THE EXTRACTION SYSTEM OF THE IMPROVED CERN SYNCHROCYCLOTRON

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Abstract

The characteristics and performance of the various options of the CERN SC extraction system are discussed.

1. General Layout and Technical Description

The basic aim of the new regenerative extraction system[1] was to increase the extraction efficiency from about 5% to about 75%. This has been achieved mainly by improving the quality of the internal beam[2], and by the provision of a new extraction channel. This consists of a 3 mm current septum carrying 12 kA (Fig. 1, pos.4), forming part of a coaxial coil (Fig. 2)[3] such that the disturbances to the machine field are negligible.
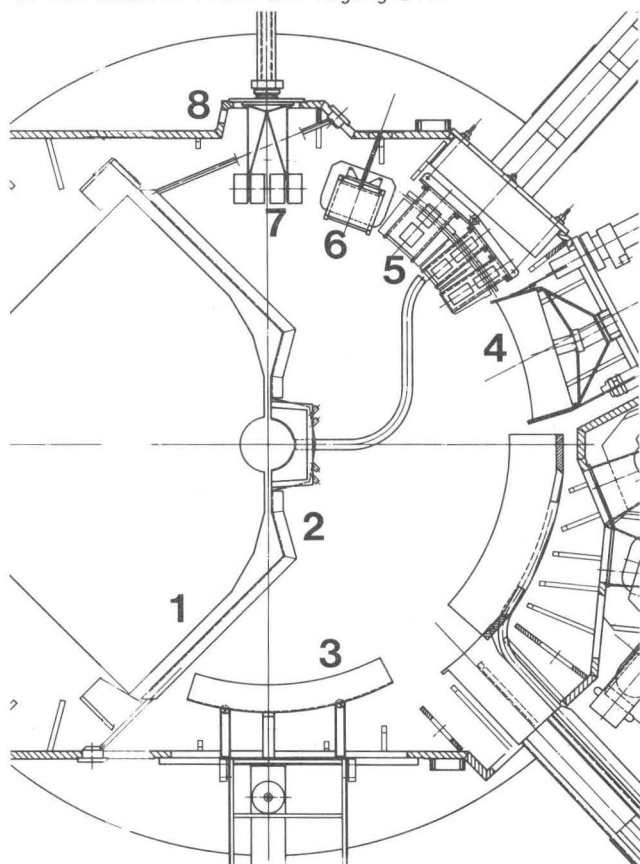

Fig. 1   General Layout of the Extraction System

The septum thickness is responsible for a beam loss of about 15%. The coaxial structure consists of a set of 10 inner and 20 outer conductors. To counteract the forces due to the high external magnetic field, the structure is embedded in radiation resistant concrete enclosed in a stainless steel box.

The whole arrangement (Fig. 3) with its 100 kW power supply is mounted on a 60 ton screening chariot. The septum is followed by 3 iron sections (Fig. 1, pos.5) of conventional type with shim bars reducing the stray field.
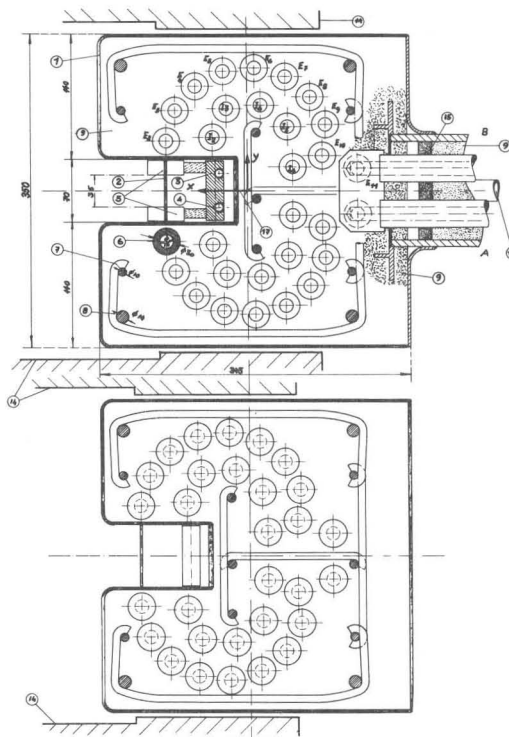

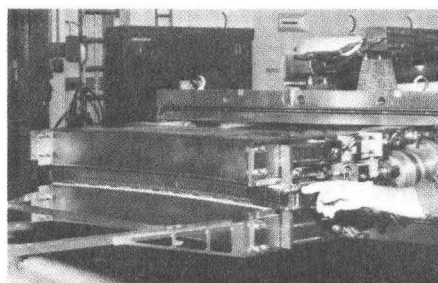Fig. 2   Cross-section of the Coaxial Coil

Fig. 3   Electromagnetic Channel

A further feature of the new machine is the possibility of extracting a long burst beam without RF structure by slowly displacing a stacked beam into the regenerator (Fig. 1, pos.6) with a pulsed field coil[4][5] (Fig. 1, pos. 7 and Fig. 4) having the following characteristics :

Radial position	2.245 m	Number of turns	3 x 2
Radial width	0.2 m	Azimuthal length	0.5 m
Aperture	0.12 m	Inductance	10 μH
Resistance	10 mΩ	Central field 115	G.m/1000A

Fig. 4 Pulsed Field Coil

Fig. 5 Azimuthal Field Integral of the Regenerator versus Radius
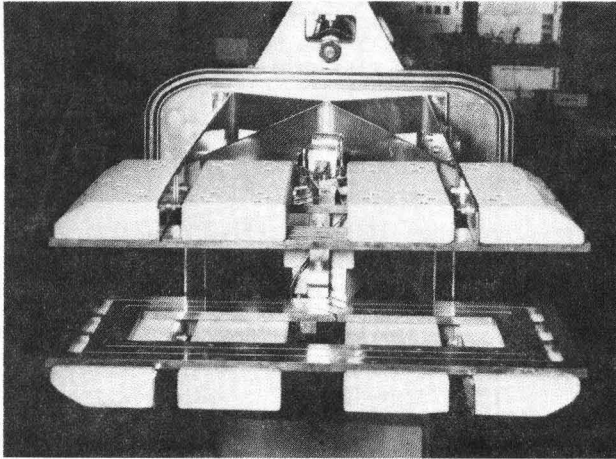
2. Regenerative Extraction

2.1 Theoretical studies

2.1.1 <u>Extraction with acceleration</u> A new regenerator (Fig. 1, pos. 6) adapted to the improved radial quality (about 1 cm maximum radial amplitude) has been designed. Its action is given by the field integral shown in Fig. 5. The resulting motion in the radial phase space at the channel entrance for three different radial amplitudes is shown in Fig. 6. The turn separation exceeds 2 cm and the average slope of the beam is about 28 mrad.

2.1.2 <u>Extraction with the pulsed field coil(PFC)</u> The idea is to stack the beam at the end of the acceleration programme and to displace it slowly into the regenerator with a biased time-dependant magnetic field. Fig. 7 shows the field value at the axis of the coil necessary to shrink the stable radial phase space area available for a given radial amplitude and energy. The strips on the figure take into account statistical errors in the calculation. However, this dipolar field also modified the slope of the beam at channel entrance. The theoretical value is about 40 mrad (Fig. 8) using zero bias in the coil.

2.2 Experimental results

2.2.1 <u>Short burst</u> The extracted beam intensity was first optimized by moving the electromagnetic channel with its current septum and the regenerator; their relative positions detemine the turn separation, which of course should match the aperture of the channel and the septum thickness. By this optimisation an extraction efficiency of 70 + 5% was found. Then, we have measured the optical properties of the beam entering the channel (essentially the turn separation and slope) with a 12 channel secondary emission chamber.
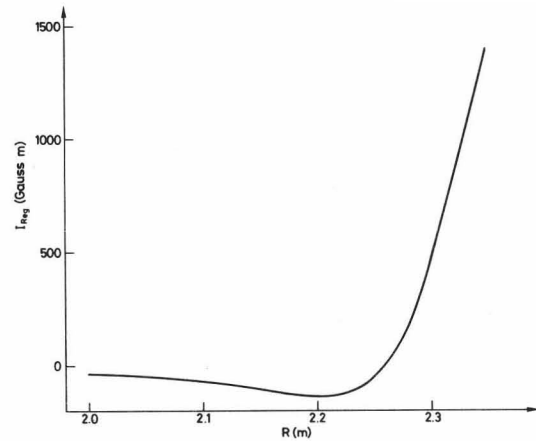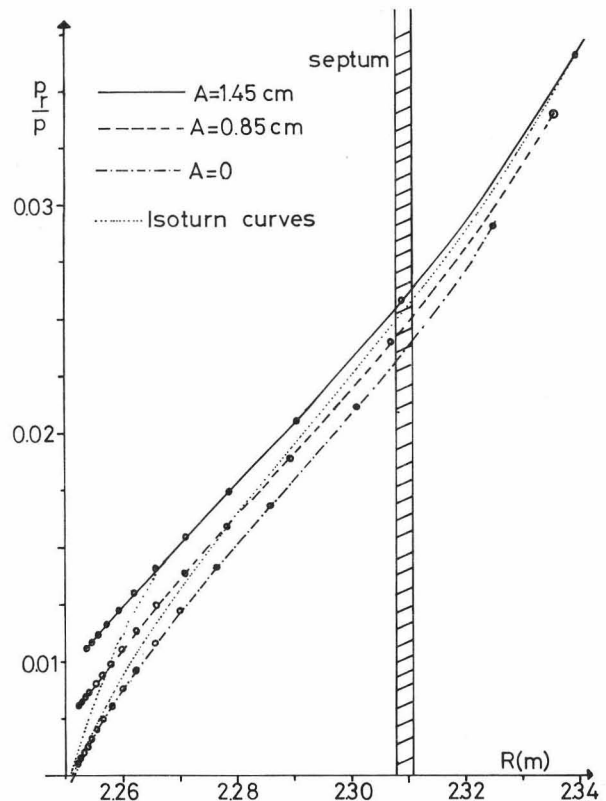

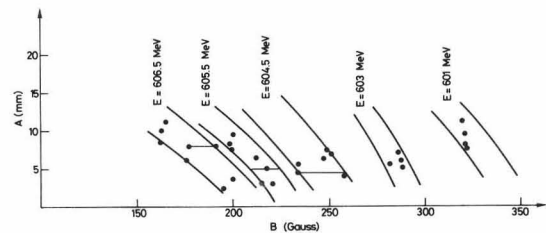Fig. 6 Radial Phase Space at Channel Entrance with Acceleration

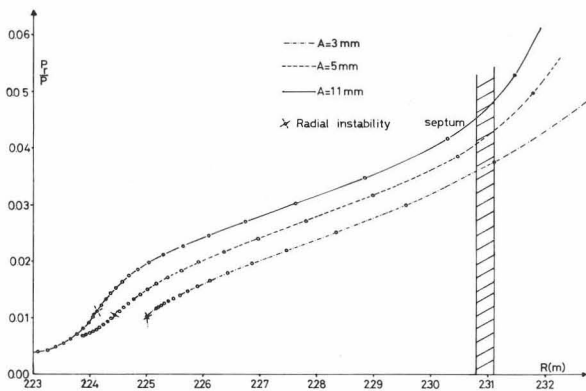Fig. 7 PFC Maximum Field giving Radial Instability

Fig. 8   Radial phase space at channel entrance with the PFC

Fig. 9 shows the outmost beam position at different azimuths before the channel entrance. One deduces the turn separation for the nominal regenerator position, of ΔR = 17.5 mm (theoretical value ΔR = 20 mm).
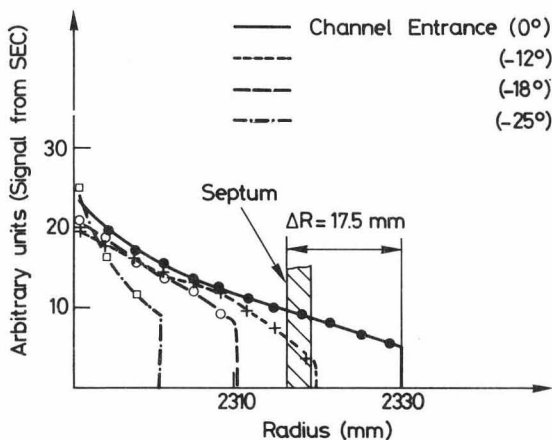

Fig. 9   Integrated signal from the SEC at different azimuths showing the outermost beam position and the mean separation at channel entrance

Fig. 10 shows the radial beam enevelope for two regenerator positions. This gives the slope of the beam at the channel entrance, i.e. ∿ 23 mrad for the nominal position of the regenerator, which is comparable with the theoretical value 28 mrad.
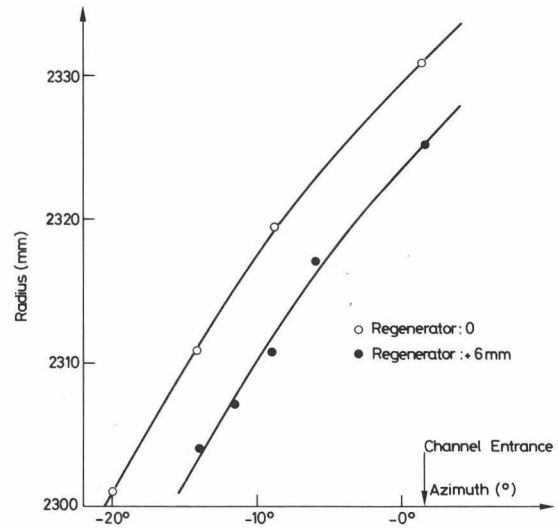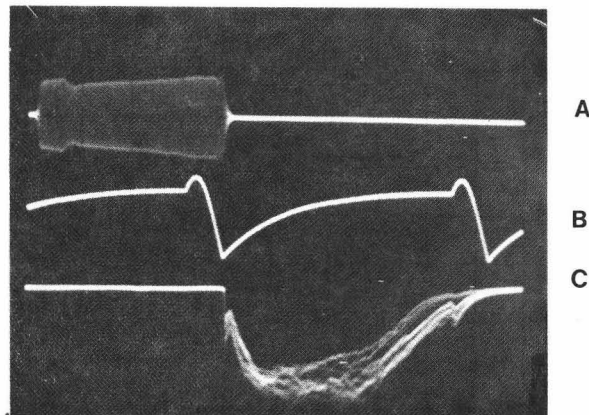
2.2.2   Long burst   Fig. 11 shows

   A   the envelope of the RF programme

   B   the pulsed field coil current

   C   the stretched beam pulse.

This spectrum of the long burst (Fig. 12) shows a continuous signal over about 1200 sec. giving a duty cycle of the order of 60% which is a very good performance for a synchrocyclotron. The maximum field integral required for this spectrum is about 122 G.m in good agreement with the theoretical prescription.

Fig. 10   Slope of the outermost beam position versus azimuth

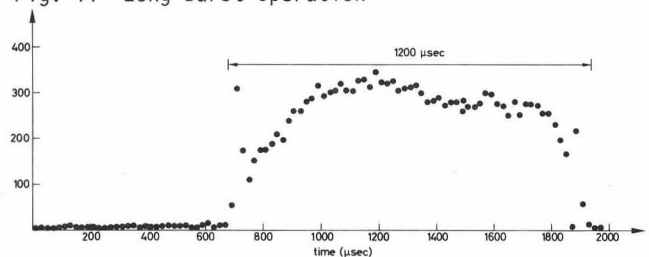Fig. 11   Long Burst Operation

Fig. 12   Spectrum of the stretched Beam

3.   Extraction Channel Dynamics

In order to determine theoretically the extraction channel acceptance and transmission a number of orbits for different energies (defined by numbering on Figs. 13 to 16) were calculated using the measured channel field (Table 1). The orbits were followed from the channel entrance through the vacuum tank window (Fig. 1, pos. 8) up to the first beam lens. The channel acceptance is shown in Fig. 13. The radial and axial emittances calculated in section 2.1 are then used to compute the axial (Fig. 14) and

radial (Figs. 15 and 16) phase space at the channel exit and at the entrance to the first lens. Using Fig. 6 the percentage of beam in a 0.5 cm radial interval may be calculated (Fig. 17) Assuming an uniform particle distribution along the lines on fig. 13 the extraction efficiency becomes 73% for energies of 602.45 $\pm$ 0.7 MeV.

Table 1 : Extraction Channel Characteristics

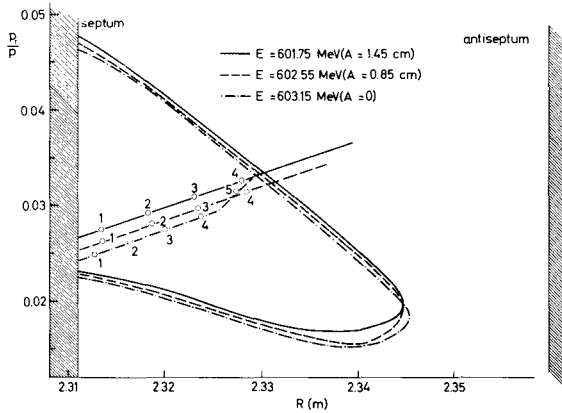|	Mean Radial gradient (G/cm)	Field reduction (G)
Electromagnetic channel	– 4	2000
Section 1	619	1490
Iron channel Section 2	324	3120
Section 3	778	3450

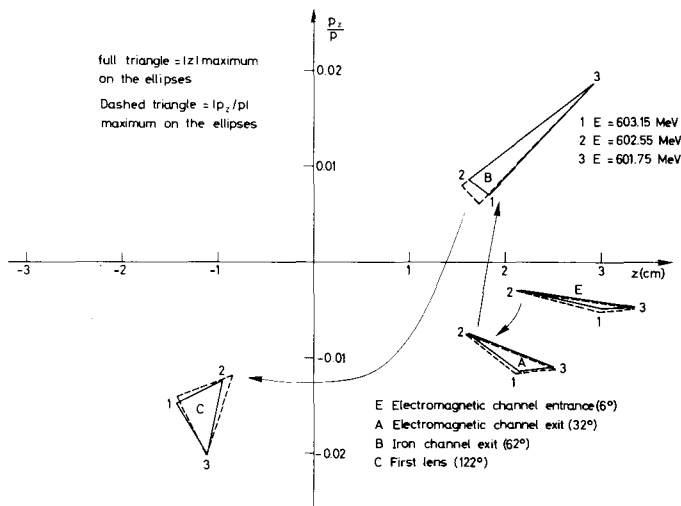Fig. 13 Radial Emittance at Channel Entrance and Extraction System Acceptance

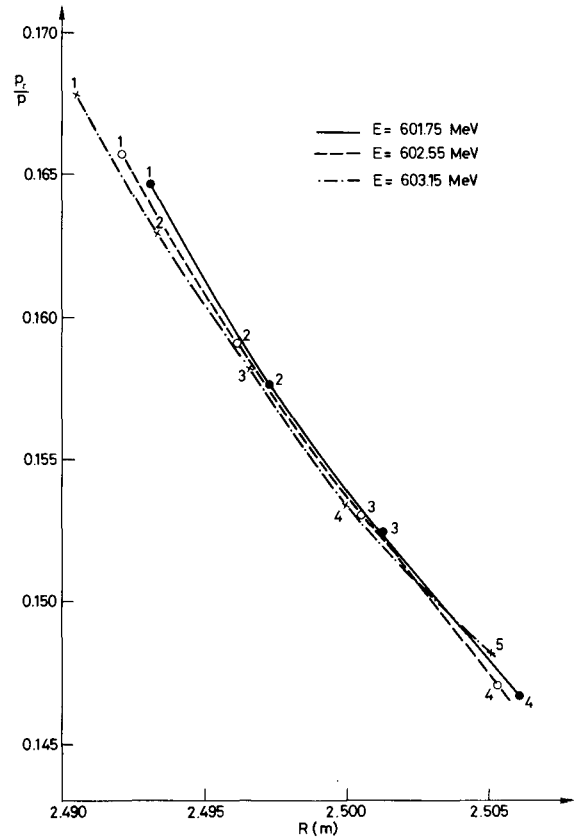Fig. 14 Vertical Phase space During Extraction at various Azimuths
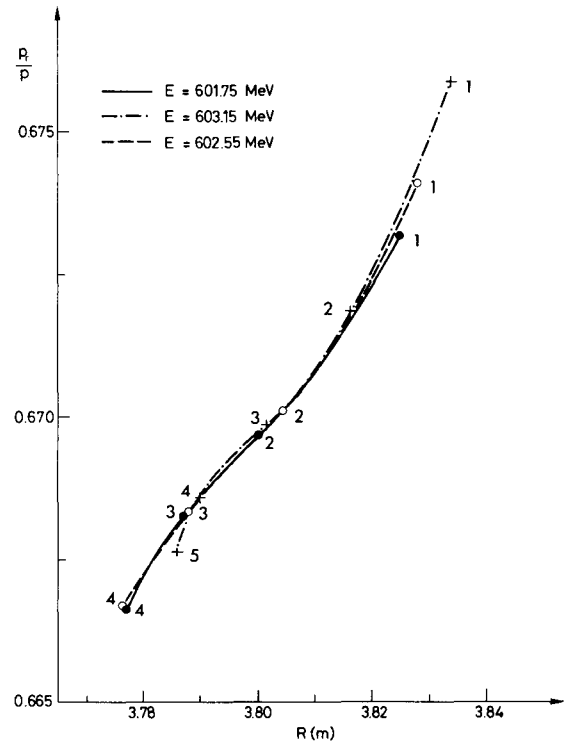

Fig. 15 Radial Phase Space at Channel Exit

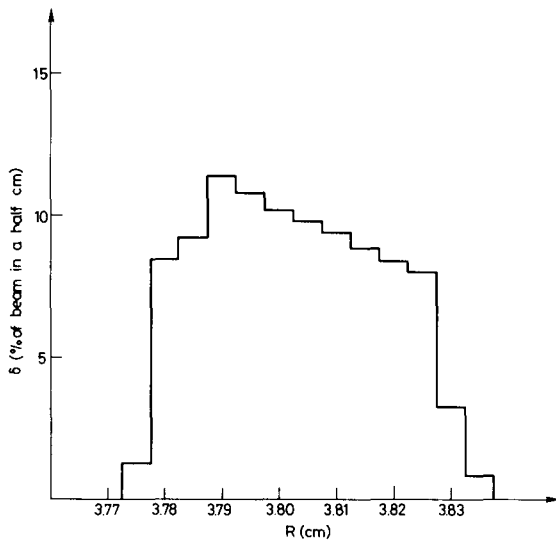Fig. 16 Radial Phase Space at first Lens

Fig. 17 Radial Beam Density at First Lens

4. Emittance Measurements

By measuring the cross-section of the beam a certain distance after a quadrupole lens first with the lens off then focusing horizontally, then vertically, one can calculate position, size and divergence in the two planes for the virtual source of the beam entering the lens. The beam size was measured by irradiating Al-foils and also by using a pair of wire beam scanners provided by K. Erdman, TRIUMF.

The emittance had to be corrected for scattering in the exit window of the cyclotron. This could be accomplished with a modified version of the beam transport program BEAMOP[6]. The emittance before the window changes with Dee-voltage and source position, etc. Typical values are

$$E_{horizontal} = 4.7 \; \pi \;\; mm \times mrad$$

$$E_{vertical} \;\;= 1.3 \; \pi \;\; mm \times mrad \; .$$

Conclusions

The behaviour of the CERN SC extraction system is in good agreement with calculation. In particular the measured extraction efficiency (70%) is very near to the calculated value (73%).

It should be noted also that the fairly high value of the total duty-cycle obtained with the Pulsed Field Coil (60%), is a value that has hardly been reached before in a Synchrocyclotron.

References

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