Energy-Spread Effect on Output Power in an Ion-Channel Guiding FEL

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***Abstract*—It is found that, unlike the situation in a conventional free-electron laser (FEL), output power in an ion-channel guiding FEL is slightly affected by the energy spread of the electron beam. Physical explanation is presented to this phenomenon.**

I. Introduction

THE free-electron lasers have been recognized to be high-power, high-efficiency radiation sources in the whole spectrum from microwave to x-ray. When the electron beam has a high current, it always needs an external focusing system to confine the electron motion so as to ensure a good quality of the electron beam transport. So far, there are two kinds of the focusing systems: one is magnetic focusing mechanism provided by dipole/quadrupole magnets or an axial guide magnetic field; the other is electric focusing mechanism provided by an ion-channel guiding [1,2].

Despite the efficient effect of the magnetic focusing system, output power is strongly decreased by the energy spread of the electron beam. However, we shall show that in an ion-channel guiding FEL output power is slightly affected by the beam energy spread.

II. Results

We simulate the dependence of output power on the beam energy spread by employing the basic design parameters in the MIT experiment [3]. In that experiment, the electron beam had an energy of 750 keV and a current of 300 A with an energy spread of 1.5 %, the wiggler had a period of 3.18 cm, an amplitude of 630 G and a total length of 200 cm, the laser wave was a TE_{11} mode at a frequency of 33.39 GHz with an efficient input power of 8.5 kW, and the axial guide magnetic field was 4060 G. According to principal requirements of a FEL with magnetic focusing mechanism [3], the beam energy spread must be limited within 1.6 % for these parameters.

However, situation changes when we use an ion-channel guiding to replace the axial guide magnetic field, where the ratio of the ion-channel ion density to the electron-beam density is 21.5. Figure 1 shows the output power evolution versus the longitudinal position in the beam-wave interaction for different energy spread. It can be found from the figure that dependence of power on the energy spread is slightly affected. At the exit the device gets an output power of 8.9 MW, 8.8 MW, and 8.3 MW for the energy spread being 0, 1 %, and 4 %, respectively. That is to say, even the energy spread is 4 %, the output power has trivial decrease.

III. Summary

Our simulation reveals an advantage of the ion-channel guiding FEL over the FEL with an axial guide magnetic field that the energy spread of the electron beam has a slightly negative effect on the output power.

This phenomenon may result from the differentia of the focusing mechanisms. In the magnetic focusing mechanism the axial guide magnetic field generates a magnetic force to superpose a periodic Larmor rotation on the electrons, which dominates the transverse motion and confine the electrons within a limited region. Whereas, the ion core of an ion-channel guiding generates an electrostatic field, which directly attracts the electrons inward in the radial direction. As the results, electrons in the ion-channel guiding mechanism get smaller Larmor radius and smaller deviation of guiding-center shift off the axis than in the magnetic focusing mechanism, and consequently, get better quality of electron beam transport.

This physical explanation has been supported by the nonlinear simulations. Results indicate that for the magnetic focusing by an axial guide magnetic field (Group-I) mentioned above, evolution of the normalized transversel velocity spans in a range of 0.14-0.21 for an initial energy spread of 1 %, whereas it heavily expands to 0.13-0.23 for an initial energy spread of 4 %. However, situation changes for the electrostatic focusing by an ion-channel guide field: it spans in a range of 0.06-0.09 and 0.065-0.100 for an initial energy spread of 1 % and 4 %, respectively, which has a neglectable change.

Acknowledgement

. This work was supported by the NSFC (Grant No. 61275043, 60471047) and the Shenzhen Science Bureau (Grant No. 200805, CXB201105050064A).

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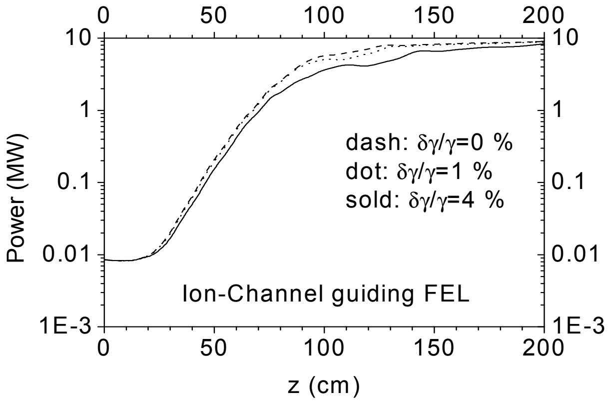

Fig. 1. Power evolution versus the longitudinal position in an ion-channel guiding free-electron laser for various values of the electron-beam energy spread.