CYCLOTRON CENTER REGION STUDY AND BEAM DIAGNOSTIC AT ORLEANS CYCLOTRON

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Abstract

Orléans' cyclotron is an intermediate energy machine designed to produce α particle up to 50 MeV. The compactness of the machine, its large energy range and the high beam make necessary a good design of the center region. In order to evaluate with accuracy the vertical component of RF field far from the medium plan, a three-dimensions computer program have been etablished to solve the Laplace's equation. Configuration of the center region has been found by optimizing the radial and the vertical motions for three harmonics (2, 3 and 4).

Theoretical and experimental results are reported.

1. Introduction

The Orléans' Cyclotron was designed to produce α particle up to the energy of 50 MeV, for a guaranteed value of 45 MeV. It is an intermediate energy 680-Model cyclotron, taking place between the CGR-MeV high energy 930-Model (Louvain, Belgium and NIRS,Japan) and the compact 520-Model (Orsay, France; Liège and Gand, Belgium).

The two-dees conception was taken from the high energy model but the dee angle is 60° instead of 90°. This choice, despite of the small gap of the electro-magnet, on one hand, leads to a small value of the dee capacitance, ensuring a good shunt impedance of the RF cavities and, on the other hand, make possible the use of high radio-frequency and thence of RF cavities of small size.

The use of three harmonics (2, 3 and 4), as a consequence of the economic consideration, and the assumption to use a single fixed puller with a roughly single orbit for all energy and particle, as a consequence of the desire of simplicity, make necessary a precise design of the center region.

For high current production purpose, beam, at least at the center region, is allowed to occupy the whole dee clearance (28 mm). The effects of vertical electric field must be then taken into account with a good accuracy. The classical processus used in the past consisting in electric field mapping on the median plan followed by field derivation outside this plan, is juged unadequate. A three-dimensions REVOL-program has been established to solve the Laplace's equation in the volume, and the search of the optimal geometry of the center region has been achieved, by considering the behaviour of the radial motion, the vertical motion and the phase acceptance for the three harmonics, using the CENTRE-program.

2. General considerations

The parameters available to ensure simultaneously the orbit centering and a good vertical motion, for a large RF phase range, are the following :

- the initial phase of particle leaving the ion source,
- the transit time factor of each accelerating gap,
- the crossing phase of particle through these gaps,
- and the vertical geometries of the dees and counter-dees at the central region.

Unhappily, in most cases, where the facing edges of dee and counter-dee are parallel, the transit time factor and the vertical focusing are depending strongly each other. In our case, to ensure the success of the design, we must get rid of this contraint in giving to the puller, the dee and the counter-dee extremities unusual geometries.

To suppress the vertical component of RF field at the entrance of the second gap the puller has a special geometry and in the 3rd and 4th gaps posts are used to hide the horizontal edges of the counter-dees from electric field.

The first orbits are centered by balancing the effect of phase value of particle accross the 3rd and 4th gaps and the effect of transit time, chiefly in the 2nd. Gaps are considered two by two, choosing as criteria, for each pair, the minimum of $\partial W/\partial \emptyset$, W and $\emptyset$ being respectively energy and phase, and equal energy gain by half turn .

At the meantime vertical motions are considered.

Optimization is performed by iterration, in modifying the geometries step by step, field distribution being determined by solving the LAPLACE equation at each step. Orbit calculation is treated using a separate program, taking into account the calculated electric field and the measured magnetic field.

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3. Computer programs

3.1 REVOL-Program

This program solves the three-dimensions Laplace's equation by relaxation method using an UNIVAC 1110. As the number of points required to represent a realistic cyclotron center is estimated about 50,000, and the accuracy of the potentials obtained is wanted better than 10^{-3}, our main attention was to minimize the number of memories, and to limit the relaxation time. The bounderies are chosen confounded with resolution nods. The surrelaxation coefficient, between 1.8 to 1.85, and the relaxation number, between 50 to 100, following the number of meshes, are fixed in advance : as a large number of cases is to be considered, the correct figures are obtained for the firstly tried geometry and applied to the others. To save memories, conductor contours are specified only by their potentials + 1 or - 1. To accelerate relaxation process certain bounderies, particularly those which are far from accelerating gaps, are fixed arbitrarely, with set potentials satisfying the integral of field.

Typically, one case is treated in about 1 minute.

3.2 CENTRE-program

Orbits are calculated from potentials given by REVOL, taking into account magnetic field measured in the median plan. As for REVOL, CENTRE has been concieved with emphasis on economy of time and memories. Calculations are done in investigating successive areas of space, liberating the corresponding memories each time an area is treated.

Typically, 10 sec are necessary to treat 10 particles during two first turns.

4. Theoretical results

Obviously, the case of harmonic 4 is the most difficult to handle. For this reason this harmonic has been considered at first. It has appeared necessary to solve the vertical motion problem at the first beginning, in minimizing the effects of the vertical component of the accelerating field by choosing an appropriate vertical geometry, before solving the orbit centering problem. Figure 1 represents a typical result showing energy gain of gaps taken two by two as a function of initial phase. The condition $\partial W / \partial \emptyset$ is fulfilled fairly in a large phase range. Energy gain in the first orbit, curves (1 + 2) and (3 + 4), is well distributed between the two dees. The first half of the second turn undergoes a slightly smaller acceleration than the second half, due to the transit time effect which becomes negligible since the third turn.

Figures 2 to 7 show final results obtained for three considered harmonics. Figures 2 and 3 show respectively the radial motion and the vertical one for harmonic 2. The parameter Ø is the initial phase of particle at the ion source. Figures 4 and 5 correspond to harmonic 3 and figures 6 and 7 to harmonic 4.

One can see that the single orbit assumption is correctely fulfilled and the vertical behaviour of particles is quite satisfactory, in a large phase range and for three harmonics.

4. Beam diagnostic

4.1 Test facilities

Beam diagnostic is performed with the aid of :

- 1 remotecontrolled main probe situated at 180° from the electrostatique deflector and roughly 120° from the ion source, for the measurement of internal current and of its density, from the first turn to the extraction radius. When desired, a special head can be mounted for the vertical control.

- 1 remotecontrolled extraction probe, situated at the exit of the electrostatic deflector, for the measurement of extracted beam size and current.

- 1 defining slit, situated at 120° angle from the ion source, which can be used also for beam size measurement at the first turn, by the shadow method.

- 1 movable post situated approximately at the same radius as the ion source for the measurement of beam size and position of the five first turns by the shadow method.

4.2 Beam tunning

The first step consists in centering the first turn according to the theoretical result, in fixing three calculated positions by adjusting the dees voltages. The positions of the other turns are then verified at two angles using the main differential probe and the movable post. Beam is brought until the extraction radius by trim coils current tuning. The turn pattern may show compression or depression, resulting either from radial oscillations or from phase oscillations. Sometimes the radial oscillations can be identified easely by off-centering the ions source, particularly when phase diagram is correct, and by observing the periodicity of theses oscillations.

In order to verify the correct tuning of trim coils, phase diagram is plotted by a method used currently consisting in recording the radius where beam is lost as a function of magnetic field or radio frequency deviation. To obtain a correct accuracy, beam are previously selected by means of a defining slit (1 mm). A typical phase diagram obtained is shown by the solid curves of figure 8 corresponding to an uncorrect trimming between 10 to 20 cm. This mistuning can be assertained by the orbit compression observed between 20 to 30 cm. The correct setting of trim coils current can be performed then easely without aid of computer. The dashed line curves show phase diagram for a whole beam (without defining slit) when tuning is judged satisfactory. Figure 9 shows the corresponding record of the orbit pattern. Orbit compression observed at about 55 cm corresponds to the phase lag (see figure 8) which is in fact necessary for a correct extraction.

The high pic observed at the end of the record is the effect of the extraction field produced by the harmonic coils : the differential probe being at 180° angle from the electrostatic deflector, the required high spacing of orbits at the extraction angle causes indeed a compression at opposite angle.

5. Conclusion

The theoretical predictions concerning beam positions are fairly verifyed by the experimental investigations. The quality of the center region is demontrated by the low beam loss. For proton and deuteron, typically, less than half of the current is lost between the first and a few following turns, for α particle, losses never exceed the two thirds.

Up to now, somes of guaranteed performances are already met or exceeded. Following are somes typical results :

	Energy	Extracted current
α particle	50 MeV	36 μA
	35 MeV	20 μA
	20 MeV	11 μA
Deuteron	25 MeV	80 μA
	10 MeV	62 μA
Proton	25 MeV	20 μA
	15 MeV	100 μA
	10 MeV	50 μA
	5 MeV	30 μA

The maximum proton energy guaranteed (38 MeV) is not yet achieved. Presentely the limitation comes from the too high deflecting voltage required, due to a not very happy choice of the septum curvature. The septum is now redesigned and beam test will take place again this fall. The acceptance protocole is forseen for the end of this year.

Another machine of this type is now under construction and will be installed at Tohoku University, Sendai, Japan. RF system is boosted, to rise proton energy up to 40 MeV.

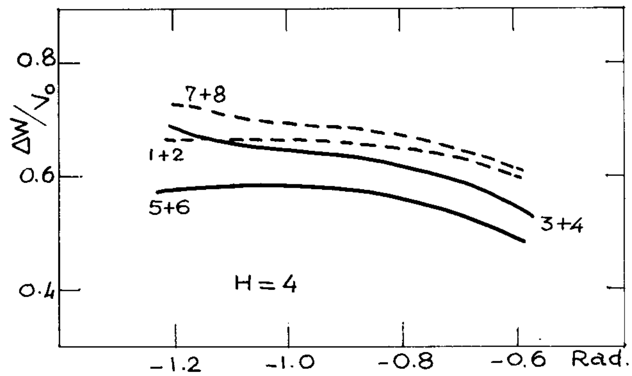

Figure 1 - Transit Time effect of Accelerating Gaps

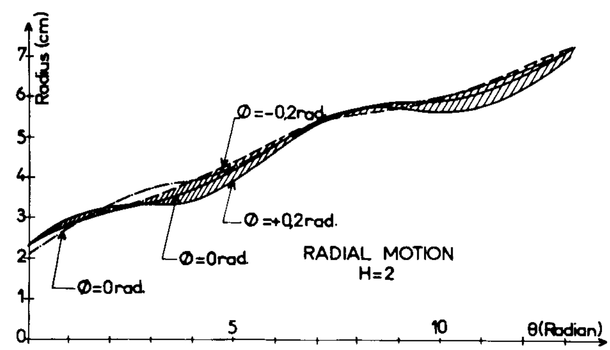

Figure 2 - Radial Motion H = 2

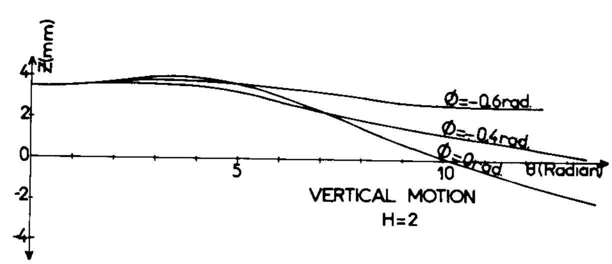

Figure 3 - Vertical Motion H = 2

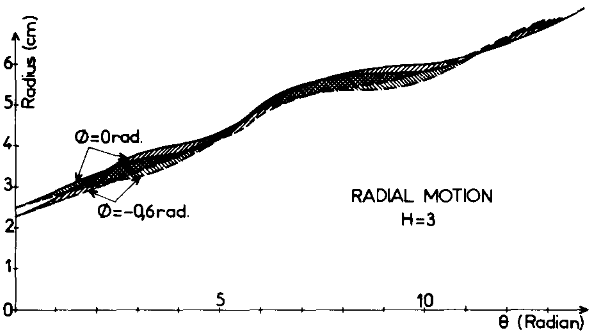

Figure 4 - Radial Motion H = 3

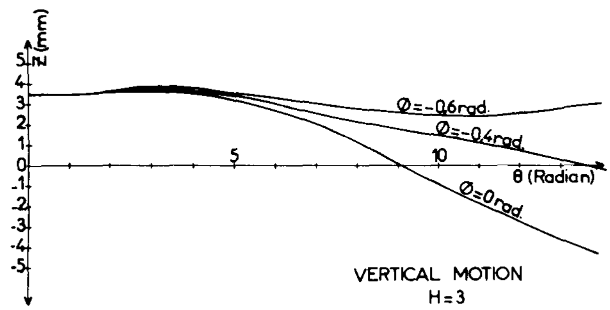

Figure 5 - Vertical Motion H = 3

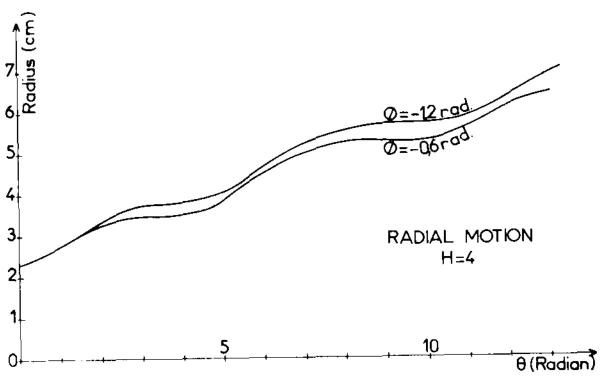

Figure 6 - Radial Motion H = 4

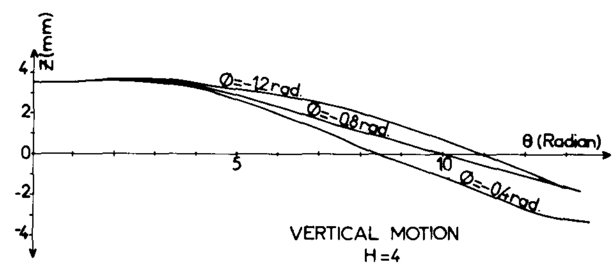

Figure 7 - Vertical Motion H = 4

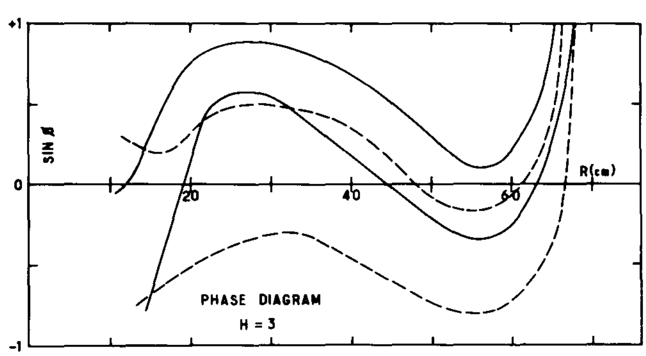

Figure 8 - Phase diagrams. Solids curves : wrong trimming, with 1 mm slit. Dashed lines : correct trimming, no slit.

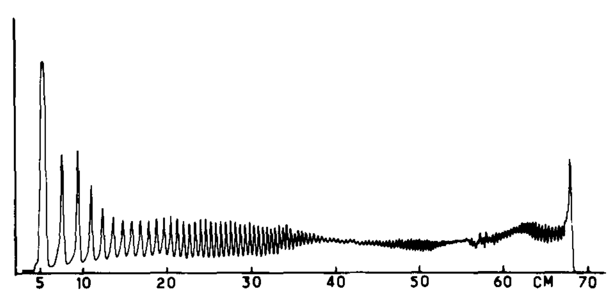

Figure 9 - Orbit pattern H = 3