STATUS REPORT ON ACCELERATION OF POLARIZED PROTONS AND DEUTERONS OF THE SATURNE LINAC

JL. LEMAIRE
Laboratoire National Saturne, CEN SACLAY (France)

ABSTRACT

In 1982 new pulsed power supplies were added to the linac in order to accelerate polarized deuterons and ions of q/a = 0.5 : the linac operation in the $2\beta\lambda$ mode and FDFD transverse focusing periodicity was described in earlier papers. In this paper we give the last results obtained after this improvement, for polarized proton and deuteron acceleration : source improvements, automatic transverse matching, linac efficiency and emittance measurements.

INTRODUCTION

The 20 MeV Alvarez linac is now currently accelerating particles which velocity is half of the velocity of the protons accelerated in the normal $2\beta\lambda$ mode for which it was initially designed. Polarized protons and deuterons coming from a source at a high voltage of about 190 kV/A are accelerated in this way and recently, fully stripped heavy ions such as Ne^{10+}, N^{7+} and C^{6+} produced by the new preinjector system Cryebis-RFQ. The final energy at the exit of the linac is the same for all these species : 5 MeV/nucleus. Early polarized proton results were given at the last conference and since, we have made improvements to increase the total proton accelerated beam and to produce polarized deuterons in order to reach a final intensity of 10^{10} particles per pulse in the main accelerator ring.

POLARIZED SOURCE OPERATION

The polarized source improvements were carried out gradually from july 1980 to the end of 1983 by improving the ionizer, then the dissociator and the atomic jet and finally the beam transport at 15 kV (see fig. n° 1).

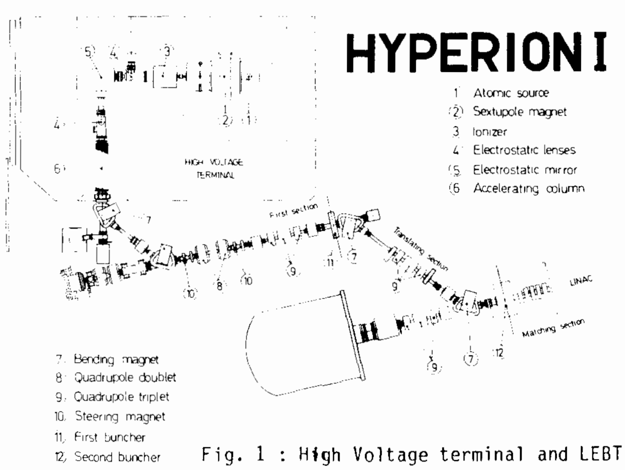

Fig. 1 : High Voltage terminal and LEBT

- 1°) the ionizer

We recall that the ionizer is a reflex type one, so that the longest the back and forth travel of the electrons is, the highest the ionisation efficiency will be for a given electronic current. At first order one needs a perfect alignement for both magnetostatic and electrotatic field mappings. This operation was carried out just a few weeks after the starting up of the ionizer, because it was unstable. Polarized proton intensity was about 5 μA. After that the ionizer was running more realiably and beam reached 18 μA.

- 2°) the atomic jet

- a) pulsed mode

Since the source is pulsed, it is possible to increase the peak value of pulsed parameters whithout having trouble with there mean values. Thus we have increased the dissociator RF power without risks of warming up to much electronics and bottle. In the same way, if we were increasing a DC gas flow, the pressure in the sextupole compartment will generate a diffusion of the atomic jet but in a pulsed mode one can increase the intensity of the atomic jet if we simply increase the diameter of the bottle from 2.4 to 4 mm, provided we decrease the flowing constants of the atomic gas.

We used a pulsed piezoelectric valve and a single straight bottle rather than a double V shaped bottle. The RF power generator has to be an auto oscillating system since the impedance of the discharge varies during the switching-on process.

It is worthwhile to notice that those modifications have only historically demonstrated there importance because they have made possible the following improvements. Nevertheless one can claim that they have allowed to increase the beam intensity from 45 μA to 95 μA.

- b) nozzle cooling

If the pressure inside the bottle is fixed then the gas flow through the nozzle is known. Let us assume that the conductance of the nozzle is a constant, the intensity of the gas in the ionizer should increase when the atoms are cooled down (the cooling system is represented on fig. n° 2). In fact, due to the diffusion of the jet on to the background gas at the input of the sextupole, experience showed that the beam intensity does not increased as predicted.

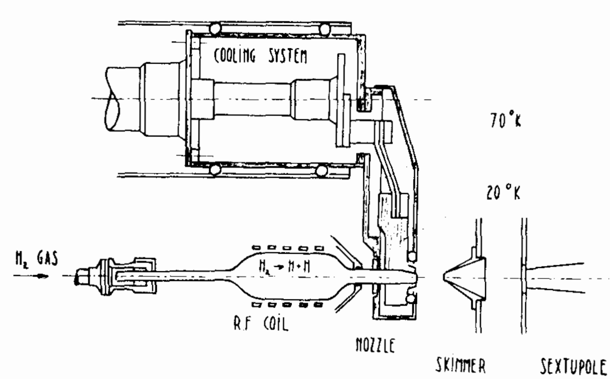

Fig. 2 : the nozzle cooling system

- c) sextupole acceptance

When the atomic gas is cooled down, it is possible to bring the current low in the sextupole magnet, so we have opened up the sextupole bore radius. As a consequence gas flow increased and pumping capability in to the sextupole improved. The beam intensity reached 230 μA for polarized protons and 180 μA for polarized deuterons + background of 5 μA.

Remark

Operating experience showed that the optimum temperature is about 100° K, and this optimum is flat. The increase of the density which should result in a decrease of the atom velocities is compensated by a large diffusion in the sextupole part. In an other hand, bringing the temperature low allows to operate the sextupole magnet at a lower current.

- d) 15 keV energy beam transport

At the exit of the ionizer, when it is extracted the beam has an unknown energy spread. So it is important that the electrostatic deflector which rotates the spin of the polarized particles perpendicularly to the beam axis, be achromatic. We have choosen an electrostatic mirror of which ground electrode is made of tungsten wires horizontally fixed. A step of 1.6 mm using wires of 80μ diameter is a good optimum between the transmission of the mirror and the minimisation of the aberrations generated by the weaving the grounded electrode.

Diagram on fig. n° 3 summurizes all the major improvements made on the source.

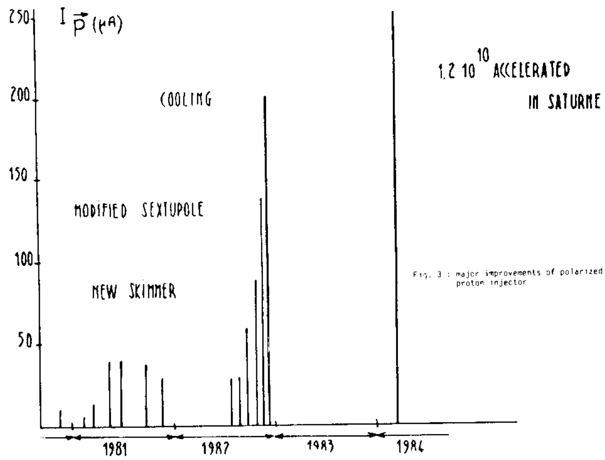

Fig. 3 : major improvements of polarized proton injector

LOW ENERGY BEAM TRANSPORT

As shown on figure n° 1, the low energy beam transporting system is made of 3 sections. The first section has 2 identical C bending magnets which total deviation is 102°. These magnets have a 14 cm large gap and identical input and output 13° wedges allowing to focuse the beam in the vertical plan. This section ends up with a non symetric triplet to permit in both horizontal and vertical plans transverse matching to the next section. The second section has to translate the beam in order to have the beam in the axis of the linear accelerator. Originally, it was made of 2 bendings magnets identical to the previous one described and again a non sysmetric short lenses triplet located in between the 2 magnets. The section had to make a waist in the buncher and translate the beam axis. The enveloppes given on the figure n° 4 correspond to a theoretical beam of which normalised emittance is 3.10^{-6} m.rad in both plans. The third section has five quadrupole lenses alternatively focusing defocusing to ease the beam matching to the linac. This last section is the same as the one for the 750 keV proton beam coming from the Amalthee preinjector.

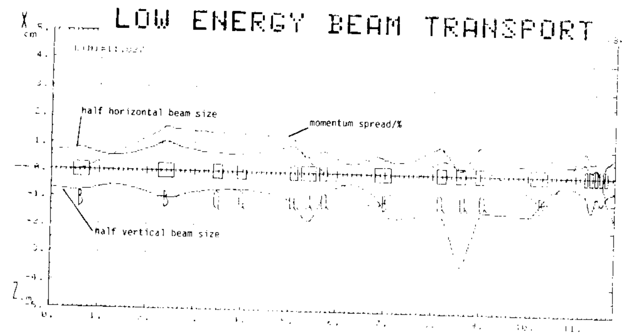

Fig. 4

At the time the transport line was built, no emittance measurements were possible, since we did not have any emittance meter device and beam enveloppes were calculated with a 3.10^{-6} m.rad normalised emittance as pointed out earlier, assuming that the beam was at a waist at the exit of the accelerating column. Tuning the line was difficult and we had two possibilities : either we obtained a rather good transmission until we reached the input of the linac whithout being capable to match the beam and accelerate it, or we had a poor transmission of the transport line and the beam was well accelerated through the linac. This meant that the beam was not at a waist at the end of the accelerating column and we had no possibility to match it further down and that the emittance was larger than expected. We made 2 modifications.

- a) extra quadrupole doublet

A quadrupole-doublet was added to the first section, just after the second bending magnet at a location where indeed beam imaging was not correct. After that, tuning became more simple and we obtained a 55% transmission of polarized protons through the linac (ref. 1).

- b) redesigned translating section

In order to improve the linac capture efficiency, it was decided to put a second buncher. It was located at the very entrance of the translating section were the waist is. But the beam will spread out in the section because of the energy spread generated. In order to recombine the energies before entering the next buncher, the section had to be achromatic. Between possible solutions we have choosen to modify the magnet wedges and to replace the 3 quadrupole lenses by a symetric triplet. Initially, calculations showed that wedges had to be -34° and 34° but we had to find a compromise between the magnetic field due to the wedge and the magnetic field due to the coils which where not parallele to the end plate of the magnet. We found in the same time that this problem did exit with the 13° wedges but was much less important. The figure n° 5 shows the beam enveloppe for this translating section. Transfer matrix between the two bunchers leads to a correspondance object image with a unity magnitude. Both vertical and horizontal enveloppes are at waists which have to give a beam size as small as possible in order to avoid non linearities in the bunchers.

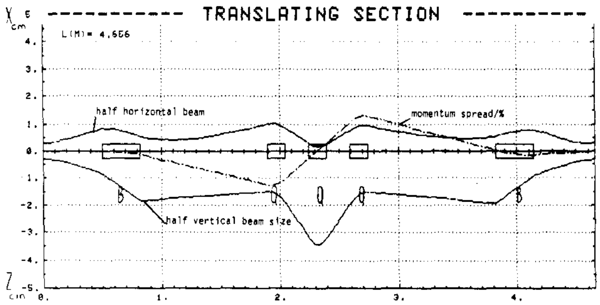

Fig. 5

- c) emittance measurements

The emittance was measured very recently at 190 keV at the exit of the preinjector for polarized protons. It is done manually. A 9 fixed slits of 0.2 mm width distant of 4 mm gives ribbon beams which are collected on a moving wire. The beam has to be tuned first to diverge and to have a size as small as possible. In addition, depending upon the tuning of the 15 keV transport line, extraction voltage and solenoid current the beam may have aberrations.

The results given on figure n° 6 correspond to a 105 A polarized proton beam and is calculated for a cut at 10 %. So it represents 90 % of the peaks. The value of 9.10^{-6} m.rad entirely explains why we have beam losses when going through the low energy beam transport.

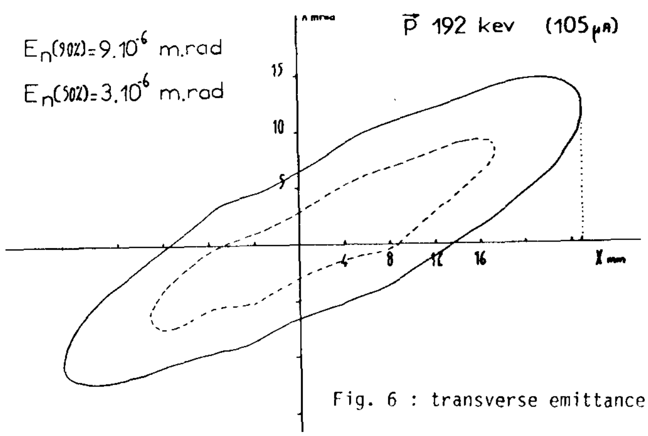

Fig. 6 : transverse emittance

- d) on line matching

We have developped a computer code to ease the process of tuning the transport lines. This code is used on-line and has proved to be very efficient when we were worrying simultaneously about the transmission of the low energy beam transport and the linac transmission, at the time we did not have emittance measurement. More details are given in ref. 2.

LINAC OPERATION

We have already shown in early reports that the FDFD focusing periodicity for the quadrupoles in the drift tubes yields a stable space in the stability diagram much larger than for the FFDD focusing periodicity, as far as the $2\beta\lambda$ acceleration mode is concerned. Indeed, the operating line just represents the synchronous particle and the Δ defocusing effect of the accelerating gaps is different for the non-synchronous particles (ref. 1). Thus they would not stay in the stable diagramm and this is why we could not get a better transmission than 30 %.

Turning to this other focusing periodicity requires a much higher current in the quadrupoles as indicated by the relation ship :

$$\Theta_0^2 = K \epsilon h \frac{\delta Br}{\delta r}$$

where h is the operating mode

$$\epsilon = q/A$$

$\frac{\delta Br}{\delta r}$ the quadrupole gradient

We decided to replace the 7 old power supplies by 13 new ones, having them pulsed in order to cope with the thermal heating of the quadrupoles housed in the drift tubes.

New families were setted giving more flexibility for tuning.

Under these conditions, the transmission of the linac is 67 % for a deuteron beam coming the Amalthee preinjector, using one buncher.

For this beam we have measured both emittances at the input and the output of the linac and results show that the emittance growth has decreased by 60 %.

	old power supplies		new power supplies	
	LEBT	HEBT	LEBT	HEBT
normalised emittances	0.5	1.5	0.5	0.9
beam current	27mA	4.5mA	25mA	9mA

Beam growth is now a factor of 2 instead of 3 and what is also very important is that since the transmission is higher, the brightness has increased by a factor of 5.

On another hand, the polarized deuteron beam coming from the Hyperion source leads to a maximum transmission of only 50 % with the 2 bunchers. Those results are lower than the ones obtained with the unpolarized deuteron beam and can be explained by the fact that the emittance of this latter beam is larger.

The following table summurizes the results for the linac operating in the $2\beta\lambda$ mode.

	p	d	p.protons	p.deuterons
theoretical transmission	80 %	80 %	80 %	80 %
experimental transmission	73 %	67 %	67 %	50 %
input current	20mA	12.5mA	90 A	70 A
output current	15mA	9 mA	60 A	35 A
accelerated current	x	x	$1.2\ 10^{10}$	8.10^9

The author wishes to acknowledge people who have contributed to the success of the polarized particle program. He is particularly indebted to JP. AUCLAIR, PY. BEAUVAIS, JL. BONY, PA. CHAMOUARD, JM. LAGNIEL and R. VIENET.

REFERENCES

1 - Saturne linac performances in 2 mode for polarized proton acceleration,
PA. CHAMOUARD, JM. LAGNIEL, JL. LEMAIRE,
LNS Saclay (France)
(1981 Santa Fe Linac Conference)

2 - A new way of tuning beam transport lines by using direct search methods
JM. LAGNIEL, JL. LEMAIRE,
LNS Saclay France
(this conference)