INITIAL OPERATION OF CYCLONE II[1]

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Abstract

Cyclone II is the prototype of a new kind of high intensity, low power consumption cyclotron for radioisotope production. Its construction began in September 1985. A first H^- beam was accelerated to the maximum energy of 31.5 MeV in December 1986 and variable energy extracted beams were obtained in February 87. During the initial tests, with pulsed R.F., the total power consumption was as low as 42 kW. Operation at full intensity (500 μA) is scheduled for July 87 after the installation of the prototype in its final shielding vault currently under construction.

Introduction

The "Centre de Recherches du Cyclotron" of the Catholic University in Louvain-la-Neuve is currently testing the prototype of a new kind of cyclotron for radioisotope production. This prototype, named CYCLONE II (for CYClotron of LOuvain-la-NEuve) is a fixed-field, fixed-frequency machine, accelerating H^- ions up to a maximum energy of 31.5 MeV. Two proton beams, with a maximum total intensity of 500 μA, may be extracted simultaneously at variable energies by means of two remotely adjustable stripping foils. Another unusual feature of this cyclotron is an extremely high energy conversion efficiency : less than 90 kW electrical power (including all sub-systems and auxiliary equipment) suffice to produce 15 kW of extracted beam.

The rather unorthodox design of this cyclotron has been described elsewhere [1], [2], [3].

Magnetic field

The magnet design of CYCLONE II combines some aspects of both separated- sector and solid-pole cyclotrons. [2]

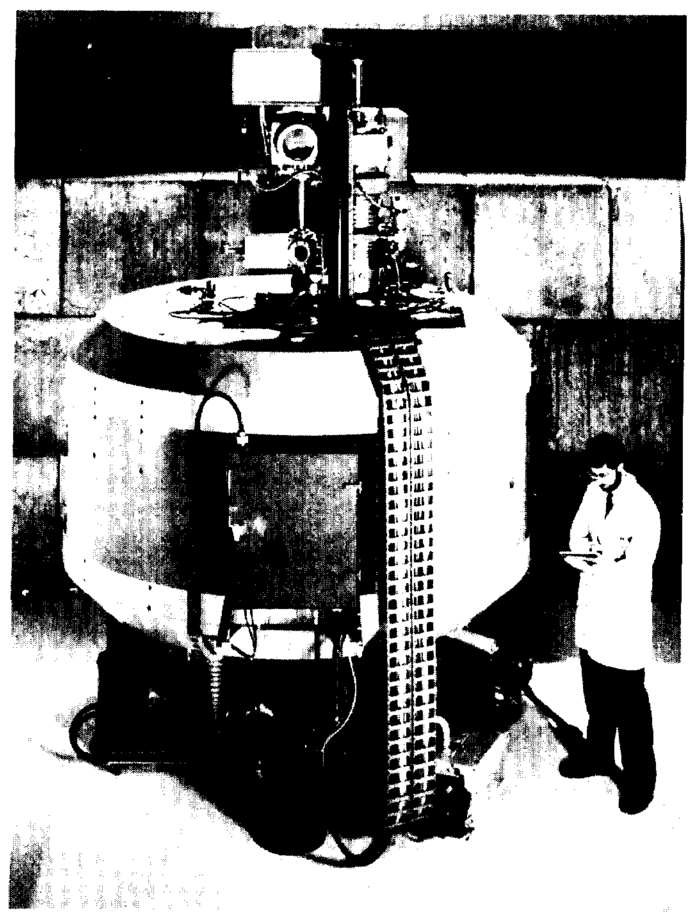
Although it uses conventional (non superconducting) copper coils, only 7 kW D.C. power is needed to produce the nominal field.

It was originally intended to accelerate deuterons to 15 MeV in the same magnet. This would have been achieved by shimming the sectors to generate an intermediate field profile between the proton and deuteron isochronous fields, and then by adjusting the radial field profile by means of two gradient coils located in opposite valleys.

This deuteron option was later judged rather useless because essentially all commonly used radioisotopes can be produced most easily by proton reactions. Furthermore, it was also somewhat conflicting with the desire of having as simple a design as possible. The deuteron option was therefore left aside for the prototype.

The pole faces of the sectors have been shimmed for the isochronous acceleration of protons up to 31 MeV. This shimming was done using an iterative procedure, until the computed R.F. phase error of the beam was less than ± 10°.

The beam tests have shown that the phase history of the beam is uniform and flat as expected. An interesting feature of this magnet design is the relatively large insensitiveness to main coil instabilities. The main coil tuning peak has a relative F.W.H.M. of 2×10^{-3} at maximum beam energy.



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R.F. System

Ions are accelerated by two 30° dees, resonating at 65.5 MHz, on the 4^{th} harmonic of the orbital frequency. The dees are supported by a half wave-length vertical line, and are connected together at the centre, below the median plane.

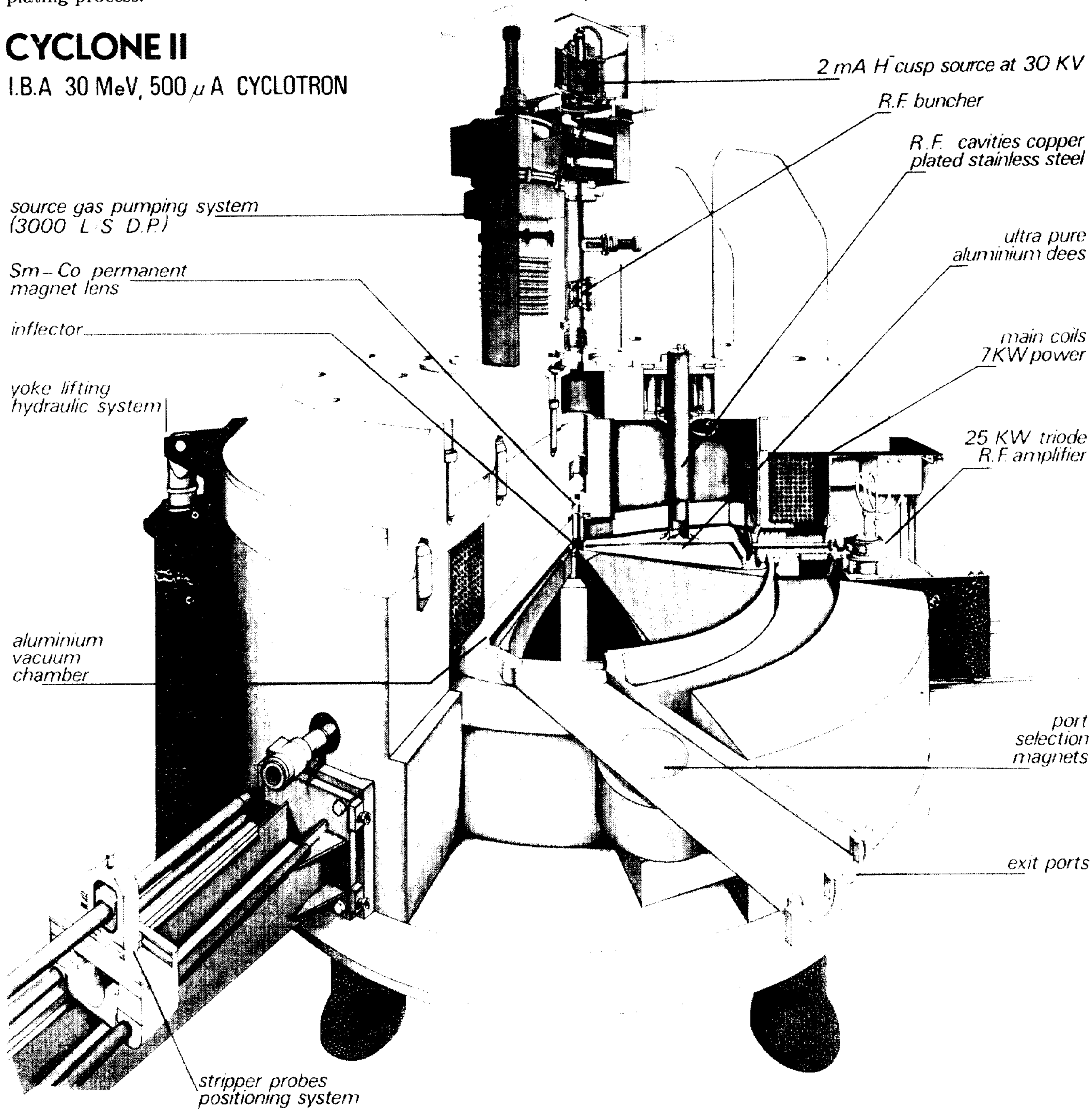
With this design, only 10 kW R.F. power is needed to reach the 50 kV nominal voltage on both dees. After an initial error in dee voltage calibration during the first beam tests, the dee voltage was accurately calibrated by the now classical X-ray method.

Some improvements were also made on the cavity design during the test period : the pure aluminium dees have been replaced by copper dees to reduce multipactoring. Also the copper-plated stainless-steel cavities have been replaced by all-copper cavities to improve heat transfer and to avoid some problems related to the plating process.

Injection and extraction

To avoid the gas load normally associated to internal P.I.G. sources, the H^- ions are produced in an external MULTICUSP source as developed in Triumf [4] and Berkeley [5]. This source, biased at 28 kV, delivers 2 mA of H^- with 2 kW arc power. The emittance of the source proved to be very small : 35 $\times$ π mm mrad for 50 % of the beam, 110 $\times$ π mm mrad for 90 % of the beam at 20 kV.

The beam is injected axially and bent in the median plane by a pseudo-cylindrical inflector. At this date (March 87) the R.F. buncher is not yet installed and an injection efficiency of 10 % has been observed. However, the optimum injection parameters were : V_{inj} = 25 kV and V_{dee} = 60 kV. The central region geometry has therefore been slightly modified to accommodate a higher injection energy (28 kV)and a lower dee voltage (50 kV).



The extraction by stripping was found to behave exactly as calculated. The emittance of the extracted beam has not been measured accurately yet, but its divergence is obviously very small, thus suppressing the need of beam optics elements for targets located close to the cyclotron. Owing to the poor shielding around the current location of the prototype, low average intensity beams could be accelerated so far. The stripping foil life-time has therefore not been estimated yet.

Acceleration at full intensity (500 μA) will only be possible when the cyclotron will be installed in its final building, now under construction.

Control

The cyclotron is entirely controlled by a high level multiprocessor-multilanguage industrial controller (SIMATIC[1]). The operator station includes a colour graphic display, an industrial grade keyboard, two "virtual" knobs which are assigned by software to various cyclotron parameters and a printer.

Normal cyclotron operation is fully automatic, and is based on a set of preset beams. An exhaustive cyclotron diagnosis routine with printer output is being implemented.

The initial experience has proven this control system to be extremely rugged, flexible and user-friendly.

Planning

The project planning can be described by a few milestones.

September 1985	: decision to build the cyclotron
March 1986	: full funding obtained
April 1986	: magnet delivery
September 1986	: magnet shimming completed
24th December 1986	: first beam accelerated to full energy
4th February 1987	: beam extracted

CYCLONE II is expected to be moved in its final vault in June and full specifications should be met before the end of July 1987.

Acknowledgements

The help of P. Schmor in Triumf and K. Leung in Berkeley was essential in the development of the "MULTICUSP" H^- ion source.

The whole team of the C.R.C. did a splendid job, working day and night to get the first beam before the end of 86, yet doing a very nice and thorough work.

Finally, our gratitude is due to the "Exécutif de la Région Wallonne" who made the construction of the prototype possible thanks to a special grant.

References

1. Y.Jongen and G. Ryckewaert : Preliminary Design for a 30 MeV, 500μA H^- Cyclotron, Particle Accelerator Conf., Vancouver, B.C., I.E.E.E. Trans. science, Vol. NS-32, N°5 (oct. 1985), pp. 2703-2705.

[1] trade mark of SIEMENS A.G.

BEAM		
Type of ions	H^-	
Energy (variable)	15 → 31.5	MeV
Maximum intensity	500	μA
Beam lines	4	
Simultaneous extracted beams	2	
MAGNETIC STRUCTURE		
Number of sectors	4	
Sector angle (radially varying)	54-58	degrees
Hill field	1.7	T
Valley field	0.12	T
Betatron frequencies (2 → 30 MeV)		
- H	1.04-1.06	
- V	0.54-0.63	
Main coils D.C. power	7.1	kW
Iron mass	45	tons
Copper mass	4	tons
R.F. SYSTEM		
Dees (connected at the centre)	2	
Dee angle (effective)	30	degrees
Harmonic mode	4	
Frequency (fixed)	65.5	MHz
Nominal dee voltage	50	kV
Dissipated power per dee (50 kV)	5	kW
Beam acceleration power	15	kW
INJECTION		
Type of source (external)	"CUSP"	
Filament power	0.5	kW
Arc power	2	kW
H_2 flow	15	st.cc/m
Filament lifetime at full power	> 200	H
Source bias	28	kV
Injected H^- current	2	mA

Table I : Main Parameters

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3. Y. Jongen, G. Ryckewaert and S. Zaremba : Beam Dynamics Aspects of high Intensity Isotope Production Cyclotron, 11th Int. Conf. on Cyclotrons and their Applications, Tokyo, October 13-17 1986, to be published.

4. K.R. Kendall, P.W. Schmor et al.,- Measurements on a D.C. volume H^- multicusp ion source for Triumf - Feb. 1986, submitted to Rev. Sc. Instrum.

5. K.N. Leung, K.W. Ehlers et al.,- Extraction of H^- beams from a magnetically filtered multicusp source - Rev. Sc. Instrum. 55 (5) May 1984.