NEW INJECTION and EJECTION PROCESSES at SATURNE

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1. Injection at variable energy

Principle

In order to inject a maximum proton beam intensity while the magnetic field of the synchrotron magnet is rising, the particles' energy is ramped in such a way that the equilibrium orbit constantly goes through the inflector septum.

For 20 MeV protons the spiral pitch is 0.63 mm per turn and the first injected particles reach the vacuum chamber wall after 623 μs, corresponding to 550 injected turns.

Curve number 1 shows the required energy variation versus time.

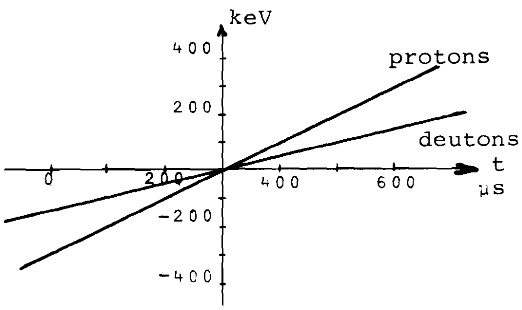


Fig. n° 1

Particles energy variation during the injection process

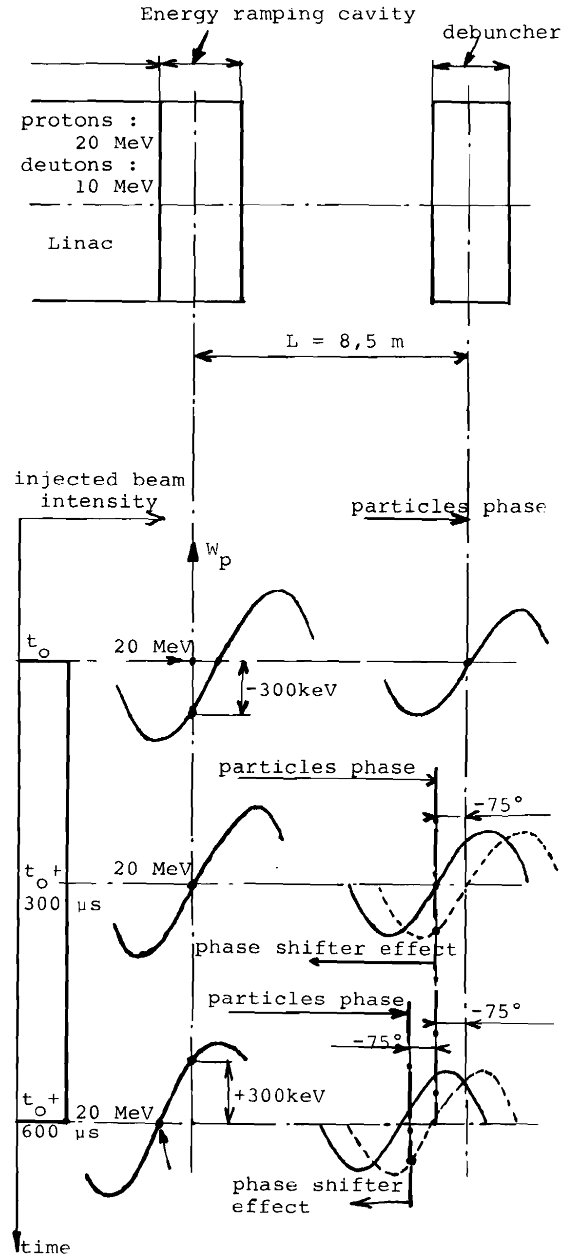
Taking into account the beam emittance and the avoiding of the inflector, it can be calculated that a 8 mA beam may be injected for 600 μs[1].

2. Ramping cavity and debuncher

The energy ramping is obtained from a cavity directly coupled to the high energy end of the linac. This cavity is phase shifted with respect to the linac during injection time.

The fast phase shifting is obtained from a LTT ferrite phase shifter. This phase shifter happens to be a good power transmitter, providing it is correctly prebiased, capable of 100 kW at 200 MHz.

These phase shifters have recently been housed in pressurized containers



L = 8,5 m corresponds to :

$\Delta\phi_p = \phi_p$static + 25°/100keV for protons,

$\Delta\phi_d = \phi_d$static + 100°/100 keV for deuterons.

Fig. n° 2

Energy ramping cavity and debuncher phases variation during injection

(2 atm. SF6) in order to avoid failures from sparking in case of sudden increase of reflected power from the load cavities (from multipactoring sparking in cavity gap or accidental mistuning).

A debuncher is used to reduce the beam energy spread from ± 120 keV to ± 40 keV. This debuncher must be kept constant in phase with respect to the ramping cavity for the particles to be always centered on the zero synchronous phase of the debuncher (see figure 2).

The parameters are as follow :

	20 MeV protons	10 MeV deuterons
max voltage on ramping cavity	430 kV	430 kV
$\Delta\Phi_V$	-45° ↗ +45°	-45° ↗ +45°
max voltage on debuncher	230 kV	230 kV
$\Delta\Phi_D$	-75° ↗ +75°	-150° ↗ +150°
transit	1	1/2

These parameters provide the energy variation shown on figure 1 for protons and deuterons.

We numerically tried to find the precision required for each of these parameters, the results are as follow : Everything else being kept constant, a 10 % error either on the max. voltage of the debuncher, or of the ramping cavity, or on the ramping cavity phase variation law does not lead to a significant variation in the slope of the curve.

The particles that have been too much or too little accelerated by the ramping cavity arrive with $\Phi_s \neq 0$ inside the debuncher which decelerates or accelerates them. Therefore within a certain range, the debuncher corrects for the ramping cavity tuning errors effects. Finally the origin of the curve is not critical because it can be compensated for tuning the injection time. However, everything else being kept constant, a ten per cent error on the debuncher slope results in an appreciable error on the energy variation law : 60 keV between the first and the last particles.

This 60 keV energy error corresponds to a 3 cm displacement of the equilibrium orbit, which is what is precisely needed to miss the back of the inflector, it is therefore clear that a 10 % misadjustment of the debuncher slope cannot be tolerated.

Experimental observations have confirmed the necessity of a careful adjustment of the debuncher phase variation.

3. Capture and acceleration performances

3.10^{12} protons are captured. After 4 ms $1.6.10^{12}$ protons remain and $1.2.10^{12}$ at the end of the acceleration cycle.

For deuterons 7.10^{11} particles are measured at 4 ms and are kept until the end of the cycle (850 ms).

In order to increase the particles number, we have undertaken several studies:

- injection : inflector loading. When the beam passes inside the gap, the applied voltage is modified by leak currents,
- acceleration : instabilities.

These instabilities have been demonstrated during acceleration, but they also may occur at capture.

These instabilities did not appear when we used to inject at a 3.6 MeV energy, for a similar intensity. They make the tunings of the machine much more difficult. We shall try to summarize our different observations.

4. Instabilities

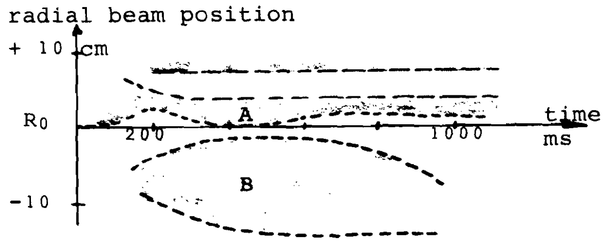
4.1. Observed phenomena

By action on the servo radial loop of the ring RF cavity it is possible to shift the beam from the outside to the inside wall of the vacuum chamber.

Under these conditions it could be observed that in some radial regions no intensity loss occured while in others heavy or slow partial losses were detected.

4.2. Possible explanations

- Vertical or horizontal oscillations appear in some radial regions. These oscillations may be eliminated if incoherence is induced, and it was also noticed that these oscillations only appear for a threshold of 2.10^{11} particles per cycle.
- ν_z measurements[2)] showed that $\nu_x = 2/3$ and $2\nu_x - \nu_z = 1$ resonances could be crossed. This could explain the slow losses observed in unstable regions where the coherent effect is not detected. (see figure n° 4).



A : slow losses or horizontal coherent oscillations

B : vertical coherent oscillations

Fig. n° 3

Radial stable regions versus time

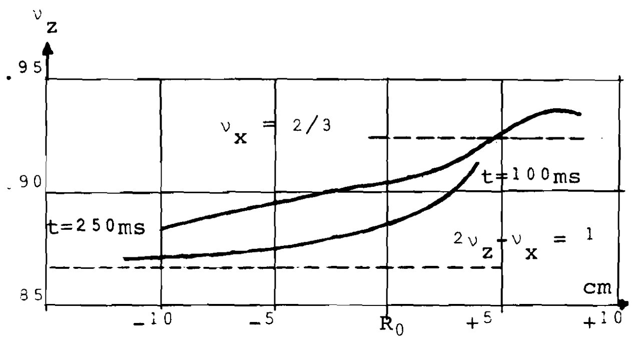


Fig. n° 4 - ν_z versus R and time

- The resonant effect has been put into evidence by a slight variation on the field index (by the order of 0.02) leading to 2 to 3 cm displacement of the instable region.

4.3. Unsolved theoretical problems

- Preliminary classical calculations indicate that horizontal coherent effects should only appear for 10^{13} per cycle intensities. This needs to be confirmed by further calculations.

- RF cavity loading instabilities,

- Why were coherent oscillations losses not observed at 3.6 MeV injection energy for 2.10^{11} beams ?

4.4. Present corrections

These phenomena have been cured by :

- a detection system for the oscillations that feed them back on damping plates with opposite phase. Vertical oscillations of order 1 could thus be eliminated.

- use of correction windings on the pole faces that create an index defect such that the average index depends upon the particles betatron amplitude, by doing so the beam loses its coherence.

These two methods made the machine more stable and allowed for easier tunings.

5. New resonant extraction

This extraction must provide a small horizontal emittance beam.

In order to do so the tuning is as follow (see figure n° 5).

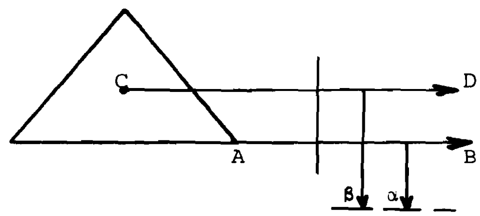


Fig. n° 5

Septum magnet deflection angle variation

In the course of the ejection process particles are extracted first along the separatrix AB, then along the separatrix CD.

The deflection angle given by the septum extraction magnet varies between α and β.

Besides if one takes into account the energy spread (± 2 cm) the index must be constant along the radius in order to eject simultaneously the same betatron oscillations.

These tunings have not yet been optimized.

Until now we reached 20 % efficiency and the emittance has not been measured for the whole beam.

References

1. G. Rommel
Acceptance de Saturne à 20 MeV
SEFS TD 66/60 - IHE 51
Internal report

2. D. Boireau and al
ν_z measurements
SEFS TD 70/80 - AS 196
Internal report.

(+) S.E.F.S. : Service chargé de l'Entretien et du Fonctionnement de Saturne.