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Resonance Control Cooling System for 973 RFQ at IHEP

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Abstract: Since the beam transmission of a Radio Frequency Quadrupole(RFQ) Accelerator is very sensitive to the field profile, the ordinary frequency tuning method by the local movable tuner is no more adopted in an RFQ operation. The tuning method by controlling cooling water temperature is widely adopted to tune the RFQ due to the less affect on the RFQ field profile. A Resonance Control Cooling System (RCCS) is developed and commissioned for the 973 RFQ, which is a R&D project for C-ADS and CSNS RFQ at IHEP. This system adopts the RF phase difference as control variable to tune the RFQ. The control accuracy of the RF phase difference is about $\pm1°$. The running of the 973 RFQ shows that the RCCS works very well and fully satisfies the operation requirement of the RFQ. In this paper, the water skid, resonance control system of the RCCS and the operation experiences will be presented.

Key words: RFQ; RCCS; water-cooling skid; control system

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1 Introduction

China Accelerator Driven Sub-critical reactor System (C-ADS) and China Spallation Neutron Source (CSNS) are two large scientific projects underway in China. C-ADS is a strategic plan to solve the nuclear waste and the resource problems for nuclear power plants in China. A RFQ is adopted in the low energy section of linear accelerators for both C-ADS and CSNS[1], and the 973 RFQ which has been developed at Institute of High Energy Physics (IHEP), Chinese Academy of Sciences, is a R&D work for C-ADS and CSNS RFQ . The main parameters of the 973 RFQ at IHEP are shown in the Table 1.

Table 1 The main parameters of the 973 RFQ at IHEP

Parameters	Value
Input energy / keV	75
Output energy / MeV	3.5
RF frequency / MHz	352.2
Pulsed beam current / mA	44
Beam duty factor / %	~ 15
RF duty factor / %	~ 17
Cavity power dissipation / kW	430
Total RFQ length / m	4.75
Structure	4-vane
Module number	4

It is very important for the RFQ to keep in the resonant state in operation. The RFQ resonant state is kept by adjusting the RFQ resonance frequency same as the RF frequency which is fixed by the Low Level RF (LLRF) control system. It is obvious that the RFQ resonance frequency is only a function of its internal geometry. Using the movable tuner, the geometry and the resonance frequency can be adjusted. However, because the movable tuner changes the field profile when it is used to tune the RFQ and the beam transmission of RFQ is highly sensitive to the field profile, the movable tuner is not suitable for RFQ. The geometry can be also adjusted through controlling the temperature of the cooling water for RFQ. In addition, because the cooling water channels are normally drilled symmetrically in the RFQ, the deformation caused by the cooling

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water temperature variation is also symmetrical. Therefore, to tune the RFQ by controlling the temperature of the coo-ling water for RFQ can basically not affect the field profile. RCCS for RFQ is a system that replaces the traditional resonance control loop which uses movable tuners by controlling the temperature of the cavity cooling water.

According to the results of the thermal analysis of CSNS RFQ and J-PARC RFQ, the RFQ resonance frequency is nearly linear with the temperature of the cooling water[2−3]. There are four ways to tune the 4-vane type RFQ by water-cooling system. The first one is to adjust the temperature of the cooling water in both the vanes and the cavity wall together. The second one and the third one are to adjust the temperature of the cooling water in the cavity wall while keeping the temperature of the cooling water in the vanes stable, or conversely. The last one is to adjust the temperature of the cooling water in the vanes and the cavity wall separately at the same time. Comparing the frequency shift sensitivities to the temperature of the cooling water among the four tuning ways, it is known that the frequency shift sensitivity of the first way is much lower than those of the other three[2]. The first way is generally not adopted. In the meantime, the fourth makes the control system more complicated. It is not adopted neither. At present, the RCCS for the 973 RFQ adopts the second one. In the near future, the third one will be also adopted and comparisons between the second and third ways will be carried out. Here only RCCS using the second method is introduced.

2 Water-cooling skid

In Fig. 1, the water-cooling skid is shown. The vanes and the wall of the RFQ cavity are cooled respectively by two independent deionized water-cooling systems.

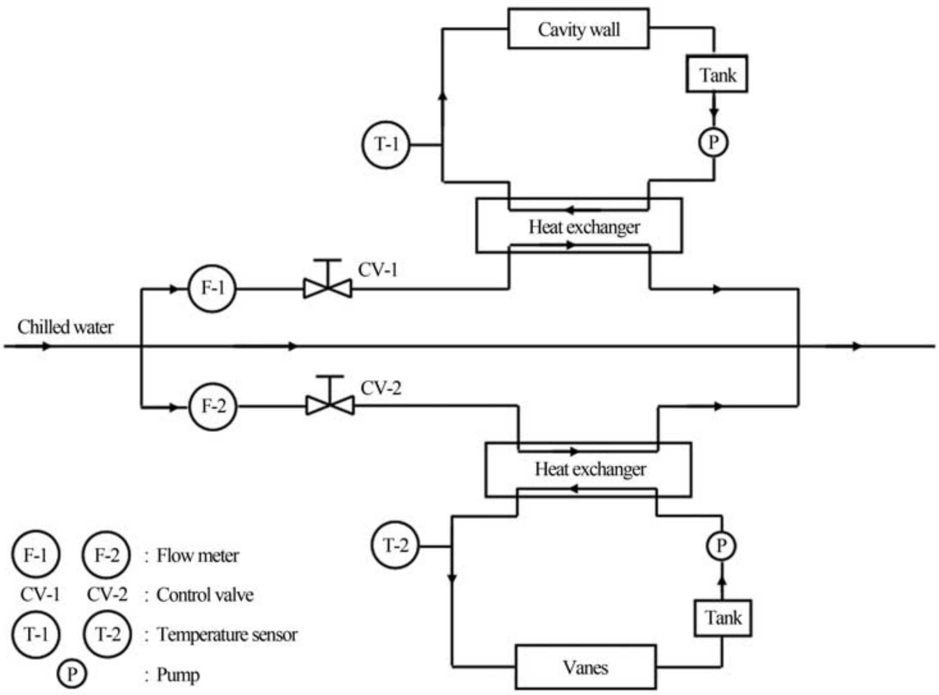

Fig. 1 The water-cooling skid.

As shown in Fig. 1, the temperature of the water that is used to cool the cavity wall and the vanes are manipulated by controlling the chilled water flow through controlling valve CV-1 and CV-2, respectively. While the water flow in the two water-cooling loops keeps constant, the chilled water flow in the two chilled water loops is monitored by flow meters F-1 and F-2, respectively. The chilled water with a temperature about 10 °C at the cold sides of the two heat exchangers is fed from conventional facilities. The temperature of the cooling water will decrease or increase when the flow of the chilled water through the heat exchanger is raised or lowered, respectively. The capacity of each tank is about 1 ton and the water in the two tanks participates the water-cooling loop directly.

3 The resonance control system

The resonance control system is divided into two subsystems in function.

3.1 The water cooling control subsystem for the cavity wall

The water cooling control subsystem for the cavity wall adjusts the temperature of the cooling water in the cavity wall. It has two working modes, the phase mode and the temperature mode.

The RF phase difference $\Delta\varphi$ between the RF phase picked from the cavity and the RF phase picked at the end of the waveguide is chosen as the controlled variable in the phase mode. Because the RF phase difference $\Delta\varphi$ is approximately linear to the resonance frequency shift when the RFQ cavity is near the resonant state, it can be used to show whether the RFQ is resonant or not and how far the RFQ is from the resonant state. The RF phase difference corresponding to the resonant state of the RFQ is denoted by $\Delta\varphi_0$. It is obtained through experiments. The objective of the water cooling control subsystem for the cavity wall is to adjust $\Delta\varphi$ to $\Delta\varphi_0$ when it is running in the phase mode. Proportional integral derivative (PID) control algorithm is adopted for this mode. In the experiments, the input digital value of $\Delta\varphi$ is supplied by LLRF control system. In the temperature mode, the subsystem only adjusts the temperature of the cooling water in the cavity wall to a pre-set temperature value but do not care about the $\Delta\varphi$ variation. The temperature mode can't ensure the RFQ staying in the resonant state any more when the cavity power dissipation changes. This is the disadvantage of temperature mode.

Fig. 2 is the state diagram of the water cooling control subsystem for the cavity wall. When the subsystem starts, it firstly runs in the temperature mode to let the temperature of the cooling water in the cavity wall near to the RFQ working temperature. If the initial temperature of the cooling water is higher than the RFQ working temperature, the subsystem can easily make it decrease. But if it is lower than the RFQ working temperature, the warming up process will take a long period of time. In order to shorten this warming up process, a heater is generally adopted in the cooling systems applied in some other labs. However, the heater damages the quality of the deionized water based on our operation experience. The method that we adopt is to feed the RF power into the RFQ cavity while LLRF control system adjusts the RF frequency to the RFQ resonance frequency. After the temperature of the cooling water reaches the RFQ working temperature, the LLRF control system fixes the RF frequency to working frequency and the subsystem starts to run in the phase mode to ensure that the RFQ operating in the resonant state. If there is a problem with the LLRF system, the subsystem will switch from the phase mode to the temperature mode automatically. This will be described in detail below.

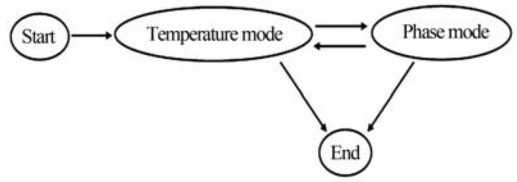

Fig. 2 State diagram of the water cooling control subsystem for the cavity wall.

3.2 The water cooling control subsystem for vanes

As the water cooling control subsystem for the cavity wall running in the temperature mode, the water cooling control subsystem for vanes is to adjust the temperature of the cooling water in the vanes to the reference temperature 20 °C.

3.3 The hardware structure of the resonance control system

Fig. 3 shows the hardware structure of the resonance control system.

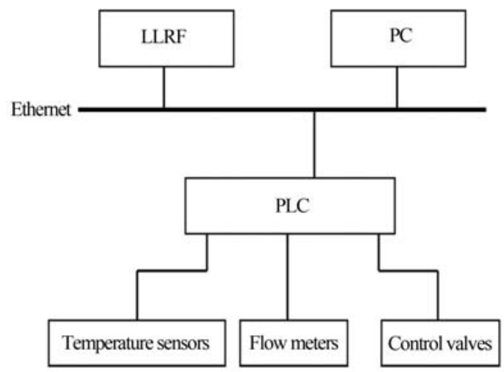

Fig. 3 The hardware structure of RCCS.

The control program is running on a PC. The communication between LLRF and the PC is through the Ethernet. The YOKOGAWA PLC is adopted as the interface between PC and field equipments. And the control software is developed using EPICS (Experimental Physics and Industrial Control System)[4].

4 The commissioning results of RCCS

The stability of the RF phase difference $\Delta\varphi$ is within $\pm 1°$ around the reference phase difference $\Delta\varphi_0$ after a period of transient time. The results are got with the water cooling control subsystem for the cavity wall working in the phase mode. Based on the beam dynamic simulation of RFQ, the resonance frequency shift of an RFQ should be limited within ± 20 kHz*m[2]. So, for our 4.75 m length RFQ, the tolerable resonance frequency shift is within about ± 4.21 kHz. And the corresponding tolerable RF phase difference $\Delta\varphi$ is within $\Delta\varphi_0 \pm 4.67°$. So the developed RCCS fully satisfies the requirement of RFQ on the cavity resonance condition. Fig. 4 shows one of the commissioning results of RCCS for the RFQ. The trace shows the evolution of RF phase difference $\Delta\varphi(\Delta\varphi_0 = -153°)$.

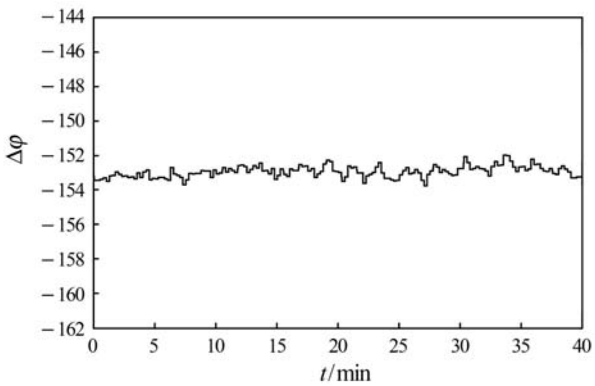

Fig. 4 The commissioning result of RCCS for RFQ.

During the operation, we find that when there is a problem with the LLRF system, the phase difference signal $\Delta\varphi$ got from the LLRF control system moves up and down sharply as shown in Fig. 5. If the water cooling control subsystem for the cavity wall is in the phase mode, the position of the control valve will change frequently. Obviously, this is what we don't expect to see. So in this case the water cooling control subsystem for cavity wall switches from the phase mode to the temperature mode automatically. After the LLRF system recovers, the subsystem will return to the phase mode.

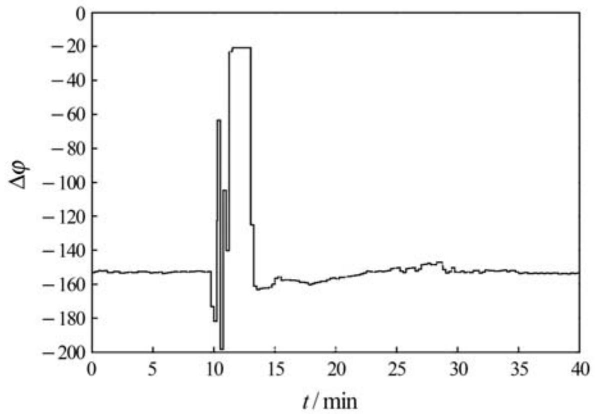

Fig. 5 The oscillation of the phase difference signal when the LLRF system has a problem.

5 Conclusions and plans

An RCCS for RFQ is developed. The experimental results show that, with the water cooling control subsystem for the cavity wall working in the phase mode, the stability of RF phase difference $\Delta\varphi$ can be kept within $\pm 1°$ around the reference phase $\Delta\varphi_0$. The developed RCCS fully satisfies the requirement of RFQ on the cavity resonance condition. The other method, to stabilize the temperature of the cooling water in the cavity wall and to adjust the temperature of the cooling water in the vanes, will be also adopted and comparison between the two methods will be carried out. Experiments will be done to improve the stability of the chilled water on temperature and pressure.

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973 RFQ 水冷调谐系统

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摘要： 由于束流的传输效率对射频四极场加速器 (RFQ) 中射频场的分布极其敏感，所以在 RFQ 的运行过程中不再采用传统的调谐器调谐 RFQ。水冷调谐的方法基本上不影响 RFQ 射频场的分布，所以适用于 RFQ 的调谐。中国科学院高能物理研究所为 C-ADS、CSNS 预研 RFQ 项目开发建造了一套水冷调谐系统，使用 RF 相位差作为控制量进行 RFQ 水冷调谐，相位差的控制精度达到了±1°，运行结果显示该系统满足了 RFQ 的调谐需求。介绍了该系统的水冷系统、调谐控制系统和一些运行经验。

关键词： 射频四极场加速器；水冷调谐系统；水冷系统；控制系统

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