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# COLLIMATOR FOR BEAM POSITION MEASUREMENT AND BEAM COLLIMATION FOR CYCLOTRON

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*Abstract*

In order to restrict the beam dispersion and diffusion at the extraction area of the cyclotron and to detect abnormal beam loss, a beam collimator system has been designed to collimate the beam and to measure its transverse positions. The collimator system is composed of a vacuum cavity, two pairs of beam targets, a set of driving and supporting mechanism, and a measurement and control unit. The beam target with the size determined by the diameter of the beam pipe, the particle energy and beam intensity, will generate current signal during particle deposition. Each pair of beam targets has bilateral blocks which forms a slit in either horizontal or vertical direction. Servo motor and screw rod are used so that the target can reciprocate with the repeatability of less than 0.1mm. The measurement and control system based on LabVIEW can realize the motion control and current measurement of the targets and then calculate the beam transverse positions.

## INTRODUCTION

The project of superconducting cyclotron for proton therapy SC200 is under development at ASIPP (Hefei, China) and JINR, which will be able to accelerate protons to the energy 200 MeV with the maximum beam current of 400 nA [1-3].

The collimator has been developed to reduce beam diffusion at the extraction area of the cyclotron and to detect abnormal beam loss, and then to measure the beam positions in horizontal and vertical directions.

The beam collimation system works in high-radiation areas and requires high heat dissipation, radiation resistance, positioning accuracy, stability and high vacuum performance, while considering the remote operation and maintenance functions of the collimator [4].

## STRUCTURAL DESIGN

### Mechanical Design

The collimator system is composed of a support gantry, servo drive unit, a vacuum chamber, bellows, and tungsten targets.

The vacuum chamber of the collimator is connected to the beam line through the flange before and after, and the overall leak rate is less than $1.0 \times 10^{-11}$ Pa·m$^2$/s. Four tungsten targets are installed respectively in the upper, lower, left and right directions of the vacuum chamber to collimate the beam and to measure its transverse positions.

The tungsten target is connected to the slide table of the lead screw through a transmission rod. A bellows is used to ensure the vacuum of the vacuum chamber. The lead screw is driven by a servo motor.

The entire collimator is mounted on the support structure, and four bolts are used to achieve height adjustment and level adjustment of the collimator.

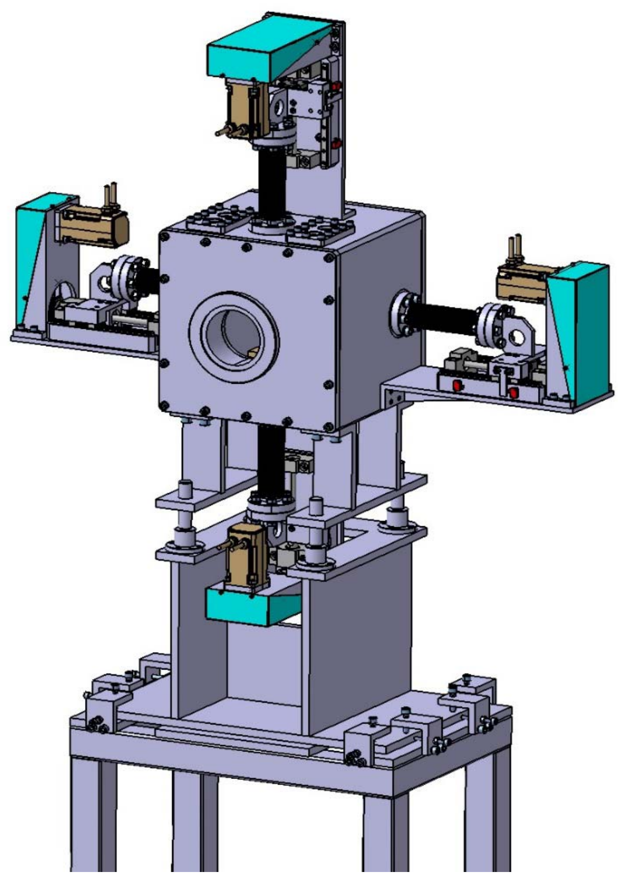

Figure 1: Layout of the collimator.

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### *Installation Position*

The collimator is installed at the Beam extraction area of the cyclotron, and the distance between the collimator and the centre of the cyclotron is 1.8m. The assembly picture of the collimator is shown in Fig. 2.

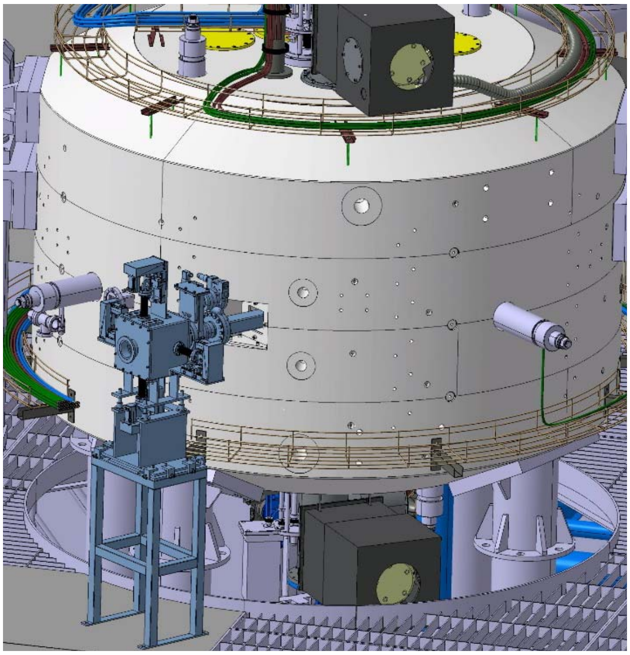

Figure 2: The assembly picture of the collimator.

## THERMAL STRUCTURAL COUPLING ANALYSIS

Thermal structural coupling analysis has been performed to provide guidance for the structural design and material selection of the collimator system.

Energy deposition occurs when beam is bombarded onto a tungsten target, so thermal analysis of the tungsten target is required. The calculation results indicates that when the insulating block material is made of peek engineering plastic, the temperature of peek is much greater than its melting point. Because of the higher thermal conductivity and higher melting point of the alumina ceramics, the material of the insulating block is replaced with alumina ceramic from peek. The calculation result which shown in Fig. 3 indicates that the maximum temperature of the target is 392.47 ° C, which meets the design requirements.

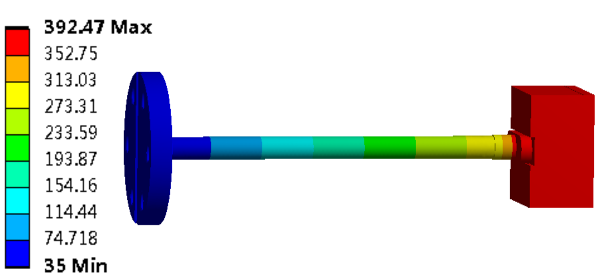


Figure 3: The distribution of the temperature field/℃.

The size of each tungsten target is 40mm×40mm×25mm. According to the design requirements, the deformation of the tungsten target and the transmission rod due to its own weight must be less than 0.5mm.

According to the thermal structure coupling calculation which shown in figure 4, the maximum deformation is 0.288mm, and it can be eliminated by applying pre-stress.

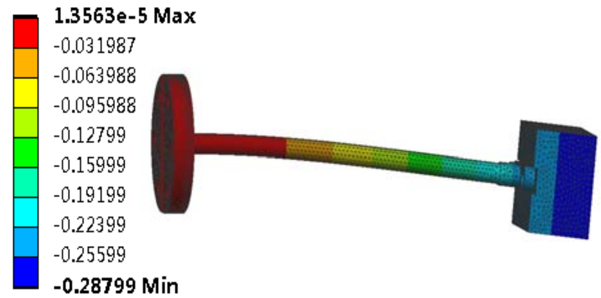


Figure 4: The distribution of the displacement.

## CONTROL SYSTEM

### *Design Requirements*

The control system can achieve precise control of the displacement of the collimator target and achieve high precision measurement of beam current. According to the physical design requirements, the repeat positioning accuracy is required to be higher than ±0.1mm, and the beam current intensity measurement accuracy is higher than ±(1+5%rdg)nA.

### *Hardware Design*

The control system consists of a motion control unit and a beam current measurement unit, whose hardware architecture diagram is shown in Fig. 5.

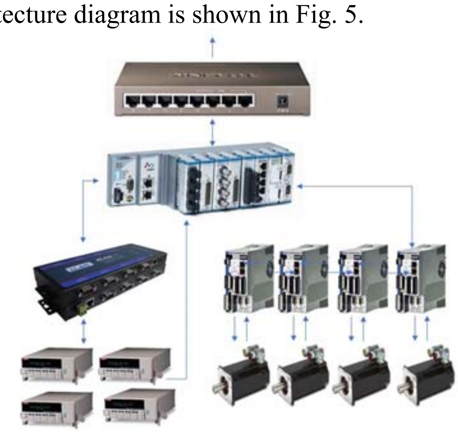

Figure 5: Hardware architecture.

The collimator control system is built on a distributed architecture, and the NI CompactRIO real-time controller is used as the server computer to realize the integrated control of the underlying device. Four Keithley 6485 picoammeters have been adopted to realize accurate measurement of the beam current from four tungsten targets. A serial server is equipped to convert serial ports of picoammeters to one Ethernet port for integrated control and communication.

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Keithley 6485 picoammeters has the function of converting input current into analog voltage signal proportionately [5]. Moreover, an analog input module has been equipped for the rapid measurement of the analog voltage output by picoammeters.

In order to achieve high-precision beam collimation and adjust the beam shape and beam quality, a high precision multi-axis motion control system is designed. The motion control system uses servo motors as actuators to reduce motion errors caused by knocking. Considering that the centre position of the bunch may be offset from the centre of the axis of the collimator, the extreme position of the tungsten target crosses the centre axis, which results in the possibility of collision between the two opposing tungsten targets during the movement. In order to ensure the safety of the movement, the software limit is designed at the same time while the hardware limit switch is set to prevent the collision of the two tungsten targets.

Four servo motors are all controlled by the CompactRIO real-time controller, and the communication protocol is EtherCAT which has the advantages of good synchronization, strong real-time performance, and suitable for any topology [6].

### *Software Design*

As the client of the distributed system, the accelerator control system (ACS) works as the GUI client, and realizes the display, processing and storage of data. The OPC UA communication protocol is used for communication between the collimator control system and the accelerator control system.

The local control system of collimator requires functions such as data acquisition, picoammeter control, motion control, heartbeat monitoring, error handling, and master control communication, and requires synchronization of data acquisition and motion control. The components of the local control program need to communicate constantly with each other, between the components, and between the local control and the ACS. The communication logic is very complicated and difficult to implement with general control logic.

The AMC (Asynchronous Message Communication) reference library is a general-purpose LabVIEW API that can be used to transfer messages within one process, between processes, and between different LabVIEW terminals. The QMH (Queued Message Handler) design template is a general-purpose VI program architecture. The QMH design template based on the AMC API can realize the transmission and reception of messages within the process, between different processes and between different terminals [7, 8]. So the QMH design template based on AMC reference library has been adopted to achieve the programming of the software of the collimator local control system.

## TESTING AND CALIBRATION

According to the design experience, the insulation between different tungsten targets and the insulation to the ground must be greater than 100MΩ to ensure that the leakage current is small enough, and then to increase measurement accuracy. The insulation resistances have been measured by using a megger. It is known from the measurement results that the insulation resistance between the targets of the collimator is greater than 2000 MΩ, and the insulation resistance to ground is greater than 1000 MΩ, which all meet the design requirements.

The measurement accuracy of the collimator control system may be affected by the environmental background noise, so the background noise has also been measured. The background noise measurement results are shown in Fig. 6, which indicates that the background noise is small enough.

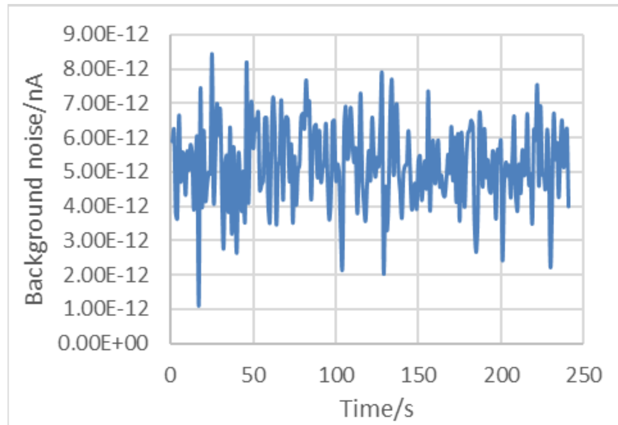


Figure 6: The background noise.

In order to ensure that the measurement accuracy of the collimator control system meets the design requirements, a high-precision current source is used as a reference signal to simulate the true beam current. The current input values are set to 15%, 25%, 50%, 75%, and 100% of the range for the 2nA, 20nA, 200nA, and 2μA ranges of the Picoammeter, respectively. Taking the ratio of the current set value to the picoammeter range as the abscissa, the relative error between the measured average value and the set value is plotted on the ordinate. The relative error of the measurement of different current input values under different ranges can be obtained, as shown in Fig. 7.

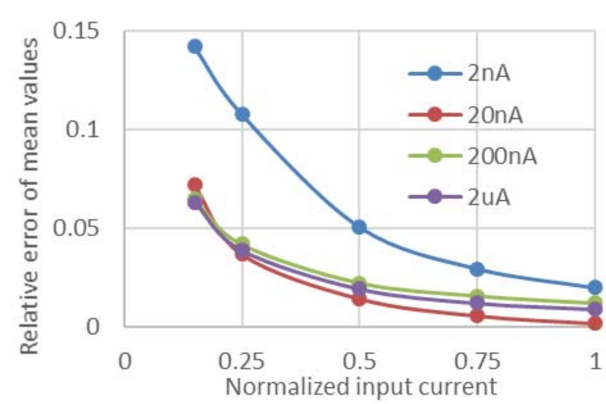


Figure 7: The relationship curves between relative measurement errors and normalized input current at different measurement ranges of the picoammeter.

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As can be seen from Fig. 7, the measurement accuracy meets the design requirements.

The repetitive positioning accuracy of the transmission unit has also been measured by a micrometer to make sure that the motion accuracy meets the design requirements. And the measurement results which are shown in Fig. 8 indicate that the repetitive positioning accuracy is about ±0.006mm, which is much smaller than ±0.1mm.

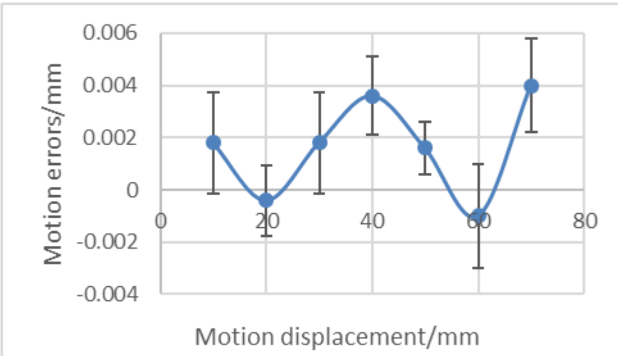


Figure 8: The repetitive positioning accuracy of the transmission unit.

## CONCLUSION

The beam collimation system has been machined and assembled, and its key parameters have also been tested, and all test items have been proven to meet design requirements.

## ACKNOWLEDGEMENTS

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