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CRYEBIS, A MULTI-PURPOSE EBIS FOR THE SYNCHROTRON SATURNE II

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Summary

An EBIS has been built to provide nuclei up to Ne^{10+} (10^{10}ppp) and polarized particles (3.10^{11} with storage). This EBIS uses a superconducting solenoid (3T, 1.5 m long). The electron density is higher than 10^3 A.cm^{-2} by space charge neutralization. Results of preliminary experiments show spectra with Ne^{10+}, A^{18+}, Kr^{34+} and Xe^{44+}. Further applications of CRYEBIS are discussed.

Introduction

Since 1975, we have studied and realized a CRyogenic Electron Beam Ion Source (CRYEBIS)[1] able to provide nuclei up to Ne^{10+} and to store about 3.10^{11} polarized ions for the synchrotron Saturne II. This device, sponsored by the National Institute of Nuclear Physics and Particle Physics (IN2P3) and the Atomic Energy Commission (LNS) is now operationnal.

Basic choices of the design

We shall not recall the basic principles of this kind of source[2]. The required ionization factor to get Ne^{10+} is 50 C.cm^{-2} ; for an average background pressure in the ionization volume of 10^{-10}Torr, the maximum allowable containment time is 100 ms then the electron beam density must be higher than 500 A.cm^{-2}. Besides, the production of polarized ions from an atomic jet injected colinearly with the electron beam requires a high enough electron density for a single ionization during the time of flight of the particles along the source but not too high to maintain a sufficient yield. Then the ion source must be able to work within a large range of density ($50 \div 10^3$ A.cm^{-2}). The low pressure is obtained by using a cryopannel at the liquid helium temperature surrounding and cooling the confinement tubes.

The electron injection

The range of density previously defined is reached from an external convergent gun[3] which initiates a stable flow on the axis of a first classical solenoid. At 0.52 T, the average density is 63 A.cm^{-2} for a cathode-to-anode potential drop of 10 kV and an electronic current of 2 A. This injection is followed by a variable post-magneto-compression between the classical solenoid (SOLIN) and the main solenoid which is superconducting (SUPERSOLO) ; for a main field from 0.5 T to 3 T, the density effectively varies in the predicted range.

The superconducting solenoid

The ion source is held at a potential of 400 kV, which entails for such high magnetic field the solution of a superconducting solenoid. The winding parameters are chosen considering that the ion yield is directly proportionnal to the source length (i.e. the main solenoid length), but this length is limited by the H.V. terminal dimensions.

The characteristics of SUPERSOLO are :

Winding diameter	320 mm	- Number of turns	∿ 700
Winding length	1500 mm	- Wire length	5600 m
Maximum induction	3 T	- Maximum current	630 A

The winding can be short-circuited by a superconducting key. Then the time constant is 2.10^8s. The liquid helium dewar has been manufactured in order to adjust the magnetic axis with the source one, its capacity is 114ℓ and the consumption of the whole system is 4.3ℓ/h with the transfers.

The ion source itself[4]

The ionization volume is surrounded by a succession of 32 stainless steel tubes (56 mm long, 5 mm inner diameter) insulated from each other by a thin vacuum gap. These tubes are fixed on alumina insulators adjusted in a long rigid bed of hiduminium, which is placed into a cylindrical liquid helium cooled cryopannel (consumption 1.5 ℓ/h). The mechanical alignment accuracy is better than 0.05 mm even at 4.2°K. Each tube is biased through a constantan wire. The electronics of the tubes potential distribution is rather complicated by the large variation of the magnetic field along the axis. The position

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of the electron-collector is determined by using a third classical solenoid (SOLEX) whatever the main field may be.

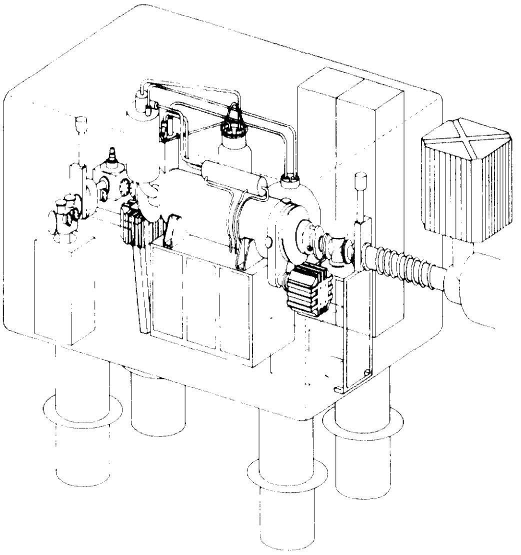

Fig. 1. The CRYEBIS pre-injector

Description of the pre-injector (HYPERION) Fig. 1

The polarized atomic beam comes from the generator at the earth potential ; it passes through a classical insulating tube before being mechanically pulsed (to avoid poisoning of the cryopannels by the polarized atoms during the useless period). The jet passes through the gun cathode and enters the ionization volume. For "heavy atoms", the injection is transverse to the electron beam near the gun and only ions can go towards the confinement region because of the cryosorption of the LHe cooled tubes. The ions leave the source with an energy of Z_i times 5 keV. The separation between the electron and ion beams occurs inside the collector-extractor region. The collector can dissipate an average power of more than 2 kW, and the extractor is biased in order to repell the electrons from the ion beam line. This line is composed of a lens, a pair of electrostatic steerers and a modulator for time of flight analysis of ions. Then an electrostatic spherical inflector changes the beam direction leaving the spin horizontal but perpendicular to the trajectory and a small solenoid precess is to a transverse direction for a proper acceleration into the synchrotron ; this arrangement is followed by two unipotential lenses to adapt the ion beam shape before the acceleration at 187.5 keV/nucleon.

Preliminary experimental results

Experimental measurements of the density in the nominal conditions without ions yield a value of 1020 A.cm^{-2}. The electron beam transmission through the tubes is 99.99% with some shimmings at the end of SUPERSOLO. We have verified that the main ionization process is a step-by-step one. The highlights of results are summarized in the table I, with a

Table 1

Electron beam parameters	3.8 keV 0.19A	4.3 keV 0.25A	6.5 keV 0.6A	4.8 keV 0.33A	4.8 keV 0.33A
Ion, Maximum charge state	N^{7+}	Ne^{10+}	A^{18+}	Kr^{34+}	Xe^{44+}
Containment time	6ms	7ms	8ms	5ms	5ms
Abundance in the spectrum	100%	100%	>70%	70%	10%
Number of particles per pulse	5.10^9	3.10^9	2.10^8	2.10^8	3.10^7

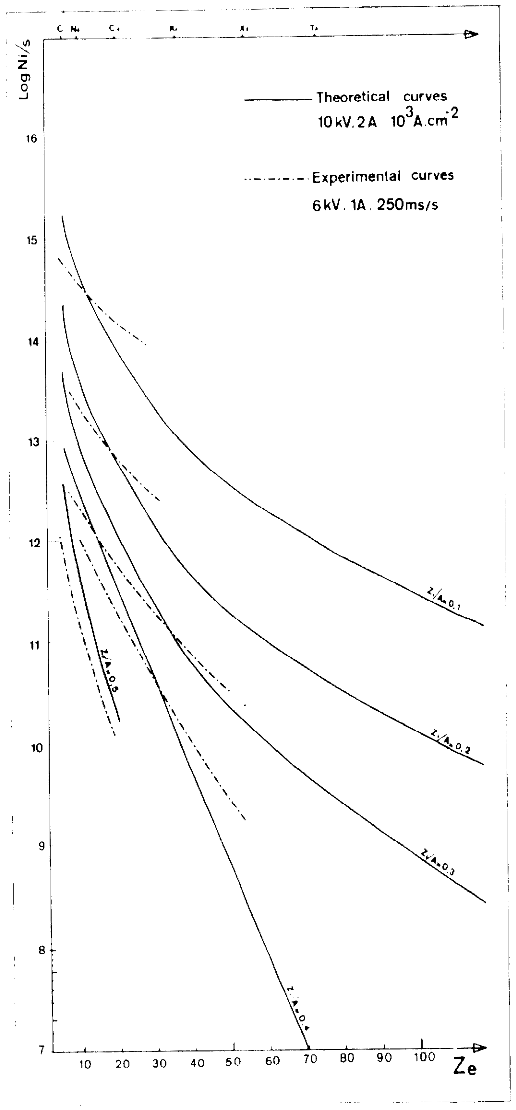

Fig. 2. Experimental yields in the cyclotron mode of CRYEBIS.

collected ion beam equivalent to 50 ÷ 80% of the electron space charge, taking into account the beam transport efficiency down to the T.O.F. Faraday cup (3 m from the source).

These results have been obtained at 1.5 T and far from the nominal conditions (10 kV.2 A). The containment times are abnormally short, so it seems we have densities higher than 10^5 A.cm^{-2} (in the case of Kr^{34+}). Other phenomena may occur and explain the shortness of containment times but the consequences as for applications of such ion sources onto fast cycle accelerators are extremely important. For the synchrotron Saturne II, we have to gain an order of magnitude in ion-density by increasing the electronic intensity to fit the theoretical predictions. For cyclotron applications, we have also shown that it is possible to expell ions from the source with times within the range 50 µs ÷ 5 ms, which obviously means duty-cycles as high as 50%. Actually, the dissipation capacity of the electron collector is such that the electron beam duty-cycle is 25% at 6 kV-1 A so that the practical yields per second for the noble gases correspond with the Fig.2. The measured beam emittance 30 cm away from the extraction is 1.2 π 10^{-7} m.rad (normalized). The measured energy spread is 2.10^{-2} for H^+ and about 1.4 $10^{-2}/Z_i$ for heavy ions (estimated from the time of flight spread). We begin experiments on polarized particles storage (estimated yield : 3.10^{11} $H^{\uparrow +}$ per pulse), both with metallic ions production with evaporation of a target by laser shots.

References

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