CONSTRUCTION OF THE LOUVAIN-LA-NEUVE 30 MeV 500 μA H^- CYCLOTRON

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ABSTRACT

The prototype of a new design of a 30 MeV H^- cyclotron for isotope production is in construction in Louvain-la-Neuve (Belgium).

The original magnet design combines the advantages of compact and separated sector cyclotrons and requires less than 7 kW of electrical power. The ions are produced in a external "CUSP" ion source biased at 30 kV, and injected axially. The two 30° dees, supported on half-wave length vertical resonators are connected at the center. The R.F. frequency is 65 MHz, and the power for 50 kV dee voltage is 5 kW for one cavity. The cyclotron operation will be fully automatic, using a high-level programmable controller. The magnetic field shimming is completed. Vacuum and R.F. tests are underway. The first beams are expected at the end of 1986.

1. INTRODUCTION

The "Centre de Recherches du Cyclotron" of the Catholic University of Louvain-la-Neuve is currently constructing the prototype of a new 30 MeV H^- cyclotron. This project is part of a research program aiming at the development of high intensity, energy-efficient cyclotrons.

One goal of this project is to build a cyclotron able to produce 15 kW of extracted beam, while using less than 100 kW of electrical power. Actually the power used by the cyclotron is only 60 kW at low beam intensity. This ratio of beam to electrical power indicates an energy conversion efficiency of 15 percent. Present day cyclotrons have on the average an energy conversion efficiency less than 1 percent.

This cyclotron is designed to be used for high intensity isotope production, in hospitals or isotope production centers.

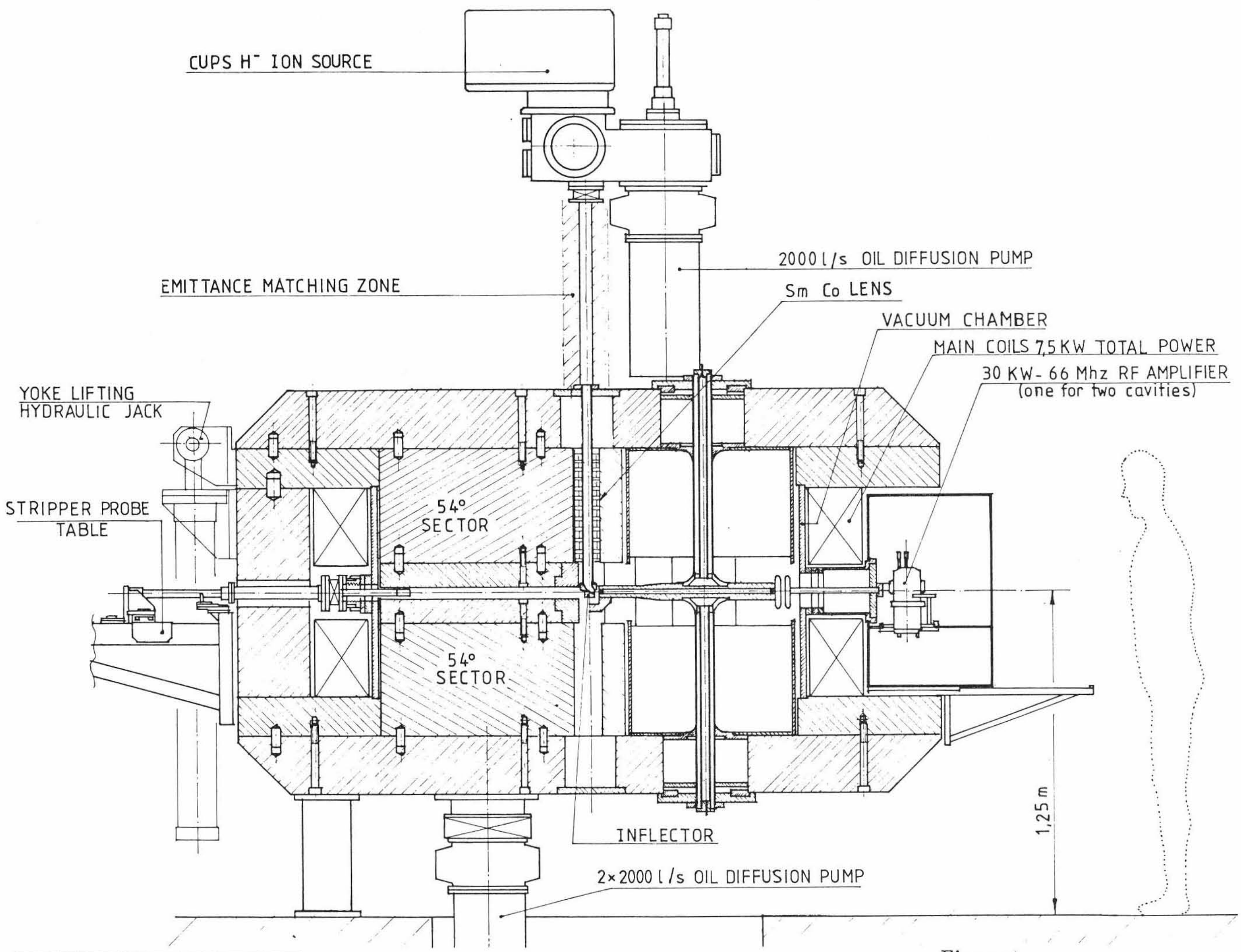

Figure 1
CYCLONE 30 MeV H- Cyclotron

[1]Work supported by
Ion Beam Applications S.A. place de l'Universite 1 - B - 1348 Louvain-la-Neuve, Belgium
and
Executif de la Region Wallonne de Belgique, Service des Technologies Nouvelles, Place Josephine Charlotte 7 - B - 5100 Jambes, Belgium

2. GENERAL DESIGN FEATURES

The proposed cyclotron is a fixed field, fixed frequency machine, accelerating H^- ions up to 30 MeV. The energy of the extracted beams is variable from 15 MeV to 30 MeV by a variation of the radius of the stripper foil.

Two beams of different energies can be extracted simultaneously using partially intercepting strippers.

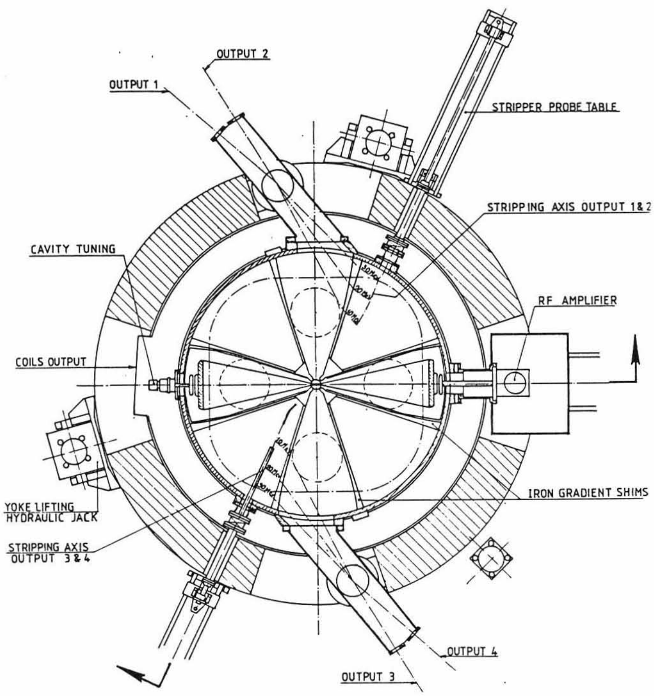

Figure 2
Median Plane View of CYCLONE.

3. MAGNETIC STRUCTURE

The unusual magnetic strucure has been especially designed to reduce the electrical power. It can be seen as a synthesis between separated sectors cyclotrons and compact cyclotrons.

Usually, separated sectors cyclotrons have the advantage of having a small gap (and therefore a small number of ampere-turns) and low capacity dees. However, due to the lack of space, the main coils of S.S.C's have usually a small cross section and a high current density. For this reason, the electrical power required by S.S.C's is not so small. In addition, the magnetic field of S.S.C.'s does not extend up to the center. This feature requires the use of high injection energies. Finally, S.S.C.'s usually have complicated vacuum chambers and require a careful and difficult alignment of the sectors.

In contrast, the new structure combines the advantages of S.S.C.'s and of compact cyclotrons.

Advantages of S.S.C. :
- small hill gap
- strong vertical focusing
- good extracted beam optics
- low dee capacity
- vertical resonators in the valleys
- perfect 4-fold symmetry

Advantages of a compact cyclotron :
- simple, large cross section, low current density, circular main coils
- simple vacuum chamber
- no alignment problems
- uniform field at the center allowing a low axial injection energy

Since this cyclotron is a single field design, the isochronism condition is achieved by an appropriate pole shaping. For simplicity reasons, the gap is held constant and the sector angle is radially adjusted to reach the required main field value. Removable pole faces permit the convenient changing of the sector angle without major cyclotron dismantling.

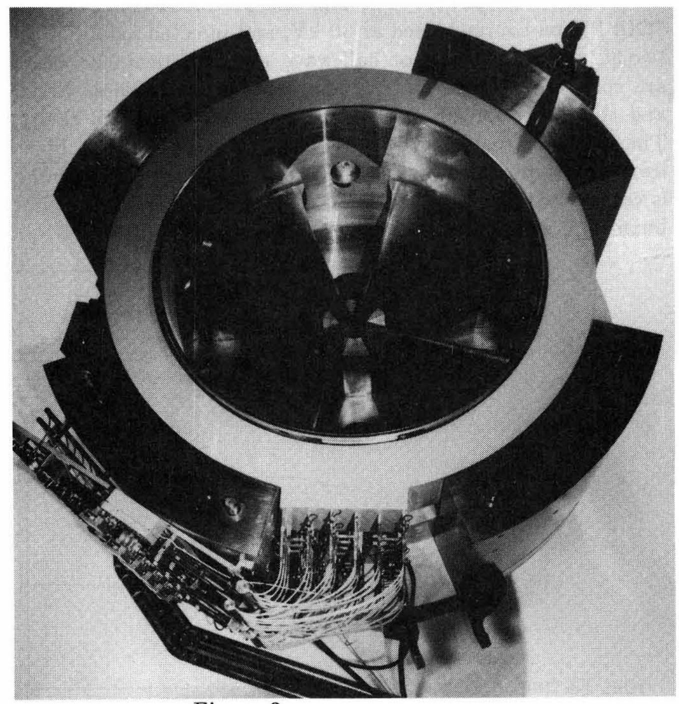

Figure 3
View of CYCLONE magnet.

4. INJECTION AND EXTRACTION

Existing H^- cyclotrons for isotope production normally use an internal P.I.G. source. P.I.G. sources used for H^- production require a relatively high neutral gas pressure in the source and, therefore, release significant amounts of hydrogen gas in the cyclotron through the extraction slits. This neutral gas in the acceleration chamber causes, a partial stripping of the H^- beam during acceleration. To avoid this problem in the new cyclotron, the H^- ions are produced in an external source fitted with a separate pumping system.

Different sources were tested to produce the required intensity of 2 mA with a minimum gas load.

Initially, an Electron Cyclotron Resonance source, operating at 2.45 GHz in a coaxial geometry, was tried [1]. This source was very simple, and operated reliably, but failed to deliver more than 200 μA at 30 kV.

Then, based on the succesfull experience of P. Schmor et al. in Triumf [2] and of K. Leung et al. in Berkeley [3], a "CUSP" source using a D.C. arc discharge was tested succesfully. This source, illustrated in Fig. 4 produces easily the needed 2 mA H^- beam and will be used in the initial tests.

Finally, another E.C.R. H^- source using a magnetic confinement, is also under development.

To inject the beam into the cyclotron, the source is biased at 30 kV. The focusing lenses are based on Sm-Co permanent magnets. Some active lenses are also foreseen to correct for the time shift induced by transversal space charge forces in the axial injection.

A dual-gap gridded drift tube buncher is used at the fundamental cyclotron frequency and is located 87 cm away from the median plane.

A pseudo-cylindrical inflector with tilted electric field is used to deflect and center the injected beam [4].

For extraction, two stripping probes located symmetrically from the center can be used. Each probe can move radially to vary the energy of the extracted beam from 15 to 32 MeV, and azimuthally to center the extracted beam in the port selection magnet. Each probe is fitted with an airlock and with an external automatic foil-changing mechanism.

The extracted beam crosses only essentially straight sectors edges, at an angle not too small. Therefore, defocusing effects and sextupole contributions are minimized. The optical properties of the extracted beam are good and, for production targets located close to the cyclotron, no further focusing element is required.

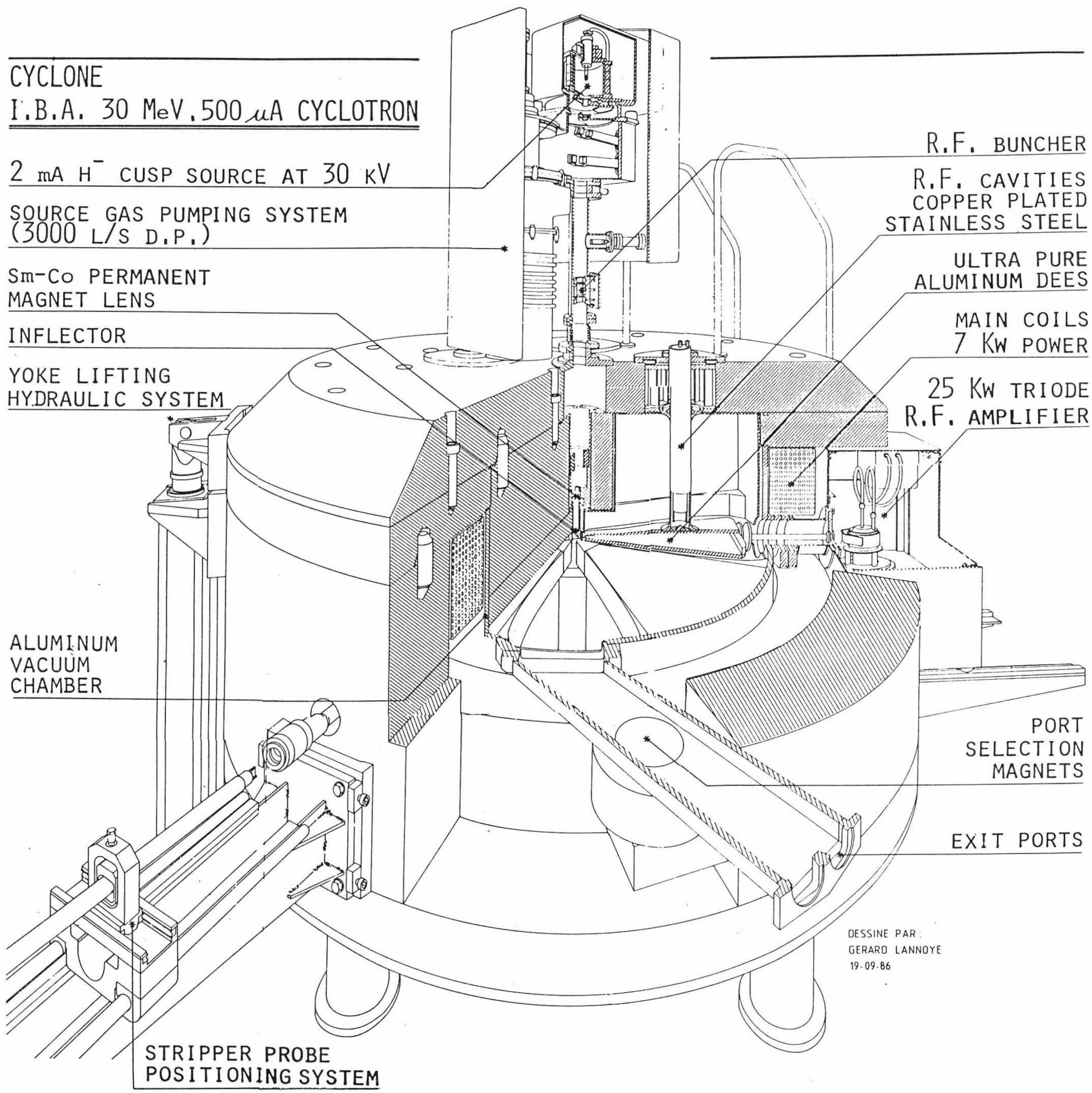

Figure 4
General Design.

5. R.F. SYSTEM

The two 30° dees are operated in the 4th harmonic mode, giving an electrical length of 120°.

The dees are supported on a vertical line, resonating in a half-wavelength mode.

The cavity is entirely located in the valley. The R.F. power needed to obtain 50 kV of dee voltage is approximately 5 kW for one cavity. In addition, 15 kW of R.F. power are foreseen for the beam acceleration.

The two dees are connected at the center, below the median plane, to allow room for the injection inflector.

A single R.F. amplifier, delivering 25 kW of R.F. power at 65 MHz, is installed in the median plane and is directly coupled to the cavity by a capacitive coupling. By this method, the variable load due to the beam appears as a variable load resistor on the final tube, and the amplifier operates always at peak efficiency.

The final 25 kW amplifier, as well as the 2 kW driver amplifier, uses zero-bias grounded grid triodes. This design gives to the system an unconditional stability and allows the suppression of the grid and screengrid power supplies.

To improve the mechanical properties of the system, the cavity is made of stainless steel, electroplated with 200 μm of copper.

Only the dees and dummy dees are made of high purity aluminium to limit the machine activation.

Special care was taken in the design of the cavities water-cooling, to keep a laminar flow everywhere. In this way, mechanical vibrations induced by water turbulence are avoided.

6. CONTROL

The operation of the cyclotron will be fully automatic, requiring no operator during normal production runs. After an automatic start-up routine, the user will have the choice of a number of preset beams, or of manual operation.

All controls and interlocks are handled by a high-level industrial programmable controller : the SIMATIC system from SIEMENS. Additional space is left in the control system to include the users targetry monitoring and isotope processing controls.

The operator station includes a color graphic monitor, two "virtual" knobs and a keyboard. A complete cyclotron troubleshooting software will be implemented.

7. PLANNING

At the time of this conference (October 1986), the magnet shimming is completed. Vacuum and R.F. tests are in progress. The first beams are expected by the end of this year.

Full beam specifications should be met during 1987.

8. AKNOWLEDGMENTS

We would like to thank Dr. P. Schmor in Triumf and Dr. K. Leung in Berkeley : their advices and informations were crucial for the development of the "CUSP" source.

Also, the impressive progresses in this project were based on the skilled and intensive work of all members of the "Centre de Recherches du Cyclotron".

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9. REFERENCES

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Table 1 : Main Parameters

BEAM		
Type of ions	H^- (D^-)[1]	
Energy (variable)	15 - 32	MeV
(for D^-)	(7.5 - 11)	MeV
Maximum intensity	500	μA
(for D^-)	(50)	μA
Number of beam lines	4	
Number of simultaneous extracted beams	2	
Norm. emittance of the beams		
- internal	5π	mm.mrad
- extracted	5π	mm.mrad
MAGNETIC STRUCTURE		
Number of sectors	4	
Sector angle (radially varying)	54 - 58	°
Hill field	1.7	T
Valley field	0.12	T
D.C. power in the main coils	7.1	kW
Iron weight	45	tons
Copper weight	4	tons
Betatron frequencies (2 MeV to 32 MeV)		
- H	1.04 - 1.06	
- V	0.54 - 0.63	
R.F. SYSTEM		
Number of dees (conn. at the center)	2	
Dee angle (effective)	30	°
Harmonic mode	4	
Frequency (fixed)	65	MHz
Nominal dee voltage	50	kV
Dissipated power cavity (50 kV)	5	kW
Beam acceleration	15	kW
INJECTION		
Type of source (external)	"CUSP"	
Filament power	0.5	kW
Arc power	2	kW
H_2 flow	5 - 10	st.cc/m
Filament lifetime at max. power	120	hours
Source bias	30	kV
Injected H^- current	2	mA

[1] D^- possible only with additional valley coils