DIAGNOSTIC TOOLS FOR OPERATION AND OPTIMIZATION OF THE ELBE-FEL

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Abstract

One of the applications of the ELBE cw-electron accelerator is a FEL in the mid infrared range. The successful operation of the lasing process for different wavelengths is mainly determined by the alignment of the optical cavity, the bunch length and the energy spread of the electron beam as well as the transversal adjustment of the beam through the FEL. The energy spread and the bunch length of the electron beam have their minima at different phase conditions of the accelerator. For various energy settings of the accelerator a special adjustment of both parameters has to be found for the lasing process. This presentation describes the diagnostic tools used at ELBE for the correct alignment of the optical cavity, the steering of the electron beam through the FEL and the adjustment of the electron beam parameters with respect to energy spread and bunch length.

MOTIVATION

At the superconducting Radio Frequency (RF) accelerator ELBE at the Research Center Rossendorf MeV-bremsstrahlung, channeling radiation, neutrons, positrons and intensive infrared radiation are produced [1]. At present the wavelength range from 4 to 22 µm is covered. Pulse energies of about one µJ at 13 MHz repetition rate have been reached. Due to the use of the superconducting accelerator technology stable cw-operation can be accomplished. The average radiation power of the infrared beam can reach 30 W. After commissioning of a second FEL we plan to cover the long wavelength range up to 150 µm [2].

The first lasing of the U27 FEL in 2004 [3] was followed by a very fast transition to routine user operation. In the period from May 2004 until August 2005 altogether 400 hours user beam time were delivered at the FEL. In addition since summer 2005 user 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 [4]). Figure 1 shows the layout of the ELBE infrared facility including the user laboratories.

For routine user operation at ELBE it is of great importance that after changing of the beam path or after beam interruptions stable operation in all wavelength ranges can be guarantied within a very short time (some minutes). Extensive diagnostics both for the electron beam as well as the optical components of the FEL are extraordinary important to achieve fast availability. In addition it was shown that one must follow certain procedures to achieve stable laser conditions. The substantial elements of this plan are first of all an alignment procedure for the optical cavity of the FEL, second the adjustment of the transverse electron beam properties in the undulator and third an optimization procedure to minimize the electron bunch length and energy spread. For these steps special diagnostic tools exist at ELBE, which are described in the following.

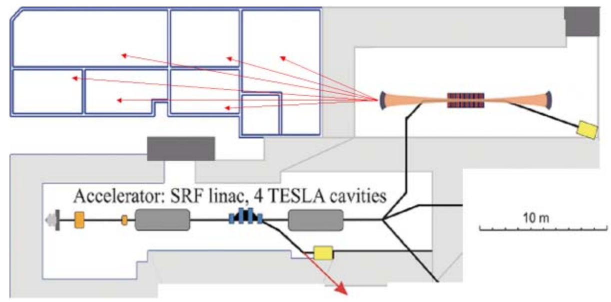

Figure 1: Schema of the ELBE main accelerator hall, the FEL cave and the user labs. Each of the two acceleration modules contains two nine cell Tesla cavities. The electron energy for operating the FEL between 22 µm and 4 µm ranges from 15 MeV to 34 MeV. The permanent magnet undulator U27 (27 mm period) consists of two segments and has a minimum gap of 13.8 mm. The infrared laser beam can be distributed to different laboratories.

ALIGNMENT OF THE OPTICAL CAVITY

To ensure the stability of the resonator at wavelengths down to 4 µm the mirror angular adjustment is required to have a resolution and stability in the order of 6 µrad. The initial accuracy is about 20 µrad, achieved by two wall markers and 11 movable adjustment apertures inside the cavity. The alignment system is schematically shown in Figure 2. Beam expanders are used to focus the collinear He-Ne laser beams at a point near the center of the undulator. Since the beam profile at the waist position was not completely circular symmetric we used two iris diaphragms to define the beam position close to the S_{i2} mirrors (see Figure 2). The diffraction rings caused by the aperture can be used to accurately determine the beam center at other positions along the beam. With an aperture diameter of 7 mm the radius of the first dark ring at position T_0 is 0.1 mm larger then the radius of the aperture hole (1 mm), which is convenient for centering the beam with respect to the hole. To prevent any temperature drift the optical cavity length is kept constant to approximately 1 µm with the help of an interferometer system.

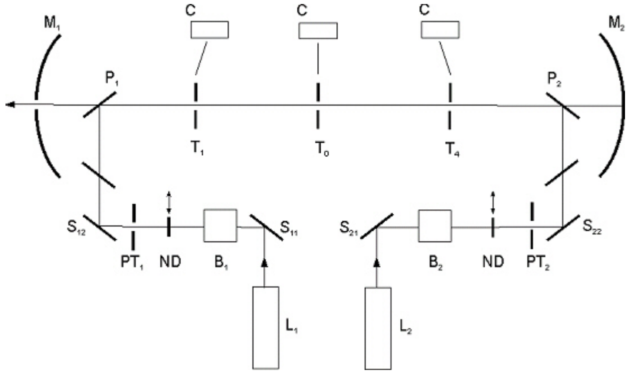

Figure 2: Schematic diagram of the optical cavity and components for the alignment system (M_i: cavity mirrors, P_i: pop-in mirrors, T_i: adjustment apertures, C: monitoring cameras, S_{ij}: steering mirrors, PT_i: iris diaphragm, ND: neutral density filters, B_i: beam expanders, L_i: He-Ne alignment lasers)

ADJUSTMENT OF BEAM POSITION AND FOCUS

In order to ensure the optimal overlap between electron beam and infrared beam, seven Be prisms can be inserted into the undulator vacuum chamber. These prisms have a 1 mm hole, through which the electron beam can be directed. At the edges of the holes the electron beam produces optical transition radiation. Thus its position and the focusing can be checked. At the same prisms the beam of an adjustment laser is reflected into the same cameras. With this technology it is possible to align the electron beam accurately to the axis of the optical resonator. Figure 3 demonstrates the imaging of the electron beam in respect to the cavity axis defined by the hole.

For non destructive monitoring of the electron beam position during lasing we use stripline monitors, which are represented in Figure 4. These monitors have a spatial resolution of less than 10 µm. They were developed together with the readout electronics by FZR and Jefferson Lab [5].

OPTIMIZATION OF BUNCH LENGTH AND ENERGY SPREAD

The final step for setting up the laser condition is the optimal choice of the longitudinal phase space parameters, bunch length and energy spread. Since the lasing process depends very sensitively on them, it is essential to determine and purposefully to set these parameters. The electron bunch length at ELBE is measured by means of a Martin Pupplett interferometer [6]. Coherent optical transition radiation is produced at analuminum foil and the autocorrelation function is determined in the interferometer. From this the electron bunch length can be computed under certain assumption of the pulse shape and the detector characteristics. For a simple minimization of the bunch length the coherent OTR signal measured in a Golay cell can be used. Maximum radiation power is correlated to the smallest

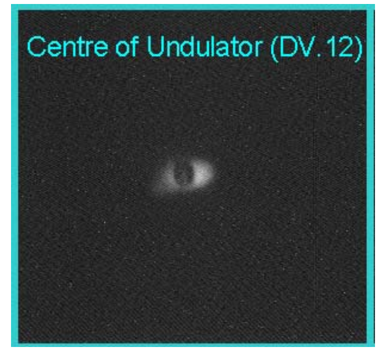

Figure 3: OTR view screen picture from the undulator. The picture shows the position and shape of the electron beam in the undulator. The diameter of the hole in the view screens is 1mm.

Figure 4: Picture of the 1/4 λ and 3/4 λ beam position monitors used at ELBE.

pulse length as shown in Figure 5. Measurement of the energy spread of the electron beam is made at different dispersive beam line sections detecting the OTR emission. Downstream the undulator we also installed such a measuring station. Thus, the dramatic enlargement of the energy spread at the startup of lasing can be observed. The necessary balance of bunch length and energy spread for reaching lasing condition depends strongly on the wavelength of the IR radiation. At short wavelengths a low bunch length is necessary and at long wavelength a small energy spread plays a crucial role. Figure 6 demonstrates the importance of a small energy spread for lasing at large wave length (20 µm). The lasing window correlates to small energy spread.

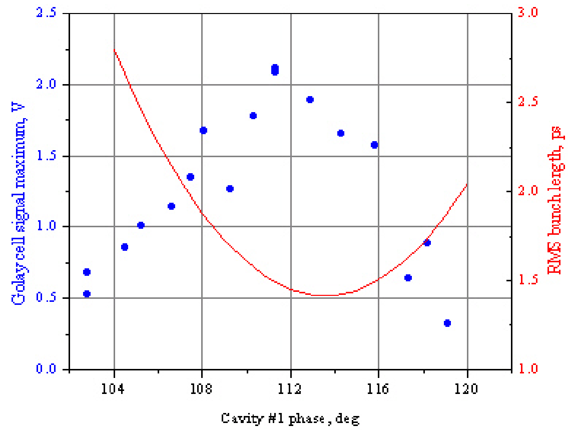

Figure 5: Measured Golay signals (dots) and RMS bunch length (line) as a function of the cavity #1 phase. The RMS bunch length is measured with the Martin-Puplett interferometer. The plot shows that the Golay cell signal alone is a useful tool to adjust different bunch length conditions of the electron beam.

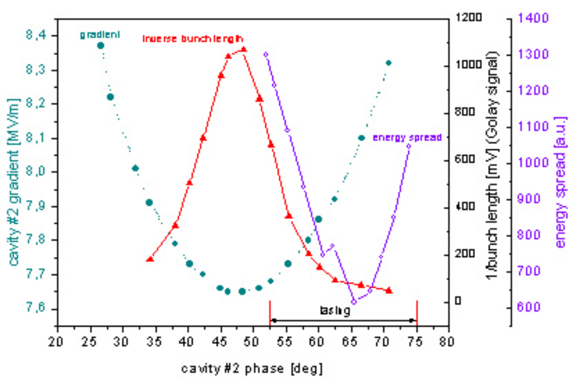

Figure 6: Plot of the energy spread and Golay signal measured as function of cavity #2 phase for the ELBE setup with one accelerating module.

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