Update on the MicroFEL-TEUFEL-project (*)

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Abstract
The status is given of the 10 μm radiation Free Electron Laser project of the Twente and Eindhoven University and of UCN. The injector is a 6 to 25 MeV Racetrack Microtron. The preaccelerator is a Linac equiped with a photo-cathode for electron generation by a high-power pulsed Nd-YLF laser. The maximum current from the Linac is approximately 400 A. Details will be given of the microtron construction and parameters, and of the Linac performance. The project also includes the construction of a second microtron similar in shape but with final energy 70 MeV, which will inject in a 400 MeV synchrotron radiation storage ring.

Introduction

The aim of the TEUFEL-project (ref. 1) (Twente/Eindhoven University UCN Free Electron Laser) is to contribute to the technological and scientific developments of free electron lasers.
To meet that goal a FEL will be constructed with a wavelength around 10 μm. In particular we are interested in the potentials of a pulsed, high-current race-track microtron for producing the required 25 MeV electron beam. The FEL will contain a photo-cathode injector at about 6 MeV delivering a maximum current of approximately 400 A, a race-track microtron for acceleration of the electrons up to 25 MeV and a hybrid undulator. The project will be carried out in two stages.
In the first stage a FEL will be built with the 6 MeV injector accelerator only. The wavelength of the produced FEL radiation will be around 200 μm. In the second stage the RT microtron will be incorporated into the system.

Location construction

At the moment we are designing a bunker for the FEL experiment that fulfils the radiation shielding requirements. We expect to be able to start the construction of the 6 x 15 m^2 bunker in August. About half a year will be needed to complete it.

The injector

The photo-cathode injector will be constructed at Los Alamos National Laboratories. It will consist of six RF cavities (actually the first one is a "half" cavity), accelerating the pulses of up to 400 A to an energy of 6 MeV. See figure 1. The 10 Hz macropulses, having a length of 10 μs, will consist of micropulses at 81.25 MHz. The length of the micropulses will be approximately 30 ps.

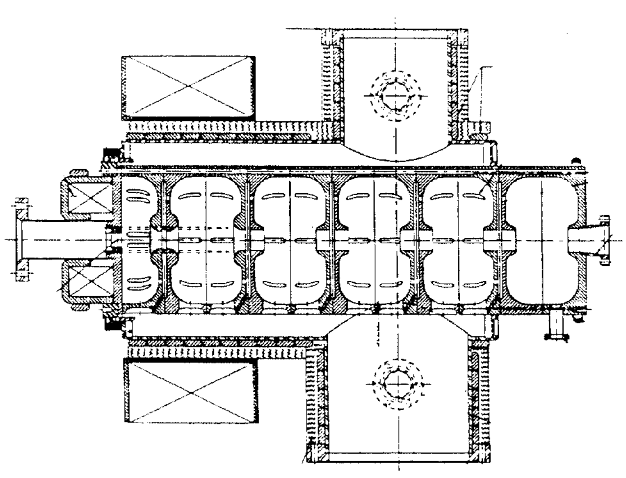

Figure 1. Drawing of the Los Alamos Photo Cathode Injector

As a photo-cathode material we will try out several possibilities. One possibility is a semiconductor (C_sK_2Sb). Advantages of this material are its high quantum efficiency and its low work function.
A disadvantage is its limited life-time due to its easy poisening by very small amounts of water vapour and CO_2.
Alternative materials are metals or metal oxides. These are rugged materials with a long life-time. However, the requirements for the laser which has to illuminate the cathode are much more severe.
As a laser source we will use a mode-locked Nd:YLF laser mainly because of its better phase stability and shorter pulse duration compared with Nd:YAG. A slicer has to be used for making the 10 Hz, 10 sec long macropulses. To increase the power of the laser several shapes of pulsed Nd:YLF or ND:glass amplifiers will be used (see fig. 2). In order to compensate for the droop in the pulse envelope due to saturation effects in the amplifier chain a feedback loop will be incorporated. We hope to be able to keep the flatness of the envelope within 1%.

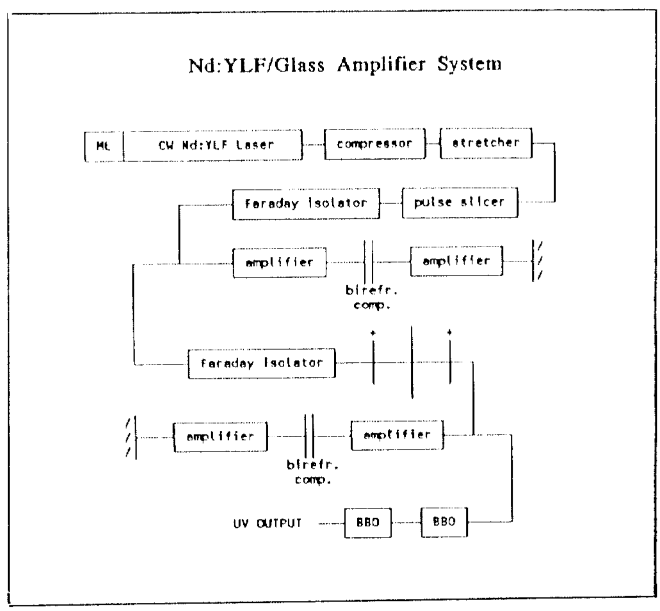

Figure 2. Schematic overview of the amplifier system

Very important for a good operation of the FEL is the exact synchronization of the 81.25 MHz mode-locked laser pulses and the 1.3 GHz RF signal for the accelerator. That is why a central driver will be used for both the 40.625 MHz mode-locker power supply and the 1.3 GHz signal for the klystron. A schematic system layout is presented in fig. 3. The klystron will be a Thomson type TH 2022C. It can deliver 20 M Watt output power for a time duration of 20 sec at 1.3 GHz. The modulator is under construction. It will be a PFN type modulator with 20 capacitors and a thyrat ron as output switch. If necessary we are able to add a clipper triode tube in order to keep the voltage very constant.

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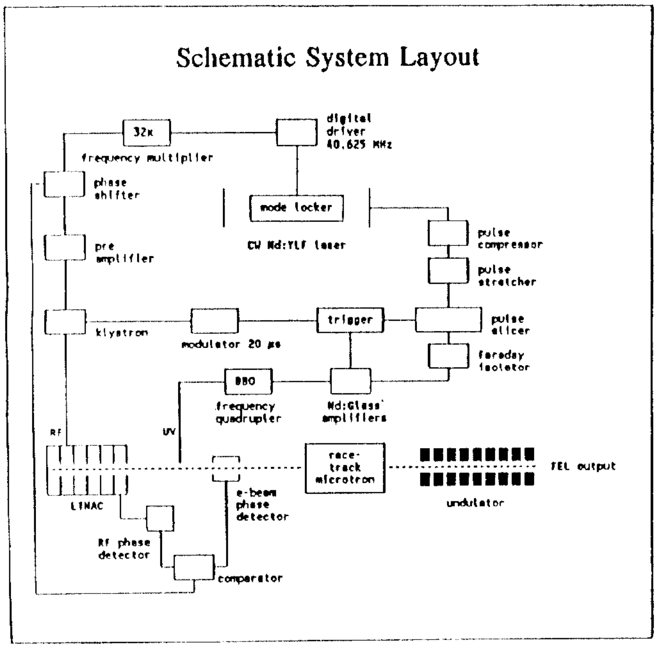

Figure 3.TEUFEL system layout

The racetrack microtron

The racetrack microtron ha two inhomogenous sector magnets separated by a free space of 57 cm. The RF cavity operating at 1.3 GHz provides a peak voltage of 2.2 MV. The main parameters are given in table 1. General features of the microtron have been described in ref. 1. The sector magnets will be equiped with focusing valleys at an angle of approximately 45 deg. with respect to magnet faces for providing sufficient axial focusing.
An account of the determination of the parameters of the focusing valley, and of the resulting magnetic field shape is given in a separate paper (2).

Table 1 Microtron parameters

Cavity frequency	ν_{RF}	1300 MHz
Cavity voltage	V_{cav}	2.22 MV
Cavity wavelength	λ_{RF}	23.1 cm
Dipole field	B	0.192 T
Dipole length		140 cm
Dipole width		50 cm
Magnet apperture		5 cm
Extraction energy	T_N	25 MeV
Harmonic number	h	1
Injection energy	T_0	6 MeV
Number of orbits	N	9
Orbit Separation	$2\Delta\bar{p}$	7.34 cm
Sector Separation	L	56.7 cm
Wavelengths in first orbit	n_a	8

The extra edge focusing in the non-homogenous bending magnet is used to combat space charge effects which arise during the transport and acceleration of the high beam currents necessary for operating the FEL. We aim to accelerate 100 A pulses with the microtron. The effect of space charge will be studied by computer simulations (3) and by an accompanying Hamiltonian description.
For this a Hamiltonian theory is set up for the transverse and longitudinal particle motion in the microtron. This is separately described elsewhere in thesee proceedings (4).
A start has been made to incorporate the space charge forces in the Hamiltonian (5). The micropulse frequency of 81.25 MHz implies pulse selection of 1 out of 16 with respect to the linac and RTM cavity frequency of 1.3 GHz. This avoids too heavy cavity loading since no more than one electron bunch at a time appears in the cavity, see fig. 4.

The microtron is being constructed in the University workshop. Figures 5 and 6 show the iron blocks composing the magnets in which the coil channels have been made, and the assembled parts. The iron weight of a single sector magnet is about 2 tons, its dimensions are: height 0.35 m, length 1.4 m, width 0.5 m.
The north and south pole of the magnet form a part of the vacuum chamber; the rest is an aluminum case to be inserted between the poles. These have also been constructed. They contain a passage channel to the middle vacuum chamber in the drift space between the magnets, and for the RF cavity. The coils are ready, and consist of 36 turns of hollow copper 6 x 6 mm^2 conductor. They require 4.4 kA per coil to excite the magnet to 0.2 T, consuming a power of 4.2 kW for the total microtron.
Field measurements will be performed for which a new automated measuring device has been constructed. A focusing valley larger than necessary will be machined out of the poles, and an iron insert piece will be placed inthe obtained channel. We expect to need three to four iterations of field measurements, orbit calculations and resulting shimming of the insert pieces.
Correction coils will also be constructed on the insert pieces, for adjusting turn by turn the isochronism.
The cavity will be constructed in the near future. It will be powered by the Thomson klystron. A phase and amplitude regulation system has to be designed.
A similar racetrack microtron suitable for acceleration up to about 70 MeV is simultaneously being constructed. It will serve as an injector for the synchrotron radiation source EUTERPE (6).
Both the pre-accelerator and the accelerating structure in the microtron are medical linacs of 12 MeV and 6 MeV respectively, that were obtained for moderate transportation cost. For this mictron space charge problems are not an issue. Therefore the magnets were constructed with a gap of 2 cm, and somewhat larger iron blocks, however, with the same pole area and coils as for the FEL microtron.

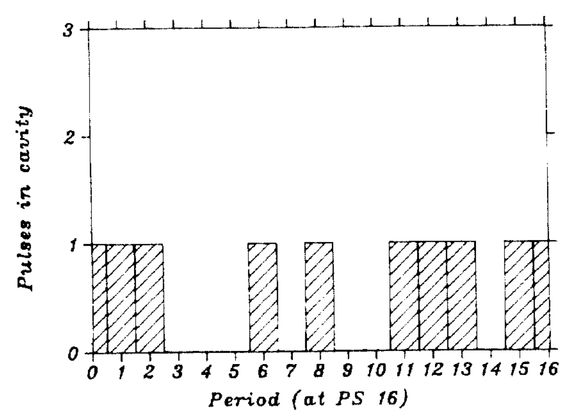

Figure 4. Cavity load for pulse selection (PS) of 1 out of 16

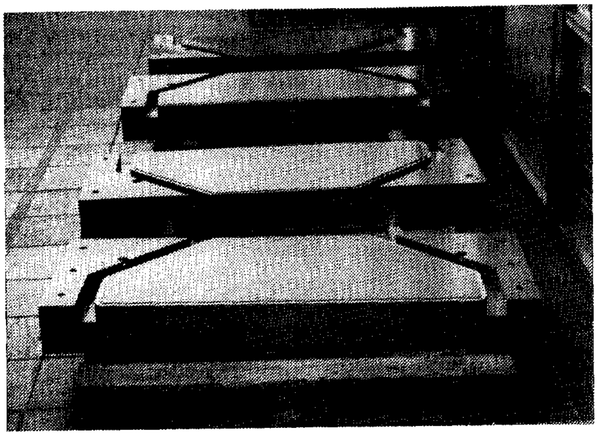

Figure 5. The magnet pieces with coil channels

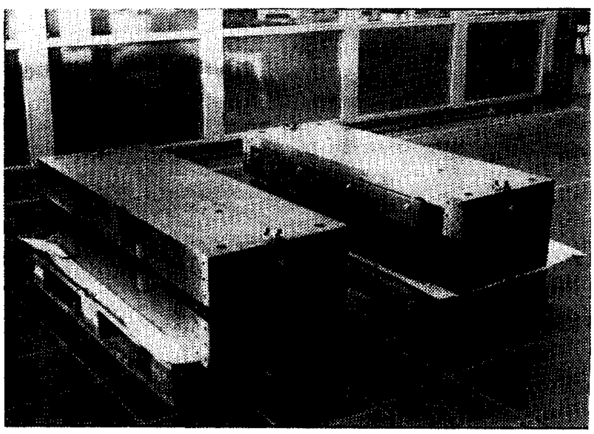

Figure 6. The assembled racetrack body

Undulator

The parameters of the FEL (electron energy = 25 MeV, undulator parameter K = 1 FEL-wavelength = 10 mm) require an undulator wavelength of 25 mm. The minimum full gap distance is 12 mm, determined by the vacuum chamber and the emittance of the electron beam. A hybrid type undualtor will have the highest performance under these conditions. The undulator will be constructed from Nd-Fe-B permanent magnets to supply the magnetic field. The use of poles makes the design less sensitive to magnetization errors of the permanent magnets. The design procedure is based on the Halbach method (ref. 7).

By modeling 2D-fluxes a full 3D-design can be optimized. The 2D-modeling is done with a combination of analytical methods like conformal mapping, and numerical methods using the POISSON Group of computer codes. An optimization of the permanent magnet thickness to the pole thickness ratio is performed to obtain the maximum field in the fundamental undulator wavelength. Overhang of the permanent magnets on top and sides is applied to reduce the amount of permanent material needed and to increase the performance of the magnetic system, respectively. The pole face near the electron beam is shaped to avoid saturation of the pole material, and to minimize the harmonic content of the magnetic field. The pole is also shaped in the transverse direction to obtain a correct focusing of the electron beam.

Conclusion

The complete MicroFEL-TEUFEL project, including the construction of two microtrons, is in progress. Numerical simulations and analytical theories of beam dynamics aspects have been set up.

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