OPERATION OF THE ORSAY CEVIL AND ITS EXTRACTION SYSTEMS.

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Abstract

It is possible to obtain an isochronous magnetic field over a wide range of average induction for a given ion by changing the structure of the electro-magnet. This new structure allows great reduction of correcting adjustements.

We obtained, at Orsay, encouraging results by the use of shims with variable permeability and damping gaps. Only two correction coils were necessary to make the average field isochronous to within 30 gauss, for all the ions.

The internal beam tests confirmed the good quality of the magnetic field and verified the theoretical calculations ; the intensity of the multicharged ion beam was generally greater than the initial evaluation.

Two extractors are at present set up : an electrostatic deflector and a stripping extractor.

This latter device perserves the optical qualities of the beam. Furthermore, one or more simultaneous beams can be obtained with an excellent efficiency, and with various energies, depending on the radius.

Introduction : the magnetic field

The CEVIL was designed to accelerate only heavy ions and alpha particles. This has permitted the use of peripheral cobalt steel shims (because of the low activation due to heavy ions) and of straight sectors, which are sufficient to provide focusing, and allow easy realization of the shimming and a relatively wide magnet gap.

The magnetic field was established by means of the following :
1) Nickel and steel shims (50 % Nickel) in the central region, allowing to compensate the saturation effect at large radii by an equivalent saturation in the center.
2) Cobalt steel shims (AFK1 Imphy 35 % Co) allowing to reduce the saturating effects on the edges of the poles.
3) Damping magnet gaps between poles and edge shims in the hill and in the valley, also allowing to reduce the saturation effects on the edges of the poles.
4) Only two correcting coils on each pole (6500 AT) which give ± 150 Gauss (average field) sufficient for residual corrections for all proposed ions between 8,000 and 15,000 Gauss.

Table 1 below shows, for various average inductions refering to the induction at the extraction radius, the detail of these various corrections in gauss, converning alpha particles.

Table I

	Nickel	Valley magnet gap			Hill magnet gap			Electric shimming			
R/R_{max}	< 0,5	0,6	0,7	0,8	0,6	0,7	0,8	0,2	0,4	0,6	0,8
8 Kgauss	750	---	---	---	---	---	---	-10	-30	-40	-70
10 Kgauss	650	---	---	---	---	---	---	-10	-35	-80	-125
12 Kgauss	350	10	70	110	---	20	100	-10	-40	-95	-125
13 Kgauss	---	10	80	120	---	20	100	---	---	---	---
14 Kgauss	---	30	90	140	---	20	1120	0	0	+20	+70

A radial section of the shims in hill and valley is shown on fig.1. This shims are made from blocks and adjustment shims. Harmonic corrections were carried out by means of adjustment shims.

Field measurements were carried out by means of a rotating wheel for positionning, and a Hall effect probe, kept at a constant temperature and fed by a very high-stability current ($\pm$ 1,10^{-5}).The device allowed a medium measurement accuracy equal to 10^{-4} at all points, and the reproductibility over one rotation was generally guaranteed with an error of $\pm$ 1 Gauss.

Field harmonics were given by direct field measurements by means of Fourier's series field expansion on circles. The Hall voltages, directly perforated on IBM cards, were used for computing on Univac 764.

The average magnetic field is isochronal without electric corrections at 14,000 Gauss for N^{4+} C^{4+} N^{5+} and at 13,000 Gauss for alpha particles (Fig.2).

The non-corrected electrically induction for which the phase shift losses are negligibles range, for instance as far as N^{4+} ions are concerned, from 15,000 Gauss to 12,500 Gauss, with an accelerating voltage of 100 KV peak.

The two correcting coils on each pole that we kept (out of five initially planned) permit to reverse the average field curve, and to allow isochronism with an error of 30 Gauss between 15,000 and 8,000 Gauss for all planned ions.

Two harmonic coils operating near the extraction radius may be used to facilitate the electrostatic extraction (Fig. 3).

Studies of the central orbits[1,2] showed that for positive phases greater than 30°, the beam extracted from the ion source is overfocused. To avoid this, we created a bump in the central field (Fig.4). By associating electric and magnetic lenses, the focal length is greater than that of the electric lens alone. A gradient of 20-25 Gauss/cm between 4 and 10 cm radii, realized by means of a magnetic cone is sufficient to focuse completely a beam with a divergence of 5°, whatever its phase may be.

The existence of a magnetic field bump implies that the beam should go through the resonance $\nu_r = 1$, which requires that the magnetic cone should be very well centred, in order to avoid harmonic n°1 in that area. This operation is quite fastidious, knowing that a mere 2 mm translation of the cylinder can increase harmonic n°1 from 1 to 2 Gauss.

Fig.5 and 6 show the average field given in two cases, and the isochronism curves for alpha particles.Fig. 7 shows the amplitude and phase of harmonic n°1 given at 13,920 Gauss. Fig.8 shows how νr and ν_z vary, with an average induction of 12,000 Gauss.

The internal beam

Central orbits

The tests on the first revolutions were done with fine bronze wire gauzes, which were vertical and supported by the source's arm or the defining slit's one. These tests are possible only with very intense beams, which leads to use an He^+ beam. For a given accelerating voltage, the holes drilled through the gauze by the consecutive paths give a good approximation of the central-region focusing and allow as well as possible an adjustment of dee's position, and so that of the extraction slit standing in a vertical axis. Thus we could observe the first five revolutions.

Median plane

The beam's position, relative to the median plane of the accelerating chamber, was studied with a horizontal three-fingered probe able to measure currents and with a probe holding a willemite-coated quartz blade. (The coating was applied on the side opposite the beam impact) the latter was observed with a television camera. The beam's position was brought to coïncide perfectly with the median plane for large radii, by shunting one of the coils of the electromagnet by means of a constantan resistance. As this adjustment varies as a function of the average induction, a resistance commutation is used. We are considering changing the latter for a transistor equipment bound to the principal field.

Orbit centring

We used two current-measuring probes, mobile in a radial direction, and a graphite screen standing in Dee and able to occupy various fixed radial positions. Positions of probes and screen are shown on Fig.9. Every probe-holden could be fit out with quartz, a rectangular cooled probe or two or three-fingered horizontal cooled probes.

The tests were carried out with a fixed radial position of the ion source, for various values of the accelerating voltage. The inductions ranged from 8,000 to 15,000 Gauss with N^{4+} or N^{5+} so that the chamber did not actually need to be activated.

The results of these tests show that the radial oscillation amplitude is really what we planned by means of the central orbit calculations, that is ± 1 cm, and that two probes at 120° are sufficient to center the beam.

In the final installation, the graphite screen and one of the probes are removed when positioning the electrostatic deflector. On the other hand, at the deflector's entrance point, a small-movement mobile probe permits the centring of the beam near the extraction radius.

We must point out serious difficulties particular to the use of multicharged heavy ions, which leads to be suspicious about current measurements.

In fact, in spite of special cases applied to the center (analysing slit) parasitic ions streams may reach the target, especially if the chamber pressure is greater than 2 or 3 10^{-6} torr. Effectively, the charge transfer probability increases quickly as a function of the pressure.

An interesting serrated target is now being used and allows to clear the uncertainty. As the target is not cooled its tips become white-hot by the beam and can be observed with a television camera. It is possible, with the former, to control the median plane, and to center it accurately by means of the second fixed target (which stands, in front of the electrostatic deflector's septum) when this target moves in a radial direction from the inner part towards the outer part, the portion that the beam illuminated narrows down to the central head, then to its end. During the experiments with N^{4+}, when letting the chamber pressure vary, we observed that, when the pressure increases, the target's illumination decreases quickly whereas the enregistered current increases. This phenomenon can be explained by the disaffearance of the N^{4+} beam in the area of high energies, and by the affearance of parasitic beams in the area of low energies. A target protected by a thin foil that stops the low-energy beams could also be used, but is much more complicated. Lastly, a result control by irradiation can easily be done.

Beam height

Beam height depends on the height of the ion source slit. It can be observed, either directly by means of a quartz and willemite target, or by target irradiations. A slit 20 mm high gives a beam approximately 15 mm high, from the 40 cm radius. A slit 10 mm high, gives a beam approximately 7 mm high.

Tests carried out with a differential probe

Current density measurements were carried out by means of a differential probe. Typical results are shown on Fig.10. ν_r calculations with these curves cannot be very accurate, but gives results in agreement with the theoretical ν_r calculations. For instance the ν_r calculated by means of this curve for radius 60 is 1.03, whereas its theoretical value is 1.027.

The use of this differential probe to center the beam by minimizing the amplitude variations seems to be less convenient than that of two probes at 120°.

Beam intensity and adjustment of the correcting coils

We could fear losses from multicharged ions, by charge exchanges with the residual gas, so an excellent vacuum appears to be necessary and a relatively high accelerating voltage interesting[3] (100 KV for instance).

The N^{4+} or N^{5+} beam intensity with respect to the isochronal radius is remarkably constant. Beyond the isochronism losses by phase shift interfere and can be counterbalanced by adjusting the two correcting currents. As the number of parameters is very small, it is unnecessary to set up an intensity curve with regard to the radius to control the coils or to use an adjustment dictionary. However these controls have been calculated by means of a minimum phase-shift program.

Stripping extraction

This new extraction process[4] can be applied to multicharged, non-completely ionized heavy ions and allows an excellent efficiency and a sage beam geometry, though keeping the internal beam's energetic definition. Tests made with this extraction were carried out during the end of 1965.

The extraction principle consists in "peeling" the accelerated ions by directing them through a thin target, and in using then the sudden variation in magnetic rigidity and the induction azimuthal modulation to direct the path towards the excit window (Fig.11). The device used for these studies was made of a target holder the internal part of which supported a thin aluminium foil with free edges (thickness 5μ , 3μ or 1μ). In the outer part of this target holder (photography Fig.12) a copper plate was irradiated by the after-stripping beam, after one or several revolutions.

The radial amplification and the distribution of the beam striking the irradiated target were measured for various angular positions and for various radii of the stripping target. Fig. 13 shows an example of the results given by N^{4+} at 14 000 gauss, with the stripping target standing on radius $R = 80$ cm. These results are in agreement with those given by the calculations on paths in the true magnetic field. The stripping efficiencies over the various charges answer to those formerly published in other experimental conditions with incident N^{4+} at 74 MeV ions, we get, for instance 15 % N^{6+} and 85 % N^{7+}.

The target position chosen on the CEVIL will allow to orientate the beam to the same direction as that of the beam extracted by means of the electrostatic deflection. That commands to change the present D, a part of the inner vertical surface of which becomes obstacle to certain paths. We must point out that this device also allows multiple simultaneous outlets in various directions.

Electrostatic deflector extraction

The electrostatic deflection is a double-channeled type as that of the 88-inch cyclotron in Berkeley[5,6]. The whole deflector mechanism can turn round an axis, so that the deflector can be easily and completely taken out of the accelerating chamber.

The removable septum is now a tungsten one, we have planned to change it subsequently for a wire septum as in Karlsruhe. Seven positioning parameters are announced on the control bord by means of nixies tubes. The movement-end safeties are ensured by a repeater directly connected with the mobile elements.

The direct voltage supplies can give 100 KV 10 mA from the 50 Hz controlled sector. A 5M serie resistance is inserted on every connexion to the deflector inputs. The breakdown tests vacuum with a magnetic field gave the following results :

Channel n°1 : 128 KV/cm the two blades standing 5mm apart
Channel n°2 : 98 KV/cm the two blades standing 5mm apart
and with a dark current lesser than 0,8 mA.

An isolated and cooled target, mobile relative to the septum allows beam intensity measurements at the deflector's entrance point and also the path centring. The harmonic coils can increase the path separation at the deflector's entrance point by controlling amplitude and phase of harmonic 4 % at the extraction radius.

The electric field gradients necessary to extract various ions, for average inductions of 14,000 , 10,000 and 8,000 Gauss are shown in table II below.

Table II

Ion		N^{5+}			N^{4+}			He^{2+}		
Average induction (Kgauss)		14	10	8	14	10	8	14	10	8
Energie (MeV)		125	67	37	80	43	23,5	70	39	21
Channel I	Entrance	61	29	30	49	23	24	92	40	42
	Exit	51	14,5	25	41	11,5	20	77	20	21
Channel II	Entrance	51	64	63	41	51	50,5	77	89	88
	Exit	19	58	60	15	46,5	48	29	81	84

As it appears on this table, the voltage gradients do not reach excessive values. The deflector's calculated efficiency gives 35 % for alpha particles at 14,000 Gauss, with a 5 mm opening at the channel's entrance point and 70 % for a 10 mm-opening.

Low intensity tests are on at the time being, so as the actual results cannot yet be communicated.

Beam transport system

A calculation program of optics by matrix has been realized and used for the theoretical adjustments of the various beams elements. Quite alike the OPTIK program from Berkeley, it will be improved by a better accomodation to the accelerator problems in Orsay.

We are also studying a system that could give us :
-The electric determination of the extracted beam's "internal conditions".
-By means of an analogical computer, a visualization in the horizontal and vertical plane of the beam going through the various magnetic devices.

This intricate system is designed to quicker beam controls and seems to become useful to such a multiple-practicability cyclotron as the CEVIL.

References

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4. G.N. Vialov, Y. Oganessian, G.N. Flerov Institut unifié de recherches nucléaires. Dubna (1964).
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6. H.A. Grunder, F.B. Selph and H. Atterling "Operating experience with the Berkeley 88-inch cyclotron electrostatic deflector" U.C.R.L. 10759 (1963).

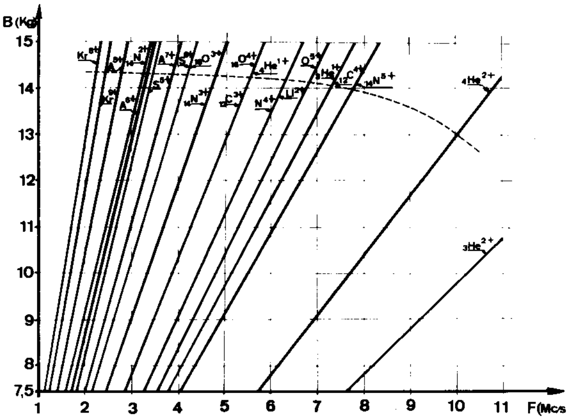

Fig. 2. Resonance conditions for various heavy ions in C.E.V.I.L. The dashed line shows the isochronous magnetic field without trimming-coil currents.

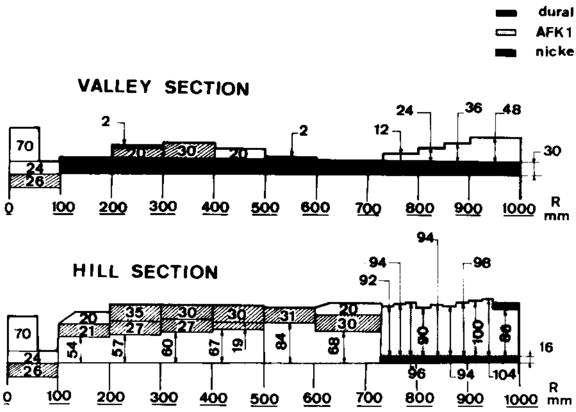

Fig. 1. Sections of shims C.E.V.I.L.

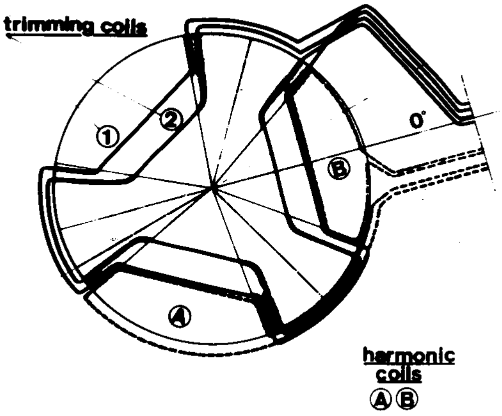

Fig. 3. Geometry of trimming coils and harmonic coils.

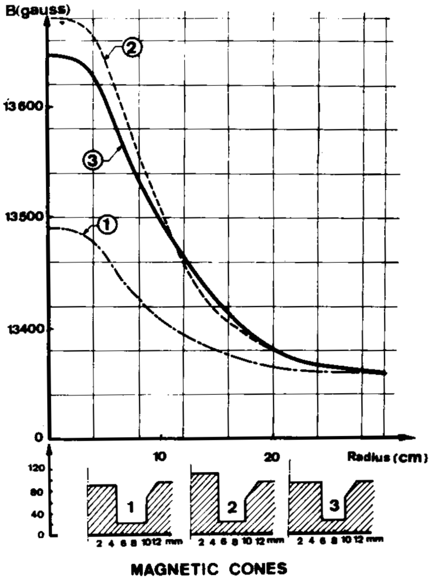

Fig. 4. Magnitic cone in the central region.

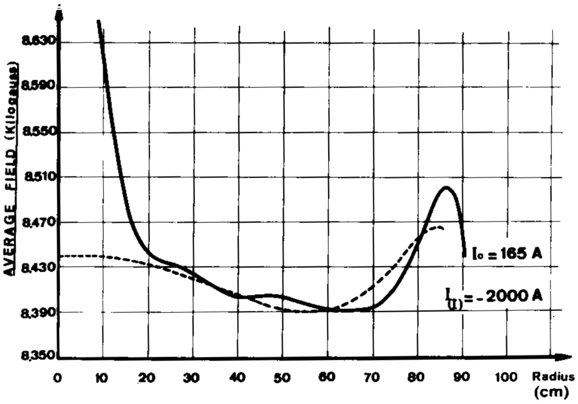

Fig. 6. Average magnetic field.

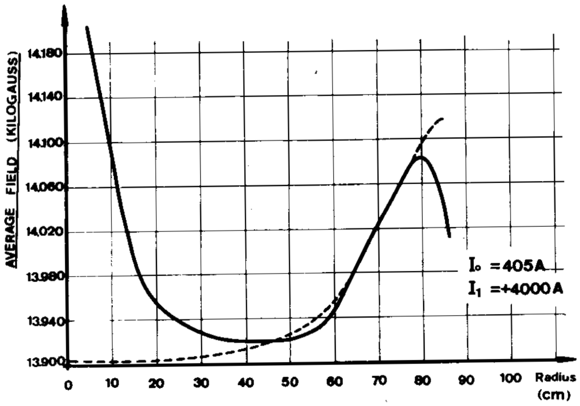

Fig. 5. Average magnetic field.

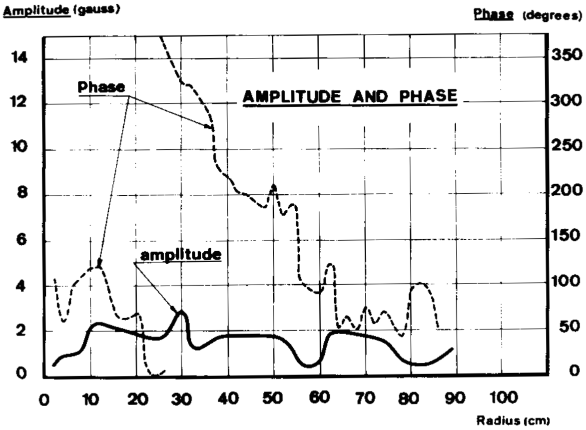

Fig. 7. Amplitude and phase of first harmonic in magnetic field vs radius.

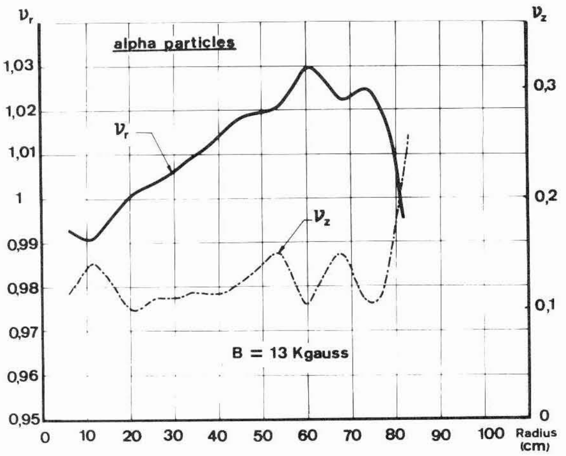

Fig. 8. Vertical and horizontal frequencies.

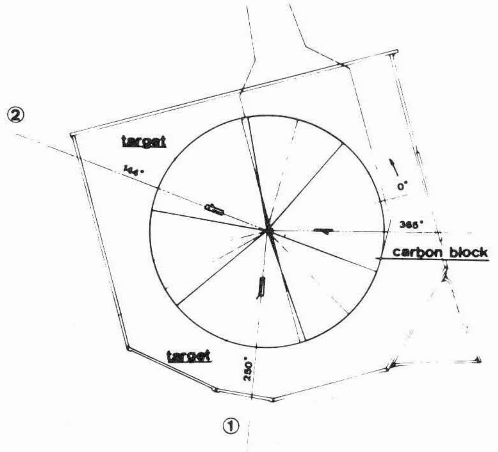

Fig. 9. Azimuthal position of probes.

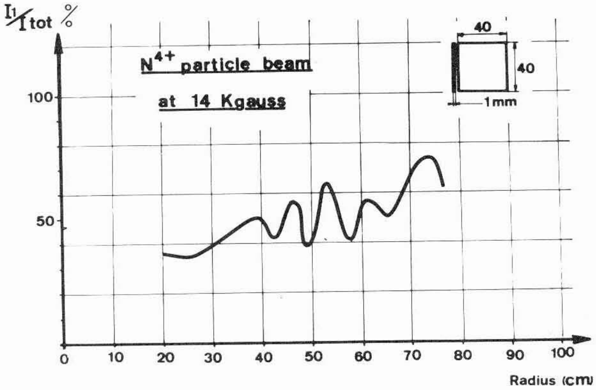

Fig. 10. Beam density vs radius.

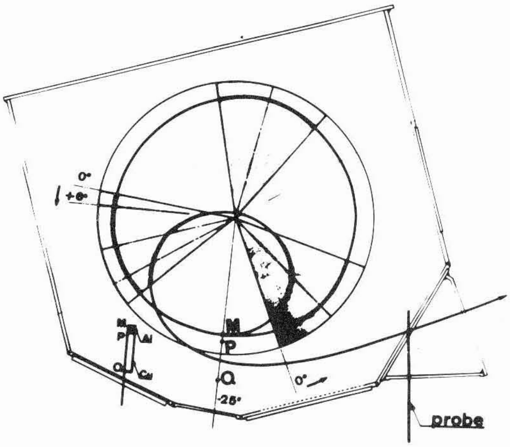

Fig. 11. Stripping extraction.

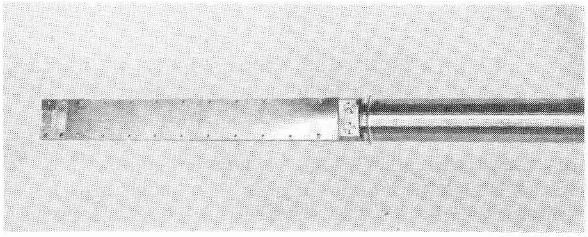

Fig. 12. Experimental stripping target.

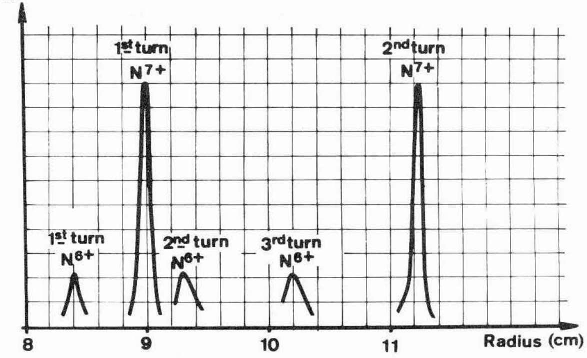

Fig. 13. Radial distribution.