DESIGN AND PERFORMANCE OF RESONANCE FREQUENCY CONTROL COOLING SYSTEM OF PEFP DTL*

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Abstract

The objectives of the cooling system of Proton Engineering Frontier Project (PEFP) Drift Tube Linac (DTL) operated in combination with the low-level RF system (LLRF) are to regulate the resonant frequency of the drift tube cavities of 350 MHz. To provide an effective means of bringing the PEFP DTL up for a resonance condition within ±5 kHz, the prototype of the cooling system has been designed and fabricated to investigate the performance features for the servo stabilization of the cavity resonant frequency. As a result, it is estimated that the resonant frequency could be regulated less than ±1 kHz with this proposed feedback temperature controlled cooling system although introducing a little nonlinear features as the reference operating temperature changes. This report describes the design and performance test results of a cooling system, including the size of water pumping skid components and the temperature control scheme.

INTRODUCTION

The intensive research in the PEFP of Korea Atomic Energy Research Institute (KAERI) is undergone to develop a 100 MeV proton accelerator complex in Korea [1]. The PEFP accelerator structure such as DTL requires a water cooling-based thermal tuning system to regulate the resonance frequency of the drift tube cavity to 350 MHz [2]. The PEFP 100 MeV proton linear accelerator with a maximum duty cycle of 8% and proton beam of 20 mA is being designed as a user facility for scientific and industrial research and development [3].

We have designed and fabricated the water pumping skid consisting of two loops with by-passing the cooling water through a plate heat exchanger. It achieves the required temperature by mixing aforementioned loops to control the cavity resonance frequency. The prototype water pumping skid operates in combination with the LLRF system to define the set points for the temperature control loop which controls the resonance frequency of the drift tube by regulating its temperature. The design of a cooling water system required for the temperature control of the DTL cavities was given in this report. And it focuses the modelling and simulation of the cooling system, including the component sizing, performance test results and the temperature control scheme.

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WATER PUMPING SKID

Design Specification

The water pumping skid for each DTL drift tube assembly is independently installed for the temperature control. The closed primary loop for supplying the cooling water into DT assembly is designed with constant flow concept using variable total flow depending on RF duty. For the minimization of the delay time and the disturbance, a 3-way control valve is installed on the supply leg and directs a portion of the flow through a plate heat exchanger to dump heat to the chilled water. The remainder of the water is diverted through a by-pass leg, and then the cooling water is blended to regulate the input water temperature into drift tubes. The nominal operating inlet water temperature is 27 °C and should be adjustable in the range of 27±6 °C depending on the operational RF duty modes with a stability of less than 0.1 °C. The electric heater is installed to heat up the cooling water for initial operation mode and proper resonance control during the normal operation if necessary. The water purification units are installed in by-pass line from the supply leg and monitored to preserve the LCW quality. Figure 1 displays the water pumping skid in the PEFP test facility.

A horizontal multi-stage pump, with a total flow rate of 54 m^3/hr and discharge pressure of 5 kg/cm^2, was installed to supply flow rate to the DTL structure. The inline electrical heater of the closed-loop provides warm up in the downstream of the hot-side mixed loop. Expansion tank was equipped with N_2 gas for controlling pressure of the closed-loop. A compact plate heat exchanger with counter-flow type was selected to remove heat. The diverted-type 3-way electronically actuated control valve which is installed at the discharge side of pump directs a portion of the water to the heat exchanger, and the remainder of the flow through the by-pass line regulates the mixed water temperatures supplied into the DTL structure. The cold side of the heat exchanger is supplied with chilled service water having the flow rate of 13.5 m^3/hr at 10 °C from the PEFP facility.

The valves, flanges and other components were installed to meet the pressure drop requirements. The low conductivity water system by-passing about 1~5 % of the total flow rate is composed of 5 micro filter, carbon filter, ultraviolet lamp, and 1 micro filter. The size of the water pumping skid is 3.0×2.8×3.0 m^3. The primary loop has 80A stainless steel pipe and secondary loop 50A stainless steel pipe with the instruments. The supporting structures and electrical wiring have been constructed to consider space allowance, maintenance and replacement of equipment in the klystron gallery.

Figure 1: The fabricated water pumping skid in the PEFP

Simulation Model and Component Sizing

To verify the design, size and flow balancing of the water pumping skid, a computational flow dynamics software package has been utilized. The model of a simplified water skid and flow loop is shown in Fig. 2. It is one-dimensional fluid network model to calculate flow distribution and pressure loss in the piping system. It is comprised of flow paths that are joined at each node with major components of pump, heat exchanger, heater, control valve and DTL structures. Table 1 describes the results of heat load, flow rate, volume and pressure drop for DTL21 to MEBT by using the computational code. From this result, we can predict the need of different types of water pumping skid, depending on the flow rate and pressure drop requirements.

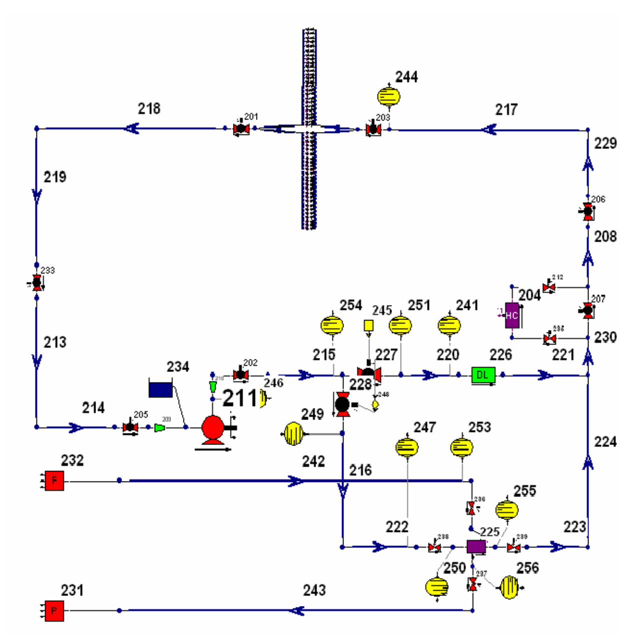

Figure 2: Network model of the pumping skid.

Table 1: Calculated Design Parameters of Water Cooling System under Various PEFP DTL Heat Loads

DTL No.	Heat load [kW]	Flow rate [m^3/hr]	Volume [m^3]	△P [kg/cm^2]
DTL21	95	54	0.6	3.6
DTL22	76	44	0.4	3.4
DTL23	67	38	0.4	3.4
DTL24	61	35	0.4	2.9
DTL101	49	28	0.3	3.9
DTL102	46	26	0.3	3.4
DTL103	45	26	0.3	3.4
DTL104	43	25	0.3	3.1
DTL105	42	24	0.3	2.9
DTL106	42	24	0.3	2.9
DTL107	42	24	0.3	2.9
RFQ	48	28	0.3	3.9
MEBT	21	12	0.2	3.7

PERFORMANCE TEST RESULTS

The water pumping skid has been fabricated and connected with a DTL20-1 structure. Fig. 3 and 4 depict the temperature trend and flow balancing with performance test results, respectively. Particularly, flow balancing in Fig. 4 with the control valve opening represents linear flow characteristics in 20% to 80% through the heat exchanger loop and by-passing leg.

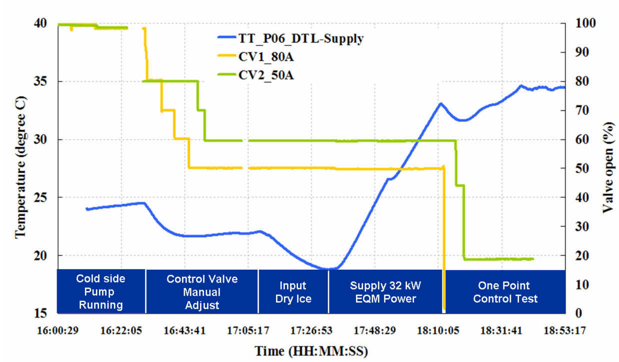

Figure 3: Temperature trend of the DTL supply water during performance test in the PEFP test facility.

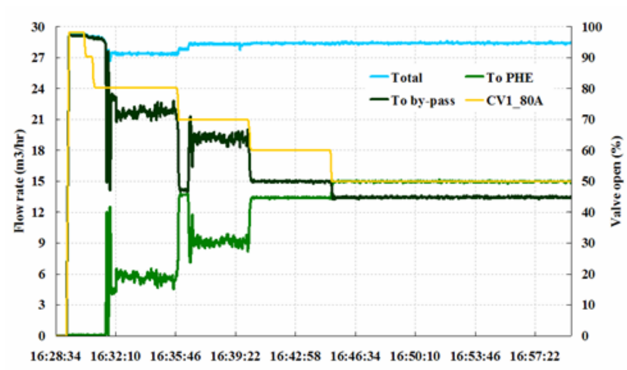

Figure 4: Flow rate balancing in case of valve openings.

TEMPERATURE CONTROL SCHEME

The RCCS water cooling system has a function of removing the heat from RF power loss inside a DTL cavity and allows fast, accurate and flexible temperature control. The mid-ranging idea is adopted as indicated in Fig. 5, that is to have the fast input U_1 controlling the process output (temperature), and to use the effect of the slower input U_2 to gradually reset or mid-range U_1 to its desired value, U_r.

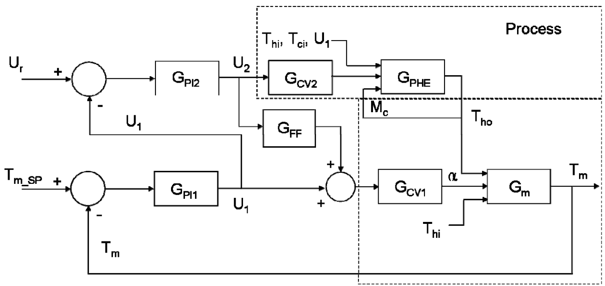

Figure 5: Features of TISO mid-ranging control.

Fig. 6 and 7 shows the step response features with mid-ranging control of the cooling water temperature. Especially, temperature behaviours with step up and step down of set points are stabilized with primary control valve opening of 50% while the secondary control valve opening is regulated depending on the flow rate through it.

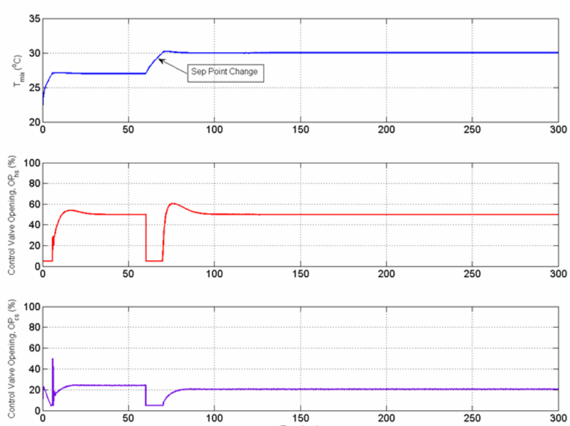

Figure 6: Step up in cooling temperature.

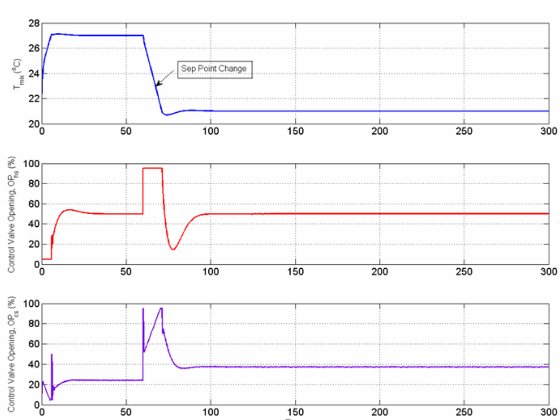

Figure 7: Step down in cooling temperature.

As indicated in Fig. 8, transient response of frequency shift from the calculation depending on RF power variation is within less than ±1 kHz for 20 % to 65 % of the hot side flow rate in the PHE loop during the 65% cold side flow rate.

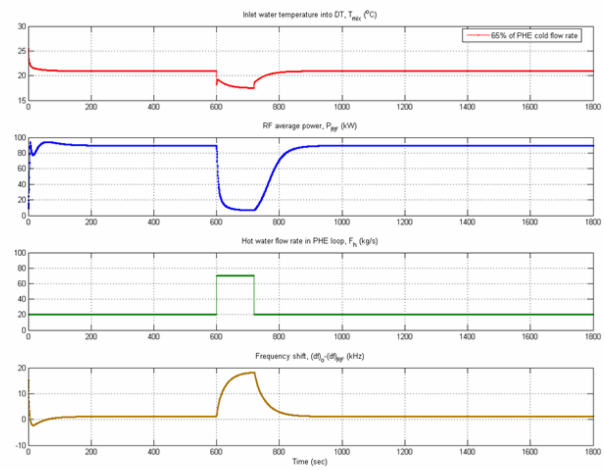

Figure 8: Transient response of frequency shift depending on the temperature variation under various flow rates.

CONCLUSION

The prototype of RCCS water cooling system of PEFP DTL for regulating the drift tube resonant frequency has been designed and fabricated. The flow balancing and pressure loss ratings for each component network has been simulated and tested. The hydraulic performances of cooling system were satisfied with the designed values. Finally, temperature control for water cooling system was simulated with mid-ranging scheme for resonance frequency or phase control. The results indicate that the mid-ranging control largely improves the performance during the large set-point changes or disturbances. However, more investigation of the tuning of mid-ranging control and how to implement the anti-windup of control valves has to be needed in real RCCS application.

REFERENCES

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