PERFORMANCE OF THE FELIX ACCELERATOR.

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Abstract

The FELIX project (Free Electron Laser for Infrared eXperiments) involves the construction and operation of a rapidly tunable FEL users facility for the infrared based on a rf linear accelerator. Lasing was obtained in the summer of 1991. The spectral region already covered is between 16 and 110 μm to be extended to below 8 μm with an additional linac section. We present measurements of several electron beam parameters along the beam line.

1. INTRODUCTION

FELIX is built up as follows: A 100 kV thermionic triode gun delivers 46 mm long electron bunches at 1 ns intervals which are compressed to 7 mm by a 1-GHz prebuncher, to 0.9 mm at 3.8 MeV by a 3-GHz buncher, and further accelerated by two 3-GHz travelling-wave linacs. One magnetostatic undulator of 38 periods of 65 mm has been placed behind the first linac (15-25 MeV) and covers the spectral range from 16 to 100 μm. An identical undulator will be placed behind the second linac (25-45 MeV) for the range from 8 to 30 μm. The first part of the injector is shown in fig 1. As variations of beam parameters during the macropulse change the wavelength and impede the build-up of the power, all beam parameters should remain stable within the 20 μs macropulse. In the near future, feed forward control will be used throughout the system to correct for the residual phase and amplitude variations in the output of the various pulsed rf sources. The rf system and the FEL performance are subjects of accompanying papers[1],[2]. We also present first results of FELSIM, an in-house developed particle simulation code for elements in which the E and B fields are known. It employs an exact 3D space charge routine [3] and allows particles to go back.

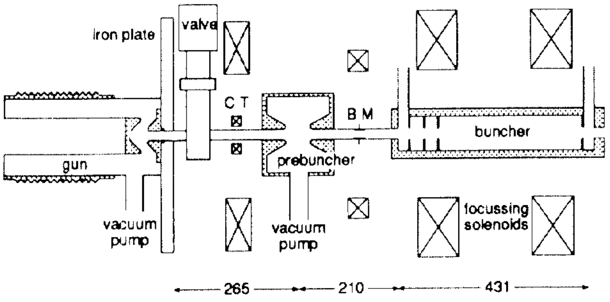

Fig.1 Schematic view of the FELIX injector. Dimensions are in mm. CT is current transformer, BM is Button Monitor.

2.THE GUN

The 100 keV triode electron gun has a thermionic cathode. Common-grid Class-C modulation at 1 GHz is used to obtain the initial 46 mm long bunches (280 ps) of 220 pC. The measured emittance is 32π mm-mrad[4]. A compensation voltage, applied to the grid in series with the grid bias supply, is used to correct for the current droop during the macropulse, due to a droop in the output of the 100 W solid state pulsed rf-driver (fig. 2). The output phase of the driver is stabilized by means of a voltage controlled phase shifter at the input. A more powerful rf amplifier has been ordered for experiments with very short initial bunch lengths. The new amplifier will also allow fast amplitude modulation of the output.

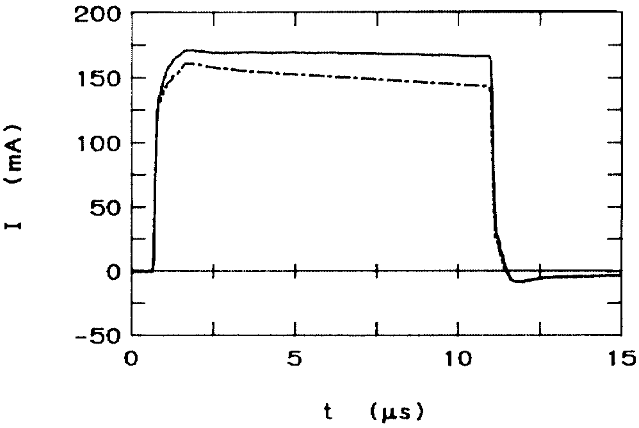

Fig.2 Uncorrected and corrected current pulse. The correction pulse used was of the form $V_0(1-\exp(-t/\tau))$ with V_0=7V and τ=6μs.

3. THE PREBUNCHER,

is a capacitively loaded re-entrant cavity operated in the TM_{010} mode with a field strength of about 1 MV/m over a gap of 50 mm. The optimum drift distance is about 0.20 m. The prebuncher is made of stainless steel in order to achieve a relatively low Q (around 1000), which reduces the influence of beam induced fields, and is equipped with a plunger giving a tuning range of 997-1004 MHz. It is powered by a 5-kW, 1-GHz amplifier (Varian). A bunch length of 25 mm (150 ps) halfway the drift space between the prebuncher and the buncher and an emittance of 40 π mm mrad have been measured[5],[6]. Later 'pragmatic tuning' has shown, that the best energy spectra are obtained at a higher power level than originally anticipated. With our new FELSIM code we also find a higher optimum value for the prebuncher voltage V^{pb}, 0.86 MV/m against 0.65 MV/m. Fig 3. shows the calculated bunch length in the drift space behind the prebuncher for the two values of V_{pb}. The specific modulation of the gun, the measured initial emittance and the actual guiding field are all taken into account.

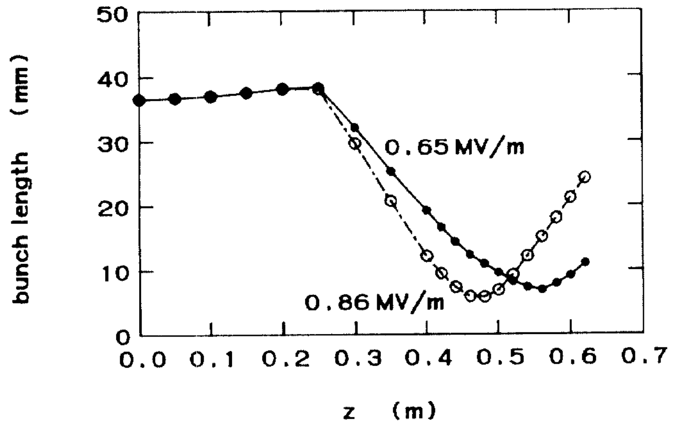

Fig.3 Bunch length in drift space after prebuncher

4. THE BUNCHER

(Interatom) employs 14 cells in the 2π/3-mode, and has a total length of 0.43 m. It uses the full 20-MW output of a klystron amplifier. The unspent 18 MW at the buncher exit is fed to the two accelerator sections (maximum of 8 MW each) after appropriate power division and phasing. The buncher gives further reduction of the bunch length from 7 mm to 1.8 mm (6 ps) whilst accelerating the electrons to 3.8 MeV.

The final compression to 0.9 mm was expected to take place in the first linac but new FELSIM simulations show that this already occurs in the drift space between the buncher and the linac. This is due to the special buncher design in which particle phase trajectories do not intersect for a wide range of input phases. At the output, therefore, there still exists a definite phase-energy relationship which leads to compression in a drift space. Fig 4. shows the calculated distribution in energy time space at the buncher exit and at the linac entrance. We measured the emittance of the beam for settings of the phase shifter ranging from 240° to 300°, see Fig. 5. From a measurement of the beam loading in the buncher we estimate an average beam energy of 4.5 MeV. Using this estimate, we find that normalized emittances range from 60π to 70π mm mrad. This is somewhat higher than the design value of 50π mm mrad, but not alarming. At present the buncher withstands 20-MW pulses of 15 μs duration, with only an occasional breakdown.

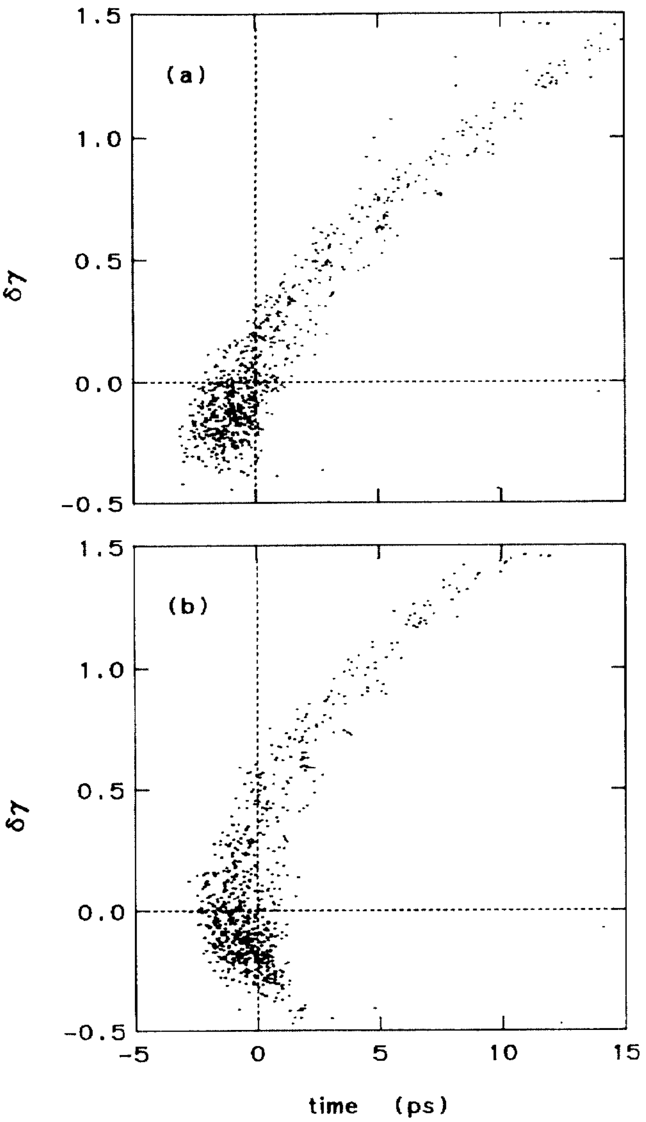

Fig.4 Evolution of the distribution in energy-time space behind the buncher.

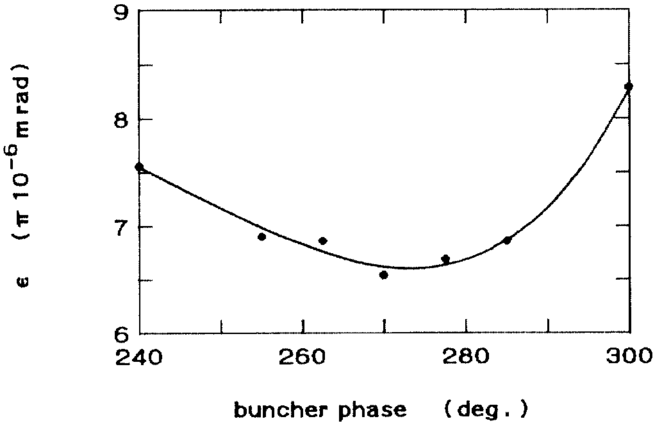

Fig.5 Measured emittance versus rf-phase at the buncher exit.

5. THE ACCELERATOR

consists of two identical constant-gradient structures (CGR-MeV) with the following characteristics: $2\pi/3$-mode, $l=3.15$ m, $\tau=0.44$, $r=61$ MΩ/m, $Q\approx12000$. Conditioning turns out to be a slow process, probably due to our low prf. The linac now withstands 7 MW at a pulse length of 13 μs without beam, 8 MW at 10 μs with beam. Eventually we intend to operate at a pulse duration of 20 μs, but only 11 μs are guaranteed by the manufacturer, CGR-MeV. On the other hand, a similar structure used in Triëste withstands 11 MW for 12 μs. The maximum beam energy at 200 mA is 24 MeV, as expected, and the measured beam loading of 34.5 MeV/A is close to the quoted value of 32 MeV/A. A secondary emission monitor (SEM) located at a distance of 0.5 m behind the first bending magnet (see fig 7) , is used to measure the energy spectrum. The dispersion is 0.2 % per channel. The collected charge is integrated over the macropulse except for the first 2 μs. Some of the best spectra obtained until now, at a central energy of 22.1 MeV and a beam current of 190 mA., are shown in fig. 6 In general, the spectra at a lower energy tend to be somewhat broader than those at a higher energy. Even when integrated over a pulse duration of 13 μs, 90 % of the beam current is contained in an energy window of 0.7 %. For comparison, the latter value would be 1.1 % for a gaussian distribution with the design value for σ_e, 0.35 %.

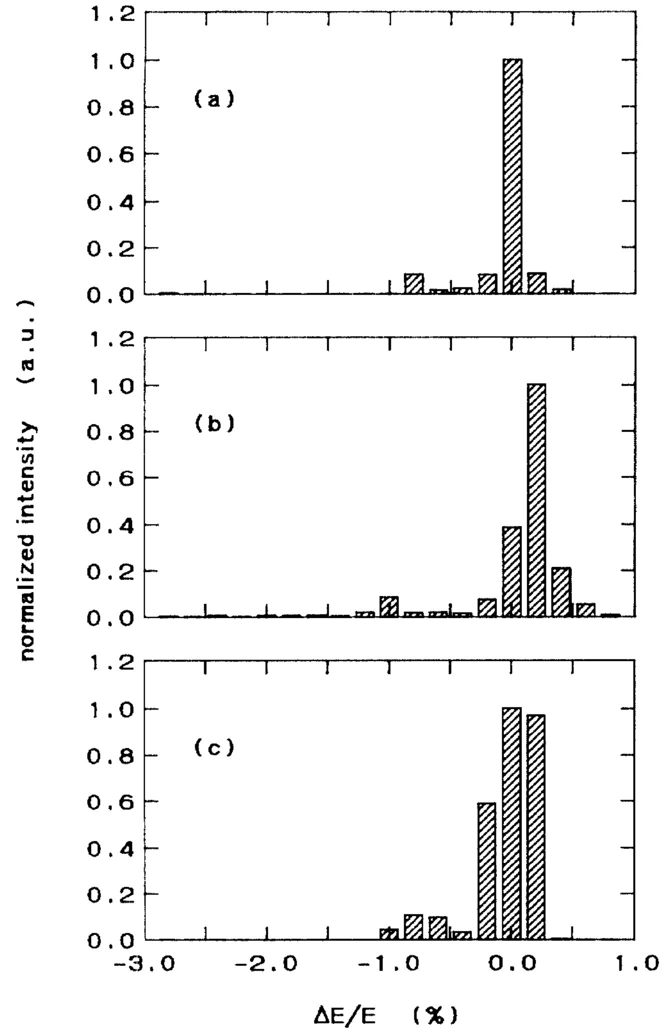

Fig.6 Some of the best energy spectra recorded until now for a pulse duration of 6 μs (a,b) and 13 μs (c)

6. BEAM TRANSPORT

In fig. 7 the beam transport system between the exit of the linac and the undulator is shown. The main purpose of quadrupole lenses 1Q10 and 1Q30 is to make the bend achromatic, while the other quads are used to control the transverse beam format. One set of steering coils is placed directly behind the linac and two other sets are placed on top of the collimators C20 and 1C10. In this part of the beam line four fluorescent screens and two non-interceptive button position monitors are available. Just behind the second bending magnet, 1B20, the energy dispersion is non-zero, which means that there the position in the bending plane also gives the beam energy versus time. When measured with the button monitor the resolution is better than 0.1 %. Probably due to the long wavelength and related large dimensions of the optical beam, the laser is on the whole rather insensitive to electron beam steering and focusing. Even when the wavelength is changed over a factor of 2 by changing the undulator gap, only small adjustments are needed.

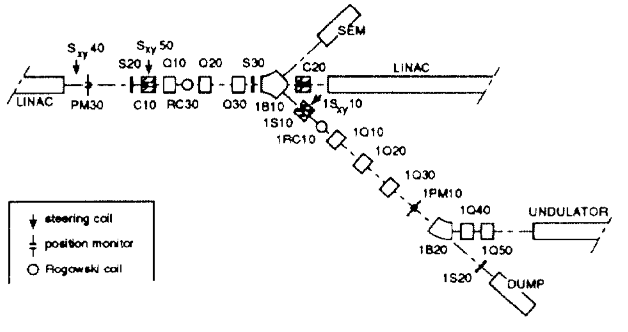

Fig 7. Beam transport system between first linac and undulator

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