IMPROVEMENT in the 20 MeV BEAM BRIGHTNESS at SATURNE

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Introduction

The performances of the 750 keV preinjector built in Saturne (Saclay) have been already reported (ref. 1). The beam brightness is large for a medium value intensity (50 to 100 mA).

Later we had pointed out that brightness performances are altered during linac acceleration (ref. 2).

Though linac beam intensity is sufficient (about 15 mA) optical beam properties were improved in order to fit the renewed Saturne transversal acceptance with a good factor of security.

The low energy beam line located between the preinjector and the linac was modified according to the following needs :

- a) reduction of beam size in the buncher,
- b) more flexible beam emittance matching with the linac acceptance, taking into account space charge effects.

In this paper, we give briefly the theoretical computation results and we discuss the experimental results.

I - Theoretical aspects

1. Buncher gap radial effect

Electric field across the gap provides a focusing effect leading to the following equation

$$\Delta r' = \frac{\pi}{\lambda} \frac{r}{\beta^3 \gamma^3} \frac{e\hat{V}}{m_o . c^2} . \sin \Phi$$

where :

$\hat{V}$ R.F peak voltage in the buncher

Φ is the particle phase with respect to linac RF

$m_o c^2$

β γ are usual relativist terms

λ is the RF wave length (1.5 m)

r is the distance of the particle with respect to the axis.

This equation states that if Φ is depending on the time the radial effect does too. Consequently the radial emittance is altered (bow-tie) and grows according to the ellipse tilt in the phase space and the beam size in the buncher.

Previously the standard tuning of the low energy-line (.75 MeV) led to a 15 mm diameter beam inside the buncher and therefore to an estimated factor 3 of emittance growth.

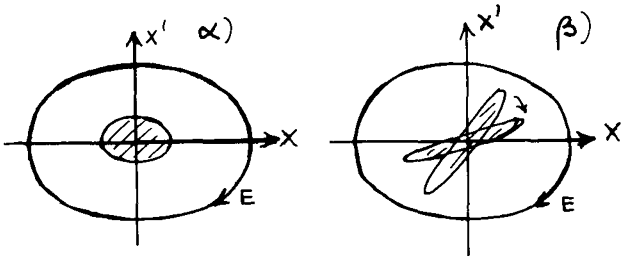
2. Beam matching to the linac entrance.

Calculations have been carried out to define beam matching requirements with transversal and longitudinal space charge (ref. 3).

From the results we can point out the following important remarks :

- a) the beam must be as close as possible to a stationary beam so that its envelope does not oscillate too much.

For example, we can consider radial emittance (x, x')



If we assume that the particles' motion in (x, x') plane is related to the E ellipse (smooth approximation), the beam is stationary if the emittance axis ratio is equal to the E axis ratio (case α). If these conditions are not achieved the beam envelope oscillates with the focusing periodicity and the beam size can be very small in some places giving large non-linear space charge effects.

The numerical calculations show that, for this last case, coupling effects between longitudinal and transversal motion can occur, increasing radial emittance (ref. 4).

One can extend these results to longitudinal motion.

– b) assuming that the beam is stationary the radial emittances at the output of the linac were numerically calculated for different values of the radial and longitudinal emittances at the entrance of the linac. Results are given on figures 1, 2 and 3 for standard beam.

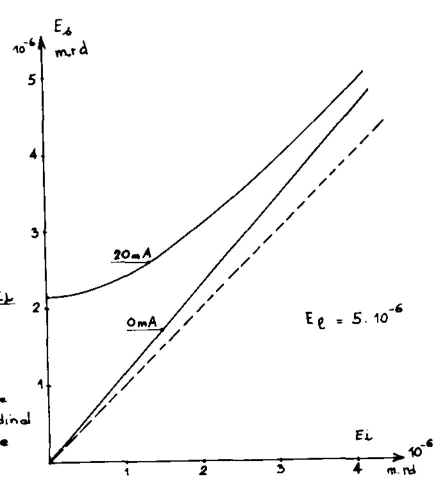


FiG 1

E_s variation versus E_i

E_s out put radial beam emittance

E_i in put radial beam emittance

E_ℓ in put longitudinal beam emittance

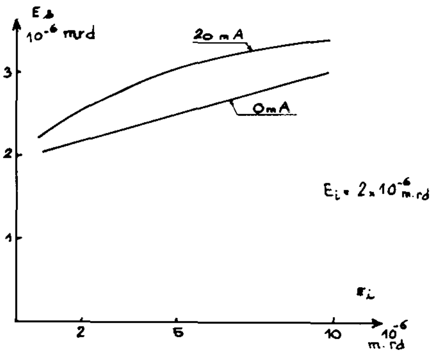
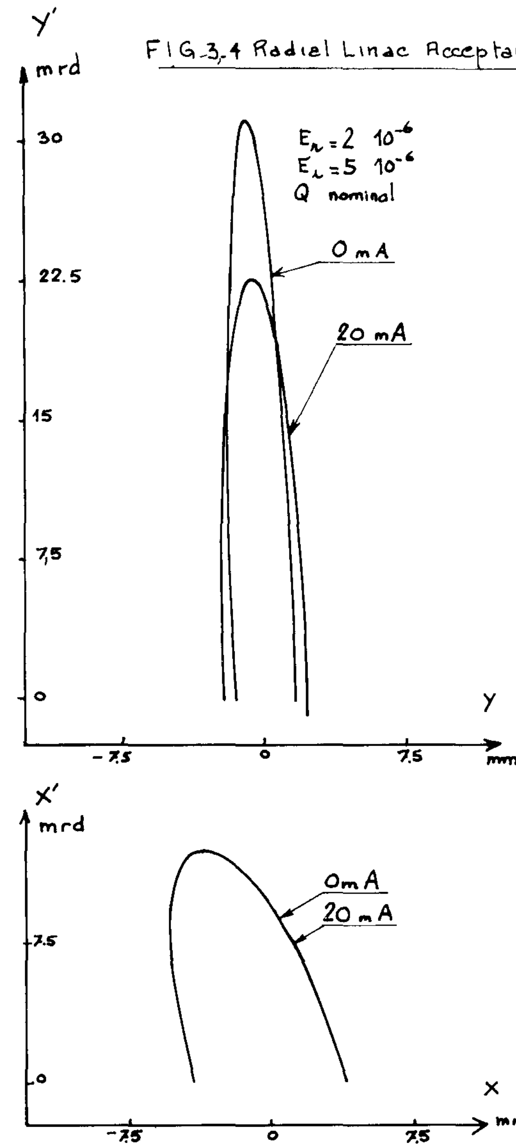


FiG 2

E_s variation versus E_ℓ

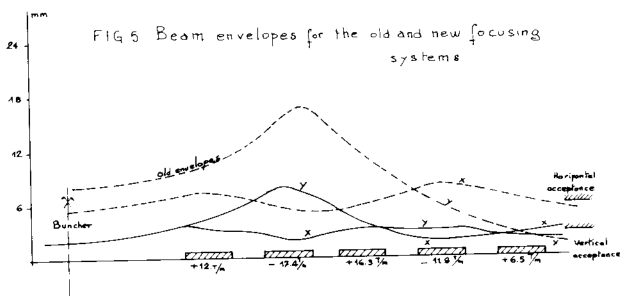
FIG 3, 4 Radial Linac Acceptances



3. New low energy beam focusing line

The triplet located at the entrance of the linac was removed and, now, a quintuplet provides the necessary matching conditions.

The fig. 5 shows the old and the new focusing system. The beam size inside the buncher gap is smaller and the new focusing system provides more flexibility to adjust the beam emittance at the linac entrance.



II - Experimental results

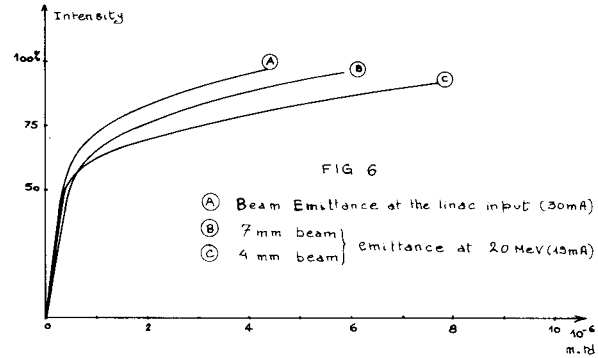
1. 20 MeV beam emittance variation versus beam diameter inside the buncher

For beam diameter larger than 7 mm the output radial beam emittance E_s increases.

For beam diameter equal to 4 mm and 7 mm we have plotted E_s versus intensity on fig. 6 (the output beam intensity is 15 mA).

One can notice :

- a) the 50 percent inner part of the beam intensity emittance is smaller for 4 mm beam size in the buncher and almost equal to the imput radial emittance E_i.



In spite of the fact that this behavior is not clearly shown on the curves the numerical data are very repetitive and well separated.

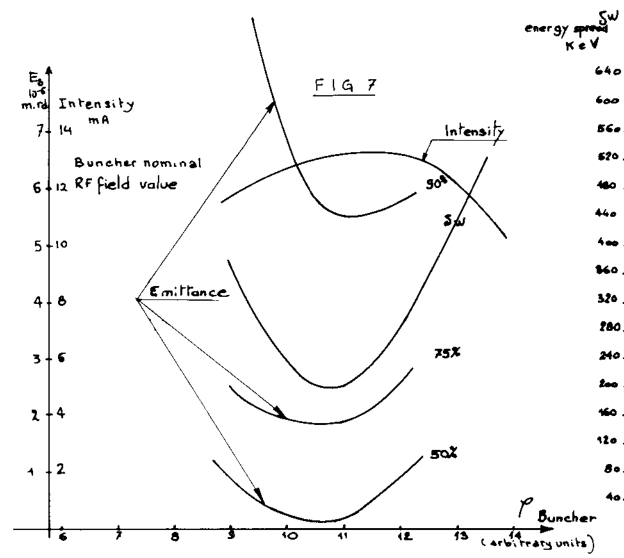
- b) the 50 percent outer part of the beam intensity emittance is smaller for 7 mm beam.

During all these measurements the other parameters had been optimized.

It is important to keep in mind that the beam size variation is produced in the buncher and the emittance measurements carried out at the output of the linac.

2. 20 MeV beam emittance E_s variation versus buncher adjustements -

- a) For standard buncher RF field level value, we change phase value with respect RF linac, the other parameters optimized at each step. The fig. 7 shows the variation of beam characteristics.



A phasis optimum value corresponding to a maximum value for E_s and beam energy spread, and a minimum beam intensity is observed.

The beam behavior could correspond to a stationary beam whose emittance increases if longitudinal emittance increases or becomes mismatched.

- b) If the buncher RF peak voltage is reduced by a factor 30 % (fig 8) it is noticed that E_s and the energy spread have opposite variations one with respect to the other.

The beam is no more stationary in longitudinal direction and emittance transfer occurs from longitudinal to transversal motion.

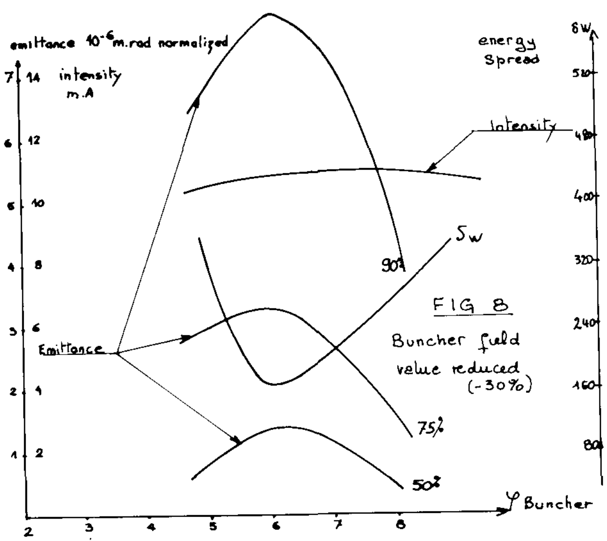


FIG 8 Buncher field value reduced (-30%)

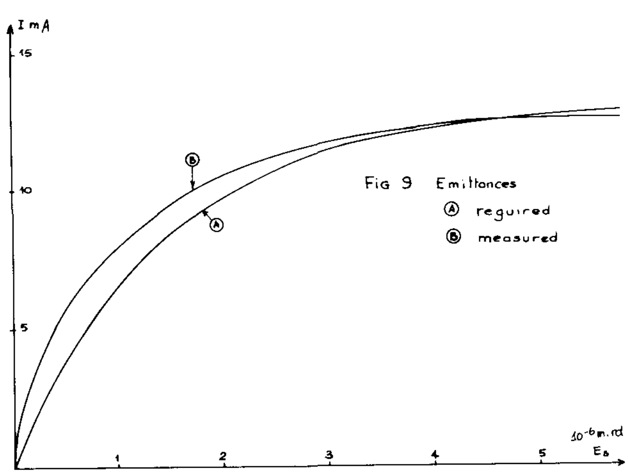


Fig 9 Emittances

Conclusion

We tried to get a growth of emittance factor as small as possible by reducing the beam size in the buncher. This factor is in a good agreement with the theory provided we consider 50 % of the beam, the rest of the beam following a different law. Due to the multiturn injection in Saturne only the heart of this beam is captured and actually we observed higher efficiency after the above described adjustments.

A very crude assumption is that the heart of the beam has a different behavior because the space charge effects are rather more linear than on the edges.

Considering the total beam behavior we can also say that if the space charge acting in the inter space buncher-linac makes the longitudinal emittance grow, according to fig. 2, the total radial emittance at the linac output will grow too. From that it is expected that varying the source brightness (by using a smaller expansion cup size) will still improve the heart emittance and should enable us to distinguish which effect is the most significant.

In addition, fig. 9 shows that the beam properties are adequate for new Saturne injection.

References

(3) Le linac injecteur de Saturne en régime de charge d'espace - SEFS 72/3 par M. PROME,

(4) Effet de la charge d'espace dans les accélérateurs linéaires à protons, thèse de M. PROME.

(1) A 100 mA Ion beam with a large brightness - 1966 Linear accelerator Conference LA 3609, page 395

(2) Complément d'information sur le 20 MeV Yerevan Conference (1969).