# DEVELOPMENT OF INTENSE PROTON ECR ION SOURCES AT IMP*

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*Abstract*

Since 1997, there have been two ECR ion sources for producing intense proton beam developed at Institute of Modern Physics (IMP). In 1999, a high current 2.45 GHz ECR proton source for Lanzhou university neutron generator, was constructed and tested at IMP. A mixed ion ($H_1^+ + H_2^+ + H_3^+$) beam current of 110 mA with CW mode was delivered from a single aperture of 6mm diameter with microwave power of 600W at the extraction voltage of 22 KV. Recently a new pulsed proton source has been designed and built at IMP for the CPHS (Compact Pulse Hadron Source) facility in Tsinghua University. Till now the commissioning of this source has been finished for 60mA pure proton beam with 50keV energy at Tisinghua University. The long time running stability and beam emittance have been tested and the results are well up to the requirements of CPHS. In this paper, the design of the proton ion source and the LEBT for the Chinese ADS project is also discussed.

## INTRODUCTION

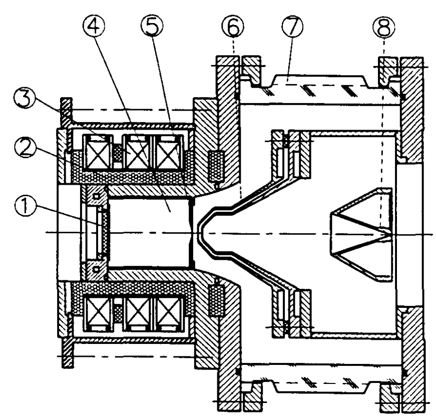
As an effective candidate, light ion Electron Cyclotron Resonance (ECR) source is always chosen to be the injector for proton accelerators. Different to the high charge state ECR ion source, which has more complicated magnetic field configuration and is driven by more than 10 GHz microwave with up to even more than 10kW power, the light ion ECR source is only considered by the simple axial magnetic field distribution and fed with 2.45 GHz microwave from magnetron of no more than 2kW power. Either electro-magnet or permanent magnet could be adopted to form the magnetic field. The ion source with all permanent magnet is very suitable to work on high voltage platform.

Today more and more proton accelerators have been, is and will be constructed for scientific research, industrial application and cancer therapy. High performance proton source is needed to satisfied different requirements. In china, there are some proton accelerator projects, such as Compact Pulsed Hadron Source (CPHS) project of Tsinghua University [1] and the china accelerator drive system (ADS) called for by Chinese Academy of Science (CAS) [2]. IMP undertook the task of proton source and LEBT for these two projects.

## FIRST PROTON SOURCE AT IMP

1997, we started the research of producing high intensity proton beam from a compact ECR source for Lanzhou university neutron generator [3]. Fig.1 shows the source structure with the extractor and a near faraday cup. The necessary magnetic field is mainly formed by a set of permanent magnet rings of NdFeB material. The outer jacket of the source is made of iron to return the path of magnetic field. In order to get a better result, three auxiliary coils, which are water-cooled in directly through the copper sheets on the surface, are used to tune the magnetic field precisely in a small range. The water-cooled plasma chamber is made of copper with both diameter and length of 70mm. The ion extraction and beam pre-focusing are realized by a three-electrode system whose tips are made of TZM alloy. The gaps are 6mm and 3mm in the accelerating and decelerating regions respectively.

With a very simple microwave feeding system, a mixed ion ($H_1^+ + H_2^+ + H_3^+$) beam current of 110 mA with CW mode was delivered from a single aperture of 6mm diameter with microwave power of 600W at the extraction voltage of 22 KV.




1. Microwave window;
2. Permanent magnets;
3. Coils;
4. Plasma chamber;
5. Plasma electrode;
6. Accel-decel electrodes;
7. Ceramics;
8. Faraday cup

Figure 1: Layout of papers.

## PROTON SOURCE FOR CPHS

In 2009 a new project for the construction of a Compact Pulsed Hadron Source (CPHS) was approved on Tinghua University [1], which consists of a proton linear accelerator, a neutron target station, and beam lines for neutron and proton applications. In this system, a high intensity current ECR proton source and a low energy

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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 and LEBT in CPHS.

Table 1: Design Parameters of Proton Source

| Parameters | Request | Status |
|---|---|---|
| Microwave power (kW) | <1.5 | <0.6 |
| Beam energy (keV) | 50 | 50 |
| Peak current (mA) | 60 | 70 |
| Repeat frequency (Hz) | 50 | 50 |
| Pulse width (ms) | 0.5 | 0.5 |
| Rise time (μs) | 100 | 80 |
| Proton fraction | >85% | to be measured |
| $\varepsilon_{RMS,\ nom}$ (π.mm.mrad) | 0.2 | 0.18 |
| Reliability (hr) | 120 | 140 |

To meet the requirements of the CPHS, the proton source and LEBT (shown in Fig. 2) are designed together with the colleague of Tsinghua University. Proton source is connected to the LEBT via a 150mm long high voltage column, in which a three-electrode extraction system is included. The whole length of LEBT is only 1283mm from source extraction hole to the RFQ entrance. Two solenoid magnets with two-direction steering magnets inside are used to focus the beam and match the Courant-Snyder parameters to the RFQ.

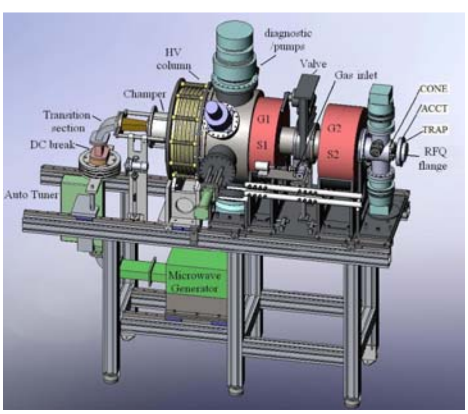


Figure 2: Layout of the proton source and LEBT.

## *Source Description*

Similar to the first proton source of IMP, this source is also ECR type and uses the permanent magnets to form the needed magnetic field with slightly adjusting from two auxiliary coils. The schematic structure of the source is shown in Fig. 3 and Fig. 4 shows the simulated magnetic field distribution. The copper plasma chamber is cylindrical, with a 60 mm diameter and a 60 mm length. Both ends of the plasma chamber are lined with 2 mm thick boron nitride discs. To enhance the proton fraction, an aluminium tube with inner diameter of 50 mm is inserted the chamber. The microwave is produced by a 1.2 kW magnetron source at 2.45 GHz and is fed into the source via standard rectangular waveguides with a three-stub tuning unit. A three section ridged waveguide transition is placed between the plasma chamber and the cooled bend to enhance the axial RF field. The RF window is located on the front end of the chamber closed to first BN disk.

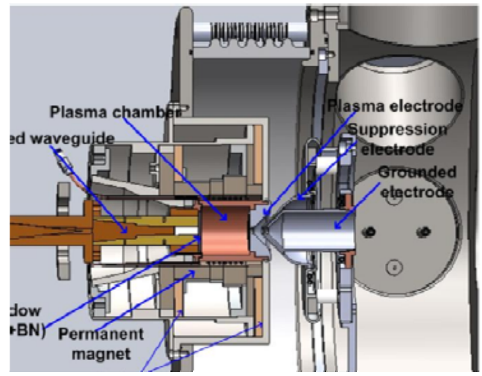


Figure 3: CPHS proton source with 3-electrode extraction.

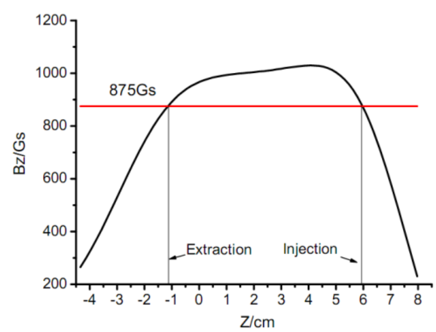


Figure 4: Simulated magnetic field of SPHS Proton Source.

## *Extraction System Design*

In the previous design, this source is equipped with a three-electrode extraction system (shown in Fig. 3). All of the electrodes have 45° shape for high current extraction focalization. The aperture diameters are 6mm, 8mm and 8mm for plasma electrode, suppression electrode and ground electrode respectively. The gap between plasma electrode and suppression electrode is 12mm and one between suppression electrode and ground electrode is 4mm. Fig.5a shows the simulation result by IGUN program. The beam extraction and transmission look very good, but there are very frequent sparks occurring in two gaps during the commissioning of the source with required 50kV high voltage and 60mA pure proton beams. To deal with this problem, we developed a new 4-electrode extraction system and its simulation result by IGUN is shown in Fig. 5b. Compared with 3-electrode system, one additional ground electrode is inserted between plasma electrode and suppression electrode. The gaps are 10mm, 3mm and 3mm respectively from plasma

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electrode to the second ground one. The final experimental result proves that the new extraction system is more reliable for long term running.

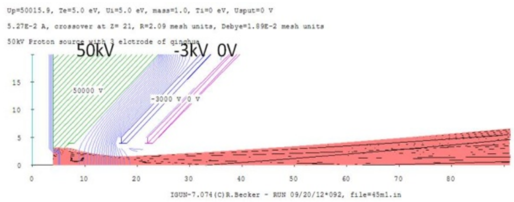

Figure 5a: Simulation result of 3-electrode extraction.

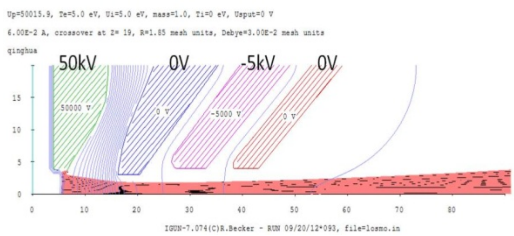

Figure 5b: Simulation result of 4electrode extraction.

### *Testing and Results*

This proton source was tuned in pulse mode by modulate the rf signal before fed into ion source. The waveform of the beam pulse detected at the exit of LEBT is shown in Fig. 6. The rise time is about 100μs, which is less than the requirement. The beam emittance near the RFQ entrance plane was also measured by an ESS detector. Here the normalized rms Emittance is about 0.18 π.mm.mrad. Fig. 7 gives the image of emittance.

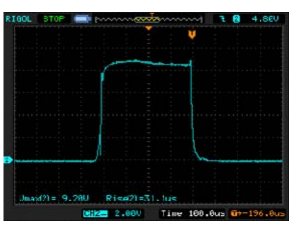
Figure 6: Beam pulse waveform.

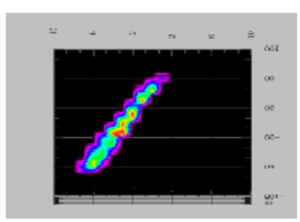
Figure 7: Emittance image.

It is not difficult for this source to produce more than 100 mA pulsed proton beam. But the long-term reliability is the key issue. More than 60mA beam current of pure proton was measured at the end of LEBT by a Faraday cup and ACCT. Long time monitoring of ion source and LEBT running were also implemented. The problem we met at the beginning is the reliability for running long time with 3-electrode extraction system. There are frequent sparks when proton beam reaches more than 50mA with 50kV extracting voltage. The discharge occurring in extraction area does not become better when decrease the extraction voltage. To deal with this problem, we developed a new 4-electrode system described in previous section. Then we got a very good result with new extraction system. Fig. 8 gives the monitoring result of 150 hr testing. There are only a few beam breaks during the running. In the graph we took the total beam current instead of the proton beam current because of the faraday cup insulation problem. The total beam current is really proportional to the proton beam current. That means the pure proton beam current was always more than 60mA during the operation.

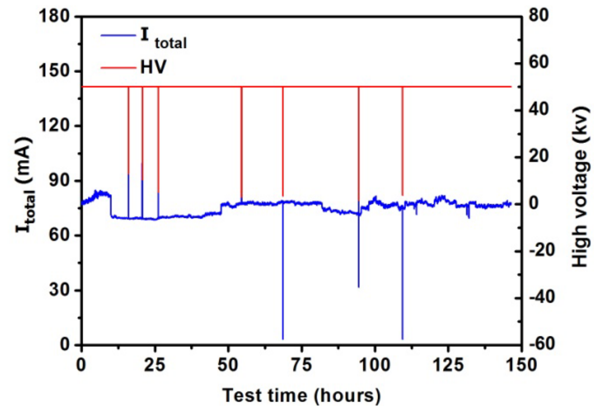

Figure 8: Long time running test of the proton source.

## PROTON SOURCE DESIGN FOR C-ADS

To meet the great demand of nuclear transmutation and power generation, the Chinese government is setting off the C-ADS project, which is aiming at constructing a 15 MW CW proton linac of 1.5 GeV and about 10 mA. The C-ADS project is structured into three stages from 2011 all the way to 2030s. The first step completes the main parts of two independent injectors to higher than 5 MeV by 2013, which include ion sourced and its LEBT, RFQ and super-conducting cavities, and the whole system should be running at CW mode. Table 2 shows the requirements of proton source for C-ADS project.

Table 2: Required Parameter of CADS Proton Source

| Parameters | Request |
|---|---|
| Beam energy (keV) | 35 |
| □E/E | 0.1% |
| Proton current (mA) | 15 (CW) |
| Proton fraction | >85% |
| $\varepsilon_{RMS,\ nom}$ (π.mm.mrad) | <0.2 |
| Reliability (hr) | 300 |

For designing this proton source, there are some key points to follow: 1). very compact source body; 2). all permanent magnet without any coils; 3). 4-electrode extraction system; 4). no tunable units on high voltage terminal. Fig. 9 shows the preliminary design of the source. We would like to make the magnetic field distribution similar to CPHS one. The simulation result suggests the magnetic field be provided by five permanent rings and be a little different to CPHS one by removing the auxiliary coils. The same extraction system



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as CPHS one was selected, but the diameter of extraction hole changed from 6mm to 4mm to minimize the beam emittance. Furthermore, the size of acceleration column will be much smaller than the previous one to enhance the vacuum pumping efficiency on this region. This proton source and its LEBT will be constructed and tested on the end of 2012.

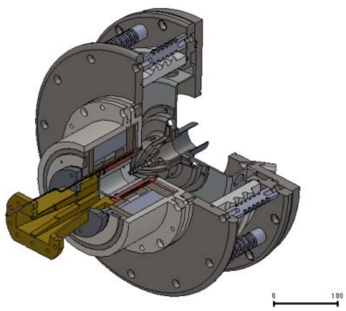

Figure 9: Schematic view of C-ADS proton source.


## ACKNOWLEDGMENT

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