NARROW LINEWIDTH, CHIRP-CONTROL AND RADIATION EXTRACTION OPTIMIZATION IN AN ELECTROSTATIC ACCELERATOR FEL OSCILLATOR

H. Marks*, A. Gover, H. Kleinman, J. Wolowolsky, Tel Aviv University, Israel
D. Borodin, M. Einat, M. Kanter, Y. Lasser, Yu. Lurie, Ariel University, Israel

Abstract

In recent years the electrostatic accelerator FEL based in Ariel has undergone many upgrades. By varying the accelerating potential the resonator allows lasing between 95-110 GHz. It is now possible to remotely control the output reflectivity of the resonator and thereby vary both the power built up in the resonator and that emitted. This has allowed fine control over the power for different user experiments. A voltage ramping device has been installed at the resonator/wiggler to correct drops in voltage which occur due to electrons striking the walls of the beam line. This has allowed stable pulses of just over 50 µs with a chirp rate of ~80 kHz/µs.

INTRODUCTION

The Israeli Electrostatic Accelerator FEL (EA-FEL) is one of the few FEL oscillators besides the UCSB FEL [1] that can operate quasi-CW. The Dutch FOM operated along similar principles and at higher power but has since been dismantled [2]. It is most fitting for studying the physics of single mode laser oscillation and developing narrow line-width high power applications in the mm-wave/THz regime, it has in an earlier configuration displayed particularly narrow line-width for an FEL [3].

The EA-FEL is a straight-line Van-de-Graaff ion accelerator. It was converted into an energy-retrieving electron accelerator. The electron beam is injected from a 50 keV electron-gun into the accelerator from ground potential. The beam is accelerated up to the positively charged high-voltage (HV) terminal in the center of the pressurised gas tank. An FEL wiggler/resonator assembly is installed in the HV terminal. After passing through the wiggler in the terminal, the beam is decelerated and transported in a straight line up to the collector. The mm-wave radiation, coupled out of the FEL resonator in the terminal, is guided through an optical transmission line

The laser was upgraded and is now providing longer higher power pulses (up to 50 µs) to a user room. A variable cavity radiation out-coupler was installed as the front mirror of the laser cavity. It is useful for realizing the concept of radiation power extraction maximization of an FEL oscillator [4]. A voltage ramp generator that was installed in the accelerator terminal made it possible to stabilize the voltage of the resonator/wiggler assembly during the laser pulse, and in this way to attain longer laser pulse operation. It also makes it possible to attain narrow laser line-width and controlled frequency chirp that may be used for spectroscopy.

METHOD

In order to improve the parameters of FEL operation beyond those reported [3] a number of steps were taken. The wiggler was removed from the system and errors in the magnetic field were corrected [5]. Next a new resonator was installed that operates using the Talbot effect to separate the electron beam from the radiation (see Fig. 1). Section 1 is a Talbot (interference) wave splitter composed of a straight rectangular waveguide 10.7X25 mm^2. It allows passage of the electrons whilst fully reflecting the split radiation pattern.

Section 2 is a waveguide with two corrugated walls 10.7X15 mm^2. The third section begins with a section of smooth walled waveguide identical to that in the first section. After 145 mm there is a transition from a rectangular waveguide to a parallel plate waveguide. In one dimension the radiation is guided, in the other free diffraction occurs. The electron beam leaves this section via a hole in an inclined parabolic mirror, whilst the radiation which is split either side of the hole is reflected upwards to a second off-axis mirror. The second off-axis mirror reflects the radiation to an outcoupling element whose reflection and transmission properties can be remotely controlled. The outcoupling element consists of 3 polarisers, the wires of the first and third of which are held vertical, perpendicular to the electric field of the radiation excited in the resonator, whilst the middle polariser is free to rotate.

The accelerator is based on the build-up of positive static charge within the tank, electrons which hit the walls of the beam line cause the accelerating voltage to drop. To correct for this a remotely controlled voltage ramp generator was developed for stabilizing the resonator/wiggler potential during the laser pulse and for controlling laser frequency chirp. The ramp generator is connected between the resonator/wiggler assembly and the high voltage terminal (that are isolated from each other). The ramp voltage generator can produce a voltage ramp of up to 25 kV during the electron beam pulse duration.

Table 1: EA-FEL Parameters

Beam Energy:	1.34-1.44 MeV
Wiggler Period:	44.4 mm
Number of Periods (N_w):	26
Radiation Frequency:	95-110 GHz
Resonator Internal Loss:	30%
Cathode Current:	0.5-3 A

---

*harry_s_marks@hotmail.com

ISBN 978-3-95450-133-5

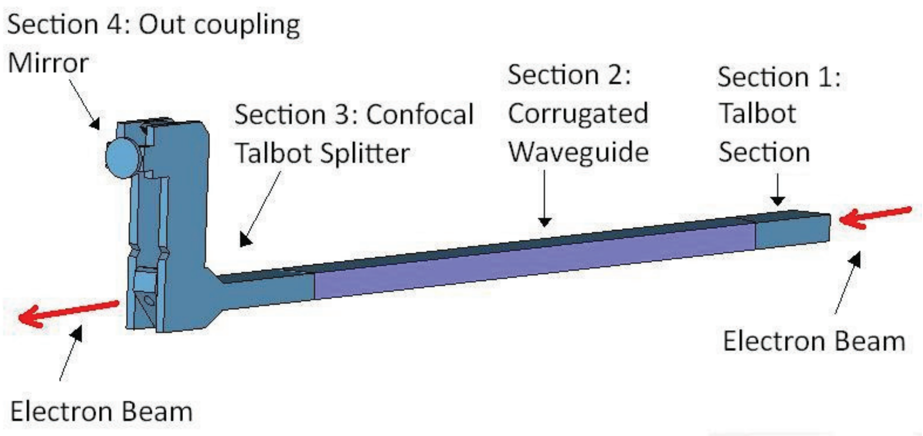

Figure 1: The mm-wave Talbot effect confocal resonator.

RESULTS

Changing the reflectivity of the outcoupling grids between pulses allows finding the maximum output power point for lasing (see Fig. 2). Power was measured in the user room (maximum 2 kW for a 0.93 A current) and extrapolated back to the resonator to compare with the simulation program FEL3D. Losses in the transmission line were measured to be ~80%, this could be reduced to 30% fairly simply, but the work has not been prioritised. The pulse to pulse variation in power is due to the ever rippling voltage of the electrostatic accelerator.

Nw is the number of wiggler periods of which there are a total of 26, 20 of these encompass the corrugated waveguide. Due to the Talbot splitting we need to consider an effective Nw.

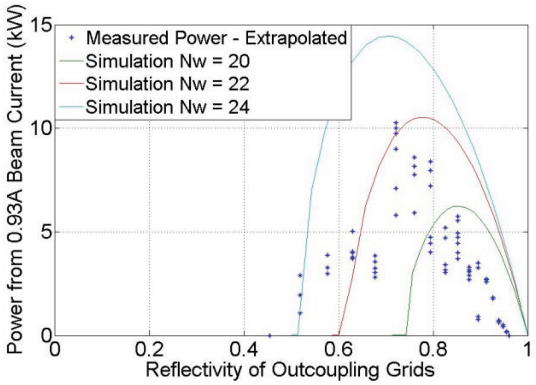

Figure 2: By changing the reflectivity of the outcoupling from the resonator it was possible to vary the power built up within and emitted from the resonator.

With imperfect transport and a consequent loss in the accelerating potential of ~0.5 kV/µs the longest pulse attainable was just over 30 µs. By using the voltage ramping at 25 kV with a time constant of 3.34 µs it was possible to attain pulses of just over 50 µs. An example of such a long pulse measured at the end of the transmission line in the user room is shown in Fig. 3. The power reflectivity of the out-coupling grids was set to 0.87, the Cathode current was 1.12 A. The total pulse energy in the user room was 39.5 mJ, which translates to 200 mJ at the resonator exit (~5 kW).

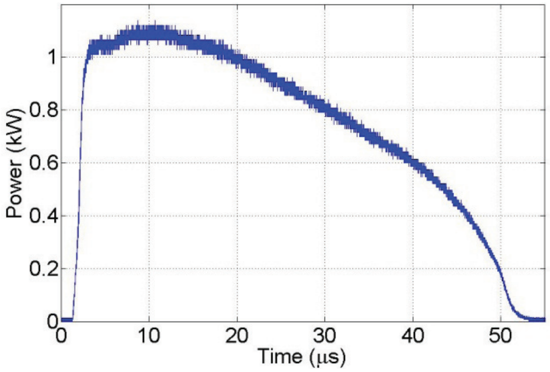

Figure 3: Sample long pulse obtained using the voltage ramping device installed within the accelerator.

To record the spectral lasing line of the FEL the laser output was mixed in the user room after attenuation with a local oscillator (LO) at a frequency close to the lasing frequency. The intermediate frequency (IF) signal out of the mixer was recorded, and the data was later processed using a Matlab spectrogram program. Single longitudinal mode operation of the FEL was verified over the course of many experiments. For the pulse shown in Fig. 3 single mode operation begins after 3.5µs. The spectrogram of this pulse after 3.5µs is shown in Fig. 4. The spectrogram of the ~50 µs pulse was taken with time windows of 2.5 µs whilst the oscilloscope was set to 500 MHz. The general trend in Fig. 4 is for the IF to increase in frequency, however, early in the pulse due to the voltage ramping the IF signal decreases before rising again. Due to the falling accelerating potential the IF frequency chirps over the 50 µs from 10 MHz to ~14 MHz, a total chirp rate of 80 kHz/µs. In this case it is clear the LO was set above the lasing frequency, hence the increasing IF as the lasing frequency drops.

The rate of change of the frequency grows with time. In the first 10 µs the linewidth is particularly narrow, $\Delta f/f =$

1.2×10^{-6}, which is close to the Fourier Transform limit. Were the chirp to be eliminated the entire signal would be Fourier Transform limited.

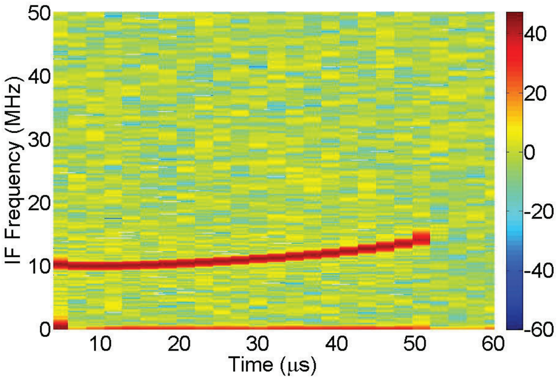

Figure 4: Spectrogram of the IF frequency of the sample pulse shown in Fig. 3.

CONCLUSION

An important milestone in the EA-FEL project has been reached demonstrating the great versatility of the system. Basic laser-oscillator physics effects can be studied in this system in the context of FEL oscillators. The record narrow linewidth achieved and the controlled chirp effect are promising features for fine single-pulse spectroscopic applications. All the new technological modifications were successfully operated. The main challenge left to overcome is to reduce beam leakage by improving the diagnostic systems. By doing so it should be possible to increase lasing pulse times to be of the order of milliseconds.

REFERENCES

[1] L. R. Elias et al, “The UCSB electrostatic accelerator free electron laser: First operation”, Nuclear Instruments and Methods in Physics Research Section A, Vol. 237, Issues 1–2, 15 June 1985, pp. 203–206.

[2] A. G. A. Verhoeven et al, “First microwave generation in the FOM free-electron maser”, Plasma Phys. Control. Fusion, Vol. 40, Issue 8A, August 1998, pp 139-156.

[3] Y. Socol et al, “Physical Review ST Accelerators and Beams”, Phys. Rev. ST Accel. Beams 8, 080701 August 2005, pp1-9.

[4] A. Abramovich et al, “Efficiency Enhancement of a Pre-Bunched Free-Electron Maser Oscillator by Locking to a Single Eigen Frequency of the Resonator”, Nuclear Instruments and Methods in Physics Research Section A, Vol. 429, 1999, pp 107-110.

[5] H. S. Marks et al, “Wiggler improvement based on single axis magnetic measurement, synthesized 3-D field simulation of trajectories and sorting of lateral focusing magnets”, Nuclear Instruments and Methods in Physics Research Section A, Vol. 660, (2011) pp. 15–21.

ISBN 978-3-95450-133-5