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Section A

Status of the "TEU-FEL" project *

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The free-electron laser of the TEU-FEL project will be realized in two phases. In phase I the FEL will be driven by a 6 MeV photoelectric linac. In phase II the linac will be used as an injector for a 25 MeV race-track microtron. Information is presented on some technical details and the status of the different subsystems.

1. Introduction

In the "TEU-FEL" project of the University of Twenty, The Netherlands, an FEL will be built which consists of a photocathode linac which will accelerate the electrons up to 6 MeV, a race-track microtron which will accelerate the electrons up to 25 MeV, a hybrid undulator, an electron bending system, and an optical cavity. The project will be carried out in two phases. In phase I an FEL will be built with the photocathode linac and the hybrid undulator only. No optical cavity will be used: the electrons will be focussed directly into the undulator so that the FEL will work as an amplifier of spontaneous emission or, eventually, as an amplifier of an injected signal. In phase II the race-track microtron will be used and the undulator will be placed inside an optical cavity and then, of course, an electron bending system will be required. The main characteristics of the project are summarized in table 1.

In the remaining part of the paper we will describe in some detail the instrumental parts of our FEL.

2. Instrumental parts

In fig. 1 is shown a schematic overview of phase I of our project. The main parts are the photocathode linac, the undulator, the mode-locked Nd : YLF laser/amplifier system, the 1.3 GHz klystron for power amplification and the modulator, feedback and feed forward circuitry to keep the amplitude and phase of the linac constant in time, and a central driver unit at 40.625 MHz to preserve frequency synchronization between the Nd : YLF laser and the linac fields.

2.1. Photocathode linac and preparation chamber

The 6 MeV linear accelerator is the main accelerator in the phase I experiment and the preaccelerator in the phase II experiment. It has been designed and constructed at Los Alamos National Laboratory. It is a five and a half cell linac and an improved version of their own linac used to upgrade HIBAF. The characteristics of the linac are given in table 2.

Table 1
Main characteristics of the TEU-FEL project

	Phase I	Phase II
Accelerator type	linac	linac + RT microtron
Accelerator energy	6 MeV	25 MeV
RF frequency	1.3 GHz	1.3 GHz
Micropulse duration	20 ps	36 ps
Micropulse rep. freq.	81.25 MHz	81.25 MHz
Peak current	350 A	100 A
Macropulse duration	15 μs	15 μs
Pulse rep. freq.	10 Hz	10 Hz
Undulator period	25 mm	25 mm
Number of und. per	50	40
K-value	1	1
Undulator gap	8 mm	8 mm
Radiation wavelength	180 μm	10 μm
Opt. cavity length	–	1.85 m

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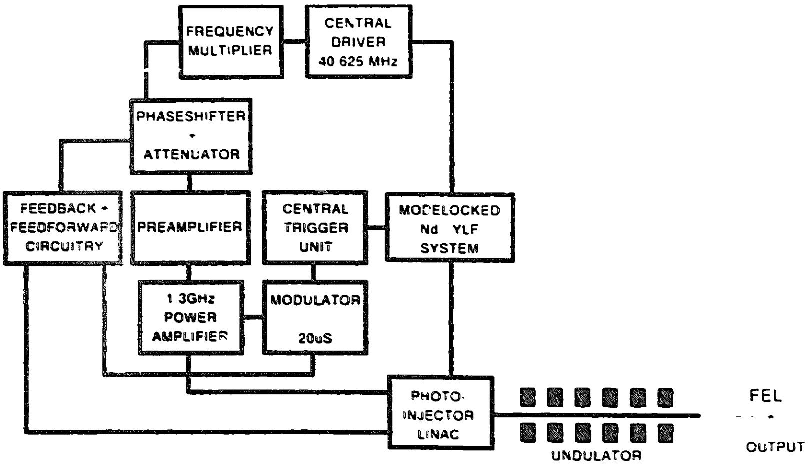

Fig. 1. Schematic overview of TEU-FEL project phase I.

In fig. 2 a drawing of the linac structure is shown. It is an on-axis-coupled linac mainly because such a structure is more compact than a side-coupled one. This enables the construction of a more compact solenoid and bucking coil. In the first half cell the photocathode is placed where the electrons are generated. Due to the high accelerating field strength at the photocathode surface, emittance growth due to space charge is reduced. Also the noses in the first one and a half cells are optimized for low emittance growth. Because CsK$_2$Sb will be used as photocathode material, ultrahigh vacuum ($\sim 10^{-10}$ Torr) is required. That is why the structure can be baked out at 350°C and the pumping speed is increased by a large number of pumping slots in each cell. Fig. 3 shows a plot of the electric field strength as a function of position. The photocathodes are prepared in a chamber which is directly attached to the linac structure as is shown in fig. 4. This makes in situ preparation of the cathodes possible; after preparation they can be put in place in the linac by a high-vacuum actuator.

2.2. Nd:YLF laser–amplifier system

A schematic view of the laser system is shown in fig. 5. As an oscillator we use an "Antares" cw Nd:YLF mode-locked laser from Coherent with a mode-lock frequency of 81.25 MHz. The time duration of the mode-locked pulses is 35 ps FWHM. The laser has excellent phase and amplitude stability. We measured the stability by analyzing the frequency spectrum of the laser amplitude around 81.25 MHz and around 2.6 GHz, which is the 32th harmonic of 81.25 MHz. We measured an rms amplitude stability better than 0.3% and an rms phase stability better than 0.7 ps.

Out of the continuous train of pulses we have to select a pulse train about 15 μs long with a repetition rate of 10 Hz maximum. This will be accomplished by the use of a traveling-wave acousto-optic modulator, which has a rise and fall time of about 125 ns. The efficiency in first order is ~ 70%. The advantage of an acousto-optic modulator compared with an electro-optic one is the very high contrast ratio and the low

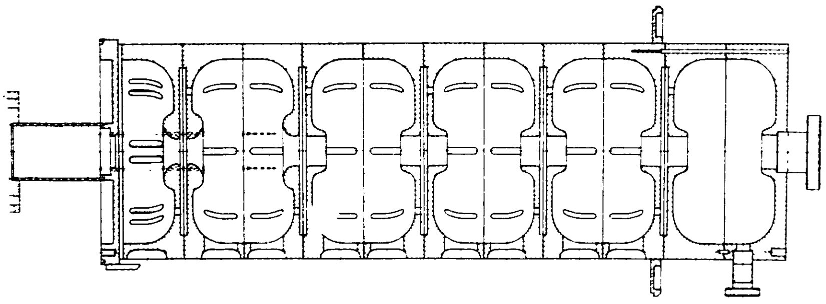

Fig. 2. Drawing of the Los Alamos photoinjector.

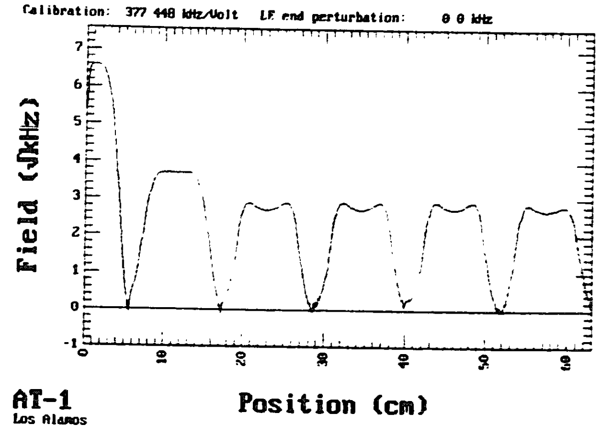

Fig. 3. Relative field strength as a function of the position inside the injector.

Table 2
Characteristics of the photocathode linac

Energy	6 MeV
Number of cells	5 1/2
RF frequency	1.3 GHz
Shunt impedance	50 MΩ/m
Q-value	18000
Axial electric field	
Cell no. 1	26.0 MV/m
Cell no. 2	14.4 MV/m
Cell no. 3 to no. 6	10.6 MV/m
Structure losses	1800 kW
Solenoid field strength	1200 G
Peak current	350 A
Micropulse duration	20 ps
Emittance (90%, norm.)	25π mm mrad

drive voltage (< 1 V) which makes the system well-suited for feedback or feed forward coupling in order to keep the light pulse envelope as flat as possible after it has been amplified in a saturated medium.

Although for a CsK_2Sb photocathode a quantum efficiency higher than 5% can be obtained for the second harmonic of Nd:YLF, its lifetime is limited. This means that the light level has to be sufficient to reach 350 A peak current for a quantum efficiency at least one order of magnitude lower than the peak value. So the laser light level at the fundamental frequency has to reach the MW power level, which means that the light pulses from the cw mode-locked Nd:YLF laser have to be amplified at least 300 times. This can be obtained easily with two double-pass amplification stages. Second harmonic generation will be obtained from a BBO or LBO crystal because of their very high damage threshold.

2.3. *Klystron and modulator*

We will use the Thomson klystron type TH 2022C. It is a 20 MW, 1.3 GHz klystron. The klystron will be powered by a line-type modulator having 20 capacitors, 50 nF each. The line will be loaded to 25 kV and uptransformed to 250 kV. By varying the inductances between the capacitors the ripple on the flat pulse top can be minimized. In fig. 6 the pulse form at a low

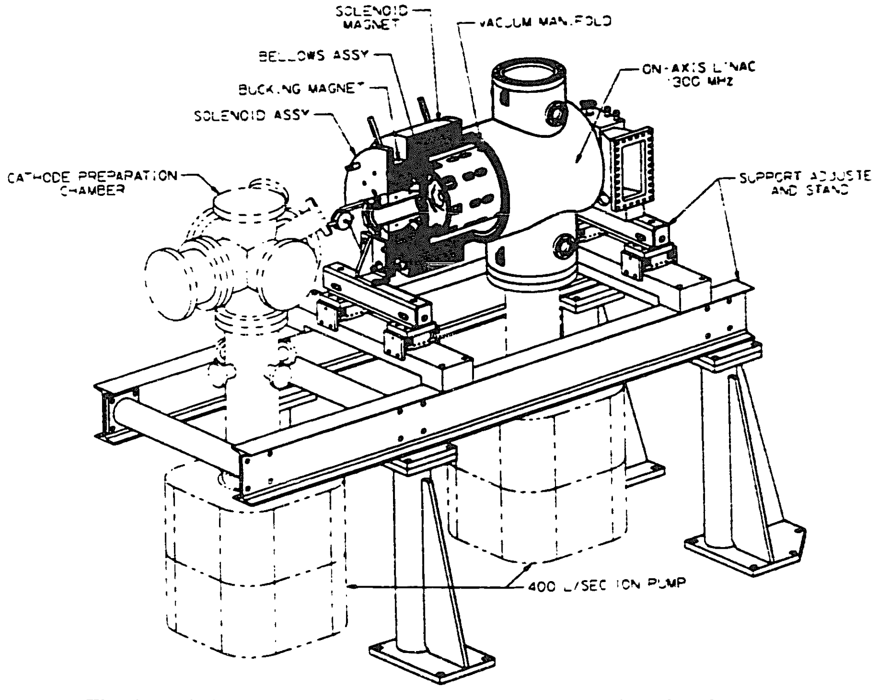

Fig. 4. Artist's view of the linac and cathode preparation chamber.

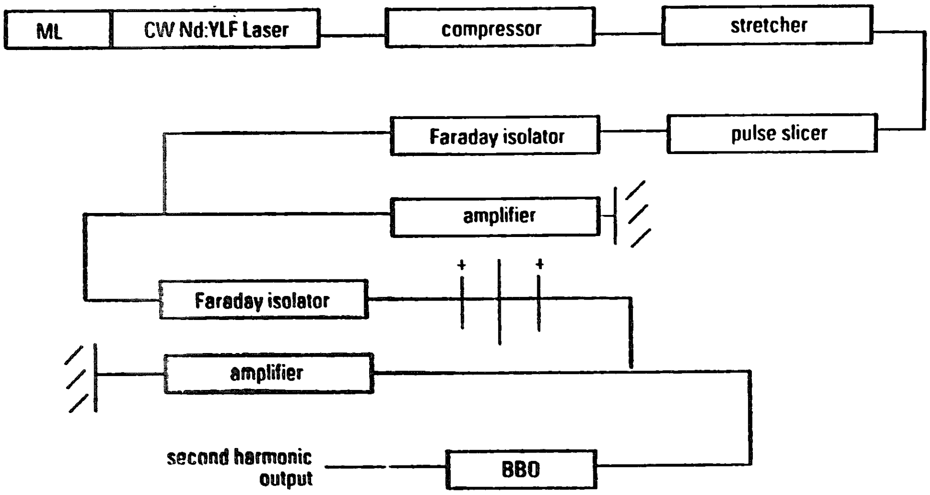

Fig. 5. Schematic view of the Nd:YLF laser system.

voltage level is shown. The ripple is around 0.1%. Although a somewhat larger ripple can be expected when used at full voltage, we are confident that a ripple smaller than a few tenths of a percent can be obtained.

2.4. Feedback and feed forward controller

When using an optical cavity the phase and amplitude of the accelerating field has to be kept as constant as possible. Important sources of fluctuations are beam loading and modulator ripple. A 1% modulator ripple gives 2.5% voltage and 10 ps phase ripple. Reduction of these ripples by at least an order of magnitude is required. There are two possible approaches. One is feedback where the klystron output is measured and fed back with a certain gain to the input signal. Some disadvantages are that such a circuitry is relatively slow (~ 500 kHz), the gain cannot be high for the frequencies of the PFN ripple, and extra power is required. The second approach is feed forward. Now the PFN ripple is measured as well as the effect of beam loading, and a feed forward correction function is created. This correction signal, superimposed on the input signal, is used as input signal for subsequent shots. Simulation studies from LANL showed that after a few μs excellent stability can be obtained for our hardware (~ 0.1%, 0.2 ps).

2.5. Race-track microtron

The RT microtron will be described in detail in a separate paper in this issue. It consists of two two-sector magnets, instead of two three-sector ones, with a valley as has been planned originally. In a three-sector magnet the focussing effect is determined by the counteracting effect of two strong lenses at the edges of the sectors. This leads to low stability against imperfections. A microtron with two-sector magnets has only one much weaker focussing lens and is therefore more stable. Moreover, the acceptance of a two-sector microtron is larger. The consequence of the use of two-sector magnets is that both magnets have to be placed at an angle with each other.

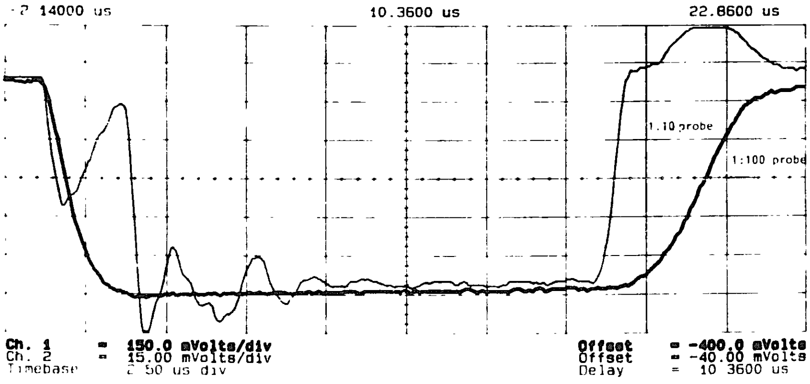

Fig. 6. Measurement of modulator pulse. The thick line shows the complete pulse. The thin line is 100 times enlarged. It can be seen that during the last 10 μs the ripple is well below 0.1%.

2.6. Undulator

The undulator will also be described in detail in another paper in this issue. It will be a hybrid undulator having 25 mm period, $K = 1$, and equal focussing in both directions. This is important mainly for the phase I experiment, where the laser beam diameter is mainly determined by electron beam guiding effects. Because of that, a concentrated electron beam gives much higher gain.

2.7. Electron injection system

Also the electron bending system will be described in detail in a separate paper in this issue. It will be a very compact system designed especially to fit into our short optical cavity of length only 1.85 m.