THE ORSAY 200 MeV SYNCHROCYCLOTRON

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The 200 MeV Synchrocyclotron was tested in June 1977; the first beams for on-line spectroscopy were provided in April 1978. For nuclear reactions two other beam lines went into service in July 1978. Fig. 1 shows the Synchrocyclotron general layout and the beam lines.

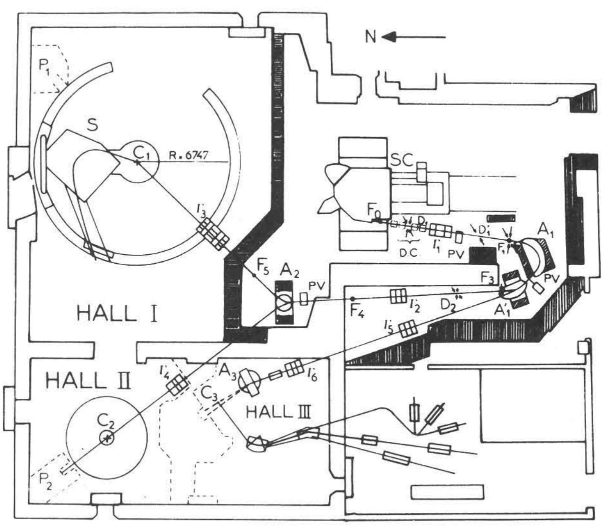

Fig. 1.

I - Synchrocyclotron technical particulars:

1. Magnetic field:
   The accelerator has two magnetic operating modes:
   - Nominal mode E_N, realized with classical circular magnetostatic shims.
   - Second mode E_N - 15%, obtained by a set of circular flat correcting coils with kapton insulation located on the pole tips on the magnet shims and fed in series with the main coils at a lower intensity.

   Table 1 shows the different workable energies:

Particles	Mode E_N $B\rho$ = 2,16 T.m.	Mode E_N-15% $B\rho$ = 1,97 T.m.
$3He^{2+}$	282,7 MeV	238 MeV
α	217,4 "	182,4 "
p	200 "	170 "
d	108 "	90,6 "

2. Ion source:
   The axial guide of the classical filament ion source is inserted in the hole made in the axis of the upper yoke (Ø = 240 mm) and poles (Ø = 80 mm). The central region is viewed by a TV camera through a symmetrical hole made in the lower yoke.

3. Radio-Frequency system: (Fig. 2)
   This is a $\lambda/2$ type structure, shortened by a rotating condenser - which is presently that of the old 157 MeV Synchrocyclotron. It delivers a sinusoidal frequency modulation of 430 Hz.
   Frequency range adjustments are realized by a variable inductor, put in series with the inner conductor, in the middle of the resonator.
   Adjustment is made by a moving short-circuit in the internal coaxial line of 68 ohms.
   The range is adjusted by two Jennings variable capacitors, located on the line at the voltage mode for the highest frequency.

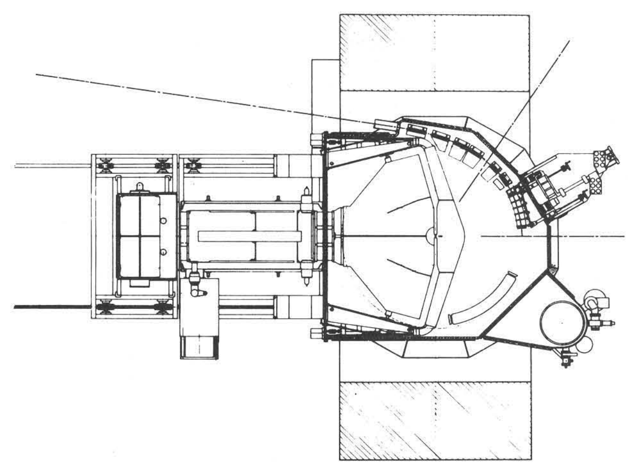

Fig. 2. Top view

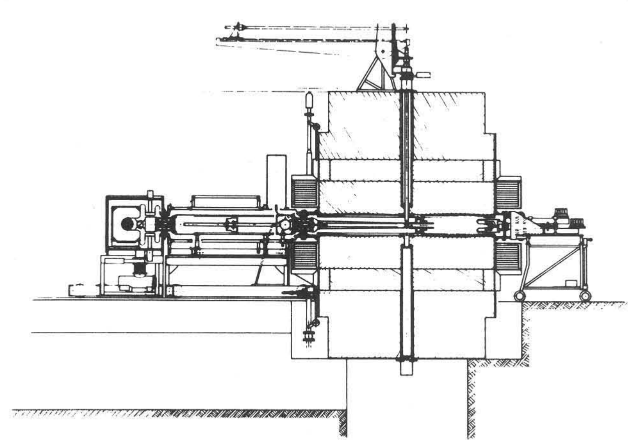

Fig. 2. Side view

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4. Extraction channels:

The first element is a magnetic channel. It is composed of a water-cooled copper septum (2,6 mm thick) and an iron-free coil. This component gives a focusing gradient of 200 G/cm in the horizontal plane and an average magnetic field drop of 0.25 Tesla on a length of 60 cm. This magnetic drop allows the beam to clear the iron septa of the four following magnetic components.

The last component (channel 5) is radially adjustable in order to optimize the exit beam direction for the two magnetic operating modes.

5. Characteristic of accelerated beams:

Fig. 3 shows accelerated beam intensities during tests of the synchrocyclotron as a function of the RF voltage applied on the "Dee" at the ion injection frequency. One finds that:

- extraction efficiency increases to 65%,
- emittances are estimated to be 8π mm-mrad vertically and 20π mm-mrad horizontally,
- time structure corresponds to pulses of 40 μs every 2.400 μs.

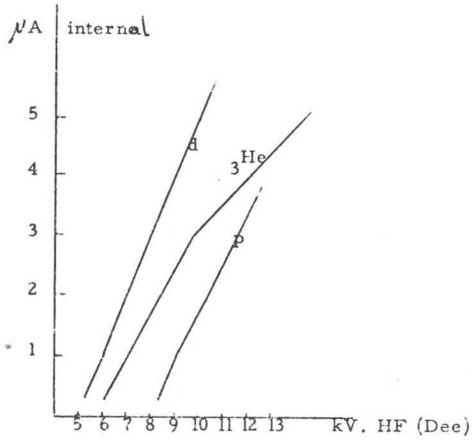

Fig. 3: Beam current versus RF voltage.

6. Parameter automatic control: (Fig. 4)

a) Every synchrocyclotron principal system is controlled, operated and measured through an integrated circuit electronic unit. Units are connected to "Micral R2E" microprocessors which assume the automatic control of the machine parameters and provide readout on three TV displays.

b) All measurements are channelled through a "Solartron" analog multiplexer.

c) In 1979 an IBM 1130 computer, connected to microprocessors will allow operation with programs for starting, regulating and supervising the machine and beam parameters.

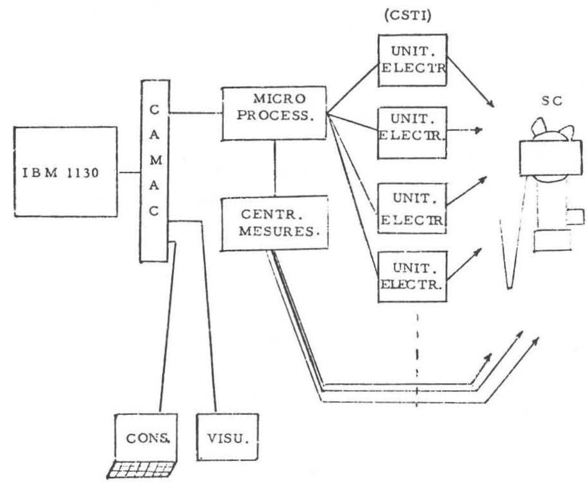

Fig. 4: Automatic control diagram.

II - Technical improvements foreseen:

1. Slow extraction (Fig. 2)

A "Cee" shaped electrode has been built; it was installed in the synchrocyclotron last June.

The aim is to obtain an almost continuous beam time structure; it is realized by an adiabatic transfer of the accelerated bucket from the "Dee" to the "Cee" by synchronizing the frequency of the "Cee" to that of the "Dee" over 30 μs. Voltage amplitude and frequency are controlled by two function generators (Fig. 5).

The resonant structure which is attached to the "Cee" electrode can be continuously tuned from 10 to 19,5 MHz. A power tube (Eimac 4 CV 25.000 A) provides the necessary current to keep a constant voltage on the "Cee" (12 kV max.) in a useful band of ± 60 KHz.

The whole apparatus will be tested in September, 1978.

2. New rotating condenser (Fig. 6)

This unit will take the place of the old one now running. The new condenser, now undergoing tests at the Institute, will have the following characteristics:

a) Variable sawtooth frequency from 700 to 1200 Hz with duty cycle of 70%.

b) Maximum voltage on fixed plates: 35 to 40 kV RF, owing to a better vacuum quality obtained by turbo-molecular stages set on the drive shaft of the condenser (compression ratio is $1:10^3$ for hydrocarbons).

c) Capacity can be reduced to 30% of nominal value without changing the sawtooth frequency. This capacity reduction allows a non-relativistic ion acceleration on the 3rd harmonic mode.

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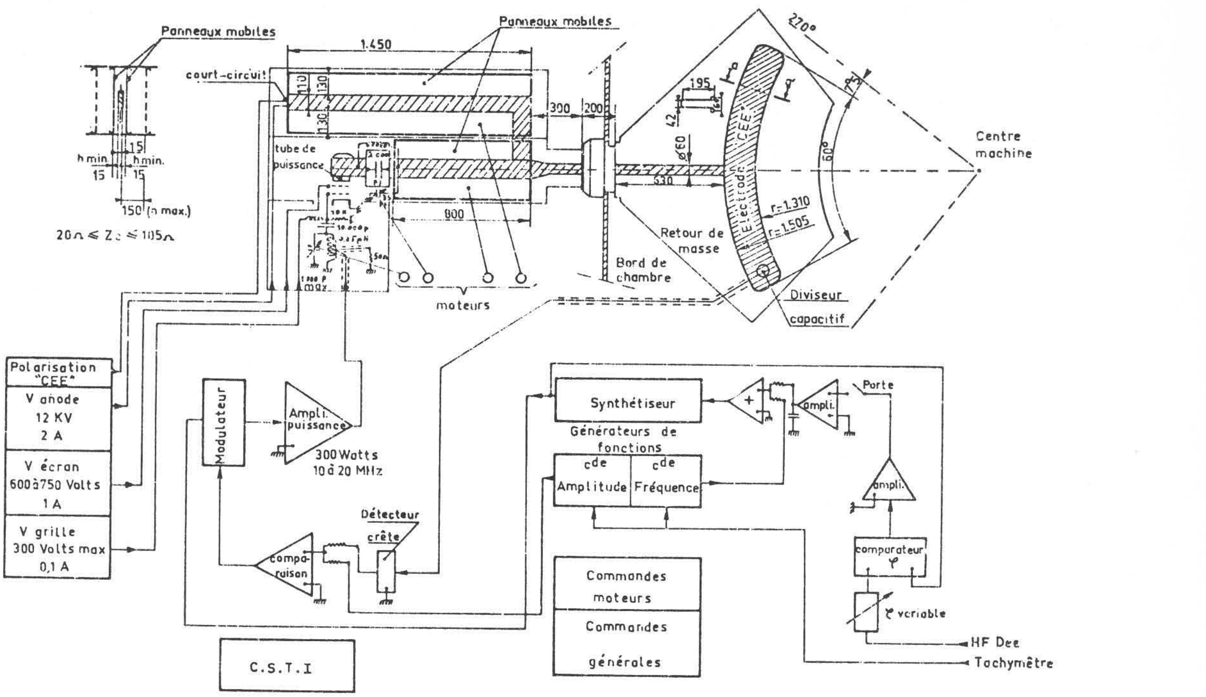

Fig. 5. Slow extraction electric diagram

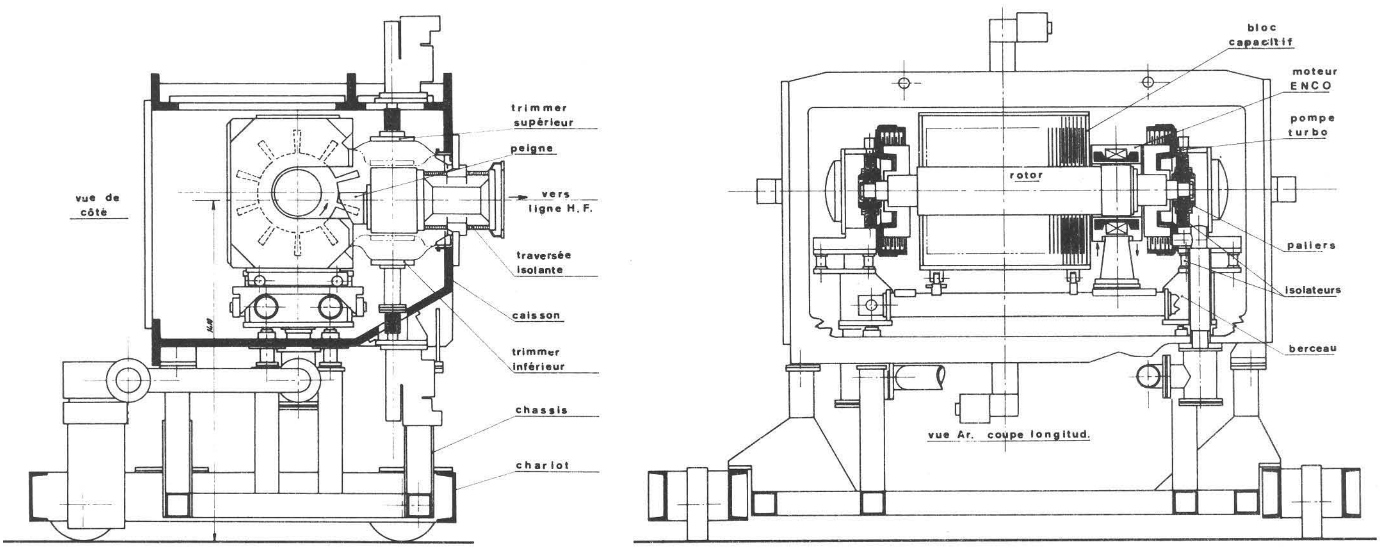

Fig. 6. Rotating Condenser.

3. Variable energy:

A theoretical study has shown that there is a linear relation between current values I_p in the magnet main coils and current values I_c in the correcting coils. This allows proton acceleration within the present energy limits from 170 to 200 MeV.

As the RF resonant structure is tuned by a moving short-circuit, and the "Cee" circuits are tuned continuously from 10 to 20 MHz, we shall be able in 1979 to obtain variable energy after making a separate correcting coil power supply.

4. 3rd harmonic mode acceleration:

The "Dee" shaped electrode has been studied to insure an energy gain per turn always higher than $E_C = 0.985.2V_D \sin \phi s$.

On the other hand, as has already been pointed out in II.2.c, the frequency can be reduced by adjusting the rotating condenser plates (Fig. 7).

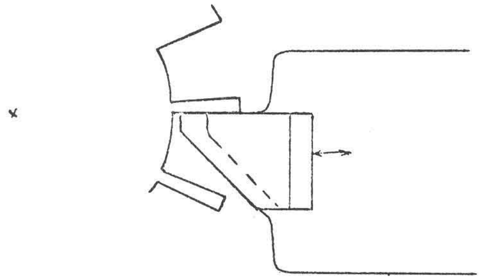

Fig. 7. Frequency excursion adjustment.

Finally, although the transit time coefficient reaches a minimum value around the central region "cones," the 3rd harmonic mode acceleration has been successful with the central region model on the synchrocyclotron at Cern, in 1970.

We can then expect - according to the ion source performance - to accelerate, on the 3rd harmonic mode, ions with a charge to mass ratio Z^i/A with respect to protons, within a range $1/6<Z^i/A<1/3$ (table 2).

5. Extraction efficiency improvement:

As can be seen in Fig. 2, there is a free gap in front of the magnetic channel to locate an electrostatic deflector with very thin septum (few hundredths mm) which would reduce considerably particle losses inside the machine.

Theoretical efficiencies higher than 95% can be obtained with a septum (length 40 Ø cm) in front of an electrode supplied with 83 kV at 15 mm spacing (the electric field would be 55 kV/cm).

6. Axial injection:

The axial hole in the magnet used presently to insert the ion source would permit, in the near future, the use of an external ion source like the Ebis model. The Ebis source has good beam characteristics in time structure and emittance, as required for axial injection into a synchrocyclotron.

References

- Internal Reports - NTTS No. 1 to 188.
- Proc. VIIth International Conference on Cyclotrons, Zürich (1975). The Orsay 200 MeV S.C.

Zi/A \ Zi	1	1	2	2	3	3	4	4	fréquences
1/3	73 $_{3}H^{+}$ 61,2	73 $_{3}He^{+}$ 61,2	146 $_{6}Li^{2+}$ 122		219 $_{9}Be^{3+}$ 183		292 $_{12}B^{4+}$ 244,8	292 $_{12}C^{4+}$ 244,8	24,75 22,86 22,7 20,98
3/10					198 $_{10}Be^{3+}$ 165,6	198 $_{10}B^{3+}$ 165,6			22,15 20,676 20,31 18,96
2/7			125,8 $_{7}Li^{2+}$ 105				251,6 $_{14}C^{4+}$ 210	251,6 $_{14}N^{4+}$ 210	21,2 19,72 19,4 18,08
1/4	55. $_{4}He^{1+}$ 46.		110,3 $_{8}Li^{2+}$ 92,3	110,3 $_{8}Be^{2+}$ 92,3	110,3 $_{12}B^{3+}$ 92,3	165,5 $_{12}C^{3+}$ 138,4	220,6 $_{16}O^{4+}$ 184,5		18,58 17,33 17,04 15,88
3/13					152,9 $_{13}C^{3+}$ 127,8				16,05 14,68 15,73 14,68
2/9			98,2 $_{9}Be^{2+}$ 82,1	$_{9}B^{2+}$			196,4 $_{18}O^{4+}$ 164	196,4 $_{18}F^{4+}$ 164.	16,5 15,459 15,14 14,154
3/14					142. $_{14}C^{3+}$ 118,8	142 $_{14}N^{3+}$ 118,8			15,90 14,92 14,6 13,66
1/5			88,5 $_{10}Be^{2+}$ 74.	88,5 $_{10}B^{2+}$ 74.	132,7 $_{15}N^{3+}$ 111.	132,7 $_{15}O^{3+}$ 111.	177. $_{20}F^{4+}$ 148	177 $_{20}Ne^{4+}$ 148	14,89 13,94 13,64 12,76
3/16					124,5 $_{16}O^{3+}$ 104.				13,94 13,08 12,79 11,97
2/11			80,5 $_{11}B^{2+}$ 67,29	80,5 $_{11}C^{2+}$ 67,29			161 $_{22}Ne^{4+}$ 134	161 $_{22}Na^{4+}$ 134	13,528 12,696 12,4 11,62
3/17					117. $_{17}O^{3+}$ 98				13,132 12,328 12,049 11,28
1/6		36,92 30,859	73,8 $_{12}B^{2+}$ 61,7	73,8 $_{12}C^{2+}$ 61,7	110,7 $_{18}O^{3+}$ 92.		147,7 $_{24}Na^{4+}$ 123.	147,7 $_{24}Mg^{4+}$ 123,4	12,42 11,65 11,38 10,65

Table 2: Range of ions $1/6<\frac{Zi}{A}<1/3$