CONCEPT OF ELECTRON BEAM DIAGNOSTICS FOR PolFEL*

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Abstract

PolFEL - Polish Free Electron Laser will be driven by a continuous wave superconducting accelerator consisting of low emittance superconducting RF electron gun, four accelerating cryomodules, bunch compressors, beam optics components and diagnostic elements. The accelerator will split in three branches leading to undulators producing VUV, IR and THz radiation, respectively. Two accelerating cryomodules will be installed before a dogleg directing electron bunches towards IR and THz branches. Additional two cryomodules will be placed in the VUV branch accelerating electron bunches up to 185 MeV at 50 kHz repetition rate. Moreover, the electron beam after passing the VUV undulator will be directed to the Inverse Compton Scattering process for high energy photons experiments in a dedicated station. In order to measure and optimise the electron beam parameters along the entire accelerator the main diagnostics components like BPMs, charge monitors, YAG screens, coherent diffraction radiation (CDR) monitors and beam loss monitors are foreseen. Within this presentation the concept of the electron beam diagnostics will be discussed.

INTRODUCTION

The Polish Free Electron Laser, PolFEL, proposed in 2009, and accepted for the Polish Roadmap for Research Infrastructures, is to be constructed in two phases. First phase is designed with lower electron energy and second – with more accelerating sections and maximum electron energy up to about 600MeV. The electron beam will be generated in the all superconducting gun (ASG) and accelerated in TESLA cavities, housed in HZDR/RI-like cryomodules. After passing through two cryomodules (with two RF-cavities each), electrons will be directed to THz and IR undulators or, after going through bunch compressors, further accelerated by remaining two cryomodules. The fast electrons will go to VUV undulators and then into electron experimental stations, e.g. Inverse Compton Scattering experiments and neutron generation station. The undulators will be made of permanent magnets, for VUV, IR and THz branches. The layout of the PolFEL is presented in Fig. 1.

The features, which make PolFEL a unique facility is the use of both superconducting gun technology and superconducting cavities, which make possible to operate in continuous wave regime and low emittance. The SRF gun provides important advantages compared to hot injectors: operation in CW mode and significant reduction of RF power dissipation [1], although it still remains immature.

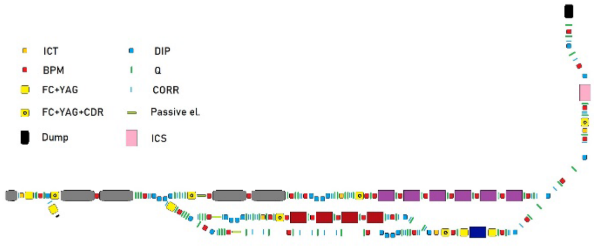

Figure 1: The layout of PolFEL facility with diagnostics components distribution.

The most important parameters of PolFEL electron accelerator are listed in Table 1 [2, 3].

Table 1: The Parameters of Polfel Electron Beam (Maximal Values, Continuous Wave Mode)

Parameter	Gun	VUV	IR	THZ
Bunch charge [pC]	250	100	250	250
Rep. rate [kHz]	50	50	50	50
Bunch length [ps]	10	0.4	1.2	1.2
Beam energy [MeV]	4	154	79	79
Beam current [µA]	12.5	5	12.5	12.5
Beam power [W]	50	770	988	988
Sliced emittance [um*rad]	0.2-1.0	<0.5	1.4	1.4

DIAGNOSTIC INSTRUMENTS

Beam Position Monitors

For the whole PolFEL linac 40 Beam Position Monitors (BPMs) are required in order to trace the beam position in the horizontal (X) and vertical (Y) planes as an input for a trajectory feedback system. Based on the resolution requirements that were set up to 10 µm along the linac, button BPMs similar to the ones used in European XFEL machine will be used in the warm sections.

If better resolution will be required especially in the undulator sections, the cavity BPMs with the resolution <1 µm are to be considered as an option or future upgrade.

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Moreover up to 6 energy BPM (EBPM) are planned to be installed in the bunch compression and dispersive section to deliver precise information about energy and energy fluctuations in the bunch compressors. The goal is to reach a few µm resolution while measuring wide distributions in a wide, but flat, vacuum chamber.

As a readout electronics LIBERA Spark is considered for usage.

Current Monitors

The beam intensity will be measured by current transformers (CT), which are installed in each warm intersection. Few types of toroid are considered for PolFEL linac. Bunch charge and transmission through the accelerator has to be determined with < 5% absolute accuracy and 1% resolution. Thus, two Turbo-ICT are planned to be installed to allow the calibration of the high(er) resolution BPM charge measurement. Additionally fast current transformers with the bandwidth not less than 0.5 GHz and rise time >2 ns are planed to be installed in few linac sections. Integrating current transformer are meant to be employed in order to measure the charge with 1% of relative resolution.

In addition to the nominal beam current *also* dark current emitted by RF resonators at high gradients is created. Especially dark current from the gun can be transported through the entire machine. Therefore 2 dark current monitors (DCM)[4] which were developed for European XFEL will be installed in the gun section and before the VUV undulators section in order to control dark current propagation and optimise the collimation efficiency.

Beam Loss Monitors

Beam loss monitor (BLM) will be operated in two modes: as a beam-tuning device, based on a regular losses, and as a safety system, based on an irregular losses. Additionally, based on BLMs one can assess the long-term exposure, along with dosimetry and other dedicated systems.

The main purpose of BLM for PolFEL is the beam loss detection. The BLMs will be mounted outside vacuum vessel in several places of linac. The selection of the BLM type was based on main important parameters as high dynamic range, high sensitivity and failsafe protection. The numerical investigations and experimental tests were done in order to design and build a fast plastic scintillator coupled with miniature photomultiplier (PMT). The design of the BLM detector is composed of H11901 miniature photomultiplier [5] and EJ-232 scintillator [6]. The detector design is presented in Fig. 2.

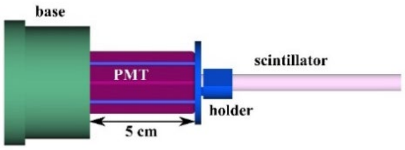

Figure 2: Scheme of a prototype version of BLM detector.

The main factors which decided on the components choice were small size, fast timing, integrated HV supplier and voltage divider, and relatively low price. The prototype, consisted of these components is under construction and will be tested thoroughly using the available sources and accelerators at NCBJ and SOLARIS.

Universal Monitor Chamber

An universal chamber will combine YAG screen, Faraday cup (FC) and radiator. It will consist of two separable parts: the first will house FC and YAG in a single shaft, the second will contain a radiator coupled with a GHz system settled at the external breadboard.

The YAG screen and the radiator target shall be configured to be watched from opposite sides of the chamber.

A simplified THz spectrometer with related optics can be used for diagnostics of the bunch length and/or for monitoring the bunch compression as explained in the section “Longitudinal profile”. The optics for the THz spectrometer will be all placed outside the camber in air, via a viewport made of transparent material, if the distance between the radiator and the viewport is shorter than 20 cm. The optical elements composing the THz spectrometer will be concave mirrors, band-pass filters and detectors (Schottky diodes or pyroelectric).

Existing FCY chamber replicated form Solaris must be adopted for radiator. Being the radiator hollow, one possibility will be to keep the radiator permanently inserted across the beam path. However, this aspect shall be clarified by means of simulations and measurements, for the generated wakefields may induce unwanted “kicks” on the electron beam. Nevertheless, such effects are minimized with a proper symmetric alignment of the beam with respect to the radiator, and they are strongly damped for relatively low charges/long bunches. The radiator will be on a motorized stage, to keep the possibility to remove it from the beam axis.

BEAM SIZE MEASUREMENTS

Transversal Profile

The transverse beam size and the beam emittance are within the set of most important parameters for the FEL beam characterisation. Therefore, emittance measurement stations (EMS) have to be available at several positions along the linac. For the PolFEL the EMS are planned in the gun diagnostics section, upstream the first cryomodule, downstream the bunch compressors and downstream the last cryomodule. The stations will be equipped with transvers beam size monitors as optical transition radiation monitors (OTRs) or/and YAG screens, as well as wire scanners. Few methods to measure the emittance are proposed, at low energy pepper pot method whereas at higher energies the quadrupole-scan method with single or multiple monitors is planned.

Additionally, synchrotron radiation monitors in the bunch compressors and post-undulator beamlines to determine the energy distribution, as well as simple screens for beam verification that is most important for start-up and early commissioning stage.

Longitudinal Profile

Coherent radiation in the THz range of the electromagnetic spectrum can be emitted by ultra-short particle beams, with a bunch length of the order of picoseconds or less. Radiation mechanisms are manyfold, and among them one can include diffraction and transition radiation [7]. Transition radiation is the radiation emitted when the beam crosses the boundary of two media with different indices of refraction. Diffraction radiation is the radiation emitted when the beam passes in the vicinity of such a boundary. It is customary to say that radiation is emitted when charged particles are accelerated, as for the case of synchrotron radiation. This scenario is not so evident for the case of transition/diffraction radiation. In order to understand this phenomenon, we shall consider that when a charged particle is accelerated an abrupt change of the electromagnetic field associated to the charge occurs, which can be seen as a damped oscillation. Such a perturbation in the electromagnetic field can propagate out of the source: this is what we call radiation. In the case of a charged particle crossing two different media, the electromagnetic field around the charge undergoes an abrupt change due to the boundary condition: in fact, polarization fields abruptly are formed and can propagate out of the source, in particular as diffraction radiation. If the transition occurs between vacuum and a metallic foil, the polarization fields are localized to the surface of such foil, since they are strongly absorbed in the bulk material. Therefore, the radiation pattern keeps memory of the status of the electron beam at the plane of the vacuum-foil interface. For example, the Coherent Diffraction Radiation (CDR) spectrum is related to the bunch duration, for it is emitted at wavelengths that are longer than the bunch length. A proper mathematical formulation shows that the coherent radiation spectrum is proportional to the square of the bunch form-factor, which is the Fourier transform of the longitudinal profile. Thus, the radiation power is proportional to the square of the bunch charge and increases with decreasing bunch length. Variations in the bunch peak current can be easily monitored in the (sub-) THz by detectors like Schottky diodes [8, 9]. Among the operational types of diagnostic tools for the reconstruction of the longitudinal phase-space of ultrashort beams are those based on infrared (IR) spectroscopy. The most commonly used IR spectrometers at the FEL facilities are normally operating in a scanning mode and are not fast enough to be applicable for monitoring variations of the bunch length in single shot [10]. Techniques as the ones based on Electro-Optical-Sampling can solve such issues but they are rather complicated [11]. On the other hand, any non-scanning single bunch spectrometer may suffer from the low amount of available intensity. If what is sought is only an indication for the bunch compression more than the full temporal profile of the accelerated bunches, then whatever source of coherent radiation cou-pled to a power-detector can provide this information [8], as the recorded power is increasing while shortening the bunch length [12]. Coherent radiation in the (sub-)THz can be coupled out of the beamlines through transparent windows, then transported in air towards power-detectors. For the purposes of PolFEL diagnostics, it was decided to use CDR radiation which allows for non-destructive bunch length measurements. The idea is based on the power balance of CDR radiation collected by Schottky diodes in different ranges of sub-THz radiation. The spectral distribution of CDR depends on the longitudinal profile, the charge and energy of the electron bunch, as well as the geometric properties of the radiator. An example of spectral-angular distribution of emitted CDR intensity is presented in Fig. 3, for beam parameters similar to the ones expected for the PolFEL machine.

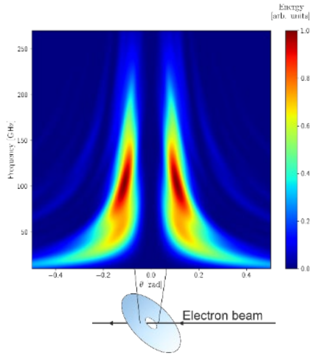

Figure 3: CDR spectral-angular distribution. Calculations for bunch of length 1 ps rms (gaussian), charge 250 pC, and energy 80 MeV. The radiator diameter has been set to 5 cm with 1 cm diameter hole for non-destructive diagnostics.

From the spectral-angular distribution of CDR it is possible to extrapolate information on the emitting bunch. In fact, the ratio of spectral intensity of two frequencies, high and low, increases while compressing the bunch length, i. e. the radiation yield in the high-frequency part of the spectrum grows faster when the bunch length is minimized. This is the principle of the diagnostic method to be used at PolFEL. Furthermore, if the general shape of the bunch profile is known by other diagnostics (or just assumed with reasonable arguments/simulations), the absolute value of bunch length can be measured via the ratio of detected radiation yield at different frequencies [8,9].

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