Preliminary design for a K = 30, 500 μA H^-/D^- Cyclotron

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Abstract

The proposed cyclotron is the first step of a program aiming at developing high intensity, energy efficient cyclotrons. The K = 30, 500 μA H^-/D^- cyclotron is designed to use less than 100 kW main power. The magnet has four 54 degree straight sectors on a common yoke. The hill gap and field are 3 cm and 1.75 T. The valley gap and field are 110 cm and 0.04 T. Two 30 degree dees operate at 66 MHz, with H = 4 for H^- and H = 8 for D^-. The vertical $\lambda/2$ cavities are located entirely in the valleys. The H^- are produced by an external E.C.R. source based at 50 kV. They are injected axially using a permanent magnet periodic focusing channel. The prototype is expected to deliver beams in 1988.

Introduction

A preliminary design for a 40 MeV, 5 mA proton industrial cyclotron was proposed by Y. Jongen in 1984 <1>. The design presented in this paper is a first step in a program aiming to develop such high intensity, energy efficient cyclotrons.

The goals of this project are:

- to test some of the ideas presented in <1> on a small scale, relatively inexpensive prototype
- to realize a cyclotron able to produce most of the radioisotopes needed for P.E.T. and other hospital uses, with an extremely low operation cost.

A first version of this project, providing only H^- beam was presented at the P.A.C. in Vancouver (March 85) <3>. Since this time, it was suggested by the isotope production group of our institute that the possibility of accelerating deuterons was a very desirable feature for P.E.T. applications.

Therefore the initial project was modified to include the possibility to accelerate also deuterons. This new option introduces some compromises and complications in the design. A careful study of the advantages and disadvantages of this option will be continued during the prototype development phase, and the final decision to include or not deuterons acceleration will be made later.

General design features

The proposed cyclotron is a fixed field, fixed frequency machine, accelerating H^- up to 30 MeV and D^- to 15 MeV. The energy of the extracted beams is variable from 10 MeV to 30 MeV by a variation of the radius of the stripper foil. Two beams can be extracted simultaneously using partially intercepting strippers.

Magnetic structure

The magnetic structure has been specially designed to use a minimum power: only 7.5 kW D.C. power are necessary in the main coils. The iron is shimmed to get a field profile intermediate between 30 MeV (H^-) and 15 MeV (D^-). The difference, due to relativistic effects, is + or − 1 % of the iron field at extraction radius. The small difference is compensated by one set of trim−coils, located in the valleys opposite to the dees. Beam dynamics calculations are underway to evaluate the effect of the harmonic 2 perturbation introduced by those trim−coils.

This original magnetic structure (a patent is pending) combines the advantages of a separated sector cyclotron and of a compact cyclotron

Separated sector cyclotron advantages:

- small gap
- low dee capacity
- possibility to locate the cavities in the valley
- good stripping optics
- four−fold symmetry

Compact cyclotron advantages are:

- simple low current density circular main coils
- simple vacuum chamber
- no sector alignment problems
- uniform field at the center, allowing a low axial injection energy

Injection and extraction

The H^- ions are produced in an external source, using the Electron Cyclotron Resonance (E.C.R.) at 2.4 GH. The injection energy will be 50 kV for H^-, 25 kV for D^-. The H^- beam is injected axially using a permanent magnet periodic structure, as developed by O.C. Dermois et al., <2>.

This design avoids the two main problems of existing low energy H^--cyclotrons:

- the use of an external source allows very low pressure in the cyclotron with moderate size pumps
- stripping of the H^- on the residual vacuum is strongly reduced
- the extracted beam crosses the magnetic field gradients at an angle not too small
- sextupole contributions are minimized
- the optical properties of the extracted beam are excellent and, for production targets located close to the cyclotron, no further focus element is required

R.F. System

Two 30 degree dees are operated in H = 4 from the orbital frequency for H^- and in H = 8 for D^-. The electrical length of the dee becomes 120 degree for H^- and 240 degree for D^-, giving a theoretical maximum acceleration of 86 % of the dee voltage at each gap.

The dees are supported on a vertical line, making a half-wavelength resonator at 66 MHz.

The cavity is entirely located in the valley. The R.F. power needed to obtain 50 kV on the dee is less than 5 kW for one cavity. The two dees are connected at the center, below the median plane, to allow room for the injection inflector. Only one R.F. amplifier is used.

The R.F. final tube is directly coupled to the cavity by capacitive coupling in the median plane, avoiding the problems of detuning the cavity coupling due to the beam load (15 kW).

Controls

The operation of the cyclotron will be fully automatic, requiring no operator. The user will have the choice of a limited number of preset beams, or of manual adjustment. All controls and interlocks will be handled by a high level industrial programmable controller.

Planning

The budget for the construction of this prototype has not yet been obtained. However, if the budgets are obtained by the end of this year (1985), the cyclotron should be operating by the end of 1988.

The steel for the yoke was ordered in august and will be delivered end of oct. 1985.

Initial field mapping of the magnet yoke are foreseen in April 1986.

It is expected that the magnet development will be completed end of 1986. The first beams are expected at the end of 87 and, according to the present schedule, the cyclotron should be completely operating end of 1988.

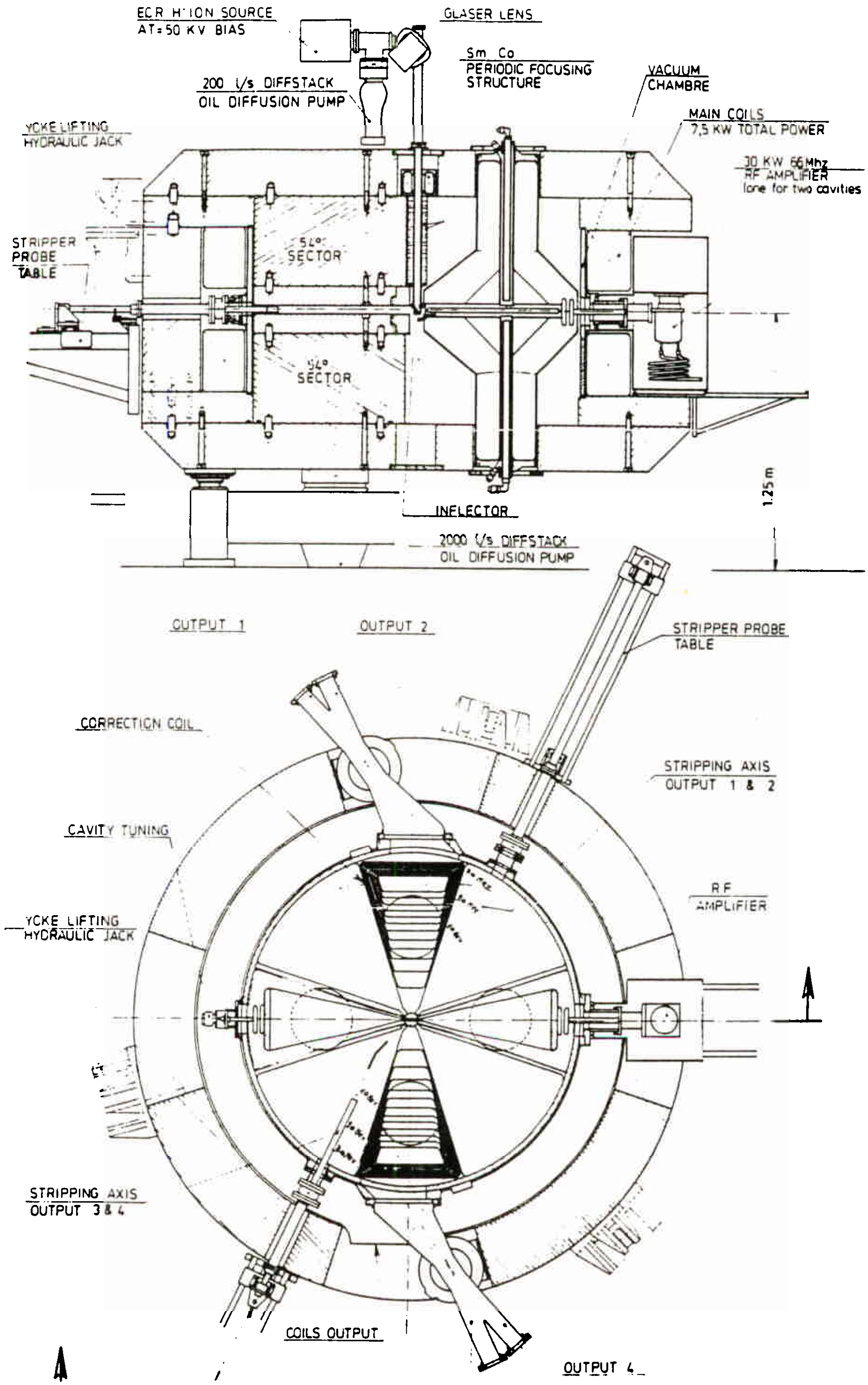
Acknowledgements

Such a project is obviously based on a collaboration of a large team, and almost every member of the "Centre de Recherches du Cyclotron" shares the paternity of this new cyclotron.

In addition, we would like to thank professor P. Macq for his continuous and active support to our project, and professor M. Cogneau of the radiochemistry department for many helpful discussion in defining the specifications of this cyclotron.

Table 1
Main Parameters

Beam	
type of ions	H^-/D^-
energy variable	10–30 MeV (H^-) 5–15 MeV (D^-)
intensity variable from	0 to 500 μA
number of beam lines	500
number of simultaneous extracted beams	4
Magnetic structure	
number of sectors	2
sector angle	54^o
hill field	1.8 T
valley field	0.04 T
number of ampere–turns	$6.6x10^4$ A
average current density in the main coils	50 A/cm^2
D.C. power in the main coils	7.2 kW
D.C. power in the trim–coil	500 W
iron weight	46.5 tons
coils weight	3.5 tons
R.F. system	
number of dees (connected at the center)	2
dee angle	30^o
harmonic mode	4 (H^-) or 8 (D^-)
frequency (fixed)	66 MHz
nominal dee voltage	50 kV
dissipated power (at nominal dee voltage)	5 kW/cavity
beam acceleration	15 kW
Beam injection	
type of source	E.C.R., external
E.C.R. frequency	2.5 GHz
injection energy	50 kV (H^-) or 25 kV (D^-)
normalized emittance	10 mrad
D.C. injected beam	1 ms


ECR H⁻ ION SOURCE
AT=50 KV BIAS
GLASER LENS
Sm Co
PERIODIC FOCUSING
STRUCTURE
VACUUM
CHAMBRE
200 l/s DIFFSTACK
OIL DIFFUSION PUMP
YOKE LIFTING
HYDRAULIC JACK
MAIN COILS
7,5 KW TOTAL POWER
30 KW 66 Mhz
RF AMPLIFIER
(one for two cavities
STRIPPER
PROBE
TABLE
54°
SECTOR
54°
SECTOR
1.25 m
INFLECTOR
2000 l/s DIFFSTACK
OIL DIFFUSION PUMP
OUTPUT 1
OUTPUT 2
STRIPPER PROBE
TABLE
CORRECTION COIL
STRIPPING AXIS
OUTPUT 1 & 2
CAVITY TUNING
R F
AMPLIFIER
YOKE LIFTING
HYDRAULIC JACK
STRIPPING AXIS
OUTPUT 3 & 4
COILS OUTPUT
OUTPUT 4

References

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