# RESONANCE CONTROL COOLING SYSTEM FOR THE APT/LEDA RFQ*

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*Abstract*

The Radio Frequency Quadrupole (RFQ) [1] resonance control cooling system (RCCS) for the Low Energy Demonstration Accelerator (LEDA) [2] in support of the Accelerator Production of Tritium (APT) [3] is described. Constant flow regulating valves to distribute the required flow to the 424 channels and to permit use of centrifugal pumps is discussed. Control system schema are described to regulate resonance frequency during steady state operation.

## 1 CONTROL OF RESONANCE FREQUENCY

Resonance frequency in the RFQ is manipulated by changing the gap between opposing vane tips in each of the four Segments. The quadrupole vanes are cooled with constant temperature 50 degree Fahrenheit water to hold their geometry constant. The RFQ cavity wall and all of the systems interfacing through the cavity wall are cooled with temperature controlled water. By manipulating the cavity wall water temperature, the vane tip gap will either increase or decrease based on whether the cavity wall diameter grows or shrinks, thus manipulating the rf resonant frequency.

## 2 COOLING SYSTEM

The resonance control cooling system is comprised of two subsystems, one open loop and one closed loop.

### *2.1 Open Loop Subsystem*

The open loop subsystem supplies constant temperature coolant to the vane and coupling plate channel passages. The open loop subsystem dissipates approximately 350 kilowatts of heat. To dissipate that heat, 360 gallons per minute of constant temperature 50 $^{o}$F water is supplied to 84 individual channels. The 84 channels are subdivided into 4 channel types that are common to each of the four 2-meter RFQ Segments. Four sets of supply and return pipes connected directly to the chilled water system distribute approximately 90 gallons per minute of the coolant to/from each of the four Segments.

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Parallel piped constant flow regulating valves are used to assure the correct total flow is supplied to each of the channel types within each Segment. Each constant flow-regulating valve supplies a manifold which distributes the coolant among the individual channels.

### *2.2 Closed Loop Subsystem*

The closed loop system supplies temperature controlled water to five different channel types in the cavity wall to dissipate approximately 910 kilowatts of heat. To dissipate that heat, a total of 1160 gallons per minute is supplied to 340 individual channels.

The closed loop subsystem is comprised of four pump loops which circulate coolant through the cavity wall channels of the four RFQ Segments. Connecting the four pump loops is an outer piping loop whose purpose is to control the water temperature being supplied to the four pump loops.

Due to the different amounts of heat dissipated in each RFQ Segment, the inlet water temperature to the cavity wall channels of each Segment must be adjustable and no two will be the same. Figure 1 illustrates a single pump loop. The inlet temperature to the cavity wall channels of each Segment is established by fixing the ratio of the mass flow of the RFQ heated returning coolant that is diverted to mix with the entering mass flow from the outer loop. Setting the stem position of each pumping loop's diverting valve controls that mass flow ratio. The final stem position will be a function of desired inlet temperature and the heat dissipated by the loop and, once established, is not changed during steady state operation.

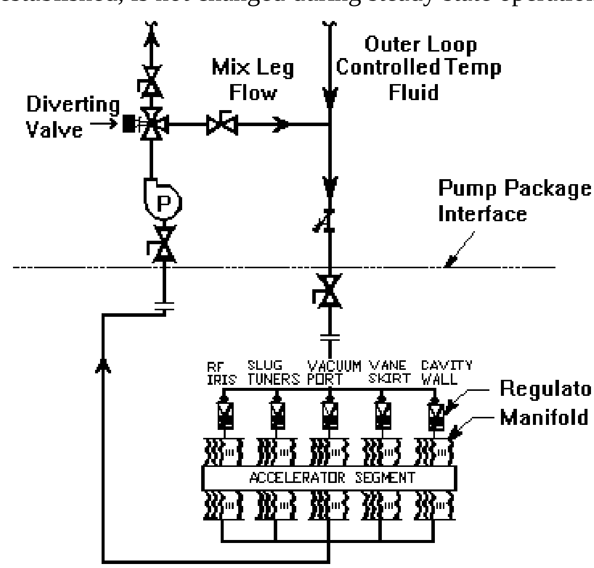


Figure 1: One of four Pump Loops

To force the cavity to the desired resonant frequency, the rf frequency controller manipulates an outer loop control valve to allow more or less constant temperature chilled water to enter the outer loop and mix with the water from the Segments which is not diverted down the mix leg. The amount of mass flow entering either lowers or raises the outer loop temperature. When the outer loop temperature changes incrementally, the inlet temperatures of all four of the RFQ Segments will increase or decrease by the same incremental amount as long as the rf power is at steady state.

## *2.3 Constant Flow Regulating Valves*

Parallel piped constant flow regulating valves are employed to assure the correct proportion of the total pump flow is supplied to each of the closed loop channel types within each Segment. Each constant flow regulating valve supplies a manifold that distributes the coolant among the individual channels within a channel type.

Flow through the regulating valve is described by the following equation.

$$Q = Cv*SQRT(dP)$$

The flow coefficient (Cv) of the constant flow regulating valves, changes as the differential pressure (dP) across the valve changes. Figure 2 depicts the internals of the AutoFlow regulating valve manufactured by Flow Design Inc. [4].

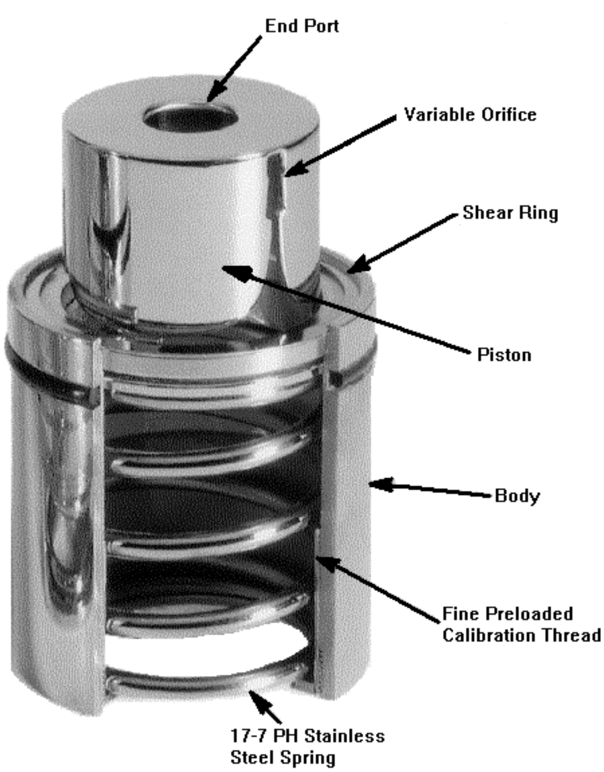


Figure 2: Internals of Constant Flow Regulating Valve

As the pressure drop increases, the piston depresses, reducing the exposed orifice area, thus reducing the Cv. The opposite is true when the pressure drop decreases. The valve's Cv increases/decreases in proportion to the square root of the differential pressure. The net effect is that the flow (Q) through the valve will remain at the designed flow rate (within +/- 5%) as long as the spring is not fully compressed or extended. Spring ranges can be purchased for two pressure drop ranges, 2-30 psi and 5-60 psi.

These flow-regulating valves are used to regulate the flow to each different channel type within a one meter RFQ Section. Since all flow paths utilize a regulating valve, the total volumetric flow of the pump is clamped to the sum of the designed regulating valve flows as long as the pressure drop variance among the channels doesn't exceed the valves spring range. Figure 3 shows the effect that the constant flow-regulating valves have on each loop's loss curve. The discontinuity in the loop loss curve begins when all valves are in the regulating range and ends when the first valve saturates. That discontinuity establishes a window that permits use of centrifugal pumps. A centrifugal pump whose head gain curve intersects the discontinuity of the loop loss curve will provide the desired volumetric flow.

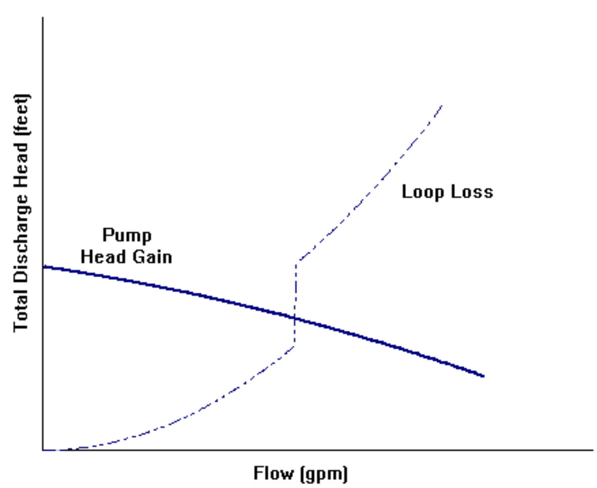


Figure 3: Loop Loss Curve with Regulating Valves

The height of the discontinuity window is dependent on the spring range of the regulating valves and the pressure drops of each of the channel types.

# 3 RESONANCE FREQUENCY CONTROL

The RFQ RCCS provides continuous and discrete control of the cooling system. Operator interface screens are provided to change setup parameters for continuous control and to initiate discrete controls. Status screens are also provided to display information about the RFQ cooling system.

The RCCS is implemented using Experimental Physics and Control System (EPICS) based hardware and software and is integrated with other networked LEDA EPICS systems. Figure 4 shows the network connections of the RCCS system. The other LEDA systems act in a supervisory role by providing information to the RCCS via EPICS Channel Access to the RCCS Input/Output Controller (IOC) database to initiate actions. Status information from the RCCS is accessible via Channel Access.

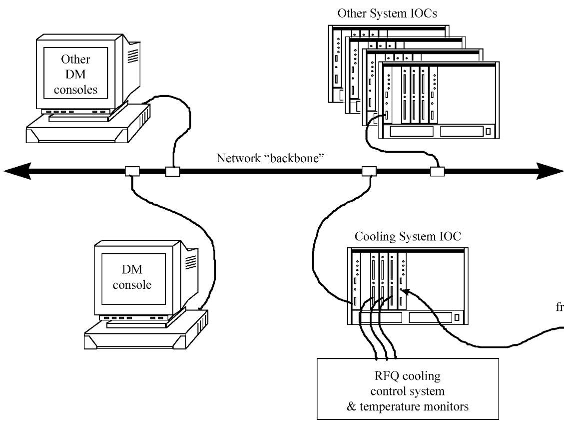


Figure 4: Network Configuration

The RCCS software is constructed using EPICS State Notational Language (SNL) to track the condition of the system and to allow certain control actions to take place. Additional C programs are used to perform the control algorithms and file operations. Figure 5 shows the state diagram that represents the overall conditions of the RCCS. Resonant Frequency Control (RFC) is obtained by going through one of two defined sequences of operations, Startup or Conditioning.

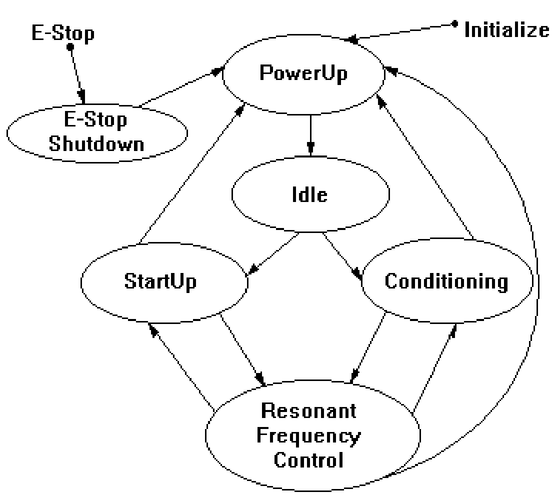


Figure 5: System Level State Diagram

RFC regulates the resonant frequency of the RFQ using a single loop Proportional Integral Derivative (PID) control algorithm that adjusts the setting of the outer loop control valve based on the frequency error provided by the Low Level RF (LLRF) control system. The valve adjustments will alter the temperature of the water flowing in the outer loop, thereby changing the frequency of the RFQ. RFC is the normal operating state of the RCCS.

RFC begins when a valid frequency error from the LLRF system is detected, ending startup or conditioning. The PID algorithm regulates the resonant frequency of the RFQ to +/- 8KHz, which corresponds to a change in water temperature supplied to the inner pumping loops of +/- 0.5°F.

The frequency error, received via an analog signal from the LLRF system, ranges from 0 to 10V DC, where +0.5V represents -50KHz error and +9.5V represents +50KHz error. Any error reading outside the +0.5V to +9.5V range is considered an invalid signal.

If the frequency error signal is lost, RFC is halted and temperature control is started to regulate the Outer Loop Common Supply at the current temperature, until the supervisory system dictates a change to another state or the frequency error returns. The setpoint for temperature control will be the average of sampled temperatures before the error signal was lost. When the frequency error signal returns, temperature control is halted and RFC is restarted.

RFC can only be halted and directed to make a transition to the proper state by the supervisory system or an emergency stop condition.

## 4 INSTALLATION STATUS

Installation of the RCCS Pump Package and under floor piping was completed in January 1998. Installation of the remainder of the distribution piping is scheduled for completion along with the control system hardware and software in September 1998.

## 5 ACKNOWLEDGEMENTS

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## 6 REFERENCES

[1] D. Schrage, et al, "CW RFQ Fabrication and Engineering", these proceedings.
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[3] G. Lawrence, "High Power Proton Linac for APT; Status of Design and Development", these proceedings.
[4] AutoFlow Valves manufactured by Flow Design Inc., 8908 Governors Row, Dallas Texas 75247.