IMPROVED TEMPERATURE REGULATION OF APS LINAC RF COMPONENTS*

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Abstract

The temperature of the APS S-Band linac's high-power rf components is regulated by water from individual closed-loop deionized (DI) water systems. The rf components are all made of oxygen-free high-conductivity copper and respond quickly to temperature changes. The SLED cavities are especially temperature-sensitive and cause beam energy instabilities when the temperature is not well regulated. Temperature regulation better than ± 0.1 °F is required to achieve good energy stability. Improvements in the closed-loop water systems have enabled us to achieve a regulation of ± 0.05 °F over long periods. Regulation philosophy and equipment are discussed and numerical results are presented.

1 INTRODUCTION

The Advanced Photon Source [1] linear accelerator system [2] consists of a 200-MeV, 2856-MHz S-band electron linac and a 2-radiation-length-thick tungsten target followed by a 450-MeV positron linac. The linac is designed to accelerate 30-ns-long pulses containing 50 nC of electrons to an energy of 200 MeV at 48 pulses per second. The linac rf system includes accelerating structures and SLED cavities that require temperature stability of ± 0.1° F or better. Stability is achieved using closed-loop water systems that provide constant temperature water to the SLEDs, accelerating structures, waveguide, loads, and to the rf reference and drive line.

The optimum temperature of each linac closed loop (LCL) system is found by a standard procedure. Water temperature is varied, and the setpoint is the value that maximizes beam energy. Results from one LCL system are shown in Figure 1. Each LCL has a unique setpoint in the range of 105-116 °F. Absolute knowledge of the temperature is not essential since the setpoint is chosen by direct measurement, but long-term stability is important.

2 GENERAL SYSTEM DESCRIPTION

All linac high-power rf components are temperature conditioned within ± 0.05 °F with DI water from the LCL pumping systems. One LCL is depicted in Figure 2 along with the klystron gallery secondary (DI process water) system (KGSS) that supplies coolant to the heat exchanger (HX) in the closed loop. The APS primary (DI process water) system (APS-PS), from which heat is ultimately rejected, is also shown in the figure. There are five LCLs, all with identical hardware components. Three of the LCLs provide total flows of 80 gpm and the other two provide 25 and 40 gpm.

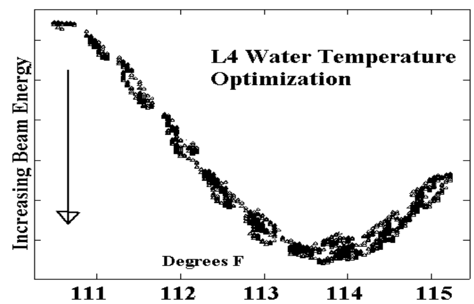

Figure 1: The optimal temperature for L4 is ≈113.7 °F.

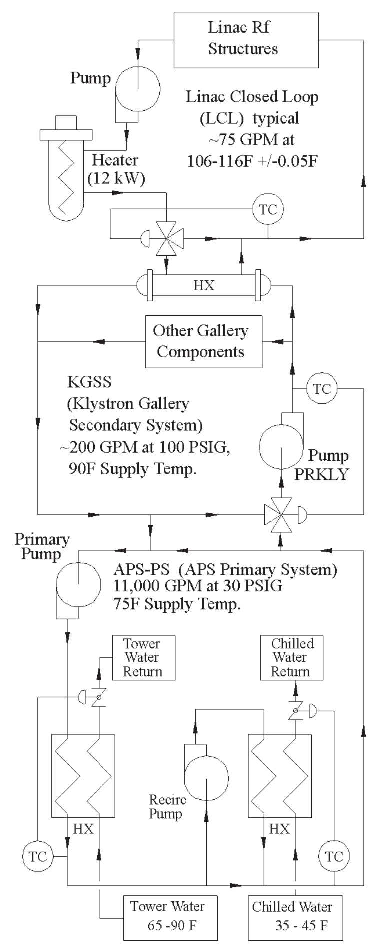

Figure 2: Overview of the linac water system.

* Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

LCL components include an end-suction centrifugal pump, a 12-kW electric heater, a shell-and-tube heat exchanger, and a 3-way mixing valve to regulate the temperature. The heater serves two functions. It provides energy input to the system on cold startup so the setpoint value is reached in a reasonable time. It also matches steady-state energy input with heat rejection capacity, as the temperature control valve and heat exchanger capacities are more than adequate to remove heat from rf power input and frictional flow losses.

All LCLs are cooled by water circulated by the KGSS pump. KGSS water temperature is controlled at 90 °F by a 3-way mixing valve. Water from the primary system at 75 °F is admitted to the recirculating KGSS.

Whenever possible, cooling of the APS-PS water is done using cooling-tower water. When the cooling tower water is too warm, an additional exchanger cools the primary water using chilled water.

2.1 Brief History of the Linac Water System

The original linac water system provided long-term temperature stability no better than ± 0.5 °F compared to the required ± 0.1°F at steady state. Human intervention was required following significant power transients or equipment upsets. Inadequate performance was primarily due to: 1) poor resolution of the temperature-sensing elements (temperature control instruments only detected changes of the same order as the required steady-state tolerance); 2) installation of thermal sensors in thermowells resulting in very slow response times; 3) variation of KGSS coolant temperature by ≥ ± 1.0 °F.

By the end of 1995 control was improved to ± 0.2 to 0.3 °F. The most notable changes were the installation of direct-immersion RTDs (resistance temperature detectors), and series installation of heater and HX units. Performance periodically became unstable due to a significant derivative term in the control algorithm.

2.2 KGSS and APS-PS Temperature Stability

Efforts to stabilize the temperature of the coolant side of the LCL heat exchangers were initiated in early 1996. A 30-gallon holding tank was installed on the coolant inlet side of the exchanger to average out the fluctuations. A similar tank was installed on the linac side of the heat exchanger to increase capacitance. These modifications reduced temperature fluctuations in the LCL to ± 0.15 °F. Linac mixing valve actuators were also upgraded to the current Worcester models at that time.

In October of 1996, attempts were made to tune the proportional-integral-derivative (PID) loop of the KGSS with partial success. It was possible to tune the system using PI control (P=400, I=1000 s). KGSS stability was ± 0.1 °F, but the system was unable to handle transient heat loads, and equipment trips resulted. Studies indicated that it took ≈60 seconds for output control signal changes to actually be noticed by the sensor due to the long distance between the KGSS RTD and the mixing valve, and because the KGSS RTD was installed in a thermowell.

In order to improve the KGSS's response, its RTD was replaced by a direct-immersion RTD and was relocated immediately downstream of the pump. This permitted improved tuning of the secondary loop with PI control. The control algorithm, executed by the Johnson Metasys system, included a “tune override” feature that imposed “stronger” PID control parameters if the temperature deviated from the setpoint by a preset amount. This feature was removed, and traditional PI tuning was implemented.

These modifications resulted in KGSS stability on the order of ± 0.1 to 0.2 °F and LCL stability of ± 0.1 °F.

2.3 Upgrades to the LCL Control Systems

In early 1997, it became clear that valve tuning was a critical element in system control and that tuning the 3-way mixing valves in the LCLs (controlled by Johnson Controls LCP controllers) was not routine. The Johnson LCP has no specific “tune override” feature, but its response to temperature disturbances did not seem “classical.” As a test, a Watlow 965FDO controller was substituted for one of the Johnson LCP controllers for a short time, during which it was observed that valve tuning in the classic closed loop manner was possible [3]. Based on these results, it was decided to search for a high-resolution, stand-alone temperature controller that could be tuned to the required tolerance.

Valve tuning experience up to this time made it clear that, while a feedback control system functions to correct an error, such a correction can occur only after the error is detected. It was necessary to be able to discern changes in temperature significantly smaller than the acceptable tolerance. The Johnson Controls LCP was able to discern changes only as small as 0.06 °F. Thus, 60% of the available tolerance had already been expended before control action was initiated.

The Honeywell Progeny, whose A/D converter can resolve changes less than 0.01 °F when scaled across the 40 °F range of the applicable transmitter, was chosen as the stand-alone controller. Using this controller, it was demonstrated that steady-state temperature could be controlled to within ± 0.05 °F.

During this time, attempts were made to reduce coolant flow through the LCL heat exchangers so that the control valves would pass 65-75% of the load-side flow through the exchanger. It was felt that more precise temperature regulation would be possible if a larger flow of water were heated or cooled. As the coolant flow was reduced below 2 or 3 gpm, the exchanger demanded 100% of the load flow yet process temperature continued to climb. At such a reduced flow, the coolant flow transitioned from turbulent to laminar resulting in a loss of overall heat transfer coefficient. The surface area of the heat exchanger was reduced by 50% by rotating one end cap of the 4-pass shell-and-tube unit by 90° so that coolant would pass through only half of the tubes.

Coolant flowrate in each LCL is now regulated at a fixed, heat-load-dependant value of 7-10 gpm by Griswold flow control cartridges. The coolant flowrate for a given station is determined by varying the flowrate until the 3-way control valve on the linac (load) side is ≈65-75% open at 100% load. The output of the electric heaters is set at a constant value to fix the heat load.

In the most recent upgrade, the Johnson Controls LCPs, the original Barber-Coleman control units, and the Honeywell Progeny were replaced by Allen-Bradley PLC-5/20 processors with 1771-N4BS analog I/O modules. Temperature changes on the order of 0.003 °F can be discerned. Previously, the system noise levels were on the order of 0.015 °F above the applicable system resolution.

Other benefits of the Allen-Bradley processors include the ability to tune valves with response characteristics that permit LCL startup from a cold condition to a steady operating temperature without supervision. This was never possible in the past. It has also been found that most rf power transients are handled well within the ± 0.05 °F tolerance range, as shown in Figure 3.

Use of Allen-Bradley PLCs permits communication between the LCL water stations and the APS control room. The LCLs can now be operated remotely in “real time” via the EPICS [4] control system.

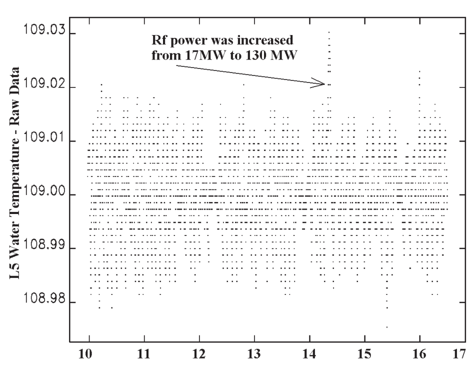

Figure 3: Temperature stability of one LCL over seven hours in April of 1998. The temperature only changed by 0.03 °F in response to an 80-MW increase in the SLED forward power.

2.4 Linac Temperature Control Systems

The LCL temperature control systems now consist of:

1) 3-way Durco ball-type control valves that divert water through or around the heat exchanger as required for stable temperature regulation.
2) Worcester series 75 electric control valve actuators with AF-17 positioners with a resolution of 0.5%.
3) Electric heaters providing fixed heat input rates; rates between 0% and 100% are chosen at setup.
4) 3-wire, direct immersion, 4-s time constant, Minco S603PD8 RTDs.
5) Analog temperature transmitters scaled in the range 85-125 °F (Minco TT676PD1QG).
6) Allen-Bradley PLC-5/20s with P/N 1771-NB4S high-resolution analog I/O cards for PID temperature control (the D feature is not used).

Use of a 3-way diverter valve in the load stream rather than a throttling valve in the coolant stream is especially important. An order of magnitude faster temperature response is obtained with the diverter valve since the final temperature is a result of mixing, and flow ratio changes are immediate upon valve movement. Throttling of the coolant flow results in relatively slower response, since the entire mass of the load stream and the mass of the heat exchanger surfaces must change temperature.

3 CONCLUSIONS

Temperature regulation of high-power rf components to within ± 0.05 °F has been achieved at the APS linac. The system responds quickly to changes in rf power load and maintains long-term temperature stability. The water system and the techniques to optimize the temperature are described more completely in [5]. System studies continue including an effort to find a source for a digital temperature transmitter with suitable resolution to address possible drift issues.

4 ACKNOWLEDGMENTS

The authors would like to acknowledge R. Damm for leading efforts to improve system performance; E. Swetin for installing holding tanks, downsizing heat exchangers, and assisting with KGSS tuning; C. Putnam and H. DeLeon for implementing the PLCs; N. Arnold and M. Kramer for implementing network communication; R. Kneebone and W. Matz for implementing changes prior to 1996; and C. Eyberger for editorial assistance.

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