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Design of an ion extractor system for a prototype ion source experiment for SST-1 neutral beam injector

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ABSTRACT

An ion extractor system has been designed for the steady state superconducting tokamak (SST-1) neutral beam injector (NBI) for an experiment using a prototype ion source with fully integrated regulated high voltage power supply (RHVPS) and data acquisition and control system (DACS) developed at Institute for Plasma Research (IPR) to obtain experience of NB operation. The extractor system is capable of extracting positive hydrogen ion beam of ∼10 A current at ∼20 kV. This paper presents the beam optics study for detailed design of an ion extraction system which could meet this requirement. It consists of 3 grid *accel–decel* system, each of the grid has 217 straight cylindrical holes of 8 mm diameter. Grids are placed on a specially designed G-10 block; a fiber reinforc plastic (FRP) isolator of outer diameter of 820 mm and 50 mm thickness. Provisions are made for supplying high voltage to the grid system through the embedded feed-throughs. Extractor system has been fabricated, mounted on the SST-1 neutral beam injector and has extracted positive hydrogen ion beam of 4 A at 20 kV till now.

1. Introduction

Neutral beam injection (NBI) is a well established technique for heating and current drive in tokamak fusion plasma [1,2]. Major components of NBI system (Fig. 1) include ion source, extractor system, neutralizer, bending magnet, ion dump, V-target, cryo pumps, power supply, data acquisition and control system (DACS). In SST-1 machine ($R = 1.2$ m, $a = 0.2$ m, $n_e = 2 \times 10^{19}$ m^{-3}, $T_e = 1$ keV), D-shaped plasma shall be produced for 1000S [3,4]. To raise the ion temperature of ∼1 keV, a neutral hydrogen beam power of 0.5 MW at 30 kV is required. Future upgrade of the SST-1 will require 1.7 MW of H° at 55 kV [5,6].As a part of the SST-1 NBI program, an experiment with positive hydrogen ion beam of ∼10 A at 20 kV is planned with prototype ion source integrated with RHVPS and DACS developed at IPR. This experiment would give us the information about performance of RHVPA and DACS needed for operation of PINI ion source. To fulfill this requirement an ion extractor system has been designed based on beam optics calculation using AXCEL-INP [7] code which takes into account the space charge effects of the ions. The output of this beam optics calculation is used for engineering design of multi-aperture 3 grid *accel–decel* extractor system. Three grids are made up of stainless steel fabricated at IPR workshop. These grids are housed on G-10 block. Single insulator block made of G-10 FRP of 50 mm thickness, 820 mm OD and 250 mm ID is chosen for grid holder (GH), where machined grooves are provided for placement of grids. The paper is organised in the following way. The ion extractor system is described in Section 2. Beam optics calculation for design of extractor grid is discussed in Section 3 and finally summary is given in Section 4.

2. Ion extractor system

Extractor system contains 3 grids and a grid holder which is made up of G-10 FRP insulator. Selected parameters of the extractor system are mentioned in Table 1. The acceleration grid plate has 430 mm outer diameter, thickness 4 mm and 217 straight cylindrical apertures each of radius 4 mm as shown in Fig. 2. Both deceleration grid of thickness 8 mm and earth grid of thickness 4 mm have same number of apertures. For holding the grids with requisite inter-grid distances we have designed grid holder system made up of single block of G-10 insulator shown in Fig. 3. Grooves are machined for fixing the grids and provision has been made for electrical connection to each grid through a specially designed vacuum tight connector made up of SS304 knurled rod of 8 mm diameter bonded with G-10 insulator. The extractor system along with all grids (Fig. 4) is mounted on NBI vacuum vessel. Then prototype ion source is attached with the extractor system shown in Fig. 5.

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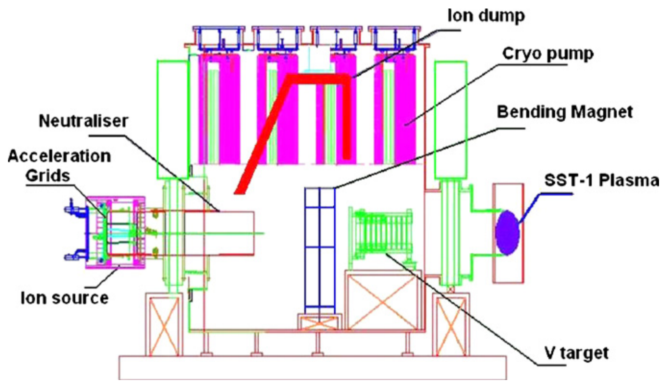

Fig. 1. Schematic of neutral beam injection system [5].

Table 1
Parameters of the extractor system.

Parameter	Value
Beam current (A)	10
Acceleration voltage (kV)	20
Deceleration voltage (kV)	−0.8
Aperture radius of acceleration grid (mm)	4
Aperture radius of deceleration grid (mm)	4
Aperture radius of earth grid (mm)	4
Acceleration gap (mm)	8
Deceleration gap (mm)	2
Diameter of acceleration grid (mm)	430
Thickness of acceleration grid (mm)	4
Diameter of deceleration grid (mm)	346
Thickness of deceleration grid (mm)	8
Diameter of earth grid (mm)	284
Thickness of earth grid	4
No. of aperture	217
Extraction area (cm^2)	109
Current density (mA/cm^2)	100

3. Beam optics calculation and design of grid geometry

As mentioned above, the aim of this prototype ion source experiment was to test the performance of in-house made regulated high voltage power supply (RHVPS) integrated with data acquisition and control system. So it was decided to design a simple ion extractor system with 3 grids each consisting of straight cylindrical apertures maintaining thickness and inter-grid distances same as actual ion extractor designed for SST-1 NBI [5,6]. It is to be noted that this prototype ion source shall be replaced by PINI ion source during actual SST-1 NBI operation. Ion beam optics calculation has been done using axis symmetry single aperture AXCEL-INP code for design of the above mentioned prototype ion extractor system consisting of 3 grids. The first grid in contact with plasma is called acceleration grid maintained at positive potential ∼20 kV. This grid separates

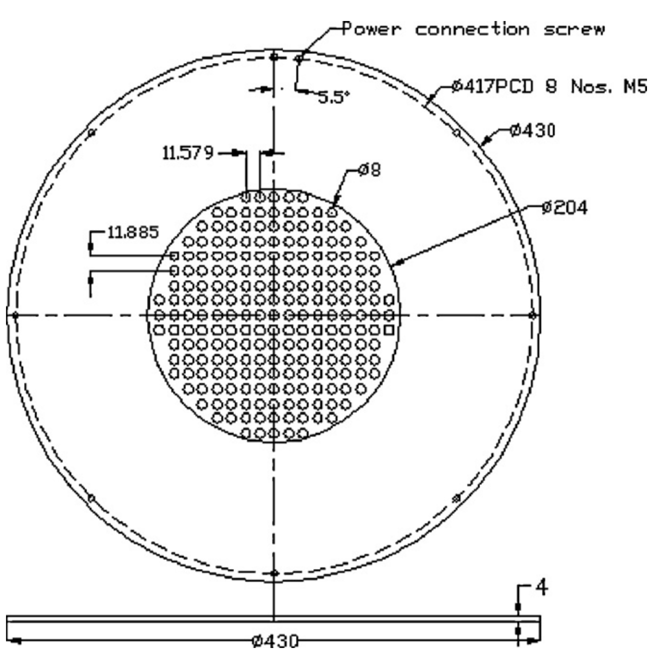

Fig. 2. Arrangement of apertures in acceleration grid.

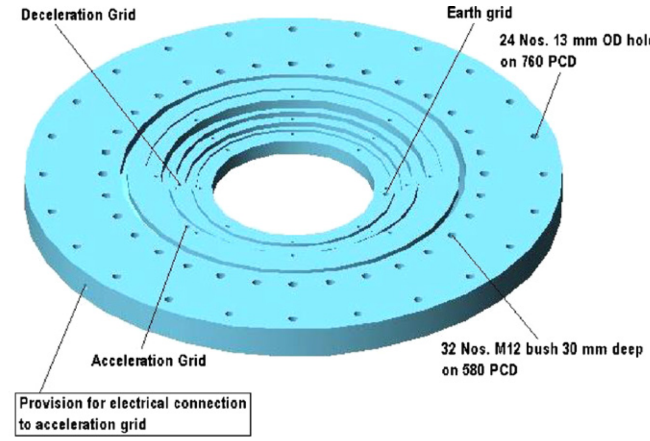

Fig. 3. Insulator G-10 FRP.

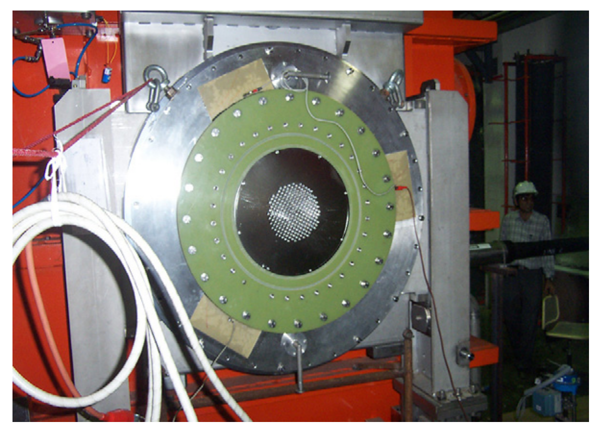

Fig. 4. Assembled extractor system mounted on SST-1 NBI vacuum vessel.

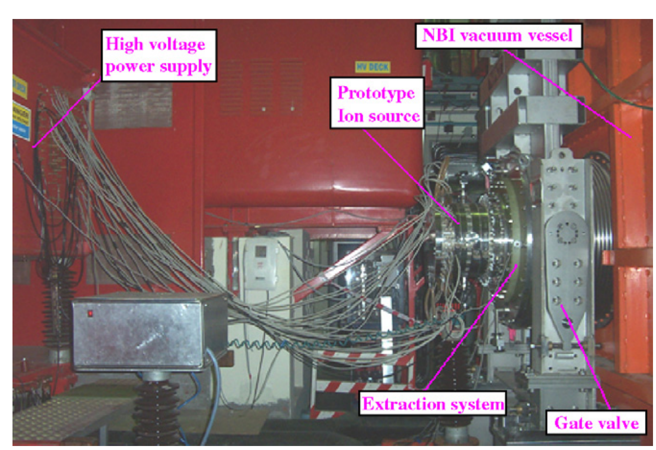

Fig. 5. Prototype ion source mounted with SST-1 NBI vacuum vessel.