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DESIGN OF INJECTION, EXTRACTION AND MAGNETIC FIELDS IN S A R A

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Abstract. - Beam transfer between the two cyclotrons has been designed to achieve good emittance and achromatism matching. Unwanted ions are cleaned out of the beam with a 90° magnet. Two magnets, one magnetic channel and an electrostatic deflector allow the injection of the beam along a variable radius (8 %) onto the second cyclotron. Magnetic measurements of the four sectors, separately, was performed and isochronism nearly achieved for 32 MeV/A, without coils but using a machined radial shim. Magnetic defects due to injection elements are being compensated.

I.-Introduction. - The project of a post-accelerator for the I.S.N. Grenoble has been described in previous as well as in present conferences. Heavy ions are accelerated in two stages and the second stage is under construction.

2 . - Beam transfer. - The second cyclotron is being installed on a space available close to the first cyclotron built in 1964.

Emittances measured at the first cyclotron exit are large (Horizontally : 16 ¶mm mrad, vertically 18¶). The emittance shapes are independant of energy and ion species . For the injection into the second cyclotron, these emittances must be quite the "eigen-ellipses" of the machine periodical structure. The beam transfer is 24 meter long.

The ions are stripped at 90° magnet so that the charges are selected and the rigidity is measured. A double waist allows a lower "straggling".

We assume the transfer achromatism when the orbit injection radius with the energy is matched.

Beam transfer calculations are separated into three parts :

- 1st : quadrupoles and magnets at the first cyclotron exit
- 2nd : straight beam guiding
- 3rd : quadrupoles and magnets at the second cyclotron injection.

The ratio between an image width and the value of the dispersion is a constant when there are no magnets (i.e. for transfer matrices we get $m_{11}/m_{16} \equiv Ct$).

The first and the third parts with magnets have been designed for having the same m_{11}/m_{16} value which will be used in the second part. In this second part, we have to match the useful magnification and the value of angular dispersion (m_{26}).

It has been impossible to assume the transfer isochronism : the maximum burst width spread is 24° RF of the second cyclotron when $\delta p/p = \pm 0.15\%$.

Unfortunately, all these settings are dependant because of the small number of optic elements.

3.-Calculation methods for injection and extraction

Methods are similar for both :

One looks for the accelerated particle orbit, without oscillation and passing by the accelerator entrance or exit. This orbit will be the central one. One uses "ANJO" [1] code with maps of magnetic field.

One looks for the extension of this central orbit through injection or extraction system (electric inflector inside the magnetic field, magnetic channel, magnets...). Finally, one obtains the central trajectory to satisfy beam and design conditions.

One uses "TRAJ 30" [2] code that gives also the transfer matrixes.

After, one computes the other trajectories using this "central trajectory". Usually, one uses phase space (R, p_R or X, X') at the injector exit or extractor entrance.

One draws in this phase space the electrods and diaphragm shadows that the beam could meet and the emittances calculated for each turn [3].

One must get as less shadows as possible upon these emittances. By iterations, one has to obtain the smallest shadows fitting septum and magnet shapes and locations.

4.- Injection

The center lay-out is found figure 1 : 2 compact and fixed magnets (di6 and di8) get the beam close to the first accelerated turn, "di9" magnetic channel (fig 2) followed by the "edi" electrostatic inflector which adjust the first orbit positioning.

The "edi" inflector and "di9" channel have to be adjusted radially so that it could realize the two machine isochronism.

The mean injection radius must be the same as the mean extraction radius of the first cyclotron. But this one changes with the magnetic field level of the first cyclotron.

The energy, measured in the beam transfer, and the RF frequency, allow us to know the value of this mean radius. Then, the Δ adjustment principle of this injection mean radius shown on figure 3 is obtained by convenient intensities of the central magnets (di6 with 42.8° ± 0.8° and di8 with 43.7 ± 3.6°), by "di9" channel rotation and by edi translation (Δ= ± 21 mm).

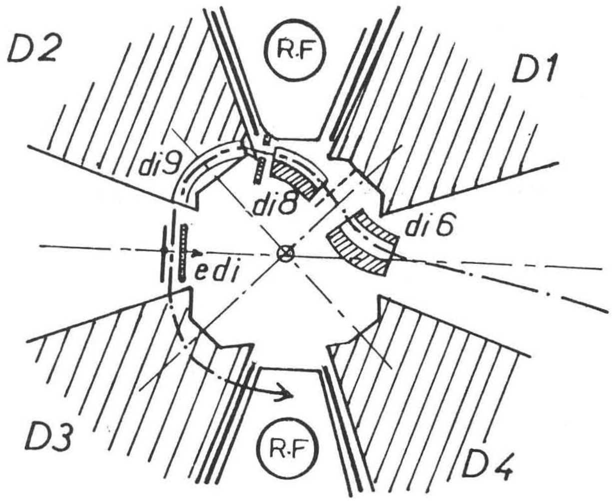

Figure 1 : lay-out of center

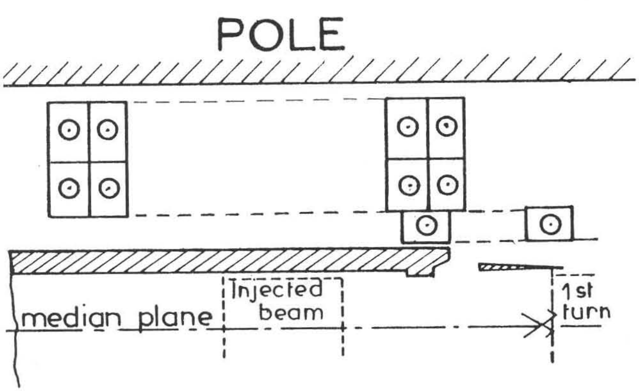

Figure 2 : /di9/ cross section

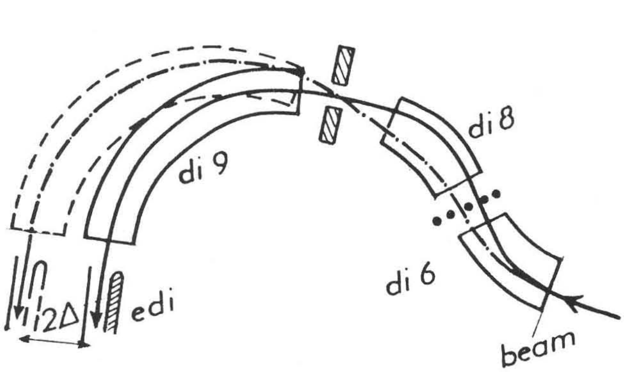

Figure 3 : Adjustment principle of injection radius

Inside edi inflector the trajectory shape does not change more than a few 1/10 mm according to its position and magnetic field level.

Radius gain per turn is only 6 mm when magnetic field first harmonic is not used. With flat-topping, we accept to use such harmonic : then the inflector position and angle must be changed because the accelerated beam is oscillating (figure 4).

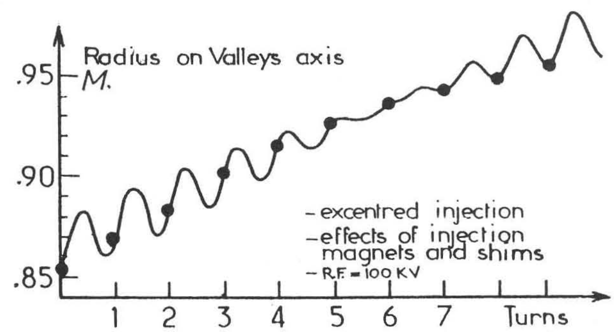

Figure 4 : orbit oscillations with 1st harmonic

5.- Extraction Inside a magnetic sector gap the "ede" electrostatic inflector allows the extraction to be done sharply. This inflector is not able to maintain an electric field larger than 45 KV/cm. This inflector 1.2 m long is bent. The relative beam position spread is not over 0.5 mm according to different uses of the post accelerator. Nevertheless, the high voltage inflector is compounded of three high voltage plates and the exit is radially movable.

Without flat-topping, the beam needs three turns to be extracted : we must avoid the production of oscillations by beam mismatching and centering error : depending on the RF phases a continuous beam is cut by the septum 0.2 mm width. The figure 5 indicates the extraction for one RF phase. The extraction efficiency seems better than 90 % but energy spread is as poor as ∿ ±0.65 %.

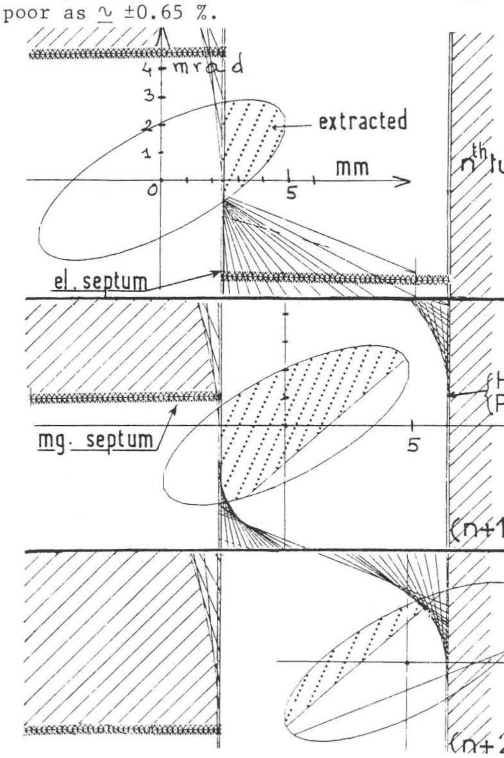

Figure 5
Three turn extraction

The "ede" inflector is immediately followed by the "del" septum magnets. Four quadrupoles and steering magnets assume the beam matching for the previously first cyclotron beam handling.

6.- Magnetic field measurement

During the first year 1979, only one magnet was available for test, the three others only just ordered, were to arrive by the end of 1980. This point mainly fixes up our mind to use a very simple measuring arm operating in polar coordinates centered on the machine axis. Hall probes chosen mainly for historical reasons drive us to the calibration of 27 probes with high accuracy. Also measuring each magnet separately gives us enough time to test the central slot shimming process.

a) measuring device

The rotation around the machine axis was measured by an optical coder having a precision of ± 0.001 degree (± 1 digit). The arm supports the 27 probes, but measuring the field between 0.708m and 1.628 was performed in three rings of 0.520m using a 0.02m probe spacing. Azimuthal steps of 1° was a good compromise between precision needed for integral calculation and time spent on having a map (78 x 95) 47° apart from the vertical symmetry plane of the magnet. An "air cushion" supports the arm on a track to help keeping the measurements being performed on the median plane (horizontal symmetry plane) at ± 1 mm.

The whole system is controlled by a small PDP 8. Data is stored on a tape.

b) shimming process

We first measured the magnet with flat poles, the central slot fed with a flat iron, 0 shim . The map obtained is used to have a first approximation of the central shim profile, which is machined at a depth 80 % of the calculated value. Shim 1 is then measured. 4 iterations were needed to obtain isochronous field along the radius. The mutual influence of magnets was taking into account using a semi empirical function.

Shim profile is approximated by .2 mm steps of variable length.

This process was used for the two first magnets, for the others we measured only the magnet with flat poles and then verify that shim 4 gave the same mean field profile along radius (figure 6).

Two main problems related to the shimming method were encountered. We were not able to calculate the correct depth of the slot in one iteration, the efficiency being a function of the depth. The variation of the field on the plateau of each magnet (- 2 to - 3 KG at 14 KG) at slot makes the calculation of trajectories to shim the magnet a necessity.

The other problem was the calibration of the 27 hall probes, in which we do not succedd to better than 5×10^{-4}

Measuring the field of the 4 magnets separately was the quickest way to adjust the mean field for isochronism at 32 MeV/A for q/m = 0.5. For injection, ejection problems a map of the four magnets "in situ" is to be done on the following months.

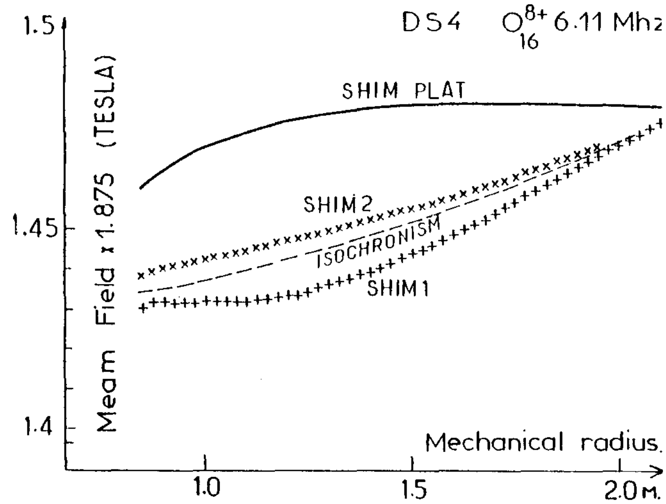

Figure 6 : mean field profiles along radius

REFERENCES

[1]) "ANJO" - G.A.N.I.L.

[2]) "TRAJ 30" - J. FERME - G.A.N.I.L.

[3]) "OMBRE" - J. CHAUVIN - I.S.N. GRENOBLE