MEASUREMENTS ON THE ELETTRA 1.5 GeV ELECTRON LINAC INJECTOR

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Abstract

Measurements of energy gains without and with RF pulse compression, evaluations of energy spread, beam size and stability, confirm the interest of Backward TW electron linacs. The data remains however incomplete today, waiting for full RF pulse availability and more processing time at high gradient.

INTRODUCTION

The 1.5 GeV linac injects electrons in the ELETTRA ring. *Figure 1* is a synoptic which shows the 7 main accelerating units following the 100 MeV preinjector part. Each unit is made of a klystron able (in principle) to delivers 45 MW pulse peak, 4.5 microseconds pulse length, to a compressor with energy storing cavities of high Q=190000. The 0.8 microsecond compressed pulse is then injected to a unique TW accelerating section of adapted filling time. When the wave has reached its end, the acceleration of electrons takes place.

The main interest of this linac is to test in full size, i.e. over 43 meters active length, a new 3pi/4 backward TW multi-structure increasing the energy efficiency for a given power x length product. At the same time the total length being well under the usual value for such high energy linac, its gradient reaches unprecedented levels at full size . See references (1-4).

The first beam at the end of the linac was obtained in August 1993, measurements were made in October 1993 at the time when the ring started to accumulate successfully electrons. Then obviously the emphasis was to keep the linac working smoothly and its energy level was not pushed forward. Some measurements could be made in march 1994. From then no significantly new measurements were made. So this paper represents certainly not the last achievement step of the linac. It presents provisional uncomplete data sets, under the target in energy but for a superior beam quality. They are presented in the two following sections.

ENERGY GAINS WITHOUT AND WITH RF PULSE-COMPRESSION

Energy gain without RF compression

The following table shows the measured RF power at the klystron and the energies measured without compression for S0(the preinjector), S1 to S7(7 units). The total energy gain is 837 MeV (+/-2%?)

	RF power MW	Energy MeV
S0		92
S1	41.3	104
S2	41.4	100
S3	46.4	110
S4	46.3	111
S5	39.1	102
S6	44.6	109
S7	45.0	109
S1-S7	304.1	745
S0-S7		837

To simplify the analysis, we uses an uncommon global "linac shunt impedance" which includes all the losses along the RF chain and from "imperfect" dynamics $Z = V^2 / (PL) = 745^2 / (304.1 \times 7 \times 6.12) = 42.6 M\Omega / m$ which is a rather low value as the section is optimized for the compression mode of acceleration: here, in the long pulse regime, the constant impedance increases slightly the losses along the structure in comparison with constant gradient alternative and, most importantly, its low attenuation of 5.2db (3) lets much power flows from the output to be wasted in the load [Our 10db attenuation 2pi/3 conventional section for IBM-OXFORD injector (5) optimized in the long pulse regime has an higher 46.7 MOhms/m value which means that a lower ratio of unused power over input power more than compensate for the inferior geometry].

If one takes into account only the power consumption along the structures, the values of linac shunt impedances becomes respectively Z=42.6/0.70=60.9 and Z=46.7/0.90=51.2 giving a 19% advantage for the backward geometry.

Energy gain with compression

The linac delivered 1250 MeV in march 1994. The beam was optimized for 70 nanoseconds, 20 mA, behind slit and deviation at 0.7% energy spread. Pulses to >100 nanos. and currents >60 mA are available.
The section S7 delivered 180 MeV in march (power level unknown). This corresponds to 180/6.12=29.4 MeV/m energy gain, highest gradient obtained so far.

The same section delivered 169 MeV in december 1993 for 29 MW at 4.0 micros. klystron pulse. This corresponds to a potentially attainable energy gain of 217 MeV for 45 MW (instead of 29 MW or 1.24 energy gain factor) at 4.5 micros. (instead of 4.0 micros. or 1.03 energy gain factor)

The following table gives the modest set of october 7, 1993, which includes reliable power measurements (higher set of energies alone was later available in routine).The energy slit was set at 1%, the current was set around 20mA, 70 nanos.

	RF power MW	Energy MeV	RF Length microsec.
S0		70	
S1	19.5 (45)	140 (222)	3.90 (4.50)
S2	26.3 (45)	140 (208)	3.11 (4.50)
S3	26.1 (45)	160 (217)	4.02 (4.50)
S4	29.9 (45)	140 (204)	2.81 (4.50)
S5	24.8 (45)	140 (211)	3.19 (4.50)
S6	26.5 (45)	150 (215)	3.34 (4.50)
S1-S6	153.1	870	3.40
S7	34.1?	160	3.42
S0-S7		1 100	

The analysis of these results takes into account S1-S6. Extrapolation figures between parenthesis gives a mean energy per section at nominal conditions of 212.8 MeV and the following shunt impedance including RF chain losses as well as beam dynamics:

$$Z = V^2 / (PL) = 870^2 / (153.1 \times 6 \times 6.12) = 134.6 M\Omega / m$$

The impedance ratio of 134.6/42.6=3.16 gives a 1.78 energy gain due to the compression. It is lower than the 1.90 expected factor as the RF pulse length is 3.40 micros. mean value instead of 4.50 micros.

Figure 2 shows (a) five compressed RF pulses properly delayed in time plus the pulse (b) 14mA pulse after energy analysis.

ENERGY SPREAD, BEAM SIZE AND STABILITY

The beam cross-section after deviation appears in routine with an extension of 2mm in the vertical plane x 6mm in the horizontal plane due to energy spread (9mm corresponds to a 1% energy band). When timing and RF phases are optimized one is able to obtain about 2mm vertical x 3mm horizontal oval shape with a jitter in position (which remains well inside the slit) of +/-0.6 mm [these values are difficult to ascertain precisely as color scale was not properly related to beam densities]. This means that the linac can with proper optimization have <0.2% energy spread stable with <0.2%jitter.
(de-Qing added later improves to 0.1%?).

Simulations with DYPAL code of C.Bourat indicates a 2mm diameter exit beam for 90% of the beam preinjected at 100 MeV with 1 pi mm mrad - increasing to 5mm dia. for 8pi mm mrad. *Figure 3* gives (a) some individual trajectories computed step by step which shows the strong RF focusing, (b) the density enveloppes for all trajectories.

CONCLUSION

The provisional data obtained until now confirm an excellent beam quality and the possibility to achieve (more than) the design energy - with full RF pulse availability if no unexpected gradient or dark current sets limit from 29.4 MeV/m (obtained) to 35.0 MeV/m (goal).

We think that new injectors based on Backward TW optimized for pulse compression are attractive. Due to the part-time very low duty factor, a cost efficient approach could associate nitrogen cooling, multiplying Q by a 4-factor: one would uses a twin modulator, 2 klystrons, simplified compressor cavities at lower mode order near the sections, 4 "long sections" each made of a cascade of 2 BTW sections of the present electrical copper RF design inside steel-jacket modified for input/output thermal isolation.

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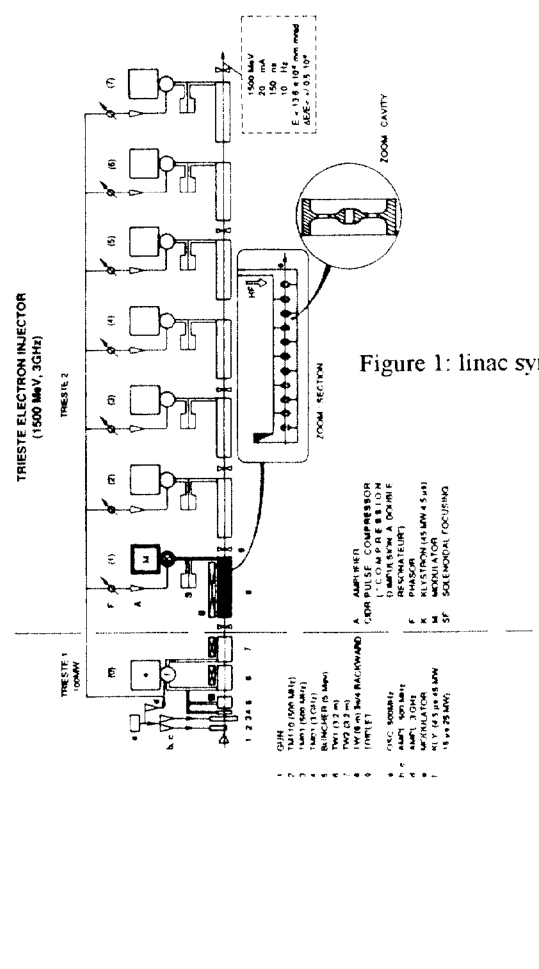
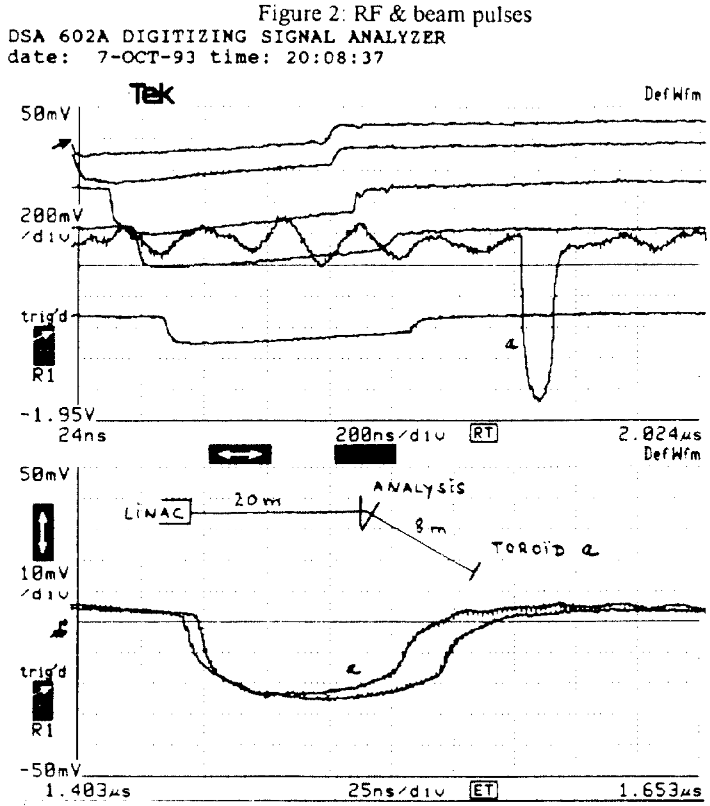


Figure 1: linac synoptic

Figure 2: RF & beam pulses



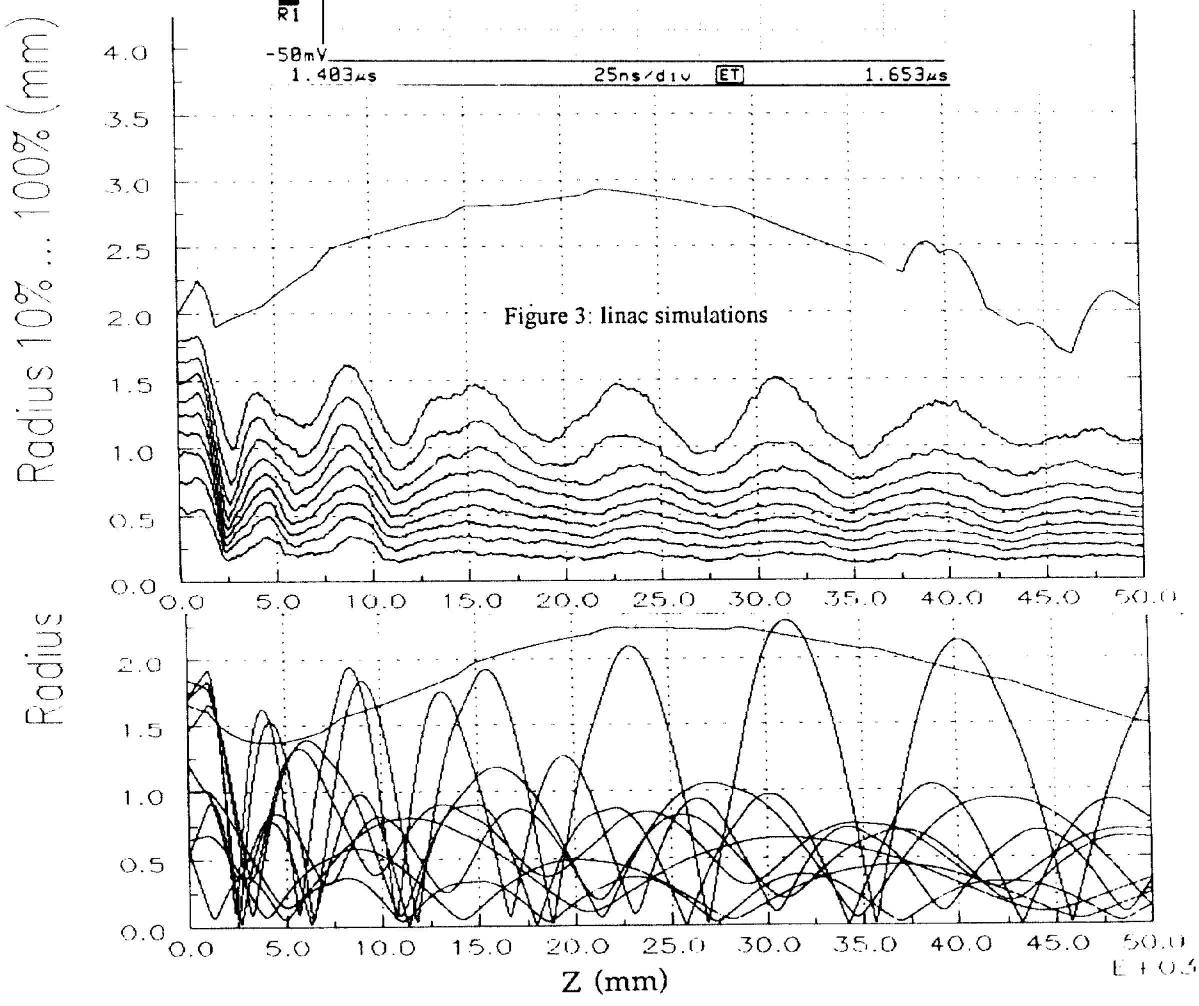


Figure 3: linac simulations