EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN - PS DIVISION

CERN/PS 93-28 (OP)

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Ch. Steinbach, H. Stucki, M. Thivent

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1993 Particle Accelerator Conference, Washington D.C., USA, May 17-20, 1993

Geneva, Switzerland
14/6/93

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Abstract

The slow extraction from the CERN PS to the East Area was completely rebuilt in March 1992. The new layout benefits from several improvements. The losses on the magnetic septa are suppressed by means of a novel concept applied to the third-integer resonance optics. The vacuum has been improved (in view of future lead ion acceleration) by means of a reduction in the number of septa and a change in their technology. Synchrotron radiation damage during lepton cycles is avoided by installing the septa on the inner side of the machine aperture. Maintenance is simplified, servicing eased and personnel radiation doses reduced by the use of modular plug-in units. The beam dynamics, the layout, the main characteristics of the hardware and the resultant performance are presented.

I. INTRODUCTION

The extracted beam from the CERN PS to the East experimental Area is used by numerous physics teams for the development of detectors. The proton momentum is 24 GeV/c and the intensity moderate (usually 3 10^{10} protons per cycle). The extraction system used until the end of 1991 had been installed 20 years ago [1]. Besides the obsolescence of some of the equipment, there were several reasons for replacing it. The acceleration of leptons for the LEP machine creates synchrotron radiation causing outgassing and damage to the magnetic septa, and severe sparking from the cathode of the electrostatic septum. The decision to accelerate heavy ions (lead) in the near future requires an improvement of the vacuum (10^{-9} torr). Finally, it was desirable to lower the number of elements in the ring to reduce maintenance and gain space for new equipment necessary for the numerous tasks of the PS, including operation for LHC in the future.

II. EXTRACTION LAYOUT

A. The resonance

The new system uses the third integer resonance 6 1/3, as did the previous extraction. The resonance is closer to the standard working point and the beam envelope fits better in the machine acceptance than for the half integer resonance.

To protect the extraction hardware from synchrotron radiation during the lepton cycles, it was decided to place the electrostatic and the thin magnetic septa on the inner side of the machine aperture, towards the machine centre.

On the 24 GeV/c flat top, the beam is brought near to the resonance from a horizontal tune of about 6.2 by pulsing two quadrupoles. RF debunching is then performed and the momentum dispersion is enlarged. Since the chromaticity is negative and the first septum is on the inside of the ring, the beam is pushed through resonance by a slowly increasing field in the main magnets of the PS.

B. The quadrupoles

The two quadrupoles have three purposes:

- increase Q_h as already mentioned,
- increase β_h at both electrostatic and thin magnetic septa to enhance the beam deflection,
- decrease the horizontal dispersion at the electrostatic septum and increase it at the thin magnetic one to adapt the extraction to the momenta of the particles belonging to different separatrices, as will be seen in II.E.

The effect of the quadrupoles is summarized in table 1.

Table 1: Lattice parameters at the positions of the septa

Location	Unperturbed machine		Machine with 2 quads	
	β horiz.	Dispersion	β horiz.	Dispersion
Electrostatic septum	22.2 m	3.04 m	36.2 m	1.27 m
Magnetic septum	22.6 m	3.04 m	35.5 m	5.01 m

C. The Sextupoles

Two sextupoles are installed to meet three requirements:

- the phase of the 19th harmonic determines the phase plane angle of the separatrix at the electrostatic septum,

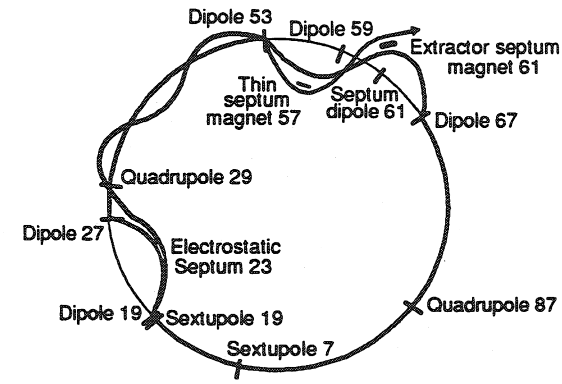

Fig.1: Schematic view of the extraction and its elements

- the amplitude of the 19th harmonic drives the resonance to give 10 mm spiral pitch at the electrostatic septum,
- the zero harmonic helps to reduce the absolute value of the chromaticity to satisfy equation (1) (see section E).

D. The septa

The electrostatic septum is almost an integer number of betatron wavelengths away from the equivalent sextupole. The deflection is 0.28 mrad. A $\lambda/2$ bump pushes the beam inside towards it. It has not been possible to superimpose the separatrices of various momenta [2] (Fig.2). The cost in efficiency is of the order of 0.5% which is quite acceptable.

The thin septum magnet is located 2.17 betatron wavelengths further downstream. The separation between extracted and circulating beam is 8 mm, amply sufficient to house the septum in spite of its outwards deflection.

The extraction septum is situated 1/4 betatron wavelength further downstream, outside the vacuum after the separation of the extraction channel from the machine chamber. The local bump is common to both magnetic septa and gives angle as well as displacement at the extractor septum magnet. It is created by 4 dipoles, one of them being a septum magnet.

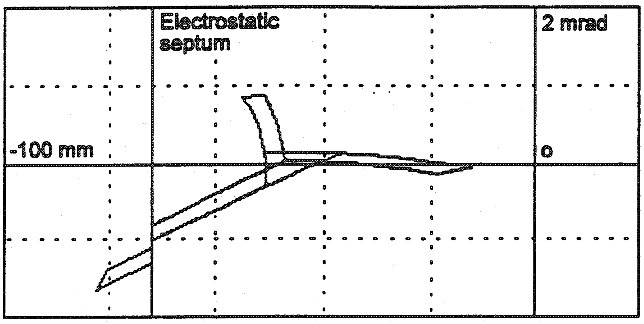

Fig.2: Phase plane at the exit of the electrostatic septum

The extracted beam crosses the fringe field of two PS standard C-shaped combined function magnets before reaching the first transfer quadrupole. The vertical emittance is doubled due to the non-linearity of the fringe field.

E. Chromatic effect at the thin septum magnet

The kick given by the electrostatic septum to the extracted beam transforms into a jump at the thin magnetic septum. In general, however, the position of this jump depends on the momentum of the particles.

This effect is corrected (Fig.3) by a proper choice of the dispersion at the septa [3], the condition to satisfy being:

$$D_{n2}\sin\varphi_1 - D_{n1}\sin\varphi_2 = \frac{8\pi Q'_x}{S}\sin(\varphi_2 - \varphi_1) \qquad (1)$$

where φ_1 and φ_2 are the betatron phase angles between the sextupole and the electrostatic and thin magnetic septa, D_{n1} and D_{n2} the normalized dispersion coefficients at these septa, Q'_x the horizontal chromaticity and S the normalized strength of the 19^{th} harmonic of the sextupolar perturbation.

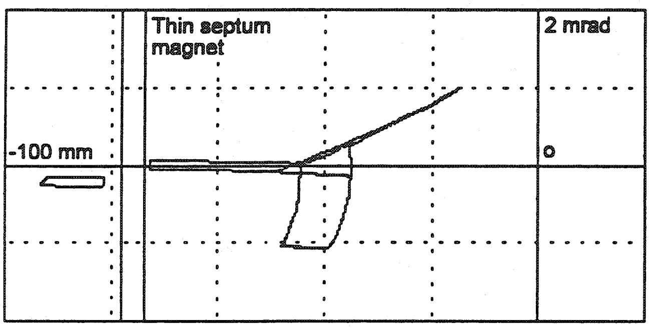

Fig.3: Phase plane at the entrance of the thin magnetic septum

We choose $S = 0.13$ which leads to $Q'_x = -3.2$

The instantaneous momentum spread of the extracted beam is given by [3]:

$$\frac{\Delta p}{p} = \frac{S\sqrt{\pi\varepsilon_o\sqrt{3}}}{24\pi Q'_x} \qquad (2)$$

For the nominal horizontal circulating beam emittance ε_o (at 2σ) of 0.5π µm at 24 GeV/c, the result is $\Delta p/p = 8\ 10^{-4}$.

III. THE ELECTROSTATIC SEPTUM

The septum itself is made up of a 0.1 mm Molybdenum foil stretched on an "Anticorodal" frame which matches the inside dimensions of the accelerator vacuum chamber to avoid impedance discontinuities for the circulating beam. The high voltage cathode is of aluminum with an 8µm thick surface oxidation obtained in a chromic acid bath. The operating voltage is 150 kV and the gap is 17 mm.

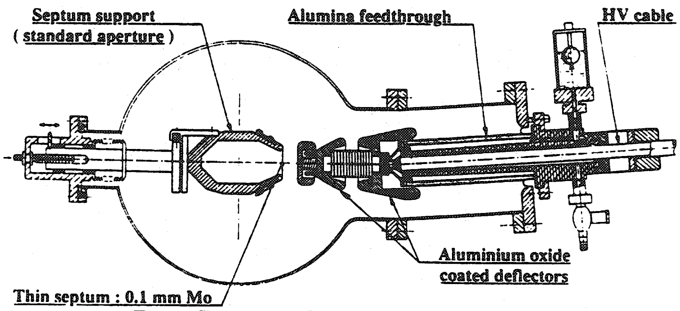

Fig.4: Drawing of the electrostatic septum

The holders and the HV feed-through are made of inorganic material: aluminum oxide brazed to metal parts. Grounded deflectors are made of stainless steel, and HV deflectors of oxidized aluminum as the cathode. A 200 Ω damping resistor is connected between the power supply and the electrode to absorb the energy in case of sparking.

IV. THE THIN SEPTUM MAGNET AND ITS TANK

The thin magnetic septum is equipped with a single-turn coil. It is slowly pulsed with 10 kA during a 600 ms flat top. The gap is 25 mm and the induction 0.7 T. The 4 mm septum is cooled by 5 water pipes of 2mm x 2mm cross section.

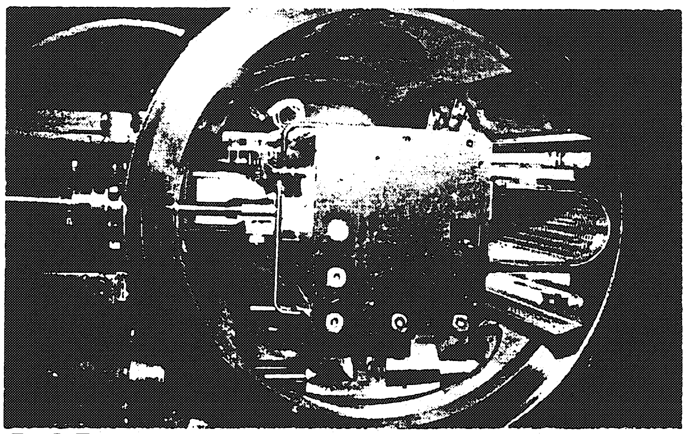
Fig.5: The thin septum magnet in the open tank before installation

The newly developed coaxial current feed-through is insulated with brazed alumina. The magnet yoke iron laminations are insulated with polyimide film every 3 mm. It can be baked at 180°C with 4 infrared lamps fitted with reflectors to keep the tank below 50°C since conventional aluminum vacuum joints are used. The power connection consists of 26 copper foils each of 0.5mm x 200 mm cross section to allow radial and angular adjustment of the magnet.

The power supply safety interlocks take into account the vacuum level and the cooling water flow.

The vacuum tank is a longitudinal stainless steel cylinder of 420 mm inside diameter and 10 mm wall thickness. All components such as septum magnet, positioning system, vacuum pump, alignment pads and beam observation system are mounted directly on the tank. Ion pumps are placed below and sublimation pumps on top of the tank. Fixed inside the tank, a gutter-shaped sheet surrounds the circulating beam aperture to lower the tank impedance as seen by the beam and avoid instabilities of high intensity beams. This constitutes a compact, easily transportable and modular plug-in unit which simplifies maintenance, eases servicing and reduces the personnel radiation dose.

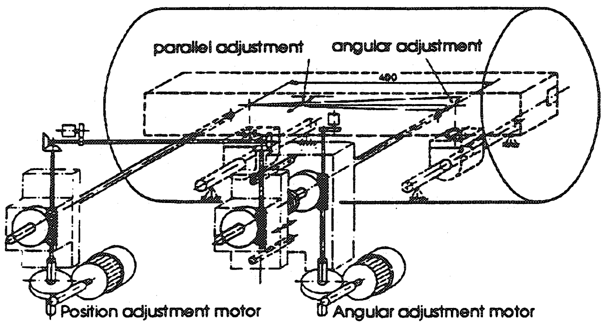

Fig.6: Sketch of the thin septum magnet position adjustment

Fig.6 shows the positioning principle of the magnet which is supported inside the tank by titanium-carbonate-coated linear stainless steel bearings. The magnet is positioned by two rods moved by a parallel adjustment motor. A second motor provides the angular positioning by moving one of the parallel drive gear boxes. The available adjustment is ±15 mm in position and ±5 mrad in angle.

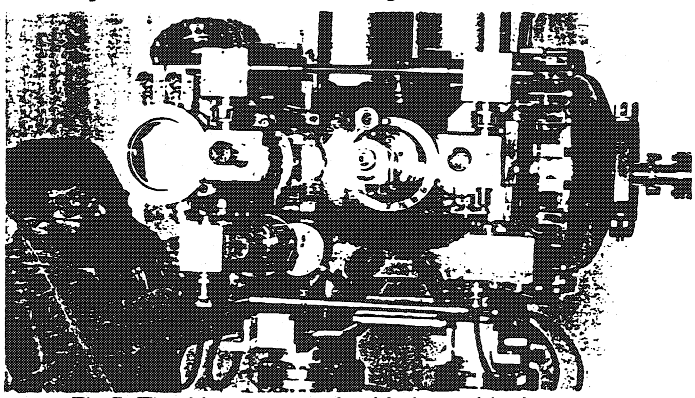

Fig.7: The thin septum tank with the positioning system

V. THE EXTRACTION AND BUMPER SEPTUM MAGNETS

These septum magnets are multiturn and placed outside the vacuum. The bumper has a 10-turn coil and the extractor a 4-turn one. They are slowly pulsed to avoid eddy currents in the chambers. Cooling is provided to each half turn of the coils and thermostats protect against possible corrosion-induced blockage.

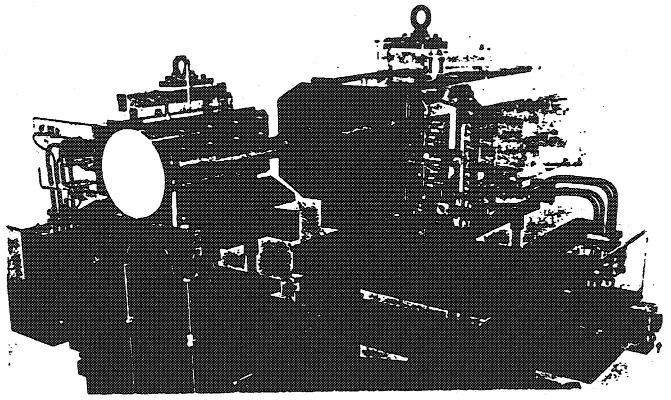

Fig.8: The extraction magnet and the septum bumper

VI. BEAM MONITORING

Tuning the extraction makes use of the general purpose measurement devices for orbit, betatron tune and losses. Dedicated monitors have also been installed: a secondary emission grid monitor and a TV screen at the thin septum magnet, another screen and a secondary electron chamber in the channel at the exit of the machine fringe field. The latter is calibrated by comparison with a beam transformer in a specially implemented fast extraction mode.

VII. PERFORMANCE

For the standard beam intensity of 3×10^{11} protons per cycle, the measured efficiency is about 95%, the horizontal and vertical extracted beam emittances are respectively 0.1 and 0.8 $\pi\mu$rad, the instantaneous $\Delta p/p$ being 0.08% for a total $\Delta p/p$ of 0.3% after debunching. Losses are essentially concentrated at the electrostatic septum. The maximum spill length is 500 ms, limited by the main magnet dissipation.

VIII. CONCLUSION

The PS slow extraction has been upgraded to answer the foreseeable needs. The septa and tanks are compatible with the vacuum quality required by the future acceleration of lead ions, they are shielded from the synchrotron radiation emitted during lepton cycles and their maintenance is easier. These improvements have been obtained while keeping the same performance in energy and efficiency.

IX. ACKNOWLEDGEMENTS

The authors wish to thank the numerous collaborators to this project and especially Y. Baconnier, B. Boileau, A. Poncet, J.P. Riunaud and J. M. Roux.

XI. REFERENCES

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