DESIGN, FABRICATION AND INITIAL TESTING OF PROTOTYPE PLASMA CHAMBER FOR H^- ION SOURCE

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Abstract

Development of a multi-cusp type H^- ion source is in progress as part of the high current H^- ion injector linac project. The multi-cusp magnetic field is generated in the cylindrical plasma chamber with the help of high grade Nd-Fe-B permanent magnets by placing them with alternating field polarity along the length of the cylinder. Each magnet pieces are protected from the heat generated by the plasma ions and electrons striking the inner wall of the plasma chamber. The plasma chamber has been designed and fabricated using stainless steel material considering the Gaussian heat deposition profile at the multi-cusp points along the length of the chamber. Detailed thermal analysis of the plasma chamber has been carried out considering different materials for the plasma chamber. Dual cooling channels of 5 mm rectangular size placed below the permanent magnets are found suitable for heat removal and magnet protection in stainless steel chamber. The end flange of the plasma chamber is designed and fabricated by brazing different cooling channels below permanent magnets using laser welding techniques. The multi-cusp magnetic field mapping of the plasma chamber has been performed using 3-D Hall probe. The results of various studies carried out for plasma chamber are reported.

INTRODUCTION

We have taken up development of a multi-cusp type H^- ion source based on the design of J-PARC having similar beam parameters [1-2]. H^- ion source design involves a plasma chamber with multi-cusp magnetic field floated at high negative dc field with respect to the ion extraction system. We have followed the scheme based on design and development of an arc discharge type filament based H^- ion source whose life time will be limited due to the life time of filament The filament based ion source follows a hybrid scheme i.e. volume as well as surface production to increase the H^- ion yield. The plasma will be created by tungsten filament heating and arc discharge between the filament and the plasma chamber generating ions bunches that can be extracted through extraction chamber. The plasma chamber is cylindrical in geometry and surrounded with high grade permanent magnets having high Curie temperature and high strength magnetic field of ~0.2 T at the inner wall of the plasma chamber by multi- cusp magnetic field distribution.

Each permanent magnet is provided with cooling channels to protect their magnetic properties due to heat generated by the plasma ion and electrons striking the chamber inner wall below multi-cusp regions of each magnet. The H^- ions from the plasma chamber are extracted through an orifice of ~10 mm diameter in the plasma electrode.

THERMAL ANALYSIS

Thermal analysis for various options of cooling channels and chamber materials (copper, aluminum and SS) were performed to decide the cooling of plasma chamber as shown in table 1. Here the heat flux is considered to have Gaussian distribution under the magnet location of the chamber and the water flow velocity of 3 m/sec is considered for convection calculations in the cooling channels. 3D FEM thermal analysis of plasma chamber made of SS 304L material using dual cooling channels is shown in fig.1. The maximum temperature in the hot region is about 175° C [at the inner wall of the plasma chamber as shown in fig. 1] and the temperature near the permanent magnets remains ~48° C. With the assumption that duty factor of < 10% and peak power is dumped in the chamber will not exceed 60 kW, the cooling arrangements have been worked out for Stainless Steel, Copper and Aluminum chambers. This has been considered keeping the average arc discharge power dumped in the plasma chamber is 4.8 kW. The particle density peaks at the cusp points below the magnets explaining the higher temperature in that region.

Table 1 various options for cooling channels and their effect on resultant temperature.

Cooling channel location	Chamber Material	Max. rise of temp. (°C inside chamber)	Temp. on magnets (max) °C
Between two magnets	Copper	69.9	65.2
Between two magnets	Aluminium	85.3	76.1
Between two magnets	SS-304L	280.7	198.8
Underneath magnets	Copper	52.4	41.5
Underneath magnets	Aluminium	61.2	44.1
Underneath magnets	SS-304L	175.8	48.2

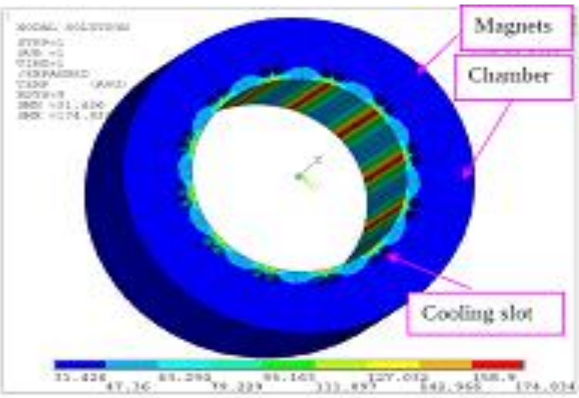

Fig.1. The plasma chamber model (top) and The plasma chamber heating along the inner wall shows the hot region (red colour) along the cusp line, permanent magnets are placed above the cooling channels(bottom) (two rectangular slots just above the heated region).

PLASMA CHAMBER

The fabrication of first prototype is done in SS-304L using the design of cooling channels the 12 magnets as shown in fig. 2. The provisions for filter magnets will be made at the neck position. There is tapering of the chamber wall towards the neck region of the plasma chamber. The end flange has 8 holes for keeping the provision of various ports for filament heating, gas feeding valve, Langmuir probe, glass viewing windows etc. There will be 5 magnets on the side flange for plasma confinement. The cooling provision is made for these magnets also as shown below in fig. 2.

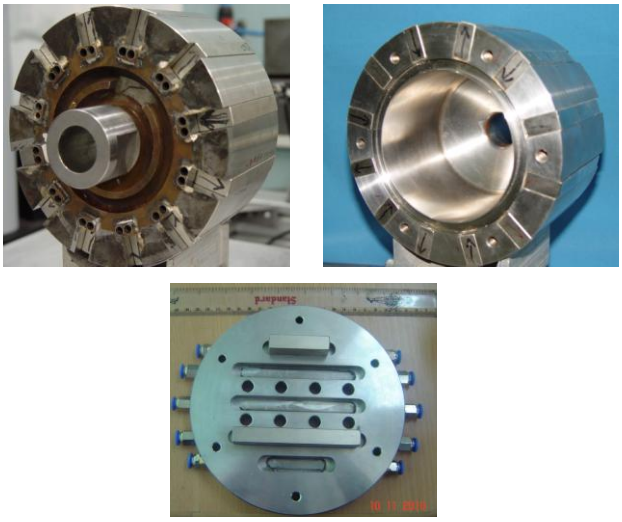

Fig.2 Plasma chamber fabricated in stainless-steel with arrangements of permanent magnets and cooling channels on the chamber and its side flange. Small cylindrical neck is provided for placement of filter magnets and coupling it with the ion extraction system.

MULTI-CUSP MAGNETIC FIELD

The multicusp magnetic field has been mapped by placing Nd-Fe-B magnets in the slots made in Al cylinder having same size as plasma chamber. Field mapping was done using the Hall probe method [3].The field variation for 4, 8 and 12 magnets have been plotted in fig.3. The field free region for the 12 magnets is ~50 mm diameter surrounding the chamber axis which is suitable for placing the filament for gas heating and ionization.

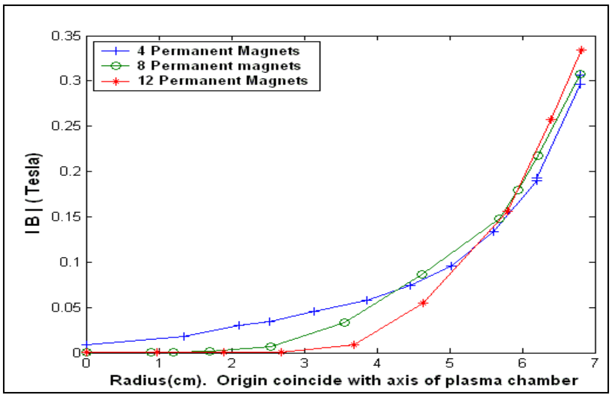

Fig. 3 The Magnetic field intensity variation along the radius of chamber (made of Al for field mapping) that passes through the cusp for combination of 4, 8 and 12 permanent magnets.

SUMMARY

The plasma chamber has been designed and fabricated with multi-cusp magnetic field and cooling system. Front flange has been provided with arrangements of hydrogen gas feeding, filament heating using high power feed-through and beam diagnostics for the plasma. Coupling of the ion extraction system with plasma chamber will be done through the placement of filter magnets near the neck of the plasma chamber. The plasma created will be characterised using the Langmuir probe to determine the plasma density and temperature suitable for ion beam extraction. Some of the work is in progress and results on plasma chamber will be reported.

ACKNOWLEDGEMENT

We are thankful to Dr. P.D. Gupta, Director, RRCAT for his keen interest, encouragement and constant support to this work. The accelerator and laser workshop staff member deserves thanks for various machining jobs carried out for the plasma chamber. We are also thankful to Shri B.N. Upadhyay and colleagues for their help in laser welding of cooling channels of the side flange.

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