ISBN: 978-3-95450-205-9 doi:10.18429/JACoW-Cyclotrons2019-TUP031

DESIGN AND CONSTRUCTION PROGRESS OF CYCLOTRON BASED PROTON IRRADIATION FACILITY FOR SPACE SCIENCE

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Abstract

The proton irradiation facility for space science research and application consists of a 50 MeV proton cyclotron, two beam lines and two radiation effect simulation experimental target stations. And the shielding plant facilities is constructed at the same time. The equipment provided by CIAE mainly includes a 50 MeV proton cyclotron, beam transport lines and experimental terminals, as well as dose monitoring and installation equipment. The 50 MeV proton cyclotron CYCIAE-50 is a compact, negative hydrogen ion cyclotron with the proton beam energy from 30 - 50 MeV, and the beam intensity is from 10 nA to 10 uA. The CYCIAE-50 is about 3.2 m in diameter, 3.5 m in total height and 80 t in total weight. The magnet of the cyclotron is a compact AVF structure electromagnet at room temperature with 30 kW exciting power. The diameter of the pole is 2 m, the outer diameter of the yoke is 3.2 m, and the height of magnet is 1.5 m. The cyclotron uses an external multi-cusp H^- ion source. The H^- beam from the ion source is injected into the center region through the axial injection beamline. Then the H^- beam is injected into the accelerating orbit by the spiral inflector. The cyclotron frequency is about 16 MHz. The RF system of the cyclotron is a pair of $\lambda/2$ cavities driven by a 23 kW transmitter. The fourth harmonic accelerating frequency is about 65 MHz. The proton beam is extracted by a single movable stripping carbon foil and the stripping extraction efficiency is more than 99%. The CYCIAE-50 has now been designed in detail, and its main components, such as the main magnets and RF cavities, are being manufactured in the factories in China.

This paper introduces the design and construction progress of the proton irradiation facility based on a 50 MeV cyclotron. The proton irradiation facility for space science is oriented to space proton radiation environment simulation. The proton radiation has an important influence on the spacecraft, and the energy of more than half of the protons in the space is no more than 50 MeV. The Proton Irradiation Facility could provide proton beam with energy range of 30-50 MeV, and beam density in the range of $5 \times 10^5 \sim 5 \times 10^9$ $p \cdot cm^{-2} \cdot s^{-1}$. It is suitable for the ground simulation test of displacement damage of optoelectronic devices, as well as the proton single particle effect ground simulation test of deep submicron devices and nanodevices. It provides technical support for the development of scientific satellite load and optoelectronic devices. Compared with the large accelerator facility, the proton irradiation facility based on the compact cyclotron is a type of space proton radiation environment simulation device with high performance and lower price. The layout diagram of the proton irradiation facility for space science is shown in Fig. 1. The proton beam from the cyclotron passes through two 45˚ deflection magnets and the energy selection system. At the experimental hall, there are two experimental beam lines for different proton radiation effects.

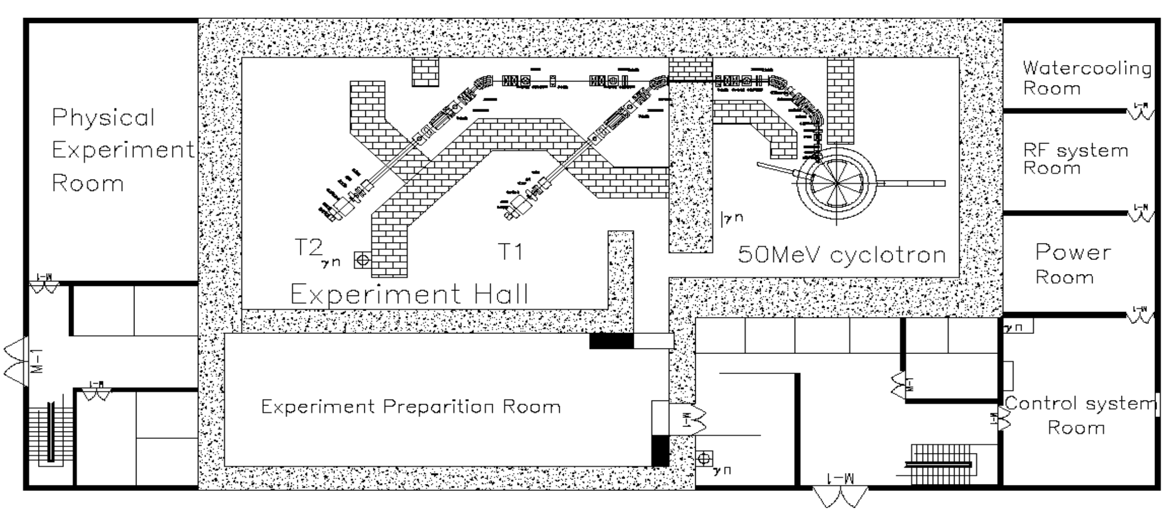

Figure 1: Layout of the proton irradiation facility based on 50 MeV cyclotron.

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The Progress of the 50 MeV Cyclotron

The 50 MeV proton cyclotron for the Proton Irradiation Facility for Space Science is a compact, negative hydrogen ion cyclotron. Thanks to the movable stripping extraction carbon foil, the proton beam energy is from 30 to 50 MeV. The beam intensity is from 10 nA to 10 μA. The CYCIAE-50 cyclotron is about 3.2 m in diameter, 3.5 m in total height and 80 t in total weight. The cyclotron uses an external multi-cusp H^- ion source is installed above the main magnet. The H^- beam from the ion source is injected into the center region through the axial injection beamline. Then the H- beam is injected into the accelerating orbit by the spiral inflector. The cyclotron frequency is about 16 MHz. The RF system of the cyclotron is a pair of 1/2 RF cavities driven by a 23 kW transmitter. The fourth harmonic accelerating frequency is about 65 MHz. The proton beam is extracted by a single movable stripping carbon foil that's stripping extraction efficiency is more than 99%. Design of main vacuum is 5×10E-7 mbar for the cyclotron. The main vacuum chamber is cylinder sealed by rubber O-rings. The Two GM cryogenic vacuum pumps are fixed on the top of the main magnet, and two turbine molecular pumps are fixed under the main magnet. The total power of the cyclotron is about 200 kW. Table 1 shows the main parameters of the 50 MeV cyclotron.

Table 1: The Parameters of the 50 MeV Proton Cyclotron

Parameter	Value
Beam Energy	30-50 MeV
Beam intensity	1 nA - 10 μA
Accelerated Particle	H-
Ion Source	H-Multi-Cusp
Magnetic field	1-1.6 T
Particle rotation frequency	16 MHz
Cyclotron Size	Φ3.5 m×2.5 m
Weight	~ 80 t
Vacuum Degree	5×10^{-7} mbar
Beam stability	1/2 hr
Total Power	~ 200 kW
standby power	~ 50 kW

The Main Magnet of CYCIAE-50

The main magnet of the cyclotron is a compact AVF structure electromagnet at room temperature. The diameter of the poles is 2 m, the outer diameter of the yokes is 3.2 m, and the height of magnet is 1.5 m. The main magnet is one of the most important components of the cyclotron, which forms an isochronous magnetic field that restricts particles to rotate along the designed orbit. The system includes magnet, excitation coils, synchronous hydraulic lifting device, high precision magnetic field measuring device, on-line temperature monitoring device, on-line magnetic field monitors, high precision and high stability power supply, etc. The main magnet adopts straight sectors and deep valleys structure without adjusting coils. Figure 2 shows the structure of the main magnet. The magnetic poles are 4 pairs of 50° sector poles, the air gap is from 40 mm to 32 mm. The average field is 1.0-1.6 T. The shimming bars used to adjust the isochronous magnetic field are embedded at the edges of the magnetic poles. The magnet material is pure iron with carbon content less than 0.025%. The manufacturing accuracy of the main parts of the magnet is better than 0.05 mm. The coils are fixed between the magnetic poles and the yokes. The excitation coils are wound by the copper hollow tubes with internal cooling water. The total exciting power of the coils is about 30 kW, and the total weight is about 5 t.

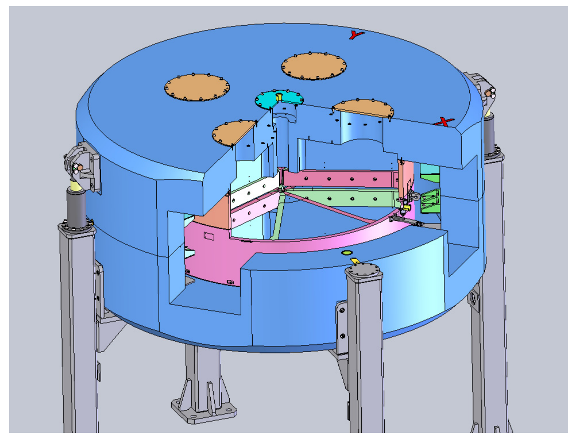

Figure 2: The main magnet of CYCIAE-50.

The main magnet structure is poles and yokes integral blank structure. That is, the poles and yokes and so on are machined from one pure iron disc blank. The magnet blank parts are vacuum smelting and vacuum casting ingots, and then forged by a free forging machine of 18500 t to create round cake-like blank parts. The magnet parts are currently being processed on a milling machine and are expected to be finished in October. Figure 3 shows that the magnet blank parts are being forged, and Fig. 4 shows that the magnet parts are being machined on a milling machine.

The RF System of CYCIAE-50

The RF system of the 50 MeV proton cyclotron consists of a RF power source with rated output power of 23 kW, a 3 in transmission line system, a low level control system and two high frequency cavities. The 23 kW RF power source is designed with easy maintenance and antireflection. The two cavities of the 50 MeV cyclotron are connected by a high frequency bridge at the central position. RF power feeds into the cavities by a coupling capacitor. The low level control system includes amplitude stable loop and frequency tuning loop. The two loops are used to stabilize the acceleration voltage of the RF cavities and control the fine tuning capacitance to compensate the deformation caused by heating. The RF power source, RF cavities, and low level control system have been designed and are being manufactured. The parameters of the RF system are detailed in Table 2.

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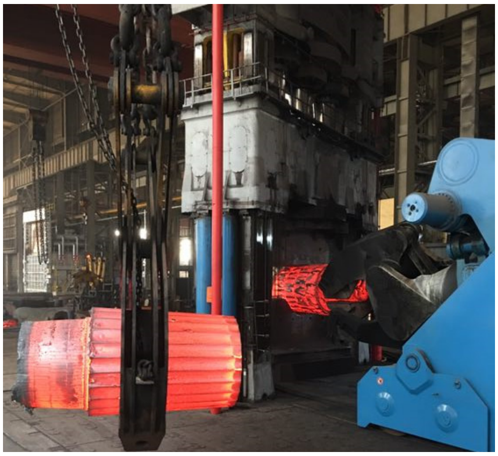

Figure 3: The magnet blank parts are being forged.

Figure 4: The magnet parts are being machined on a milling machine.

Table 2: The Parameters of the RF System

Parameter	Value
RF frequency	~ 65.4 MHz
Voltage stability	1/1000
Cavity number	2
Work model	4th harmonic acceleration
Cavity form	λ/2
Acceleration voltage	~ 50 kV
Coupling capacitor number	1
Frequency tuning	1

Other System of the 50 MeV Cyclotron

There is a permanent magnet multi-cusp H- ion source on the top of the cyclotron main magnet. The maximum H- beam intensity from the source is 5 mA, and the beam energy is 30 keV. The injection system is very simple design. The H- beam from the ion source enters the spiral inflector in the center region only through a solenoid. The ion source and the injection beamline are being manufactured. Table 3 is the main parameters of ion source and injection beamline.

Table 2: The Parameters of the Ion Source and Injection Beamline

Parameter	Value
Ion source	Multi-cusp H- source
Beam energy	30 keV
Beam intensity	5 mA
Inflector voltage	±10 kV
Injection beamline	~1 m
Inflector gap	8 mm

The 50 MeV cyclotron has a single movable stripping carbon foil that can move from 30 - 50 MeV. Ordinary the stripping extraction efficiency is more than 99%, and the beam loss is no more than 100 μA. Figure 5 shows the structure of the movable stripping target.

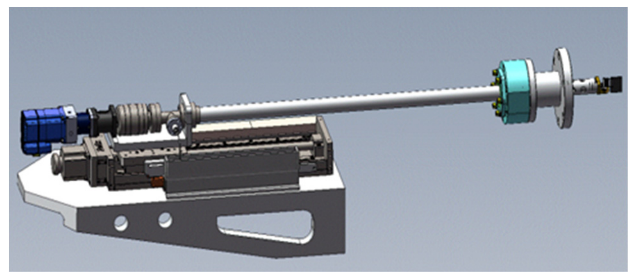

Figure 5: The structure of the movable stripping target.

CONCLUSION

The proton irradiation facility based on the 50 MeV proton cyclotron is a compact and lower price space proton radiation environment simulation facility with high performance. Now all the detail design of the 50 MeV cyclotron has been finished at CIAE. The main parts of the cyclotron such as the main magnet are being manufactured now. Beam commissioning is expected to be done at the end of the next year.

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