FIRST LASING OF THE ISRAELI TANDEM ELECTROSTATIC ACCELERATOR FREE ELECTRON LASER

J.S. Sokolowski, A. Abramovich, A. Arensburg, D. Chairman, M. Draznin, A.L. Eichenbaum, A. Gover, H. Kleinman, Y. Pinhasi, Y.M. Yakover, Department of Physical Electronics, Tel - Aviv University, Israel

A. Rosenberg, J. Shiloh, Rafael, Haifa, Israel

M. Cohen, L.A. Levin, O. Shahal, NRCN, Beer-Sheva, Israel

Abstract

First lasing at 3mm wavelength was achieved on December 4, 1996 in our FEL employing a modified EN-Tandem electrostatic accelerator as the source of energetic free electrons. A Pierce-type electron gun capable of providing a 2A beam was installed at the entrance to the accelerator and operated at 1.4A level, while the wiggler (λ_w=4.4cm, N_w=26) was located in the center of the accelerator, inside the positive HV terminal. The electron gun voltage was V_{gun}=-43kV and the terminal operating voltage V_{term}=1.4MV. The resonator, consisting of two parallel curved plates waveguide terminated by wave splitters at its both ends, was mounted inside the wiggler. Radiation pulses at 100.5 GHz of 2μsec duration and 1200W of power were obtained at intervals of 15 sec.

1 INTRODUCTION

Free electron lasers, with electrostatic accelerators operating as their high voltage sources, have the potential advantage of producing single mode radiation in quasi-cw operation. It is our long term objective to develop such an FEL; a number of modifications to the FEL reported on here will be required in order to achieve this goal. The version completed recently provides short pulses 100GHz radiation. We have also the option to convert it into an FEL of a different wavelength by changing the wiggler period λ_w (a new wiggler) and by changing the beam energy of the accelerator.

2 ELECTRON INJECTION SYSTEM

The parallel flow Pierce-type electron gun[1] designed using the Herrmannsfeldt code[2] was installed at the entrance to the accelerator. The gun employs a 2A Spectra - Mat tungsten dispenser cathode and it is followed by 4 focusing coils and a beam steerer. Helmholz coils surrounding the gun area cancel the earth’s magnetic field, which in this low energy area (-43kV) is deflecting the beam quite significantly. The gun platform is isolated at -43kV potential while the gun anode is at ground level. A pulse forming network provides the gate (grid) of the gun with pulses of 6μsec duration and +12 kV in amplitude with respect to the cathode. The steady state voltage of the gate before the pulse arrival is -6kV with respect to the cathode. The vacuum system pressure in the gun area is of the order of 10^{-8} Torr, achieved by a differential pumping system. A retractable beam viewer is located between the second and the third focusing coils and its screen is observed with the aid of a CCTV camera. Occasional measurements of the beam current at this position are possible with minor adaptations.

3 BEAM ACCELERATION AND FOCUSING

In order to enable focusing of the electron beam after acceleration (at the entrance to the wiggler) and before deceleration (at the exit from the wiggler) we have removed one of the accelerating tubes on both sides of the wiggler and replaced them by 3inch diameter stainless steel tubes on which 4 quadrupoles and a steerer were installed[3]. Thus, at the expense of reducing the high voltage terminal potential from 6MV to 3MV maximum we have gained the possibility of beam focusing at the high voltage level. The reduction of the maximum voltage of the machine does not pose any problems to us, since we are presently operating it at 1.4 MV only.

4 BEAM DIAGNOSTICS

The main diagnostic devices used in our setup are retractable fluoresecent viewers and Rogowski coils. A rather flexible retractable viewer is located immediately after the gun, it can be used as a poor-man’s Faraday cup, or a pepper-pot for emittance measurements.

The three beam viewers installed inside the accelerator tank are located as follows: the first one at the exit from the accelerator tube, the second at the entrance to the wiggler and the third one at the exit from the wiggler. The beam viewer cameras are installed inside the vacuum area and the signals from the cameras are sent to the control room via fiber optics. We have installed Rogowski coils in only three positions, we measure the current of the gun cathode, the beam current at the exit from the wiggler and the collector current. We have decided to include soon additional Rogowski coils in two other positions; at the entrance to the focusing tube and at the entrance to the wiggler.

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5 CONTROL

The basic accelerator control is the same old fashioned one as was used to run the ion accelerator. A new control system was added for pulsing of the electron beam current and for operating the beam focusing, diagnostics and steering, inside the accelerator at the high voltage terminal potential. This control system consists of a personal computer, a digital oscilloscope in the control room, an RS-232-to-fiber optics converter at the input to the accelerator tank, fiber optics along the beam tube inside the tank, a digital control box and analog control current drivers inside the high voltage terminal. Ac power to these units is supplied by a 400Hz, 108V, 1.5 kW generator driven by the belt shaft inside the high voltage terminal. Separate communication systems (using their own fiber optics) transmit the information from the beam viewer screens to the CCTV monitor and the amplitude of the beam current pulses to the oscilloscope.

We have a total of 8 quadrupoles and 4 steerer coils. Since we would like to use additional steerers, we are presently increasing the number of current drivers from 12 to 18 and modifying the digital control system.

6 THE WIGGLER AND THE RESONATOR

The wiggler (Halbach type[4] planar configuration) has 26 periods of 4.4cm each. Inside the wiggler and symmetrical about its axis is located a 100GHz resonator, built of two curved parallel plates forming the waveguiding structure, terminated at each end by a quasioptical Talbot effect wave splitter (see Fig.1). The beam splitters acting as resonator reflectors for the laser radiation allow electron beam to pass through an opening, without disturbing the reflectivity properties. This kind of resonator has low ohmic and low radiation losses, its Q-factor is of the order of 3×10^4[5,6]. Focusing of the electron beam in the wiggling plane is achieved by the use of two long permanent magnets along the axis of the whole wiggler[7]. The basic parameters of the wiggler and resonator are shown in Table 1.

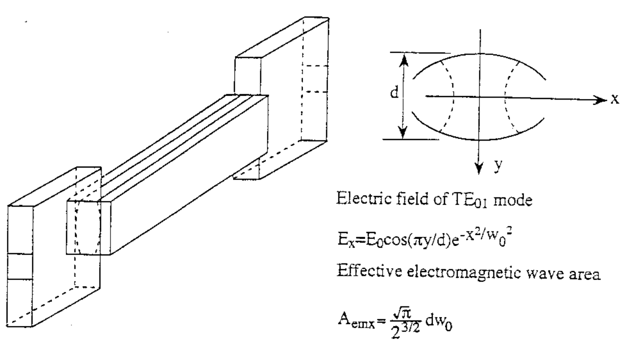

Fig. 1. The resonator.

7 BEAM TRANSPORT AND RECOVERY

The beam, received from the Pierce gun is focused and steered by three focusing coils and a pair of steering coils, enters the accelerating tube. After acceleration the beam continues through the 3inch diameter, 2m long tube on which four quadrupoles lenses and a couple of steering coils are installed. The beam is further focused by these lenses and the viewing screens located before and after the wiggler are used as diagnostics for optimizing the shape, position and diameter of the beam.

We have so far concentrated our efforts mainly on getting an appreciable part of the beam current into the wiggler, so that the basic boundary condition for lasing radiation production would be satisfied. We were able to get about 200mA through the wiggler to the collector, but we know - based on our previous experiments and simulations - that we should be able to transmit nearly all the beam to the collector. Once this is achieved, we shall collect the electron current at a voltage close to ground level (due to the energy loss for the lasing). A floating, 50kV power supply, compensating for this energy loss, will be connected in series between the collector and the gun high voltage platform, and thus we shall be able to recirculate the current. The depressed collector operation will allow the operation of the FEL at much longer pulses and at higher repetition rates thus giving a substantial average power as required in many applications.

Table 1. Basic parameters of the tandem FEL

Accelerator:	
Electron beam energy	E_k = 13-15 MeV
Cathode e-beam current	I_0 = 1.4 A
Wiggler:	
Magnetic induction	B_0 = 2 kGs
Period length	λ_w = 4.44 cm
Number of periods	N = 26
Waveguide resonator:	
Type	Curved parallel plate waveguide
Mode	TE_{01}
Interaction length	L_w = 88.9 cm
Resonator length	L_c = 131 cm
Designed-Q factor	> 20,000
Power round trip losses	1-R < 10%

8 LASING RADIATION AND MEASUREMENT

On the 4th of December 1996 the first lasing pulse was detected (Fig. 2). This radiation pulse width was approximately 0.5μsec while the electron beam pulse was 5 msec wide. During following experimentation we have reached radiation pulses of 3 μsec duration (Fig. 3). This width was limited due to the voltage droop of the high voltage terminal. The stability of the high voltage terminal potential is one of the critical parameters for laser radiation to occur and be maintained, thus if this condition is not preserved, lasing is discontinued. One can note in Fig. 3 the slow buildup of the radiation pulse (its risetime) and its sudden interruption (the falltime). The radiation decay, after the voltage falls below the lasing value, corresponds to $Q_L = 2\pi\tau_c f = 30{,}000$.

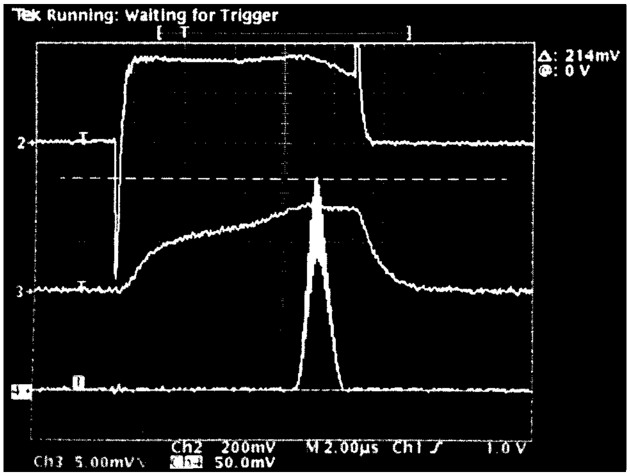

Fig. 2 The first lasing radiation pulse.

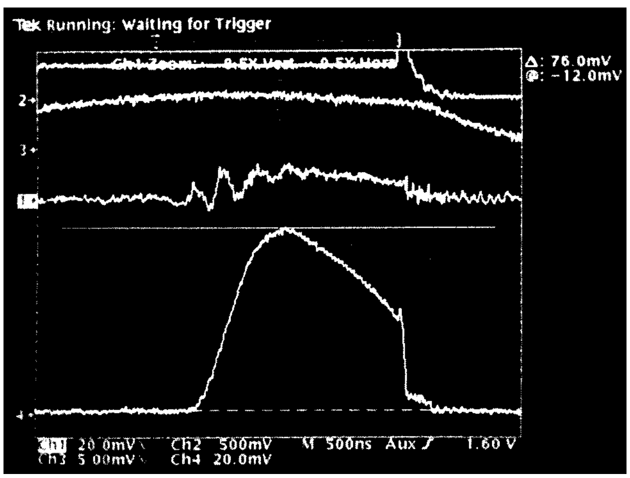

Fig. 3. The widest radiation pulse so far

The measured attenuation of the radiation path through decelerating section of the beam tube to the collector was 42dB. The power translated to the exit from the resonator was 1200W. The frequency of the radiation was checked using a heterodyne system i.e. by mixing the detected wave with a known local oscillator frequency and measuring the beat frequency between them. The measurement resolution was of the order of a few MHz and the FEL frequency was 100.55GHz - rather close to the predicted 100GHz.

9 FUTURE PLANS

Having shown that the FEL operation is close to the theoretical predictions, we will pursue further goals:

a. Gradual increase of the pulse width from the present 3µsec to 1 millisec.
b. Increase of the repetition rate from 1 in 15 seconds to 10/sec.
c. Increase of the lasing power at the exit from the resonator from 1200W to approximately 10kW.
d. Design an installation of an efficient optical transport of the lasing radiation to couple it out of the tank.
e. Adapt the FEL to operation as users' facility for industrial, medical and scientific applications.

10 CONCLUSIONS

The theoretical calculations, assumptions and simulations used in order to design the FEL were proven to be correct - the machine operates at 100.55GHz (predicted 100GHz). The low loss resonator is promising for the objective of achieving high lasing power, once we transport the beam without major losses through the wiggler. The planned improvements to the FEL and its operation in quasi-cw mode (1msec wide pulse at a rate of 10/sec) will allow it to become a users' facility for industrial, medical and scientific applications.

11 ACKNOWLEDGMENTS

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