The initial characteristics of 80keV ion source for a 5MW neutral beam injector

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A new neutral beam injector (NBI) with beam power of 5MW at 80keV energy and pulse length of 5 seconds is designed for a new tokamak called HL-2M which is under construction in Southwestern Institute of Physics of China. In order to cope with the power demand, there are four ion sources installed on one beam line, a rectangular magnetic multipole positive ion source with power of 80kV×45A and 5s pulse length is designed [1]. At present, A 80kV ion source prototype has been manufactured.The arc chamber is 560mm long, 266mm wide and 240mm high. Seven loops cobalt-samarium magnets are installed around arc chamber to form a magnetic multipole line cusp field configuration parallel to the beam axis. The arc chamber wall serves as the anode, and 16 hair-pin shaped tungsten filaments of 1.5mm in diameter are set as the cathode. The ion beam extraction system consists of four grids, called plasma grid (PG), gradient grid (GG), suppressor grid (SG) and Exit grid (EG), respectively. Material of PG is molybdenum and other grids are oxygen-free copper. The extraction area is within an area of 13.5cm×42cm. Each grid has 564 circular apertures with 6mm to 7 mm diameter. The grids have been designed to optimize cooling by the use of multiple water-cooling channels arranged between two rows of apertures.

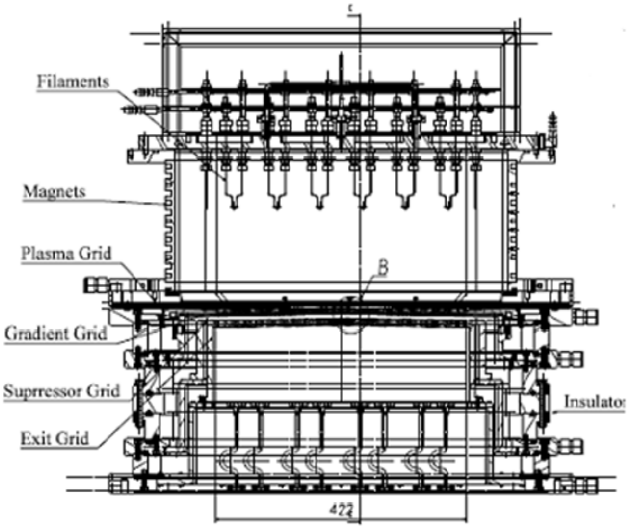

Fig.1 The 80kV ion source prototype

The 80kV ion source prototype has been installed on the test bed where high voltage power supply system pulse length is only 0.1s, Presently the ions beam power has been up to 75kV×35A. the arc efficiency is about 0.72A/kW for H ions beam and 0.65 A/kW for D ions

beam when the ion beam optics is better. The arc efficiency will decrease when the ion beam perveance is raised shown as Fig2, and increase when the voltage ratio is redued for the same ion beam perveance due to ion beam optics. Ion beam simulation results show the transmission factor through grids gap is inversely proportional to the ion beam current density for a constant beam energy, and to the field ratio for the same perveance[2]. The arc efficiency is also affected by the filament current direction show as Fig3,where the solid symblos show the extraction current varied with the arc discharge power when each filament current direction is clockwise direction alone the beam extraction axis viewing from the back plate of the arc chamber. Thus the ratio of extraction current to the arc power is larger than that obtained from the blue circle symbols (on fig3)for anticlockwise direction. The filament current of clockwise direction produces axial magnetic field whose direction is oppsited to that of residual magnetic field of cobalt-samarium magnets, thus the initial electrons is easy to reach the chamber center.

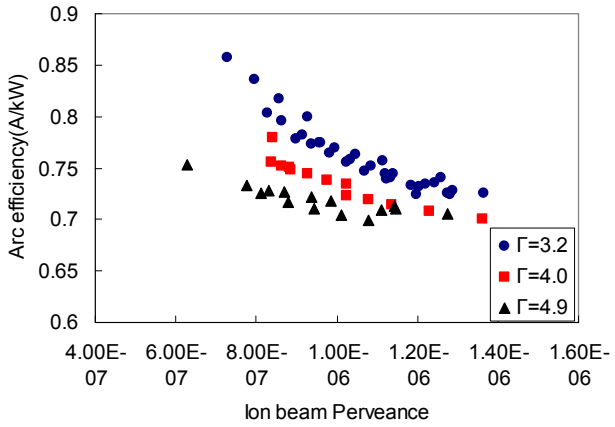

Fig.2 Arc efficiency varied with the ion beam perveance from experiment results

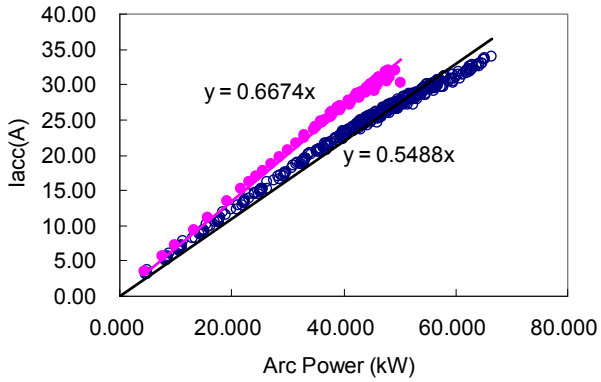

Fig3 The extraction current versus arc power for different filament current direction

The hydrogen-ion species fractions (H^+,H_2^+,H_3^+) were measured by a H_α light Doppler shift Spectroscopy, H^+ fraction raises with the ion beam current density, and the ion beam with 63% H^+ fraction can be obtained for 0.15A/cm^2 ion beam current density.

The beam power profile has been measured by Faraday cups arrays, which are installed on a calorimeter downstream 3700mm form the exit grid of accelerator on test bed. When the gaps between PG and GG and between GG and SG are 2.8mm(named d1) and 7.8mm(named d2), the optimum perveance is about 1.15×10^{-6} $A/V^{1.5}$with beam divergence angle of 1.1° for H ions beam and $0.9\times10^{-6}A/V^{1.5}$ with beam divergence angle of 1.0° for D ion beam, the 1/e half width of H^+ and D^+ beam profile are shown as Fig.4. The optimum perveance and beam divergence angle both are effected by the electrical field ratio Γ / f $(\Gamma = \frac{(V_{GG} - V_{SG})}{(V_{PG} - V_{GG})}$, f=d2/d1)between grids. The 1/e half width of H^+ beam profile varied with beam perveance for different voltages ratio Γ are shown as fig5. the 1/e half width minimum is about 78mm for Γ of 4.0, and the 1/e half width increases clearly when the voltage ratio decreases to 3.2, and which varied a little when the voltages ratio increases to 4.7. The experiments results show that voltages ratio Γ is limited below 5.0 because of practical difficulties involving direct interception of the beam on the gradient grid, which almost creates a short circuit across the extracion voltage, when the beam perveance is larger than 1.4×10^{-6} $A/V^{1.5}$. Increasing the Γ value reduces the beam divengence and is an attendant loss in extraction current. To banlance ion current and beam divergence, it is desirable to operate the source at Γ value of 4.0 for the 2.8mm extraction gap and 7.8mm acceleation gap.

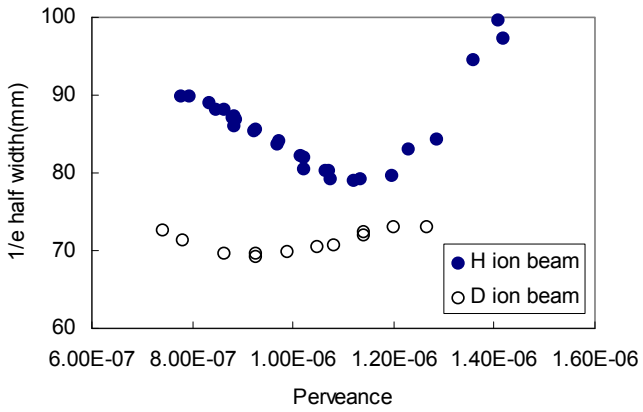

Fig4. 1/e half width of ion beam profile varied with ion beam perveance

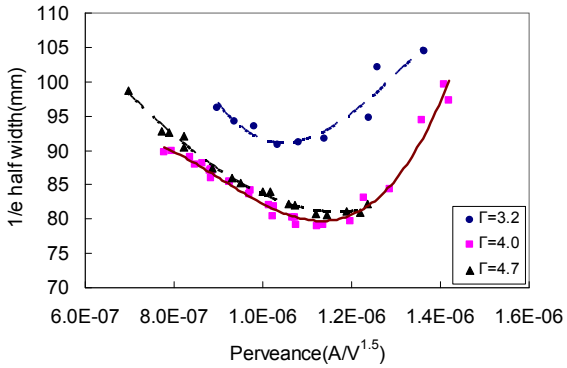

Fig 5 1/e half width in vertical direction from Faraday cups array

The present obtainable perveance is 1.5×10^{-6} $A/V^{1.5}$ with the 1/e half width is 100mm for beam energy of 74keV under the voltage ratio of 4.0. In order to realizing the design paramenters of 80keV beam energy and 45A ion current, the obtainable perveance of 1.8×10^{-6} $A/V^{1.5}$ is desirable for 80keV H^+ ion beam in the next experiments by means of decreasing the gap distance or enlarging the transparency of grids.

Reference

[1] J.Y Cao, H.L Wei, G. Q Zou, H. Liu, G.J Lei, X.M Zhang, et.al, Fusion Engineering & Design, **88,**872 (2013)
[2]Jinchoon Kim, J.H.Whealton, and Gerd Schilling, J. Appl.Phys.49(2), 517(1978)