STATUS OF THE DARMSTADT NEAR-INFRARED FREE-ELECTRON LASER*)

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Abstract

A status report of the Darmstadt near-infrared FEL which will operate between 2.5 and 5 μm will be presented. A high brightness test injector consisting of a pulsed electron gun and a subharmonic chopper-buncher system has been built and tested successfully. The emittance of the pulsed electron gun was measured at peak currents between 1 and 48 mA, a pulse width of 1 ns and a pulse repetition rate of 10 MHz. The measured value of about 1π mm·mrad at the peak current required by the FEL is well within the acceptance of the superconducting capture section. The beam transport magnets are available and the beam handling system for the FEL, which has been designed as an achromatic bypass to the first recirculation, is under construction. The wedged pole hybrid undulator system with a period length of 3.2 cm and a peak magnetic field of 4 kGauss is under construction and will be available at the end of this year.

1. Introduction

Using the newly constructed 130 MeV superconducting cw-electron accelerator, S-DALINAC, a Free-Electron Laser (FEL) project in the near-infrared started in October 1988. The basic concept of the accelerator as well as its layout has been described earlier [1-3] and a detailed status report is given elsewhere [4]. Since the design of the Darmstadt near-infrared FEL project was also presented earlier [5-8] we will after a short overview in Sect. 2 concentrate on the modification of the 250 keV injection. The injector components (electron gun, chopper and prebuncher cavities) are presented in Sect.3 and results achieved with a seperate 250 keV injection line are discussed. Section 4 deals with the additional beam transport system which allows to inject an electron beam of energies between 35 and 50 MeV into the undulator. Section 5 is about the hybrid undulator system and the optical resonator which both will be available at the end of this year.

2. Accelerator Facility and Status of the FEL

A schematic layout of the accelerator including the FEL experiment is shown in fig.1 and the main design parameters are listed in table 1. The electron gun (described in Sect. 3) is followed by a 250 keV electrostatic preacceleration and the room temperature part of the injection where preformation of the electron bunches is accomplished by a subharmonic 600 MHz chopper/prebuncher system. At the entrance of the 10 MeV superconducting injection linac an electron beam bunched for acceleration in 3 GHz cavities is available at a repetition rate of 10 MHz. The accelerated 10 MeV electron beam is then bent isochronously by 180° and injected into the superconducting main linac which gives an energy gain of up to 40 MeV. A second 180° bend, a straight section and the bypass system shown in fig.1 allow for injection of the electron beam into the undulator. In order to enable possible energy recovery experiments which are planned in a later stage of the experiment the bypass system is carried out symmetrically and the beam envelopes can be matched to the TEM_{00} mode of the optical cavity in both directions.

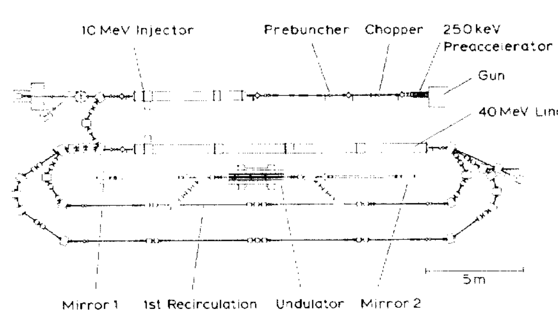

Fig. 1 *The 130 MeV accelerator and the FEL experiment*

The status of the project is as follows. According to [4] the accelarator, completed in December 1989, has produced in its different states of construction some 2200 hours of beamtime. Experience which we gained during runs for accelerator tests and during many hours of beamtime for atomic and nuclear physics experiments allows to operate the machine successfully with regard to many aspects important for the FEL project.

The Darmstadt FEL project consists of mainly four parts, the modified 250 keV injection, the bypass system transporting the electron beam to the undulator, the undulator itself and the optical resonator. A detailed description is given in the sections below.

All components needed for the modification of the 250 keV injection are tested successfully and will be installed this summer.High peak currents at an unchanged maximum average beam current of 60 μA are necessary in order to achieve sufficient gain in the optical cavity of the FEL.

Dipoles and quadrupoles for the bypass system are available and already in position. The vacuum system will be incorporated into the first recirculating beam transport line after the next shut down. The existing control system of the accelerator takes care also of this bypass.

The optical resonator with its mirror chambers at both ends is under construction as well as the undulator. The undulator, in hybrid configuration, will be delivered at the end of this year.

Table 1 Parameters of the FEL

Electron beam	
Energy [MeV]	35 – 50
Normalized emittance [π mm mrad]	2.2
Energy spread [keV]	±13
Peak current [A]	2.7
Micropulse length [ps]	1.9
Mode of operation	cw
Undulator magnet	
Period [cm]	3.2
Gap [mm]	15 – 25
Peak field [kGauss]	3.6 – 1.3
K	1.1 – 0.4
Number of central periods	80
Total magnetic length [m]	2.69
Optical cavity	
Length [m]	15.0
Rayleigh range [m]	0.74
Waist diameter (@5 μm) [mm]	2.2
Mirror radius of curvature [m]	7.59
FEL-Parameters	
Wavelength [μm]	5 – 2.5
Small signal gain [%]	16 – 13
Peak power [kW]	340 – 450
Pulse length [ps]	1.9
Repetition rate [MHz]	10
Mode of operation	continuous

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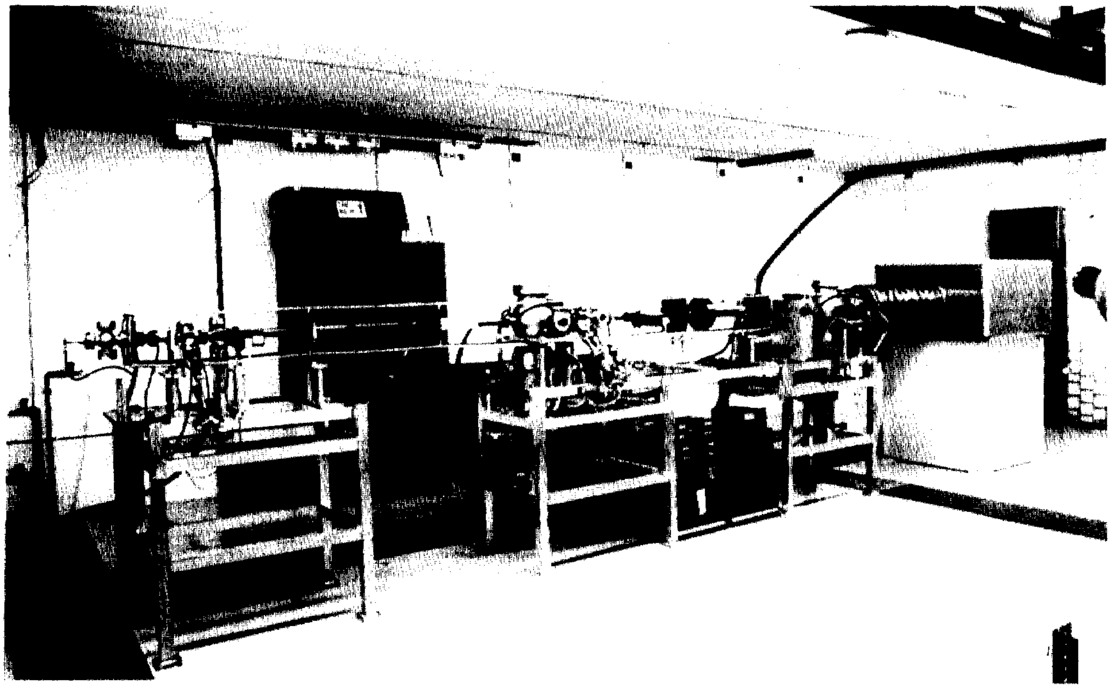

Fig. 2

The 250 keV injection test setup

3. Modified 250 keV Injection

The FEL experiment requires electron beam characteristics (see table 1) which with respect to beam current and time structure differ from the design for nuclear physics experiments. The constraints for the modified 250 keV injection are as follows. (1) The micropulse repetition rate has to match the length of the optical cavity and has to be a subharmonic of the accelerator frequency; 10 MHz was chosen as the 300th subharmonic. (2) An average current of 60 μA should not be exceeded which is a limitation caused by the available rf power needed for acceleration; the resulting time structure (see table 1) corresponds to an average beam current of about 50 μA. (3) Emittance, energy spread, beam diameter and bunch length have to be within the acceptance of the accelerator.

The design for the new injection was carried out with the program PARMELA [9] and is described in [5]. It consists of a new electron gun and a subharmonic chopper/prebuncher system.

In order to test the components an experimental test stand was set up in a separate hall. Figure 2 shows the injection consisting of the high voltage terminal housing the electron gun (extreme right), the 250 keV electrostatic preacceleration followed by some beam diagnostics, the 600 MHz subharmonic chopper cavity and two diagnostic stations with view screens and wire scanners. The beam line is completed by a coaxial Faraday cup.

3.1 Gun

In table 2 the requirements for the electron gun are listed as well as the achieved values which all match the design. The mechanical layout of the gun is shown in Fig 3. The gridded gun is operating at an anode voltage of 10 kV and is pulsed at the 300th subharmonic of the accelerator (10MHz). A 600 MHz signal phaselocked to the accelerator frequency (3GHz) is frequency divided by 60, sent to the hv-terminal via a light link, amplified and then used to drive a step-recovery-diode pulser which produces grid control voltages up to 60 V at a pulse length of less than 3 ns.

When measuring the emittance according to [10] and the electron beam diameter a halo of the electron beam was observed which obviously is caused by thermal effects and by a non ideal ratio of the cathode diameter to the aperture of the anode.

Since the delivered beam current is sufficient the halo of the 250 keV beam can be scraped off by an 8 mm aperture reducing the intensity by not more than 10%. Thus the gun delivers an electron beam with an emittance of about 1 π mm mrad (see table 2).

Table 2 Parameters of the electron gun

	specified	measured
Anode voltage [kV]	10	10
Maximum current [mA]	27	$\geq$50
Emittance [π mm mrad]	1	0.9 – 1.5
Cathode diameter [mm]	3	2.9
Pulse length [ns]	3	$\leq$3
Repetition rate [MHz]	10	10

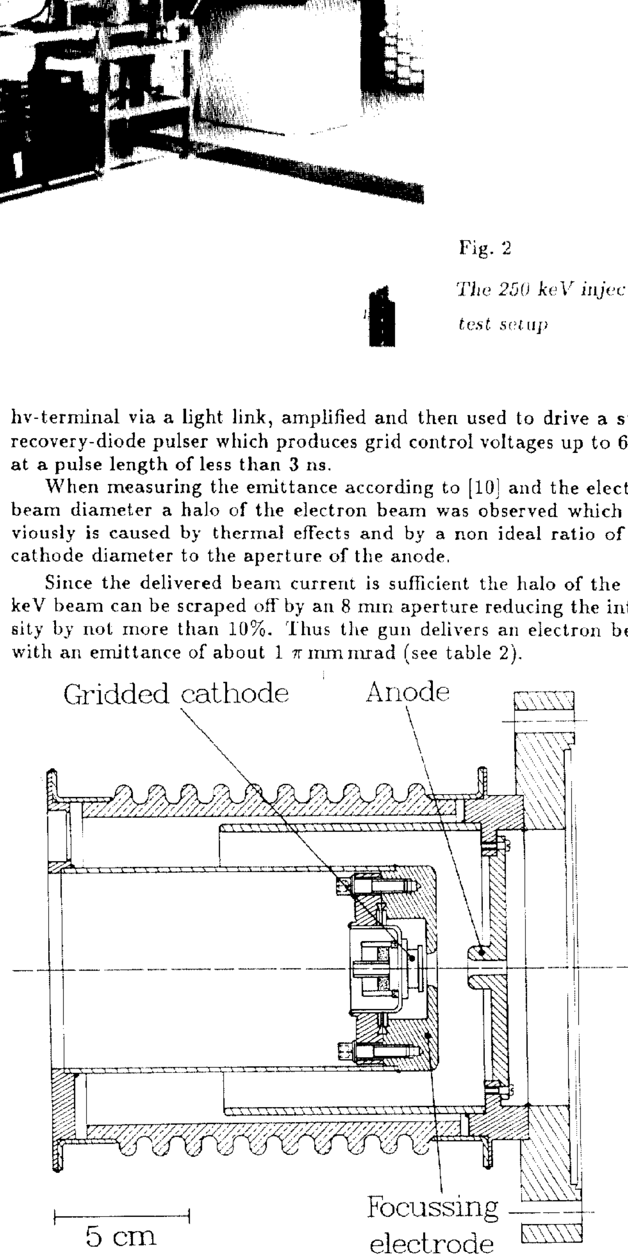

Fig. 3 *Mechanical layout of the high current electron gun*

3.2 Subharmonic Chopper/Prebuncher System

Following the injector design presented earlier [5-8] a chopper/prebuncher system operating at the 5th subharmonic (600 MHz) of the accelerator frequency is used in order to convert the 3 ns / 27 mA electron bunches produced by the gun into 6 ps long bunches with a charge of 5 pC per bunch. When compressed down to 1.9 ps by the superconducting injection linac a peak current of 2.7 A (see table 1) is achieved.

The chopper cavity which has been described in detail elsewhere [11] is a rectangular cavity operating in the TM_{110}-mode with vertical deflection. It was tested successfully with a loaded quality factor $Q_L = 4750$ at coupling constants $\beta_1 = 1.1$ and $\beta_2 = 10^{-3}$. Depending from the distance between the chopper cavity and the chopper orifice rf-power from 60 to 120 W is needed in order to meet the requirements.

The prebuncher cavity which has been described before [6-8] is a cylindrical reentrant resonator of the single cavity double frequency type. It is operating in the fundamental TM_{010}-mode at 600 MHz and in addition the first harmonic TM_{020}-mode at 1200 MHz can be excited which enlarges the phase space acceptance if proper phasing and amplitude ratio between the two modes is achieved. The prebuncher has been builtand the in- and outcoupling is from magnetic and electric type respectively at proper radial position. Here the incoupling is in the order of $\beta = 1$, the outcoupling is weak ($\beta = 10^{-2}$).The frequency of both modes are tunable relative independently by four radial tuning studs.

4. Beam Transport System

For the FEL project the present beam transport system of the accelerator is extended by a bypass of the first recirculation. The bypass is shown in fig.4 together with the results of a TRANSPORT [12] calculation. It consists of eight quadrupoles(Q) and four 45° bending magnets(D). According to our calculations this system is achromatic and a matching of the beam ellipse to the acceptance of the undulator magnet can be accomplished. The beam is well within the optical mode (see fig.4). For beam energy recovery experiments the system consisting of the undulator bypass and the remaining parts of the recirculation (see fig.1) has to be isochronous and the beam has to be phase shifted by 180° with respect to the rf-fields in the main linac when it is reinjected into the accelerator.

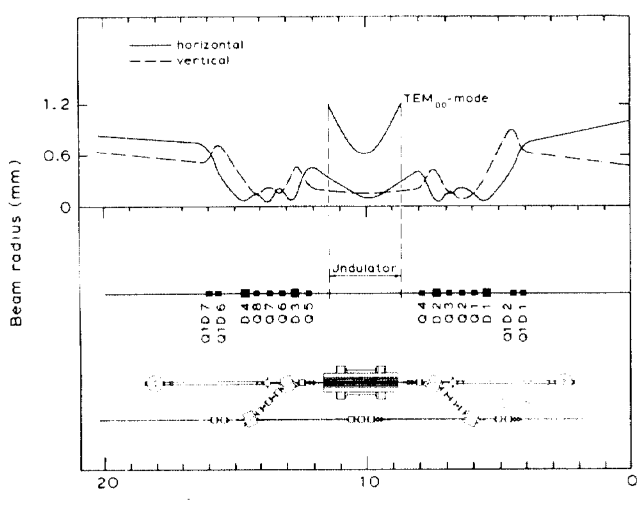

Fig. 4 *The FEL bypass and the beam envelopes calculated by TRANSPORT*

The magnets are already in position and the system will be completed with vacuum components and some electron beam diagnostic during a shut down this summer. So first beam in the bypass is expected in fall of this year.

5. Undulator and Optical Resonator

A preliminary design of the hybrid undulator has been given earlier [5]. In table 1 the main parameters are listed. The final design of the magnet and pole parameters has been carried out until the end of last year. The magnet structure differs with respect to [5] since a wedged pole configuration was chosen. This increases the peak magnetic field and allows a wider range of wavelength produced by the FEL. An undulator following the final design is under construction [13] and will be available at the end of this year.

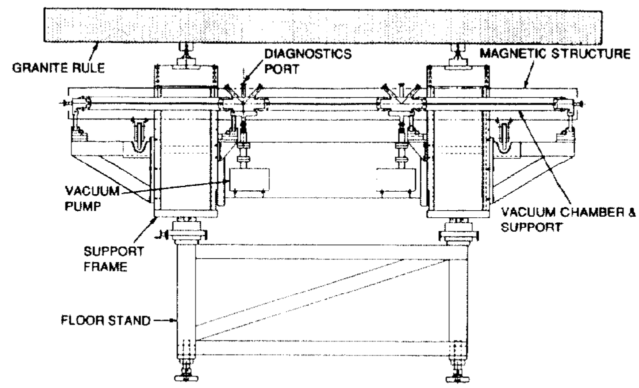

Fig. 5 *Side view of the Darmstadt undulator (courtesy of Spectra Technology Inc.)*

Figure 5 gives a side view of the Darmstadt undulator. The magnetic structure is orientated horizontal so that the electrons wiggle in vertical direction. The vacuum chamber between the two movable halfs of the 80 period structure has two pumping and diagnostic ports each located one third from the end of the undulator. The granit rule is used as a base for a system which allows precise measurement of the magnetic field amplitude.

The nearly concentric optical cavity is presently under construction. It consists of two spherical dielectric mirrors of 75 mm diameter separated by 15 meters and housed by a vacuum chamber each. Length control of the resonator will be established by means of an interferometer system designed to operate inside the main beam tube.

6. Outlook

The project is scheduled to produce the first optical beam in summer 1991. When the undulator becomes available at the end of this year first experiments with an electron beam under the influence of the 80 period magnetic field can be realized in spring 1991. We aim to use a beam energy as near as possible to the maximum of 50 MeV in order to take advantage of the larger gain in the optical cavity. Thus the corresponding optical wavelength of the first beam will be about 5 μm.

7. References

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