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LNF-88/39NT)
29 Giugno 1988

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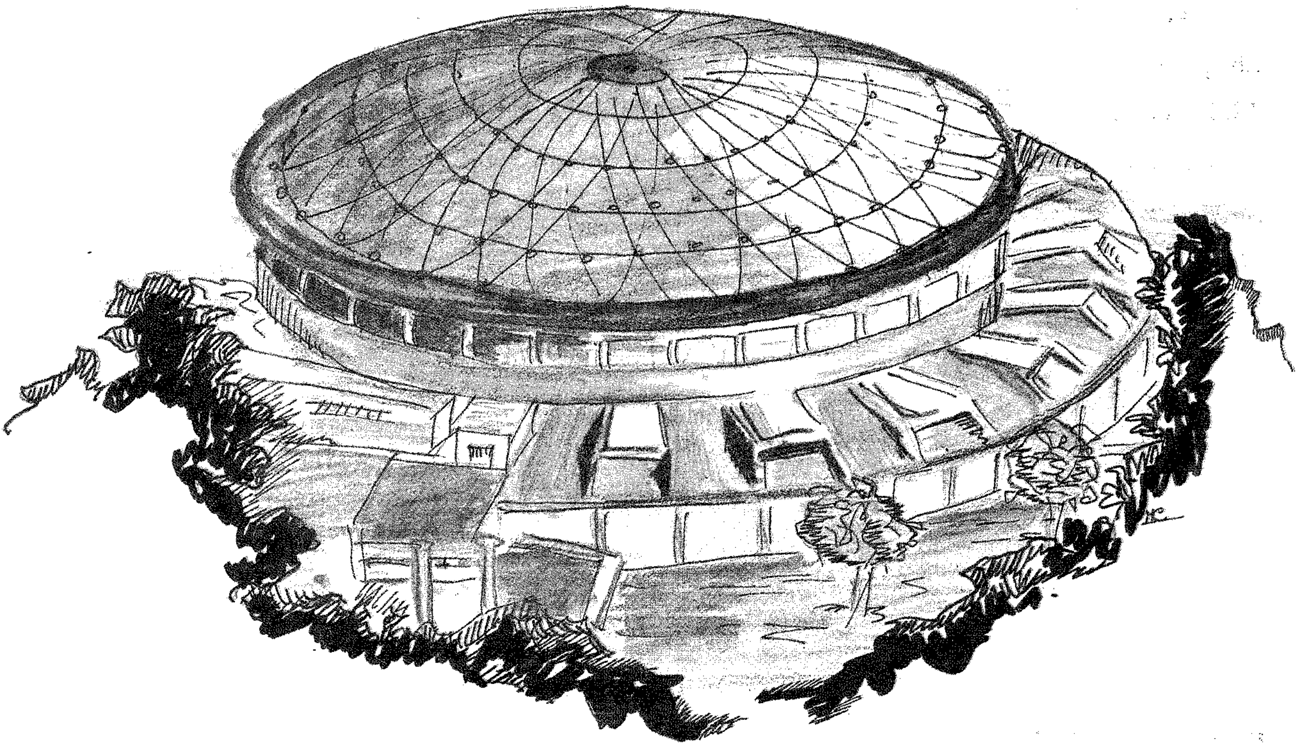
PARTICLE DYNAMICS IN THE 100 keV INJECTOR OF LISA



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PARTICLE DYNAMICS IN THE 100 keV INJECTOR OF LISA

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Introduction

The injector of the LNF project LISA[1] (LInear Superconducting Accelerator) is a room temperature system, consisting of a transport line for the beam at 100keV, of a capture section (a graded β 2.5GHz structure) which accelerates the beam to 1MeV, and of an isochronous and achromatic transport line which injects the beam into the SC-Linac after a π-bending. The elements of the injector up to the capture section have been defined: the gun[2], the chopping system[3], the prebuncher, solenoids and diagnostic elements.

The 100 keV beam from the pulsed gun can be considered continuous (pulse length 1ms). It is chopped by a double system of choppers (50 and 500 MHz) and bunched by an RF cavity at 500 MHz. The maximum current the gun can provide is 200mA; the maximum average current in the SC Linac is 2mA (this limit is set by the available feeding power). An optimization between the chopping angle, $\Delta\phi_{ch}$, and the current extracted from the gun has been performed (120mA extracted from the gun and $\Delta\phi_{ch} = 60°$) in order to obtain the maximum peak current for the injection into tl capture section, peak current which should be mantained during the transport and acceleration up to the FEL experiment.

Simulation of particle dynamics has been carried out for different currents and the beam characteristics at the positions of the diagnostic elements are presented.

Description of the line

A preliminary study of the injector for LISA is described in Ref. [4]. The scheme of the line from the gun to the capture section where the beam will undergo the first acceleration is given in Fig. 1, where the magnetic and electric elements are shown in white, the diagnostic elements in black. Table I gives the list of the different elements, with their lengths and positions; the origin of the distances is taken from the focus of the gun, where the beam envelope has the first minimum.

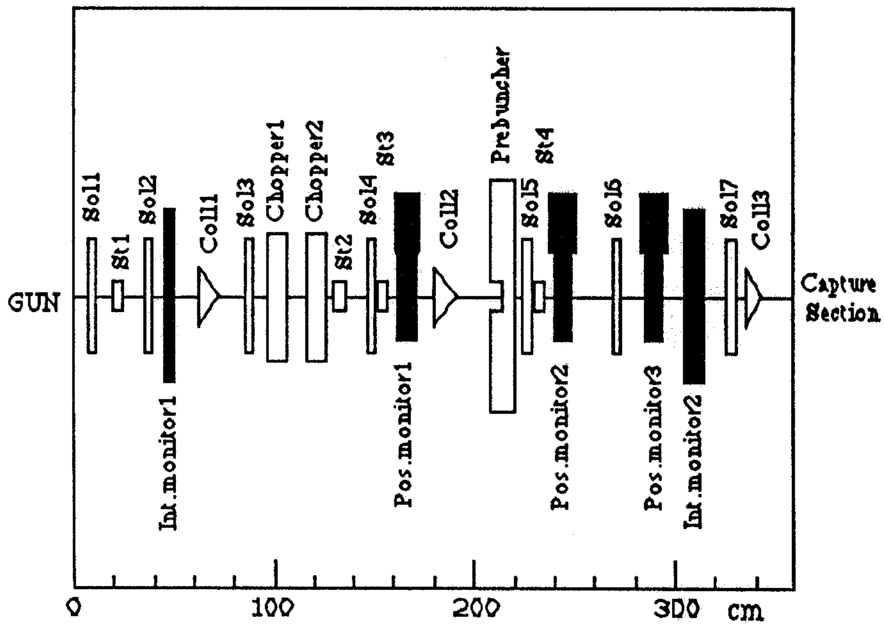

FIG. 1 - Sketch of the 100keV injector line of LISA. Diagnostic elements are represented in black.

TABLE I - Elements of the injection line.

Element	Length (cm)	Position (cm)
GUN		0.0
SOLENOID 1	4.0	7.2
STEERING 1	5.0	19.2
SOLENOID 2	4.0	35.7
INTENSITY MONITOR	5.0	49.7
COLLIMATOR 1		72.7
SOLENOID 3	4.0	85.7
CHOPPER 1	10.0	96.7
CHOPPER 2	10.0	116.7
STEERING 3	5.0	130.7
SOLENOID 4	4.0	146.7
STEERING 4	5.0	152.0
POSITION MONITOR	19.0	166.7
COLLIMATOR 2		190.7
PREBUNCHER	6.0	214.2
SOLENOID 5	4.0	224.7
POSITION MONITOR	19.0	244.7
SOLENOID 6	4.0	269.7
POSITION MONITOR	19.0	289.7
INTENSITY MONITOR	9.0	304.7
SOLENOID 7	4.0	326.2
COLLIMATOR 3		342.0
CAPTURE SECTION		358.2

The gun[2] delivers a pulsed beam of 100keV kinetic energy. The pulse length is 1ms: the beam can be considered as continuous. A double system of choppers[3] is used to select one bunch,

$\Delta\phi_{ch}$ long, over 10 rf periods: the first chopper at 50 MHz chooses one rf period over 10 and the second chopper at 500 MHz cuts the (360- $\Delta\phi_{ch}$)/3.6 % of the selected bunch, so that the total transmission is of the order of 1~1.6% as $\Delta\phi_{ch}$ is between 36~60°. The beam is deflected by the choppers, the deflection is compensated by steerings 2,3 and the selected particles pass through collimator 2. This collimator, indeed, must dump ~99% of the beam coming from the gun.

The prebuncher at 500 MHz gives the particle an energy dispersion of the order of 10%, so that the length of the bunch is led to a minimum at the input of the capture section.

Two other collimators in addition to Coll2 are used to select the emittance before the chopper (Coll1) and before the capture section (Coll3).

The solenoids (Soln, n=1,..7 in Fig. 1) positioned all along the transport line provide transverse focusing.

Particle dynamics along the line

The maximum current from the gun is 200mA[2]. The average current after the second collimator is 2mA, while the current in the micropulse is one order of magnitude larger.

The study of the line has been carried out with a modified version of the program PARMELA for different currents, in order to determine the acceptance of the system in the different working conditions: a first approach without space charge calculations, which can be applied to very low currents, a second calculation with half the maximum current and the case corresponding to the maximum current.

In the original version of PARMELA the dimensions of the mesh that defines the bunch for space charge calculations were stated just once at the input of the program, with the corresponding uncertainties in the computation of the fields excited by the bunch, expecially when the bunch size changes by an appreciable amount during the transport. In the present version the mesh dimensions are corrected to the appropriate value whenever the bunch size change by a factor 1.5 above or below the previous value.

The extremely high quality required for the beam asks for a careful adjustement of all the components of the line from the very beginning. This means that the solenoids should be fed separately in order to adjust the line to the right performance while changing the current. In fact space charge problems influence the bunch transverse dimensions and the longitudinal phase space all along the transport.

The continuous beam has been simulated by a fraction of $\Delta\phi_{ch}$ over the wavelength, with $I_{avg} = I_{gun} * \Delta\phi_{ch}/360°$, where I_{gun} is the current extracted from the gun, taking into account only transverse space charge. The initial distribution in the longitudinal phase plane is uniform in phase. The same beam has been tracked after the second collimator, now including longitudinal space charge forces. In the transverse plane the beam has been represented by an uniform distribution in 4 dimensions (x,x',y,y'). The transverse emittance and dimensions in the focus of the gun have been taken as[5]: $\varepsilon_{x,y}=10^{-5}$m rad; $e_x=e_y=0.5$mm. A total number of 200 particles has been simulated and tracked through the line.

The maximum average current of 2mA in the Linac can be obtained using an extracted beam from the gun of 200mA and a $\Delta\phi_{ch}$ of 36°, or otherwise it is possible to decrease the initial current and to increase correspondingly the chopping angle in order to counteract space charge effects. In fact the longitudinal space charge prevents the squeezing of the bunch to very short lengths at the input of the capture section. If along the distance between the second collimator and the capture section the bunch is longer the space charge effects are weaker for the same total current; furthermore decreasing the current intensity along the distance between the gun and the second collimator the emittance growth due to transverse space charge can be avoided. Calculations with different combinations of I_{gun} and $\Delta\phi_{ch}$ have shown that it is convenient to lower the current and increase the chopping angle, always keeping in mind that the energy spread particles acquire on the prebuncher increases with $\Delta\phi_{ch}$, which means that $\Delta\phi_{ch}$ must not be too large. So finally I_{gun} = 120 mA and $\Delta\phi_{ch}$ = 60° have been chosen.

Table II gives the peak voltage V on the prebuncher and the fields of the solenoids for the different currents: V must be increased when higher currents are transported because of the defocalizing effect on the longitudinal phase plane by the space charge. The strengths of the three solenoids between the prebuncher and the capture section have been relaxed when space charge is included, so that the transverse dimension of the bunch is not too small and consequently it is possible to shorten the bunch without increasing too much the current density. With good approximation the fields necessary for intermediate currents can be deduced from this Table. The intensity B of the magnetic field of the solenoids in Table II corresponds to an uniform distribution of the field and a total length L=4cm; the real solenoids will have a gaussian distribution of the field with σ=1.6cm[6], so that equivalent maximum field is given by $B_G = L/(\sigma\sqrt{2\pi}) * B = 0.99B$.

TABLE II - Fields intensities in the elements of the line.

	I_{gun}=0.	I_{gun}=60mA	I_{gun}=120mA
V(kv)	9.96	10.92	11.592
B_1 (Gauss)	410.	430.	450.
B_2	300.	320.	330.
B_3	230.	250.	260.
B_4	190.	250.	260.
B_5	150.	150.	155.
B_6	75.	100.	100.
B_7	75.	215.	200.

The horizontal beam envelopes are plotted for the different currents in Fig. 2 ; the case with no space charge calculations is indicated with I_{gun}= 0; the cylindrical symmetry in the transverse plane is mantained all along the line, so that the vertical plane has not been represented. Fig. 3 represents the emittances: it should be noticed that the emittance increases when the bunch length shortens, because of the increase in the current density. The bunch length is represented in Fig. 4; the length until the second collimator is only representative: in fact the beam is continuous until that point. The until the second collimator is only representative: in fact the beam is continuous until that point. The envelopes, emittances and bunch lengths correspond to the 90% of the total particle distribution. Figs.5-7 represent the horizontal and longitudinal phase spaces of the beam at the end of the line; they show clearly how the bunch disrupts as the current grows.

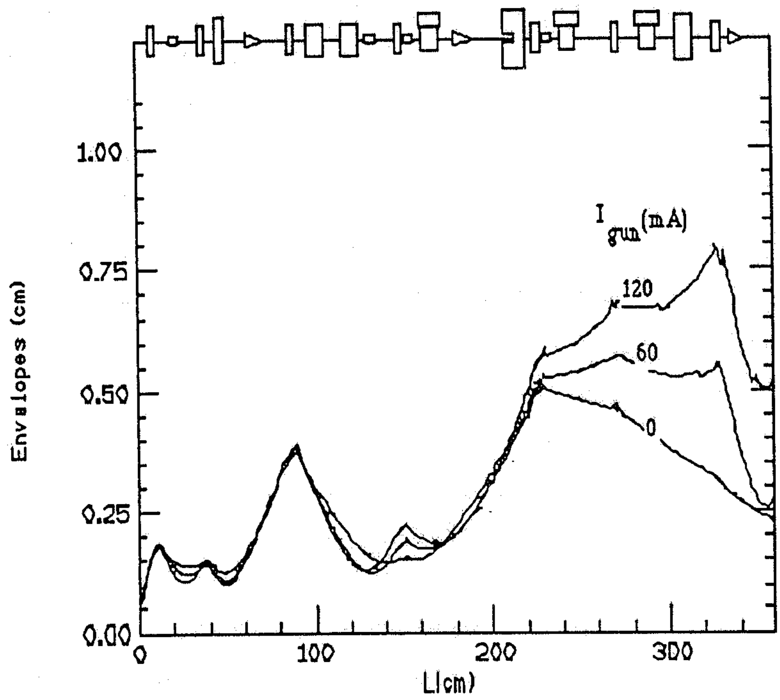

FIG. 2 - Transverse envelopes (at 90%) through the line at different currents.

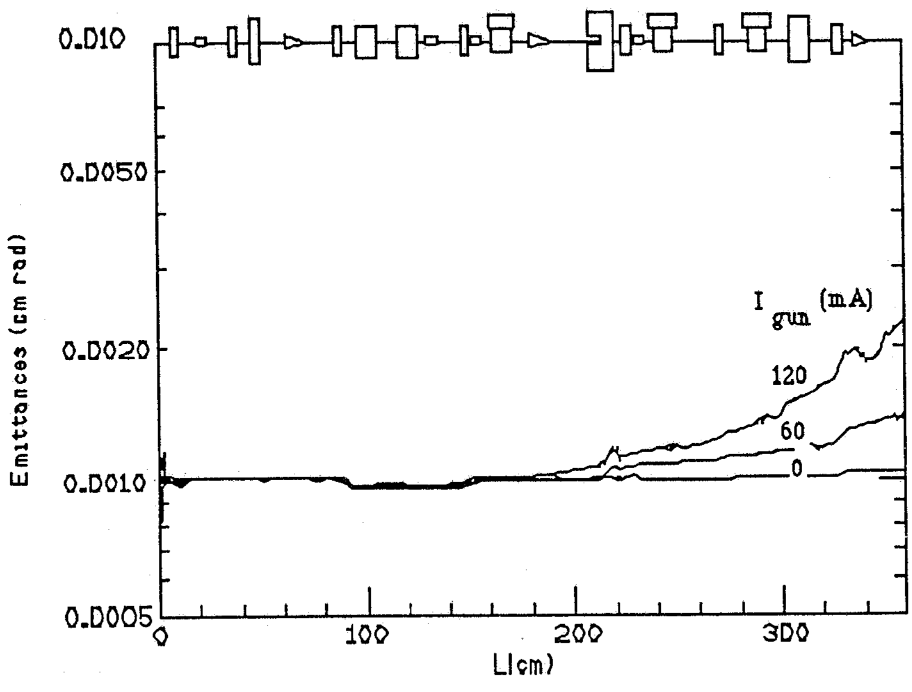

FIG. 3 -Transverse emittances (at 90%) along the line at different currents.

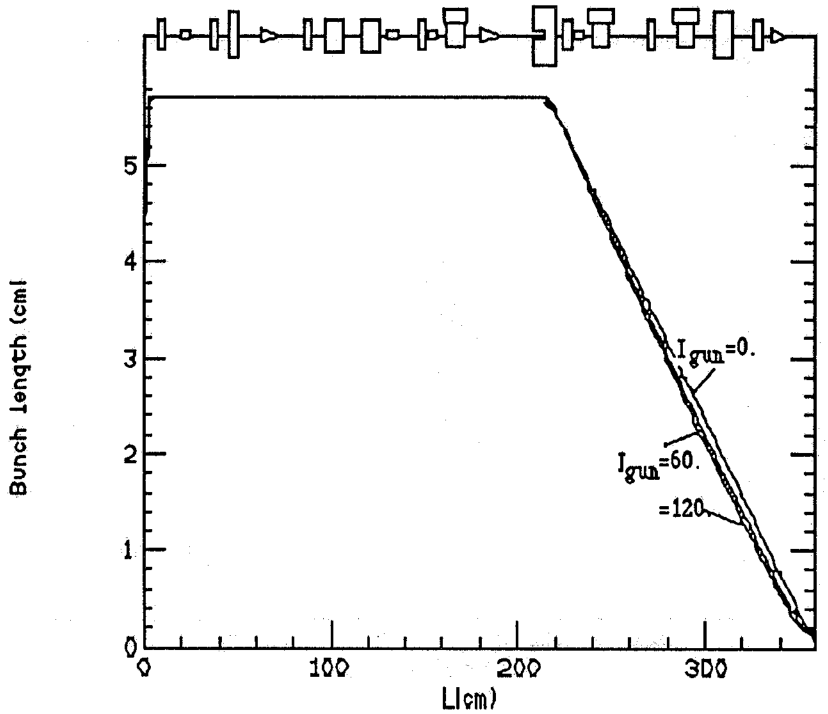

FIG. 4 - Total bunch length (at 90%) along the line for different currents.

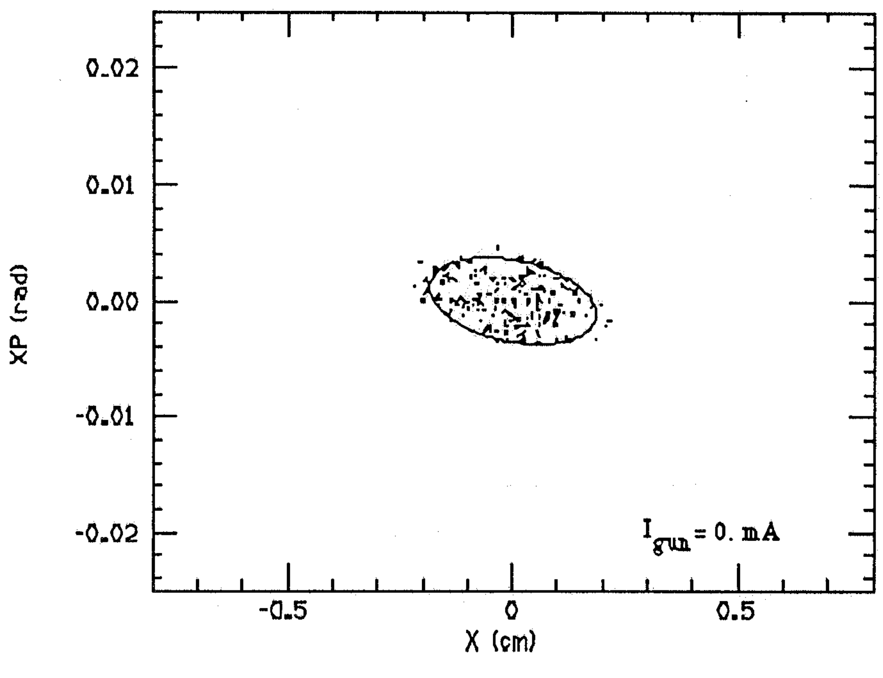

FIG. 5a - Horizontal phase space at the input of the capture section with no space charge.

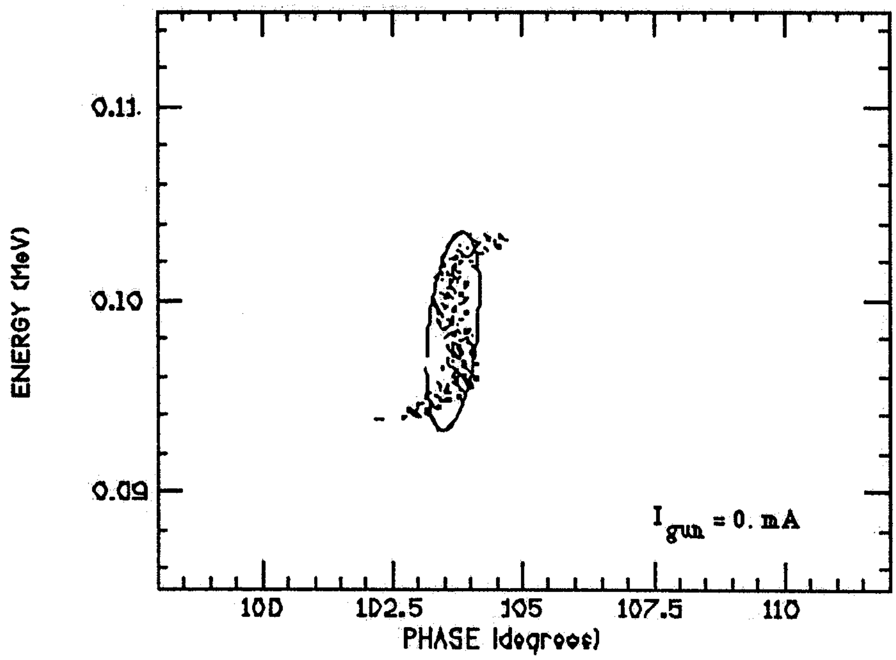

FIG.5b - Longitudinal phase space at the input of the capture section with no space charge.

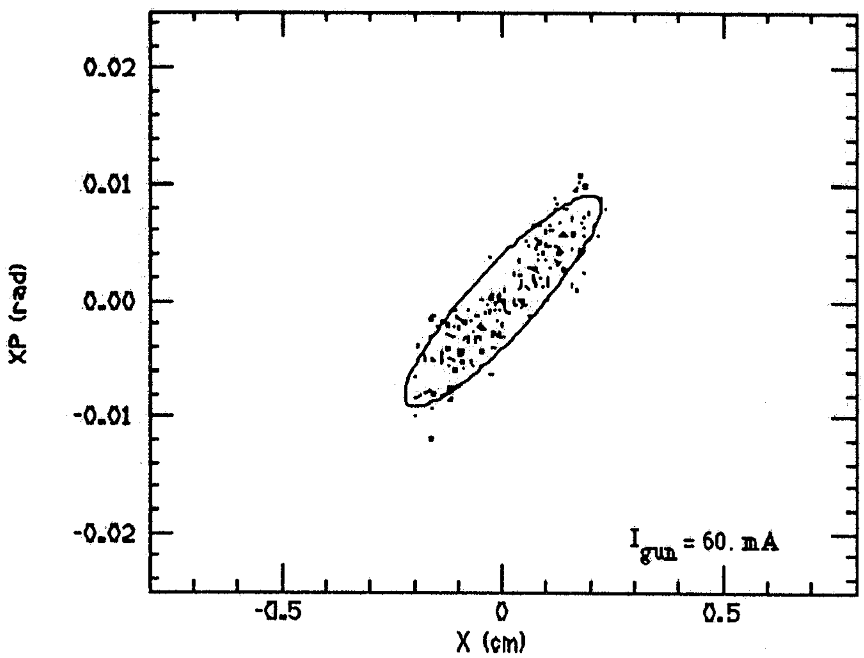

FIG. 6a - Horizontal phase space at the input of the capture section with an average current of 1mA.

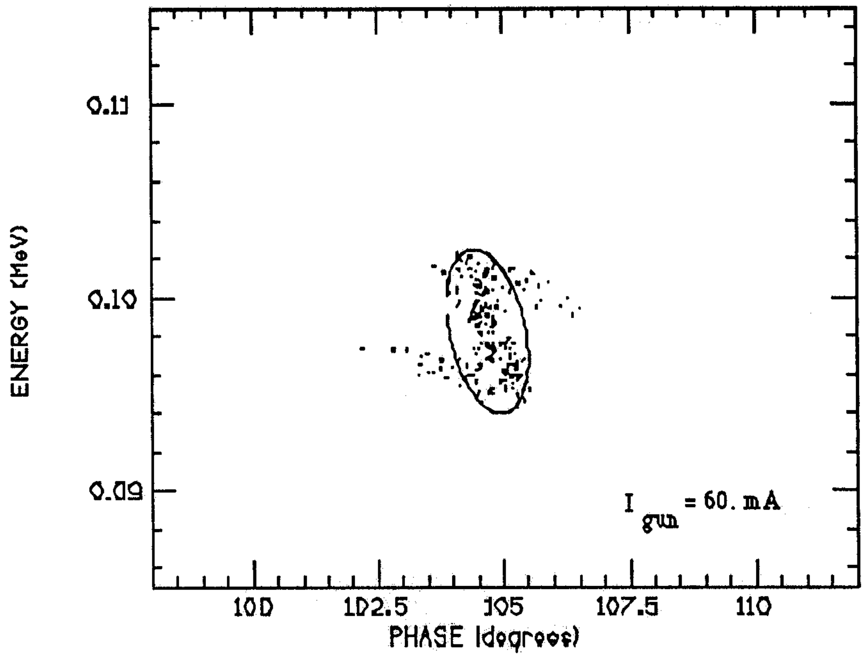

FIG.6b - Longitudinal phase space at the input of the capture section with an average current of 1mA.

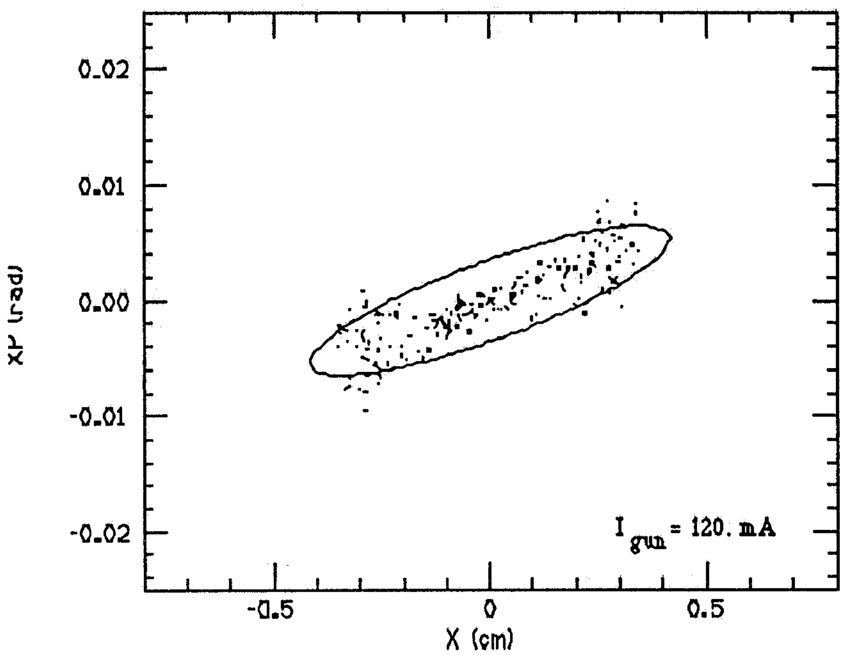

FIG.7a - Horizontal phase space at the input of the capture section with an average current of 2mA.

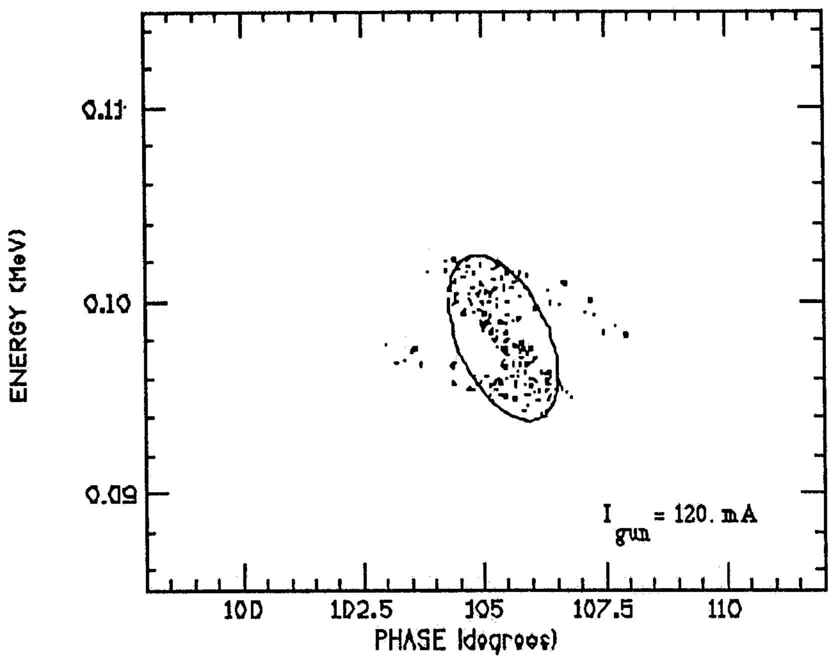

FIG. 7b - Longitudinal phase space at the input of the capture section with an average current of 2mA.

The higher the current, the more difficult to obtain very short bunches at the end of the line, which means that the peak current does not increase as the current emitted from the gun. The final peak current is given by $I_{peak} = I_{avg}*10*\lambda_{RF}*0.90/l_b$, where λ_{RF} is the rf wavelength at 500MHz and l_b is the total length of the bunch (at 90% of the total distribution). At the input of the capture section the bunch with the maximum current has l_b= .21cm, which corresponds to I_{peak} = 5.2A at the FEL if the transport until it were isochronous. When half the current is transported the final peak current is 3.6A.

It should be possible to shorten further the bunch while accelerating it in the capture section with the right choice of the accelerating phase, considering that the space charge forces become less effective as the energy of the particles increases, and that during the transport to the Linac there is a dispersive zone that could be used to bunch further the particles if they exit the capture section with a correlated longitudinal phase space. Anyway the results obtained with the present solution are in agreement with what is expected for a satisfactory performance of the FEL[7]. If the requirements on peak current are relaxed it is possible to obtain a smaller transverse envelope at the input of the capture section and to decrease the transverse emittance growth.

Diagnostics

The elements for beam diagnostics have been positioned as indicated in Fig. 1 and specified in Table I. There are two current intensity monitors, one after the gun where the beam is still continuous and the second one not far from the capture section, where the bunches are of the order of 30° length. Three targets or position monitors are positioned between the prebuncher and the capture section; they should be used also to measure transverse emittances. For sake of ease in the design and expected performance of the different diagnostic elements Table III summarize the expected characteristics of the bunch at the central position of each element and in the final point of the line: transverse dimension and emittance, bunch length, energy, energy spread, average and peak current.

TABLE III - Beam characteristics in the diagnostics and at the input of the capture section.

	I=0.0	I=60mA	I=120mA
1st intensity monitor			
Transverse envelope (cm)	0.10	0.11	0.13
Transverse emittance (cm rad)	1.0e-3	1.0e-3	1.0e-3
Bunch length (cm)	continuous	continuous	continuous
Phase spread (°)	"	"	"
Average energy (keV)	100.	100.	100.
Relative energy spread	1.e-3	1.e-3	1.e-3
Average current (mA)	/	60.	120.
Peak current (A)	/	0.06	0.12
1st position monitor			
Transverse envelope (cm)	0.17	0.18	0.19
Transverse emittance (cm rad)	1.0e-3	1.0e-3	1.0e-3
Bunch length (cm)	continuous	continuous	continuous
Phase spread (°)	"	"	"
Average energy (keV)	100.	100.	100.
Relative energy spread	1.e-3	1.e-3	1.e-3
Average current (mA)	/	60.	120.
Peak current (A)	/	0.06	0.12
2nd position monitor			
Transverse envelope (cm)	0.48	0.52	0.59
Transverse emittance (cm rad)	1.0e-3	1.1e-3	1.1e-3
Bunch length (cm)	4.54	4.44	4.54
Phase spread (°)	50.	49.	50.
Average energy (keV)	98.3	98.1	98.0
Relative energy spread	9.8e-2	10.5e-2	10.8e-2
Average current (mA)	/	1.	2.
Peak current (A)	/	0.12	0.24
3rd position monitor			
Transverse envelope (cm)	0.39	0.52	0.66
Transverse emittance (cm rad)	1.0e-3	1.1e-3	1.3e-3
Bunch length (cm)	2.74	2.54	2.54
Phase spread (°)	30.	28.	28.
Average energy (keV)	98.3	98.1	98.0
Relative energy spread	9.8e-2	10.2e-2	10.0e-2
Average current (mA)	/	1.	2.
Peak current (A)	/	0.21	0.43

TABLE III - (continued)

2nd intensity monitor			
Transverse envelope (cm)	0.35	0.51	0.68
Transverse emittance (cm rad)	1.0e-3	1.2e-3	1.4e-3
Bunch length (cm)	2.19	1.99	1.99
Phase spread (°)	24.	22.	22.
Average energy (keV)	98.3	98.1	98.0
Relative energy spread	9.8e-2	10.0e-2	10.0e-2
Average current (mA)	/	1.	2.
Peak current (A)	/	0.27	0.54
Input capture section			
Transverse envelope (cm)	0.23	0.27	0.51
Transverse emittance (cm rad)	1.0e-3	1.3e-3	2.2e-3
Bunch length (cm)	0.09	0.145	0.210
Phase spread (°)	1.0	1.6	2.3
Average energy (keV)	98.3	97.6	97.6
Relative energy spread	9.8e-2	7.8e-2	8.2e-2
Average current (mA)	/	1.	2.
Peak current (A)	/	3.7	5.2

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