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REGENERATIVE BEAM EXTRACTION ON THE BUENOS AIRES SYNCHROCYCLOTRON

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The nonlinear regenerative theory was applied to the extraction of the deuteron beam of the Buenos Aires 30 MeV synchrocyclotron. The theory of LeCouteur proved successful even though the approximation of the $n(r)$curve with two straight lines gives an n-value for the extraction radius very different from the actual one for that radius. A regenerator field of the form $T = 0.05\,\rho + 0.11\,\rho^2$ produced a radial gain up to 1.5 cm. An electrostatic channel extended over a 30° arc with a 80 kV/cm field deflected the beam 3 cm out. A magnetic channel following the electrostatic one brought the beam out from the cyclotron vacuum chamber. A fraction of 2–3% of the internal beam could be removed by such an arrangement.

1. Introduction

From previous work at Liverpool[1]) and Chicago[2]) it would appear possible to remove a considerable fraction of the circulating beam from the synchrocyclotron in this Commission and make it available for experimental purposes in the form of a well collimated beam. The nonlinear regenerative theory[3]) was applied to this particular machine giving a regenerative field

$$T = 0.05\rho + 0.11\rho^2 \qquad (\rho \text{ positive and measured in cm})$$

where

$$T = \frac{r}{H}\int_0^{2\pi} \varDelta H \, \mathrm{d}\theta \,.$$

This was the best regenerator compatible with the magnetic and geometrical machine data, fig. 1. However it was felt that this field would not give the necessary regenerative action, based as it was on an approximate n-value rather different from the actual one. It would be more reasonable to take an average n-value determined by considering the radial amplitudes of the particle motion on the inside of the starting radius for the regenerative action. Two reasonable possibilities were $n = 0.06$ and $n = 0.1$, and with these the corresponding regenerator fields were calculated, namely $T = 0.25\rho + 0.03\rho^2$ and $T = 0.35\rho + 0.04\rho^2$. These regenerators were built and tested but no evidence of regenerative action was observed. So it was decided to take the theory exactly as it is and

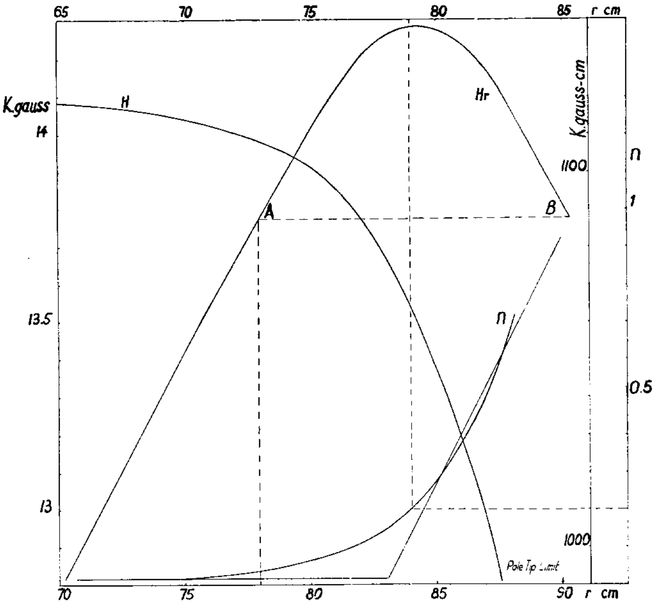

Fig. 1. Cyclotron magnetic data. The upper scale is for n; the lower one is for H and Hr.

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[1]) A. V. Crewe and J. W. G. Gregory, Proc. Roy. Soc. A **232** (1955) 242.

[2]) A. V. Crewe and U. E. Kruse, Rev. Sci. Inst. **27** (1956) 5.

[3]) K. J. LeCouteur and S. Lipton, Phil. Mag. **46** (1955) 1265.

the abovementioned field was adopted; a radial gain up to 1.5 cm was measured at 40° phase from the regenerator.

In order to improve the extraction efficiency an electrostatic channel was installed as a first stage for a magnetic one thus getting a 2–3% fraction of the circulating beam out of the machine.

2. Construction of the Regenerator

The regenerator was built with Armco iron sheets 8.75 mm thick piled up forming blocks 35 mm thick, 40 mm wide and 190 mm long held in a brass frame. The system could be moved from the outside by means of a screw. A pair of shims attached to the brass support was enough to correct the field just in front of the blocks. Fig. 2 is a view of the regenerator assembly.

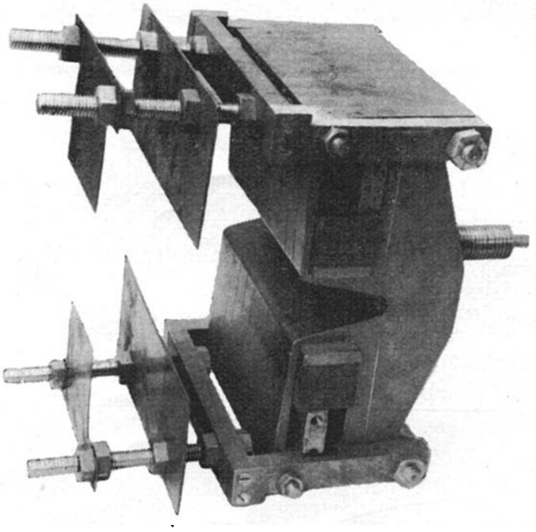

Fig. 2. Regenerator assembly.

The measuring equipment for the magnetic field was an electronic fluxmeter and a search coil which could be moved with uniform motion both radially and azimuthally. Fig. 3 is a block diagram of the fluxmeter: A is a dc Liston Mod. 10 linear amplifier with variable gain; I is an integrator of conventional design and R is a Philips PR 2000M/00 graphical recorder.

The magnetic field of the cyclotron was measured with a Varian nuclear fluxmeter with an accuracy of 1:10 000[4]) in order to provide a standard field to calibrate the electronic fluxmeter. This was done by moving the search coil radially and comparing the deflection on the pen recorder with nuclear fluxmeter data. A sensibility was thus obtained of 4 gauss per mm on the recording paper.

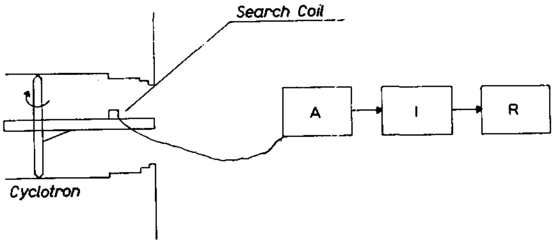

Fig. 3. Block diagram of the fluxmeter.

A synchronous motor produced the azimuthal movement at a constant angular speed of 1 rad/min. The search coil was thus made to sweep the median plane of the magnet over an angle of 90° at different radii in steps of 1 cm. The value of the field defect $\int \Delta H d\theta$ as a function

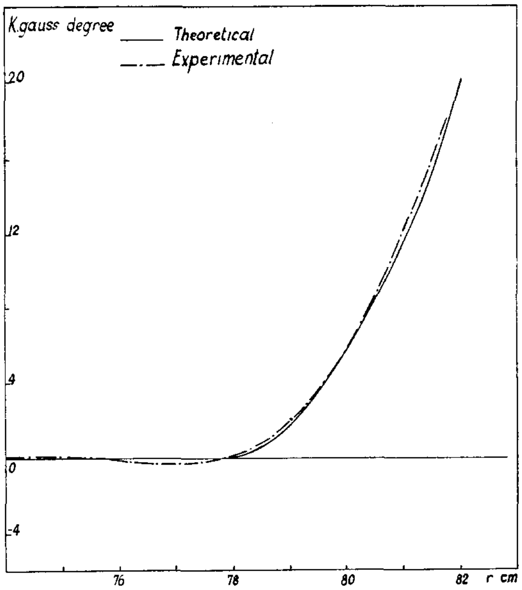

Fig. 4. Regenerator field as a function of radius.

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[4]) This was done up to a 100 gauss/cm gradient, but the whole cyclotron magnet was measured with the electronic fluxmeter.

of radius in the machine was obtained by a step-wise integration. The shims were designed according to the shape of the perturbation desired.

Fig. 4 shows the final regenerator field obtained and the theoretically desired one. The differences are within 200–300 gauss-degrees, which is the limit of the measuring apparatus.

3. Test of Regenerative Action

The regenerator action was studied by means of a special target showed in fig. 5. It consists of two insulated copper plates, a collector and a detector, used to measure radial gain and relative intensity of the deflected beam fraction.

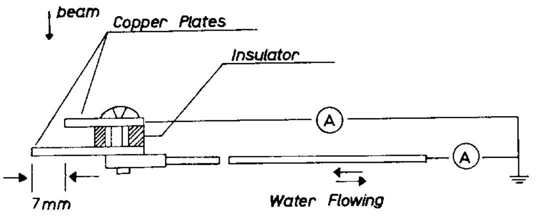

Fig. 5. Probe used to test regenerative action.

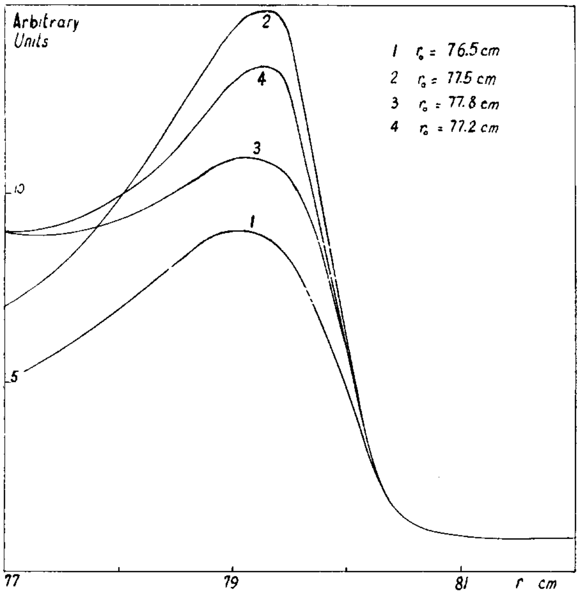

Fig. 6. Detector current versus radius for different radial position of the regenerator.

Fig. 6 is a plot of the detector current as a function of radius when the regenerator is at different radial positions. It is seen that a 10–20% fraction of the beam can be expected to enter the channel mouth, since the distance between the edges of the collector and detector in the target is 7 mm. It appears that the regenerative action starts between 77 and 77.5 cm, whereas the $n = 0.2$ point is at 79 cm radius. The autoradiographic method showed a radial gain up to 1.5 cm.

The conclusion was that a reasonable extraction efficiency can be expected under a 40° phase, with the field $T = 0.05\rho + 0.11\rho^2$ (ρ measured in cm). Considering fig. 1 it is quite astonishing that LeCouteur two straight lines approximation is the one that works for this machine. It seems that it is the best to represent the asymptotic behaviour; or may be the errors thus introduced provide a compensation to some others inherent to the theory.

4. The Electrostatic Channel

From LeCouteur approximation it was seen that the maximum radial gain obtainable in this particular machine would be of the order of 1 cm; so it was impossible to introduce a magnetic wall due to the 1 cm wide region near the wall in which the field perturbation cannot be corrected. It was decided then to use as a first section of the channel an electrostatic one which would deflect the beam over 3 cm, this distance being considered the minimum in order to continue the channel with magnetic sections, far more simple to handle.

Actually, two curved parallel plates were built with an electrostatic field of 80 kV/cm between them, equivalent to a magnetic channel with a field defect of 1.5 kG. The inner (grounded) wall is a 1 mm thick molybdenum plate held in position by a water-cooled copper frame; the outer one is a 10 mm thick oil-cooled copper plate.

The electrostatic channel was mounted on a base plate which could be moved from the outside of the accelerating chamber so that the best position could be adjusted with the circulating beam without destroying the vacuum.

5. The Magnetic Channel

The magnetic channel was installed following the electrostatic one; it consisted of three straight vertical sections made of Armco iron, the dimensions of which are given in table 1.

TABLE 1

Magnetic channel dimensions

Section	Wall thickness	Wall height	Channel width	Length	Wall material
1	10 mm	80 mm	10 mm	100 mm	Armco iron
2	17 mm	80 mm	15 mm	100 mm	Armco iron
3	17 mm	80 mm	15 mm	170 mm	Armco iron

They were aligned by the wire technique adjusting the tension and current in the wire to simulate 30 MeV deuterons.

The shims were designed by installing first each channel section independently normal to a radius of the cyclotron magnet and measuring the field reduction. When the channel sections were set in their correct position a new field correction was needed since they were far from being normal to a radius. Fig. 7 shows a view of the magnetic channel with shims.

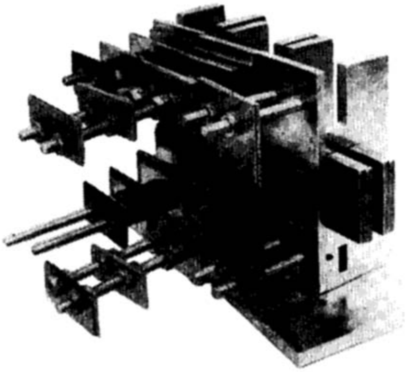

Fig. 7. Magnetic channel.

6. Assembly of the whole Extraction System and Final Tests

Once the shimming was finished, the orbit centers were determined by floating a wire loop at different radii up to 77 cm. It was found that magnetic centres were enclosed in a 4 cm diameter circle around the geometrical magnet center. This was considered good enough and the whole system was tested with the beam. An insulated copper target was installed at the end of the magnetic channel and a current of deuterons about 2–3 % of the internal current[5]) was measured with a microammeter. The energy of the beam was estimated from magnetic data as being 29 MeV.

The beam was let out of the vacuum chamber through the airlock for the ion source. Since in this region the disperse magnetic field is 9 kG, the beam is bended over an angle of about 15°, just the amount needed in order to reduce direct cyclotron radiations on the experimental room.

Photographs of the external beam were taken inside the ion source airlock by exposing photographic paper wrapped in aluminium foil. It appears that the beam is well focussed horizontally but has a rather large vertical size.

Focussing of the external beam will be made by quadrupole lenses in order to have a good spot 7 m away from the machine at the experimental room.

We would like to express here our thanks to Dr. A. V. Crewe for his invaluable help during his visit to our Institute for a six-week period. We wish to thank also the cyclotron crew, particularly Eng, C. Paganini, Mr. J. Garanzini and Mr. V. S. Tejero for their kind assistance.

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[5]) The maximum internal current attained was 30 μA.