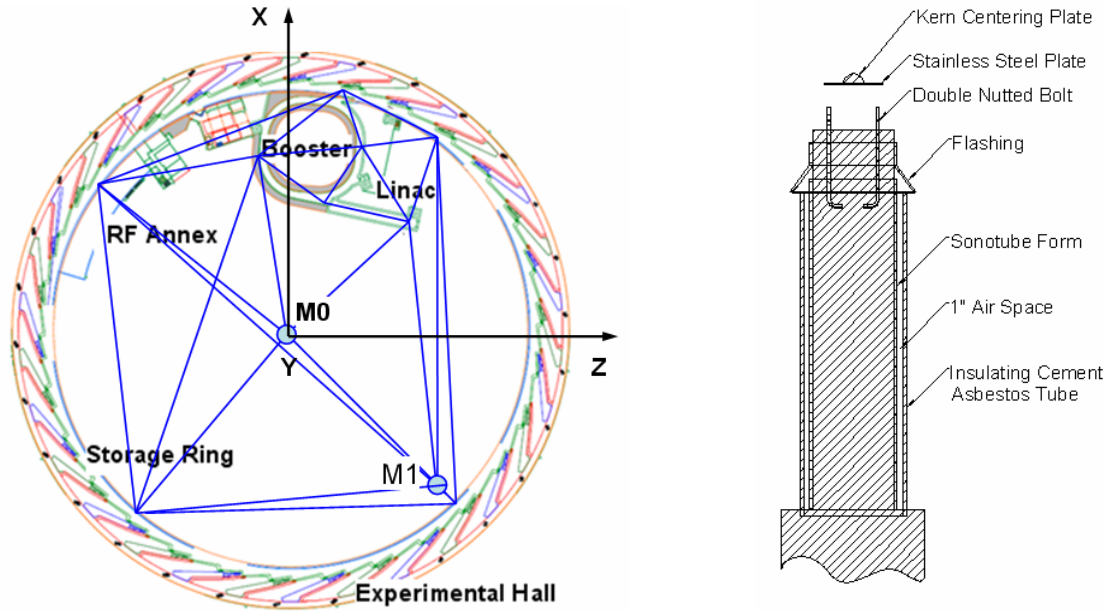


Figure 9.1.1 (Left) primary control network and global coordinate system; (Right) design of the stable monuments.

The primary control network can be measured as a trilateration network only. Current instruments are able to resolve distances to $\pm(0.1 + 0.1D [Km])$ [mm], where D is the length of the measured distance in units of kilometer. This level of accuracy is not attainable with triangulation networks. By using a trilateration network, it should be possible to obtain a control network point accuracy of ± 0.3 mm, similar to what has been achieved at the APS [9.1.3].

An alternative approach to determine the primary control network utilizes GPS observations for all primary control points. If public reference stations are not conveniently available, a local GPS reference station needs to be established at the storage ring center monument [9.1.4]. This base station supports differential GPS and would also be beneficial for the construction survey, as many survey companies have access to GPS and Real Time Kinematic (RTK) positioning technology. It is expected that utilizing DGPS, millimeter accuracies can be obtained. This approach needs to be further evaluated during the preliminary design phase to determine if it meets the requirements.

Both methods of measuring the primary network are highly dependent on the construction sequence and method, as lines of sight either between the monuments or the GPS satellites are required. This task has to be scheduled after the storage ring tunnel has been built but before the experiment hall enclosure is constructed.

9.1.3.1.2 Secondary Control Network

The design of the secondary control network is determined by the layout of the storage ring. If, as in the case of the APS, ratchet doors for each beamline are available, one can extend the secondary control network into the experiment hall (see Figure 9.1.2), providing a more stable control network design and the means to perform alignment work on beamlines while the machine is operational. The present preliminary design of NSLS-II envisions the installation of similar ratchet doors. Therefore, the secondary control network in the storage ring enclosure will be extended to the experiment hall.

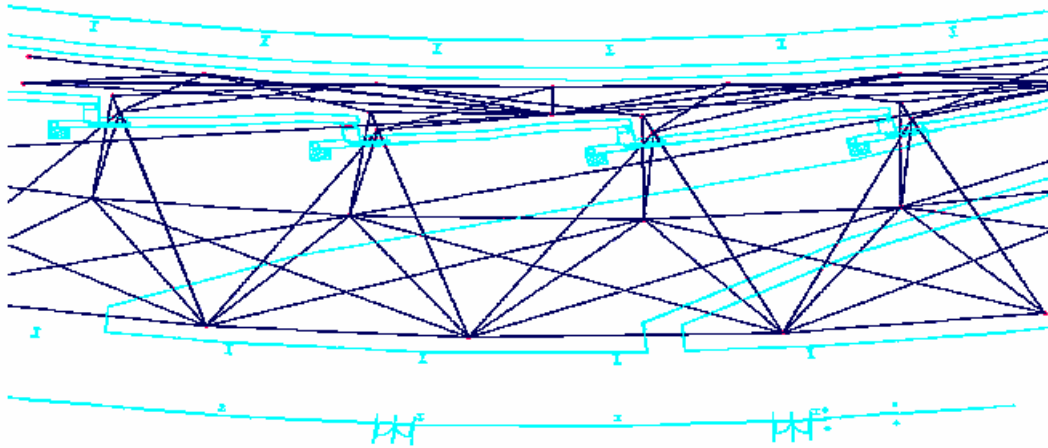


Figure 9.1.2 A secondary control network

Extending the secondary network to the experiment hall floor will benefit the layout work for the individual beamlines while the accelerator is in the commissioning phase. Each BM and ID beamline should receive two control points strategically located at an offset from the ideal beamlines and visible from the storage ring through the ratchet wall openings. Prior to the installation of the ratchet wall collimators the tie between the beamline layout in the front end and the experiment hall has to be established using optical tooling instruments. The marking of the front ends needs to be done while no girders have been placed in the tunnel and is best performed while the quadrupole and girder support locations are being laid out. Otherwise, line-of-sight to these areas will be very restricted and the markings may no longer be possible. The layout of the front-end locations is very important, as it provides the only means to extend the alignment control through the beam ports to the experiment floor.

Laser tracker instruments will be used for measuring the secondary control network, followed by a least squares analysis of the data to produce the final control points prior to setting out the machine components.

Current laser tracker systems obtain point accuracy on the order of ± 0.05 mm in a spherical volume with a radius of 10 m around the instrument measurement head. For measuring the secondary control network with laser trackers, the primary control points are included in the measurement process and are part of the data analysis. This constrains the error propagation of the secondary control network to the level achieved by the primary reference network. The primary and segments of the secondary networks must be established, measured, and analyzed before accelerator equipment can be installed. However, sufficient time has to elapse for the concrete to cure before the control network monuments can be considered stable. Installing the floor monuments of the storage ring will necessitate core drilling to recess the target fixtures. The wall-mounted targets will be attached to concrete anchors with threaded inserts.

The secondary storage ring tunnel network should consist of at least four survey monuments located in cross sections of the storage ring spaced 10 m apart, as shown in Figure 9.1.3. An *a priori* error analysis needs to be performed to estimate the optimum locations for these targets and the expected point accuracy. The envisioned tunnel network creates a compact box structure to obtain a stable network geometry. Control points on the infield side of the tunnel are usually always accessible. The control points opposite the aisle should be located such that they will be visible after the girders have been positioned. The floor monuments are measured using common geometric leveling procedures to an accuracy of ± 0.1 mm or better. This

information, in conjunction with the laser tracker measurements after proper analysis of the redundant data, provides the 3D control network that is used to place the accelerator components. An estimated accuracy of ± 0.3 mm should be achievable for the secondary control network.

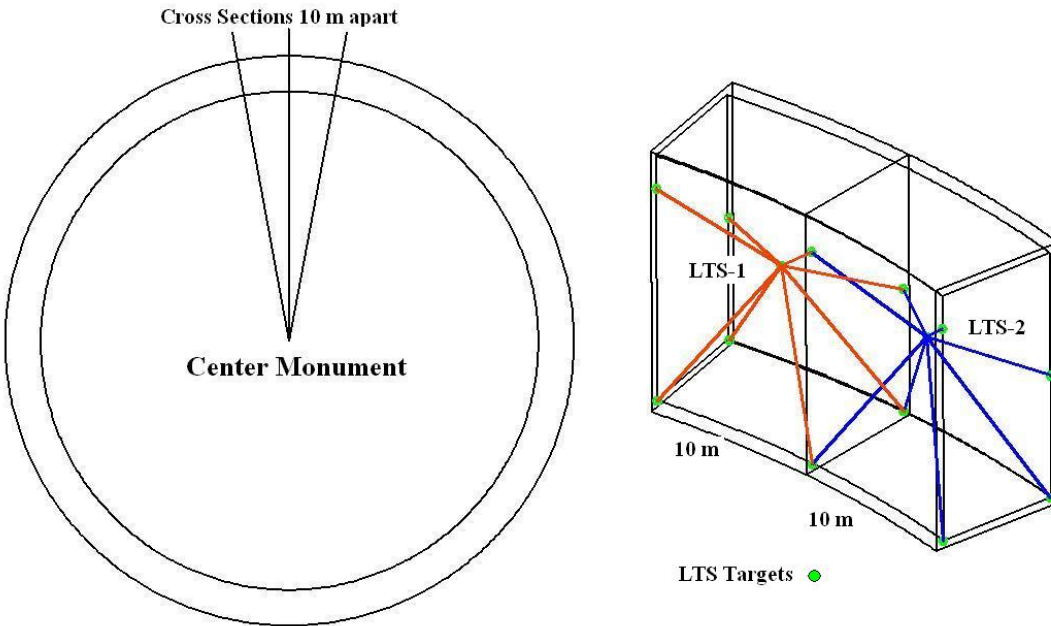


Figure 9.1.3 Sketch of a possible network design.

A variety of monuments for 1.5 inch Spherical Mounted Retro-reflectors are commercially available and can be mounted at the predetermined locations, as shown in Figure 9.1.4. This type of SMR and its accompanying receptors will be used for all survey and alignment work at NSLS-II, where possible.



Figure 9.1.4 Laser tracker 1.5 inch sphere mount.

For both the primary and secondary control network, error propagation calculations will be required before the realization of the reference network. This step provides information about the network density, optimal geometry, and minimum required measurement redundancy without diminishing the point accuracy of the control networks.

9.1.3.2 Elevation Control Network

Similar to the primary and secondary position control networks described in the previous section, we will establish primary and secondary elevation networks that are measured using common geometric level methods employing digital level instruments of proper accuracy.

Most survey instruments are referenced to local gravity. In particular, the leveling process measures elevation differences between two points with respect to the equipotential surface of the geoid. This leads to differences between a local planar system in which the accelerator is constructed and the curved geodetic reference system.

At the APS, all accelerators are located in a plane tangential to a best-fitting osculating sphere at the latitude of the center monument. The difference between this sphere and the tangential plane is on the order of 2.3 mm at 175 m from the center monument, the location of the storage ring. GEONET, the software used by APS to reduce these measurements to the reference sphere, takes local deviations into account and adjusts accordingly. In the case of NSLS-II, this may not be an issue, as the booster compared to the APS is small in size and located close to the storage ring resulting in negligible small corrections, that if necessary can be taken care of in the transfer line between the booster and storage ring injection region. This issue will be evaluated during the preliminary network analysis.

At the NSLS II components will be placed and rough-aligned first, with the components that are farthest from the tunnel entrances placed first. Care must be taken to maintain line-of-sight. To accomplish this, 3D computer graphic modeling will be used. After the heavier components are placed and aligned roughly, fine alignment will proceed using laser tracker and optical level instruments. Some settling of equipment and facilities is anticipated, and it is expected that the alignment adjustment will require checking several times during set-up, commissioning, and initial operation. Therefore, alignment equipment and expertise will have to be maintained in a constant state of readiness.

In any case, for a project the size of NSLS-II with its required high positioning tolerances, measurements for determining elevations and positions will be two distinct and separate operations. Each step requires specialty equipment designed for that purpose. Even if the existing laser trackers provide 3D point information, it is necessary to supplement the vertical information with elevation measurements derived from optical level instruments for increased accuracy.

9.1.3.3 The Lattice

In order to obtain congruence between the survey network and the lattice layout provided by the machine physicists, the datum of both of these systems must be the same. The six parameters (x, y, z, yaw, pitch, and roll) provided by the lattice for each beam component must be transferred to the Survey group and will be stored in a database that is used for all calculations to set the girders and other accelerator components. The database also contains the fiducial information of each component that needs to be placed. GEONET, a software analysis program originally developed at SLAC for this purpose and developed further at ANL and SLAC, performs these calculations and can be used at NSLS-II. However, commercial software that performs similar functions needs to be evaluated prior to starting the project and some software may need to be developed in house.

9.1.3.4 Smoothing

The initial positioning using the reference coordinate system can only be as good as the achieved network accuracy. This accuracy represents an upper limit. However, due to inherent target and instrument errors as well as environmental effects, this limit is not achievable and the actual positioning tolerance in the global system will be less than the obtained control network accuracy. Therefore a smoothing step is required.

For this part of the process, the control network is abandoned and only the local relation between adjacent girders is measured and verified. Instruments with sufficient accuracy, such as laser trackers or special offset measurement devices, can be used for this step. In particular, a comparison between the as-built and the ideal location will provide information about the relative girder position. The girder and magnet fiducial markers will be used in this step. As shown in Table 9.1.2, the girder-to-girder tolerances are relaxed in comparison to

the magnet-to-magnet requirements shown in Table 9.1.3. Nevertheless, during the fiducialization process great care has to be taken to obtain the best possible references.

Table 9.1.3 Magnet-to-Magnet Positioning Tolerances.

Relative Tolerances	Magnet-to-Magnet
Horizontal positioning	± 0.03 mm
Vertical positioning	± 0.03 mm
Roll angle	± 0.2 mrad

9.1.3.5 Fiducialization

During the fiducialization process, reference markers are determined with respect to the magnetic axis of the device. These markers are accessible after the magnet has been assembled on a girder and the vacuum chamber has been inserted. At that time, direct access to the magnetic axis is no longer possible and all positioning is performed with respect to these fiducials. Any positioning error during the fiducialization step can only be uncovered after the machine startup, with beam-based alignment methods. Unlike most of the other steps described here, this step does not provide measurement redundancy unless independent repeat measurements are performed.

For components requiring less accurate positioning, referencing to the mechanical axis may suffice. However, for the NSLS-II, the magnet-to-magnet positioning tolerances, shown in Table 9.1.3, are exceedingly stringent; therefore, a combination of magnetic and dimensional measurements is required.

Usually, rotating coils or stretched wires are used to establish the beam axis. Once the optimum position of the device is found, the information is transferred from the beam axis to the outside reference markers. This is done for each of the magnets prior to the assembly on a girder. The fiducial information is used in the assembly process. The transfer of the position information from the magnetic axis to the reference point can be performed with a 25–50 μm accuracy, depending on the method used. However, in case of NSLS-II, the accumulation of errors in determining the reference targets, the mechanical assembly of the magnets on the girder, the alignment of the magnets on the girder, and so forth may exceed the required tolerance limits. It is therefore envisioned that all multipoles will be assembled and aligned on a girder using the vibrating wire technique [9.1.5]. In this way, the intermediate steps to obtain fiducial information for each magnet separately are circumvented. After this step, the girder will be considered the smallest unit that needs to be placed in the storage ring tunnel.

The girders need to be fitted with permanently mounted SMR receptacles above each of the support feet on both the inboard and outboard side. This is required because the girder will have more than three support feet for reasons of stability and vibration damping. It is envisioned that laser trackers will be used to perform the coordinate transfer from the wire, via a touch-free probe if necessary, to the girder fiducials that are used to position the girder and to check for local deformations while aligning the girder in the storage ring tunnel. It is important that there be a defined stay-clear area around each of the girder fiducials. In particular, above each fiducial no obstructions are allowed; doing otherwise would prohibit the use of level rods on these markers.

R&D is planned to carefully evaluate this approach for the magnet alignment and fiducialization prior to construction of NSLS-II.

9.1.4 Implementation

Close coordination between the construction efforts and implementation of the control network must be maintained while NSLS-II is being built. It is also imperative that the survey and alignment team be involved

early in the design of the girder and magnet supports and moving systems, because the positioning resolution and performance are directly linked to these devices.

9.1.5 Training

At minimum, operators of survey equipment should have several years of experience in properly handling and operating instruments of that type. Instrument operators will have to work closely with the technicians who will make the required adjustments. In particular, when using laser trackers to provide real-time, online alignment capabilities, Survey and Alignment technicians will apply the required adjustments; these two steps go hand-in-hand. Most laser tracker manufacturers provide onsite training for operating their systems. For the alignment of the front ends and beamlines, optical tooling is required because space is limited. Training in the use of optical tooling instruments is commercially available. All personnel involved with the survey and alignment tasks should have experience and aptitude in the precision alignment of 3D components and hardware.

9.1.6 Component Assembly, Testing, and Calibration

Many of the instruments that are employed for survey and alignment must be tested and calibrated on a regular basis. An alignment and calibration room will be provided for this purpose. This room will be environmentally stable and will have sufficient space for secure storage of all calibration equipment (including a Coordinate Measuring Machine and one or more large surface plates), as well as for the survey instruments themselves. The alignment and calibration room will also have enough additional space to align critical assemblies. Because survey instruments are very delicate, in-house calibration is generally preferred over shipping equipment out to a vendor. Calibration procedures and training are therefore required.

The alignment and calibration room will be large enough for calibration as well as for critical assembly work to be completed in a temperature-stable environment, thus allowing alignment processes to be tested accurately before they are used for the accelerator.

9.1.7 R&D

Two important R&D tasks have been identified. The first is an error analysis of the network configuration, to determine the network layout. It is also important in that step to incorporate the anticipated construction methodology. The second important R&D task determines the magnet measurement process and its effects on the survey and alignment process. If it can be shown that the vibrating wire method can be used to position the magnets on girders, then the girder will become the smallest unit that the survey team has to contend with. However, close interaction will be required between the magnet measurement and survey groups. In particular, the girder fiducialization process needs to be established, because special equipment for the touchless wire pickup may be required.

References

- [9.1.1] H. Friedsam, "The Alignment of the Advanced Photon Source at Argonne National Laboratory," International Workshop on Accelerator Alignment, CERN, Switzerland, 1993.
- [9.1.2] R. Ruland, "Synchrotron Radiation Sources A Primer," World Scientific Publishing ISBN 981-02-1856-7.
- [9.1.3] H. Friedsam, M. Penicka, and S. Zhao, "Status Report on the Survey and Alignment Efforts and Results of the Advanced Photon Source," International Workshop on Accelerator Alignment, KEK, Japan 1995.
- [9.1.4] H. Friedsam, R. Ruland, private communication.
- [9.1.5] Z. Wolf, "A Vibrating Wire System for Quadrupole Fiducialization," SLAC, LCLS-TN-05-11.

9.2 Process Water Systems

9.2.1 Scope

The NSLS-II accelerator and beamline components require a large amount of heat rejection as well as a stringent temperature stability. A number of closed-loop water systems are used that exchange heat with the water from cooling towers and chilled water from the BNL's central plant. The preliminary designs of these closed-loop water systems are described in this section. The description for the cooling tower and chilled water systems can be found in the technical design report for the Conventional Facilities.

9.2.2 Thermal Loads

The major sources of heat generation are identified in Table 9.2.1. When all beamlines are built, the total heat rejection is approximately 7.4 MW. This heat is rejected to closed loop water systems at different inlet water temperatures as shown in column 3.

Table 9.2.1: Major heat sources in the NSLS-II facility and the nominal inlet water temperature for heat rejection. The total heat rejected adds up to 7,425 kW, not including the air-conditioning load for the building.

Heat Source	Heat Rejected (kW)	Inlet Water Temperature (°C)
Linac	100	24.0 ± 0.5
Booster	400	29.5 ± 0.5
Storage ring magnets	1400	29.5 ± 0.1
Absorber system and front ends	700	29.5 ± 0.1
RF system (klystrons)	1400	29.5 ± 0.5
Cryoplant	300	33
Power supplies and equipment	1100	7.2 ± 1.0
Beamlines (x-ray power)	250	
Beamlines (electrical)	1700	7.2 ± 1.0
Vacuum chambers	75	29.5 ± 0.05

9.2.3 Preliminary Designs of the Water Systems

There are three different closed loop water systems: (1) deionized process water systems for the copper components, (2) deionized process water system for the storage ring vacuum chambers, and (3) chilled water system for the heat exchangers of the air-cooled racks of power supplies and electronic. The first two systems are designed to exchange heat mainly with the cooling-tower water, but they can also reject partial heat load to the chilled water system on hot and humid days (wet bulb temperature of > 25 °C).

Each of these three systems are divided into five separate unit in order to keep the pipes, pumps, valves and heat exchangers to reasonable sizes. The reduced system sizes also improve their temperature stability. The pumping stations are housed in 5 mechanical equipment rooms located on the inboard side of the storage

ring (see Figure 9.2.1). Three additional pumping stations for copper systems are provided, 2 in the RF Annex and 1 in the Booster building.

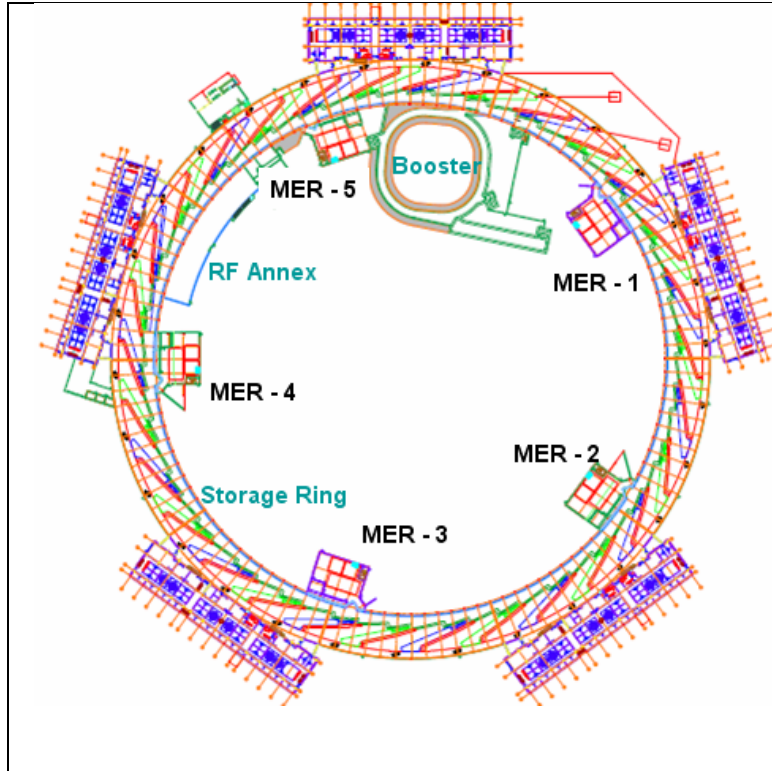


Figure 9.2.1 Mechanical equipment rooms (MERs) for the pumping stations of the closed-loop water systems. Additional pumping stations are installed in the RF Annex and Booster.

The process & instrumentation diagram (PID) for the copper water system is shown in Figure 9.2.1. The pumping station uses two 75 HP, variable frequency drive (VFD), pumps for redundancy and reliable operation. The VFD pumps, besides being energy-efficient, also provide better control over the supply-side flow, pressure and temperature. A slipstream deionizing skid keeps the resistivity and pH of the water in the specified range to minimize copper corrosion (see below).

A portion of the process water exiting from the pumps exchanges heat with the tower water in order to reject heat from magnets, absorbers, and beamline components. If necessary, heat is also exchanged with chilled water for additional cooling on hot and humid days. Mixing valves are used to regulate the water temperature to 85 ± 0.1 °C before it is supplied to the storage ring. Another chilled water heat exchanger is used, as shown in the figure, to bring down the water temperature for the beamlines to 75 ± 0.1 °C.

Each MER supplies process and chilled water to the equipment and components of six cells. The supply and returns pipes are branched out in the middle to serve 3 cells on each side.

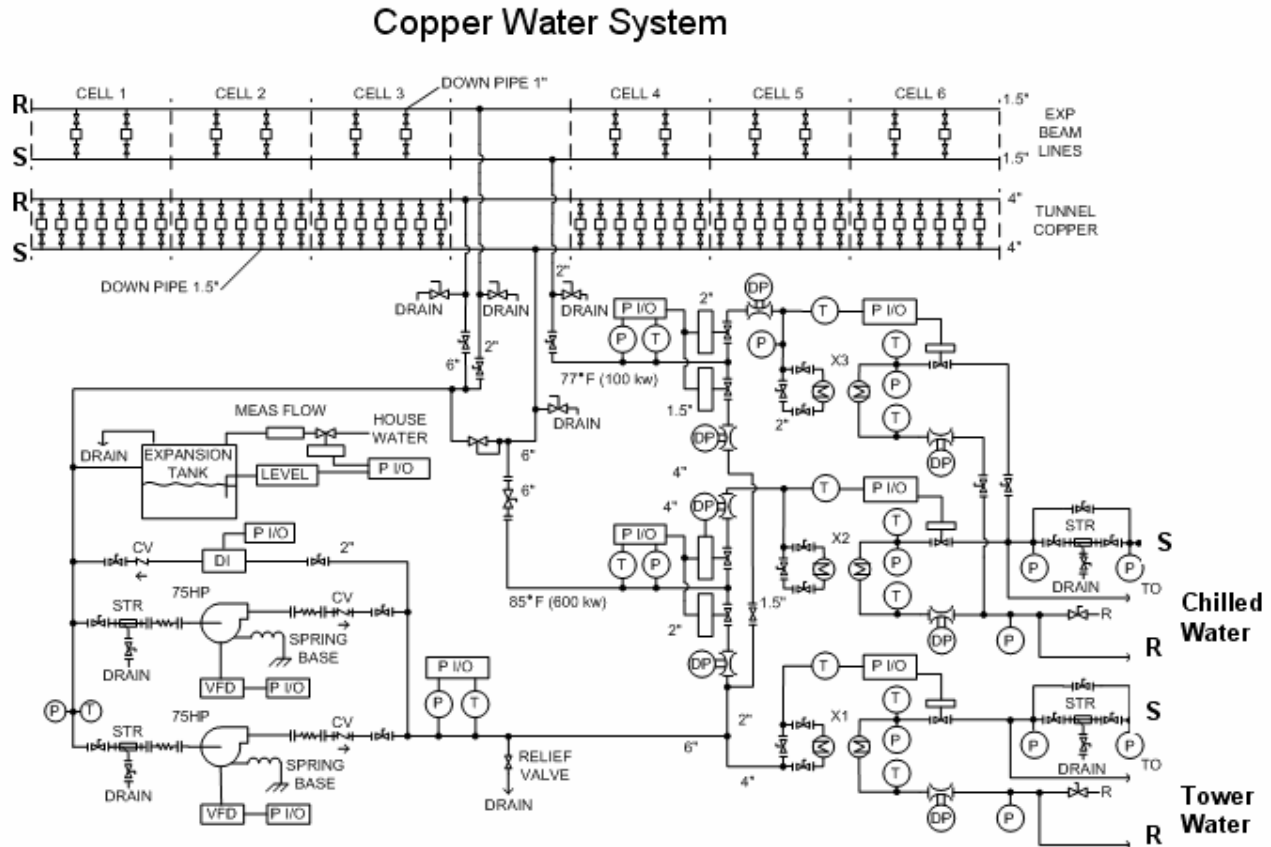


Figure 9.2.2 PID of the pumping station for the copper water system.

A similar but smaller-size pumping station with 10 HP pumps is used for the aluminum water system as shown in Figure 9.2.3. The aluminum water system is also a closed loop system which is completely isolated from the copper components and other water systems to eliminate the possibility of galvanic corrosion. The aluminum chambers of the storage ring do not directly intercept x-rays, but they do intercept x-ray power scattered from the absorbers. Another source of heat is the frictional losses from water flow through the three cooling channels of the chambers. The temperature stability of ± 0.05 °C is specified for the aluminum water system in order to keep the chamber deformations, which affect the BPM locations, to within acceptable limits.

Aluminum Water System

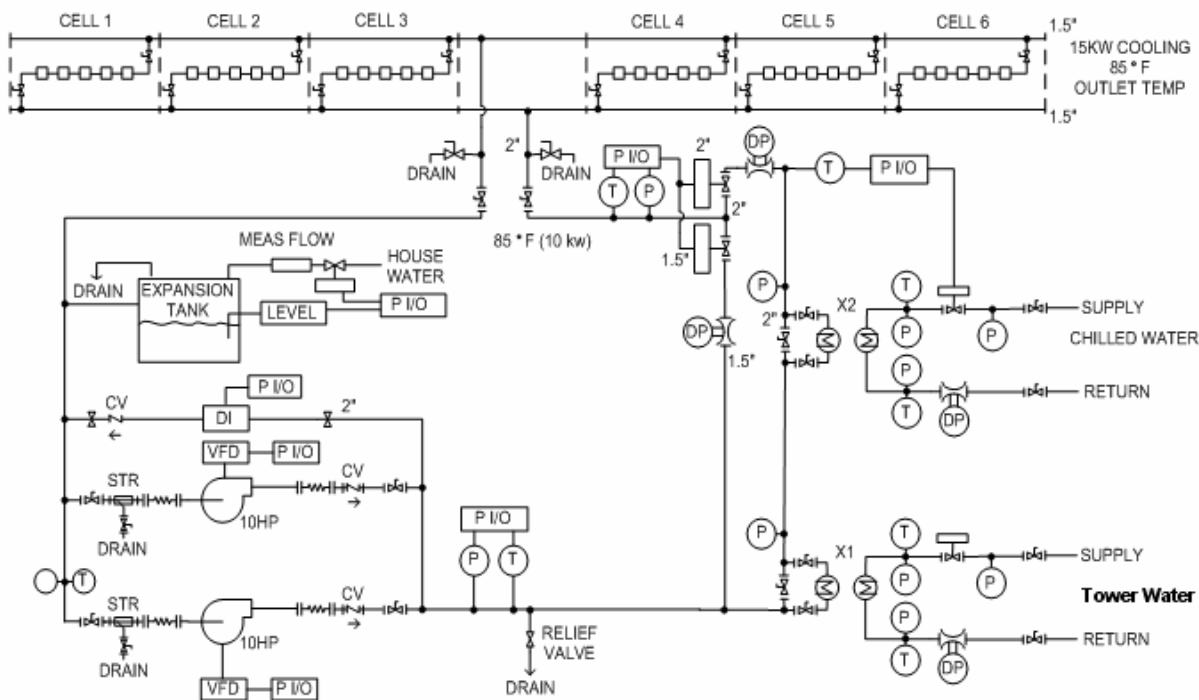


Figure 9.2.3 PID of the pumping station for the aluminum water system.

For the bakeout of aluminum chambers, the present plan is to use NEG strips or kapton heating foils. Bakeout by hot water (as is done at APS) will be considered as a less preferable option because of its complicated design and safety concerns.

The closed-loop chilled water system (not shown) exchanges heat only with the chilled water from central plant. It does not use deionizing skid and requires a moderate temperature stability of only ± 1 °C.

9.2.4 Process Water Quality Control

Copper corrosion in the copper components cooled by deionized water remains a major concern. The main factors that affect the copper corrosion process are: water resistivity, pH, dissolved oxygen and water temperature. An investigation will be made to determine the most appropriate ranges for these parameters. Based on the experience of several accelerator facilities, the following values are selected for the preliminary design:

- Resistivity = 1 M Ω -cm \pm 5%
- pH = 7.5 \pm 0.2%
- Oxygen concentration = 6 ppb \pm 1 ppb
- Water temperature < 40 °C.