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FAST EXTRACTION FROM THE 300 GeV SYNCHROTRON

BY "BEAM SHAVING"

R. Gouiran

I. INTRODUCTION

The main idea of this fast ejection is to kick-out the beam in a time which is a sizeable fraction of a revolution, in order to minimize the size, the cost and the complexity of the kicker magnet system. This process could also give the possibility to eject short bursts of particles during slow extraction.

The efficiency depends upon the scheme to be chosen, but losses less than 0.5 o/o can be expected.

II. GENERAL PRINCIPLES

By the usual orbit deformation, the beam is brought near to the septa. Then a fast kick pushes it inside the aperture of the electrostatic septum. This kick is given by a fast dipole made of ferrite. A second dipole, a wave-length apart, compensates the effect of the first one in such a way that the rest of the orbit remains unperturbed.

The dipole current rises linearly during 11.5 μs (one half of a turn) and stays flat during 23 μs. So the ring could be emptied in 1.5 turn (34.5 μs). For a partial extraction the fall time should be also controlled. During that time the electrostatic septum sweeps over the beam emittance and the relative number of particles hitting the septum are $\frac{t}{T}\ \frac{d}{W}$, where t/T is the time during which the septum is irradiated, d is the effective septum thickness ($\simeq$ 0.15 mm), W is the beam width at the septum entrance. (For a total extraction $t/T = \frac{11.5}{23} = \frac{1}{2}$).

(To these losses one should add the normal losses of any fast extraction where the extracted channel acceptance is smaller than the machine acceptance which, in the case of very intense beams, really contains the 100 o/o of the primary protons. But the use of beam scrapers should kill this difference. Furthermore all the particles hitting the septum are not really lost.)

III. BEAM OPTICS

a) Normal beam

The first kicker, located near position 2[*]), produces a beam motion at position 17 (e-s septum entrance) which is nearly parallel to the emittance axis at this point. So the emittance ellipse just slides along this direction and the extracted beam emittance area is minimized. This is a characteristic of any beam shaving ejection : the emittance axis should be parallel to the kick motion in the phase space at the septum entrance; if not, the extracted beam emittance has an unacceptable triangular shape. At 400 GeV/c, with $E_H = 0.3 \cdot 10^{-6}$ mrad. (Ref. 2), the losses for a total extraction are $\frac{1}{2} \frac{0.15}{9.8} = 0.8$ o/o. (The beam width is counted with the momentum dispersion effect.)

The jump at the electrostatic septum should be : beam divergence : 0.130 mrad, plus electromagnetic septum thickness (2 mm) : 0.087 mrad, plus momentum dispersion : 0.018; total = 0.23 mrad. Using a 7 m long septum (one metre more than already foreseen), such a deviation could be obtained with a 14 mm aperture.

b) Improved beam

By introducing a pulsed defocusing quadrupole just one superperiod[**]) before the electrostatic septum entrance, one modifies the β function in such a way that the beam emittance is maximum at position 17, when the original Q is 27.75. The beam width is larger and the beam divergence smaller; so the losses and the jump are reduced. The new β function has now three maxima around the accelerator. The α_p function is slightly modified. Using an adiabatic debunching

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*) All position numbers refer to the machine Lattice so-called MR 47 (Ref. 1).

**) One superperiod is 1/6 of the ring.

of the beam (reduced voltage and zero gain on a small 10 ms flat top), the momentum dispersion can be reduced by a factor three (one hopes that the self bunching effect will not have time to appear). Increasing β by a factor 2.4 (so the beam width is increased by a factor 1.55), and taking account of the new dispersive vector, the losses for a total extraction at 400 GeV, are $\frac{1}{2}\ \frac{0.15}{14.4} = 0.5$ o/o.

The septum should give a jump of : beam divergence : 0.084, plus electromagnetic septum thickness (2 mm) : 0.087, plus momentum dispersion : 0.002; total = 0.173 mrad. This jump could be obtained by a 7 metre long septum with an aperture of 18 mm. If the septum is made of three sections, it could be advantageous to have an aperture of 20 mm for the last two metres.

We have now $Q_H = 27.62$, $Q_V = 27.80$. No resonance effect is expected because the perturbative quadrupole can be pulsed in 20 ms and, consequently the stop-bands are quickly crossed. Nevertheless one suggests the use of a dynamic quadrupole for resonance damping; it could be used either in a programmed way for rapid Q jumps, or in a stochastic way with a noise in the 100 kHz range.

The above figures can be improved for 200 GeV by increasing β by a factor 2.8; knowing that $E_H = 0.6 \cdot 10^{-6}$ mrad at 200 GeV, one obtains losses of $\frac{1}{2}\ \frac{0.15}{22.2} = 0.35$ o/o. The electrostatic septum should be opened up to 26 mm. To make a good use of this process, the electromagnetic septum should have an aperture of 22 mm (instead of 20 mm as already foreseen). The horizontal aperture of the F quadrupole following the electrostatic septum should be free up to 70 mm from centre (instead of 62 mm as already guaranteed. The exact apertures cannot be defined before we know accurately the magnetic fields in these fringe regions.) The necessary strength of the pulsed quadrupole will be approximately 40 o/o of a machine quadrupole. It is important to note that the reduction of the momentum dispersion by adiabatic debunching, during fast extraction, has a profound positive effect on the extracted beam quality and the spot widths on targets.

IV. CHARACTERISTICS OF THE TWO KICKERS

A complete description by A. Brückner could be found in reference 3. We just mention the main features :

Material	: Ferrite Ferrite length : 2.70 m Total length : 3 m
Magnet aperture	: 100 x 100 mm
Maximum bending power	: 0.35 T.m (The nominal value is 0.26 T.m)
Rise time	: 11.5 μs
Maximum flat top	: 23 μs
Fall time	: 11.5 μs
Peak current	: 3000 A
Peak voltage	: 16 kV

The proposed aperture supposed an inner ceramic vacuum chamber with a diameter 90/100. If the magnet is installed in vacuum, its size can be reduced. The first dipole will be situated in the region where the fast kicker is already foreseen (ref. 2).

V. COMPATIBILITY WITH OTHER USERS

a) Partial fast extraction followed by slow extraction

If we want to extract first 10 o/o of the primary beam, the kickers should be energized during 8 μs (up + down time), so the losses, in case of the improved beam at 400 GeV, would be 0.35 o/o of the primary beam. As the RF remains on during the adiabatic debunching, the momentum dispersion could be adapted back to the slow extraction in a few milliseconds.[*)]

b) Short bursts during slow extraction, using beam shaving techniques

One supposes that two users (TC and NP for example) work on the same flat top and that the unique extraction channel (first stage, West Hall) can be rapidly switched from one target to the other.

By interrupting for a while ($\simeq$ 20 to 40 ms) the sextupole and the quadrupole necessary to the slow extraction, one can kick out a desired proportion of the primary beam during this gate using the beam shaving techniques. We would have, at each burst the losses as computed above, but with a non-improved beam (normal β function, large momentum dispersion); for example, kicking out 10 o/o of the circulating beam will create losses of 0.55 o/o of this circulating beam, for each short burst. But one will have two supplementary sources of losses. First, as the electrostatic septum aperture will be adjusted for the slow extraction (18 mm), the jump given by the septum will not be large enough because the beam divergence will be quite great (normal β function plus momentum dispersion). So a slight part of the fast extracted beam will hit the electro-magnetic septum, and a first estimate shows that an extra 0.5 o/o of the current could be lost that way, giving a total loss of 0.55 +0.5 $\simeq$ 1o/o of the circulating beam at each burst. Further more, each time the slow extraction is switched on, some particles are probably not trapped in the separatrix and are lost, due to transitory phenomena; though this quantity is not known, it will multiply as many times as the slow extraction is interrupted.

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*) The large momentum dispersion necessary to a good resonant extraction could have a bad effect on the extracted emittance because of the vertical 15 mrad deflection produced by the extraction magnet. It is why we suggest to modulate the field of the extraction magnet in relation with the flat top field of the accelerator in order to maintain the slow extracted beam in the channel axis.

c) Short bursts during slow extraction using slow extraction itself

Due to the difficulties mentioned in paragraph V b) it could be better to programm the extracted current (slow burst, interruption, short bursts, etc.) by means of an accurate manipulation of orbit displacement at the sextupole locations and of the sextupole current itself. This possibility needs further investigation.

This suggestion is only valid for a unique extraction channel followed by fast switching magnets.

VI. COSTS (very approximate)

Two ferrite dipoles with power supplies	1	MFr.
1 metre of electrostatic septum	0.1	"
One pulsed quadrupole with power supplies	0.1	"
	1.2	MFr.

It could be possible that, for reason of space availability, and technical convenience, the quadrupole, as well as the second dipole, be split into two pieces.

This work has been done on J. Parain's request for the "300 GeV Ejection Study Group".

Distribution :

300 GeV Machine Committee
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REFERENCES

1) MR 47 Lattice
(Note MC/42 by E.J.N. Wilson)

2) Beam extraction from the 300 GeV Synchrotron
Report by the Ejection Study Group
MPS/DL Note 70-26

3) Fast extraction from the 300 GeV Synchrotron by beam shaving
Proposal for a kicker magnet system by
A. Brückner - EJ/38 - SI/Note MAE 70-10

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SUMMARY OF REPORT

FAST EXTRACTION FROM THE 300 GeV SYNCHROTRON BY "BEAM SHAVING"

R. Gouiran

(Ref.: CERN/MPS-MU/EP 70- 3 - 1.12.1970)

SUMMARY : On the request of the "300 GeV Ejection Study Group" one has looked into the possibility of using a "beam shaving" technique for fast extraction. One has looked into the possible arrangements and into the compatibility with other uses. As this principle is not specific to the 300 GeV machine, one has thought that it would be of general interest.

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