

Improved Temperature Regulation of Process Water Systems for the APS Storage Ring

C. Putnam and R. Dortwegt

*Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439, U.S.A.
Phone: (630) 252-5915, Fax: (630) 252-5948
E-mail: ccp@aps.anl.gov*

Abstract

Beam stability and operational reliability of critical mechanical systems are key performance issues for synchrotron accelerators such as the Advanced Photon Source (APS). Stability is influenced by temperature fluctuations of the process water (PW) used for cooling and/or temperature conditioning storage ring (SR) components such as vacuum chambers, magnets, absorbers, etc. Operational reliability is crucial in maintaining facility beam operations and remaining within downtime “budgets.” Water systems for the APS storage ring were originally provided with a distributive control system (DCS) capable of regulation to $\pm 1.0^\circ\text{F}$, as specified by facility design requirements. After several years of operation, a particular mode of component mortality indicated a need for upgrade of the temperature control system. The upgrade that was implemented was chosen for both improved component reliability and temperature stability (now on the order of $\pm 0.2^\circ\text{F}$ for copper components and $\pm 0.05^\circ\text{F}$ for aluminum components). The design employs a network of programmable logic controllers (PLCs) for temperature control that functions under supervision of the existing DCS. The human-machine interface (HMI) of the PLC system employs RSView32 software. The PLC system also interfaces with the EPICS accelerator control system to provide monitoring of temperature control parameters. Eventual supervision of the PLC system by EPICS is possible with this design.

Keywords: water, temperature, control, stability, reliability

1. Introduction

The relationship between beam stability and water temperature has been the subject of studies at the Advanced Photon Source (APS) [1]. Goals have been established for overall spatial stability of ~ 1 micron [2]. Time-wise stability of the deionized (DI) process water (PW) temperature has the greatest impact on locations of electron beam position monitors installed in the aluminum vacuum chambers of the storage ring (SR). Signals from beam position monitors are processed in a feedback control system to adjust the spatial position of the electron beam. Stability of PW temperature also impacts SR magnets, absorbers, and other components in regard to beam stability, but to a much lesser degree. Even though APS beam stability has met or exceeded specified goals, improvement of beam stability is an ongoing activity at APS.

A crucial metric used to quantify accelerator reliability is downtime. Goals for beam availability have been established and exceeded at the APS [2]. Increased beam time is continually being expected by users and APS management. Departmental organizations within the APS Accelerator Division are allotted quantifiable downtime budgets. In order to minimize downtime and maximize beam availability, equipment is scrutinized for reliability. Repeated failure of similar equipment indicates a need for

attention. This can mean replacing a component with one supplied by a different manufacturer or changing or upgrading to a complete process system or operating procedure.

Another issue impacting downtime is that of personnel responsible for making repairs to system equipment. The PW system at APS was installed with a proprietary distributive control system (DCS) supplied by Johnson Controls, Inc. The human machine interface (HMI) software that operates this system is known as Metasys. Repair and upgrade of this proprietary equipment and software requires extensive training for technicians and engineers. Over the period of time this equipment has been in use, knowledge of hardware and software by APS personnel for this system has been acceptable, but has remained limited. This limitation has always been the source of fear that a serious failure of the system could lead to a longer than acceptable shutdown of APS as a result of having to wait for a specialized repair part or an individual who is specially trained. A far more secure approach is to have a control system designed, procured, installed, programmed and commissioned by in-house APS personnel.

At APS, beam stability studies indicated a need for improved temperature regulation of process water, particularly for conditioning the aluminum SR vacuum chambers. Around the same time, the failure rate of temperature control systems for copper-based magnets, power supplies, absorbers, etc. in the SR was increasing, suggesting a need for action. The approach to solving these issues was to install PLC-based equipment that would address the temperature regulation issue, the reliability issue, and the issue of being able to repair failures with APS personnel.

2. PW System

The PW system for the SR [3] comprises two distinct subsystems. One system is a set of twenty secondary pump stations that supply PW for cooling of copper-based components such as magnets, power supplies, absorbers, etc. and is sometimes termed the “copper water system.” The other system is a set of twenty closed-loop pump stations that circulate DI water for temperature conditioning of the aluminum vacuum chambers. These systems are located in the SR mechanical mezzanine outboard of the experimental floor that surrounds the SR.

A basic schematic flow diagram of one of the secondary (copper water) temperature control systems is presented in Fig. 1. Water is supplied at 78°F by the secondary pump and returns from the copper components after a temperature rise of approximately 6°F. The temperature is controlled by mixing water from the primary system at 75°F with warmer return water from the copper components. Each of the twenty such systems supplies water for two of the forty periodic “sectors” of the SR. Each such system is controlled by a Johnson Controls LCP controller. The LCP is networked via an N2 bus to a workstation in a central location.

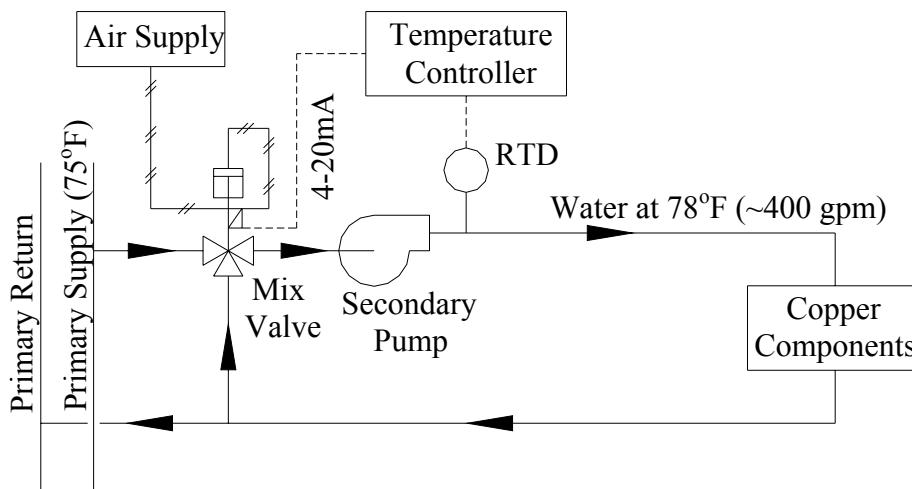


Fig. 1: Basic diagram of secondary system.

The SR secondary systems were originally supplied with temperature sensing elements installed near the point of use at the SR tunnel. This is approximately 100 ft or more away from the pump and mixing (temperature control) valve. Also, although the LCP controller produced a 4- to 20-mA signal, modulation of the mixing valve was originally by means of a 3- to 15-psig pneumatic signal after processing by an electropneumatic (E-P) converter at the LCP controller.

After several years of relatively trouble-free operation, the LCP controllers began to exhibit failures, identical in nature, and always on the same temperature control analog loop. It was found that a capacitor in the circuit of the 4- to 20-mA analog input signal from the temperature sensor was the common failure mode. This failure would manifest itself as a low value of the temperature of water being circulated. After some time, the mixing valve, trying to compensate for an apparent low temperature, would close off the supply of 75°F water. The result was overheating of magnets and power supplies in the SR.

The original specifications for the APS required temperature regulation to $\pm 1^\circ\text{F}$. Data from the original system is presented in Fig. 2, indicating regulation on the order of 0.5°F . After modifications to the control system, temperature regulation is typically $\pm 0.2^\circ\text{F}$ as indicated in Fig. 3.

Figure 4 indicates the flow diagram for the cooling of aluminum vacuum chambers of the SR. Water is supplied at 78°F by one of the two installed pumps. The water is cooled in a heat exchanger against chilled water. The temperature control valve is in the chilled water line. By far the largest heat source in the system is that of the pump motor (5 hp). The most important aspect of this system is temperature conditioning and stability. Each such system is controlled by a Johnson Controls DX9100 unit. The DX9100 is networked via the N2 bus to a workstation in the central location.

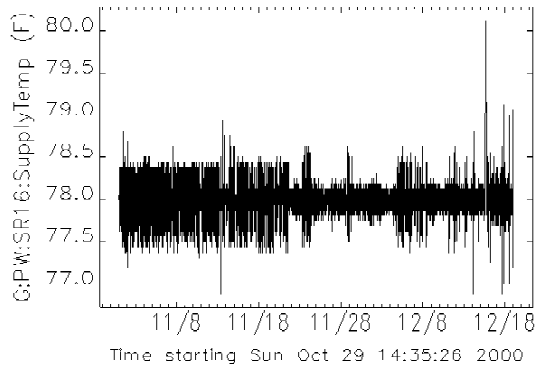


Fig. 2: Typical regulation of PW secondary system prior to modifications.

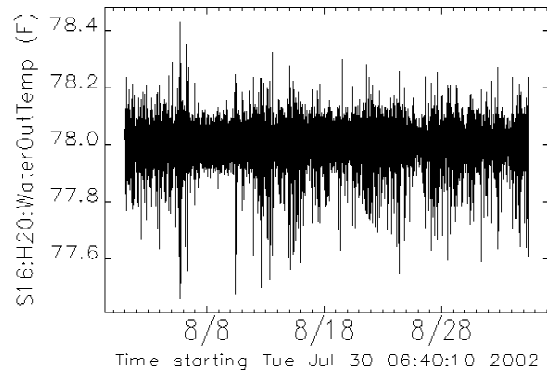


Fig. 3: Typical regulation of PW secondary system after modifications.

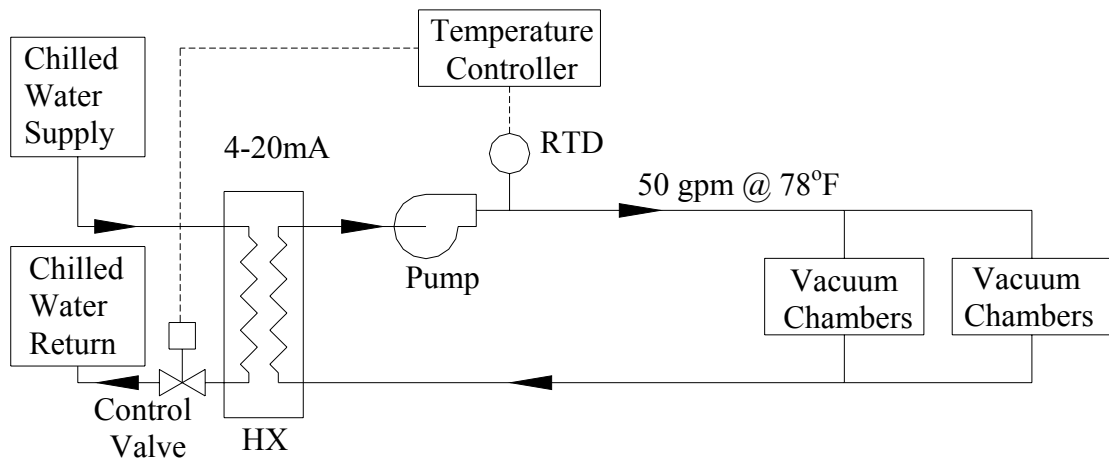


Fig. 4: Basic diagram of SR aluminum vacuum chamber water system.

There were never any failures recorded of the DX9100 units. Temperature regulation was well within $\pm 1.0^\circ\text{F}$, as indicated in Fig. 5, but beam studies indicated a need for better temperature stability. After modifications to the control system, temperature regulation is typically $\pm 0.05^\circ\text{F}$, as indicated in Fig. 6.

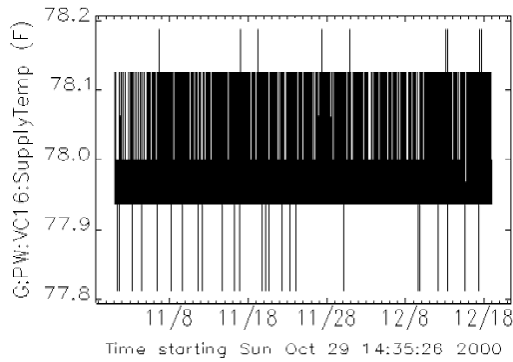


Fig. 5: Typical regulation of SR aluminum vacuum chamber system prior to modifications.

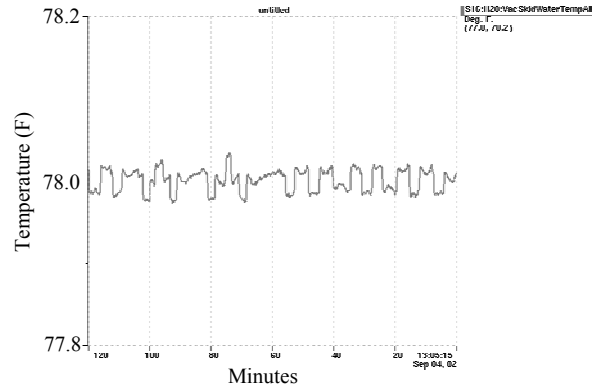


Fig. 6: Typical regulation of SR aluminum vacuum chamber system after modifications.

3. Summary of Modifications

Other work at APS [4] indicated the need to remove temperature sensors from thermowells and use RTDs that are immersed directly in the water. The RTD used at APS is the Minco S603 (3-wire) having a time constant of 4 s. This was done on both the copper and aluminum systems. Furthermore, it is imperative to have the temperature sensor physically near the temperature control valve to minimize time lag. On the secondary (copper) systems, the sensors were relocated from the point of use to a point very near the mixing valve. This results in faster response time which, for temperature control systems, is crucial to improving performance.

In order to control within a narrower tolerance, it is necessary to detect temperature changes at least ten times smaller than the desired tolerance band. Most RTD controllers are equipped with analog-to-digital (A-D) converters that divide the useful range of the RTD (sometimes on the order of 1800°F) by the number of bits available. Depending on the number of available bits, this can result in a resolution on the same order as or greater than the tolerance required. For this reason, a transmitter was employed having a 4- to 20-mA output corresponding to a temperature range of only 50°F. The temperature resolution can be determined by dividing the transmitter range by the number of bits available in the A-D converter. For a 16-bit A-D converter (15 bits resolution – 1 part in 32768 – and 1 sign bit), the resolution is approximately $50/2E15 = 0.0015^\circ\text{F}$.

The modified system employs Allen-Bradley (A-B) PLC-5 equipment for temperature control functions. The Johnson/Metasys system remains in place as the overall water system control entity. The A-B equipment is subordinate to Johnson/Metasys. The rationale for this approach stemmed from the importance of addressing reliability and temperature control issues as rapidly as possible and, at the same time, implementing required hardware and software within the framework of planned maintenance periods for a fully operational accelerator. By minimizing the

amount of PLC equipment and maintaining Johnson/Metasys viability, the upgrade became a readily feasible task and could be implemented in several secondary systems during each maintenance period. At the time these upgrades were being implemented, there were normally four such maintenance periods per year. The upgrades were accomplished in approximately nine months.

There are twenty A-B systems installed around the SR corresponding to each secondary pump installation. This corresponds to one matching A-B chassis for each Johnson LCP and DX-9100 installation. All analog input and output signals are 4 to 20 mA. Digital inputs are 24VDC (there are no digital outputs).

The A-B equipment in each rack consists of a 16-slot chassis containing:

Model 1785L/20B (5/20B processor)

Model 1771- IND (16-channel digital input module)

Model 1771-NIS (16-bit high resolution analog input module)

Model 1771-NOC (8-channel analog output module)

Model 1771-AF (fiber optics transmitter/receiver module-1 per quadrant)

Model 1771-P4S (power supply module)

When the system is in the normal operating mode, valve position is controlled by the output of the PID loop and analog output from the A-B system. Existing air actuated mixing valves were fitted with electro-pneumatic (E-P) positioners for ease of installation and quicker valve response time. Valve position can be overridden by valve status signals from Metasys or by personnel at a workstation. The mixing valve is also used to isolate the secondary system and, when not active, is commanded shut directly by Metasys. Temperature setpoint and PID parameters are programmed into the PLC because the operating temperature of the SR is fixed.

The PLC-5/20 system from A-B was selected for two primary reasons. The APS facility, commissioned in the mid-1990's, has myriad PLC-5 processors that are operating reliably. There was a conscious decision to match this equipment for obvious reasons: known reliability, commonality of spares, in-depth working knowledge by other APS groups, and commonality of software with that of other APS systems. This decision was made even though A-B was initiating sales of its new ContrologiX equipment. No data on reliability was presented by A-B for this new equipment at the time this project was implemented.

To allow faster communications and central monitoring, the twenty PLC installations are networked in four quadrants of five processors each. Each quadrant is linked by two separate networks. One network employs DataHighway Plus (DH+) and the other network employs Remote I/O.

The four DH+ links are brought into and combined with a ContrologiX gateway and are Ethernet linked to a PC workstation in the central technician work area. This workstation is used to monitor status of all twenty PLCs, but can also be employed to download new software to the PLCs from one single location. All PLC data, software, and status information is available at the PC workstation.

The HMI software for the PC workstation is RSView32. This software allows the system administrator to design custom virtual views of the process being controlled. These views can be designed and modified very readily.

The twenty PLC installations are also networked to EPICS control room hardware via the Remote I/O communications link. Each Remote I/O network consists of all five PLC processors in a quadrant linked together with “Blue Hose” and connected to a fiber-optic transceiver. Four fiber-optic links allow communication with a pair of scanner cards in the APS Main Control Room (MCR). These scanner cards are then read by the EPICS system. The purpose of this network is to permit certain selected information, such as pump status, water temperature, differential pressure, etc. to be monitored by MCR operators.

4. Benefits

The primary benefit to APS has been improved temperature regulation of process water for the APS storage ring. Typical regulation is now within $\pm 0.2^{\circ}\text{F}$ for copper components and $\pm 0.05^{\circ}\text{F}$ for aluminum components. Reliability has also improved as demonstrated by the occurrence of only one failure in the three years since implementation was initiated. Failures had been approaching the order of one per month with the originally installed system.

Another benefit is the ability to perform all software and hardware design, installation, commissioning, troubleshooting and repair with in-house APS personnel without fear that a proprietary part or software feature might fail. Upgrades to software do not require the hiring of specially trained outside technicians. The interface at the PC workstation can be customized to suit immediate needs without the cost and delay associated with hiring an outside service.

Although communication between Metasys and EPICS has been in place for some time, it is limited and slow. Data collection is routine, but updates are delayed approximately 30 seconds. Commands from EPICS, although theoretically possible, have never been implemented. Communications with EPICS and the MCR are routine with the A-B equipment and updates are essentially as useful as real-time information.

Should it be necessary to add new sensors or functions to the system, such modifications can be made simply by APS personnel. Such upgrades will be easier with a PLC-based system and can be performed much more cost effectively.

5. Future Upgrades

Allen-Bradley PLC equipment is already used for complete control of the APS linac closed loop water stations⁴ which condition the accelerating structures for that machine. Current work includes upgrade of water systems for APS injection wing and RF secondary water systems.

Long term plans are to utilize PLC equipment to replace all Johnson/Metasys systems for APS process deionized water in the APS facility itself (excluding the Utility Building where temperature stability is not as critical and reliability is addressed in the form of installed spares.) It is expected that this will require several years for design, testing and implementation since accelerator operations can not be compromised. Current operating schedules now allow for only three scheduled maintenance periods per year.

6. Acknowledgements

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7. References

- [1] L. Emery, "Measurement of Thermal Effects on the Advanced Photon Source Storage Ring Vacuum Chamber," Proceedings of the 2001 Particle Accelerator Conference, Chicago, IL, USA, June 18-22, 2001, pp. 1276-1278 (2001).
- [2] R. Gerig, private communication.
- [3] E. Swetin et al., "Cooling water Systems for Accelerator Components at the Advanced Photon Source," these proceedings.
- [4] R. Dortwegt et al., "Improved Temperature Regulation of APS Linac RF Components," XIX Int'l Linear Accelerator Conference (Linac98), Chicago, IL, USA, August 23-28, 1999, pp. 1001-1003 (1999).