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Thermo-mechanical design of the extraction grids for RF negative ion source at HUST

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HIGHLIGHTS

- An extraction system with cooling channels has been designed for HUST negative ion source.
- Corresponding heat loads onto three grids has been used in thermo-mechanical analysis.
- The analysis results could be very useful for driving the engineering design.

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ABSTRACT

Huazhong University of Science and Technology (HUST) is developing a small radio frequency negative ion source experimental setup to promote research on neutral beam injection ion sources. The extraction system for the negative ion source is the key component to obtain the negative ions. The extraction system is composed of three grids: the plasma grid, the extraction grid and the grounded grid. Each grid is impacted by different heat loads. As the grids have to fulfil specific requirements regarding ion extraction, beam optics, and thermo-mechanical issues, grid cooling systems have been included for ensuring reliable operation. This paper focuses on the thermo-hydraulic and thermo-mechanical design of the grids. Finite element calculations have been carried out to analyse the temperature and deformation of the grids under heat loads using the fluid dynamics code CFX. Based on these results, the cooling circuit design and cooling parameters are optimised to satisfy the grid requirements.

1. Introduction

Neutral beam injection (NBI) is one of the most important systems for plasma heating and current drive in nuclear fusion reactors. The primary component of the NBI systems is the ion source. A radio frequency (RF) driven negative hydrogen ion source was chosen as the new reference source for the ITER neutral beam system [1]. Max-Planck-Institut fur Plasmaphysik (IPP) has successfully developed several RF sources since 2002. A small test bed called BATMAN was used to optimise the current densities in hydrogen and deuterium with a small extraction area and short pulses, on the large test bed MANITU the extension of the extraction area up to 0.03 m^2 and the pulse length up to 3600 s and the half-size ITER plasma source ELISE with 4 RF drivers has been under operation since 2012 [2–4]. Huazhong University of Science and Technology (HUST) has started developing an experimental facility since 2011 under the support of the Ministry of Science and Technology of China. The research project for negative ions at HUST contains two phases. During the first phase, an RF driver was built to ignite the plasma successfully in 2014 [5]. The next step is to build up an extraction system to extract the negative hydrogen ions and establish a complete negative ion test facility. Table 1 shows the main parameters of the RF ion sources of the ITER ion source [6], two IPP test facilities [2,3], and the HUST setup. This paper introduces the structure of the HUST negative ion source and focuses on the design of the grids.

2. HUST negative ion source setup

Fig. 1 shows a schematic of the HUST negative ion source test facility. The HUST setup, just like BATMAN of IPP, consists of three parts [2]: the driver, where the RF is coupled to the plasma; the expansion region, where the plasma expands into the source body; and the extraction region, where the negative ions are extracted. The driver is mounted on the back of the source body and consists of an alumina cylinder with the same size as the ELISE ones

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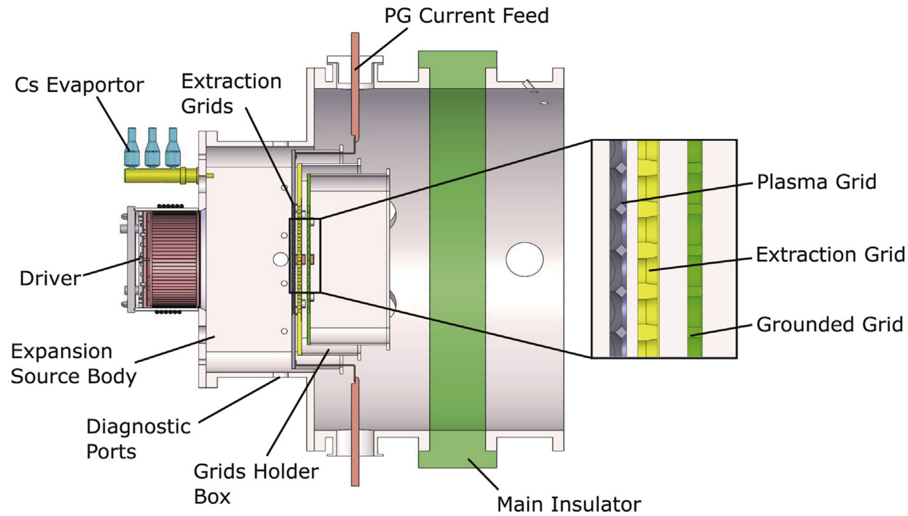

Fig. 1. Schematic view of the negative ion source test facility at HUST.

Table 1
Main parameters of the IPP test facilities and the HUST setup.

Parameter	ITER	BATMAN	ELISE	HUST setup
Isotope	H-,D-	H-,D-	H-,D-	H-
Pressure (Pa)	0.3	0.3	0.3	0.3
Extraction area (m^2)	0.2	0.0074	0.1	0.016–0.032
Extraction voltage (kV)	10	9	10	10
Accelerate voltage (kV)	870/1000 H-/D-	15	50	20
Pulse length (s)	3600	<6	3600	~4

(Φ 300 mm × 140 mm) [7]. A water-cooled RF coil (5–9 turns) connected to the RF oscillator is wound around the cylinder. Inside the cylinder, a Faraday screen protects it from the plasma. The plasma is ignited in the driver by an RF power of up to 90 kW at a fixed frequency of 1 MHz. The source body is a rectangular-shaped chamber with cross section dimensions 660 mm × 620 mm and depth 230 mm. It consists of a 10 mm thick stainless steel wall with 4 mm diameter cooling water channels. The entire inner surface of the source wall is covered with an electrodeposited nickel layer to avoid sputtering by the plasma (a coating device for molybdenum for this size was not available). There are diagnostic ports near the extraction grids for probes and spectroscopy. Caesium is delivered from an oven connected to the back of the source body. The extraction system is composed of three grids: the plasma grid (PG), the extraction grid (EG), and the grounded grid (GG). The overall dimensions of the grids in the extraction system are about 560 mm × 500 mm. All the grids are mounted onto their holder box and each of them is subject to different heat power loads. Thus, thermo-mechanical analysis is necessary for the design of the source. Most of the design of the HUST negative ion source has already been accomplished. We hope that the manufacturing of the main components will be finished this year, so that we could carry out the experiments in 2017.

3. Design description of the grids

All three grids feature 208 (13 × 16) apertures, where the ion beamlets are extracted from the expansion region and accelerated up to 30 keV. The reference design for the aperture geometry is based on the BATMAN and ELISE experiments [7]. The details of the aperture geometry are shown in Fig. 2. The apertures spacing is 20 mm × 20 mm. One of our colleagues is optimising the beam optics. Until this optimisation is finished, we use the initial designed aperture geometry in the thermo-mechanical analysis.

The plasma grid is the first grid of the extraction system, which separates the plasma and the extraction region. Most of the negative ions are generated on the plasma grid surface. An electric current is driven through the PG vertically to create a magnetic field to filter electrons, reduce the electron temperature in front of the PG below 2 eV, and for sufficient suppression of co-extraction electrons. To optimise the caesium effect on the negative hydrogen ions surface generation, the operational temperature of this grid is required to be kept in the range 150–200 °C. The cooling system in this grid is designed to control this temperature. The plasma grid is heated by the plasma from the driver, PG current, and cooling water. The power load from the plasma has been estimated from BATMAN experiments to be 20 kW/m^2. According to the design of IPP [3], the plasma grid is manufactured from copper and coated with a ~3-μm-thick molybdenum layer on the plasma side. This structure has provided good results. Nevertheless, there is a significant difference in the thermal properties between copper and molybdenum. We have not been able to find a suitable factory with a physical vapour deposition process that is refined enough for these metals. Therefore, we have resorted to another choice for manufacturing the PG: the extraction area is a molybdenum plate

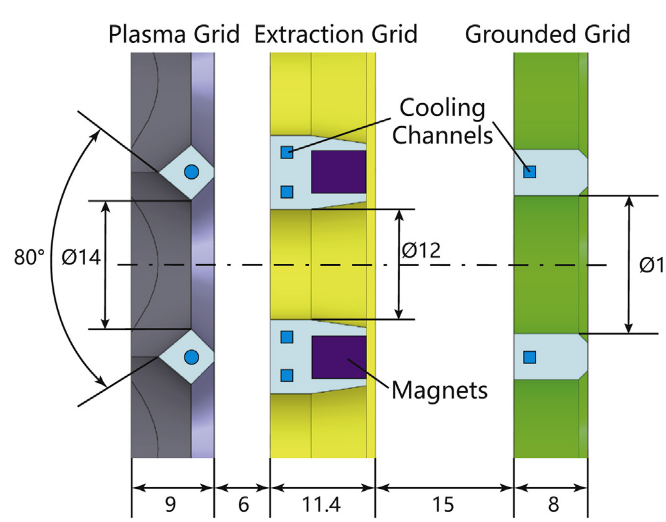

Fig. 2. Details of aperture geometry of the three grids (dimensions in mm).