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MECHANICAL DESIGN OF BEAM LINES FOR 230 MeV SC CYCLOTRON AT CIAE

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Abstract

A 230MeV SC cyclotron (CYCIAE-230) is under construction at CIAE, which can extract 230MeV proton beam for proton therapy. To develop the proton beam transfer system which used in the field of proton therapy, the mechanical design of proton beam lines based on the CYCIAE-230 has been finished at CIAE. The proton beam transfer system includes the beam lines, beam dump, gantry, nozzle, couch, image guidance system, etc. Two beam lines are designed at CIAE this moment. One is for the nozzle system, the other is for the beam dump. The beam lines include four systems: the energy selection system (ESS), the beam transportation systems (BTS), gantry system, and beam dump. The beam lines are very compact in order to match the beam optics and the space limitation. The gantry can be rotated ±180°. The collimation of beam lines is very important to get the better beam quality for the proton therapy. There are several key components in beam lines, such as magnets, energy degrader, beam diagnostics components, vacuum components, etc. The designed mechanical tolerance of the magnets is limited less than 0.1 mm. There are at least four targets on each magnet for collimation and all the components can be adjusted in three dimensions. The magnets are being manufactured now. The mechanical design of proton beam lines based on the CYCIAE-230 will be presented in this paper.

INTRODUCTION

To build a healthy China, improving cancer 5-year survival rate is one of the most important actions. In China, the deaths caused by cancer are 2.5 million, and the new cancer cases are 3.5 million each year [1]. Proton therapy is an effective way for the cancer treatment. More than 4 million cancer patients in China will be beneficial from proton therapy each year.

To meet urgent needs for proton therapy, one of the technology innovation plan in “Dragon 2020 — major medical equipment - medical cyclotron key technology and engineering research” had launched by China National Nuclear Corporation (CNNC) [2]. In this project, a 230 MeV compact superconducting cyclotron is developing at China Institute of Atomic Energy (CIAE) to extract 230 MeV proton beam [3]. Beam lines for the 230 MeV SC cyclotron to transport the beam to the nozzle system and to the beam dump are under construction at the same time.

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The whole project consists of a 230 MeV SC cyclotron (CYCIAE-230), the energy selection system (ESS), the beam transportation systems (BTS), a gantry and a beam dump, as shown in the Fig. 1 [4].

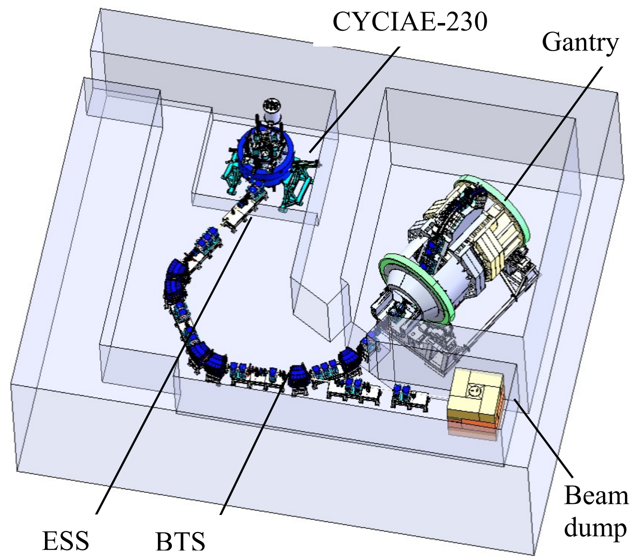

Figure 1: Layout of CYCIAE-230 and beam lines.

The beam line is about 47 m long. The ESS is 5.2 m long. The BTS is 19.8 m long, which is the longest system in beam lines. The beam line on gantry is 13.5 m long and the beam line to beam dump is 8.5 m long.

BEAM LINES ON GROUND

The beam lines on ground divided into three parts, include ESS, BTS and the beam line to beam dump. The height of the beam on ground is 1.25 m, all of the components in beam lines on ground are designed to meet this requirement.

There are trenches at both sides of the beam lines on ground. Along the beam direction, cables are put into the left trench and water pipes are put into the right trench. All of the components are designed to meet this layout. The mechanical specifications of the components in beam lines on ground are listed in Table 1.

There are many components in ESS, one of the most important component is the energy degrader. The energy degrader is used to adjust the proton energy, which can fit to the depth of the tumor [5]. To test the performance of the degrader, two types of degrader had been made. The shape of the two degraders are wedge and circle, as shown in the Fig. 2. The energy distribution of the circular degrader is

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discrete and the energy distribution of the wedge degrader is continuous.

Tabel.1: Mechanical Specifications of Components on Ground

Code	Components	Dimensions [mm]	Weight [kg]	System
ED	Energy Degrader	691× Φ 640	570	Degrader
Q	Quadrupole	385×700 ×708	700	magnet
SXY	Steering Magnet	187×339 ×364	260	
B30	30° Dipole	(R1007-R2005)× 30° ×978	5800	
BPM	Beam Position Monitor	170×240 ×563	17	Beam diagnostics
FC	Faraday Cup	230×260 ×755	30	
RC	Round Hole Collimator	100× Φ 145	22	
C	Four Collimator	220×836 ×836	26	
T	Turbo Pump	430× Φ 230	27	Vacuum
RV	Release Valve	200× Φ92	2	
G	Gauge	80× Φ15.5	0.5	
V	Valve	60×166× 506	18	

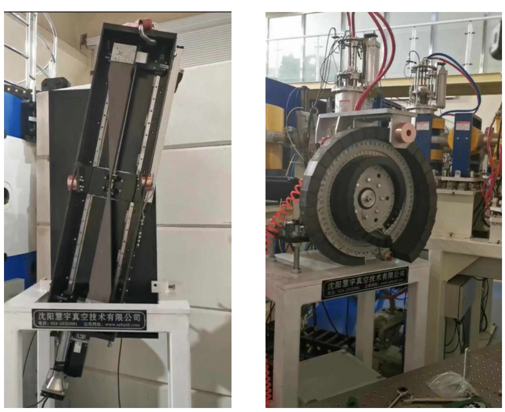

Figure 2: Photos of two types of energy degrader (left: wedge right: circle).

A spiral rotating disk, which is driving by motor, is fixed on the cylinder. There are twenty blocks with different thickness on the disk, which can adjust the energy step by step. The material of blocks is graphite. Two collimators are fixed at beam entrance and exit of the energy degrader to guarantee the quality of the beam [6].

The magnets are another important component on the beam line. They are all water-cooled conventional ac electromagnets. The changes of magnetic field should be 300 Gauss/20 ms to meet the requirement of pencil beam scanning.

There are three kinds magnets in BTS, among them, the 30°-dipoles are used to deflect the beam. Neutrons are produced when the beam through the energy degrader. To protect the patients from irradiation by neutrons, the protons are deflected to the treatment room and the neutrons are shield by thick cement walls.

The 30°-dipoles have a large leakage magnetic field, which can influence the performance of the components nearby. So two magnetic shielding plates are added at each ends of the magnets [7], as shown in Fig. 3. There are at four targets on each 30° dipoles for collimation. There are beam entering and beam extracting vacuum pipes welding on the vacuum chambers of 30°-dipoles, and a third vacuum pipe welding right to beam entering pipe at opposite direction for collimation at installation stage and installing fluorescent target at beam debugging stage. There are two bellows before and after the 30°-dipoles vacuum pipes for easy installation. There is an adjustable support under 30° dipoles. The designed mechanical tolerance of the 30° dipoles is limited less than 0.1 mm.

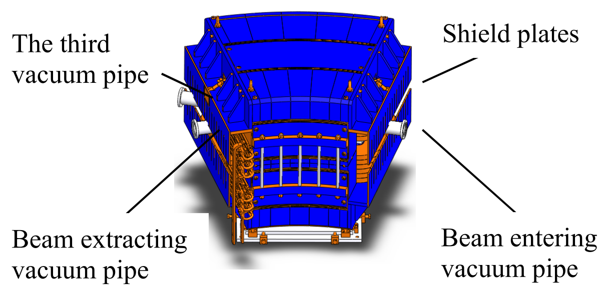

Figure 3: Model diagram of 30°-dipoles.

BEAM LINE ON GANTRY

The beam energy is continuously adjustable from 70 MeV to 230 MeV in the beam line on gantry [8]. At the exit of the gantry, the beam enters the nozzle and transmit to the isocenter where the tumor is located. The beam line is composed of a 60°-dipole, three double quadrupoles, a pair of 75°-dipoles with thin-thick-thin triple quadrupoles between them, the diagnostic components and vacuum components, as shown in Fig. 4 [9]. All the magnets on gantry are room temperature to get rapid change. The two 75° dipoles are arranged symmetrically with the thin-thick-thin triple quadrupoles between them which can eliminate the dispersion on the beam line [10]. The pair of XY fast scanning magnets are installed in the nozzle just after the second 75°-dipole for the fast pencil beam scanning.

One 60°-dipole and two 75°-dipoles fixed on gantry to bend the beam from level to vertical. These dipoles are rotate on gantry ±180°. At both sides of each dipole, there is an adjustable support to fix the dipole on gantry and to adjust the X and Y position, the Z position can be adjusted by add gasket into the gap between the dipole and the support, as shown in Fig. 5. The connectors of electricity and water are integrated in a box on the top of the dipole.

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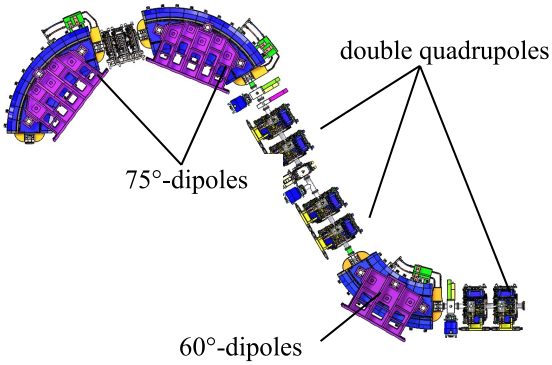

Figure 4: Layout of beam line on gantry.

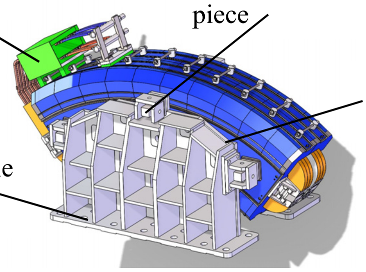

Figure 5: Model diagram of 75°-dipoles.

There are three kinds of quadrupoles in beam lines. All of the quadrupoles have iron outside with water-cooled copper coils inside. The coils are wound into individual "saddle" coils. Each coils are fixed surround the poles of the quadrupoles. The diameters of the bore are large enough to fit the diameter of the beam tubes. Different numbers of quadrupoles form different combinations to meet the requirement of beam optics. There are four kinds of combinations, including single quadrupole, double quadrupoles, triple quadrupoles and thin-thick-thin triple quadrupoles. There is an adjustable support under each combination to adjust the quadrupoles together, as shown in the Fig. 6.

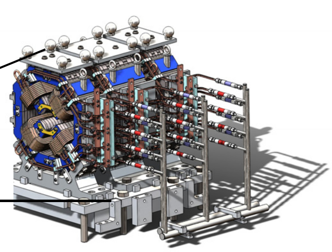

Figure 6: Model diagram of thin-thick-thin triple quadrupoles.

The designed mechanical tolerance of the quadrupole is limited less than 0.1 mm. There are four targets on each quadrupole for collimation.

CONCLUSIONS

Based on the beam optical design and considering the space limitation, the design of the beam lines layout had been finished, including ESS, BTS, the beam line on gantry and the beam line to beam dump. According to the layout of the beam lines, the mechanical design of beam lines and the main components on beam lines had been finished. In the design process of the magnets, many technical details had been considered, such as magnetic shielding plates, a third vacuum pipes in 30°-dipoles and position adjust gaskets in 60°- and 75°-dipoles on gantry. The designed mechanical tolerance of the magnets is limited less than 0.1 mm.

The beam lines are under construction now. The assembly of the beam lines will finish in 2019, and the beam debugging of the beam lines will start in 2020.

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