THE SNS RESONANCE CONTROL COOLING SYSTEM CONTROL VALVE UPGRADE PERFORMANCE *

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Abstract

The normal-conducting linac of the Spallation Neutron Source (SNS) uses 10 separate Resonance Control Cooling System (RCCS) water skids to control the resonance of 6 Drift Tube Linac (DTL) and 4 Coupled Cavity Linac (CCL) accelerating structures. The RCCS water skids use 2 control valves; one to regulate the chilled water flow and the other to bypass water to a chilled water heat exchanger. These valves have hydraulic actuators that provide position and feedback to the control system. Frequency oscillations occur using these hydraulic actuators due to their coarse movement and control of the valves. New pneumatic actuator and control positioners have been installed on the DTL3 RCCS water skid to give finer control and regulation of DTL3 cavity temperature. This paper shows a comparison of resonance control performance for the two valve configurations.

INTRODUCTION

The RCCS water skid primary components for controlling resonance are the water pump, heat exchanger, 3-way control valve, and the 2-way valve (figure 1).

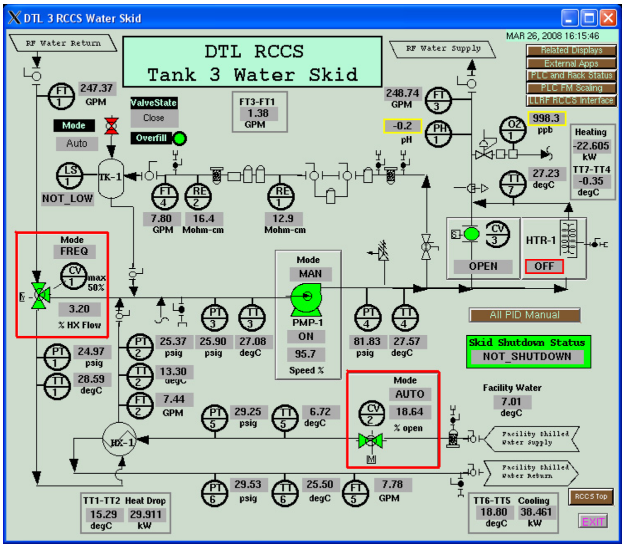

Figure 1 – DTL3 Water Skid

The water skid is a closed-loop system and water temperature is controlled by adjusting the distribution of flow between the heat exchanger and the heat exchanger bypass line [1]. By diverting more or less water with the 3-way control valve (CV1) the thermal effect on the geometry of the cavities can be changed. The removal of the heat load on the cold side of the heat exchanger is regulated by controlling the chilled water flow using the 2-way control valve (CV2). The resonant frequencies of the DTL and CCL structures are finely controlled by the RCCS and the Low Level RF (LLRF) systems.

Much effort and study have been applied to the RCCS design and to understanding instabilities of resonance control at low RF power levels during the ramp up phase of the project. The cooling skids provided by Los Alamos and built by AVANTech were designed for full duty factor operations. Even at full duty RF there is too much cooling capacity with the original water skid design, due to the heat exchanger being 262% larger than required [2]. This over-cooling design makes it difficulty to operate the water control valves in areas for stable temperature control.

COMPONENTS OF FOCUS

The main focus of changes on the water skid has been on the control valves for both CV1 and CV2. Early in the RF power ramp up it was discovered that the electrohydraulic actuator control valves did not have good resolution. The dead band for movement was 2% input change before valve movement. The dead band to unseat the valve was worse and took a 6% input before the valve would open. Once CV1 opened the flow rate would jump to 16 GPM on the mixing leg through the heat exchanger. The chart below (figure 2) illustrates 1% step changes on the CV1 valve and flow rates were recorded by monitoring the flow transmitter on the hot side of heat exchanger. The yellow plot is with the electrohydraulic actuator control. The surge of water through the heat exchanger would dramatically cause a drop in water temperature going to the accelerating cavity. Even after the valve was operating above 6% open range these 2% steps changed the flow rate on the order of 6-10 GPM.

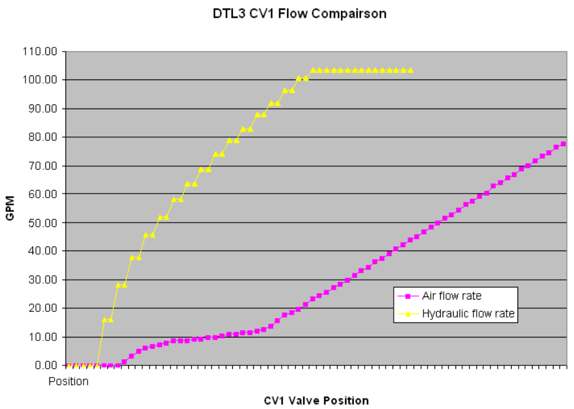

Figure 2 – CV1 Flow Comparison

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The Samson type 3274 electrohydraulic actuator was replaced with a Samson type 3730-2 electropneumatic actuator [3]. The dead band for movement with the new actuator was virtually nonexistent. Even with a step change of 0.25% the valve would move in agreement. The unseating of the valve was much smoother with the flow only increasing to ~2 GPM on the initial unseating. In figure 2 the pink plot shows the flow response with the first 30 points at 0.25% changes and the remainder at 1% step changes. This fine resolution of valve control dramatically decreased the temperature instabilities in the cavity. The original valve body trim set flow coefficients were 90/70 split with 90 for heat exchanger and 70 for the bypass leg. A new trim set for CV1 was installed with a 30/70 split to reduce flow through the hot side of the heat exchanger.

The same actuator replacement was performed on the CV2 chilled water valve on the cold side of the heat exchanger. Also to mitigate the oversized heat exchanger the trim set in the valve body was reduced from a flow coefficient of 95 to 30 at full open to reduce the flow rate of the chilled water. Operational experience has shown a small change, i.e. 2 GPM, in chilled water flow can influence the temperature of the cavity. These two changes on CV2 give the resolution needed to finely control the chilled water flow rate for stable heat exchanger performance.

COMPARISON OF RESONANCE CONTROL

The resonance control has greatly improved with these valve modifications. Figure 3 shows a comparison of DTL3 RCCS control operation with electrohydraulic actuator in January 2007 and new electropneumatic actuator in November 2007. The chart (figure 3) on the top is electrohydraulic and the bottom is the electropneumatic actuator. This data was taken with the chilled water valve open to a fixed position. The over cooling of the system is observed by the action on the mix valve operating in an open-closed mode. These oscillations influence the cavity temperature and frequency error as to be expected, but also the forward power fluctuates for the LLRF system trying to maintain proper field levels in the cavity due to these instabilities.

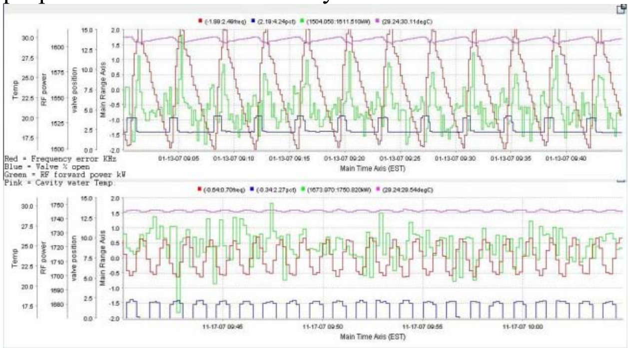

Figure 3

Even with the CV1 operation in this open-closed mode the frequency error (shown in red on figure 3) oscillations amplitudes were reduced from 4 KHz to 1.2 KHz peak to peak. To eliminate the mix valve from the open-closed mode the chilled water valve was adjusted to reduce flow on the cold side of the heat exchange. Once the CV2 valve was correctly set then CV1 mix valve regulated in an open position and these oscillations were controlled. This manual adjusting of CV2 can be time consuming and must be readjusted if RF duty factor in the cavity changes. Also if the chilled water supply pressure or temperature changes it will cause a change in the heat removal rate and manual readjustment of CV2 will be required to provide stable resonance control.

CONTROL LOGIC FOR THE VALVES

Each RCCS water skid uses an Allen-Bradley ControlLogix5000 Programmable Logic Controller (PLC) [4] to control pump speed, valve positions, and monitor all instrumentation including flow, temperature, and pressures. Both valves use PID control built into the PLC. The PID control for 3-way valve CV1 on the water skid has three modes of operation: frequency, temperature, and manual. Frequency Mode uses DTL cavity frequency error signal generated from LLRF. The error signal is read from the Global Control System (EPICS) and moved to the Frequency PID Process Variable in the PLC. The set point for this PID controller is set to a value that the operator chooses between +/– 10 KHz. The nominal value for the set point is zero. The DTL resonant frequency is 402.5MHz and that is where the RCCS and LLRF will try to maintain the DTL tanks. The frequency error can be positive or negative with respect to the 402.5MHz. Temperature Mode uses a set point from EPICS for the PID setpoint that the operator enters to control the water temperature. The operator selects the temperature PID process variable which can be one of four temperatures read backs within the system. The Manual Mode allows the operator to control the CV1 position manually.

New logic for chilled water valve control

The original PID control logic for the CV2 was to control the flow rate on the cold side of the heat exchanger by using flow as the process variable. The setpoint was entered for the current RF duty for that cavity. The new electropneumatic actuator is able to control the flow rate nicely; however a change in process chilled water temperature will cause a change in the dynamics of the heat exchanger. Also if the RF heat load changed in the cavity the setpoint on the CV2 would have to change accordingly. To eliminate these factors a change in the PLC logic was made to have CV2 chilled water valve monitor the position of the CV1 mix valve to maintain CV1 in an always open position when RF power is in the cavity.

If flow is reduced on the cold side of the heat exchanger by closing CV2, then to remove the heat load from the cavity, CV1 will have to open further and divert more water through the hot side. If the PID setpoint of the CV2 control loop is “maintain CV1 at 8% open” and the process variable is the position of the CV1, then it is possible to control the operational position of CV1 to around 8% open. A dead band of +/– 3% is used in the CV2 control to eliminate constant correction when CV1 valve is controlling around the setpoint of 8% open. With these two valves interacting with one another a coarse control using CV2 and a fine control using CV1 is created to maintain cavity resonance.

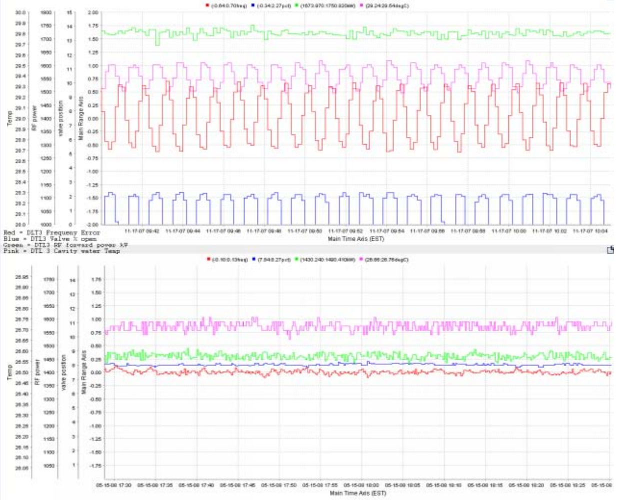

Figure 4 – CV2 New Logic Comparison

In figure 4 the top chart shows the CV1 in the open-close mode and bottom chart CV1 is now remaining open around the 8% open as regulated by the new interaction of the CV2 valve. The frequency error is maintained 0.25 KHz peak to peak compared to 1 KHz. The forward power variations are eliminated due to the more stable temperature with the new interaction valve control logic scheme.

An 8% setpoint was used because it is just above the start of the linear flow range. A higher setpoint could be used, but too high of a setpoint would require the chilled water valve CV2 to operate near the closed position. When RF is first turned on in a cavity there is some warm-up time before additional cooling is needed. If the setpoint is set too high then CV2 will not react promptly and a large overshoot is created. A low RF duty factor and a high CV1 setpoint would cause CV2 to oscillate open and closed to maintain CV1 at the higher setpoint. More study time is needed to sweep through the range of RF duty factors and find the optimal setpoint.

FUTURE PLANS FOR RCCS

The new valve actuator and logic control scheme has greatly improved the resonant control for the DTL3 structure. In figure 5 the frequency error comparison can be seen between all the DTL cavities. DLT3 frequency error is in red.

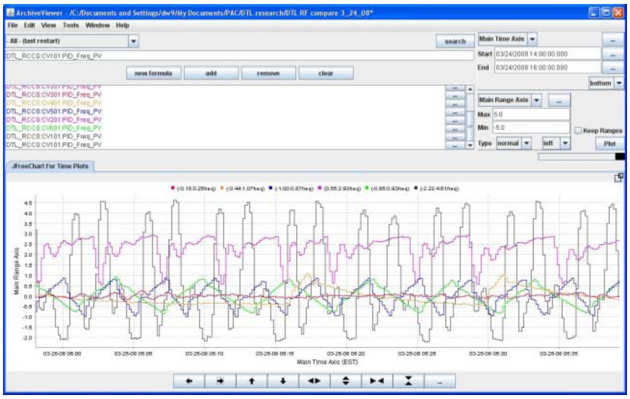
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Figure 5

With the new valve trim set and actuator changes on DTL3 the data shows stable resonance without changing the over sized heat exchanger. Although this paper has focused on the DTL cavities, the 4 CCL water skids are designed with these same problems. The testing of DTL3 changes provides confidence to move forward to implement these changes on the remaining water skids.

The plan is to replace the valves on the 4 CCL water skids and the remaining 5 DTL water skids in the next scheduled maintenance outage. There is also a quad magnet cool system (QMCS) that provides cooling for the CCL quad magnets and CCL RF windows. This cooling skid has the same design except without the need to control resonance of any cavity. The valve actuators will be changed to maintain consistency throughout the facility. This consistency will improve management of spares.

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