Proceedings of the International Conference on Isochronous Cyclotrons, Gatlinburg, Tennessee, 1966

ACCELERATION OF H^- IONS AND EXTRACTED BEAM MEASUREMENTS IN THE MILAN CYCLOTRON (+)

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Abstract

The characteristics of the proton beam extracted from the Milan AVF cyclotron by H^- ion stripping have been studied. Quality and phase measurements were made in an external beam which was obtained without any geometrical definition of the internal H^- beam path.

Introduction

Since the announcement by the Colorado cyclotron group[1] at the Los Angeles conference four years ago of their success in the acceleration of negative ions, other laboratories[2-5] have tried out the method, which is by now an established addition to the versatility of AVF cyclotrons.

In Milan, we are in the process of setting up a proton beam extracted by H^- ion stripping. We expect to use this beam for nuclear physics experiments. In the present contribution, we want to report briefly on the characteristics of the beam obtained from our machine.

H^- ion source and central region geometry

A conventional Livingston source with a hot filament has been slightly modified to give a reasonable output of H^- ions. The electron collimating hole in the chimney base was relocated 1.2 mm back from the peripheric position usual for protons. In laboratory tests, H^- ion yields of up to 300 μA were currently obtained with an hydrogen flux not exceeding 3 cm^3/min, and an arc current of 1.5 A. The hydrogen inlet was near the base of the chimney: Ehlers's[6] suggestion of feeding the gas directly in the region of the ion exit slit was tried, but resulted in a rather modest increase ($<$ 15%) of the output of our source. Therefore, we preferred not to complicate the geometry of the ion source.

In comparison with the proton operation the only change in the central region of the cyclotron was the addition of a copper flag to the source structure. This helped to avoid the building up of a spurious proton beam; it was apparent, however, that also the puller contributed remarkably to stop the protons. Checks with a twin-plate probe which revealed separately the H^- beam and the spurious protons circulating in opposite directions, showed that the proton current was not higher than about 2 - 3% of the negative ion current. These measurements were performed up to a distance of some 35 cm from the ion source; a further check, which gave the same result, was made at the extraction radius, by recording the current collected on two 6-mm thick copper blocks placed at the sides of the stripping foil.

H^- ion acceleration

The acceleration of H^- ions was accomplished with practically no change in the cyclotron settings used for protons operation. With the same azimuthal position of the stripping foil, external proton beams of 45 and 38 MeV have been obtained by merely varying the extraction radius. The external beam lines were about 8° apart for the two energies mentioned.

Due to temporary failure of the vacuum conditions, the pressure in the vacuum tank resulted of the order of 1.10^{-5} mm Hg; the beam current accelerated to the extraction radius of 67 cm (38 MeV) was limited to about 1 μA.

Measurements of beam attenuation due to residual gas stripping, performed in the present conditions, showed a 90%

(+) Work performed under the Euratom-CNEN/INFN research contract.

 Reprinted from IEEE Transactions on Nuclear Science NS-13 (4), Aug 1966

current decrease between the radii of 30 and 67 cm, corresponding to energies of 8 and 38 MeV respectively. These results are well consistent with the measured residual pressure and the reports from other laboratories[2-4].

Extracted beam quality measurements

The characteristics of the 38 MeV external beam have been examined in view of its transport and utilization. These measurements were performed in the following conditions:

a) the H^- ion beam was accelerated without geometrical path limitation (i.e., there were no defining slits);

b) the dee voltage, set for a peak RF value of nearly 60 kV, was quite stable on the average, but was affected by a ripple amounting to some ± 5%;

c) the stripper was an aluminium foil 2 mg/cm^2 thick.

The external beam energy of 38 MeV was determined by the stripper radius and by the extraction path. The radial and axial beam current distributions were investigated by means of a "density" probe, whose sensing element was a 0.5 mm strip driven across the beam. Figs. 1 and 2 give the results obtained at a distance of 90 cm from the vacuum tank wall. The dimensions of the beam cross-section containing 90% of the particles are 16 mm radially by 28 mm axially.

Quality measurements were then carried out by intercepting the beam with a plane grating placed at 90 cm from the vacuum tank, and recording separately the radial and axial beam distributions, 65 cm downstream from the grating, with the density probe. After testing a few grating constants, we finally settled for a slit width of 0.5 mm and a separation of 4 mm between slits. A typical density probe record is shown in fig. 3. From sets of such measurements, plots of beam emittance in (x, dx/dl) and (z, dz/dl) coordinates have been drawn. The results show emittances of between 80 and 100 mm-mrad in the radial (x, dx/dl) plane, and between 170 and 200 mm-mrad axially, all values being referred to 90% of the beam intensity.

As is apparent from these plots the angular divergency of the various sections of the beam behind the grating was not larger than ±2.6 mrad radially, and ±3 mrad axially. Errors in divergence caused by the finite dimensions of the slits and of the probe were estimated to amount to about 15%.

Two examples of emittance plots are reproduced in figs. 4 and 5.

From these measurements we can also evaluate the position and width of the virtual source. We estimate the radial source to be 6 mm wide and positioned 1.20 meters upstream of the intercepting grating; the axial source turns out to be about 7.5 mm wide, lying 1.10 meters away from the grating.

Preliminary tests of the beam time structure

Time structure measurements have been made on the external beam. For this purpose we used a thin plastic scintillator coupled to a Philips 56 AVP photomultiplier.

Output signals were displayed on the screen of a sampling oscilloscope synchronized with a reference voltage signal from the R.F. system. Beyond the evaluation of the beam duty cycle, the scope of these tests was to ascertain the possibility of a coupling system between radiofrequency and magnetic field, in order to obtain automatic beam tuning.

A specimen of the oscillograms obtained by varying the cyclotron magnetic field by small amounts, while the RF is held constant, is reproduced in fig. 6. From these measurements the duty cycle turns out to be of the order of 25%.

The oscillograms also show that, with this technique, we can obtain reliable phase error signals, sufficient for controlling the magnet current regulator.

References

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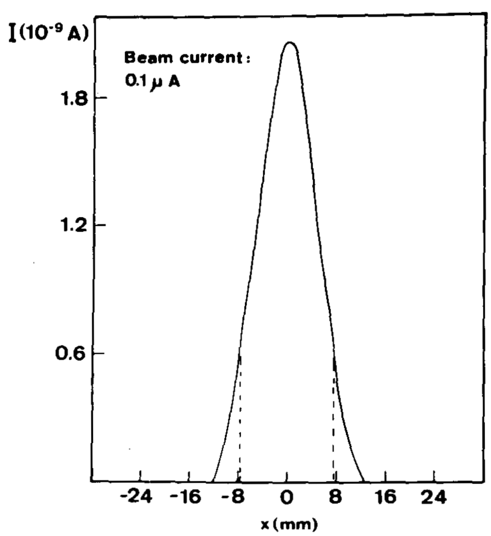

Fig. 1. Radial beam distribution observed at 90 cm from the vacuum tank. The area bounded by the dashed lines represents 90% of the beam.

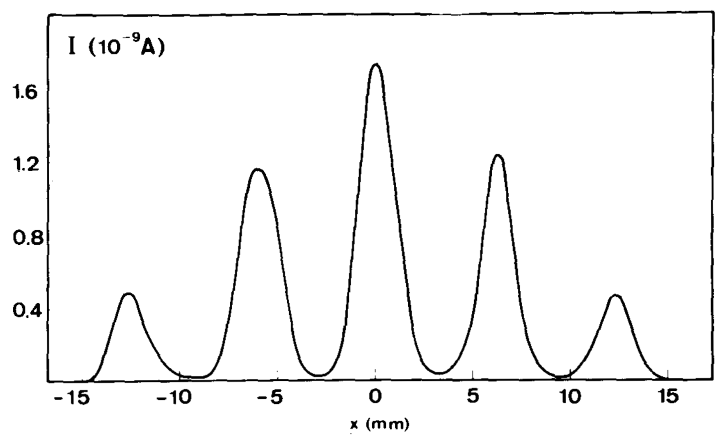

Fig. 3. Typical density probe record obtained 65 cm down-stream from a beam intercepting grating.

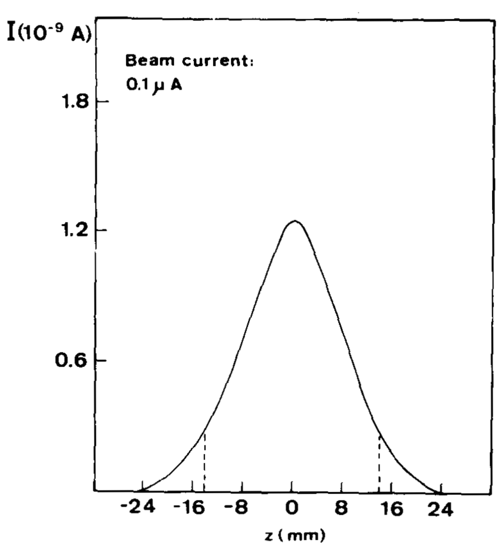

Fig. 2. Vertical beam distribution observed at 90 cm from the vacuum tank. The area bounded by the dashed lines represents 90% of the beam.

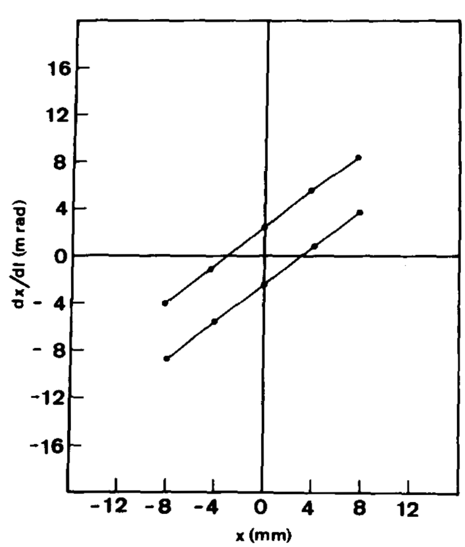

Fig. 4. Radial emittance (90% of the beam): 80 mm-mrad.

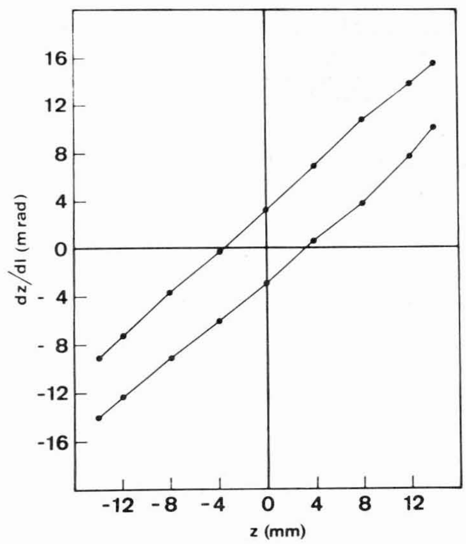

Fig. 5. Vertical emittance (90% of the beam): 170 mm-mrad.

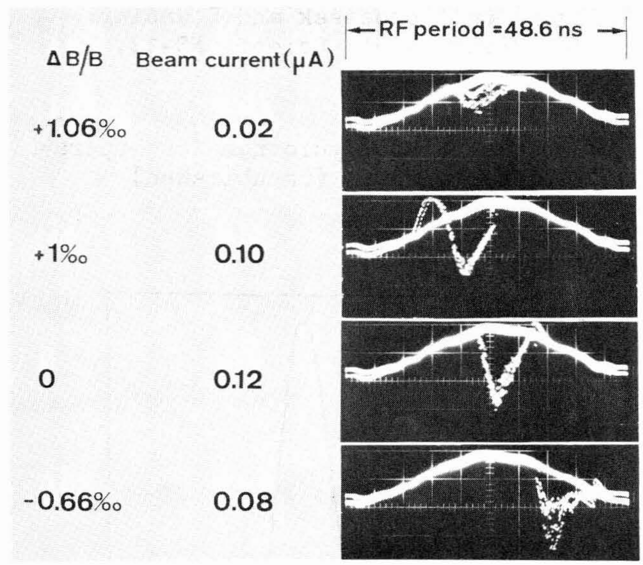

Fig. 6. Beam phase oscillograms at different values of magnetic field.
Horizontal scale: 5 n sec/cm
Vertical scale: 50 mV/cm
Resonant frequency 20.552 MHz.

DISCUSSION

WRIGHT: Did the 5% voltage ripple have any observable effect on the time structure in the beam?

RESMINI: Yes. We believe this is actually the case, but we didn't have very much time for looking at those effects in more detail. We expect to have better regulated voltage within a few weeks.

LIVINGSTON: Have you given any thought to extracting the negative ions to be used subsequently as negative ions.

RESMINI: This would be a very interesting thing. We now plan to install the conventional electrostatic deflector, and magnetic channel, in the next few months. We may pursue such a research line, but of course there are the usual problems involved with holding high positive voltage.

RICKEY: At Colorado, we did a fair amount of work on extracting negative ions. As anticipated, and amply pointed out at Los Angeles, holding positive voltage is a real problem.

The highest energy that we were able to get was about 19 MeV, whereas the proton energy for the machine is 28 MeV. Electron dumps installed on the deflector helped a great deal in protecting the insulator, but they did not eliminate discharge problems. Running at 19 MeV was quite difficult, it required continual resetting of the deflector.

Two things have been suggested. One is the possibility of using other material. We used copper, which is not particularly good, in terms of work function. It has also been suggested, of course, that with rf on the deflector there should be no problem in extracting the negative ions.