THE LOUVAIN-LA-NEUVE INJECTOR CYCLOTRON PROJECT

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Abstract

A 70 Q^2/A heavy ion cyclotron is proposed as an injector for Cyclone. This two-cyclotron combination will be capable of accelerating high currents of ions with a maximum energy of 27 MeV/a.m.u. up to Neon. With decreasing energy and intensity ions up to Xenon can be obtained.

Some unusual features of the magnet and RF system design are described.

1. Introduction

The isochronous cyclotron of the University of Louvain-la-Neuve (CYCLONE) described elsewhere in the Proceedings of this conference [1)], was originally designed for light ions (p, d, $^3He^{2+}$, $^4H^{2+}$) acceleration. Although good intensities of heavier ions are routinely accelerated, the particular qualities of our machine are best encountered in the acceleration of large beam currents with high charge-to-mass ratio up to energies of 27 MeV/nucleon.

So, to make the best use of our cyclotron in the growing field of heavy ions acceleration, it was decided to build a second accelerator as injector and run CYCLONE as an energy booster.

Three kinds of injector accelerators were evaluated : a) a small linear accelerator ; b) a Van de Graaff tandem ; c) a cyclotron. Finally the cyclotron seemed to have the best price to performance ratio.

2. Basic requirements

To reach a good stripping efficiency, the injection energy has to lie in the 1 MeV/nucleon region. The exact ideal value depends on the final charge state, but is quite uncritical. On the other hand, to allow median plane injection, the magnetic rigidity of the injector has to be at least 0.7 times the magnetic rigidity of the main cyclotron and preferably more to shorten the path in the fringing field. To reach a high injector efficiency, the RF of both cyclotrons have to be harmonically related ; also phase, burst length, horizontal and vertical emittance figures, and energy dispersion have to be carefully matched.

Finally, to hold the intensity limit of the main cyclotron (2 kW extracted beam as a conservative figure), the injector extracted beam should be around $3 \cdot 10^{14}$ p.p.s.

Due to the high turn separation in the injector, and related high theoretical extraction efficiencies, this figure seems possible for the lightest "heavy" ions. For heavier ones, the source will be the main limitation.

Besides these technical requirements, there is another important feature : to be accepted by the funding authorities, the project has to make a maximum use of existing material, facilities and present staff thus requiring a minimum of additional budget.

Summarizing this, we find :

magnetic rigidity of injector
: 70 MeV . Q^2/M with a possibility of upgrading to 100 MeV . Q^2/M

charge-to-mass ratio
: $1/17 < Q/M < 1/7$

orbital frequencies
: 1,25 to 3,75 Mc/s

intensity limit of injector
: $3 \cdot 10^{14}$ p.p.s.

horizontal and vertical emittance
: <50 mm . mrad.

burst lengths
: 5 ns < ℓ <10 ns

energy dispersion
: $<1 \; 10^{-2}$

additional budget required
: 25 millions B. Fr. (approx. 650.000 \$)

3. Expected currents

The expected extracted currents from the main cyclotron have been computed as follows :

$$I = I_s \times \eta_1 \times \eta_2 \times \eta_3 \times \eta_4 \times \eta_5$$

where

I_s is the actual source current for the considered charge state in the injector. I_s has been taken from "routine operation figures" from Dubna and Orsay accelerators [2-3-4)]

η_1 is the injector cyclotron acceleration and extraction efficiency assumed to be 50 % ($I_s \times \eta_1$ is arbitrary limited to 3.10^{14} p.p.s.)

η_2 is the stripping efficiency computed as a function of the energy, ion, final charge state, stripper material and thickness. The formulae being extracted from ref. 4 and 5

η_3 is the injection efficiency due to mismatching between cyclotrons and assumed to be 50 %

η_4 = 1/a if a/b is the ratio between injector and main cyclotron RF

η_5 is the accelerator and extraction efficiency of the main cyclotron, assumed to be 50 %.

We shall point out that for each final beam of the main cyclotron, several (sometimes several tens of) combinations of charge states and frequencies, are possible for the injector. A computer code, called FRINJ, has been written to compute the expected current corresponding to each possibility and to select the better ones. Final choice will be done by experience. Expected results are summarized in Fig. 1.

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4. Magnet design

It was found that the most economical field level balancing the construction and operation costs was 16 kG, which to reach the given magnetic rigidity turns in an extraction radius of 77,5 cm. Concerning the vertical focusing, only a small amount of flutter is required as the relativistic mass increase is about 10^{-3} only. A large spiral angle was choosen, as it allows the reduction of the valley gap to a minimum for a given hill gap, thus minimizing magnetizing power and fringing field.

Vertical dimensioning was managed around a minimum ν_z of 0.1. This gives a maximum beam height of 20 mm in our case, inside dees of 30 mm, outside 44 mm, useful gap between copper sleeves 100 mm (Dee voltage 35 kV only). Hill gap 110 mm and valley gap 140 mm.

Because of the large radius of first turns and small gap, no field bump is required in the center. Furthermore, a high power P.I.G. source seems to require a magnetic field as homogeneous as possible. For those reasons, it was decided to keep at the center, within a diameter of 30 cm, a flat field region and to have no axial holes in the poles.

The magnet requires only 60 kW of magnetizing power, with an efficiency of 85 %. However, the coils are designed to stand four times this power. In this case (the upgraded version) the magnetic field should reach 19 kG, giving the cyclotron a K of 100 MeV Q^2/M.

To check those computations, two sets of model measurements are planned. The first model, with a scale factor of 6.39, has allowed the verification of the computed efficiencies and the measurement of isochronism and flutter. Early measurements indicate that vertical focusing is good but the hill to valley ratio versus radius will be modified to have a better tracking of the isochronous field. However, final determination of sector profiles and trimcoils will be done in a larger scale model, to reach a better accuracy.

The final ideal field will probably not be always the isochronous one : after the central flat field region, whose value is mainly fixed by central geometry problems, will be a transition region whose field has to meet two different conditions :

1) make as much phase focusing as possible
2) bring back the central phase to the top of the accelerating voltage.

In the third and final region (from radius 30 cm to extraction), field will be as isochronous as possible, to keep the phase around 0° to minimize the energy spread and allow single turn extraction.

5. R.F. design

Because of the low orbital frequencies, two possibilities are present :

1) to have the usual RF frequency range and high harmonic modes : this solution has the advantage to allow a classical cavity design, and to simplify burst length matching. But central geometry problems become more and more difficult to overcome as the harmonic number is increased. Finally the only way to achieve a good central region efficiency at such high harmonic modes seems the use of a biased source. However with a high power P.I.G. source this solution is at least difficult.
2) to use a classical harmonic mode (for instance harmonic 2 with two 90° dees) but a very low radio frequency (in this case 2,5 to 7,5 MHz). At those low frequencies, classical cavities become unpractically large. For this reason, two short helicaly-wound coaxial lines were choosen as resonators. The realization of a movable short on an helical line looking somewhat tricky, it was decided to use a variable capacitor under vacuum for fine tuning and to have five different coils to exchange manually for the subrange switching.

The power needed to reach 35 kV peak dee voltage is computed to be less than 15 kW per cavity at any frequency.

Harmonic number being always two, the two dees are connected together at the center which gives automatically voltage and phase equality, and also a more stable mechanical structure.

The required power will be fed from one 30 kW power amplifier located on one cavity. The unbalance in dee voltage due to this unsymetrical excitation is computed to be less than 1 10^{-3}. The reference RF signal will arrive from the main cyclotron through suitable multiplying-dividing and dephasing circuits.

6. Beam matching

The beam line between the cyclotron has to perform the following task :

1) match the horizontal and vertical emittances
2) match the dispersive effects of the extraction and injection paths, to get finally an achromatic and non time-dispersive system.

Although full computations have not been completed, early results show that the minimal configuration shown in Fig. 3 could do the job. The elements are

1) a quadrupole triplet
2) a focus with emittance defining slits
3) a quadrupole doublet
4) a dispersion matching magnet
5) perhaps a sextupole to correct some second order effects.

References

1) Y. Jongen and G. Ryckewaert, Proc. of this Conf. N° A21

2) P.M. Morosov et al., Atomnaya Energiya 3, 272 (1957)

3) A.S. Passiuk et al., Atomnaya Energiya 24, 21 (1968)

4) Rapport du G.A.N.I.L. (IN2P3 - CEA, France), July 1973

5) E. Baron, Thèse de Doctorat (Orsay, France) 1975

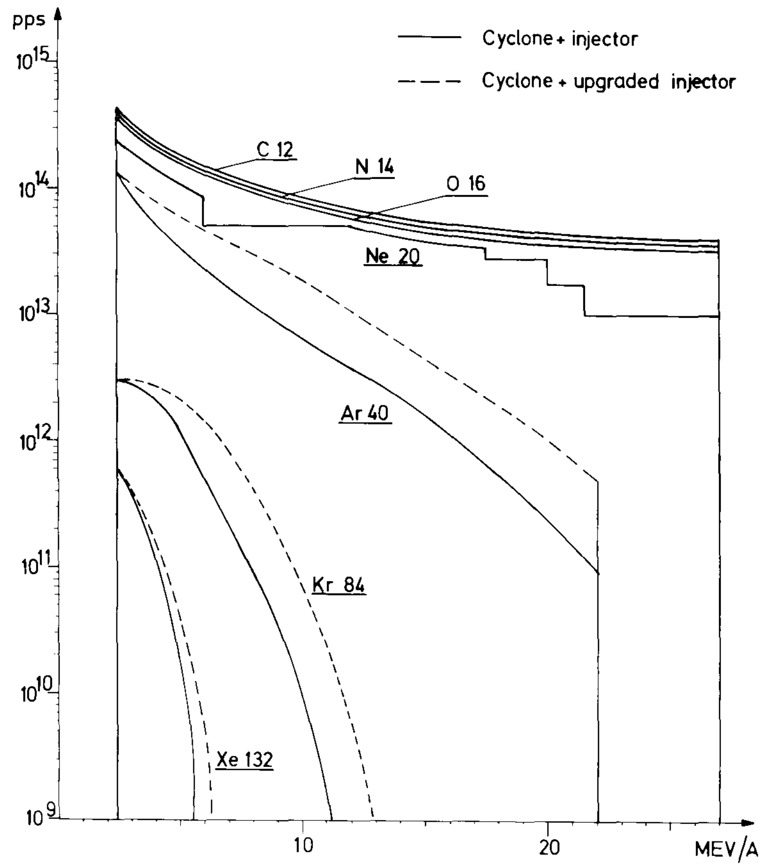
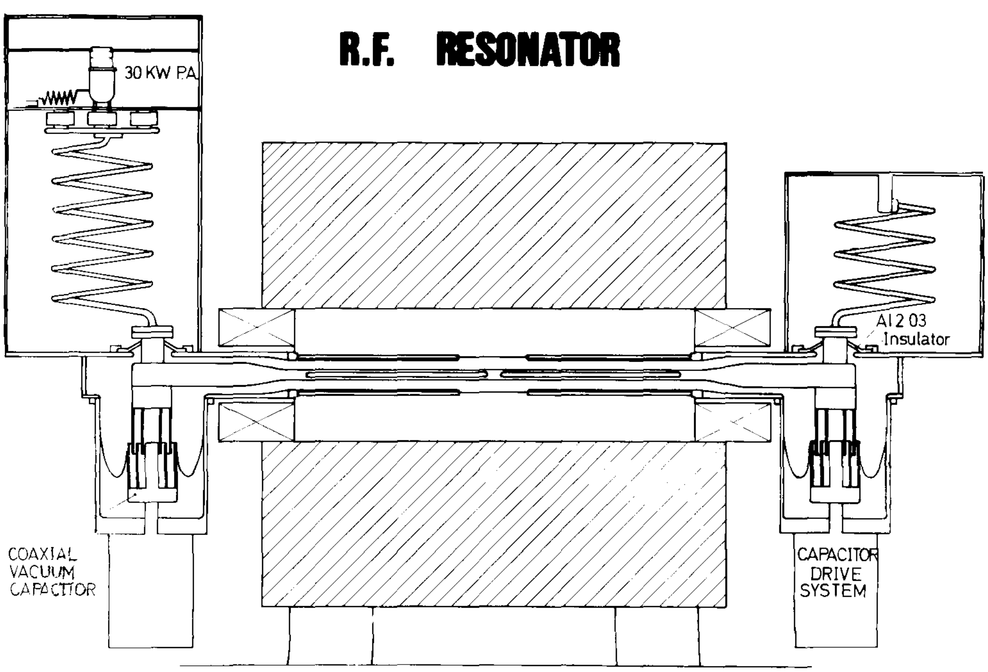


fig. 1 : computed currents versus energy for typical ions



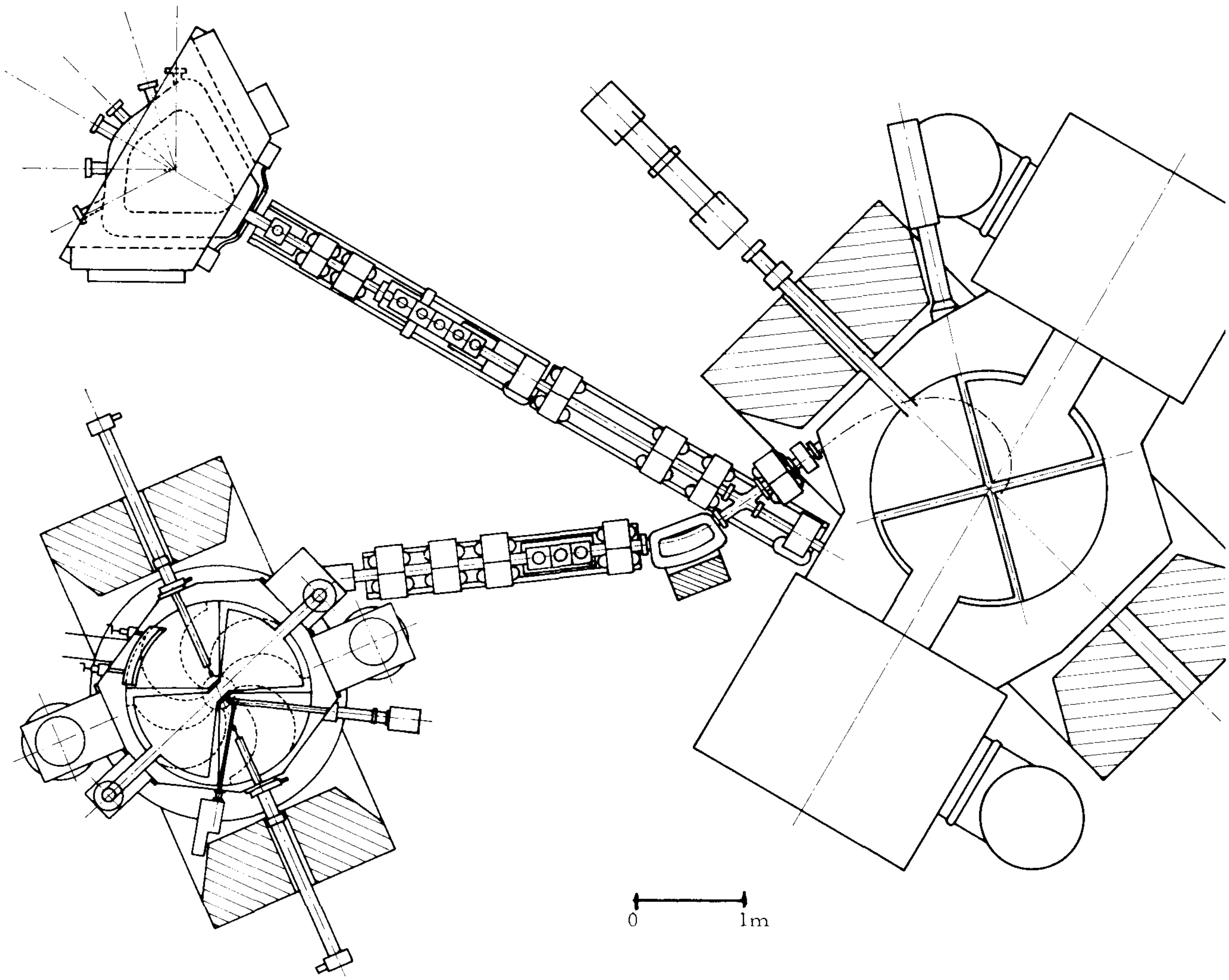


fig. 3 : general layout of both cyclotrons and beam matching system .