A.3 Physics design and modeling of H^- ion source

Power Supply Division of RRCAT has initiated the development of an arc discharge driven cesiated H^- ion source for the high current, high energy (50 keV) H^- injector for a spallation neutron source. Both surface and volume production of H^- ions will be used to increase the yield.

The plasma will be produced by arc discharge with multiple filaments and confined by multi-cusp magnetic field configuration. The design of this magnetic field and heat removal system for the H^- ion source plasma chamber has been carried out through mathematical modeling using finite element analysis. A cylindrical plasma chamber of 12 cm inner diameter and 12 cm length has been considered. The magnetic field is assumed to be produced by equal strength permanent bar magnets of dimension 12 x 2.5 x 2.5 cm, of coercivity (H_c) 5.7 x10^5 A/m and remanence of 0.8 T. The results (Fig.A.3.1) indicate that the magnetic field near the chamber wall is 0.23 T, which is desirable for the plasma confinement in the ion source. The field free region ($|B| < 10$ G) with 12 bar magnets is about 50 mm diameter surrounding the chamber axis. Considering a duty factor of ion source = 10% and peak power dumped in the chamber not exceeding 60 kW, the cooling system parameters have been worked out both for SS and OFHC Cu plasma chamber.

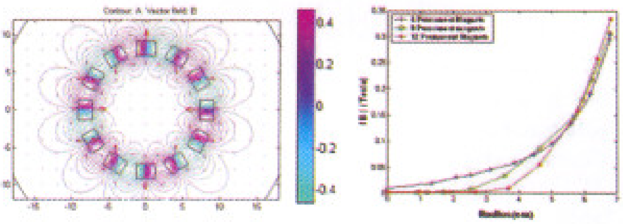

Fig.A.3.1: (a) Multi-cusp magnetic field lines with 12 permanent magnets placed along the cylinder length. (b) Magnetic field intensity variation along a radius that passes through the cusp for different combinations of magnets.

Computer simulations have also been performed using fluid model considering sheath formation near the boundary wall of the plasma chamber under electro-negative plasma equilibrium conditions to get an estimate of the spatial density variation of different species in the H^- plasma. The average cross-sections for various reactions responsible for H^- ion formation and their destruction have been taken into account. The total power requirement for the ion source has been computed using energy and particle balance (Fig. A.3.2). Finally various parameters of the arc discharge and RF discharge have been computed by modeling the plasma generation mechanism through arc and RF discharge. The required plasma density is found to be ~10^{19} m^{-3}.

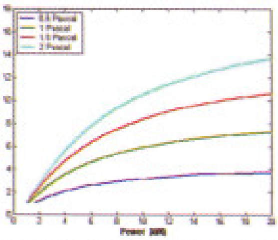

Fig.A.3.2: Variation of RF power absorption in the H^- ion source plasma with H^- ion current at different gas pressure in the plasma chamber.

A Particle-In-Cell (PIC) Monte Carlo Computation (MCC) code has been developed to take into account numerous reactions taking place inside the plasma chamber. The PIC code incorporates elementary module of the MCC algorithm. The extraction code is functioning and has been tested for H^- ions as shown in the Fig.A.3.3 A fast Fourier transform (FFT) based Poisson solver has been used coupled with capacitance matrix to incorporate any arbitrary electrode geometry. In order to overcome the limitations of the FFT solver, a matrix decomposition based Poisson solver has been developed.

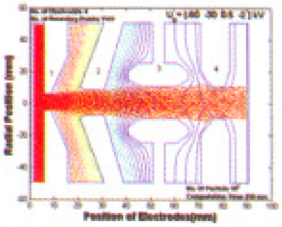

Fig.A.3.3: Extraction of negative ions, through tetrode geometry is shown. The red dot represents the H^- ions and 1, 2, 3 and 4 represent plasma, extractor, accelerator and screening electrode respectively.

Further, the extraction and optimization of H^- ions through various electrode geometries from an ion source has been studied using the IGUN software. The extraction setup shown in Fig.A.3.4 gives an rms emittance of 0.182 cm-mrad and an angular divergence of 6.2 mrad. Sharp corners and steep inclined edges are avoided in the high potential drop region between the puller electrode and the ground electrode to reduce the possibility of electrical breakdown. This study also helps in the understanding of H^- ion extraction.

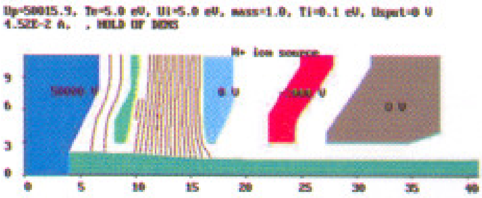

Fig.A.3.4: The five electrode extraction system for obtaining high quality ion beam using the IGUN code.

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