COMMISSIONING THE ELECTRON ACCELERATOR FOR FELIX

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Abstract

The Free Electron Laser for Infrared eXperiments (FELIX) is meant to provide a rapidly tunable source of infrared radiation. The accelerating system consists of a thermionic gun operated at 1 GHz, a 1-GHz prebuncher, a 3-GHz buncher with an exit energy of 3.8 MeV, and two 3-GHz linacs. The peak current at the exit of the accelerator is 70 A, at a bunch length of 3 ps. The system has been designed to minimize the energy spread in the electron beam. The beam can be bent into undulators at two locations: after the first (15-25 MeV) and after the second linac (25-45 MeV). The commissioning phase for the accelerating system started in late 1989. First results are presented.

Introduction

The basic layout of FELIX is shown in Fig. 1. The accelerating system consists of a bunching system and two linacs. The energy range between 15 and 25 MeV will be covered with the first linac, and the range between 25 and 45 MeV with the second linac. The undulator of the former UK-FEL project will be used in the first stage of the project.[1] This undulator consists of 4 sections, each containing 19 periods of REC magnets with a period of 65 mm. The maximum field on axis is 0.44 T. Two sections of the UK-FEL undulator will be placed behind the first linac, covering the spectral range from 17 to (at least) 80 μm. The other two sections will be placed behind the second linac, covering the range from 5 to 30 μm. The accelerating system has been designed to deliver bunches with a peak current of 70 A and a duration of 3 ps. This high peak current is needed to achieve a FEL gain of at least 20 % per pass, which is required to reach saturation of the radiation intensity sufficiently long before the end of the macropulse (20 μs), and to overcome the cavity losses, especially in the set-up with an intracavity etalon. The latter will be inserted to achieve phase locking of the light pulses, which reduces the number of active modes of the optical cavity. It then becomes possible to provide radiation with a narrow bandwidth and a reasonably high power to external users. A bunch repetition rate of (at least) 1 GHz is needed for this technique.[2]

The Electron Gun

The electron gun, which was manufactured by Hermosa Electronics, is similar to the one in use at the LBL light source. It uses a dispenser cathode with an area of 100-mm^2 and a cathode-grid spacing of 0.15 mm. The 100-kV power supply for the gun can deliver a maximum current of 2 mA. A capacitor of 0.22 μF in parallel with the power supply keeps the voltage droop during the macropulse below 20 V. The presence of this capacitor makes it necessary to have a protection circuit against breakdowns, consisting of a vacuum spark gap and a trigger circuit. The delay between a breakdown and the triggering of the spark gap is less than 2 μs.

Fig. 2 shows the gun characteristics measured in common-cathode configuration. From the I_a-V_c characteristic we see that saturation occurs at 60 kV, which is well below our operating voltage of 100 kV. From the I_a-V_g characteristics we see that I_a is rather linear with V_g at R_g=0, and that the cut-off voltage is around -10 V. The data points for R_g=0 are calculated from the measurements at R_g=220 Ω and R_g=470 Ω; in order to suppress oscillations at a few MHz, it was necessary to insert at least 220 Ω and 10 μH in series with the grid lead. The I_g-V_g characteristic is also calculated from the measured I_a-V_g characteristics. It shows that the grid interception, $I_g/(I_a+I_g)$, increases strongly with I_a up to 27 % at I_a=1.3 A.

The required repetition rate of the electron bunches is 1 GHz and, hence, the electron gun will be operated this frequency. For common-

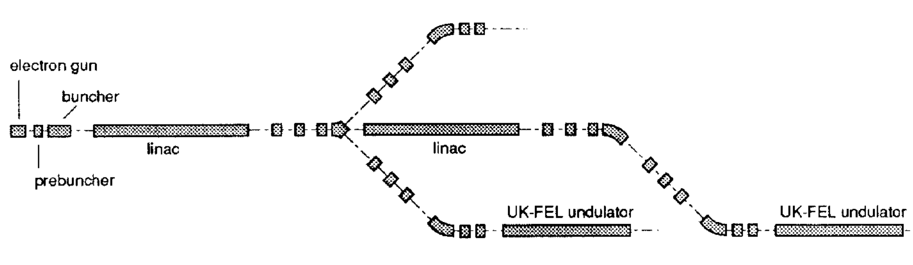

Fig. 1. Basic Layout of FELIX, Stage I.

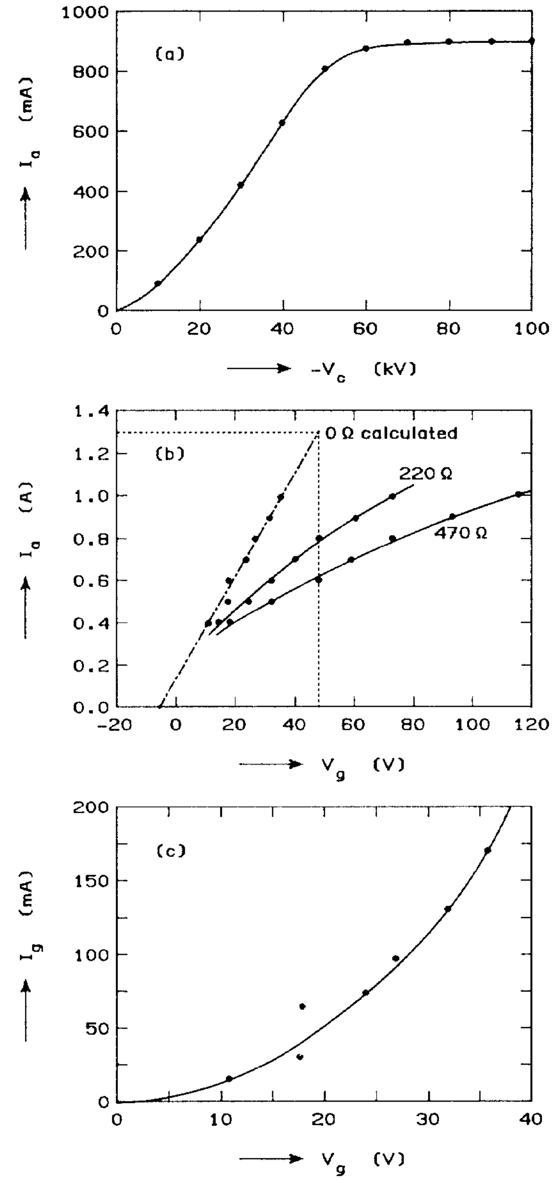

Fig. 2. Triode characteristics. Plot b and c are taken at a cathode voltage of -100 kV.

grid class-C modulation with a conduction angle of 90° and a charge per bunch of 220 pC, the peak current is 1.3 A. From the I_a-V_g characteristic we see that 50 V of grid voltage is needed to obtain this current. Therefore, the sum of the amplitude of the rf voltage, $V_{g,rf}$, and the dc bias voltage, $V_{g,b}$, has to be 50 V, while at cut-off $V_{g,rf} \cos(45°)+V_{g,b}$=-10 V, from which follows that $V_{g,rf}$=205 V and $V_{g,b}$=-155 V. The maximum voltage between the grid and the cathode is then $V_{g,rf}+V_{g,b}$=-360 V, which is well below the breakdown limit specified by the manufacturer, 600 V. The corresponding rf power (for common-grid modulation) is 58 W, whereas our rf generator can deliver up to 100 W. It is matched to the cathode-grid assembly by means of a λ/4-transformer.

Fig. 3a shows an example of an output current pulse. This is one of the first measurements, so the matching had not yet been optimized. The droop in the pulse is due to the series capacitor in the bias circuit. This capacitor is charged by the cathode current, thereby making the bias voltage more negative which results in a decrease of the conduction angle and the average current. This change in bias voltage can be calculated from the cathode current and the value of the capacitor, 0.22 μF. From this and the reduction in current when the rf power was halved, it was found that $V_{g,rf}$ is only some 65 V and that the conduction angle decreases from 140° to 100° during the pulse. Optimum matching led to an average current of 250 mA at a conduction angle of 120°. Further narrowing of the conduction angle to 90° will increase the real part of the input impedance and, hence, a modified λ/4-transformer has been constructed.

Not all of the droop in the current is caused by the droop in the bias voltage, however, as can be seen from Fig. 3b, where the current is shown after the capacitance has been increased to 500 μF. The cause of the remaining 4-% droop is as yet unclear. Although it should be fairly straightforward to eliminate it by appropriately ramping the bias voltage, this will probably affect the bunch length adversely. Further investigations will therefore be undertaken.

We have also measured the beam emittance behind the gun. The emittance measuring device consists of a stepping-motor controlled slit, a drift space (0.5 m) and a set of 30 charge-collecting foils. A focussing coil has been placed in between the gun and the slit in order to reduce the divergence of the electron beam to within the range accepted by the emittance measuring device. Fig. 4 shows the phase-space diagram. The normalized emittance (90-%) is 32 π mm mrad.

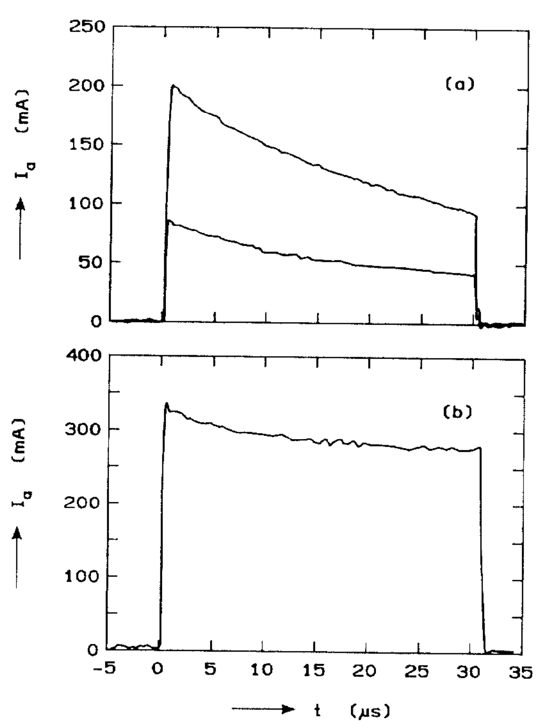

Fig. 3. Typical beam current pulse with rf modulation. a: upper trace at full power (100 W), lower trace at half this power. b: residual droop in case of a 500-μF capacitor in the bias circuit.

The Prebuncher

The bunching system has been designed to give the required compression of the bunches whilst maintaining a low energy spread. Eventually, the rf modulated gun is expected to emit only over a 90° phase range and, hence, at the input to the prebuncher cavity there will be an approximately linear relationship between bunching forces and phase error. However, the degree of bunching is limited by space charge forces, so it is best to use a high field and a correspondingly short drift distance. We will operate around an effective peak voltage of 50 kV, given by creating a gradient of 1 MV/m over 50 mm. PARMELA studies have shown that it is possible to compress the bunches so that over 90 % of the electrons lie within a 20° range, corresponding to 60° at 3 GHz. The optimum drift distance is about 195 mm from the centre of the cavity.

A problem is that the current extracted from the gun has a strong 1-GHz component and, hence, induces a field in the prebuncher cavity. The bunch train is 90° out of phase with the field from the external generator and since the beam-induced field is in phase with the bunches, the latter field is also 90° out of phase with the generator field. Consequently, the resulting total field is strongly phase shifted relative to the intended value. However, at a certain amount of detuning of the prebuncher cavity, the total field can have the correct phase.[3] The prebuncher impedance seen by the generator is then identical to the impedance in the absence of beam loading.

For this case we have calculated the response of the prebuncher when the electron beam enters, and found that for a copper cavity it takes 10 μs before the field is stable within 1 %. Consequently, 50 % of the macropulse would be used for building up the prebuncher field. For this reason we choose stainless steel as the material for the prebuncher cavity; the build-up time is then reduced to 2 μs. A second advantage of using stainless steel is that the induced voltage at the start of the macropulse is smaller, 13 kV instead of 65 kV.

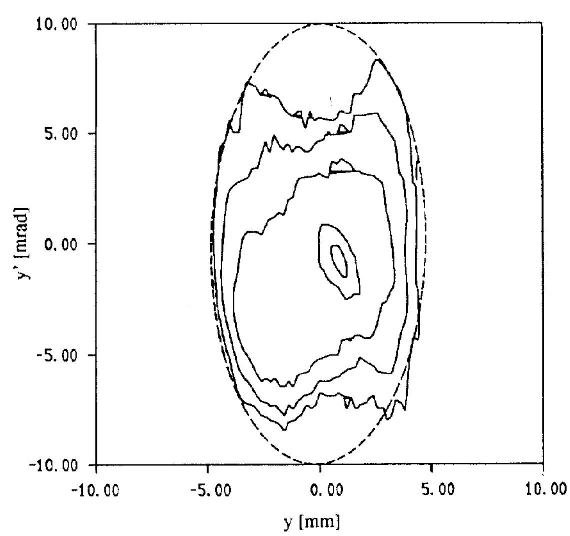

Fig. 4. Intensity contours for rf modulated gun. The solid lines give contours where a fraction (0.1, 0.2, 0.4, 0.8, 0.95) of the maximum intensity is reached. The dashed line gives the 90-% rms ellipse.

The prebuncher has been manufactured by Interatom. It is equipped with a plunge tuner having a range of 997-1004 MHz and will be powered by a 5-kW, 1-GHz amplifier which was custom-made by Varian. Measurements of the prebunching process are in progress.

The Buncher

The buncher is designed to give a further reduction of the bunch length to 6° whilst accelerating the electrons to 3.8 MeV. The final compression to 3° is expected to take place in the first linac. This is ensured by the special buncher design which reduces the phase spread smoothly, that is, particle phase trajectories do not intersect for a wide range of input phase.[4] The output, therefore, has the unambiguous phase-energy relationship needed to give further compression in the later sections.

The buncher employs 14 cells in the $2\pi/3$ mode, and has a total length of 430 mm. Because of the relatively high field gradients it will use the full output of a 20-MW klystron. After traversing the buncher the residual power of 16.5 MW will be used, after suitable power division and phasing, to feed the linacs.

The buncher is still being manufactured by Interatom and delivery is expected this summer. The linacs (CGR-MeV) and the 20-MW klystron (Thomson-CSF) are available.

Acknowledgements

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References

1 M.W. Poole *et al.*, Nucl. Instr. Meth. A **237** (1985) 207.
2 D. Oepts *et al.*, Nucl. Instr. Meth. A 285 (1989) 204.
3 B. Faatz *et al.*, Rijnhuizen Rept. 89-184, 1989.
4 P.W. van Amersfoort *et al.*, 1988 Linear Accelerator Conf. Proc., CEBAF-Rept.-89-001, 1989, p. 305.