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THE SPS AS LEAD-ION ACCELERATOR

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Abstract

In 1995 the CERN SPS was used during two months to accelerate fully stripped ions of the Pb^{208} isotope from the equivalent proton momentum of 13 GeV/c to 400 GeV/c. The radio frequency swing which is needed in order to keep the synchronism during acceleration is too big to have the SPS cavities deliver enough voltage for all frequencies. In a first stage, the beam is accelerated from 13 GeV/c to 26 GeV/c using the fixed frequency mode. During this stage the beam is grouped in four 2μsec batches, separated by 3μsec holes during which the frequency is changed in order to keep synchronism. At 26 GeV the beams are de-bunched and recaptured in order to fill the 3μsec holes. From there on the lead ions are then accelerated up to 400 GeV/c with the normal frequency program. The de-bunching and recapture at 26 GeV improved the effective spill at extraction by a factor of three. Intensities up to 3.9 10^{10} charges could be obtained at 400 GeV/c. The total efficiency of the two RF captures was 64%.

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1 INTRODUCTION

Since 1994 the SPS is used to accelerate fully stripped Pb^{82+} ions from 13 GeV/c to 400 GeV/c proton equivalent. The injector, the CERN PS, accelerates Pb^{53+} ions which are subsequently fully stripped in the transfer line to the SPS. The stripper thickness has to be chosen in such a way that it gives maximum stripping efficiency for a minimum emittance blow up.

The RF frequency at injection is much smaller than that for protons at the equivalent energy. The frequency swing which is needed for the acceleration of Pb-ions is bigger than the bandwidth of the traveling wave cavities. In order to overcome this problem the technique of constant frequency acceleration is used [1]. In order to be able to use this technique the beam has to be bunched in four 2µsec batches, separated by 3µsec holes. In 1994 it was found that this structure gave a very bad spill during the resonant extraction, unacceptable for some experiments. For that reason a 26 GeV platform was introduced in 1995. On this platform the beam is de-bunched and recaptured. The beam is then accelerated using a normal synchronous frequency program. In this way the 2µsec structure is very much reduced at the moment of extraction.

2 STRIPPERS

The injector accelerates Pb^{53+} ions which are subsequently fully stripped to Pb^{82+}ions in the transfer line by means of an Al-foil. The choice of the stripper thickness is very important. The emittance of the Pb-ion beam is such that the aperture of the SPS is completely filled at injection. It is therefore very important to keep the thickness of the stripping foil as small as possible on order to avoid emittance blow-up. In 1994 a 0.5 mm thick foil was used. It was found that for this thickness there was still about 20% contamination of Pb^{81+} ions present. In 1995 tests were done with different stripper thickness, in order to find the right trade off between stripping efficiencies and emittance blow up [2]. The results are shown in table 1. The best compromise between blow up and efficiency was found for the 1mm stripper which was used throughout the 1995 period.

Thickness (mm)	Fraction Pb^{82+}	$\Delta\varepsilon_H$ πmmmrad	$\Delta\varepsilon_V$ πmmmrad	DT/T %
0.5	83%	0.43	0.214	0.164
0.8	96%	0.56	0.427	0.291
1.0	98%	0.73	0.550	0.269

Table 1 : Stripping efficiencies, emittance blow up and kinetic energy loss (DT/T), for different foil thickness.

2 ACCELERATION

The radio frequency swing which is needed in order to keep the synchronism during acceleration is too big for the bandwidth of the SPS traveling wave cavities. To overcome this problem we operate the RF frequency in the so called ‘fixed frequency’ mode [1]. How this works is schematically illustrated in figure 1. One SPS turn consists of four 2µsec batches separated by 3µsec holes. When a batch is passing the cavities, the frequency is at a fixed value, well within the bandwidth of the cavities. During the 3 µsec holes the frequency is varied in such a way that the revolution frequency is adapted to the ions' velocity at each energy. This mode of acceleration was successfully used in 1994.

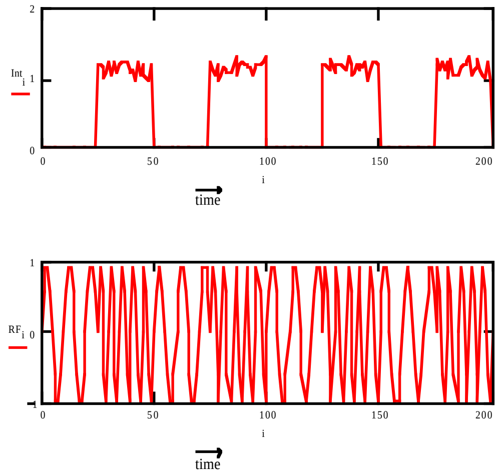

Figure 1 : Schematic illustration of the fixed frequency mode. When the 2 µsec batch is passing through the cavities the frequency is put at fixed value within the bandwidth of the cavities. During the holes, the frequency is varied as to keep the revolution frequency adapted to the velocity of the ions.

3 DEBUNCHING AND SPILLS

The batch structure separated by the 3 µsec holes, which is necessary for the fixed frequency acceleration, has rather bad consequences on the spill of the extracted beam. At 400 GeV the ions are slowly extracted, simultaneous to the north and west experimental areas, using a third order resonance. During the extraction the chromaticity is put to a high negative value in order to have a better control on the extracted flux. In this way only particles of a certain momentum are on the resonant condition. At 400 GeV the radio frequency is cut so that the beam can de-bunch during the extraction process. However, although during the de-bunching the time structure is lost on the circulating beam, the 2 µsec structure stays visible on the extracted beam. During the de-bunching process, time and momentum stay correlated so that during the extraction process, which cuts only a small slowly changing momentum slice, the time structure stays visible on the extracted beam (figure 2.).

In order to destroy the correlation between momentum and time one has to let the beam de-bunch and then

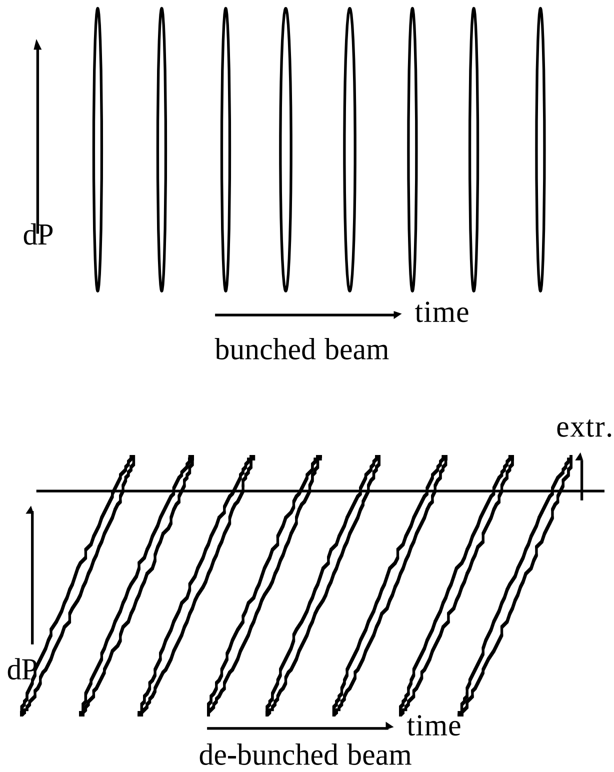

Figure 2 : A debunched beam still gives a "bunch like" extraction since only a small, slowly moving slice of the monentum is taken out during the slow extraction.

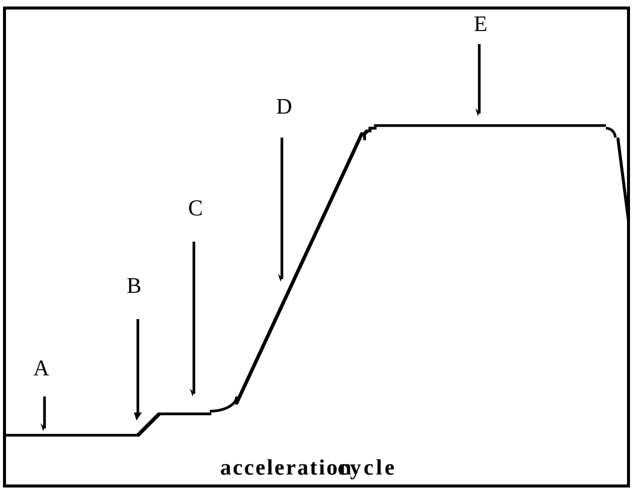

Figure 3 : the different stages of the Pb acceleration cycle :

A : injection platform (13 GeV/c)
B : acceleration (fixed frequency)
C : de-bunching and recapture. (26 GeV/c)
D : acceleration (normal synchronous frequency)
E : slow extraction (400 GeV/c)

capture it again. At 400 GeV/c the de-bunching time is in the order of 1 sec so that this procedure would take too much time and reduce considerably the duty cycle. For that reason an intermediate flat top was introduced at 26 GeV/c. At this energy the de-bunching time is only 280 msec and the velocity of the Pb-ions is already high enough such that the RF frequency for normal synchronous acceleration falls in the bandwidth of the cavities. At the beginning of this platform the RF is cut so that the beam can de-bunch. At the end of the platform the beam is recaptured and accelerated with the normal synchronous frequency program (figure 3.).

In figure 4 the result of this procedure on the extraction spill is shown. Without de-bunching re-capture the 2µsec beam structure is still very strong. The effective spill, defined as (1) is only 0.3. Using the de-bunching recapture technique, effective spills of 0.82 could be obtained.

$$\frac{\left(\int_0^T I.dt\right)^2}{T.\int_0^T I^2.dt} \qquad (1)$$

T is the spill duration and *I* the instantaneous intensity.

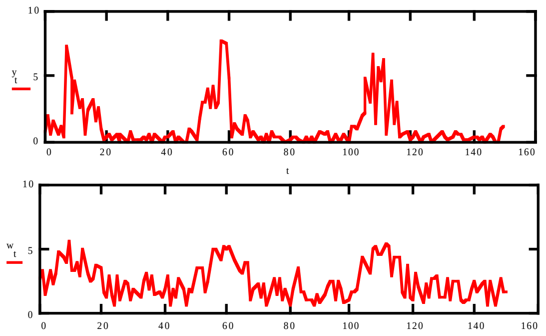

Figure 4 : extraction spill with (bottom) and without (top) de-bunching and re-capture procedure.

4 PERFORMANCES

In 1995 an intensity of 3.9 10^{10} charges could be accelerated up to 400 GeV/c. The transfer efficiency from CPS to SPS is only 60%. The losses mainly occur at injection because the emittance is filling the whole SPS aperture. The efficiency of both RF captures at 13 GeV/c and 26GeV/c are about 80% each, resulting in a 64% transmission from 13 GeV/c to 400 GeV/c. Roughly 84% of the accelerated beam is arriving at the experiments. A total of 15.2 10^{14} charges was delivered to the experiments throughout the 1995 period, more than twice the integrated intensity in 1994.

REFERENCES

[1] T. Bohl et al. , "Non Integer Harmonic Number Acceleration of Lead Ions in the CERN SPS", PAC proceedings, Dallas, 1995.

[2] G. Arduini et al., 'Lead ion beam emittance and transmission studies in the PS-SPS complex at CERN', This Proceedings.