Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2012

Development Strategy of RF Ion Source for Neutral Beam Injector in Fusion Devices

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1. Introduction

Large-area RF-driven ion source is being developed at Germany for the heating and current drive of ITER device [1, 2]. Negative hydrogen ion sources are major components of neutral beam injection systems in future large-scale fusion experiments such as ITER and DEMO. RF sources for the production of positive hydrogen ions have been successfully developed at IPP (Max-Planck-Institute for Plasma Physics), Garching, for the ASDEX Upgrade and the W7-AS neutral beam heating systems [3, 4].

In recent, the first NBI system (NBI-1) has been developed successfully for the KSTAR device [5, 6]. The first long-pulse ion source (LPIS-1) consists of a magnetic bucket plasma generator with multi-pole cusp fields, filament heating structure, and a set of prototype tetrode accelerators with circular apertures.

There is a development plan of RF ion source at the KAERI to extract the positive ions, which can be used for the second NBI system (NBI-2) of KSTAR and to extract the negative ions for future fusion devices such as ITER and K-DEMO. The development strategy and processes are described in this presentation.

2. Strategy of RF Source Development

2.1 Objectives

The requirements of high current densities over a large area coupled with long pulse operation have initiated a development program for negative ion sources. The ITER neutral beam heating and current drive system is based on the acceleration of negative hydrogen ions due to their high neutralization efficiency (0.6) at the required 1 MeV beam energy. In order to inject the required 17MW, the source has to deliver 40A of negative ion current. As an alternative to the conventionally filamented arc sources, the RF source for negative ion production has been recently developed for the ITER neutral beam system. The primary focus of research is to improve the understanding of the physical processes that occur in the RF source and develop effective RF-based NBI strategies. We shall investigate the physical performances of the high-power RF ion source for the KSTAR and ITER NBI systems by a) performing the diagnosis of high-density RF plasmas by using Langmuir probe, OES, laser detachment method, et al., b) developing the large and high-density RF plasma sources for KSTAR and ITER NBI systems, c) improving the plasma homogeneity of large sources and the beam homogeneity, d) improving the long pulse stability of large RF sources, e) describing the physical processes in RF plasmas and the positive/negative ion transport from the converter to the extraction region, and f) better understanding the negative ion extraction process to optimize the source efficiency.

2.2 Research Background

Significant design changes have been made to the ITER NB injector over past few years. One of the main changes is that the RF driven negative ion source has replaced the filamented ion source as a reference design. There are open issues which cannot be addressed for large or high-power RF sources with the NBI system.

The main task of research is to better understand the physical process occurring in the high density RF plasmas and production of negative hydrogen ions, and to improve the long pulse stability and homogeneity of a large-area RF source.

The extraction, and thus a realistic potential distribution in the plasma, changes the plasma parameters in front of the plasma grid. Hence, the extraction and the magnets in the extraction grid play an important role for the negative ion and electron transport. It is therefore essential to optimize the magnetic filter field (and the plasma grid bias) with respect to the plasma uniformity together with a sufficiently suppressed co-extracted electron current. Therefore, there is an issue of plasma homogeneity of large sources and the result on the beam homogeneity which has to be addressed. Hence, long pulse large scale extraction from the half-size ITER source is highly desirable for a better understanding of the physics and the performance of large RF source.

For a good transmission ITER requires a beam homogeneity in terms of extracted current density of ±10%. This is directly connected with the negative ion density distribution at the plasma meniscus. To fully exploit this experiment, at least the plasma source has to be operated with long pulse, as the consumption and re-distribution of the caesium during a pulse is regarded as the main factor possibly limiting the long pulse performance. While the plasma source has to run continuously for an extended time it is acceptable to extract a beam with a duty cycle of 10 s/160 s repetitively throughout the plasma pulse. The experience of the manufacturing and operation of such a large scale, long pulse extraction system may have some influence on the design and the construction of the European Neutral Beam Test Facility (NBTF, presently constructed by Consorzio RFX, Padova) which is a full size text facility and the prototype for the ITER neutral beam system.

Standard diagnostics for ion sources are electrical measurements of extracted ion and electron currents, and calorimetrically measured ion current densities. Electron density and temperature can be obtained with conventional Langmuir probe measurements, whereas simple in situ diagnostic methods for negative ion densities are still highly desirable. Two diagnostic methods for negative hydrogen ions will be used as standard for small laboratory plasmas. One of them is the laser detachment method: an intense laser beam detaches the additional electron, the enhancement in electron density is detected with a Langmuir probe system. This method allows for spatially and time resolved measurements. The second method is the non-invasive cavity ring down spectroscopy. This very sensitive absorption technique measures the laser light absorbed in the detachment process. The OES will be used as an easy and simple non-invasive technique for in situ measurements of negative ion densities.

Understanding of the ion extraction process is essential to optimize the source efficiency, but is still an open issue. Numerical models can help to enhance the understanding of the physical processes within the RF plasmas and the ion source in order to optimize the performance and to predict the results of parameter changes. This is especially important for beam optics calculations, where the current density distribution is used as an input parameter. The understanding of the experimental results will be supported by modeling.

2.3 Development Processes

Objectives are to investigate the physical and technical issues of positive and negative RF ion sources including the reliable simulation processes. KAERI researchers will develop, at first-step, a positive RF ion source including a helical antenna with several turns using 10 kW RF power for a pulse duration of 300 s (or CW operation). Basic diagnostic tools will be the electrostatic probe systems in the first RF ion source. The mission of neutral beam power in the KSTAR NBI-2 device must be to develop a multi-megawatt system. Various diagnostic methods (using electrostatics, optics, lasers, etc.) should be employed for the characterization of high power RF ion source plasmas. The characteristics of positive ion beams should be investigated in the prototype ion source. For second-step, a prototype positive RF ion source including an RF power of ~100 kW will be developed for the KSTAR NBI-2 system. The physical and technical issues, simulation processes, and basic experiments of negative RF ion source are also investigated and experienced during the development of positive ion sources.

3. Structure of RF Ion Source

Compared to the conventional arc discharge sources RF sources have less parts, requiring a source body, an RF coil, and a matching transformer and are therefore cheaper to build and basically maintenance free, excluding the filament heating structure, in operation. Inside of the RF sources cannot be contaminated by the surface coating originated from the evaporation of tungsten filament in which the arc discharge characteristics can be affected by higher impurity fraction. The conceptual schematics of positive RF ion source are shown in Figure 1.

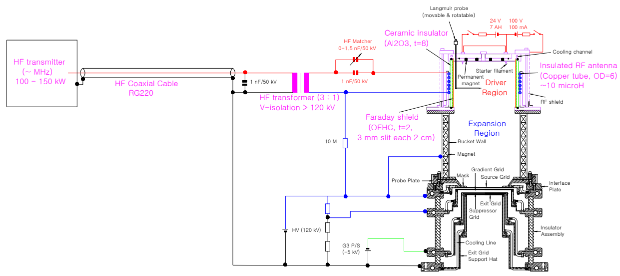

Fig. 1. Conceptual schematics of positive RF ion source

4. Conclusions

There is a development plan of positive and negative RF ion sources at the KAERI to extract the positive and negative ions, which can be used for the KSTAR, ITER, K-DEMO, and future fusion devices.

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