# THE DRIFT SOURCE : A NEGATIVE ION SOURCE MODULE FOR DC MULTI-AMPERES ION BEAMS

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*Abstract*

The concept of a modular large size ion source is under investigation in our laboratory for the development of the very intense (tens of amperes) negative ion ($D^-$) beams needed for neutral beam injection in Thermonuclear Fusion Research. The basic idea is to develop a compact small ion source producing the required ion flux (20-30mA/cm$^2$) over a total surface of about 200cm$^2$ and designed in such a way that it can easily juxtaposed with other identical modules. A large negative ion source of any size (up to several m$^2$) and shape could be realised as a set of several modules. The anticipated advantage of this concept is the minimisation of the risk inherent in a large extrapolation in size (e.g. ≈1.0m$^2$ for ITER) of the present ion sources. In this context, we have developed and tested a source module, called the DRIFT source, whose main properties are presented in this paper. The particular magnetic field configuration of this module ensures, in a simplified way, a very good plasma confinement allowing operation of the source at very low filling pressures.

Up to now, a $D^-$ current of 1A (20mA/cm$^2$) 50keV energy, 1s pulse length, was obtained with Caesium vapour seeding at 0.15Pa source pressure with an arc power of 2.5kW/litre (12kW).

## 1 INTRODUCTION

In the field of Thermonuclear Fusion research, R&D programs are underway for the production of high energy (300-1000keV) high powers (10 to 50MW) deuterium neutral beams for plasma heating. At these energies, the neutral beam injectors are necessarily based on negative ions for which neutralisation rates of 60% can be achieved. The constraint on the negative ion source to meet the previous parameters are very stringent : a high DC current density (20-30mA/cm$^2$) of deuterium negative ions must be uniformly produced over large extraction surfaces with good discharge electrical power efficiency and at very low source filling pressure (<0.2Pa) to minimise the beam stripping losses in the accelerating gap. An additional problem is that ion sources of different size or shape are to be developed depending on the specific requirements of each particular fusion experiment. Multi-cusp ion sources operated with Cs vapour seeded plasmas have, up to now, been adequate for the attainment of intense negative ion beams. For instance, with a large ion source of this type, H- beams of about 15 A are produced in Japan for Fusion Machines (JT60 [1], LHD [2]). At Cadarache laboratory a concept of modular source is now under investigation. It consists in developing a very compact ion source capable of producing, with Cs seeding, a dense ion flux (20-30mA/cm$^2$) over a moderate size extraction surface (10cm x 20cm). It is designed in such a way that it can be mounted side by side (horizontally or vertically) with other identical allowing intense beams of any required size or shape to be produced.

This paper presents the main features of a module which is called the DRIFT source, and the first experimental results therefrom.

## 2 Description of the DRIFT source .

The (x,y,z) dimensions of the source discharge chamber are : 22 x 13 x 16 cm$^3$ (volume about 4.5 litres) ; 'z' being the ion beam axis (see figures 1-2).

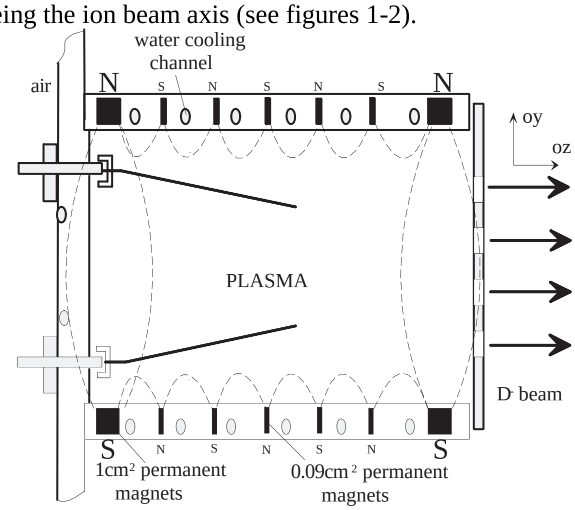


Figure1 : Horizontal cross section of the source

The essential components of this chamber are two water cooled rectangular copper plates parallel to each other 13cm apart in vacuum, on which are disposed arrays of permanent magnets which create the magnetic field configuration. The discharge plasma is confined horizontally (y direction) by the multi-cusp field created by small permanent magnets of 0.09cm$^2$ cross section arranged over the surface of each plate, whereas the confinement in the other two directions is provided by a transverse peripheral magnetic field created by four lines of permanent magnets (1cm$^2$ cross section) along the borders of each plate (see figures 1 and 2). The transverse field created across the ion extraction plane acts also as a magnetic filter (of about 300 gauss.cm), which reduces the co-extracted electrons current.

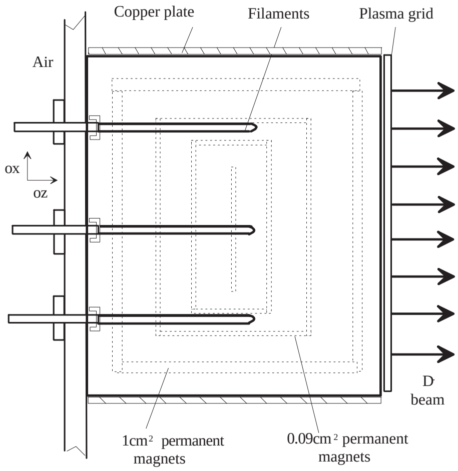


Figure2 : Vertical cross section of the source

With this magnet arrangement a region of approximately zero magnetic field strength exists near the centre of the discharge chamber. The discharge primary electrons are supplied by eight tungsten filaments whose heating current feed-throughs are placed at the rear of the device on a vacuum-tight flange, such as to allow the side by side source disposition. The plasma grid, from which ions are extracted, is parallel to the rear of the source, 16cm away. A 3D code has been developed to simulate the trajectories of the confined primary electrons (50-100eV) and ions (0.5eV $D^+$) in this particular magnetic field topology. This code does not take into account any collision processes. The numerical simulation shows that the trajectories are completely dominated by the (M/e)$^{\cdot}$ (B x grad(B) ) drift (where M = magnetic moment, e = electron charge). The electrons, in absence of collisions, rotate indefinitely around the centre of the discharge (see figure 3).

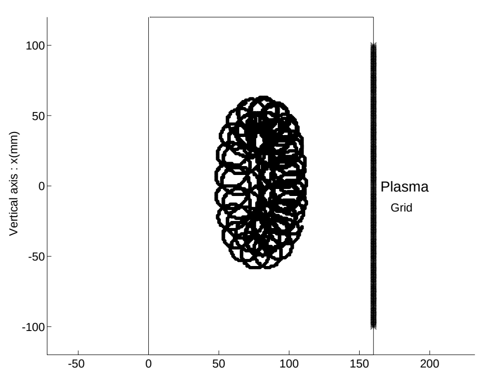


Figure3 : Primary electron trajectory simulation in the source

The transverse magnetic field gradient (directed from the centre to the outside of the chamber (approximately 10 to 80 gauss)) generates a plasma electrons rotational drift in the median plane ; for this reason the device is called DRIFT source.

Owing to the plasma diamagnetism, the plasma density peaks near the centre of the source where the magnetic field vanishes. We point out that a quiescent well contained plasma is generally obtained in multicusp configurations ; see for instance .[3].

## 3 Juxtaposition of DRIFT sources for multi-amperes negative ion sources

The juxtaposition of DRIFT sources on the vertical direction is possible due to the transverse magnetic field which separates each plasma from the others : metal wall separation between the modules should not be needed.

In the horizontal direction, the simplest juxtaposition should consist in preserving the arrays of permanent magnets of 1cm$^2$ used for the transverse field on the median plane of two adjacent modules. This can be done by enclosing these magnets into a peripheral water cooled frame. A simulation of electron and ion trajectories in this simplified configuration doesn't show any particular problem.

## 4 Advantages of the modular DRIFT source concept

The development of large size sources for ITER (40A of $D^-$ with 20-30mA/cm$^2$ over $\approx$ 1.0m$^2$ of extraction surface), which significantly exceeds the present size devices is very expensive and presents some uncertainties concerning, for instance, the plasma homogeneity or the choice of an adequate magnetic filter to limit the co-extracted electrons.

A uniform ion flux on the entire extraction surface is an essential issue to be solved. With the DRIFT source module, the uniformity should be guaranteed independently of the size and shape of the extraction surface.

To reduce the electron current extracted with the negative ions, which could be up to $\approx$ 60 $e^-$ per ion, to less than one electron per ion, a magnetic filter is added in the present multicusp sources [1], [2]. Nevertheless, the extrapolation of this method to large devices poses difficulties as the penetration of the filter field inside the ion source and the beam accelerating channel can produce respectively : a) plasma inhomogeneities ; b) important perturbations on the ion beam trajectories.

## 5 Experimental apparatus

The ion beam is created with a multi-hole three electrodes system, producing 48 beamlets of 1cm2 each. The first grid, made of molybdenum, is fixed on a water cooled copper frame by thermal bridges to control the temperature of the grid during the discharge. It is at the ground potential. The second grid G2 incorporates permanent magnets to suppress the extracted electrons [4]; no electron leakage has been measured from this grid. This grid is polarised at the extraction voltage $V_{g2}$ in the range 2-12 kV. The third grid G3 is polarised at the acceleration voltage up to 55kV.

The negative ion beam is transmitted through a chamber (130 cm in length and 10x25 $cm^2$ cross-section) toward a target. Inside the chamber an auxiliary magnetic field, created by two external coils, allows to separate the residual accelerated electrons component from the $D^-$ beam. Previous measurements showed that this component amounts to less than 3/1000 of the total beam current. In the first experiment, the $D^-$ beam current was determined by measuring the drain current, $I_{drain}$, of the high voltage power supply. Subsequently, a water cooled target was installed at the end of the chamber to measure the equivalent calorimetric target current, $I_{target}$.

## 6 First experimental results

### 6.1) The discharge characteristics :

A very important feature of this plasma confinement is that it allows low operating source pressure. In spite of the small source dimensions, powerful discharges can be sustained at source pressure as low as 0.05Pa. Very stable plasmas (breakdown free) were obtained even at high power density (arc current : 600A and arc voltage 60V : 8kW/liter). Figure 4 shows the discharge characteristic at 0.15Pa pressure.

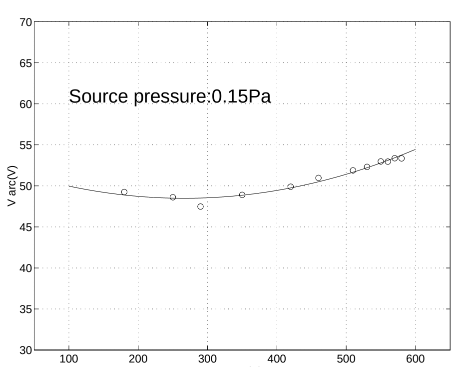


Figure4 : The discharge characteristic at 0.15Pa

### 6.2) Experiments with Deuterium :

#### 6.2.1) Without Caesium Seeding :

In these experiments, the target consisted of a thin (1mm) molybdenum plate without water cooling. An infra-red CCD camera located outside the tank, monitored the rear face of this target to record the beam profile which is representative of the plasma beam footprint. A very good homogeneity (a variation of only 10% across the profile) is obtained with a perveance matched beam (4.5mA/$cm^2$). Figure 5 shows the saturation of drain current $I_{drain}$ at 220mA (4.5mA/$cm^2$) with the extraction voltage $V_{g2}$ for an arc power of 2.5kW/liters and a source pressure of 0.9Pa. At 0.15Pa the maximum $I_{drain}$ is 50mA (1mA/$cm^2$).

#### 6.2.2) Experiments with Cs Seeding :

After Cs vapour injection into the source (about 100mg), the $D^-$ ion current increases depending on the plasma grid temperature, with a maximum being observed at a grid temperature of ≈ 250°C. The optimum source pressure is 0.15Pa. Figure 5 shows the dependence of the $I_{drain}$ with the extraction voltage. It follows a Child-Landgmuir law : $I = k\, V_{g2}^{3/2}$, where k is a constant depending on the extraction gap size and particle mass, and $V_{g2}$ is the extraction voltage. A total current of 1A has been accelerated corresponding to 20mA/$cm^2$ with an arc power of 2.5kW/liters ; the co-extracted electron current intercepted by the extraction grid is of the order of 2.5 electrons per ion.

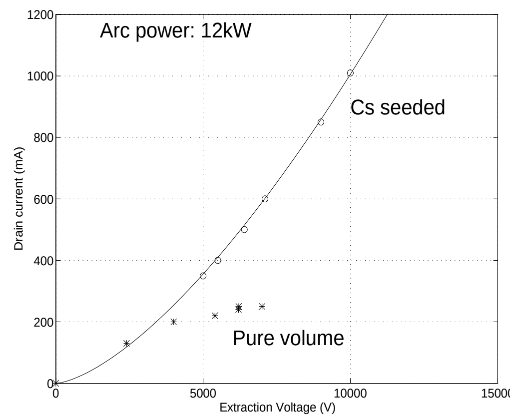


Figure5 : Dependence of the drain current (mA) with the extraction voltage $V_{g2}$(V).

The perveance value giving the minimum beam divergence is $P = 5.10^{-8}\ AV^{-3/2}$ with $V_{g3}/V_{g2} = 6$. The calorimetric measurements showed that under these conditions the beam transmitted power $I_{target}/I_{drain}$, is about 85% indicating good beam optics.

## 7 CONCLUSION

Owing to its interesting features like : compactness, low operating pressure, high negative ion flux, plasma homogeneity and stability, the DRIFT source appears to be very promising. The juxtaposition of two or more source will be the next step of this development.

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