THE IR-BEAM TRANSPORT SYSTEM FROM THE ELBE-FELs TO THE USER LABS

W. Seidel, E. Grosse, M. Justus, K.-W. Leege, D. Proehl, R. Schlenk, A. Winter, D. Wohlfarth, R. Wuensch
Forschungszentrum Dresden-Rossendorf, Dresden, Germany

Abstract

In the Forschungszentrum Dresden-Rossendorf, two free-electron lasers (FELs) have been put into operation. They produce laser light in the medium and the far infrared wavelength range (4-150 μm). The IR ligh is transported to several laboratories in the same building and to the adjacent building of the High Magnetic Field Laboratory as well, where the experimental setups are up to 70 m away from the FELs. Constructional peculiarities, the large wavelength range, the high average power in cw regime, and the beam property requirements of the users pose a challenge to the beam line design. The transport system includes vacuum pipes, diagnostic elements, plane and toroidal gold-covered copper mirrors, and exit windows. The designed transport system produces a beam waist at selected spots in each laboratory representing a magnified image of the outcoupling hole. Spot size and position are independent of the wavelength.

INTRODUCTION

The Radiation Source ELBE [1] at the Forschungszentrum Dresden-Rossendorf is centered around a superconducting Electron Linear accelerator of high Brilliance and low Emittance (ELBE), constructed to produce cw electron beams up to 1 mA beam current at 12-34 MeV. The electron beam is used to generate various kinds of secondary radiation, mainly to drive two free-electron lasers in the infrared region (4-150 μm). Starting in the summer 2005, beam time is offered to external users in the frame of the EC funded "Integrating Activity on Synchrotron and Free Electron Laser Science" (FELBE project [2]).

The IR radiation is produced in one of the two hybrid magnet undulators U27 and U100. Changing the undulator gap or the electron energy the wavelength of the produced IR beam can be varied from 4 to 22 μm (U27) and from 20 to 150 μm (U100). Additionally, a 633 nm beam from a HeNe laser used for mirror alignment has to be transported by the beam line.

The outcoupled laser power to be transported by the beam line depends strongly on the parameters of the electron beam and of the FEL undulator and resonator. Till now a maximum average cw power of 25 W has been obtained. Theoretical estimates predict a maximum cw power of about 35 W.

The IR light is transported to several laboratories in the same building and to the adjacent building (through a tunnel which is 27 m long) of the Dresden High Magnetic Field Laboratory (HLD, [3]) as well, where the experimental setups are up to 70 m away from the FELs.

The beam arriving at the user laboratories should be sufficiently narrow (a few millimeters). Its Rayleigh range should be long enough (10 cm at minimum). The profile should be circular with a Gaussian shape. It should not vary to much with the wavelength, with the size of the outcoupling hole and the used FEL. Linear polarization in horizontal or vertical direction should be conserved.

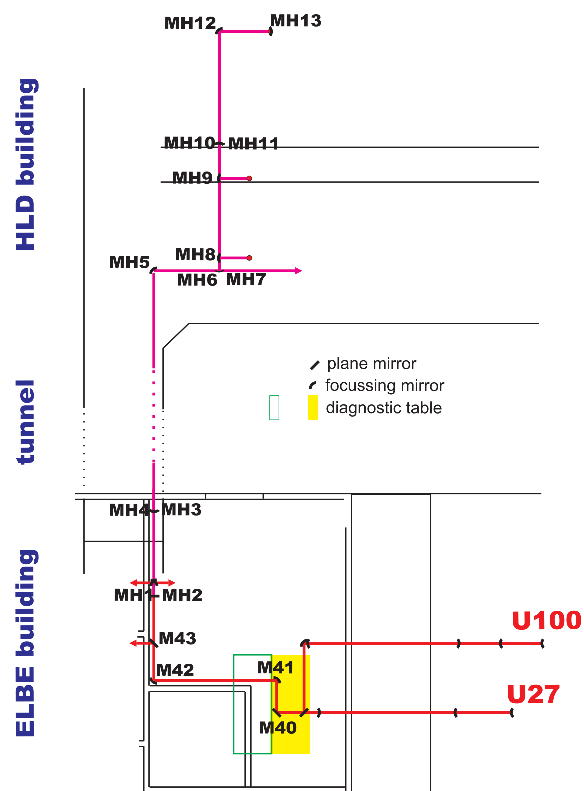

Figure 2: Top view of the beam line from the U100 and U27 FEL in the ELBE building to the user station in the HLD building via diagnostic table and tunnel.

DESCRIPTION OF THE BEAM LINE

The designed beam line is able to transport IR light in the wavelength range between 4 and 200 μm without noticeable diffraction and absorption losses. The HeNe adjustment beam is visible in the whole transport system. To avoid the absorption of IR light in the ambient air the beam is guided in pipes which are either evacuated or purged with

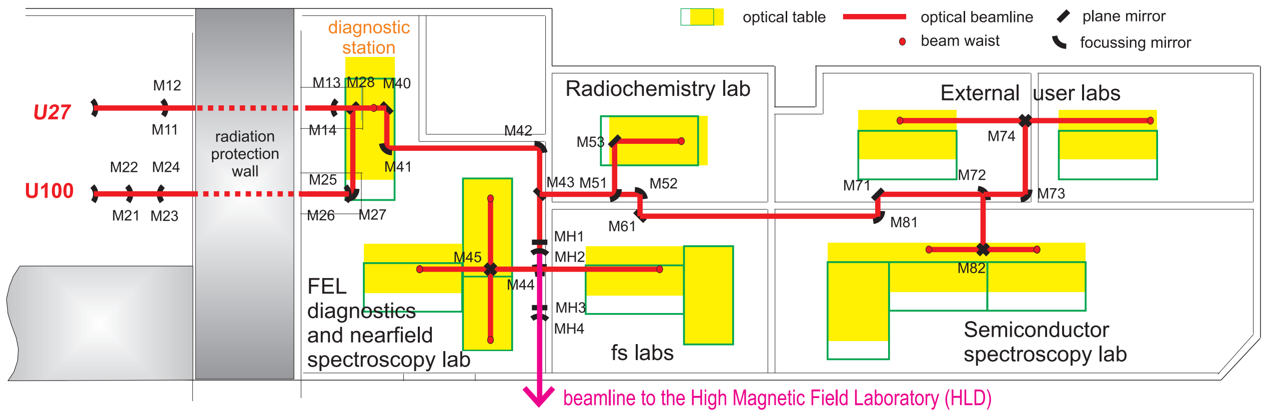

Figure 1: Top view of the beam line (red line) from the outcoupling holes of U27 and U100 through the diagnostic station to the optical tables in the various user laboratories.

dry nitrogen gas. The mirrors are mounted along the walls of the laboratories on supports 105 cm above floor, in general. Because of the large wavelength range we use reflective optics with metal mirrors [4] (gold-coated copper and stainless steel). Their reflectivity is 98.8% [4], the surface roughness is below 0.2 μm. In many cases the mirrors are used simultaneously to deflect and to refocus the beam. The distance between refocusing mirrors must be considerably smaller for the far infrared than for visible light.

Altogether 16 flat and 27 focusing mirrors are used in the transport system (all are fixed in gimbal mounts). They deflect the beam by 90 degrees. We use bifocal toroidal mirrors to have the same focal length in the meridional and in the saggital plane. In this way we reduce the number of mirrors to a minimum. To keep spherical aberration small the radii of curvature must be larger than the beam radius is. In general, the distance between two focusing mirrors is short enough to keep the beam narrow enough for a 10 cm beam pipe. In the tunnel to the HLD, a long straight distance has to be covered without any corner. Here we chose a 20 cm pipe to avoid refocusing within a straight section of the beam line. Farther, in the magnetic laboratories the beam pipe can be reduced to 16 cm. The effective diameter of the mirrors (viewed in beam direction) is 10, 20 and 16 cm accordingly. The path of the IR beam from the FELs to the experimental tables in the user laboratories is displayed in Fig. 1.

The beamline starts in the FEL cave at the outcoupling holes in one of the resonator mirrors of the U27- or U100-FEL (left side of Fig. 1). There is a diamond window roughly 4 cm behind the outcoupling holes. It separates the ultra-high vacuum in the resonator from the beam line. The window is mounted under the Brewster angle of 67 degrees to let pass horizontally polarized light without reflecting it. The window aperture has a diameter of 8 mm (U27) and 12 mm (U100), respectively. To sustain the static and dynamic pressure difference the diamond slab is 350 μm (U27) and 570 μm thick. Further windows are placed on the diagnostic table (Diamond) and at the ends of each particular beam line (ZnSe, KRS-5, TPX, Quartz, Diamond, respectively the beam properties). From the outcoupling hole the beam is transported to a diagnostic table in the neighboring room where the beam parameters can be measured. Some of them (average power, repetition rate) can also be modified [5].

The FEL cave is separated from the user laboratories by a radiation protection wall which is 2.6 m thick (see Fig. 1). This wall has to be by-passed by the laser beam. A straight connection between these rooms would allow γ-quanta and free neutrons produced by the high-energy electron beam in the FEL cave to enter the diagnostic laboratory.

Behind the diagnostic table the beam is transported into 6 laboratories in the ELBE building and additionally into the High Magnetic Field Laboratory in a separate building. The latter is connected with the ELBE building by a tunnel which is 27 m long. The branch guiding the beam to the HLD is shown in Fig. 2.

To evaluate the beam propagation theoretically we used the method of the equivalent Gaussian beam [6]. The beam passing the outcoupling hole is described as a circular Gaussian beam with a waist at the hole. The slight curvature of the wave front at the outcoupling hole can be neglected. The waist size w_0 in the hole is determined by the diameter D_h of the hole according to $w_0 = 0.7 * D_h/2$. The same relation is used to assign a nominal diameter $D_b = 2*w/\,0.7$ to the Gaussian beam at any place in the beam line. The description as a Gaussian beam is considered an approximation which allows analytically to evaluate the propagation of the outcoupled beam. We have tested this approximation in several cases by means of the wave optical code GLAD [7]. The diameter of apertures in the beam line should be larger than the beam diameter D_b, to avoid power losses and diffraction ripples in the beam profile. Fig. 3 shows the beam diameter D_b along the beam line from the outcoupling hole to the diagnostic table for both FELs. On its path, the beam is sufficiently slight to

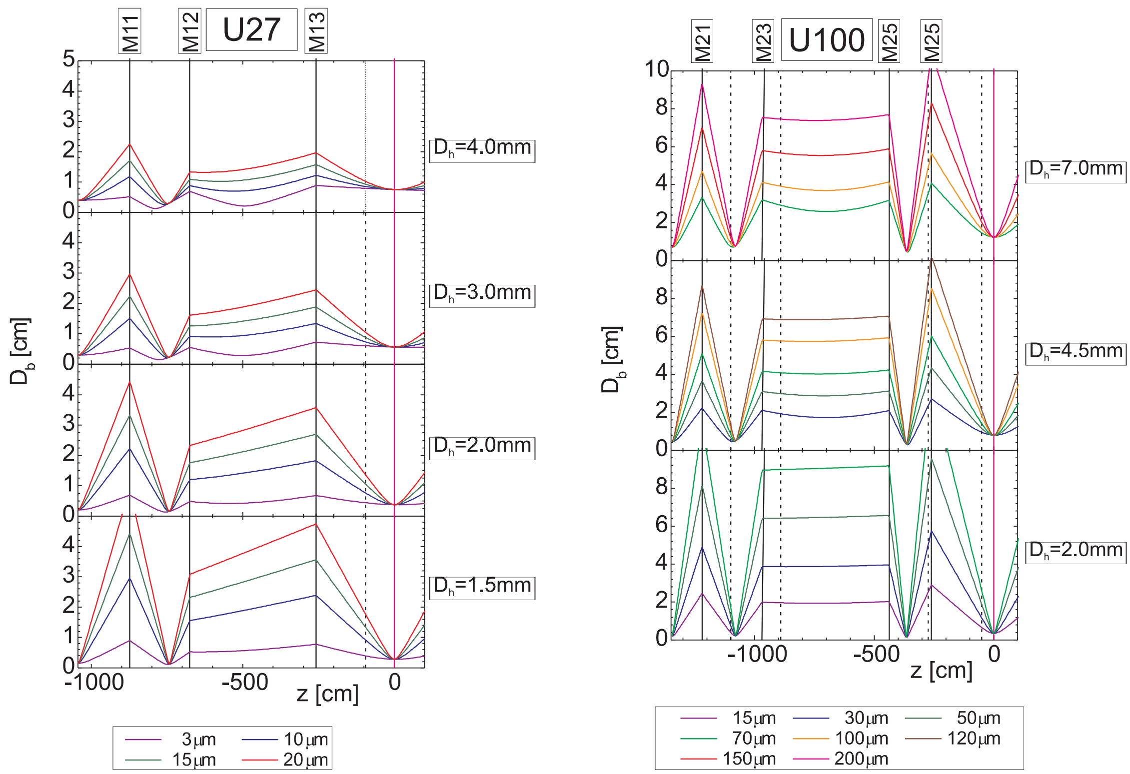

Figure 3: Diameter D_b of the IR beam calculated along the beam line from the outcoupling hole to the waist on the diagnostic table (z=0) for various wavelengths and outcoupling holes with diameter D_h. Focusing (Mik) and flat mirrors are indicated by vertical solid and broken lines, respectively. The position of the diagnostic waist is indicated by the magenta line. Left panel: U27-FEL, right panel: U100-FEL.

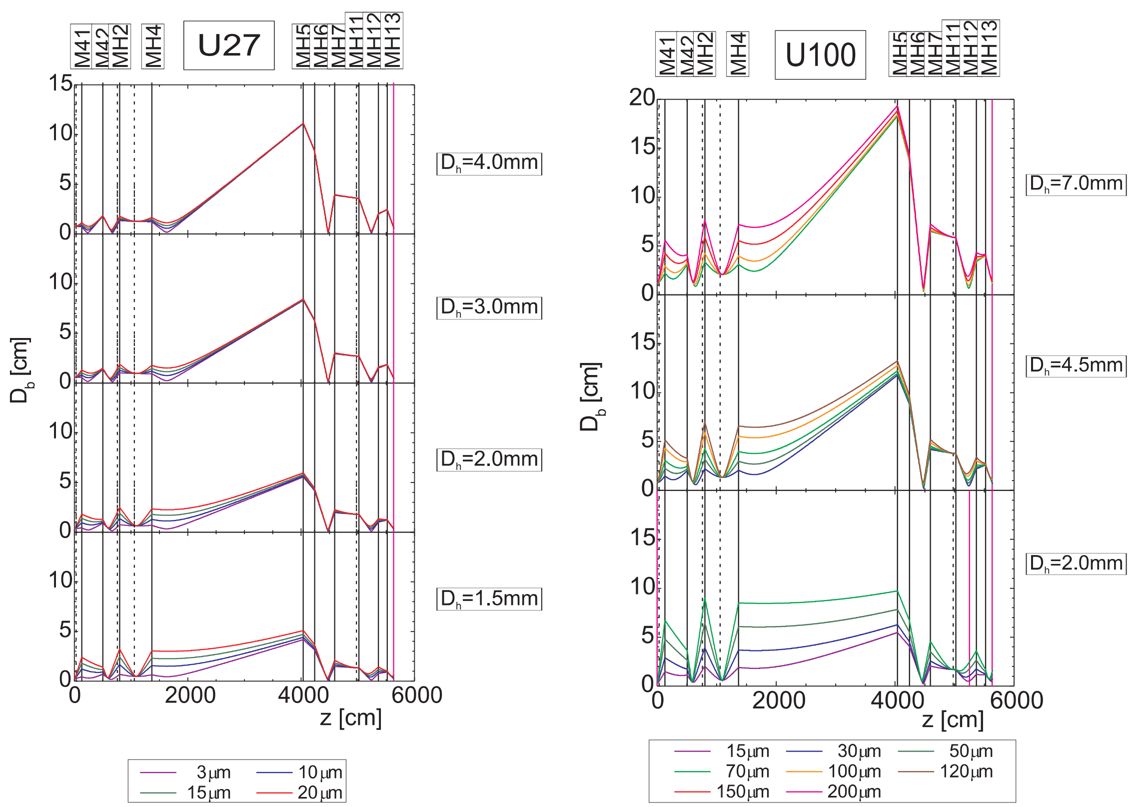

Figure 4: The same as in Fig. 3 for the beam line from the waist on the diagnostic table (z=0) to the HLD.

fit into a 10 cm beam pipe. On the other hand, it is broad enough not to damage the mirror surfaces by a big power density. The waist on the diagnostic table ($z = 0$ in Fig. 3) is common to the beams from each outcoupling hole in either FEL and to all wavelengths as well. Only the waist size is proportional to the diameter of the outcoupling hole. The narrow beam in the vicinity of the waist is used for beam measurements and modifications.

The beam line to the HLD is a particular branch of the general line delivering the laser light from the IR FELs to several user laboratories. It branches off from the general line behind mirror M43 by inserting the flat mirror MH1 (see Fig. 1) into the beam line. It bents the beam down to a specific line guiding the beam via mirrors MH2 - MH4 into a tunnel on basement level which connects the ELBE building with the HLD. Arriving the tunnel the beam is refocused (MH4) to a nearly parallel beam. However, diffraction increases the IR-beam size much stronger than in the range of visible light. Towards the end of the tunnel the beam is too thick for a 10 cm pipe and the pipe diameter has to be increased to 20 cm. The beam size calculated along the beam line is shown in Fig. 4.

In order to test the validity of the approximation by a Gaussian beam, the beam profile behind the outcoupling hole and on several positions in the beam line has been measured. These profiles are in conformity with the corresponding Gaussian profile. The power transmission of the beam line depends strongly from the used windows, the wavelength and the length of the beam line and was measured to be 15-90 %.

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