SATURNE LINAC PERFORMANCES in 2 βλ MODE for POLARIZED PROTONS ACCELERATION

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Summary

At the last conference, we reported on experimental results of deuteron and helium acceleration achieved with the 20 MeV Saturn linear accelerator operating in the 2βλ mode. This paper gives the results recently obtained with polarized protons accelerated at 5 MeV. Set up of the source, tune up of the very low energy beam transport (15 keV), low energy beam transport (187 keV), linac and high energy beam transport (5 MeV) are also described.

Introduction

The 20 MeV Alvarez linear accelerator, designed initially to accelerate protons in the βλ is able to operate in the 2βλ mode in order to produce particles such as deuterons and heliums having the same kinetic energy per nucleus (5 MeV/A). Nevertheless, the efficiencies in this 2βλ mode operation were behind the expected values, although the total intensity given by the Saturn accelerator was good enough for the particle physics program. In the recent past, experimenters expressed interest for polarized protons and deuterons and a polarized proton terminal has been built. Due to housing and cost considerations, the high voltage terminal was limited to 400 kV which led us to operate the linac in the 2βλ mode. We thus undertook theoretical studies in order to investigate the parameters able to limit the linac efficiency.

Theoretical aspects

Since losses could be explained by a reduced longitudinal acceptance and/or an inadequate quadrupole focusing, we wilful decoupled the two possibilities by considering first the longitudinal acceptance problem, assuming that the quadrupole focusing was correct.

A) Longitudinal acceptance

Using the experimental field gradient law and the corresponding transit time factors in the 2βλ mode, we obtained a theoretical acceptance in disagreement with the experimental one (fig. 1); computer simulation of a located gradient disturbance showed that it could occur in the first 15 cells. Indeed, transit time factors are the lowest in this low energy region. Looking carefully into the position of the 3 frequency tuning balls, we established that the low energy region tuning ball setting was likely to produce the expected gradient perturbation. We further corrected the gradient tuning ball position taking into account the low energy frequency tuning ball setting.

It is clear that this field gradient perturbation was also existing in the βλ mode operation, because of the remote control tuning process, and after correction we could measure the theoretical longitudinal acceptance which proved the real existence of the perturbation. Thus, the linac efficiency using the existing buncher reached 70 % (fig. 2).

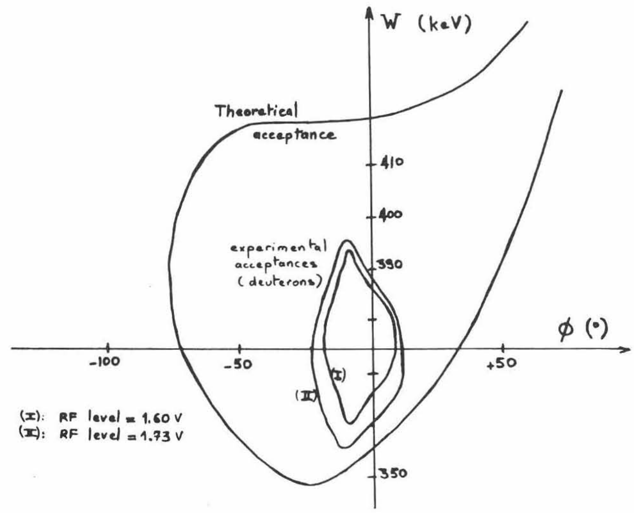
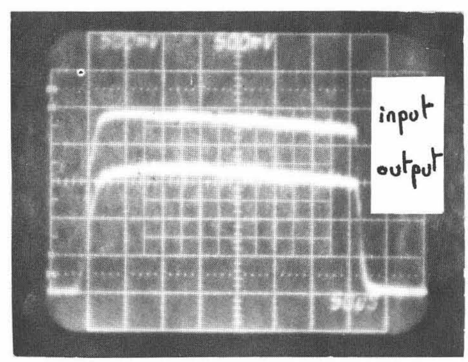


Fig. 1 - Theoretical and measured acceptances in the 2 βλ mode



100 mV/mA

Fig. 2 - Input and ouput intensities in the βλ mode (protons)

Unfortunately, this correction did not give noticeable improvement in the 2βλ mode and as far as this operating mode was concerned the perturbation of the field gradient could not explain entirely the poor efficiency.

B) Transverse focusing effects

The transverse focusing effects have been investigated using the usual stability diagram (ref. 1) in which the transverse defocusing of each accelerating gap is considered to be equivalent to a thin lens and described by the Δ parameter.

$$\Delta = h^2\ \varepsilon\ E\ \frac{e}{m_o \gamma^3 f^2 L}\ \sin\phi\ \sin\frac{h\pi g}{L}$$

while the Θ_o^2 parameter corresponding to the quadrupole focusing in given by

$$\Theta_o^2 = K\ \varepsilon\ h\ \frac{\partial Br}{\partial r}$$

where h is the operating mode

$\varepsilon = q/A$

E is the mean accelerating field

ϕ is the synchronous phase

K is a constant

$\frac{\partial Br}{\partial r}$ is the quadrupole gradient

Recalling that the focusing periodicity is FFDD, we can see that operating point of every cell is stable in the diagram (fig. 3) for the $\beta\lambda$ mode.

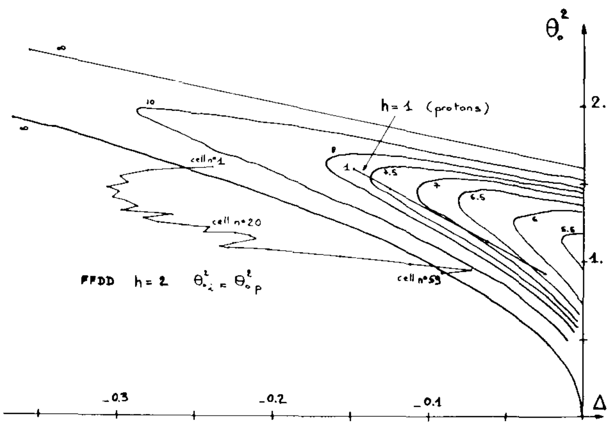


Fig. 3 – FFDD stability diagram, βλ and 2 βλ modes

For any given particles, accelerated in the $2\beta\lambda$ mode one has

$$\Delta_i = \Delta_p \cdot 4\varepsilon_i \frac{E_i}{E_p} \cdot \frac{\sin\phi_i}{\sin\phi_p} \cdot \frac{\sin\frac{2\pi g}{L}}{\sin\frac{\pi g}{L}}$$

where "i" is related to the considered particle and "p" is related to the proton in the $\beta\lambda$ mode acceleration.

Using the relationship :

$$4\varepsilon_i\ E_i\ T_2\ \cos\phi_i = E_p\ T_1\ \cos\phi_p$$

one can write the following expression which gives the parameter Δ_i for any ion accelerated in the $2\beta\lambda$ mode, whatever the ε value. This relationship will permit to represent the operating point of every cell in the same diagram as for protons

$$\Delta_i = \Delta_p \frac{T_1}{T_2}\ \frac{tg\ \phi_i}{tg\ \phi_p}\ \frac{\sin\frac{2\pi g}{L}}{\sin\frac{\pi g}{L}}$$

It is clear from fig. 3 that increasing the quadrupole field would not help, since it is not possible to keep all the operating points in a stable region. This proves that the transverse instability is intrinsic to the present linac and that the only way to avoid it, is to change the focusing periodicity to FDFD.

Figure n° 4 shows that it should be easy to obtain a stable beam provided we increase the quadrupole field by a factor of 2.5 (ref. 2).

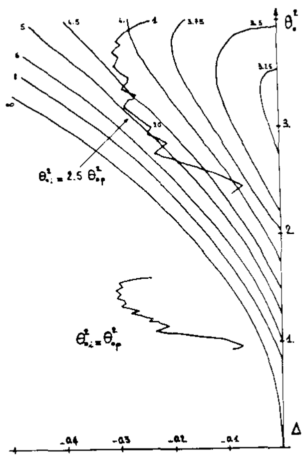


Fig. 4 – FDFD stability diagram, 2 βλ mode

Experimental results

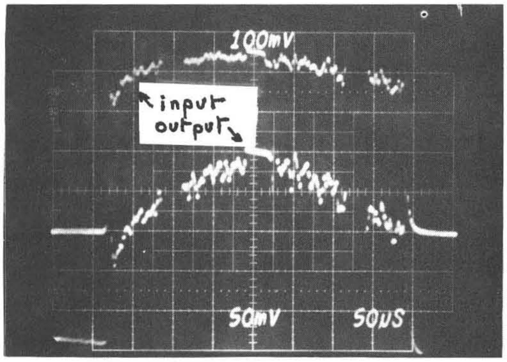
Experimental studies have been carried out with protons produced by the usual preinjector Amalthée, while the polarized proton terminal was under construction.

The new focusing periodicity (FDFD) made possible only proton acceleration, since current requirements are beyond permitted values for the power supplies in the case of deuteron acceleration. New power supplies will replace the old DC ones. They will be pulsed because of the increasing of thermal heating in the quadrupoles ; the drift tubes housing the quadrupoles were filled with a silicon gel in order to insure a good mechanical maintain.

Experimental results with unpolarized protons are given in the following table.

	FFDD Focusing		FDFD Focusing	
$2\beta\lambda$ mode	field level	eff. without buncher	field level	eff. without buncher
with field gradient perturbation	0.8	12.5 %	0.85	30 % (ϕ_s=36°)
without	0.65	12.5 %	0.7	33 % (ϕ_s=39°)

Under this conditions, the linac efficiency with the buncher has been put to 55 % (fig. 5).



100 mV/mA

Fig. 5 - Input and output intensities in the 2βλ mode (protons)

remark : the buncher location has been optimised for h = 1 and is evidently not optimized for h = 2 (This is why the efficiency is only 55 %).

The new type of running has been kept for polarized proton acceleration with the linac. Additional improvements presently under work will be given further down.

HYPERION - Polarized particle preinjector

A) Description

This equipment is dedicated to produce polarized protons and deuterons, but to date, only proton acceleration has been required by the physicist community.

The polarized proton source is installed in a 400 kV high voltage terminal (fig. 6). It contains :

- an atomic source (ground state type) including a dissociator (f = 20 MHz) operating at room temperature;a conventionnal sextupole, longitudinaly tapered;a set of RF transitions (for protons 2 RF transitions (16,2 MHz and 1430 MHz) giving the required 2 polarisation states : they can be replaced by 3 RF transitions in the case of deuteron production given the whole polarisation states : (10,8 - 343 and 415 MHz).

- a high field gradient ionizer supplied by ANAC from which ions are extracted at about 13 keV. The ionizer is running DC. Only the dissociator is pulsed (gas and RF) and operates with a beam pulse width of 20 msec duration.

- an electrostatic beam transport at 13 keV (VLEBT) made of a set of Einzel lenses. Along this transport the longitudinal polarization of the beam coming out of the ionizer is turned to a vertical polarization after the beam is deflected by means of an electrostatic deflector and crosses a solenoïd.

Because of uncertainties on the energy spread of the beam at the exit of the ionizer, the initial spherical deflector giving the 90° deflection has been replaced by an electrostatic mirror of which the transparency is 80 %.

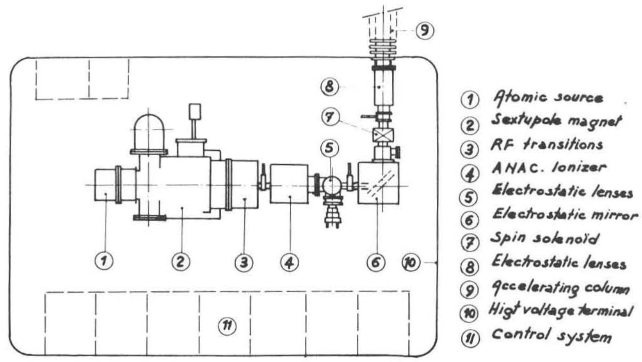


Fig. 6 - 400 kV terminal

This change allowed a better transmission to the accelerating column (low gradient column 4kV/cm)

The beam transport line to the linac needs 4 bending magnet having a deviation of 51° and 2 triplets (fig. 7).

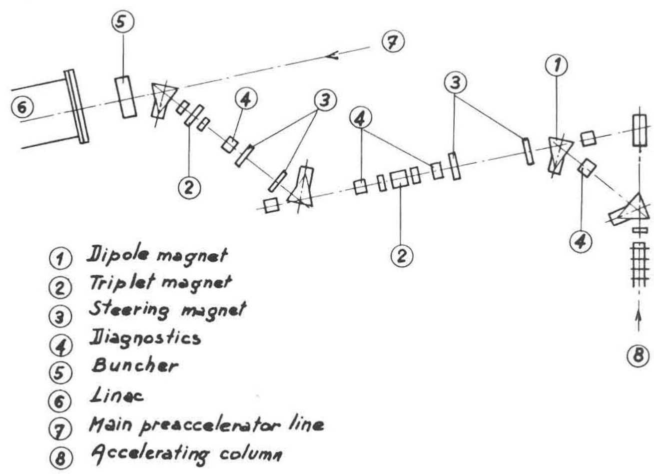


Fig. 7 - Beam transport line to the linac

B) Experimental results

- graphite targets are used to measure the beam intensity (bias voltage of 30 V). The first one is located about 1 meter downstream of the ionizer. Right behind of this target, a bending magnet can provide beam analysing species.

- the other targets and beam diagnostics as scintillators and position detectors are all located after acceleration at 187 keV takes place.

- the following results are given for a standart operation

total ionizer current	40µA	
atomic jet contribution	35µA	
divided in 2 species	28µA	H^+
	7µA	H_2^+
dissociation rate (fig. 8)	80 %	

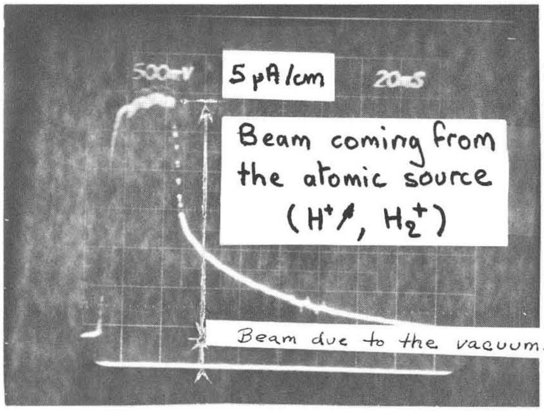


Fig. 8 - Beam coming from the ionizer

- Thus the $H^+ \uparrow$ beam entering the linac is composed of 90 % of protons from the atomic source

beam intensity at linac input	12μA
beam intensity at linac output	6.5μA
linac efficiency	54 %

- This standard beam leads to 4.10^8 accelerated polarized protons per cycle having a polarisation of 80 % measured at 800 MeV.

Improvements to increase the intensity of the polarized source are underway.

- 1°) as shown on fig. 9, pulsed operation of the dissociator did not increase the beam intensity compared to the DC operation mode. Since it is not the case at ANL and at CERN (ref. 3), we do think that it is due to a difference between the bottles used at these labs. Our kind of bottle seems not to be suitable to a fast pulsed gas flow. Consequently a new dissociator device having new bottle and new oscillator has been built and is under test on a bench.

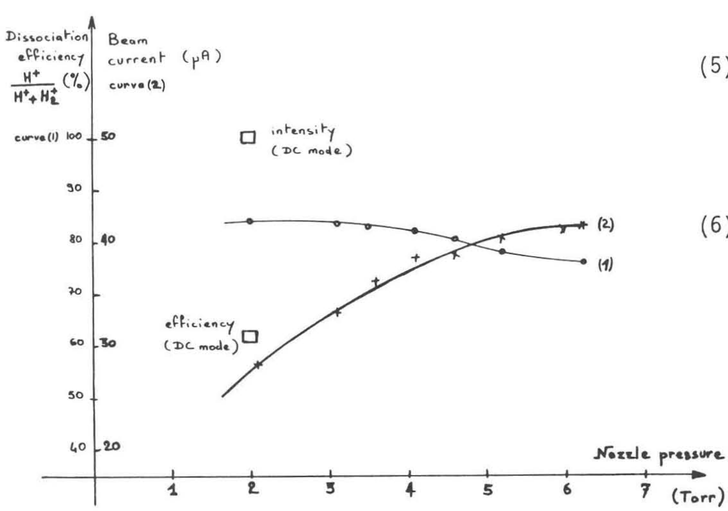


Fig. 9 - Efficiency of the dissociator

- 2°) cooling of the nozzle at 4°K should give a net increase of intensity which combined with the new dissociator will lead to a gain of a factor 2.

Conclusion

As far as polarized proton acceleration is concerned (2βλ operating mode, FDFD periodic focusing) the linac efficiency has been put to 55 %. It was previously 20 % (2βλ operating mode, FFDD periodic focusing). Calculations show that a second single harmonic buncher will improve the linac efficiency up to 80 %. The last bending section will have to be achromatic in order to deal with the momentum spread generated. The achromatism is obtained by 3 quadrupoles and modified magnetic wedges.

The improvements of the source itself combined to the installation of the second buncher will give a factor of 3 in intensity.

In 1982, new pulsed power supplies will allow deuteron operation in the FDFD focusing periodicity and the linac efficiency for this mode would be of the order of 80%.

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