The FELIX RF System

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Abstract

We discuss the performance of the RF system for the Free Electron Laser for Infrared eXperiments (FELIX), which has produced the first laser pulses in the summer of 1991. The RF system provides the input power for a triode gun (1 GHz, 100 W), a prebuncher (1 GHz, 10 kW), a buncher (3 GHZ, 20 MW), and two linacs (3 GHz, 8 MW each). The pulse length in the system is 20 μs. The required electron beam stability imposes the following demands on the RF system: a phase stability better than 0.3° for the 1 GHz signals and better than 1° for the 3 GHz signals; the amplitude stability has to be better than 1% for the 1 GHz and better than 0.2% for the 3 GHz signals.

1. INTRODUCTION

The main parameters of the electron beam of FELIX are maximum energy 25 MeV with one linac in use or 45 MeV when two linacs are operated. The average current during a 20 μs macropulse is 200 mA. The beam is bunched by a 1 GHz modulating signal on the grid of the gun triode. The macropulse is generated by switching the RF signal. The electron beam system and laser performance are covered in other contributions to this conference [1,2], this paper addresses the RF system. Functionally the system can be divided in two parts: (1) the low power circuit which delivers signals with the frequency, phase and pulse length required, at a power level of tens of milliwatts, and (2) the high power circuit with amplifiers which deliver the required power and with provisions to measure power and phase. Special attention is given to the phase stability of some components. The circuits for power and phase measurement and the control and safety system will not be addressed in this paper.

2. LOW POWER CIRCUIT

The principle of the low-power circuit is depicted in Fig. 1. To obtain phase coherent 1 GHz and 3 GHz signals two oscillators are phase-locked to a crystal-controlled master oscillator. The 1 GHz signal is split to obtain a signal for the gun amplifier and one for the prebuncher amplifier. The three signals are switched independently by PIN diode modulators. Although the modulators are of the absorbing type isolators were inserted to improve the phase stability of the oscillators during RF-on time. An electronic phase shifter is inserted in the gun branch to compensate the phase change introduced by the 100 W amplifier during the macropulse. To accomplish this the phase shifter is fed with an experimentally determined pulse shape. The results are given in Fig.2. The vertical scale is in degrees for 3 GHz signals; for 1 GHz the values along the axis have to be divided by 3.
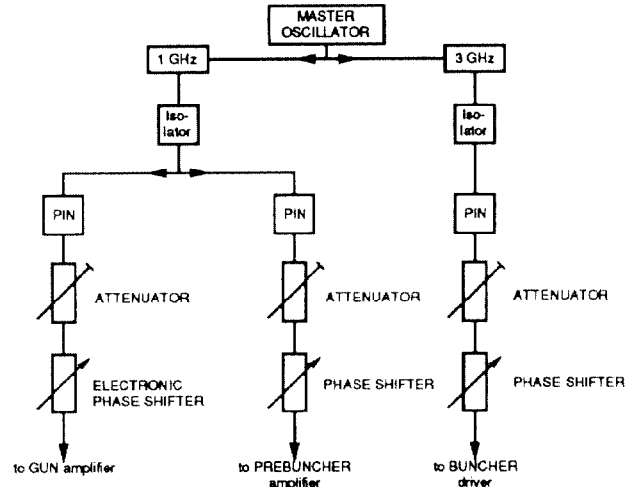

Fig. 1. Low power circuit.

Fig. 2 shows a phase change of more than 2° during a 14-μs pulse; this decreases to 0.3° with an electronic phase shifter and a very simple pulse shaping network. In future experiments this phase shifter will be used also to deliberately shape the phase evolution during the pulse in order to influence the synchronisation of electron beam pulses and light pulses in the laser cavity during the macropulse. For this purpose an arbitrary-pulse shaper is being developed. Mechanical phase shifters in the prebuncher and buncher branches control the phase between gun and prebuncher and gun and buncher respectively. The low power circuitry is located in the control room. The amplifiers are situated near the accelerator and the connections to them are made by low-loss, phase stable cables.
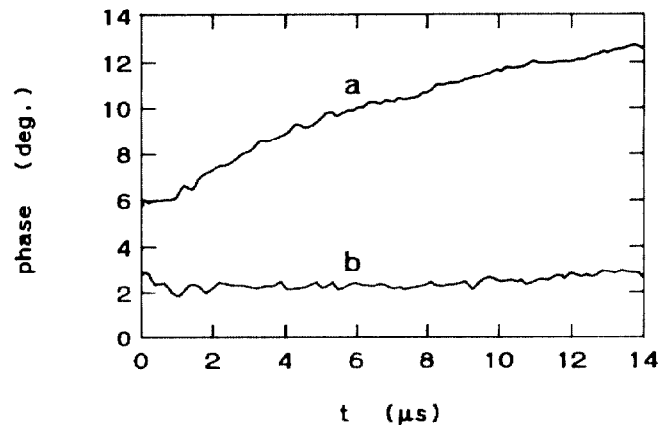

Fig. 2. Phase evolution of signal to the gun without (a) and with (b) electronic phase shifter.
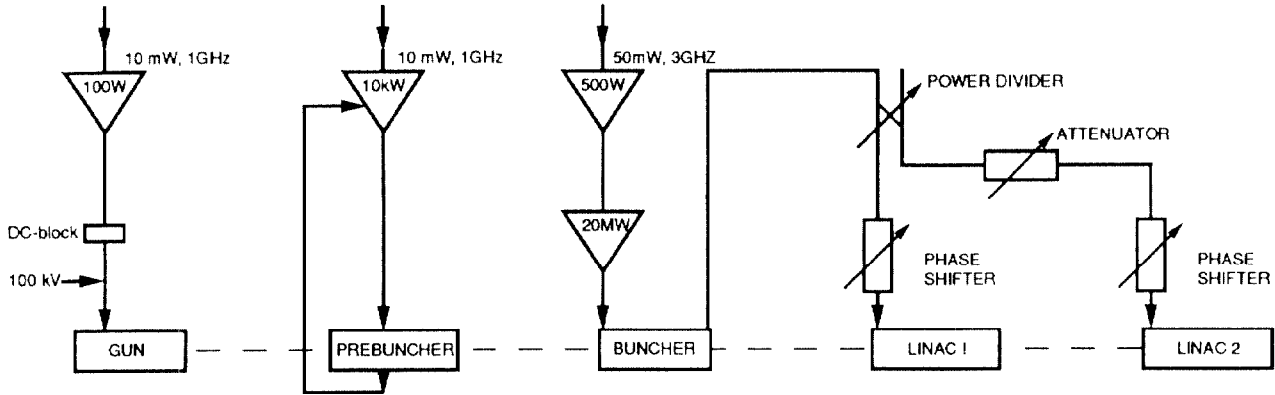
Fig. 3. High power amplifiers and waveguide system.

3. HIGH POWER CIRCUIT

A schematic drawing of the high power circuit is given in Fig. 3. For the 1 GHz connections the low loss cables mentioned above are used also. The 3 GHz power is transported by thick walled WR284 waveguide. Because the gun cathode and grid are on a negative 100 kV potential the RF signal to the gun assembly is fed through a DC block. This block consists of two waveguide-to-coax adaptors isolated by layers of polyethylene foil. The power for the prebuncher is coupled into the cavity by means of a loop; a second loop is used to couple out a small amount of power to monitor the field inside. 20 MW of 3 GHz power, delivered by a klystron amplifier (Thomson CSF), is fed to the buncher. Due to ohmic losses and beam loading the power at the buncher exit amounts to about 18 MW. This power is led to a continuously variable power divider with outputs to the first and the second linac. Phase shifters in the waveguides to the linacs control the phase at each linac entrance with respect to the signal at the buncher exit. An attenuator is inserted in the feed to the second linac to enable indepent control of power to the two linacs. The waveguides and other components (Spinner) are filled with 2.5 bars of SF_6. The waveguide system is kept on a constant temperature by thermostrated water to stabilize the phases in the system against changing room temperature.

On the high voltage deck of the gun a coaxial circuit is installed which serves the following purposes: matching of the cathode-grid impedance to the amplifier output (100 W) and feedthrough of heater supply and cathode-grid bias voltage. The grid is biased such that the triode acts a class-C amplifier. The conduction angle and average current of the gun can be varied by changing RF power, bias voltage or both. The power to the gun is measured with a calibrated diode detector and a directional coupler before the DC block.

The prebuncher is a tunable low-Q cavity excited in the TM_{010} mode and fed by a 10 kW triode amplifier (Varian-Eimac) with provisions for closed-loop control of amplitude and phase. This feature enables stabilization of the field inside the cavity. To achieve this the signal of the cavity monitor output is used as an input to the amplifier control loop. The electron beam bunches induce a high field in the cavity when

it is at resonance and a very high power would be needed to set up the 90° shifted field required for prebunching. The cavity can be tuned by means of a movable plunger. A detuning of 1 MHz above the generator frequency and a power of 5 kW satisfy to compress the electron bunches from 250 ps to 60 ps. Couplers and diode detectors are used to measure transmitted and reflected power. The field inside the cavity is measured with a detector and appropriate attenuators connected directly to the monitor loop.
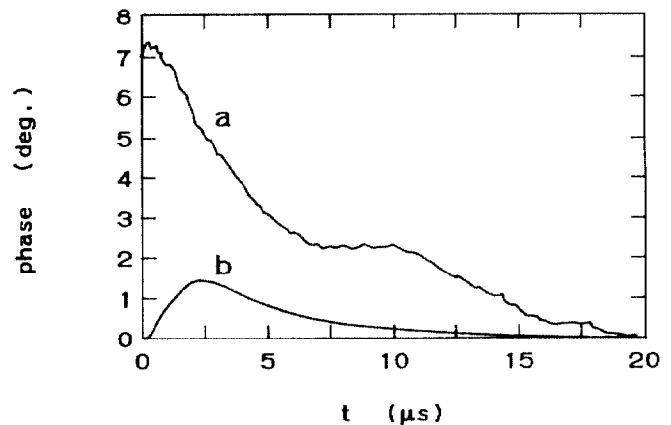

Fig. 4. Phase response of the driver klystron in the saturated mode (a) and in the linear mode (b).

The buncher is designed to compress electron bunches from 60 ps to 6 ps with an input power of 20 MW. The klystron amplifier is powered by a 500 W driver. Measurements in Fig.4 show that the phase change of this driver when driven into saturation is unacceptable; the phase proves to be within specification for at least 15 μs of the 20 μs macropulse when the driver is operated in the linear mode. Not too much emphasis is put on the phase stability in the first part of the pulse because the transient beam loading influences the electron beam quality more strongly. Installation of an electronic phase shifter as described for the low-power gun circuit can be done easily when the residual phase shift appears to be too high.
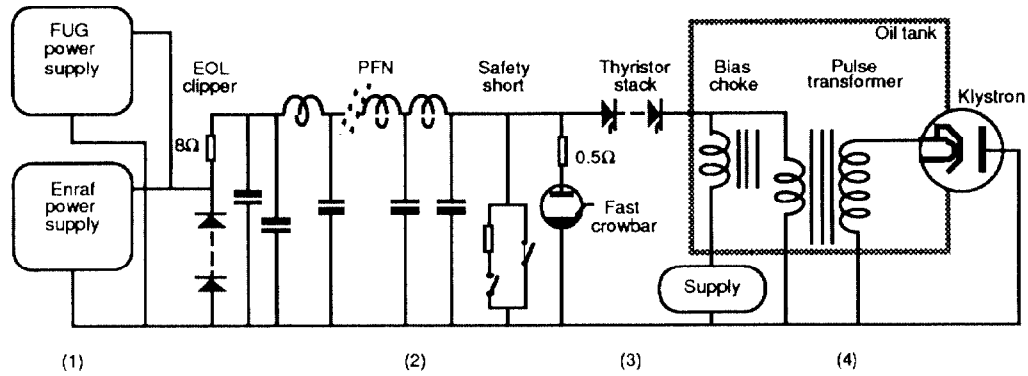
Fig. 5. 20 MW klystron with supply circuit:
(1) 40 kV DC supply, (2) Pulse Forming Network, (3) line switch, (4) klystron on oil tank with pulse transformer and heater supply.

The high voltage for the 20 MW klystron is supplied by a PFN modulator with a line switch consisting of 32 thyristors in series. The PFN consists of four lines in parallel each having 20 capacitor-coil sections. Within the tolerances of the capacitors they were sorted such that four almost identical lines could be assembled. The coils are adjusted with taps; a moving disc enables fine tuning of the inductance [3]. A voltage ripple considerably less than 0.1% during the full 20 μs PFN pulse was achieved by careful tuning of the inductors using a low supply voltage and a dummy circuit instead of line switch and oil tank. This ripple was measured with a dummy load replacing the impedance of the transformer loaded with the klystron. The actual circuit gave a phase ripple across the klystron as shown in Fig. 6a. A circuit to damp out oscillations, caused by stray inductance and capacitance, was installed in the oil tank. Fine tuning of the PFN during operation than gave the phase against time dependence of Fig. 6b. It can be seen that the initial phase change (excluding rise and fall) of more than 5° is reduced to 1.5° peak-to-peak in the first 5 μs and to much less in the remaining part of the pulse. Near the vacuum windows of the buncher and the linacs directional loops are placed in the waveguide to measure transmitted and reflected power. These points are also used to measure the relative phases of buncher and linac input signals.

4. CONCLUSIONS

As shown by measurements the tight specifications for phase stability, as set by the energy spread requirements, have been met during the major part of the macropulse.

5. ACKNOWLEDGMENTS

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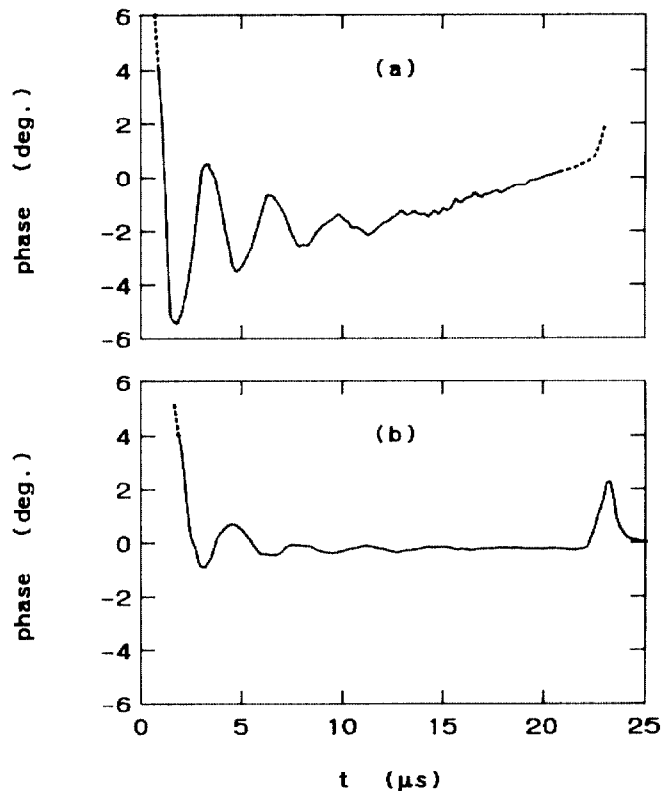

Fig. 6. Phase of 20 MW klystron as a function of time: (a) PFN initially tuned, (b) damping circuit installed and PFN fine tuned.

6. REFERENCES.

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[3]   P.W. van Amersfoort et al. "Update on FELIX", Nuclear Instruments and Methods in Physics Research A, vol.304 , pp.163-167, 1991.