THE PARTIAL-WAVEGUIDE RESONATOR OF THE U100-FEL AT FZ ROSSENDORF

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THE U100-FEL

At the radiation source ELBE [1] an FEL with a permanent magnet undulator (U100) [2] has been constructed to extend the wavelength range to above 150 μm. Its lowest wavelength (20 μm) overlaps with the existing U27-FEL (Fig. 1). There is a first experimental evidence that wavelengths below 20 μm, maybe down to 15 μm, can also be reached.

The undulator is composed of 38 magnetic periods, each 100 mm long. The hybrid structure consists of SmCo 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 $K_{\rm rms}$ varies from 2.7 to 0.3.

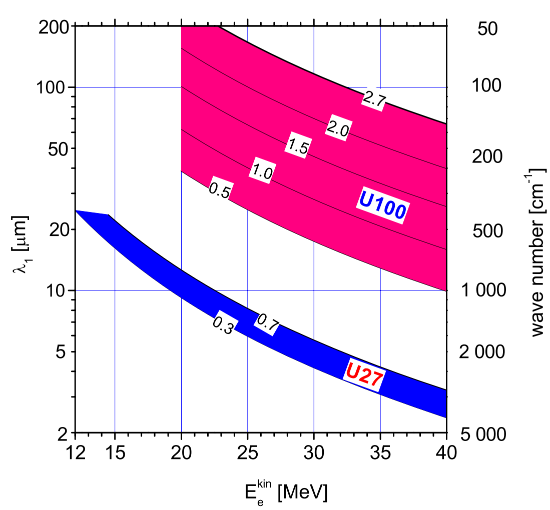

Figure 1: Wavelength λ_1 (fundamental harmonic) of the U27- and U-100 FELs as a function of the kinetic electron energy $E_{\rm e}^{\rm kin}$ calculated for the indicated undulator parameters $K_{\rm rms}$.

A waveguide was installed to fit the optical resonator mode into the undulator gap. It is 10 mm high and spans over 7.92 m from the undulator entrance to the resonator mirror M2 on the opposite side of the resonator (Fig. 2). The waveguide consists of two parallel plates, each 5 mm thick and divided into three pieces made out of non-magnetic stainless steel. In the horizontal direction the waveguide is wide enough to allow a free propagation of the optical beam. On the upstream side of the electron beam the optical beam propagates freely - both horizontally and vertically - through quadrupole and dipole magnets up to the toroidal mirror M1 with an outcoupling hole in the center.

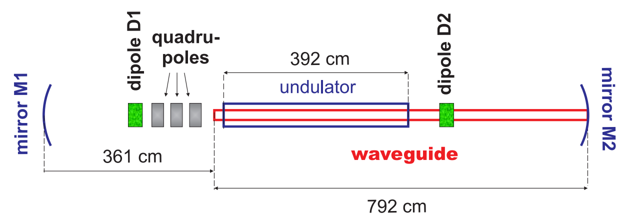

Figure 2: Scheme of the U100 resonator with partial waveguide. The electron beam enters the resonator at the dipole magnet D1 and leaves it at D2.

The partial waveguide causes a series of problems which are not present in the case of an open resonator. The mirrors must have different curvatures in horizontal and vertical direction. Although embedded in the waveguide, the downstream mirror M2 must be movable to adjust beam direction and resonator length. The narrow waveguide complicates the entering of screens and mirrors for beam diagnostics, and impedes the evacuation of the vacuum chamber.

RESONATOR MIRRORS

In the horizontal direction the infrared beam has a Gaussian shape. The curvature of the resonator mirrors corresponds to a Rayleigh length of 180 cm with a waist in the center of the undulator. Within the waveguide the vertical propagation is confined by the upper and lower plate of the waveguide. The downstream mirror M2 is cylindrical and focuses the beam only in horizontal direction. On the opposite side the vertical beam size increases rapidly behind the exit of the waveguide. The size of the beam at the surface of mirror M1 depends strongly on the wavelength. This is illustrated in Fig. 3. The size of the mirrors (black rectangle) covers more than 99% of the beam intensity even at 150 μm.

At the entrance into the waveguide, the optical mode must be converted from a freely propagating one into a waveguide mode and vice versa. This conversion causes optical losses which reduces the net gain of the laser. In general, the curvature of mirror M1 which minimizes the mode conversion losses depends on the wavelength. In our case, the waveguide is sufficiently far away from M1 and we can use a common radius of curvature for all wave-

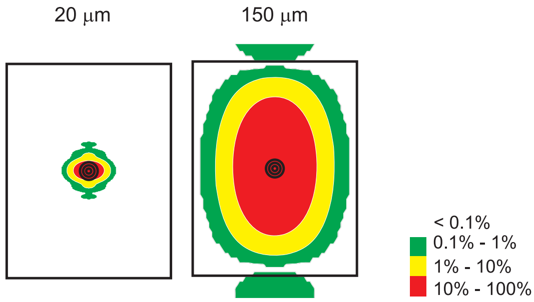

Figure 3: Transverse distribution of the light intensity at the surface of the outcoupling mirror M1 in comparison with the mirror size (black rectangle) calculated for the shortest (20 μm) and the longest wavelength (150 μm). The various colors represent the relative intensity in percent while the small circles in the center indicate the various outcoupling holes.

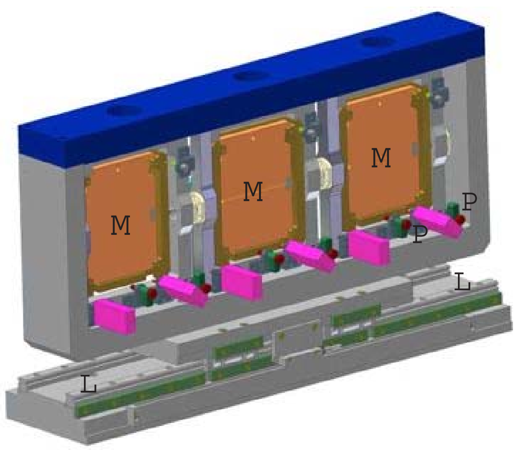

Figure 4: Support for the three mirrors M1. M: mirror, P: piezoelectric drives, L: linear translation stage,

lengths of the operating range of the U100-FEL. Above 35 μm the calculated coupling losses per round trip are below 5% [2]. Only at wavelengths below 25 μm they exceed 10% (simulations by means of the code GLAD [3]).

The beam is outcoupled through a circular hole in the center of mirror M1. Because of the large variation of the beam radius (factor 3) and of the expected laser gain (factor 5) in the operational range of the U100-FEL we need outcoupling holes of different size. We chose a set of 3 mirrors with the same curvature and holes with a diameter of 2, 4.5 and 7 mm. They are mounted on a support (Fig. 4). Using a linear translation stage the appropriate mirror can be shifted into the right position. The mirrors are gold-coated copper mirrors and cooled by water. They can be tilted horizontally and vertically by means of piezoelectric drives.

MIRROR ALIGNMENT AND CONTROL SYSTEM

Fig. 5 shows the scheme of the resonator alignment control system. It is similar to the system developed and used for the U27-FEL [4]. The correct location of the resonator axis is checked by means of two HeNe laser beams introduced into the resonator by auxiliary and pop-in mirrors.

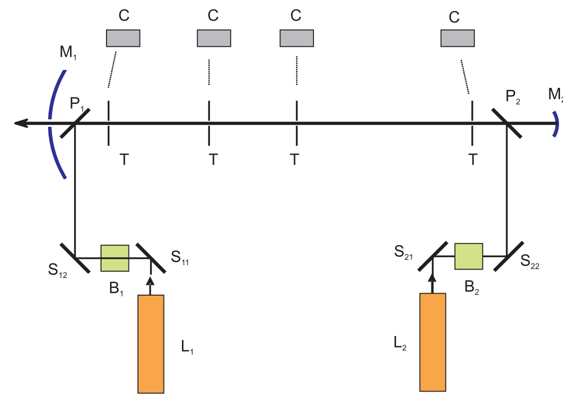

Figure 5: Schematic view of the resonator alignment system. $M_{1,2}$: resonator mirrors, $L_{1,2}$: HeNe alignment lasers, $B_{1,2}$: beam expander, $S_{11,12,21,22}$: steering mirrors, $P_{1,2}$: pop-in mirrors, T: adjustment apertures, C: monitoring cameras

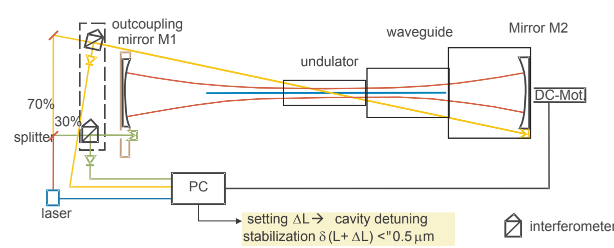

Figure 6: Schematic view of the resonator length control system.

A Hewlett-Packard interferometer system [5] is used for monitoring the resonator length (Fig. 6). It has also been taken from the U27-FEL.

The resonator has to be set and stabilized to a certain length and its axis has to be aligned to the electron beam. For that aim the mirrors are gimbal-mounted and can be tilted horizontally and vertically by means of piezoelectric (M1) and DC drives (M2). They allow the mirrors to be tilted up to 15 mrad in steps of 1 μrad. Moreover the cylindrical mirror M2 can be shifted along the resonator axis by 3.6 mm in steps of 100 nm (hysteresis 2 μm) by means of remote controlled DC drives (Fig. 7). Steps and hysteresis can additionally be reduced by a factor of about 30 by means of a beam in bending. Fig. 8 shows the opened mirror chamber M2.

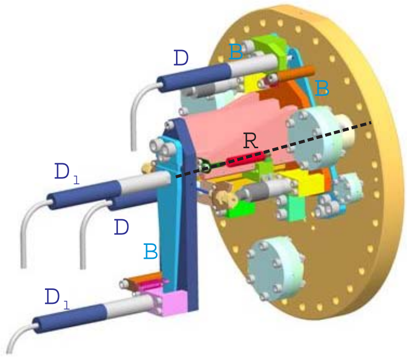

Figure 7: Back side of the flange of mirror chamber M2 with control elements. The mirror is mounted on the center of the front side. Schematic view with DC drives (D) for mirror tilting and shifting (D_l). The broken line (R) indicates the hidden driving rod, which transfers the motion onto the mirror on the front side. The beams in bending are labelled by B.

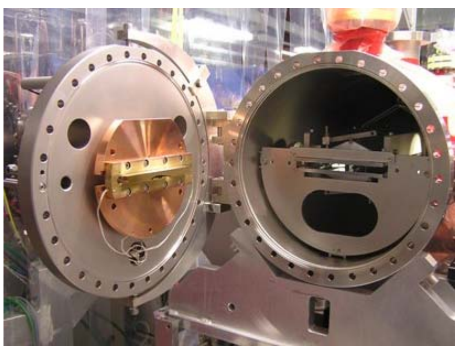

Figure 8: Open mirror chamber M2 with the rectangular cylindrical mirror (left side) and the end of the waveguide (right side).

BEAM DIAGNOSTICS

There is an extensive beam diagnostics system within the resonator region consisting of 20 view screens, markers and auxiliary mirrors. Most of them have to be inserted into the waveguide. They are not allowed to touch the polished surface of the waveguide, which is only 10 mm high. Fig. 9 shows the scheme of an auxiliary mirror with the corresponding insertion unit. The mirror is mounted at the end of a rod extending into the waveguide. The rod can be shifted into the waveguide by means of a pneumatic cylinder. It can precisely be moved along and perpendicular to the resonator axis, and allows an additional torsion of the rod which leads to a controlled and extremely sensitive tilting of the mirror at its head. The accuracy is 30 μm and 5μrad, respectively. Similar insertion units are used for OTR screens (7 mm high) made of beryllium with a 1 mm hole, foil screens consisting of a stretched aluminum foil, and markers (8 mm high) with a hole for the alignment and interferometer lasers. Among them are the pop-in mirrors and apertures used for the resonator alignment system (Fig. 5). CCD cameras in lead housings are used for observing the screens and markers through the viewports (Fig. 9).

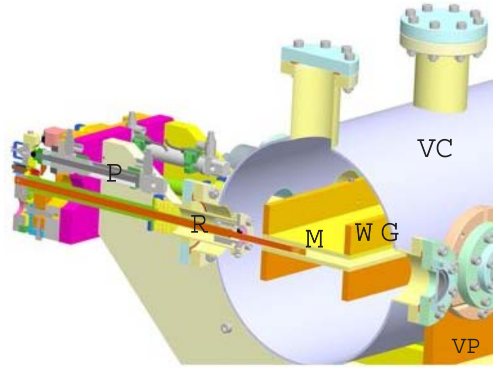

Figure 9: Diagnostic mirror for resonator axis tuning insertable into the waveguide. M: mirror, R: rod, P: pneumatic cylinder, VC: vacuum chamber, WG: waveguide, VP: view port.

Beam positioning monitors with an aperture of 75 mm have been developed for the online measurement of the electron beam position. One of them is located in front of the waveguide entrance.

VACUUM MANIFOLD

The presence of the waveguide does not allow to place the getter pumps directly below the beam line. A vacuum manifold with 6 getter pumps and 7 ports (Fig. 10) is installed below the waveguide instead. Their total throughput amounts to 520 l/s. An additional getter pump with 350 l/s throughput is fixed below each mirror chamber. The electron beam line can be separated by vacuum valves upstream and downstream the resonator. Another valve separates the mirror chamber M1 with the outcoupling window. Additionally, four powerful turbomolecular pumps are linked to the manifold and to both mirror chamber as

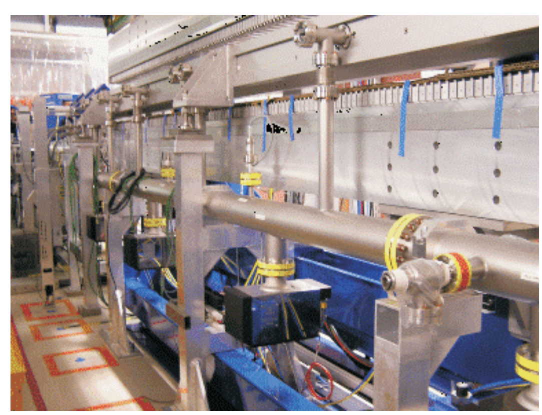

Figure 10: Collective vacuum line with getter pumps and connectors to the waveguide.

well. They ensure to hold the vacuum in the whole system in the case of a local rise in pressure. Membrane pumps serve as fore-vacuum pumps. In stand-by mode the turbo- and membrane pumps can be switched off.

The system can be vented by means of needle valves with dry and particle-free nitrogen gas. A mass spectrometer allows to analyze the residual gas. The pressure in the vacuum line and in the mirror chambers is measured by means of Penning and Pirani vacuum gage heads.

SUMMARY

At the radiation source ELBE, another free-electron laser has started to produce light in the far infrared region. It is capable of producing IR radiation between 20 and 200 μm. Its resonator was equipped with a partial waveguide to allow a small undulator gap. Curvature and size of the resonator mirrors were adapted to minimimum optical losses. To optimize the outcoupled laser power three mirrors with circular holes of different size were installed on a linear translation stage. The resonator was equipped with a control and alignment laser system which allows to adjust and stabilize the resonator length and to align the resonator mirrors. Special beam diagnostic elements, which can be inserted into the waveguide, and a vacuum manifold were developed to fix the beam position and to ensure an extreme vacuum within the narrow waveguide.

REFERENCES

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