Radiation measurements in the new tandem accelerator FEL

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The Israeli Tandem Electrostatic Accelerator FEL (EA-FEL), which is based on an electrostatic Van der Graaff accelerator was relocated to Ariel 3 years ago, and has now returned to operation under a new configuration. In the present FEL, the millimeter-wave radiation generated in the resonator is separated from the electron beam by means of a perforated Talbot effect reflector. A quasi-optic delivery system transmits the out-coupled power through a window in the pressurized gas accelerator tank into the measurement room (in the previous configuration, radiation was transmitted through the accelerator tubes with 40 dB attenuation). This makes it possible to transmit useful power out of the accelerator and into the user laboratories.

After re-configuring the FEL electron gun and the e-beam transport optics and installing a two stage depressed collector, the e-beam current was raised to 2 A. This recently enabled us to measure both spontaneous and stimulated emissions of radiation in the newly configured FEL for the first time. The radiation at the W-band was measured and characterized. The results match the predictions of our earlier theoretical modeling and calculations.

1. Introduction

The Israeli electrostatic accelerator FEL (EA-FEL) is based on a 6 MeV EN-Tandem Van der Graaff accelerator, which was originally used as an ion accelerator for nuclear physics experiments \cite{1}. The scheme employs straight geometry for the electron beam transport, where the electron gun and the collector are installed outside of the accelerator region. Lasing was reported in a previous configuration, where radiation was transmitted through the accelerator tubes with 40dB attenuation \cite{2,3}.

In the present version of the FEL, which was relocated to Ariel, the millimeter-wave radiation generated in the resonator is separated from the electron beam by means of a perforated Talbot effect reflector \cite{4,5}. A quasi-optic delivery system transmits the out-coupled power through a window in the pressurized gas accelerator tank. The basic parameters of the FEL are summarized in Table 1. The acceleration voltage is set to be $E_k = 1.4 \text{ MeV}$ in order to tune the frequency of the FEL radiation to the W-band near 100 GHz.

In the following sections, we present an analysis and the results of spontaneous and stimulated emissions measurements carried out recently.

2. Spontaneous emission in a resonator

Random electron distribution in the e-beam causes fluctuations in current density, identified as \textit{shot noise} in the beam current. Electrons passing through a magnetic undulator emit a partially coherent radiation, which is called \textit{undulator synchrotron radiation}. The electromagnetic fields excited by each electron add incoherently, resulting in a \textit{spontaneous emission} with generated power spectral density \cite{6}:

$$\frac{dP_{sp}(L_W)}{df} = \tau_{sp} P_{sp}(L_W) \text{sinc}^2 \left( \frac{1}{2} \theta L_W \right)$$

where $P_{sp}(L_W)$ is the expected value of the spontaneous emission power, $\tau_{sp} =$
The spontaneous emission power of the Israeli EA-FEL, as calculated with equation (1), is 1/τsp ≈ 9 GHz. The number of longitudinal modes within the spontaneous emission bandwidth is then N_{modes} = (1/τsp)/(1/FSR) ≈ 80. Thus the total spontaneous emission power measured at the output of the resonator is given as follows:

\[ P_{sp}^{out} = N_{modes} \cdot P_{sp}^{out}(m) \]

\[ \approx \frac{T}{(1 - \sqrt{R})^2} \cdot P_{sp}(L_W) \]  

Using equation (2), we expect up to \( P_{sp}^{out}(L_W) \approx 120 \mu W \) spontaneous emission power.
to be generated inside the resonator. From (5), the power emitted from the resonator out-coupler is reduced to $P_{out}^{sp} \approx 24 \mu W$. The attenuation of the wave-guiding system, delivering the power from the resonator, located inside the high-voltage terminal, to the measurement apparatus is 10dB. Consequently, the spontaneous emission power expected at the detector sight is 2.4 $\mu W$. The traces shown in Fig. 2, describe the electron beam current pulse and the signal obtained at the detector video output, corresponding to the measured spontaneous emission RF power.

![Figure 1. Spontaneous emission power spectrum at resonator output (for $I_0 = 1$ A).](image)

Figure 2. Spontaneous emission power measurement.

where $\Delta P \approx 35$ kW for a beam current of $I_0 = 1$ A. The resulted power obtained from the out-coupler is given as follows:

$$P_{out} = \frac{T}{1 - R} \Delta P$$

and evaluated to be $P_{out} = 7$ kW. Considering the attenuation of the transmission system, 700 W is expected at the detector. Fig. 3 shows recent measurement of 150 W radiation power at the end of the optical transmission line in the measurement room. We note that in the present preliminary experiments, only a fraction of the cathode current was transported through the wiggler, and no beam circulation (transport up to the collector) was achieved. The charging of the terminal caused voltage drop of the terminal of 125 kV during the pulse duration. Evidently, the FEL had not yet reached saturation because the radiation mode built inside the resonator went out of synchronism with the beam before reaching saturation.

### 3. Stimulated emission

In the present operation regime of the FEL, the efficiency of energy extraction from the electron beam is given in terms of the number of wiggler’s periods $N_w$ by the approximate formula $\eta_{ext} \approx 1/2N_w = 2.5 \%$. The stimulated radiation power generated inside the resonator at steady state is given as follows:

$$\Delta P = \eta_{ext} E_k I_0$$

(6)

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Figure 3. Stimulated emission (lasing) power measurement.

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