Introduction for the Alignment of Wuwei HIMM

Wenjun Chen[1,2*]. Yaqing Yang[1]. Guozhu Cai[1]. Shaoming Wang[1]. Jiandong Yhu[1]

[1]Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China

[2]University of Chinese Academy of Sciences, Beijing 100049, China

[*]Corresponding author. *E-mail address:*wenjun8061@impcas.ac.cn

*Tel:*18509316692

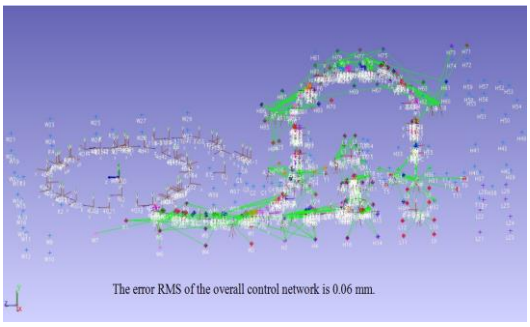
Abstract

Wuwei heavy ion medical machine is the most compact heavy ion accelerator cancer treatment device in the world. The perimeter of the synchronous ring is as small as 56.1m, and the height difference between the high energy line climbing section of the device is about 19m, which is the height difference in the domestic accelerator. The device with the largest span spans tens of thousands of components, and many critical components require sub-millimeter installations. Wuwei heavy ion cancer treatment installations require high positioning accuracy components including beam position detectors, high-frequency cavity, electrostatic deflection plate, peeling film, etc., in which the accuracy of the synchronization ring quadrupoles requirements 0.1mm, Through the application of new techniques and methods in alignment, the technical difficulties of various alignment and installations are solved, and all the components of the device are installed in place with high efficiency and high precision in a short time.

Wuwei heavy ion medical machine control network layout

Due to the large scale of Wuwei's heavy ion devices, various types of buildings on the construction site make the task of alignment a arduous task. The measurement personnel must work hard to do a good job of measurement work with a high degree of responsibility. The establishment of the control network must first meet the accuracy requirements of the stakeout, so that all parts of the installed components are correctly staked out according to the designed plane position and elevation position. Secondly, it should be easy to use and long-term retention. From this perspective, the coordinate system of the control network built should be consistent with the coordinate system used in the architectural design. The control network built by Wuwei heavy ion medical machine has the characteristics of high precision, high density of control points and high use frequency compared with the general control network. This requires us to fully consider these factors when laying out the control network. The accuracy of the layout of the control network should be determined based on the tolerances of the installation components of the installation. Because the tolerance of the installation components is a standard for engineering acceptance, it should also be the basis for determining the measurement accuracy.

Fig.1 3D control network SA software screenshot



Due to the dense installation of components inside the device building and the large amount of work required for layout, it is required that the deployed control network has a sufficient density. Taking into account the need to measure the positioning during the installation of the device at all stages, the use of control network points increases, which requires the control of the network site is stable, easy to use, and easy to long-term preservation. Wuwei heavy ion medical machines have a large span, and the installation of various parts of the device

is complex and it is impossible to use full-scale networks with the highest accuracy and large density to fill up at once. According to the installation requirements of the device, it is necessary to adopt the principle of hierarchical network deployment and step-by-step control. That is to say, a high-precision and sparse first-level network should be used to cover the entire area as far as possible along each beam line, and then a local control network should be laid out according to the needs of the device and the site environment.

Calibration and magnetic alignment of dipoles in Wuwei heavy ion medical machine

The dipoles of Wuwei's heavy ion cancer treatment project are all made of laminated silicon steel sheet with a thickness of 0.5 mm. The weight of a single magnet is about 20 tons. The purpose of the calibration of the dipole magnet is to establish the positional relationship between the geometric center or physical center of the collimated target reserved on the outer surface of the magnet and the magnet itself, and the position of the target on the surface of the collimated magnet during installation is used to realize the geometry of the magnet. The center or physical center coincides with the designed beam center. Component calibration is the front-end and more critical part of the alignment and installation of Wuwei Heavy Ion Therapy Equipment. Each installation element must have correct calibration data, and the installation work at the site can be carried out smoothly. Therefore, the

Fig.2 Fiducialization of the quadrupole

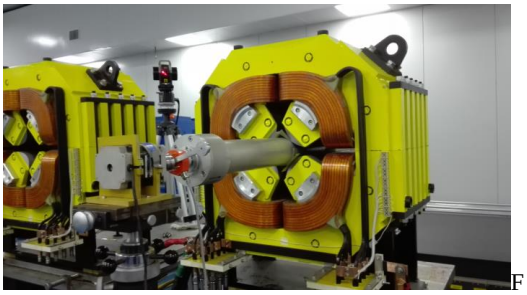


Fig.3 Fiducialization of the dipole

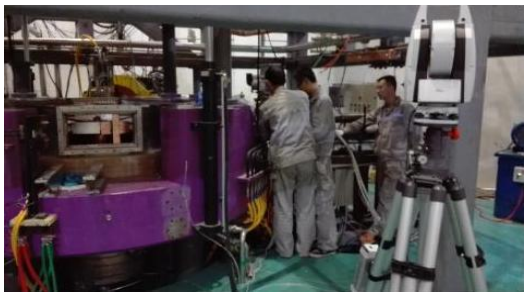
accuracy, rationality, and calibration accuracy of the original calibration must be strictly controlled. Otherwise, the calibration error of the component will affect the final installation error, and the recalibration of the original components such as the quadrupoles and the diode due to the connection of the internal vacuum pipe will be very troublesome after the installation. Therefore, he calibration of each original must be repeated at least twice, the reproducibility of the original target that requires several calibrations is less than 0.05 mm, and the average of the calibrations is taken several times. The components that need to be calibrated in the Wuwei heavy ion medical machine mainly include the dipoles, quadrupoles, six-pole lens, high-frequency cavity, electrostatic deflection plate, vacuum chamber and other originals. The workload is very large and there are more repetitive tasks. In order to improve the efficiency of component calibration, many calibration procedures are taken into consideration when setting up the calibration scheme. Many repetitive data processing and result analysis work are avoided as much as possible, which reduces the calibration errors and errors that may be caused by measurement data. The calibration data of all components have been correctly and effectively guaranteed.

Alignment of Wuwei heavy ion medical machine ion source and cyclotron

The Wuwei heavy ion medical machine is designed and equipped with two sets of ECR ion source systems. The main components of each ion source system are an ion source body, a GLASS lens, and a bidirectional 90-degree

deflection magnet used together. In the entire alignment process, the cyclotron was first installed, and the Wuwei heavy ion therapy cyclotron weighed about 50 tons. The extracted energy was 7 MEeV/U, and the flow intensity was above 10 uA. It was the injector of the Wuwei heavy ion medical machine. Due to the fact that the quality of the roundabout itself is too heavy and its volume is large, it is transported by splitting it into parts when transporting from Lanzhou to Wuwei. Therefore, it is also used in the installation from the bottom-up hierarchical block installation.

Fig.4 Alignment of cyclotron



First of all, the three-dimensional adjustable stent in the small-circumferential reference hole is staked and adjusted within a certain range of accuracy. Install and fix the lowest-level components of the convolute on the adjusted bracket, level it with a leveling instrument, and control the horizontal error within 0.05 mm. Then install the four pillars and the fan block that rotate, position and level and then install the bottom coil and vacuum box. Then install the high-frequency devices and mirrors and other originals, as well as radial probes with particularly high position requirements. Radial probe is the only device in which the beam inside the cyclotron is detected. The installation accuracy of the position directly affects the subsequent beam adjustment. The installation of radial probes requires knowledge of the travel path of the probe and the coordinates of the work center relative to the cyclotron. And other internal components are all installed after the alignment completed and the top of the convolution is finally closed. At this point, the assembly of the cyclotron is completed.

Alignment of the synchronous ring of heavy ion medical machine

Wuwei heavy ion medical machine has a perimeter of 56.1m and consists of many complex components. It is also the most compact synchronous ring in the world's heavy ion accelerators. The quadrupoles of the synchronizer ring and the dipoles are required to have the highest precision in installation of the entire cancer treatment device. Because the particles in the synchronous ring under the constraint of the magnetic field force are required to travel in the annular orbit at the speed of one-sixth of the speed of light, but also to travel tens of thousands or even hundreds of thousands of turns. Therefore, the positioning accuracy of the synchronizing ring mounting element directly affects the beam output, beam quality, and transmission efficiency of the entire device. Among the installation components of the synchronizer ring, the most demanding components for the installation and positioning accuracy are the quadrupole focusing lens and dipoles requiring a positioning accuracy of 0.1 mm, which is a serious problem for the installation and alignment of the device. challenge. Choosing the right alignment adjustment method is directly related to the installation efficiency and time of the synchrotron. It is understood that in several domestically-built annular accelerators, the alignment installation in the second phase of the BEPCII transformation, and the second phase of the Hefei synchrotron radiation installation in the alignment and installation are all the adjustment of the magnetic elements in the global coordinate system collimate work. The method of alignment the global coordinate system has the advantages of strong intuition in the non-angled straight line segment of adjacent magnets, easy to find coordinate points of measuring elements, and high alignment efficiency.

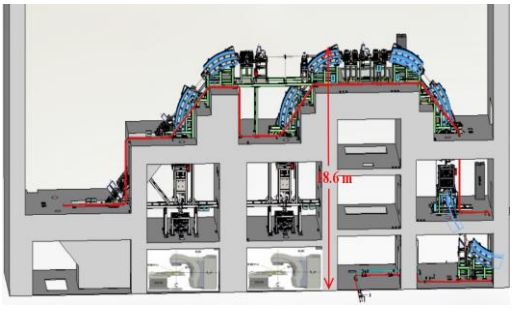
Fig.5 Alignment of synchronous ring

However, in the annular accelerator where the adjacent magnets have angles with each other, especially when the measurement is set for the initial installation, finding the coordinates of the components is relatively time-consuming and laborious. Combining the characteristics of the laser tracker and some of the knowledge of measurement, through the conversion of the three-dimensional control network and multi-coordinate systems, the method of adjusting the components in their own coordinates was used to efficiently complete the installation of the Wuwei heavy ion medical machine Synchronizing ring.

Alignment of high-energy transport lines for Wuwei heavy ion medical machine

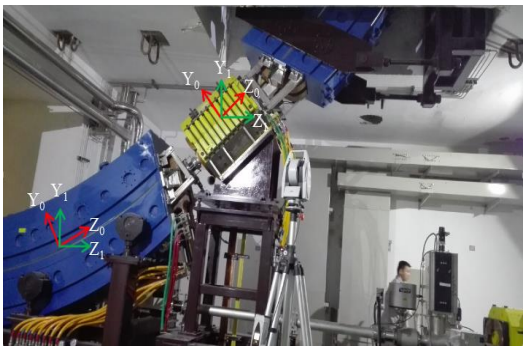
The Wuwei heavy ion medical machine's high-energy transport line is divided into the ground part and the high altitude part. The beam line in the ground segment has a wide field of view, which is relatively easy to install and can be installed with reference to the alignment and installation method of the middle beam line. However, the high-altitude installation of the alignment faces many difficulties.

Fig.6 Layout of high-energy transport lines



First, the upper-level components need to be suspended and installed in upper, middle and lower three-tier relatively independent chambers. The top and bottom floors have a span of about 20 meters or so. The reserved space for components is very narrow, and the adjacent floors are adjacent. The visibility conditions are very poor. In addition, the size of the components that need to be installed and the weight of the components make it difficult to install the alignment. The entire high-energy line needs to install 19 quadrupoles and 5 dipoles. Each dipole weighs more than 20 tons and is mounted and fixed on a huge support system.

Fig.7 Alignment of high-energy transport lines



The installation accuracy in each direction is 0.2 mm. Because of the particularity of the position of the high-energy beamline mounting element, that is, the position and angle of the mounting element in the vertical portion and the climbing portion, the data used for the mounting and the data used for calibration have a certain degree of angular adjustment. Since all component calibrations are performed after the components themselves are leveled first, it is difficult to use horizontally calibrated components to calibrate the data horizontally. In the installation of high-energy beam lines, the original calibration target data is combined with the field installation angle. The comparison uses SA software to convert the component coordinate system, and converts the calibration data of the vertically-mounted component on the ground, so that the conversion data is consistent with the direction of installation and adjustment, so that

the final high-energy beamline installation work is quick and easy. It is convenient and saves a lot of time for the installation of the project.

Summary

The collimated installation of Wuwei's heavy ion cancer treatment equipment began in April 2014 and completed the installation of the global control network, the encryption of local control networks, and the placement and scribing of various beamline components. Completed installation in September 2014, from the ion source to the cyclotron injection system, to the alignment of the medium energy transport line, the synchronous storage ring, to the high energy transport line, and the various treatment terminals. It took more than a year . Through the continuous efforts and cooperation of the staff of various systems of heavy ion cancer treatment devices, Wuwei's heavy ion cancer treatment device successfully emerged in December 2015, enabling the Wuwei heavy ion medical machine to achieve full-line carbon ion beam acceleration and The nonlinear resonance of the synchronization loop leads slowly. The injected energy is 7 MeV/u, the flow intensity is 11euA, and the terminal energy is more than 400 MeV/u, which fully meets or exceeds the original physical design index. This also proves that the basic work of Wuwei Heavy Ion Accelerator is perfect and in place, and the alignment work has also been fully affirmed.

References:

1. W.J. Chen, L.Z. Ma, G.Z. Cai et al, Alignment and installation of high energy beamline for Wuwei heavy ion medical machine. High Power Laser Part. Beams.28 (8), 085101-058105(2015) (in Chinese)

2. W.J. Chen, K.D. Man, S.M. Wang et al, Survey and alignment technology of Lanzhou heavy ion research facility. Nucl. Tech.33 (1), 65-68(2010) (in Chinese).

3. C.H. Yu. Ph.D. thesis, Shanghai Institute of Applied Physics. CAS(2008)

4. G.Z. Cai, W.J. Chen, K.D. Man et al, Using the target accelerator magnet alignment installation positioning solution. Sci. Surv. Mapp. 25(1),82-87(2013) (in Chinese).

5. G.Z. Cai, W.J. Chen, K.D. Man et al, Application of laser tracker and SA software in large particle accelerators in collimating measurement. Sci. Surv. Mapp.38 (4), 162-164(2013) (in Chinese)

6. Y.X. Kong. Control and Measurement (Wuhan University Press, Wuhan, China,1996), pp.65-66

7. D.Y. Wang, X.L. Zhang, Q. Ma et al., Procrustes method in coordinate transformation on multistation of large-scale measurement. Opt. Precis. Eng. 22(4), 949-955 (2014). doi: 10.3788/ OPE.20142204.0949. (in Chinese)

8. C.H. Yu, L.X. Yin, H.W. Du et al, Alignment and survey design of Shanghai light source. High Power Laser and Particle Beams.18(7),1167-1172(2008) (in Chinese).

9. W.J. Chen, L.Z. Ma, G.Z. Cai et al, Survey and Alignment of synchrotron ring for Wuwei Heavy Ion Medical machine. Nucl. Phys. Rev.33 (3),297-301(2015) (in Chinese).

10. Y.T. Fei. Error Theory and Data Processing. (Mechanical Industry Press, Wuhan, China,2010), pp.102

11. Z.L. Zhang, G.Y. Li, G.R. Pan, et al, Engineering Surveying. (Wuhan University Press. Wuhan. China .2005).pp.98-98

12. W.J. Chen, L.Z. Ma, G.Z. Cai et al, Survey and Alignment of cyclotron injection system for Wuwei heavy ion medical machine. High Power Laser Part.Beams.28 (10) ,106003-106008(2016) (in Chinese)

13. W. Wang. Ph.D. thesis, Hefei University of Science and Technology of China(2016)

14. Z.L. Zhang, M.D. Wu, R. Yang et al, Precision Engineering Measurement. (Survey and Mapping Press, Beijing, China,1992), pp.56