

THE SPS AS ACCELERATOR OF Pb^{82+} IONS

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In 1994 the CERN SPS was used for the first time to accelerate fully stripped ions of the Pb^{208} isotope from the equivalent proton momentum of 13 GeV/c to 400 GeV/c. In the CERN PS, which was used as injector, the lead was accelerated as Pb^{53+} ions and then fully stripped in the transfer line from PS to SPS. 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. For that reason a new technique of fixed frequency acceleration was used. With this technique up to 70% of the injected beam could be captured and accelerated up to the extraction energy, the equivalent of $2.2 \cdot 10^{10}$ charges. The beam was extracted over a 5 sec. long spill and was then delivered to different experiments at the same time.

I. SPECIFIC PROBLEMS

In 1994 the SPS was used for the first time to accelerate fully stripped Pb^{82+} ions from 13 GeV/c to 400 GeV/c proton equivalent. The injector, the CERN PS, accelerated Pb^{53+} ions which were subsequently fully stripped in the transfer line to the SPS.

One of the specific problems with the lead ion operation is the low intensities involved ($1 \cdot 10^{10}$ charges). This requires special monitoring. High gain FET amplifiers had to be installed close to monitors in order to keep the signal to noise ratio to an acceptable level. However, for secondary emission monitors in the transfer lines the signal is high because it is proportional to Z^2 . For the same reason, the energy loss in any foil of material, like secondary emission monitors, or luminescent screens is also much higher than for protons. A luminescent screen in the injection line for example, changes the energy by 0.5%, so special care had to be taken during the steering process.

The closed orbit pickups were fully equipped with new amplifiers. This was the first time a complete closed orbit could be measured for the heavy ion intensities. In previous heavy ion runs only a few pickups were equipped with special amplifiers.

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 a new technique of constant frequency acceleration is used as will be explained in a subsequent chapter.

II. STRIPPING EFFICIENCIES

The Pb^{53+} ions from the CPS injector were fully stripped by an aluminum-foil in the transfer line to the SPS. First a 2 mm aluminum-foil was used. This gave a stripping efficiency of 100% Pb^{82+} . However, this foil gave a normalized emittance growth of 1π mmmrad in both planes. The resulting normalized emittance of 3π mmmrad in the vertical and 4π mmmrad in the horizontal plane was too big to fit into the acceptance of the SPS which is of the order of 2.5π mmmrad vertical and 3.5π mmmrad horizontal. This resulted in a poor acceleration efficiency of only 25%. Later a stripper of 0.5 mm was used. For this thickness no emittance blow up was observed but, according to profile measurements using a luminescent screen and a camera (fig. 1), a contamination of 20% Pb^{81+} -ions could be observed.

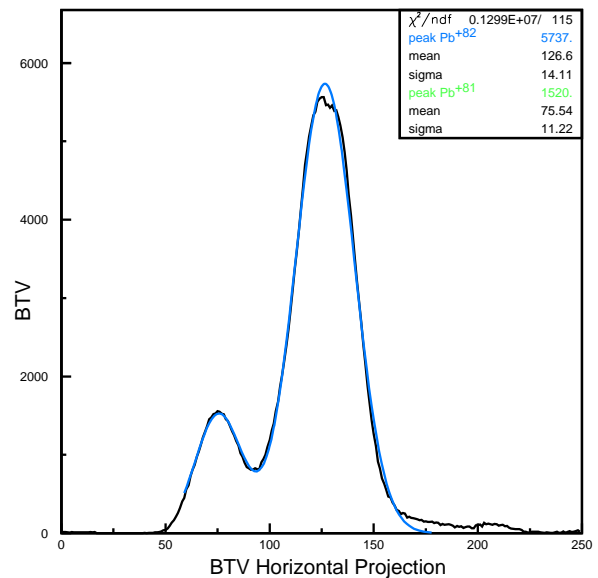


Fig 1. Beam profile measured with a camera showing both the Pb^{81+} (left) and the Pb^{82+} (right) peak.

The response of the screen-camera system is very nonlinear and an empirical calibration against intensity had to be performed. The result of this is shown in Fig. 2. There is still some doubt for the lower part of the curve which seems to show a behavior that is not completely understood. The next period with lead ions we will try to perform the measurements again with a more linear camera. We will also have current transformers available in order to increase the precision.

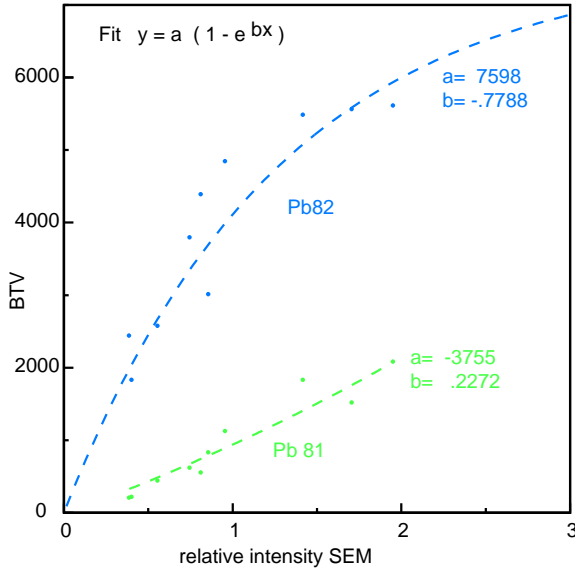


Fig .2: Intensity calibration of the screen-camera response against secondary emission monitors.

At the end of the run a 1mm stripper was also tested. The results can be summarized as follows :

- 2 mm Al : V normalized emittance 3π mm mrad
H normalized emittance 4π mm mrad
No Pb⁸¹⁺ contamination
Momentum loss 0.5%
- 1 mm Al : V normalized emittance 2.5π mm mrad
H normalized emittance 3.5π mm mrad
5 % Pb⁸¹⁺ contamination
Momentum loss 0.2%
- .5 mm Al : V normalized emittance 2π mm mrad
H normalized emittance 3π mm mrad
20% Pb⁸¹⁺ contamination
Momentum loss 0.1%

III CONSTANT FREQUENCY ACCELERATION

The RF cavities used to accelerate lead ions and protons in the SPS are of the untuned traveling wave type. Their bandwidth is sufficiently large to allow acceleration of protons at fixed harmonic number but the frequency swing for lead ions is too large. Changing harmonic number on intermediate flat tops in the cycle is one way round this problem but a more elegant method is to use non-integer harmonic number acceleration.

In this scheme advantage is taken of the short filling times of the cavity, 0.8 μ s compared to revolution period, 22 μ s. The ions are injected and accelerated in short batches, 2 μ s long, and the cavity frequency is held constant at a value giving maximum voltage each time the batch traverses the

cavities. After the batch has passed the cavity, the power is switched off and the frequency of the generator is modulated to adjust the phase of the RF ready for the next transit of the batch through the cavity for which the power is switched on again. Thus the batches always see the same frequency but the average frequency of the generator varies with the revolution frequency of the ions. The system is fast enough to allow four batches of ions spaced around the circumference to be accelerated in this way.

This novel beam control system is described elsewhere [1], but here we mention that the fundamental requirement was the development of a fast switching, voltage controlled oscillator. Considerable modifications to the power amplifiers were also necessary to allow full power switching at 180kHz with rise and fall times of less than 1 μ s.

The four batches of ions are injected at 1.2s intervals from the injector. Each batch is allowed to debunch for 10ms and is then captured adiabatically and held along the injection plateau at fixed frequency while the other batches are likewise injected and captured. Individual capture of each batch is possible by counterphasing the voltages of two cavities at four times the revolution frequency. When all the batches are in, they are accelerated using a radial loop with sensitive pick-up to control the mean frequency of the oscillator.

After initial setting-up, capture efficiencies of 80% were regularly obtained during this short run. There is some evidence that this figure will be improved by reducing the noise at multiples of the revolution frequency, inherent to this type of oscillator.

IV PERFORMANCES

For the 2 mm stripper, the transverse emittances were too big for the machine aperture. This resulted not only in transverse losses at injection, but also in capture losses. The horizontal aperture of the machine being limited in the high dispersion regions resulted in a strong reduction of the momentum acceptance so that adiabatic capture became very inefficient. Only 25% acceleration efficiency could be obtained. When the stripper was changed to 0.5 mm, 70% of the injected beam could be accelerated.

The transmission throughout the system for a good cycle can be summarized as follows :

- Before stripper :
9 10^9 charges (Current transformer)
- After stripper :
13 10^9 charges (Current transformer)
- TT10:
7 10^9 charges (Secondary emission monitor)

Injected:

$7 \cdot 10^9$ charges (Current transformer)

400 GeV (4 injections):

$22 \cdot 10^9$ charges (Current transformer)

These numbers indicate that there is a serious loss between the stripper and TT10. However, the calibration of the secondary emission monitors (SEM) against intensity is not obvious. Only with protons could a cross calibration be done with a current transformer. For lead the Z^2 law was used in order to scale the sensitivity of the SEM. For next year two current transformers will be upgraded for measuring low intensities, so we will be able to cross check the calibration for lead-ions.

At the end of the lead running period, which lasted only a month, a total of $7.25 \cdot 10^{14}$ charges was accumulated on the targets (Fig.3).

The most striking feature was the stability of the ion source, delivering the same intensity at every cycle.

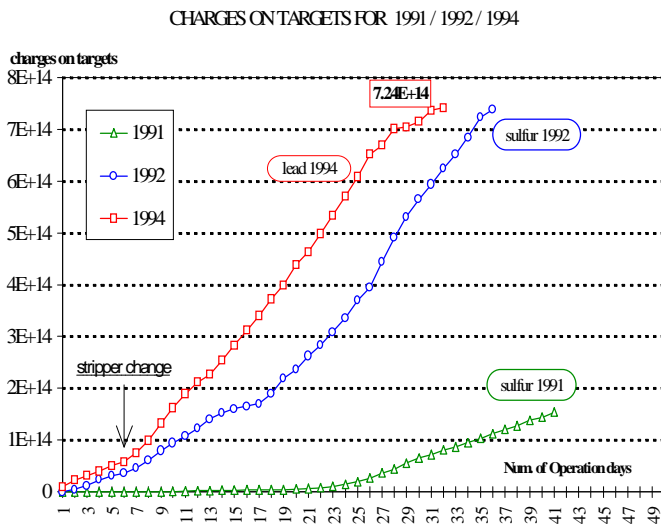


Fig. 3: accumulated intensity of the lead charges on target, compared with previous heavy ion runs.

V REFERENCES

[1] T. Bohl et al. , “Non Integer Harmonic Number Acceleration of Lead Ions in the CERN SPS”, This conference.