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THE RF SYSTEM FOR THE LOS ALAMOS FREE-ELECTRON LASER (FEL)*

Carl C. Friedrichs, Paul J. Tallerico and William J. Hoffert, AT-5, MS H827
Los Alamos National Laboratory, Los Alamos, NM 87545

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Summary

The FEL electron linac consists of three buncher cavities: two accelerator cavities and a deflection cavity, each with its own phase-coherent rf source. All sources will be pulsed for 100 μ s at a 1-pps rate. The phase and amplitude stability requirements are $\pm 1/2^\circ$, and $\pm 1/2\%$. There are two subharmonic bunchers, each requiring 5 kW at 108.33 MHz. All remaining cavities operate at 1300 MHz. The fundamental buncher requires 5 kW, whereas each of the accelerating cavities requires at least 3 MW. The deflection cavity requires up to 100 kW, which is coupled from one of the accelerator cavity rf sources. Prominent features of the rf system are the phase and amplitude control circuits and the multimegawatt klystron amplifiers. Three L3707 klystrons were obtained from the AMPAD radar site at White Sands, which was decommissioned in the early 1970s. The tubes originally were designed to produce 10-MW, 10- μ s pulses. Each tube has delivered over 3.6-MW, 100- μ s pulses in the FEL system.

Accelerator Description

The Los Alamos FEL uses the output of a specialized electron linac to produce high-energy-light pulses in the far infrared region.

The following description of the linac, used in the FEL oscillator experiment, will clarify the functions of each of the rf systems and will lead to an understanding of the ingredients that dictate the rf systems' requirements.

The linac output beam consists of a train of micropulses, 100-A peak, 30 ps wide and 46 ns apart. The train, 100 μ s long, occurs once every second.

The linac is composed of an 80-kV injector, followed by three bunchers then two accelerator sections. Final beam energy is 21 MeV. The accelerator sections are side-coupled-cavity structures and are operated at 1.3 GHz, which is the linac's fundamental frequency.

The beam is modulated within the injector at one-sixtieth of the fundamental frequency, or 21.67 MHz. The period of this frequency determines the spacing of the micropulses. The modulated injector output beam passes through two subharmonic bunchers that are operated at one-twelfth of the fundamental frequency, or 108.33 MHz. These bunchers serve to squeeze the width of the beam-modulation pulses down to 360 ps. These bunchers are followed by a fundamental buncher and then the two accelerating cavities. Final squeezing of the micropulse width to 30 ps occurs in these fundamental-frequency structures.

There is, in addition to the linac, a 1.3-GHz deflection cavity that is used for electron beam diagnostics following energy exchange to the laser.

The rf Requirements

Table I presents the major requirements of each rf power system for the FEL Project. Each system obtains its excitation from a master oscillator that produces coherent signals at 21.67 MHz, 108.33 MHz, and 1.3 GHz. Each system's output must be amplitude

TABLE I

FREE ELECTRON LASER RF REQUIREMENTS

Subharmonic buncher sources (2)	
Frequency	108.33 MHz
Power (peak)	5 kW
Fundamental buncher source (1)	
Frequency	1300 MHz
Power (peak)	5 kW
Accelerating cavity sources (2)	
Frequency	1300 MHz
Power (peak)	3.2 MW
Deflection cavity source (1)	
Frequency	1300 MHz
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and phase stable within $\pm 1/2^\circ$ and $\pm 1/2\%$ respectively. The powers listed are peak powers; the rf pulse duration is 100 μ s, occurring at a 1-pps rate.

The rf Power Sources

Figure 1 is a block diagram of the FEL rf power sources. Each of the two accelerator cavities is powered by a Litton L3707 klystron.

Power for each of the bunchers as well as the klystron drive is provided by individual 5-kW linear amplifiers. These amplifiers require an -14-dBm input level to produce 5-kW output. The amplifiers are made up of a solid-state Class A amplifier followed by several triode stages in cascade. The triodes are operated Class B. Power for the deflection cavity is coupled from the waveguide going to the first accelerator.

Figure 2 shows the details of the deflection-cavity power-coupling scheme. Power in Hybrid 1, Port A is split equally between Ports C and D, with Port C lagging by 90° . The power into Hybrid 2, Port A is split in similar fashion. Adjustable shorts are connected to Ports C and D of both Hybrids 2 and 4. If the distances from C and D to the shorts are equal, the reflections from those shorts will be combined in Port B only; therefore, Hybrids 2 and 4, with their associated adjustable shorts, function simply

Fig. 1. FEL rf power sources.

*Work performed for Defense Advanced Research Projects Agency under the auspices of US Department of Energy.

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AUTHOR(S): Carl C. Friedrichs, Paul J. Tallerico, and William J. Hoffert

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Fig. 1. FEL rf power sources.

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presented somewhat of a dilemma. There were no tubes currently in production, nor had any been built since the 1960s that would meet the power and frequency requirements. This meant that both the time and expense of a tube-development program would be necessary to procure tubes. Tube-development time simply was not consistent with the program schedule. Worldwide, the only known tubes in existence that possibly could meet the requirements were the three surplus Litton L3707 klystrons at White Sands. These tubes had been stored at White Sands under unknown conditions, then brought to Los Alamos in the late 1970s and stored outdoors. With this history it would be impossible to make a confident prediction regarding the workability of the tubes.

Fundamental tests were undertaken on the L3707s. These tests indicated that all three tubes still had a suitable vacuum, their filaments had continuity, and the electrode hold-off voltages were encouraging. Following these tests, a successful beam-current test was performed on one of the tubes. The test was made with 85-kV beam voltage, and 100-A, 100- μ s pulses were obtained. Following this last test, we decided to initiate a tube procurement, and to proceed with the program on the assumption that the L3707s would provide the required power, at least until new tube delivery could be made.

The L3707s were designed to operate at 170 kV with a 175-A, 10- μ s maximum pulse at a 0.007 duty cycle. The peak rf output power was 10 MW. In spite of the successful beam current test on one of the L3707s, there remained a lingering doubt regarding the available space charge to support the required 100-A 100- μ s pulses.

The FEL rf test stand was completed in the early fall of 1982, and testing of the L3707s followed. Ultimately, the test results were completely satisfactory on all three tubes. Just before testing one of the tubes, we found that it had sustained severe freezing damage, and multiple leaks were present in its cavity water-cooling courses. No encouragement could be found from the repair sections of the domestic klystron manufacturing companies. Repair at Los Alamos was successfully performed by the klystron repair section of the LAMPF accelerator's support group. Waveforms typical of all three klystrons are shown in Fig. 5.

A developmental contract has been awarded, with delivery of three new klystrons expected in late 1983.

Fig. 5. Litton L3707 klystron amplifier waveforms. (110-kV beam voltage)

Conclusions

The klystron uncertainties that characterized the early part of the program appear to have dissipated; in fact, the klystrons situation has become one of the more promising phases of the FEL program.

The phase and amplitude control systems are in the very early stages of testing; thus, no firm conclusions regarding their performance can be made at this time. Using past experience on similar systems as a predictor, only routine problems are expected.