PROGRESS OF THE RF NEGATIVE ION SOURCE RESEARCH AT HUST*

D.Z. Chen, D. Li, K.F. Liu, H.K. Yue, X.F. Li, C. Zhou, D.W. Liu, J. Huang, Z. Zhang
State Key Laboratory of Advanced Electromagnetic Engineering and Technology,
Huazhong University of Science and Technology, Wuhan 430074 , China

Abstract

Powerful negative ion sources are the primary component for a neutral beam injection system used in fusion reactors. Under the support of the Ministry of Science and Technology of China, HUST is developing an experimental facility for RF driven hydrogen negative ion source. The research work is presented.

INTRODUCTION

Magnetic confinement fusion (MCF) shows promise as a future energy source. To initiate a sustained fusion reaction, it is necessary to heat the plasma up to the ignition temperature (~20 keV) inside a fusion reactor. Neutral beam injection (NBI) is one of the most important mechanisms for plasma heating and current driving, and ion sources are the primary component of the NBI systems. Differing from those ion sources used in accelerators usually delivering currents below 100 mA with diameters of some mm, the NBI ion sources are much large and powerful, with multi-aperture extraction of currents of several tens of amperes at a pressure of typically 0.3 Pa, as shown in Table 1 [1].

Because the neutralization efficiency of positive ions decreases as the beam energy increases, becoming unacceptably low at energies 100 keV/nucleon, negative ions are the inevitable choice for NBI systems of future fusion devices, such as International Thermonuclear Experimental Reactor (ITER) with beam energies up to 1 MeV.

Two kinds of ion sources can be used for NBI purpose, filament arc driven sources and RF driven sources. The RF driven source has no filament making it maintenance free which is most attractive for operating in the radioactive environment. Together with other advantages such as with fewer components making it cheaper and more reliable, also due to the progress achieved by IPP Garching, RF negative ion source was chosen the reference source for ITER in 2007 [2].

To promote the research and talent cultivation for ITER negative ion sources, HUST has started to develop an experimental facility since 2011 under the support of Ministry of Science and Technology of China. The project contains two phases. During the first phase, we are building a RF driver which will produce the plasma required for yielding negative ions, while the beam extraction system will be finished in the next phase.

Table 1: Main Parameters of ITER Negative Ion Source

Species	Energy	Beam current	Pressure	Extraction area	Source size	Uniformity	Pulse length
H^- (for diagnose)	0.87 MeV	48 A	0.3 Pa	0.2 m^2	1.9 x 0.9 m^2	$<10\%$	3600 s
D^- (for heating)	1 MeV	40 A					400 s

HUST SETUP

According to IPP's design, a RF driven negative ion source consists of three parts: the driver, where the RF power is coupled into the plasma, the expansion region, where the plasma expands into the actual source body, and the extraction region, as shown in Fig. 1. During the current stage, the facility we are developing includes the driver and the expansion chamber, but except the extraction.

In Fig. 2 is shown the schematics of the HUST negative ion source testing facility. The driver is mounted on the back of the source body consisting of an alumina cylinder with outer diameter of 300 mm and thickness of 8 mm, the same size of the ITER source. A water-cooled RF coil wound around the cylinder, is connected to the RF oscillator. The coil is made of copper tube with 6 mm OD and 4 mm ID, and is sleeved with a 10 mm OD poly propylene tubing and the inter-space is filled with transformer oil for inter-turn isolation. Several coils with turn number from 5 to 9 turns have been manufactured to examine turn number effect on the RF couple efficiency.

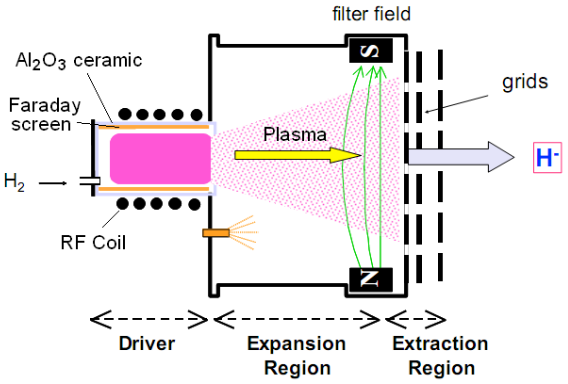

Figure 1: Schematic view of a RF driven negative ion source.

---

*Work supported by the ministry of Science and Technology of China.
Email: dzhchen@mail.hust.edu.cn

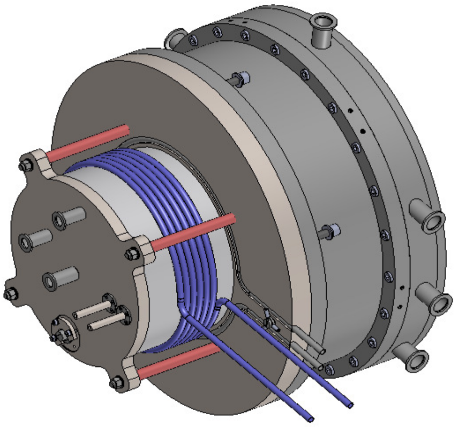

Figure 2: The HUST negative ion source testing setup.

Inside the ceramic cylinder is a copper Faraday screen to protect the alumina cylinder from the plasma. Considering the source is designed for pulse operation within a few seconds, only the back plate of the Faraday screen is water cooled. Two Faraday shields were manufactured with slits number of 80 and 40, respectively, to examine the slit effect on the plasma ignition. A starter filament is applied helping to ignite the plasma together with a gas puff.

Differing from BATMAN, a similar experimental setup developed by IPP, which uses a rectangle shaped expansion chamber, HUST facility uses a circular chamber with diameter of 500 mm and depth of 230 mm. A circular chamber is much easier for manufacturing and more convenient for arranging the filter magnet, water cooling and diagnose system. A dummy grid is placed at the actual plasma grid position in order to simulate the plasma operation situation as if there was the extraction system.

The RF generator is competent to output maximum RF power of 90 kW at a fixed frequency of 1 MHz. The matching network, matching the impedance of the RF driver to 50 Ohm transmission line connecting the RF generator, contains a series capacitance Cs and a shunt capacitance Cp together with a 3:1 transformer in the shunt arm. Tuning Cp and Cs helps to ensure proper matching. The transformer helps to isolate the source from the generator in the event of source being floated at high potential during beam extraction, as shown in Figure 3.

The RF magnetic field distributions were calculated by using FEM, according to different ionization rate. Also the equivalent impedance of the RF coil is obtained through the FEM simulation, where the real part of the impedance, R, represents the power absorbed by the plasma, while the imaginary part, ωL, represents the magnetic energy stored in the system. From the circuit point of view, $P = I^2R$ is the active power, while $Q = I^2\omega L$ is the reactive power; here I is current flowing through the RF coil. These figures show how the ionization rate, which determines the conductivity of the plasma, affect the penetration of magnetic fluxes into the plasma, and how it affect the equivalent impedance of the coil. These results are used for directing the decision of the parameters of the matching network.

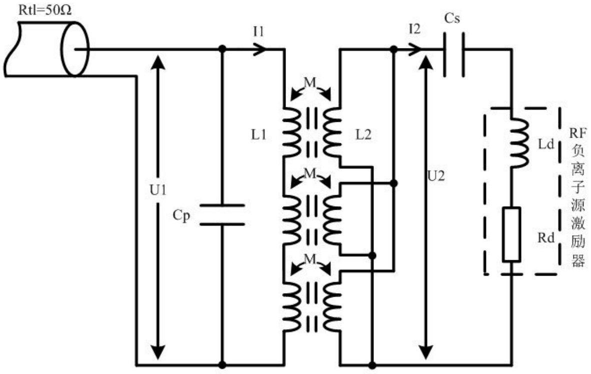

Figure 3: The matching network.

Both a molecular pump with pumping speed of 900 l/m and a cryopump with pumping speed of 10,000 l/s are used for the vacuum system. A Langmiur probe and optical emission spectroscopy are used for the diagnosis of the plasma. To protect the signal from the RF interference, the link between the source and the computer is established through fiber optic cables and modules mutually converting electric signal and optical signal.

Because the 90 kW RF generator was seriously delayed due to the supplier side reason, we built a small quartz cylinder with outer diameter of 110 mm instead of the 300 mm cylinder and apply a small RF amplifier with maximum output power of 1 kHz and with adjustable frequency from 1 MHz to 10 MHz, so we can test the effect of frequency on the plasma ignition. Before the 90 kW RF generator arrived, series of experiments had been carried out on the small driver with the 1 kW RF amplifier. In Fig. 4 is shown the integrated system, also a picture of the plasma is given at the right and bottom in Fig. 4. The measured plasma temperature and electron density is shown in Fig 5. The measure condition is: pressure of 6 Pa, frequency of 1MHz, 6 coil turns, RF power of 600 W, with no Faraday shield.

Series of experiments have been carried out on the small driver to examine the dependence of the plasma ignition on different operation parameters. These experiments will be presented in another paper.

The 90 kW RF generator arrived in April 2014, and is presently under commissioning.

Figure 4: The integrated system with the small cylinder. At right and bottom is the photo of plasma ignition.

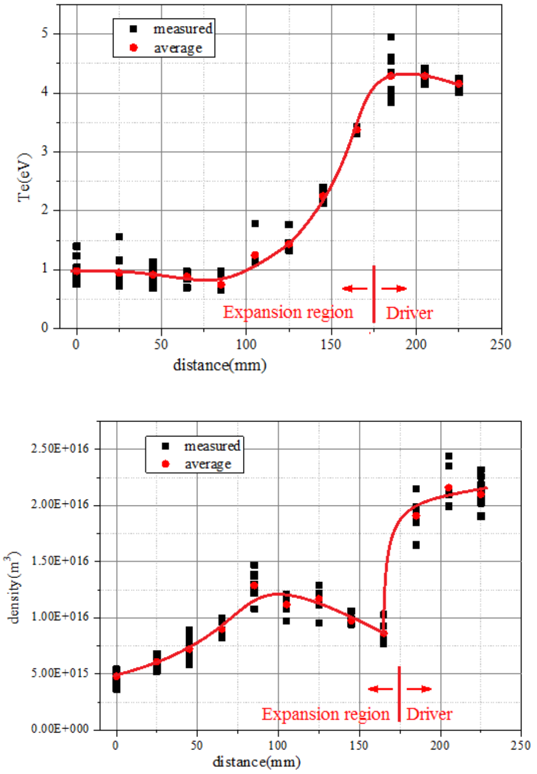

Figure 5: Plasma parameters obtained on small driver.

CONCLUSION

A test bed for RF driven plasma experiments has been built at HUST as the first phase toward a RF negative ion source, and series of experiments on the plasma ignition have been performed. These experiments help us to understand the behaviors of the RF ignition plasma on different operation parameters of the source.

ACKNOWLEDGMENT

During the development of the HUST facility, we have got a lot of help from IPP Garching in many aspects, so we would like to express our thank to IPP, especially to Prof. U. Fantz, Dr. P Franzen and Dr. W. Kraus.

REFERENCES

[1] Froschle M, Speth E, Falter H, et al. Progress in the Development of RF Driven Negative Ion Sources for ITER NBI[C]//Fusion Engineering 2005, Twenty-First IEEE/NPS Symposium on. IEEE, 2005: 1-4.
[2] U. Fantz, P. Franzen, D. Wünderlich. Development of negative hydrogen ion sources for fusion: Experiments and modeling. Chemical Physics 398 (2012) 7–16.