H^- BEAM INTENSITY IMPROVEMENTS AT THE MILAN AVF CYCLOTRON

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Abstract

In order to increase the available H^- beam intensity at the Milan AVF Cyclotron a development program has been underway for some time. This involved both machine vacuum and hot filament ion source improvements.

At an arc current of 5 A and with hydrogen fluxes of 20-30 cc/min, beam currents of 45 μA have been obtained at the full energy of 45 MeV.

1. Introduction

The goal of the H^- beam improvement program was to reach intensities in the tens of μA range, which are needed for many experiments, using energy analysed beams, or for isotopes production with external irradiation set-ups.

The program was centered upon:

a) design of a new high power internal ion source, for up to 10 amperes arc current

b) improvements of the machine operating vacuum, so as to reduce the beam losses due to residual gas stripping, or else to allow a larger gas inlet for the same operating pressure in the cyclotron.

2. The H^- source

The source was designed on the basis of previous experience available at our and other laboratories [1,2], and it is sketched in fig.1.

The chimney is built out of electrolytic pure copper and is water-cooled along the whole length.

The reflecting anticathode is inserted in the copper water-cooled cap and is insulated from the latter by alumina rings. The anticathode is a 7 mm thick tantalum cylinder, 16 mm in diameter, and it can be either kept floating (source A) or else electrically connected to the filament current leads, kept at negative voltage. The connection is made with tungsten wires, passing through the chimney. Cooling of the anticathode is therefore only through irradiation to the chimney cap.

Various slits dimensions were tried. All slits are milled into a 1 mm thick tantalum insert which tapers down to 0.4 mm at the slit edge, giving rise to a slightly concave surface.

The discharge chamber is cylindrical in shape, with 10 mm diameter and a 3 mm collimating hole. The center of the hole is however 1.5+0.3=1.8 mm away from the inner wall of the chimney, normally to the exit slit.

Hydrogen inlet is directly in the chimney. There are three inlets, 1 mm in diameter, opposite to the exit slit, as shown in the figure. A fourth inlet, also 1 mm in diameter, is at the chimney base near the collimating hole. So far experiments have been carried out only with all four inlets simultaneously working.

The tantalum filament has a rectangular section and is 3.5 mm thick and 4.5 mm wide, with a shape shown also in fig.1.

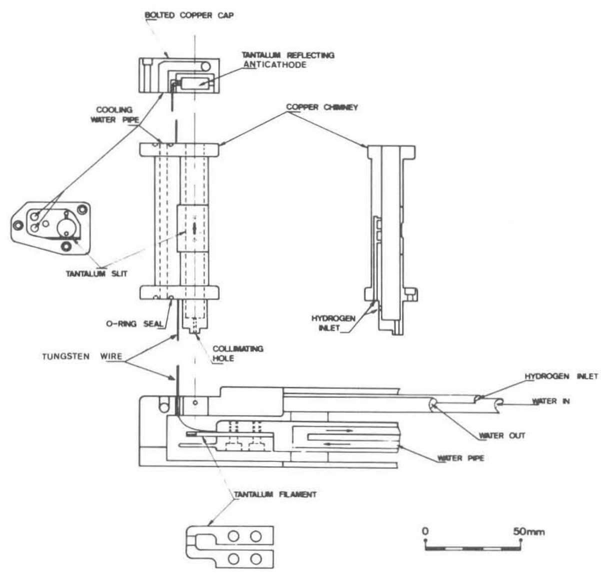

Fig. 1 The hot filament H^- source.

In the region immediately beneath the collimating hole, the filament thickness is reduced from 3.5 to 1.7 mm.

In this way the filament temperature can be high in the useful electron emitting region, while the rest of the filament runs at a lower temperature. The maximum current used with this type of filament has been of 520 A.

With this geometry and with arc currents of the order of 1 A, filaments have shown lifetimes of more than 180 hours with negligible erosion and tolerable deformations.

3. Beam losses due to stripping in residual gas

For an H^- beam accelerated in a cyclotron to a kinetic energy T, the final intensity I is related to the initial intensity I_0 by:

$$I=I_0 \exp\left(-2A_0 T^{1/2} \sum_n k_n \varrho_n\right)$$

where $A_0=2\pi\sqrt{2E_0}/3B\,\Delta T$, E_0 being the proton rest mass (MeV), B the field intensity in Wb/m^2 and ΔT the energy gain per turn, in MeV. The term $\sum_n k_n \varrho_n$ is related to the residual gas mixture present in the vacuum chamber. In particular $\varrho_n = 3.5\times10^{16}\, p_n$, p_n and ϱ_n being respectively the density and partial pressure of the n-th gas in the

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mixture, in mm Hg. The k_n coefficients enter in the relationship $(\sigma_{-1,0})_n = k_n T^{-1}$ between the stripping cross section for the n-th gas and the H^- kinetic energy. *

The envisaged hydrogen fluxes for the operation of the new ion source would fall in the 10 to 30 cc/min range. It was therefore clear that the installation of an additional vacuum pump was necessary, in order to have reasonable residual gas pressures. Therefore, in addition to the two existing 12.000 ℓ/sec diffusion pumps, a third one, with a nominal pumping speed of 17.000 ℓ/sec was installed. It was estimated that the effective total pumping speed available would approximatively double, i.e. from 8.000 ℓ/sec up to ~ 15.000 ℓ/sec.

The resulting partial pressures for N_2 and H_2, as measured in the accelerating region of the vacuum chamber for various hydrogen fluxes in the ion source, are shown in fig. 2

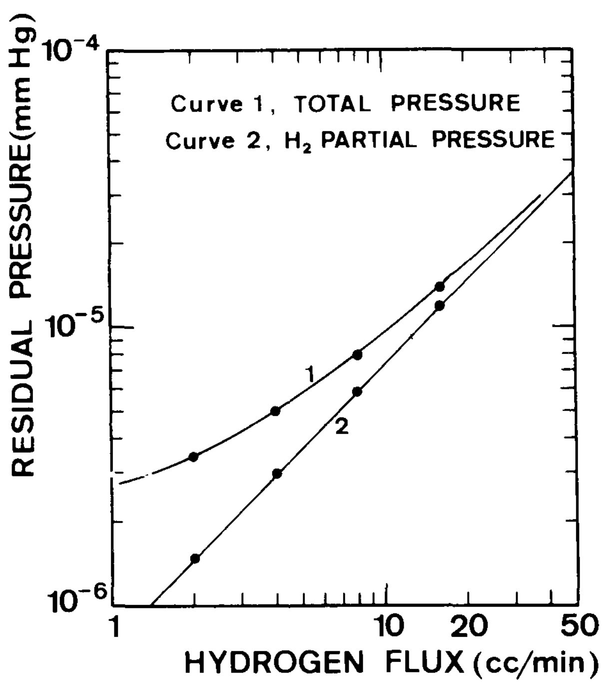

Fig.2 Gas pressures in the accelerating region.

From these pressure values, assuming $k_{N_2} = 4.5 \times 10^{-16} cm^2\,MeV$ and $k_{H_2} = 8.0 \times 10^{-17} cm^2\,MeV$ and for a peak R F voltage of 48 KV, one can calculate H^- beam losses for different values of the hydrogen flux.

The theoretical results are shown in fig.3. The expected beam losses, even for very large hydrogen fluxes (20-30 cc/min), would not be higher than 50%-60% from essentially zero energy up to the final 45 MeV energy.

The experimental data, to be reported in the following are in substantial agreement with these estimates between the H^- energy of 10 and 45 MeV, where data could be reliably measured.

4. Experimental results

The data reported here refer to internal beam measurements. Extraction by stripping at the large resulting beam intensities could not be made with the usual uncooled aluminium stripping foil.

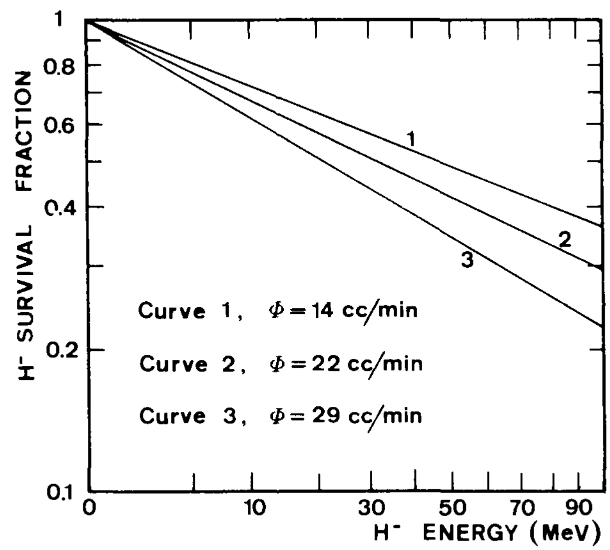

Fig. 3 Residual gas stripping effect vs. H^- energy at different H_2 fluxes Φ (cc/min).

The latter in fact would not withstand beam currents larger than 10 μA.

A 200 $\mu g/cm^2$ carbon foil has been used in preliminary tests up to 30 μA. However we cannot give reliable data on its lifetime.

The results for the H^- beam intensities as a function of the arc current, and for different H_2 fluxes, are reported in figs. 4 and 5 at the energies of 20 and 45 MeV respectively. The peak R F voltage was 48 KV. The ion source employed was the type referred previously as (A), with floating antithode and a 6x1.2 mm^2 slit.

It can be noticed that for increasing H_2 fluxes the beam intensity drops for small arc currents, and goes up for high arc currents, the crossing point for different characteristics being around 1 A arc current.

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* This relationship only holds for gases up to oxygen. For Argon, in the 1 to 50 MeV H^- energy range it is rather of the form:

$$(\sigma_{-1,0})_{Ar} = k_{Ar} T^{-1/2}$$

It was found that for H_2 fluxes larger than 22 cc/min the obtainable beam intensity both at 20 and 45 MeV goes down, presumabily because of the stripping effect in the increased gas pressure. For this particular ion source it looks therefore like a 20 to 25 cc/min H_2 flux is the optimum, and maximum currents of 40 μA and 28 μA at 20 and 45 MeV respectively can be reached.

It has been possible to operate this source (A) under fairly stable conditions. The arc voltage was kept around 220 V up to arc currents of about 1.5 A, decreasing to 170 V for the extreme currents of 4-5 A.

Operation of the source (B), namely with the anticathode electrically connected to the filament, yielded rather different results. The latter are reported in fig.6 e 7, again for 20 and 45 MeV H^- energy. Curves (1) and (2) refer to a 6×1.2 mm^2

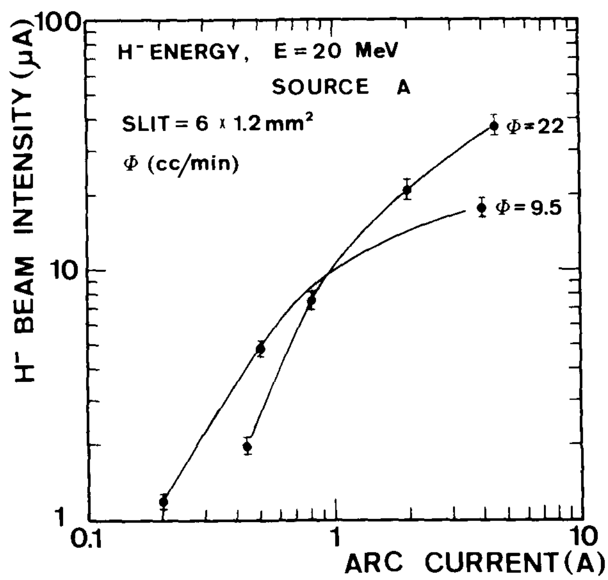

Fig.4 H^- intensity at 20 MeV, vs. arc current, at different H_2 fluxes Φ (cc/min). Source(A), floating anticathode.

slit, as before, while curve (3) is for a 4x1.2 mm^2 slit.

With respect to the performance of ion source (A) the beam intensities at the same arc current are definitely large. In fact the maximum beam currents so far obtained are 62 μA and 45 μA at 20 and 45 MeV. This means an increase of ~ 50% over source (A).

It is interesting to compare the curves (2) and (3) of figs. 6 and 7, which refer to two different sizes of the exit slit, as mentioned above.

The smaller slit allows a larger intensity with a lower gas flux and a lower arc current. In fact measurements with a larger slit (9x1.2 mm^2), although not reported in the figures, showed a further decrease in the achievable intensity with respect to curve (3), (6x1.2 mm^2). This points out that even a smaller slit than the 4x1.2 mm^2 of curve (2) might be successful, and further measurements will be made to check this point.

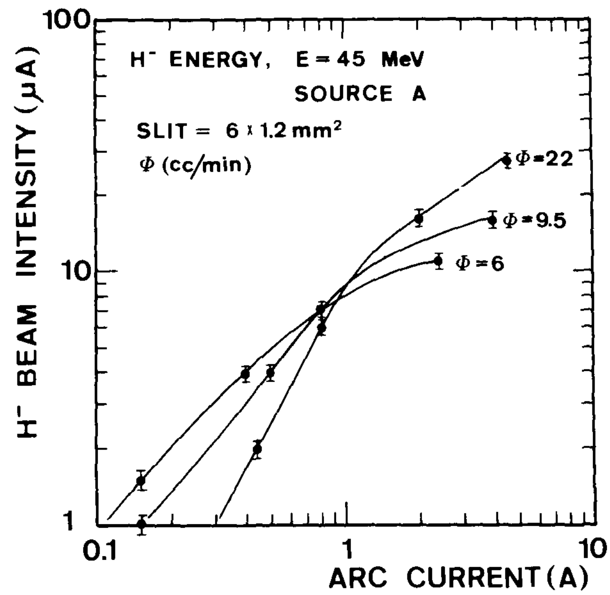

Fig.5 H^- intensity at 45 MeV vs. arc current, at different H_2 fluxes Φ (cc/min). Source(A), floating anticathode.

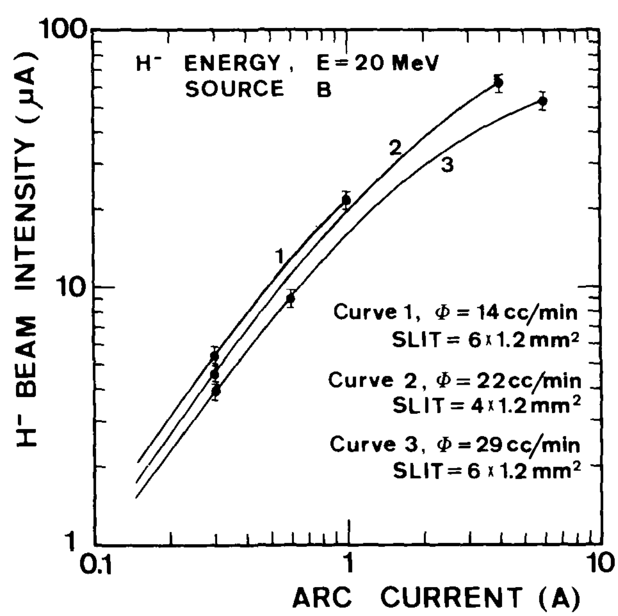

Fig.6 H^- intensity at 20 MeV vs. arc current, at different H_2 fluxes Φ (cc/min), for two slit dimensions. Source (B) anticathode at filament voltage.

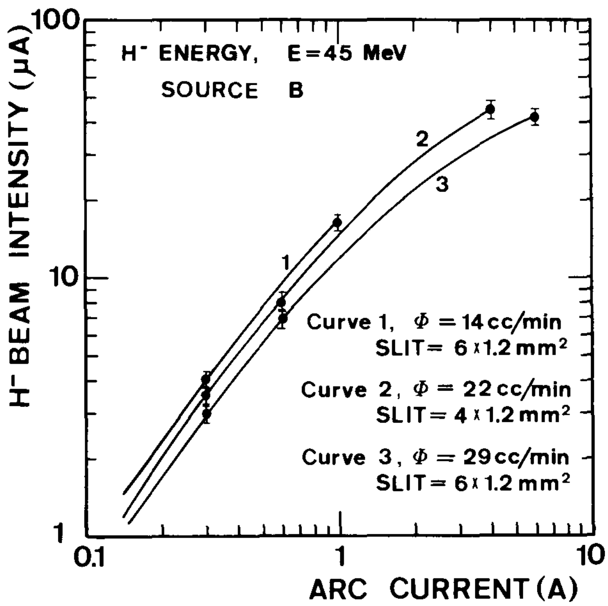

Fig. 7 H^- intensity at 45 MeV vs. arc current, at different H_2 fluxes Φ (cc/min), for two slit dimensions. Source (B), anticathode at filament voltage.

It should finally be mentioned that the operating conditions of this source could not be made really stable so far between 1 A and 4-5 A arc current, while the source was indeed stable at the maximum operating points.

5. Concluding remarks

Since, as mentioned above, no extracted beam measurements were carried out, we are unable to give values for the beam emittances relative to these sources.

As for the sources themselves, both have shown the capability to produce substantially more intense beams than were previously available at our cyclotron. We have not so far a sufficient statistics on filament lifetime at arc currents larger than 3 A. With source (A) a filament lasted 8 hours at an arc current of 5 A and this is the only filament failure we can report.

No other lifetime tests have been made so far.

References

1) K.W. Ehlers
Nucl. Instr. and Meth. 32, (1965) 309

2) G. Indreas and T. Tauth
Nucl. Instr. and Meth. 44 (1966) 353