A FAR-INFRARED FEL FOR THE RADIATION SOURCE ELBE

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A permanent magnet undulator (U100) is being constructed to extend the wavelength range of the FEL at the radiation source ELBE [1] to above 150 μm. At its lowest wavelengths it overlaps with the existing U27 undulator (see fig. 1). The undulator is composed of 38 magnetic periods each 10 cm long. The hybrid structure consists of Sm/Co magnets and soft iron poles. It guarantees a sufficiently high magnetic field at a reasonable undulator gap and a high radiation resistance. Increasing the gap from 24 to 85 mm the undulator parameter K_{rms} varies from 2.7 to 0.3.

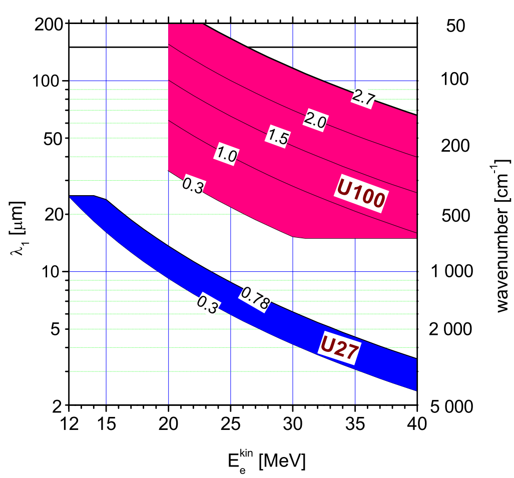

Figure 1: Wavelength ranges of the U27 and U100 undulators of ELBE as a function of the kinetic electron energy E_e^{kin}. The colored areas indicate the wavelength λ_1 of the first harmonic. The black lines correspond to the indicated undulator parameters K_{rms}.

Fig. 2 shows the main components of the new FEL. It is equipped with a parallel-plate waveguide which is 10 mm high and sufficiently wide to allow a free propagation in horizontal direction. It spans from the undulator entrance on the upstream side to the cylindrical downstream mirror. On the upstream (left) side the optical beam propagates freely through the quadrupole magnets and the dipole. The waveguide reduces the beam size within the undulator, increases the laser gain and allows a smaller undulator gap.

To minimize the coupling losses between free and waveguide propagation the vertical curvature of the upstream mirror (M1) has to be different from the horizontal one (M2). While the horizontal curvature of M1 and M2 corresponds to a Rayleigh length of 180 cm the vertical radius of curvature of the upstream mirror corresponds to the distance between M1 and the undulator entrance (361 cm).

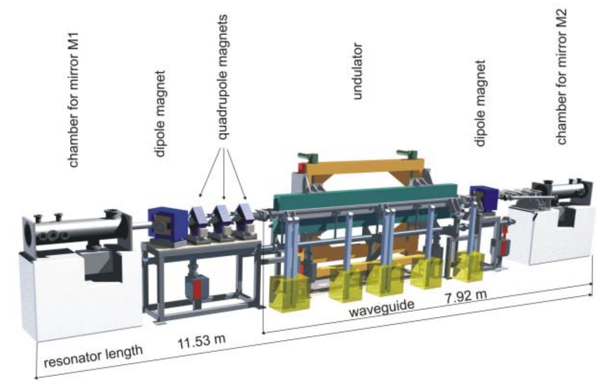

Figure 2: Schema of FEL2 at the ELBE facility. The electron beam enters the FEL at the dipole magnet on the left side and leaves it at the right-side magnet.

The resonator will be controlled and stabilized similarly to the resonator of the U27 undulator. An alignment system consisting of two collinear He-Ne lasers guarantees an angular adjustment of 25 μrad. A Hewlett-Packard interferometer system will be used for monitoring and stabilizing the resonator length.

Calculations using the code GLAD [2] have shown (fig. 3) that the optical losses in the resonator (without outcoupling) do not exceed 6% per pass. Notice that losses calculated with outcoupling are quite well approximated by the sum of the losses without outcoupling and *twice* the outcoupled fraction (see fig. 3). The hole does not only reduce

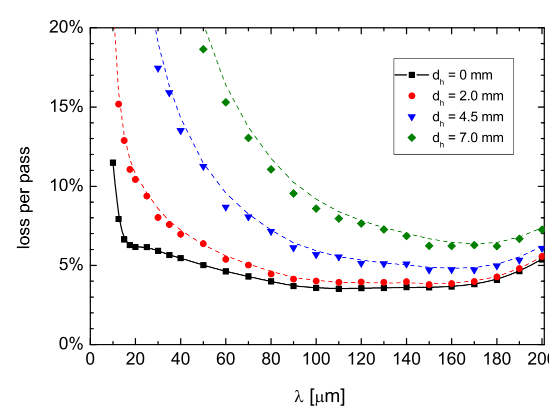

Figure 3: Optical losses per pass as a function of the wavelength λ for various diameters d_h of the outcoupling hole. The broken lines show the sum of the losses without outcoupling (black) and twice the corresponding outcoupled fraction.

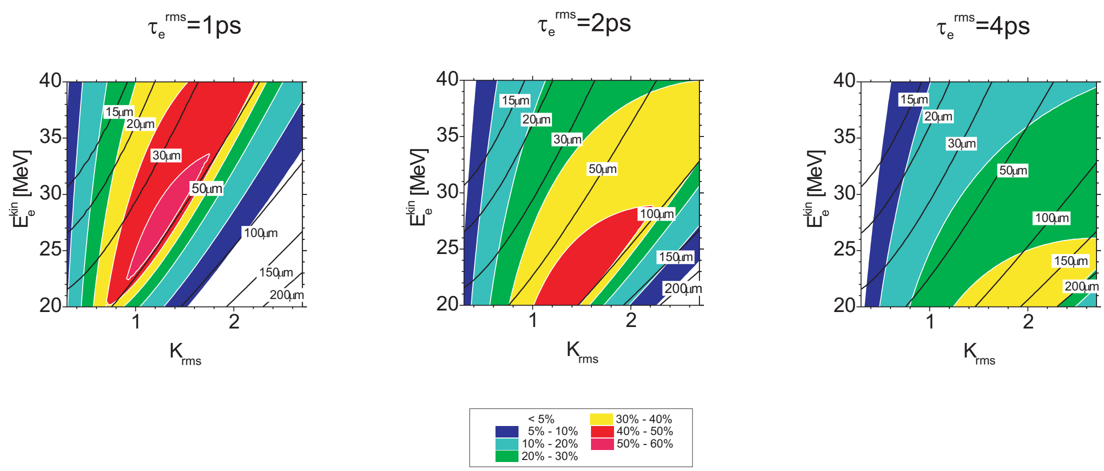

Figure 4: Laser gain predicted for the U100 undulator for 1, 2 and 4 ps (rms) electron pulses of ELBE as a function of undulator parameter K_{rms} and kinetic electron energy E_e^{kin}.

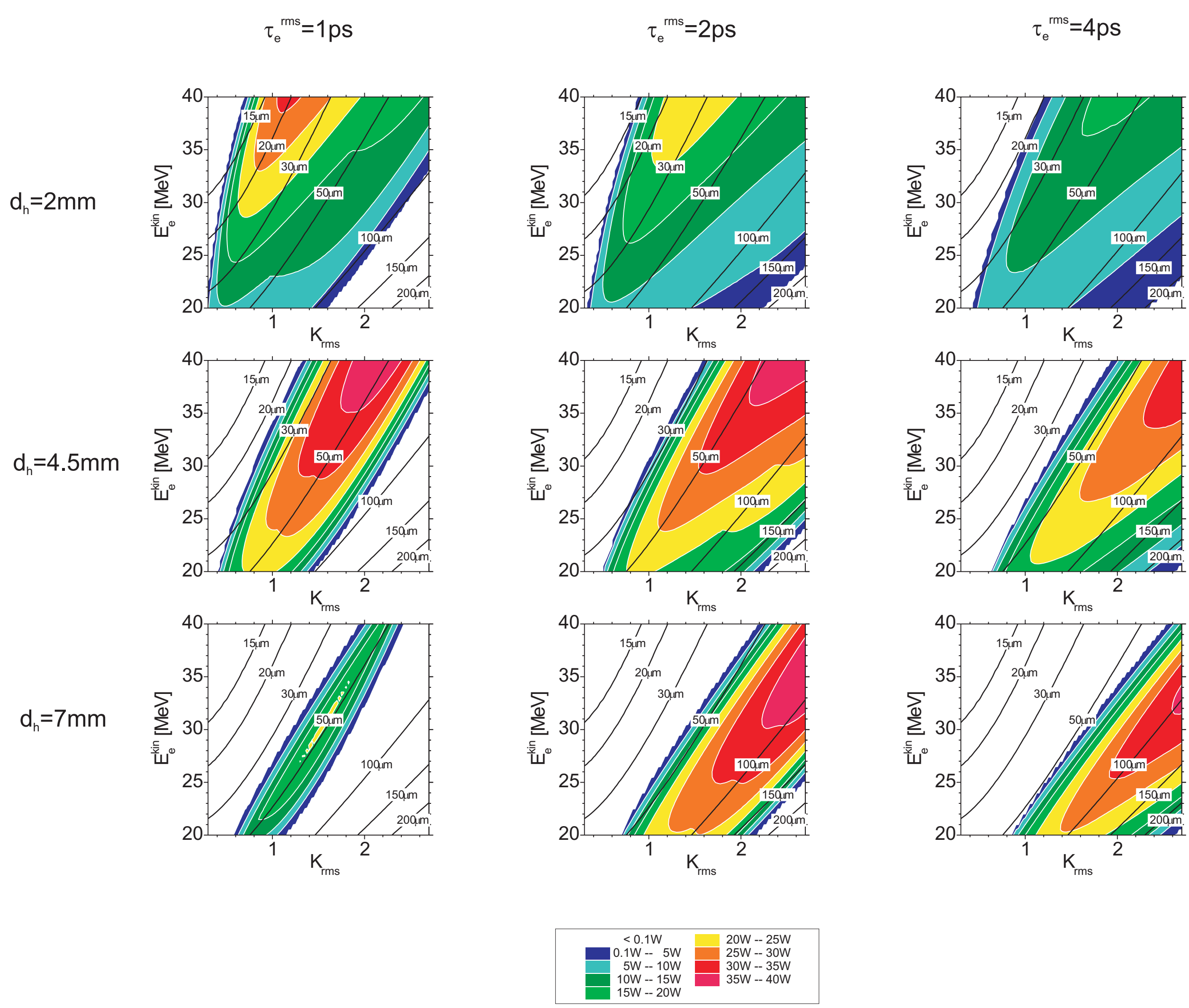

Figure 5: Maximum outcoupled average laser power for outcoupling holes with diameter d_h=2, 4.5 and 7 mm predicted for 1, 2 and 4 ps (rms) electron pulses of ELBE as a function of undulator parameter K_{rms} and kinetic electron energy E_e^{kin}.

the reflected beam by the outcoupled fraction but also diffracts the reflected beam leading to losses approximately of the same magnitude.

To vary the outcoupled beam fraction and to fit it to different beam radii the size of the outcoupling hole can be altered. For that aim three mirrors with the same curvature but different outcoupling holes with diameters of 2, 4.5 and 7 mm, respectively, will be mounted on a horizontal girder. A separate beamline will guide the outcoupled beam to the diagnostic cave. From there it will be distributed to the optical laboratories by a line [3] shared with the beam from the U27 undulator.

Using the scheme developed by S.V. Benson [4] and taking into account the calculated optical losses we have estimated the single-pass gain and the outcoupled average laser power. Changing the rms pulse length from 1 to 4 ps the position of maximum gain is shifted from 40 μm (50%) to 150 μm (30%). Using an appropriate pulse length the gain exceeds 25% in the whole wavelength range. Notice that fig. 4 displays the gain maximum with respect to resonator desynchronization.

The maximum average outcoupled power is predicted to be 35 W in a quite large wavelength range (40 - 100 μm). Above and below this range up to 20 W can be obtained. The gold-coated copper mirrors reflect 98.8% of the incoming power. Using an outcoupling mirror with a rather small hole for long wavelengths the energy stored in the resonator may reach rather large values, according to our estimate up to 4 kW. The power of 50 W absorbed by the mirrors will be cooled away by water.

The U100 undulator will be delivered by DANFYSIK in December 2005. The FEL should be ready for operation at the end of 2006.

REFERENCES

[1] P. Michel et al., FEL2004; http://www.fz-rossendorf.de/FELBE.

[2] GLAD, Applied Optics Research, Woodland, WA 98674, USA.

[3] Th. Dekorsy et al., Proc. of FEL2002, p. II-35

[4] S.V. Benson, CEBAF TN#94-065.