

DESIGN OF THE 2.45 GHZ ECR PROTON SOURCE AND LEBT IN CPHS (COMPACT PULSED HADRON SOURCE)*

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Abstract

Responding to the demand of accelerator front inject system of the Compact Pulsed Hadron Source (CPHS) in Tsinghua university in 2009, an electron cyclotron resonance (ECR) proton source (2.45 GHz, 1.5 KW) and a low-energy-beam-transport (LEBT) system are designed and manufactured. In this source, the H₂ plasma is restricted by an axial magnetic field shaped by the source body produced by an all-permanent-magnet design (NdFeB rings). The 50-keV pulsed proton beam (50 Hz/0.5 ms) extracted from the proton source passes through the LEBT system (1283 mm long), which is consist of two solenoid lens, two steering magnets and a cone configuration optically matches to the RFQ where the Twiss parameters $\alpha=1.354$, $\beta=7.731$. The beam with 97% space charge neutralization rate has been simulated at 100 mA, 150 mm.mrad RFQ output current by Trace-3D and PBGUN. In this study, we describe the design of the proton source and LEBT technical systems along with intended operation.

INTRODUCTION

In 2009 Tsinghua University approved a new project for the construction of a Compact Pulsed Hadron Source (CPHS) on the university campus in Beijing, China. The CPHS Project^[1], led by the Department of Engineering Physics, consists of a proton linear accelerator, a neutron target station, and beam lines for neutron and proton applications. The accelerator system is driven by a 2.45 GHz, 1.5 kW ECR proton source, a 3 MeV radiofrequency quadrupole linac (RFQ), and a 13 MeV drift-tube linac (DTL). The target-moderator-reflector (TMR) system is responsible for thermal and cold neutron production based on the Be(n,p) nuclear reaction, supplying cold neutrons to at least 4 beam ports. Two neutron beamlines will be configured to support a small-angle scattering instrument and an imaging/radiography station. These three components—proton linac, TMR, and 2 neutron instruments—comprise the first phase of the CPHS Project, to be completed in about 3 years. Additional neutron and proton beamlines and instruments will be added in the second phase of the project. More details of the CPHS and the long-term goals of neutron and proton applications are given in another paper by J. Wei at al. in this proceeding^[1].

CPHS has an injection system for proton linear

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accelerator similar to the Los Alamos National Laboratory (LANL) facility in USA^[2]. In this system, a high intensity current ECR proton source (PS) and a low energy proton beam transport line (LEBT) are included. The 50-keV proton beam is extracted from the ion source, after the line LEBT transmission, focusing to match with the RFQ before injecting into it. Table 1 shows the primary parameters of the proton source in CPHS, the layout of the proton source and LEBT is shown in Figure 1. The physical and technical design of it has a very close relationship with the stability and reliability of the whole system running.

Table 1: CPHS Primary Design Parameters

Parameters	Numbers	Units
Microwave power	1~1.5	kW
Microwave frequency	2.45	GHz
Output beam energy	50	keV
Repeat. frequency	50	Hz
Duration of pulse	0.5	ms
Proton intensity	60	mA
Emittance (normalized rms)	0.2	μ m
Proton fraction	>85	%
Reliability	120	hour

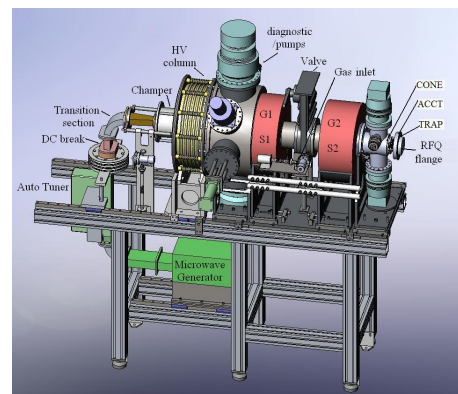


Figure 1: Layout of proton source and LEBT.

At the outset, domestic and international collaborations were recognized as an important element of the CPHS project. We design this PS-LEBT system together with the institute of modern physics (IMP) of Chinese Academy of Sciences in Lanzhou for their ten years experiences in ECR ion source designing, the CPHS

project benefited substantially from the first international workshop held at Tsinghua University in June 2009 in which Professor Hongwei Zhao from IMP was among the participants. Our design efforts are also benefited from the experiences of proton applications at CEA/Saclay^[3] and the Hokkaido University neutron facility^[4], as well as the proton applications at the 20-MeV platform of the Proton Engineering Frontier Project (PEFP)^[5]. The goal is to get the high proton ratio and quality beam to match with RFQ with the Twiss parameters of $\alpha=1.354$, $\beta=7.73087$. This paper summarizes the major technical design aspects of the PS-LEBT in CPHS.

50-KeV PROTON SOURCE DESIGN

The proton source chosen for the CPHS project was originally developed at Los Alamos National Laboratory (LANL) [6, 7]. The LANL plasma generator has been integrated and modified to a 50 kV accel structure at CPHS (Figure 2). The proton source complex consists of three major systems (subsystems): microwave coupling system, magnet field configuration, four-electrodes system.

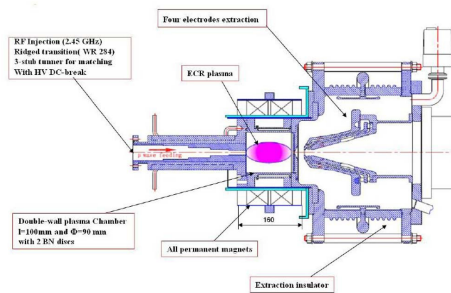


Figure 2: Schematic layout of ECR proton source.

Microwave Coupling System

2.45 GHz pulsed microwave generator (Repeat Frequency is 50Hz, Duration of Pulse is 0.5 ms) is used in the microwave coupling system heat the H_2 gas, with 1.5 kW maximum RF power delivered by the magnetron, the H_2 plasma with a certain ion density ($\sim 10^{11} \text{ cm}^{-3}$) enough to reach the requested beam intensity is produced under the proper vacuum condition ($\sim 10^{-2}$ mbar). Microwave power is fed into the plasma chamber through a ridged waveguide with a four-stubs auto tuner, which can concentrate microwave power at the center of the microwave window. The matching of microwave can be adjusted through the tuner automatically. The 2.45 GHz magnetron discharge power supply is isolated from the 50 kV ion source potential by the high-voltage (HV) waveguide break. To avoid the influence of the temperature increase during the discharge to the discharge chamber and magnetic rings, we use two layers water-cooling system installing on the surface of them to solve these problems.

Magnet Field Configuration

In order to make the proton source more compact and

easier to operate, we use all-permanent magnet configuration, namely, the axial magnetic field is produced by teams of high-performance 7 NdFeB rings and ferromagnetic materials, which have higher temperature coefficient and larger remanence and $(BH)_{\text{max}}$ that is flexible and stable enough to form the magnetic distribution we need. a set of 2 movable magnet rings close to the RF window. In this configuration, the axial magnetic field can be optimized to confine the plasma, especially for leading to optimize the design in order to facilitate the formation of proton beam generation and leads to the magnetic field configuration. The axial magnet field distribution in the source is shown in Figure 3. We can set the ECR surface and the magnetic field distribution near the microwave injection and proton extraction district by adjusting the gap and the number of the rings to extract the beam more efficient.

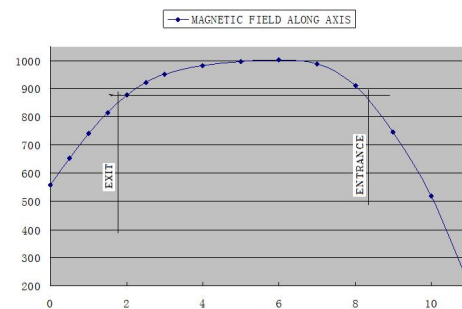


Figure 3: The axial magnet field distribution in the source.

Four Electrode System

As shown in Figure 4, the four-electrode system consists of the plasma electrode, mid-electrode, suppression electrode, and extraction electrode. We add the mid-electrode to adjust the grads of the electric field and optimize the beam emitting surface; the suppression electrode can prevents LEBT low-energy electrons reaching the proton source destroying the microwave window and neutralizing the protons. The final electrode of this accelerating structure is a ground electrode which quickly establishes beam neutralization in the LEBT. Each electrode is made of Cu, the aperture of the plasma electrode is 5 mm and the ones of the other three electrodes are 7 mm. In order to minimize beam divergence and reach the maximum space charge compensation as close as possible to the source, we set the distance between the plasma electrode and mid-electrode to be 12 mm, the distance between mid-electrode and suppression electrode to be 7 mm and we reduce the distance between the suppression electrode and extraction electrode (the grounded electrode) to 7 mm. The ion-source HV is separated by use of two ceramic insulators which have an inside diameter of 50.4 cm. The whole system also uses the high intensity water-cooling of the electrodes configuration to guarantee the ECRIS working stable and reliable. A PBGUNS model for this extraction system is shown in Figure 5 for a 50 keV, 100 mA proton beam.

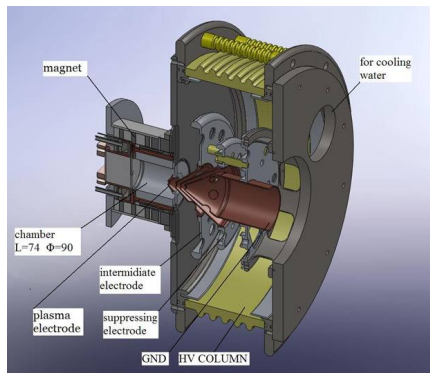


Figure 4: The schematic of four-electrode system.

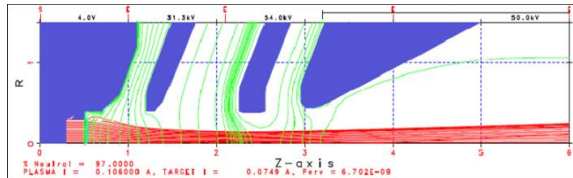


Figure 5: PBGUNS model for the extraction system.

greater momentum than the proton one, are less focused by the solenoid field. For this reason, a fraction of contaminants is lost in the line between magnets, another fraction is lost in the line after the second solenoid. To prevent the contaminant ions injecting into the RFQ, in other words, to maximize their lost fraction, we use this cone configuration before the RFQ entrance to enhance the proton ratio.

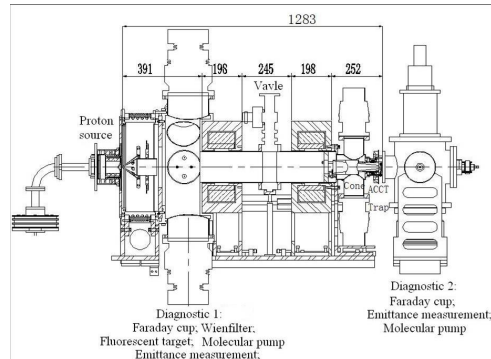


Figure 6: The layout of LEBT.

BEAM TRANSPORT AND LEBT DESIGN

For initial operation of the CPHS RFQ, a 1283-mm-long LEBT is being assembled according to the main reference to the French CEA/Saclay for the IFMIF designing for low-energy beam lines. LEBT consists of major systems: two magnet lens, two steering magnets, two diagnostic chambers, cone structure (cone, ACCT, electronic traps). This section discusses the design of the major technical subsystems.

Layout and Component Parameters

Figure 6 shows the layout of injector LEBT. In this location, the whole length of LEBT is 1283 mm from the source exit to RFQ entrance. Two solenoid magnets G1 and G2 are used to capture the beam from the ion source, and then to focus the beam into the RFQ. In order to decrease the beam divergence, we try to shorten the distance from the source to G1 to 391 mm compare to the French CEA/Saclay ion source design of 500 mm. In order to shorten the length of LEBT, two-direction correction of steering magnets eventually be placed inside a solenoid lens. As a result the beam centroid control in the LEBT can be accomplished by using this configuration. LEBT beam currents are monitored at the ion source exit (Diagnostics/Pump 1 in Figure 1) and at the RFQ entrance ((Diagnostics/Pump 2 in Figure 1). A cone configuration consisting of cone, ACCT, electron trap is located between S2 and the RFQ entrance. The exit of S2 is located 25 cm upstream from the RFQ entrance. As we know, contaminant ions like H_2^+ , H_3^+ , having a

CONCLUSIONS

Integrating the design features outlined above the whole system is expected to enable a 120 hour endurance run to meet the CPHS beam availability requirement. The first 1283-mm-long CPHS LEBT will be tested in end-2010 and be ready for operation with the CPHS RFQ in early 2011.

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