Concepts of Magnetic Filter Fields in Powerful Negative Ion Sources for Fusion[a)]

W. Kraus[b)], U. Fantz, B. Heinemann and D. Wünderlich

Max Planck Institute for Plasma Physics, Boltzmannstr. 2, 85748 Garching, Germany

(Presented XXXXX; received XXXXX; accepted XXXXX; published online XXXXX)
(Dates appearing here are provided by the Editorial Office)

The performance of large negative ion sources used in neutral beam injection systems (NBI) is in long pulses mainly determined by the increase of the currents of co-extracted electrons. This is in particular a problem in deuterium and limits the ion currents which are for long pulses below the requirements for the ITER source. In the source of the ELISE test facility the magnetic field in front of the first grid, which is essential to reduce the electron current, is generated by a current of several kA flowing through the plasma facing grid. Weakening of this field by the addition of permanent magnets placed close to the lateral walls has led to a reduction of the electron current by a factor three without loss of ion current when source was operated in volume production. If this effect can validated for the cesiated source, it would be a large step towards achieving the ITER parameter in long pulses.

I. INTRODUCTION

At Max Planck Institute for Plasma Physics two RF sources are currently being tested, the small 0.3 x 0.6 m^2 prototype source at the BATMAN testbed[1] and at the ELISE test facility[2] a 0.9 x 1.0 m^2 source, which has the same width, but only half of the height of the negative ion sources of the ITER NBI systems[3]. The negative ions are generated by surface conversion of hydrogen or deuterium ions and mainly atoms on the plasma grid surface which is covered by a thin caesium layer. The goal of the ELISE experiment is to demonstrate the negative ion currents required for the ITER source in pulses up to one hour under the condition that the currents of the co-extracted electrons are lower than the ion currents[3]. This has already been achieved in short pulses by a combination of biasing the plasma grid positively with respect to the source body and by a magnetic filter field parallel to the plasma grid[2,5,6]. The purpose of this field is to lower the electron temperature in order to reduce the destruction of negative ions by collisions with electrons and to increase the extraction probability for the surface produced negative ions. Deflection by this magnetic field contributes to direct the negative ions from the surface to the extraction apertures[4]. In long pulses, however, the electron current increases at higher power. So either the pulse length or the RF power has to be reduced in order to restrict the electron current. Due to this power limitation the achievable ion currents are below the required ITER values in long pulses. This has been observed at the small source[6] as well as recently at the large ELISE source[7].

In the BATMAN source the magnetic field is created by two rows of permanent magnets placed close to the plasma grid at the lateral walls. In extensive experiments it was found out that in hydrogen a field strength of 3 mT in front of the plasma grid is needed in the middle of the source for maximum ion extraction and an integrated field of about 1.25 mTm for sufficient electron suppression[8,9]. The filter field at ELISE is created by a current of up to 5.3 kA flowing through the plasma grid in the vertical direction (PG field). The required strength of the magnetic filter field is considerably lower than expected from the experience with the small source: For ion extraction at the minimum 0.95 mT close to the plasma grid and for an electron/ion ratio below one near the plasma grid of 1.6 mT and an integrated field of about 0.3 mTm is needed[2]. This discrepancy indicates that the values of the field strength only are not sufficient to characterize the filter field. It has to be considered that the field topology plays also an important role[9]. In case of the permanent magnets the field has a minimum in the middle and increases parallel to the plasma grid steeply to very high values close to the magnets. This field topology confines the plasma in front of the plasma grid which is not the case for the field produced by the PG current.

At the ELISE source the effect of changing the field topology by combining both – PG current and permanent magnets – on the source performance and in particular on the electron currents was investigated.

[a)]Contributed paper published as part of the Proceedings of the 16th International Conference on Ion Sources, New York City, USA, August, 2015.
[b)] Corresponding Author: Werner Kraus, e-mail address: kraus@ipp.mpg.de

II. VARIATIONS OF THE ELISE FILTER FIELD

Fig 1a shows the standard filter field configuration of ELISE. The plasma is generated four circular RF driven drivers and expands into the main source chamber. The return conductors are located between the drivers in order to reduce the field on the beam side and also in the drivers[9].

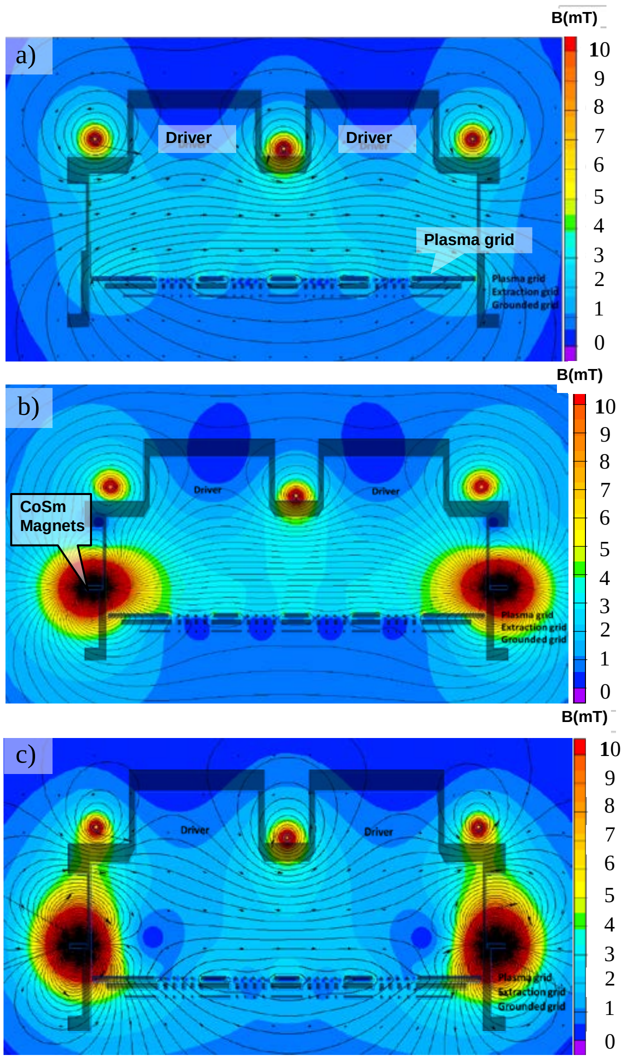

FIG. 1. Horizontal cross section of the ELISE filter field
a) at 2.5 kA, b) strengthened c) weakened by permanent magnets

In order to change the field topology three rows of CoSm permanent magnets, each with a cross section 9x13mm^2, were mounted to the side walls of the source in 60 mm distance to the plasma grid. At first the polarity was chosen such that the initial field of the PG current was strengthened (see Fig. 1b), resulting in a field topology similar to that in the BATMAN source[8]. For a second experiment the polarity of the permanent magnets was reversed. The superposition of both fields now resulted in a slightly weaker field in the central part. Close to the magnets are areas with weak or almost no field (see Fig. 1c). The B field profiles in Fig. 2, calculated for a distance of 20 mm to the plasma grid, show the principal differences. The field parallel to the plasma grid is almost constant for PG current only. The fluctuations result from the inhomogeneous current distribution in the grid. Strengthened by the permanent magnets it increases from middle to outside. Weakened by the magnets the field decreases from the middle to outside and increases only close to the permanent magnets. This characteristic was tested for the first time with a negative ion source and was expected to affect the plasma expansion from the drivers.

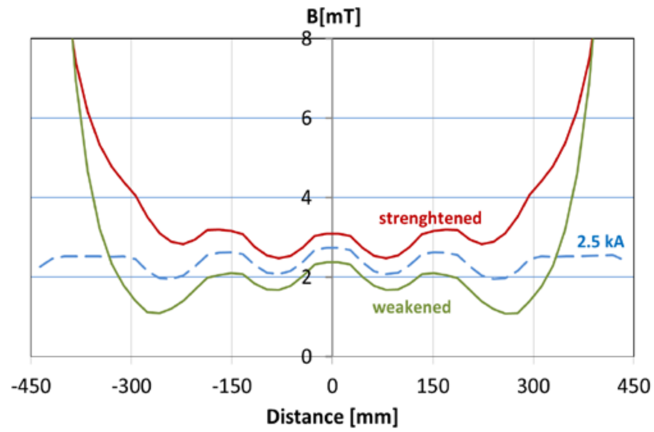

FIG. 2. B field in 20 mm distance parallel to the plasma grid.

III. RESULTS

The experiments were carried out by 10s beam pulses in hydrogen without caesium, i.e in pure volume production of negative ions. This provides a high reproducibility of the results. The distribution of the plasma light observed through a side window showed substantial differences, in case of the weaker field the expanding plasma seemed to be directed to the side walls.

Standard parameters for the beam pulses were: RF power 80 kW, pressure 0.6 Pa, plasma grid current 2.5 kA corresponding to 2.4 mT, bias current 55 A and extraction voltage 4 kV. Scans of the extracted ion current density and the relation of the currents of co-extracted electrons and ions as function of PG current, source pressure bias current and RF power were carried out.

Common to all scans is that the ion current densities did not change very much after variation of the filter field. Strengthening of field led to considerably higher electrons currents (see Figs 3 to 6). The PG current had to be raised by about 0.5 kA to achieve the same electron current as with the standard field (Fig. 3). This is consistent with the observation that in the BATMAN source a higher field is required than in the ELISE source.

The most important result, however, is that after weakening of the field the electron currents dropped approximately by a factor of three. It is even possible to reach a ratio of electron to ion currents densities of one by raising the PG current (Fig. 3), or the bias current (Fig. 4).

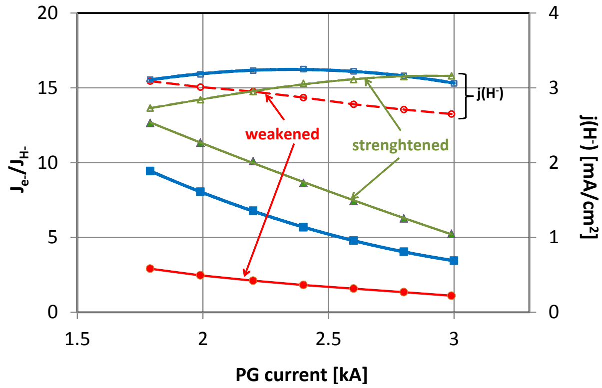

FIG. 3. Ratio electron to ion current as function of the PG current

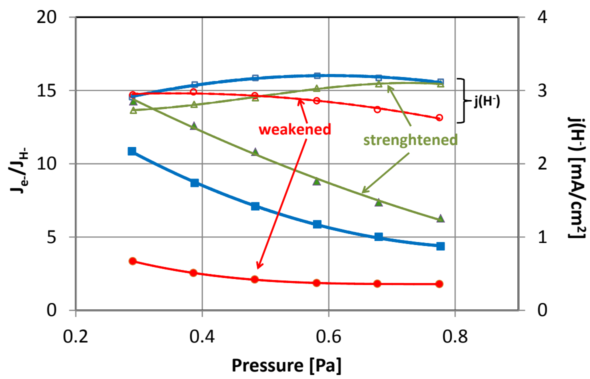

FIG. 4. Ratio electron to ion current as function of the source pressure

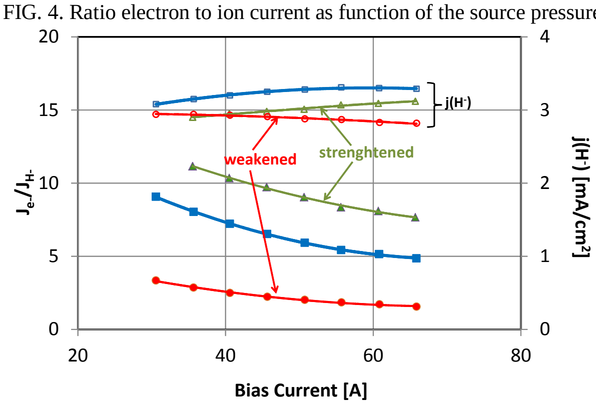

FIG. 5. Ratio electron to ion current as function of the bias current

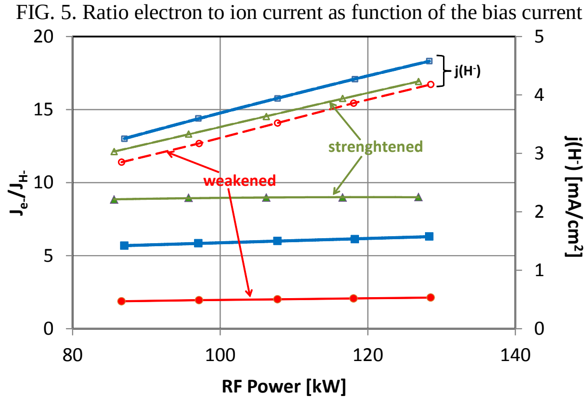

FIG. 6. Ratio electron to ion current as function of the RF power

Such low electron/ion ratios have not been achieved in volume H^- sources so far[11]. It is also remarkable that at 0.3 Pa the electron to ion ratio is “only” three, without loss of ion current. The bias voltage necessary to sustain the adjusted 55 A bias current increased from 23 V to 27 V when the field was weakened. This indicates a lower plasma density in front of the plasma grid.

IV. CONCLUSION

At the ELISE source the filter field has been weakened by an additional field of permanent magnets. Although the tested configuration is far from being optimized, the electron currents have been reduced substantially. A possible explanation can be that plasma confinement in front of the plasma grid is avoided and the expanding plasma is directed to the side walls. This will in future be investigated in more detail by using refined diagnostics.

The next step will be to test this configuration with the cesiated source. Then the magnetic fields are expected to affect the negative ion currents by changing the extraction probability[4]. If efficient electron suppression can also be demonstrated with surface production of the negative ions, the tailoring of the filter field topology by the superposition of magnetic fields can provide a solution for the problem of increasing electron currents in long pulses.

ACKNOWLEDGEMENT

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

[1]E. Speth, H.D. Falter, P. Franzen, U. Fantz, M. Bandyopadhyay, S. Christ, A. Encheva, M. Fröschle, D. Holtum, B. Heinemann, W. Kraus, A. Lorenz, Ch. Martens, P. McNeely, S. Obermayer, R. Riedl, R. Süss, A. Tanga, R. Wilhelm and D. Wünderlich, Nucl. Fusion 46(2006)220–238
[2]P. Franzen, U. Fantz, D. W¨ underlich, B. Heinemann, R. Riedl, W. Kraus, M. Fr öschle, B. Ruf, R. Nocentini and the NNBI Team, Nucl. Fusion 55 (2015) 053005
[3]Hemsworth, H. Decamps, J. Graceffa, B. Schunke, M. Tanaka, M. Dremel, A. Tanga, H.P. De Esch, F. Geli, J. Milnes, T. Inoue, D. Marcuzzi, P. Sonato, and P. Zaccaria, Nucl. Fusion 49, 045006 (2009).
[4]R. Gutser, D Wünderlich, U Fantz, Plasma Phys. Control. Fusion 51 (2009) 045005
[5]Franzen P., Wuenderlich D., Fantz U. and the NNBI Team, Plasma Phys. Control. Fusion, 56, 025007 (2014)
[6]W. Kraus, U. Fantz, P. Franzen, M. Fröschle, B. Heinemann et al., Rev. Sci. Instrum. 83, 02B104 (2012)
[7]U. Fantz, B. Heinemann, D. Wünderlich, R. Riedl, W. Kraus, R. Nocentini, F., Bonomo and the NNBI Team, this conference
[8]P Franzen, L Schiesko, M Fr¨oschle, D Wünderlich, U Fantz and the NNBI Team, Plasma Phys. Control. Fusion 53 (2011) 115006
[9]U Fantz, L Schiesko and D Wünderlich, Plasma Sources Sci. Technol. 23 (2014) 044002
[10]M. Fröschle, U. Fantz, P. Franzen, W. Kraus, R. Nocentini, L. Schiesko, D. Wünderlich, the NNBI Team, Fusion Engineering and Design 88 (2013) 1015– 1019
[11]M. Bacal and M. Wada, Applied Physics Reviews 2, 021305 (2015).