Design Study For The ELFA Linac

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Abstract

The accelerator for ELFA must provide a 6 MeV electron beam to drive a single pass free electron laser at 100 GHz.

The 1.3 GHz linac will operate at low repetition rate (10 Hz) and short macropulse (2 ns) and should provide peak current over 50 A.

The envisaged accelerator includes a gridded electron gun, a prebuncher and a multicell bunching/accelerating section.

The general characteristics of the accelerator and the expected performances, as evaluated by beam dynamics studies, are presented.

I. Introduction

ELFA (Electron Laser Facility for Acceleration) is a high gain, single pass free electron laser designed to operate in the microwave region (100 GHz) to explore fundamental FEL physics with short bunches.

The project has been revised in 1992 to obtain a reduction in cost, schedule and technical risk while maintaining the physic goals of the original proposal. A detailed rewiew of the project is presented elsewhere at this conference [1].

The minimum beam characteristic satisfying the above requirements are reported in Table I.

The micropulse length of 35 ps, corresponding to three optical wavelength of the 100 GHz radiation, implies the choice of a L-band (1.3 GHz) accelerator in order to minimize the micropulse energy spread.

Table I- Beam parameters

Nominal energy	6 MeV
Peak current	> 50 A
Energy spread, rms	< 1%
Norm. rms emittance *	< 50 π mm mrad
micropulse length	>35 ps
number of micropulses	3
repetition rate	10 Hz

* $\varepsilon_{nrms} = \beta\gamma\,\sigma_x\sigma_{x'}$

II. The accelerator

The specifications of table I can be easily met and exceeded by a photocathode RF gun of the type in operation at Los Alamos.

It was felt however that a photocathode RF gun requires a considerable staff effort to be developed and operated. Also, the cost and delivery time can be kept at minimum with a more conventional configuration.

The preference is therefore versus a design that allows the option to buy a commercially available technology and to concentrate the efforts on the experiment.

The design study has been focused on an accelerator with

- a gridded electron gun
- a prebunching cavity at the fundamental frequency
- a bunching/accelerating section

A scheme of the accelerator is shown in fig 1. The main components are described in the following.

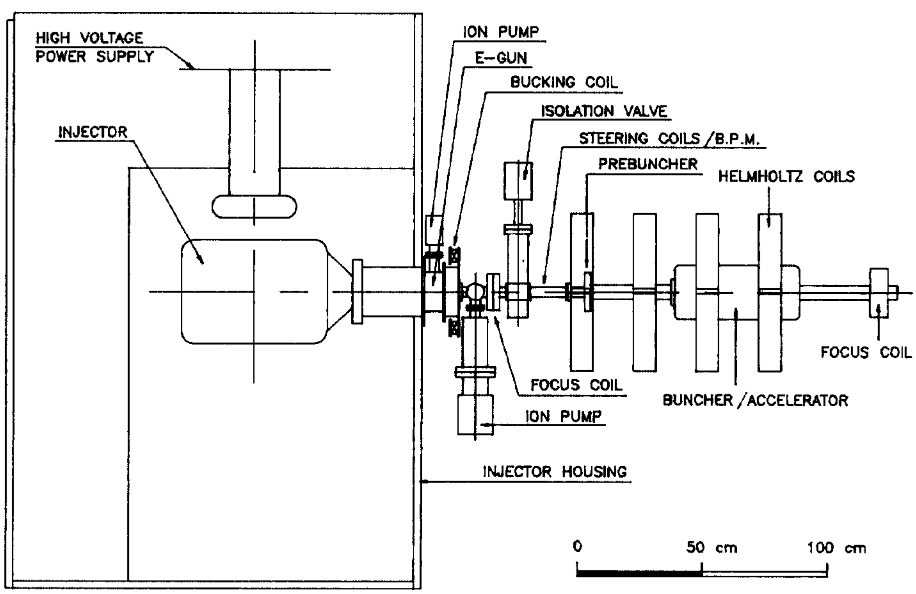

Fig. 1. Schematic view of the accelerator.

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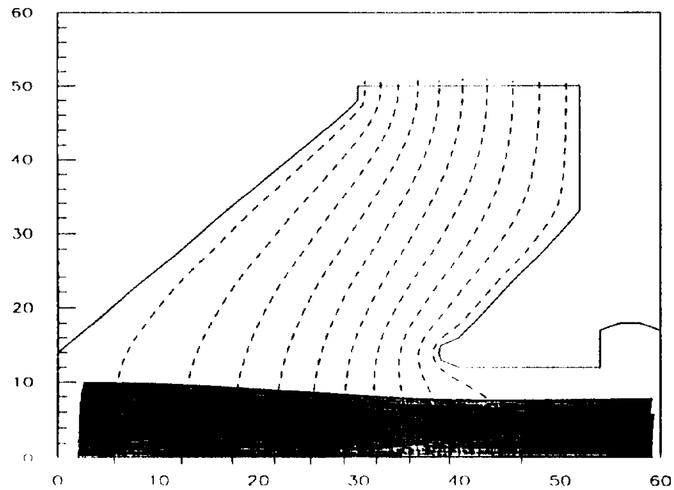

Fig. 2. Electron beam trajectories in the gun. Voltage 120 kV, I= 11 A. Units in mm.

Electron gun

The electron source is a standard, high current gun of the type now in use at SLAC. At 120 kV it should provide up to 10 A pulses with a flattop of 2 ns and subnanosecond rise and fall time.

The gun is a classical Pierce gridded gun with a 3 cm^2 thermoionic dispenser cathode . The grid is expected to intercept less than 20% of the cathode current.

The geometry and the performances of the gun have been evaluated with the EGUN code[2]. The geometry indicated in fig 2,according to the EGUN simulation, gives 11 A corresponding to a perveance .27 μP.

The calculated emittance at exit of the gun, including the thermal effects, is $\varepsilon_{nrms} = 3\ \pi$ mm mrad. A realistic value for the emittance, assumed as nominal value for the beam dynamic evaluation, is $\varepsilon_{nrms} = 5\ \pi$ mm mrad when considering the grid lens effects.

At the gun exit the beam has an edge radius r =.8 cm and is very close to a waist.

Prebuncher

After a drift of 40 cm from the exit of the gun, to allow for pumping and isolation valve, the beam is focused with a thin solenoidal lens to the prebuncher.

The prebuncher will operating at the fundamental frequency of the linac, 1.3 GHz, and should have a peak energy gain up to 40 keV. To minimize the effects of beam loading a low Q value is desired; the peak power should be of the order of few kW.

The prebuncher should compress more than 50% of the beam in 60° RF at the entrance of accelerator located 40 cm downstream.

Bunching/accelerating section

A travelling wave, $2\pi/3$ mode, SLAC type structure has been investigated to bunch and accelerate the beam at 6 MeV.

The section is very short (two wavelengths) and is not graded although the beam at entrance has $\beta = 0.6$.

The structure has a round shape to further increase the shunt impedance and to avoid possible multipactoring problems. A schematic tridimensional view of the structure, including the entrance and exit couplers, is shown in fig. 3.

The required accelerating gradient is 15 Mv/m and the corresponding peak surface field is $\approx$ 30 MV/m. The quality factor is Q = 22000 and the group velocity is $v_g \approx 0.5\%$.

This section will operate in the storage energy mode with a single pulse beam loading of $\approx$ 0.5%

An alternative approach for the accelerating section is to use a 4 cells standing wave cavity operating near the π mode. The proposed structure has a shape similar to that used for superconducting cavities with a large bore .

The quality factor of the structure is Q = 30000. The peak values of the electric field are 25 MV/m on axis and approximately 50% more on the surface. The corresponding dissipated power is 2.5 MW. The stored energy is 9 J; the corresponding bunch to bunch energy variation should be less than 0.25%.

A detailed description of the design and test of the prototypes for these two structures is given elsewhere in this conference[4].

Both types of structures (as well as other standing wave types) are suitable for the accelerator. The main drawback of the TW structure is the need of a careful design and realisation of the input and exit cell and couplers in order to avoid, especially at the entrance, the dipole field component.

RF system

A klystron, with 5 MW of peak power and 8 μs pulse, at 10 Hz repetition rate, should be sufficient to power the linac for all the possible structures choices (TW or SW).

Particularly important for the experiment is the pulse to pulse repeatibility of the beam characteristics; the amplitude jitter of the klystron should be of the order of 0.1%.

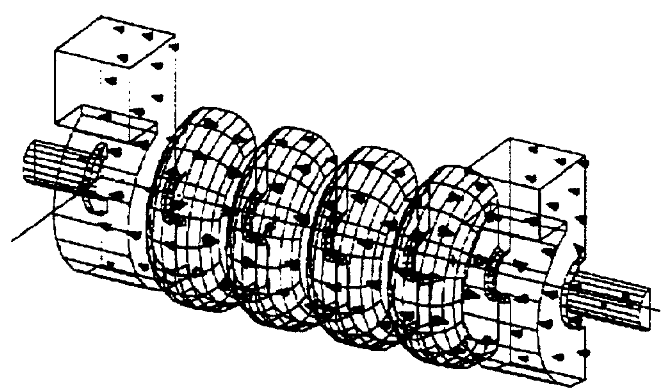

Fig. 3. Tridimensional view of the TW section.

III. Beam dynamics

The beam dynamics has been studied with the code PARMELA[3] which simulated the motion of the electrons in RF cavities (and along beam line) including transversal and longitudinal space charge effects.

The study has been carried out for the following configuration:

- gun at 120 kV,10 A extracted current, beam radius (edge) 8.5 mm, edge emittance 30 π mm mrad (ε_{nrms} =5 π mm mrad)
- focusing solenoid (peak field 300 Gauss) placed 15 cm after the exit of the gun
- prebuncher with a peak energy gain 22 KeV
- a 6 cells, $2\pi/3$ mode, travelling wave section with an accelerating gradient of 15 MeV/m
- focusing solenoids providing up to 1.1 Kgauss peak field at the center of the accelerating section

The beam produced by the gun is focused at the prebuncher location and then refocused at the entrance of the accelerating section.

Here the beam emittance has increased to ε_{nrms} =15 π mm mrad, due to space charge and to RF coupling effects in the prebuncher, and 75% of the bunch is compressed in 120° RF.

The RF phase of the section is chosen to maximize the bunching process, which is completed in the first cell where the beam reach the energy of .9 MeV, and to minimize the energy spread of the final beam.

The phase plots and the beam profile at the exit of the accelerator are shown in fig. 4. The capture efficiency, 75%, is quite high and this implies long tails in the phase and energy profiles as partialy shown in the figure.

Considering the core of the beam, i.e. the beam included in 30° RF around the peak density, as shown the figure, the capture efficiency is 60% (620 particles of the 1000 simulating the bunch) and the corresponding peak current is close to 75 A.

The rms normalized emittance is 30 π mm mrad and the full width energy spread of the beam core is 200 keV corresponding to an rms enrgy spread of 0.8 %.

An optimization of the beam dynamics inside the accelerating section should improve the energy spread and the pulse length (i.e. the peak current) of the beam core.

Comparable values can be obtained with a standing wave section with a proper tailoring of the field in the first cell.

These results are consistent, or even better, with the minimum requirements of the beam also when allowance is given to tuning errors and beam loading effects in the accelerator.

The long tails of the pulse, in energy and phase, should be removed by scraping or by an analysing system along the beam transport and matching line to the wiggler.

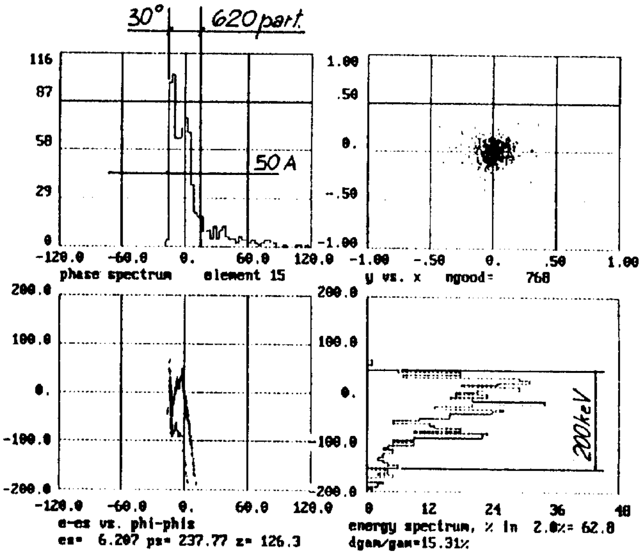

Fig. 4. Phase space plots at the exit of the accelerator. Beam energy 6.2 MeV. Units: cm, mrad, RF°, keV.

IV. Conclusions

The design study has shown that the beam specifications can be met with a conventional accelerator and with different thecnical solutions (SW or TW).

More detailed investigations will be carried out in order to determine if there are clear advantages, in term of performances, cost, reliability and operation, for some specific configuration.

As already mentioned the accelerator will be ordered as a turn-key machine upon approval and funding of the project.

References

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[2] W. B. Herrmansfeldt - EGUN - SLAC Report 331 (1988)

[3] K.R.Crandall and L.Young - PARMELA - unpublished

[4] G.Bellomo et al. - Design and test of prototype cavities for the ELFA linac - these Proceedings