# SIMULATION AND DESIGN OF THE HIGH PRECISION TEMPERATURE CONTROL FOR THE DE-IONIZED COOLING WATER SYSTEM

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*Abstract*

Previously, the Taiwan Light Source (TLS) has proven that the temperature stability of de-ionized cooling water is one of the most critical factors of electron beam stability. A series of efforts were devoted to these studies and promoted the temperature stability of the de-ionized cooling water system within ±0.1 ℃. Further, a high precision temperature control ±0.01℃ has been conducted to meet the more critical stability requirement. Using flow mixing mechanism and specified control philosophy can minimize temperature variations effectively. The paper addresses the mechanism through simulation and verifies the practical influences. The significant improvement of temperature stability between cooling devices and de-ionized water are also presented.

## INTRODUCTION

A system for cooling de-ionized water is important in the accelerator field. TLS continues to investigate the improvement of thermal effects related to its accelerator machine [1~3]. To achieve a highly precise control of the temperature of water within ±0.01 $^{o}$C, the preliminary work [4] on a system to cool de-ionized water serves as a basis of further comprehensive investigation for the future Taiwan Photon Source (TPS). The nonlinear water flow caused by control valves and the heat exchangers dominate the highly precise temperature control. Here we decouple the temperature variations mainly on the basis of the frequency of oscillations. The variations at low frequency will be regulated with the oscillating control of a valve. The variations at high frequency will be suppressed with a sufficiently large tank as a mixing buffer. The other interference related to precision control is also considered carefully.

## TEMPERATURE VARIATIONS RELATED TO WATER FLOW CONTROL

For precise control, we use a commercial controller (NI PAC), which has a 24-bit RTD module with a temperature range -200 ~ 850 $^{o}$C that is operable in a high-resolution mode with noise level 0.003 $^{o}$C. Unlike other controllers, this 24-bit resolution can fulfil our requirement for detailed observation of phenomena, and the mode with high resolution and high speed is an optimal option for data at varied frequency. As shown in Figure 1, the high-speed mode has a greater noise level (in range 3200~5900 s) than the high-resolution mode (in range 0~3200s). The temperature sensor and control valve must be chosen carefully. Because we seek to implement control that is precise but not accurate, only 1/10 DIN Class B temperature sensors are selected for cost effect in the overall distribution of the future. The equal percentage of control valves has been selected with corresponding to heat exchangers, but water flows still have a serious non-linear phenomenon as Figure 2 shows. This command of the control valve cannot match the feedback signal of the control valve, because valves generally have a range ability only 2 %, which results in a step control and misleads for a continuous PID control. This variations of the temperature of the supply water has drifts and jumps.

To overcome this problem, an oscillating control of valves will be implemented. The oscillating command can actuate the valve control with 2 % greater fine tuning than previously. Although the water temperature has larger variations, the time average of variations at a low frequency will be stable, and the average process will be implemented in a buffer tank for sequential mixing.

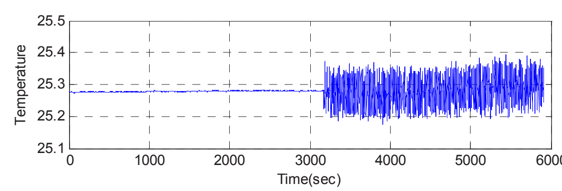


Figure 1: Comparison of noise level between high-resolution and high-speed modes.

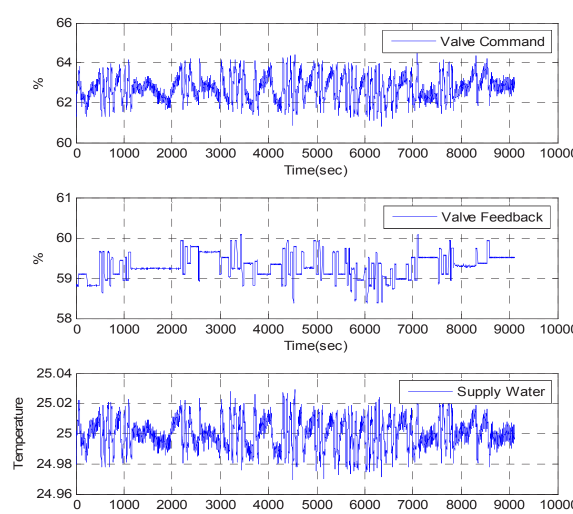


Figure 2: Range ability effect of a valve.

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## TEMPERATURE VARIATIONS RELATED TO MECHANISM OF MIXING

Because control is oscillatory, the temperature variations induced at a high frequency must be suppressed with a mixing mechanism. We use a sufficiently large buffer tank to undertake the mixing. Assume that the inlet water of a tank as shown in the red area of Figure 3 can be completely mixed with the remaining storage water as shown in the blue area of Figure 3. The inlet water has capacity $C_i$ with temperature variations $T_b \pm t_b$ °C; the remaining storage water has capacity $C_t - C_i$ with temperature variations $T_a$ °C. Complete mixing is expressed as

$$T = \frac{C_t - C_i}{C_t} T_a + \frac{C_i}{C_t}(T_b \pm t_b) \qquad (1)$$

Based on equation (1), if total capacity $C_t$ is sufficiently larger than inlet water $C_i$, the temperature variations of the outlet water can be suppressed automatically. We therefore design a large tank with a complete mixing mechanism to achieve small variations of temperature.

For recursive calculation of the variations of the temperature of the inlet and outlet water with a constant flow rate, the equation derived becomes

$$T(k+1) = \frac{C_t - C_i}{C_t} T(k) + \frac{C_i}{C_t} u(k) \qquad (2)$$

The complete mixing temperature $T(k+1)$ is achieved, if $u(k)$ is the inlet water temperature and $T(k)$ is the storage water temperature at time *k*. As shown in Figure 4, the numerical simulation yields the best result of the variations of the outlet temperature within ±0.005 °C for variations of inlet water temperature within ±0.1℃. The simulation therefore provides a satisfactory reference to design an excellent mixing mechanism for the buffer tank.

The CFD simulation shows the flow pattern of the tank as shown in Figure 5. The bottom port is the inlet of water and the top port is the outlet. The water flows along with the inner circumference of the tank, which shapes a helical flow pattern to mix the water. The experimental result shows variations of the water temperature after the tank can keep within ±0.01 °C, even if variations of the water temperature before the tank is within ±0.1 °C and a perturbation occurs in the return loop as shown in Figure 6. To shrink the buffer tank in consideration of space, the mixing mechanism must be optimized further.

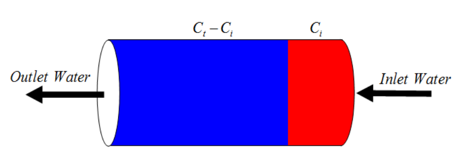


Figure 3: Scheme of the mixing buffer tank.

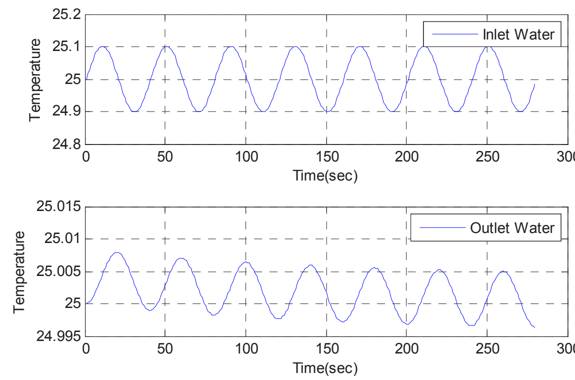


Figure 4: Numerical simulation of flow mixing in the buffer tank.

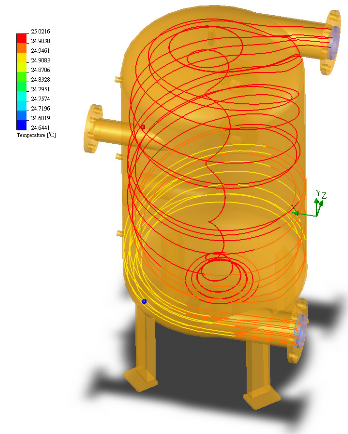

Figure 5: CFD simulation results of flow mixing in the buffer tank.

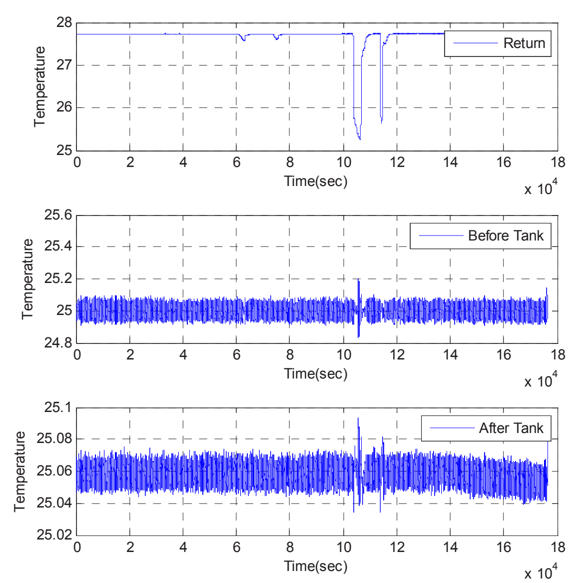


Figure 6: Temperature variations after and before the buffer tank.

## TEMPERATURE VARIATIONS RELATED TO OTHER ISSUES

Besides the above description, other issue with temperature variations around 0.03 °C have significant influence on the high precision control with order of magnitude with ±0.01 °C. The thermal isolation of the piping and facilities must be considered carefully. As shown in Figure 7, the temperature variations of the supply water coupled with environmental temperature variations has a large extent of difference with headwater located after the tank. The feedback temperature sensor must be carefully installed. Figure 8 shows that the varied thickness of a thermal paste can affect the sensor response, and give a different control feedback signal. The occasional coupling effects of electronic circuits must be clarified further as shown in Figure 9. The temperature of the supply water and the thermostat has a strong correlation, whereas these systems are complete independence except using the same data acquisition modules.

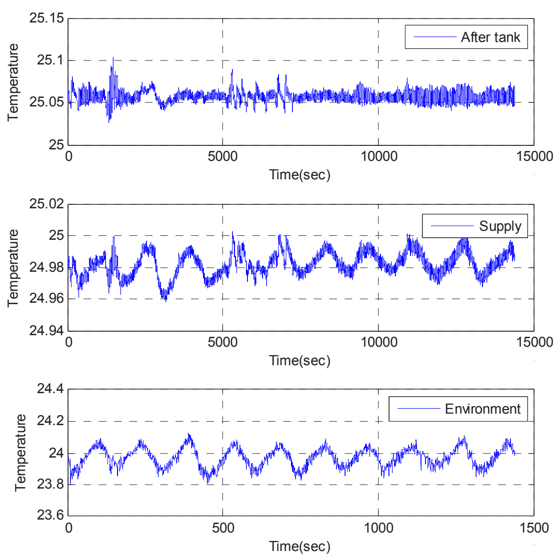


Figure 7: Temperature variations of changes of environmental temperature.

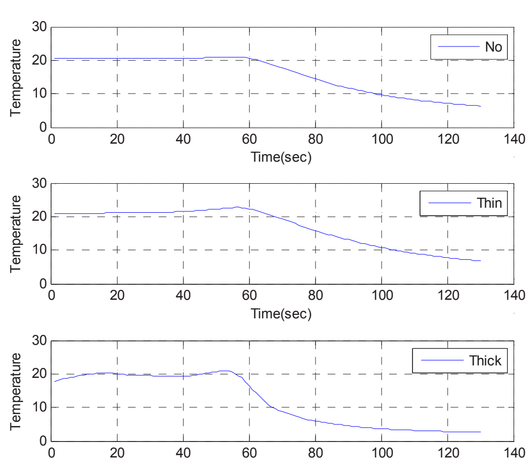


Figure 8: Temperature variations of the varied thickness of a thermal paste.

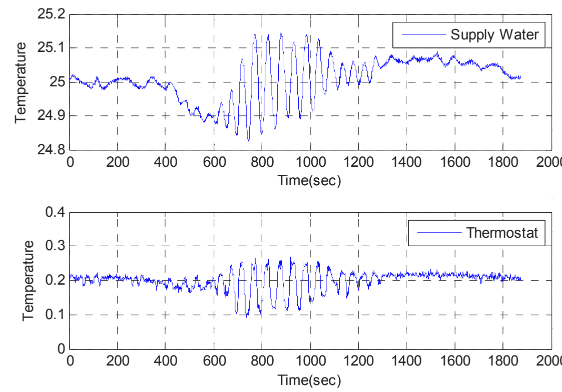


Figure 9: Temperature variations of coupling effects of electronic circuits.

## CONCLUSION

We here describe a highly precise control of the temperature of de-ionized water in a cooling system. These efforts are devoted to improve the nonlinear flow control and to suppress temperature variations. The system adopts mainly an oscillating valve control to regulate temperature variations at a low frequency and a mixing tank as buffer to suppress variations at a high frequency. Other issues also been carefully implemented, including effects of the environmental temperature, thermal paste and electronic coupling.

## ACKNOWLEDGEMENT

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