AIP | Conference Proceedings

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Citation: AIP Conf. Proc. **210**, 255 (1990); doi: 10.1063/1.39595
View online: http://dx.doi.org/10.1063/1.39595
View Table of Contents: http://proceedings.aip.org/dbt/dbt.jsp?KEY=APCPCS&Volume=210&Issue=1
Published by the American Institute of Physics.

PHYSICS TESTS OF AN ELECTRON SUPPRESSOR WITH VARIABLE ELECTRIC AND MAGNETIC FIELDS

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ABSTRACT

This paper reports tests of an electron suppressor, for volume negative ion sources with variable electric and magnetic fields. The experiments have been carried out with a source and accelerator operating d.c. and with an extraction aperture of 16 mm diameter. The results are compared to those obtained with a permanent magnet suppressor and to a theoretical model of the transport of electrons by diffusion across the magnetic field.

INTRODUCTION

Practical applications of negative ion sources require stringent control of any extracted electrons. For volume negative ion sources operating in hydrogen the electron current can be of the order of 50 times the negative ion current if nothing were done to reduce the extracted electron current. Lea et al.[1] have recently described an electron suppressor with variable magnetic and electric fields which showed some promise. However their experiments used a small probe accelerator with an extraction aperture of 1.5 mm diameter. We have installed such a suppressor on the Culham Ion Source Test Stand using a 16 mm diameter extraction aperture and operating d.c.. The results are compared to those obtained using a suppressor with permanent magnets and to a diffusion model[2] of the electron transport across the magnetic field.

EXPERIMENTAL DETAILS

The volume source and accelerator used in this work have been described elsewhere[3,4]. The plasma generator is a copper magnetic multipole bucket of dimensions 195 x 140 x 85 mm^3. The source filter field was configured in two modes, as shown in Figure 1, the dipole filter has a field strength of ~ 30 Gauss at the extraction aperture whereas the tent filter has only a field of ~ 5 Gauss at the extraction aperture and will produce a more uniform plasma across the extraction plane. The extraction aperture on the source was 16 mm diameter. The accelerator was a triode design which enabled the extracted electrons to be dumped within the accelerator structure at an energy of about 1/6 of the final ion beam energy. The extracted ion beam was measured downstream by a d.c. beam transformer. Figure 2 shows the schematic source and accelerator.

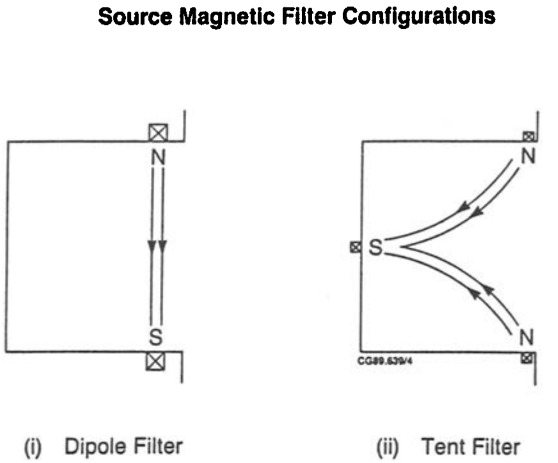

Figure 1 The source filter field configurations.

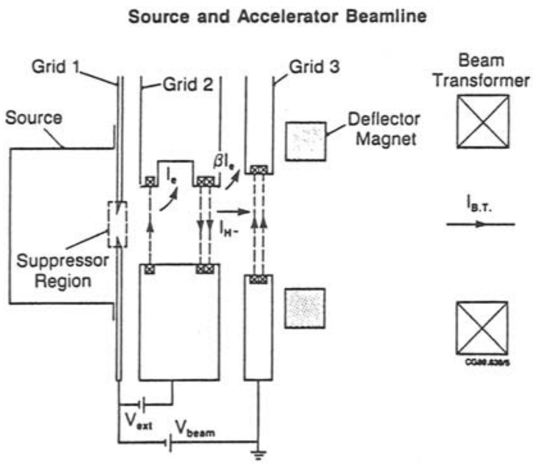

Figure 2 The source and accelerator.

Figure 3 shows a schematic diagram of an electron suppressor. A magnetic field in the region of the extraction aperture magnetises the electrons which might otherwise have been extracted. These electrons move along the field lines and are collected on a biasable electrode threaded by the magnetic field.

Figure 4 shows the permanent magnet suppressor used previously[3,4]. It consists of two 37 x 4 x 4 mm^3 samarium cobalt magnets arranged in a quadrupole configuration. The integral field in the source is ~ 100 Gauss cms. A portion of the extraction electrode forms the electron collector.

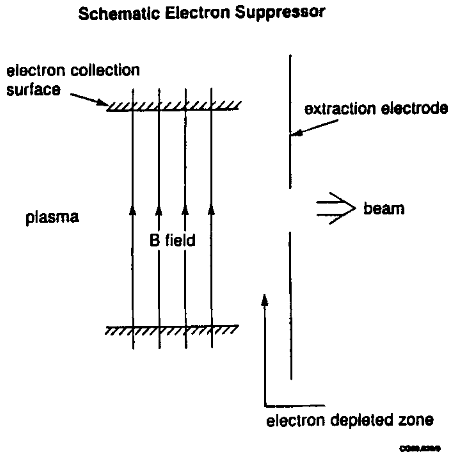

Figure 3 A schematic electron suppressor.

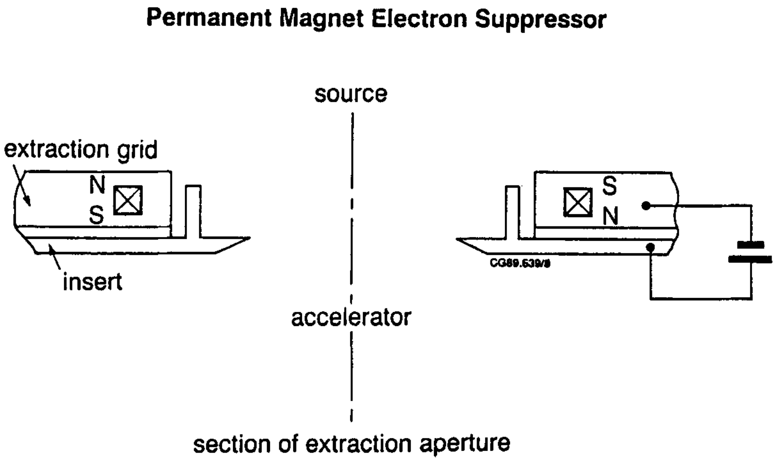

Figure 4 The permanent magnet suppressor.

Figure 5 shows the variable field suppressor. The field is produced by a flat solenoidal coil made of wires space 5 mm apart. The field profile has a FWHM of ~ 5 mm and an peak intensity of ~ 1 Gauss/ Ampere. Thermal considerations limit the coil current to 150 A. At each end of the array of wires is the collection electrode.

THEORETICAL MODEL

Green[2] has used a diffusion model to describe the electrons transport across the magnetic field. The electrons diffuse by electron-molecule collisions and are then extracted. Some move along the field lines and are collected by the biasable plate. This model

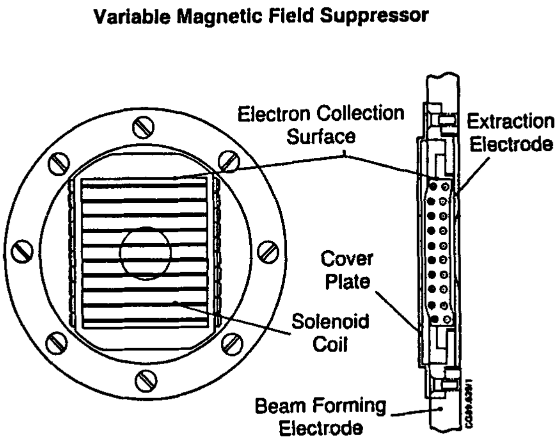

Figure 5 The variable field suppressor.

gives the following relations for the extracted electron current, I_e, the current deposited on the collection electrode, I_{ins}, the magnetic field strength B and the pressure in the suppressor region, p:

$$I_e = (K/B) \exp(-\gamma B) \quad (1)$$

$$\ln(I_e/I_{ins}) = a - bI_{ins} \quad (2)$$

and

$$\ln(I_e/I_{ins}) = c - d/p^{1/2} \quad (3)$$

where K, γ, a, b, c, d are constants.

These equations can be tested directly against the data. The work of Green[2] has already shown that the permanent magnet suppressor is described well by the diffusion model through equations (2) and (3) however because of the fixed value of magnetic field equation (1) could not be tested for this type of suppressor.

Just as important as the effect on the electrons is the effect of the suppressor on the extracted ion current. The diffusion model does not address the possible repercussions for the ion current.

EXPERIMENTAL RESULTS

a) Comparison between the suppressors

Figure 6 shows the electron suppression action of the two devices as a function of the collector bias, V_{ins}.

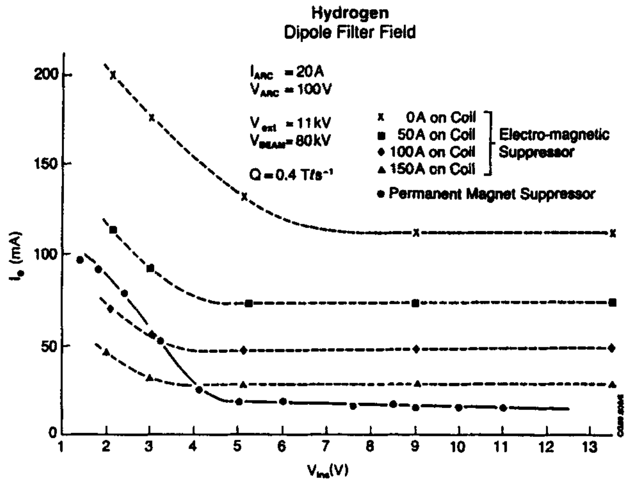

Figure 6 The dependence of extracted electron current on collector voltage for both suppressors.

Both devices do indeed suppress the extracted electron current. The degree of suppression obtained with the variable field device does indeed depend on the strength of the magnetic field. Even at the relatively low arc current used of 20 A, coil currents of > 150 A arc needed to reduce the extracted electron current as low as that from permanent field device.

Of course just as important is that the control of the extracted electron flux does not have a drastic effect on the extracted negative ion current. In Figure 7 we show the corresponding data for the ion current, $I_{B.T.}$, as measured at 0.82 m downstream by the d.c. beam transformer.

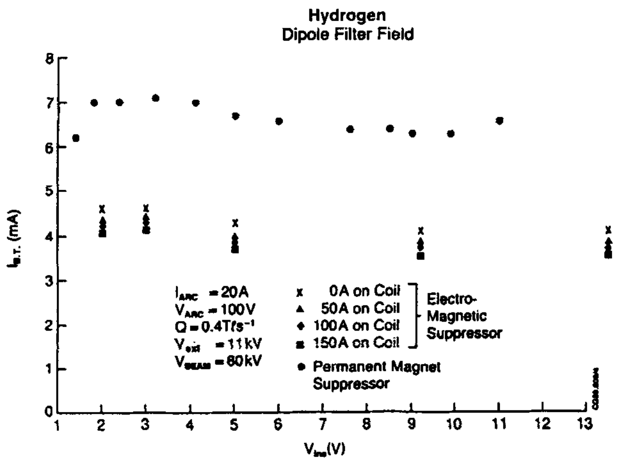

Figure 7 The dependence of extracted negative ion current on collector voltage for both suppressors.

Although the ion current does not vary by more than 10% with the collector voltage for either suppressor, the extracted ion current in the case of the variable field or electro-magnetic suppressor is ~ 60% of that for the permanent magnet suppressor. Now the transparency of the two sets of wires in the variable field suppressor is ~ $(0.75)^2 = 0.55$. This would be the transparency one would expect if the negative ions were created before the suppressor field in the coils. However this is not the case as shown by Lea et al.[1]. They removed the source filter but still found negative ions being produced due to the suppressor field acting as a filter field. It could be that there are further insertion losses associated with the suppressor leading to a decrease in plasma density and hence negative ion production.

What Lea et al.[1] also found was that as the B-field was increased from zero then the negative ion yield increased from 40% to 80% of the current density obtained in the absence of the suppressor and then decreased slowly. This has also be observed by Bacal[5]. The data in Figure 7 does not show this behaviour. The negative ion current decreases with increasing B-field. This experiment was carried out with the source filter field in the dipole configuration. The integrated field from the peak to the extraction aperture due to be dipole field ~ 200 Gauss cms and the field strength at the extraction aperture is ~ 30 Gauss although 1-2 Gauss of this comes from the accelerator fields. Thus even with zero coil current the field is never zero. Thus the results of Lea et al. could not be observed in this filter configuration.

In order to test this hypothesis we reconfigured the source filter field into the tent configuration as shown in Figure 1(b). The field at the extraction aperture then falls to ~ 5 Gauss. In Figure 8 will show a comparison of the dependence of the ion negative current on the coil current (or B-field) for the two filter configurations.

It is seen that as the coil B-field approaches to zero in the tent mode the negative ion current falls hence proving the hypothesis. The coil current is not set to zero because the electron current approaches 1 A which poses a difficulty in thermal management. This large electron current at such a low arc current is associated with the low value of ion current. This is almost certainly due to the fact that in the tent configuration the filaments penetrate the filter field thus increasing the plasma temperature in the extraction region of the source and so producing a decrease in the density of negative ions.

That this is so is shown in Figure 9 where we plot $\ell n\ (I_e)$ versus I_{coil} (or B) for both filter configurations. In the tent filter case the electron current is ~ 10 times that in the dipole filter case. Also the slope of the line for the tent filter data is less than that for the dipole filter. The efficiency of the suppression will decrease with increasing temperature thus we see

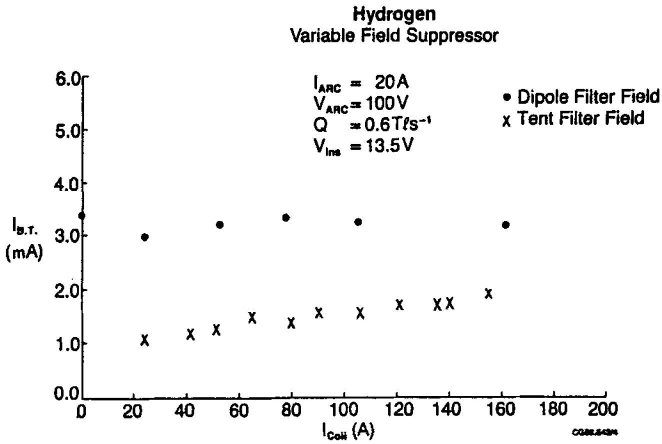

Figure 8 The dependence of extracted negative ion current on magnetic field for both source filter configurations.

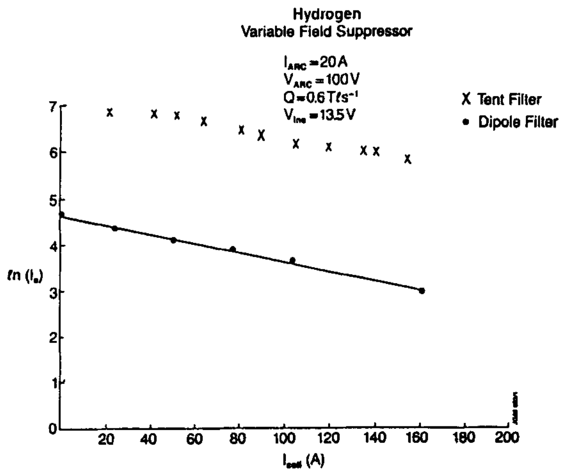

Figure 9 The dependence of extracted electron current on magnetic field for both source filter field configurations.

that the electrons are hotter in the tent filter mode. These hotter electrons will lead to a reduction in negative ion yield through destruction by electron impact.

We are presently redesigning the filaments in the source to avoid the creation of a hot plasma beyond the nominal filter field and so increase the yield of negative ions beyond what we have at present in the tent configuration.

b) Comparison with theory

The dependence of extracted electron current on B-field as given on equation (1) can be tested for the variable field suppressor. Instead of the functional form in equation (1) we find a purely exponential dependence as shown in Figure 10 which plots ℓn (I_e) versus I_{coil} (or B).

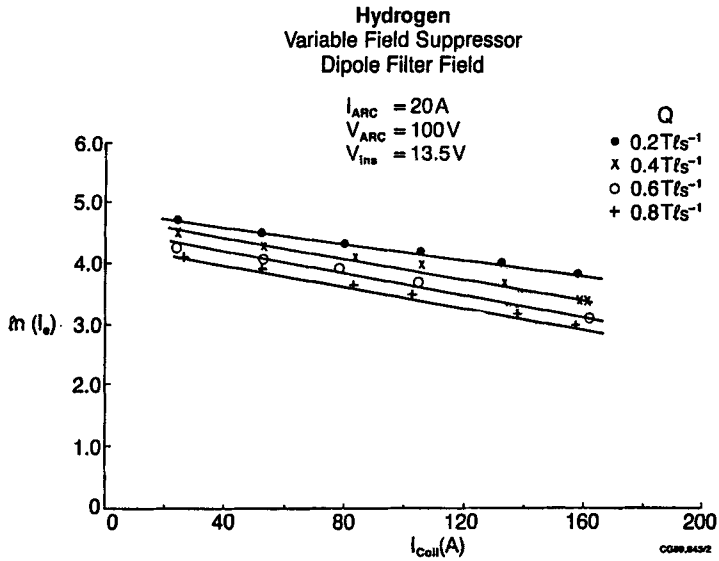

Figure 10 The exponential dependence of extracted electron current on magnetic field strength.

The remaining experimental tests given by the diffusion model can be used for both devices. The dependence of $\ell n(I_e/I_{ins})$ versus I_{ins} is obtained by varying the electron collector voltage. The results for the two suppressors are shown in Figures 11 and 12.

For the permanent magnet suppressor the linearity of this curve (and hence agreement with the diffusion model) is much more pronounced than for the variable field suppressor. The deviation from linearity at the lower values of I_{ins} is not entirely due to a failure of the model. At these low values of collection voltage, positive ions are also collected because the plasma potential has not been exceeded thus leading to an apparent decrease in the collected positive current.

The diffusion model is based on electron-molecule scattering in the suppressor region leading to transport across the magnetic field. Thus the pressure dependence of the suppressor action ought to be a very good test of its validity. This dependence is expressed through equation (3). Instead of using pressure we use the gas flow, Q, the two being directly proportional.

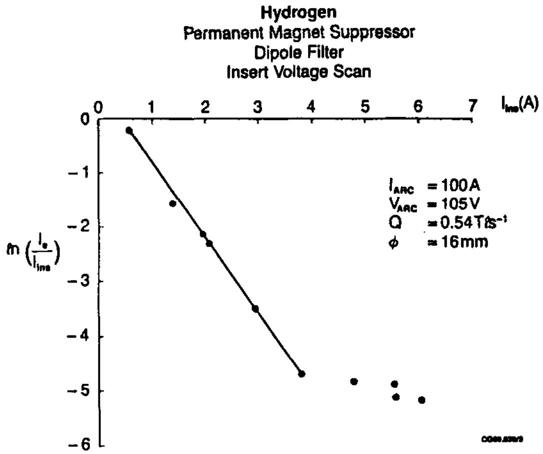

Figure 11 The dependence of ℓn (I_e/I_{ins}) on I_{ins} for the permanent magnet suppressor.

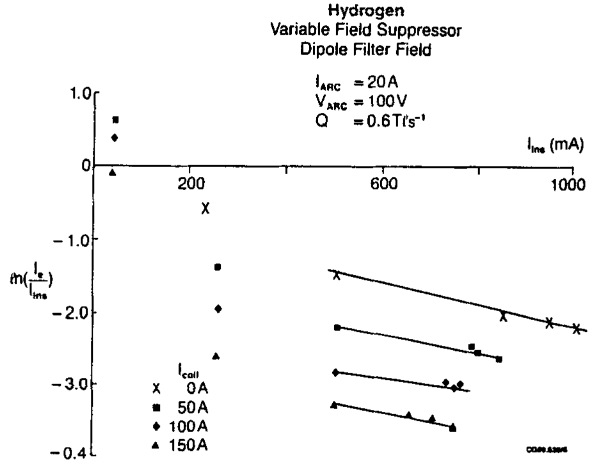

Figure 12 The dependence of ℓn (I_e/I_{ins}) on I_{ins} for the variable field suppressor.

Figures 13 and 14 show data for both suppressors plotted in the form ℓn (I_e/I_{ins}) or ℓn (I_e) versus $Q^{-1/2}$ in accordance with equation (3). For the permanent magnet suppressor $\ell n(I_{ins})$ only changed by 5% hence the use of ℓn (I_e).

It is apparent that the diffusion model is in good agreement with the data from the permanent magnet suppressor but not at all in agreement for the variable field suppressor where it is almost independent of pressure. The deviation from linearity at high pressures (or Q) in the case of the permanent magnet device has been shown previously by McAdams et al[4] to be due to the collection, in

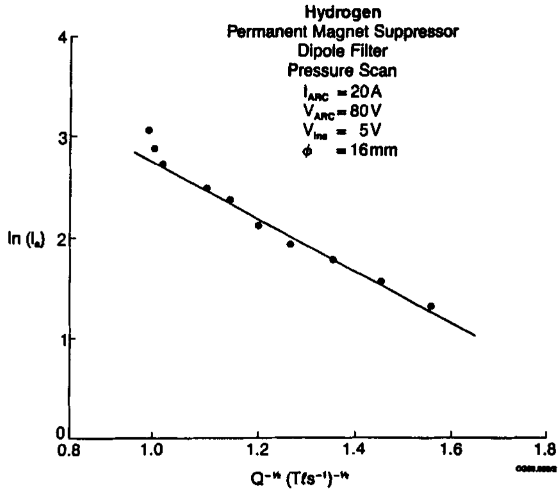

Figure 13 The dependence of ℓn (I_e) versus $Q^{-1/2}$ for the permanent magnet suppressor.

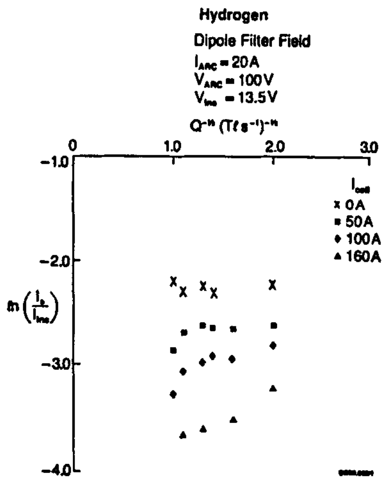

Figure 14 The dependence of ℓn (I_e/I_{ins}) versus $Q^{-1/2}$ for the variable field suppressor.

the accelerator, of electron produced by stripping of the H^- in collisions with the gas flowing from the source.

CONCLUSIONS

We have described a new electron suppressor with variable electric and magnetic fields based on an extension of previous ideas and guided by previous data[1]. This device worked well with small extraction apertures i.e. with a diameter smaller than the wire spacing but its performance for large extraction aperture diameters is very poor compared to the permanent magnet device. This loss of performance appears to be associated mainly with the transparency of the device. However what we have shown with this variable field device, and Bacal[5], magnetic field close to the extraction aperture leads to an enhancement of the negative ion yield confirming the results of Lea et al.[1].

In our experiments on this enhancement the performance was limited by the filaments penetrating the filter field leading to a hotter plasma and hence lower densities of negative ions. Thus in our continuing work we will optimise the filament/tent filter design in order to see if the enhancement persists of higher negative ion current densities. Until this is done the full potential of the enhancement effect will not be realised.

The characteristics of the suppressor action are well described by a diffusion model in the case of a permanent magnet device. This is not the case for the variable field device. The reasons for this could be in a number of areas. Notably the scale lengths of fields for each suppressor are different as is the detailed magnetic geometry. This problem is being addressed by Holmes and Haas[6] using a hydrodynamic model.

ACKNOWLEDGEMENTS

The authors would like to thank Dr A. Holmes and Dr T. Green for many discussions on electron suppressor action. This work was supported by USAFOSR under contract number F49620-86-C-0064.

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