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THE RADIAL DETECTOR IN THE CYCLOTRON OF HIMM

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Abstract

The cyclotron is designed as the injector of the Heavy Ion Medical Machine (HIMM) in Wuwei city, China. It provides 10 uA carbon beams to fulfill the requirement of the accumulation in the following synchrotron. The Radial detector is used to measure the beam current and beam turn motion in this Cyclotron. The beam current signal gathered by radial detector is acquired by four picoammeters, meanwhile the beam time structure is measured with FPGA and real time operating system. This paper introduces the design of radial detector, the motion control and data acquisition system for it of the cyclotron.Finally, the beam current and turn pattern measurement results at HIMM are presented in this paper.

INTRODUCTION

The first Heavy Ion Medical Machine (HIMM) has passed the registration tests and now enters the clinical trials phase which was constructed at the Institute of Modern Physics, China [1]. A compact cyclotron is designed as the injector of a synchrotron which forms the HIMM, and it accelerates the $^{12}C^{5+}$ from ion source to 7.0MeV/u, meanwhile the extracted beam current is more than 10uA [2].

As its compact structure of the cyclotron, there are 2 radial probes installed on the hill and in the valley respectively of Cyclotron. The one installed in the valley is used to monitor the beam current during the injection period, and the other one installed between the extraction deflector and extraction dipole is used to monitor the extraction beam current. Furthermore, the beam centre measurement can be done with the two targets during the acceleration period. The radial probe installed on the hill is shown in Fig.1. And for each radial probe, it is driven with a servo motor. The moving distance of the radial probe is 795 mm.

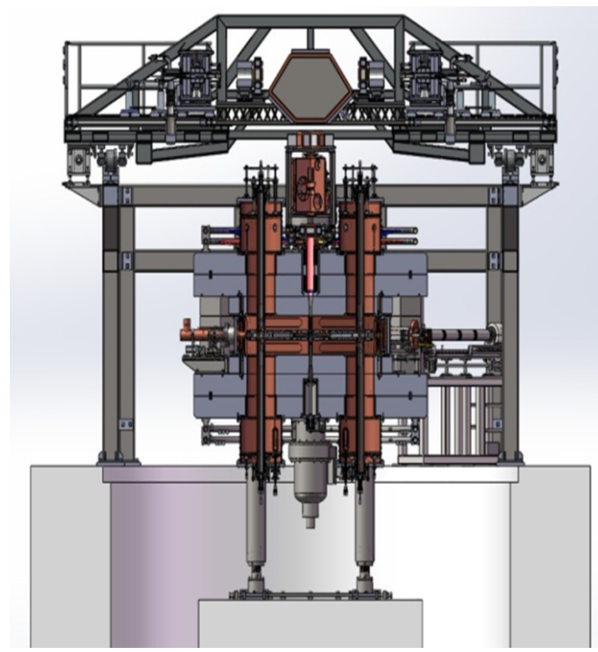

Figure 1: Radial probe installed on the Cyclotron.

DESIGN OF RADIAL PROBE

Mechanical Design

The radial probe target tip, making up by one integral block and 3 differential fingers which are distributed concurrently in the horizontal direction, measure the beam distribution on axial and radial directions by blocking the beam [3]. The 3 differential fingers are distributed uniformly in the vertical direction with the gap of 5mm. The sizes of the integral and differential target tips are listed in table 1.The radial probe target tips are made by copper. The top view of the radial probe is displayed in Fig.2 and the target probe structure is shown in Fig.3.

Table 1: The Size of Four Fingers

Finger Name	Size(mm)
Integral Finger	40
Differential Top	10
Differential Middle	10
Differential Bottom	10

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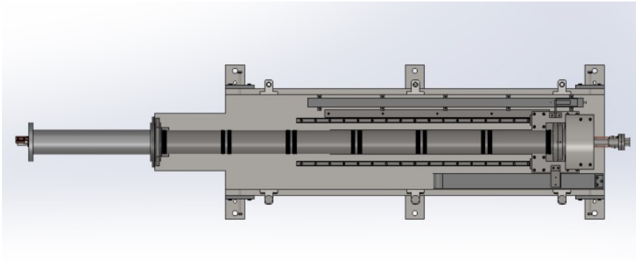

Figure 2: Structure of the radial probe from the top view.

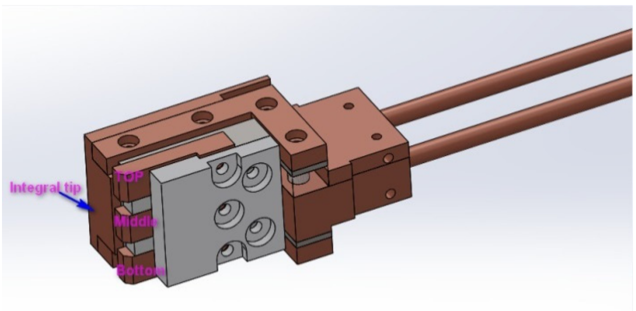

Figure 3: Structure of the radial probe the target tips.

Thermal Structural Analysis

The extraction beam energy of Cyclotron is 7MeV/u, and the beam current is 10uA.The beam profile hit on the radial probe is set to 10 mm. The structure of the radial probe without and with water-cooled is analysed with the above parameters in this paper. As shown in Fig. 4, it can be seen that the temperature of the radial probe target tips is more than 2500°C which exceeds the melting point of the copper, which can directly cause damage to the target. As a result, it is essential that a water-cooled structure is a necessary design.

For the water-cooled structure of the probe, by setting the flow rate is 4m/s, the water pressure is 5kg, and then the flow analysis result is introduced into the thermal analysis. According to the results of thermal analysis, as shown in Fig.5, it can be seen that the maximum surface temperature is about 500°C, which is much lower than the melting point of tantalum of 2996°C, also much lower than the melting point of copper of 1083°C. Therefore, the water-cooled radial probe structure with these designed parameters is in the range of the thermal tolerance. What's more, between the integral and the differential tips is a layer of heat conducting ceramic made of aluminium nitride that can enhance the effect of water cooling[3].

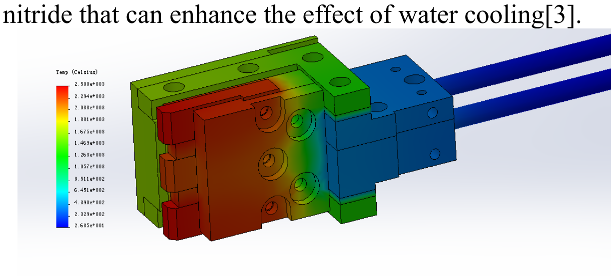

Figure 4: Thermal structural analysis of the radial probe without water-cooled design.

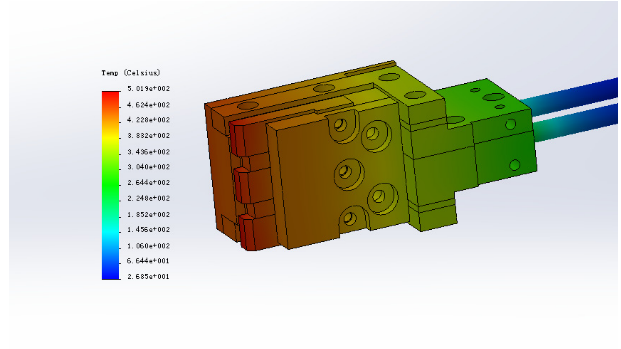

Figure 5: Thermal structural analysis of the radial probe with water-cooled design.

CONTROL AND THE DATA ACQUISITION SYSTEM OF THE RADIAL PROBE

The control hardware of the radial probe is based on FPGA and real-time (RT) operating system. The application of FPGA can realize the precise timing, trigger, control, synchronization and user-defined high speed communication protocol requirements. The real-time operating system can ensure the realization of the deterministic control, data processing and data logging. Furthermore, the whole control system is based on the National Instruments CompactRIO hardware. The control and the data acquisition system are shown in Fig.6.

The NI CompactRIO 9075[4] is in charging of acquiring the beam current from the picoameters where the beam current is convert to voltage linearly. Meanwhile, the position of the radial probe detector is read by the resolver and sampled simultaneously with the beam current signal at the FPGA and then transferred to RT by FIFO. Accordingly, the beam current and the related position are finally parsed at the GUI. The position information is acquired from the Kollmorgen servo motor with a resolver encoder whose resolution is 24 bits [5]. And the mechanical position precision is less than 1mm almost to 0.5 mm which means the whole control system can reach the 0.5 mm position precision compared with the encoder position resolution.

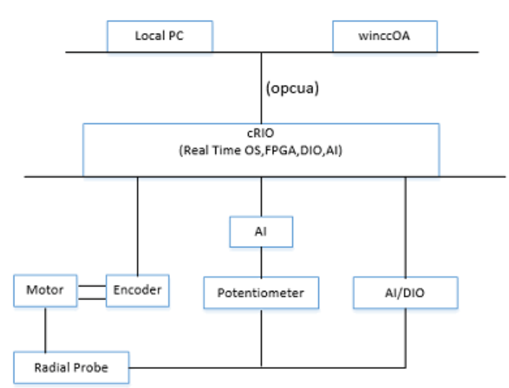

Figure 6: The hardware framework of the radial probe control system.

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The software framework is designed and implemented with modularity technology which is organized by the producer-consumer design pattern. The modularity design makes it fast to transplant the modules to the other similar projects of beam diagnostics front-end control system of the heavy ion accelerator transparently. The automated variables publication of OPC UA communication protocol [6] is implemented based on the XML configuration files [7]. The XML file for the radial probe is shown in Fig.7. Furthermore, it is validated the feasibility of accessing the database by OPC UA variables. The control information is sent into the beam diagnostics database developed with MariaDB[8]. And there are three tables for the target which are the motion table, the DAQ table and a static table consists of the detector's installation, connection cables, and the network connection and so on.

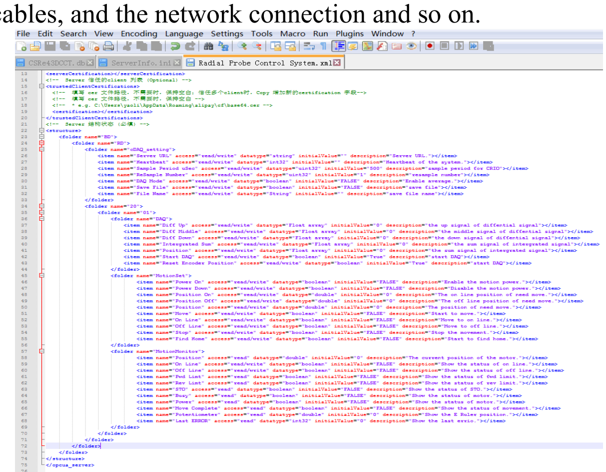

Figure 7: The XML configuration file for radial probe control system

TEST RESULTS

As mentioned above, there are two channels output signal from the picoameters, one is read out from the serial port for daily monitoring during the commissioning. The control and monitoring information is shown in Fig.8 when there is no beam. While the read out data connected to the CompactRIO is used to measure the beam time structure and analyse the signal frequency information for diagnostics purpose shown in Fig.9.

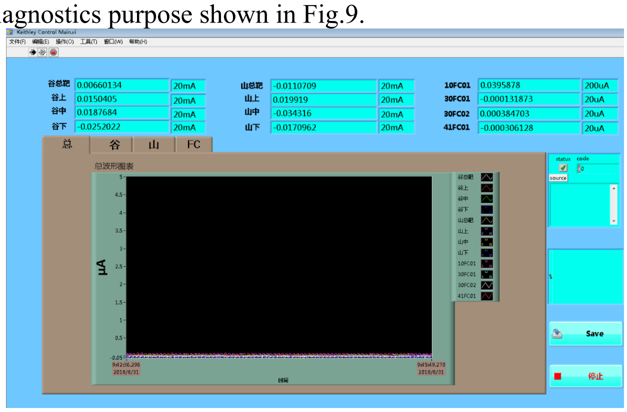

Figure 8: The beam current measurement for Radial Probes and Faraday Cups by serial port connection.

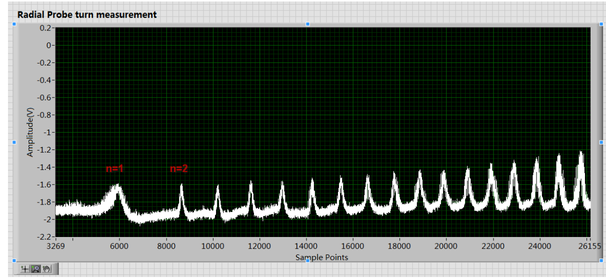

Figure 9: Beam turn measurement.

CONCLUSION

The two radial probe installed in the HIMM cyclotron can measure the beam intensity at low energy region and get the beam turn pattern information. According to its application and the test results of the radial probe, it plays an important role in the commissioning and operation period for HIMM. As a result, it is essential in improving the efficiency of beam injection and extraction.

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