THE 100-MEV BEAM DIAGNOSTIC STATION FOR THE FERMI LINAC

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Abstract

In order to transversally match the beam coming out from the injector to the FERMI@Elettra [1] linac lattice, a beam diagnostic station will be placed at 100 MeV. It is equipped with quadrupoles and Optical Transition Radiation (OTR) screens to measure and correct the beam Twiss parameters and to evaluate the transverse emittances through a three-screen technique. Moreover, the second OTR screen is placed close to the laser heater undulator to know the transverse beam dimension in the interaction region. The diagnostic station is completed by another screen before the undulator, a Beam Position Monitor (BPM) and by a spectrometer after the laser heater chicane. Design optimization studies and simulation results are presented in this paper.

LAYOUT

The 100 MeV diagnostic station of the FERMI electron beam delivery system is located at the junction of the injector and of the main linac (see, Figure 1).

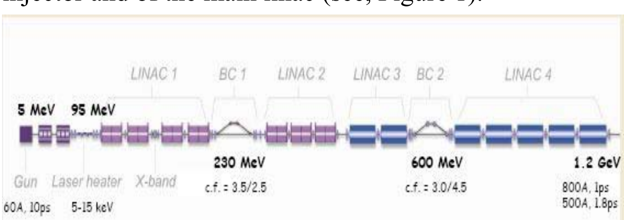

Figure 1: FERMI@elettra layout.

It includes four quadrupoles followed by three screens for the measurement of the transverse emittances and of the Twiss parameters. The screens are across the laser heater chicane that contains an undulator and whose layout allows the laser seeding of the electron beam. The photon/electron interaction in the undulator increases the uncorrelated energy spread of the electron beam to suppress the microbunching instability [2]. BPMs and correctors are included in this machine section. In particular, a BPM is placed inside the chicane to lock through a feedback loop the electron beam trajectory during the machine operation. A detailed layout is showed in Figure 2.

The laser heater chicane is followed by the spectrometer to characterize the electron beam energy distribution.

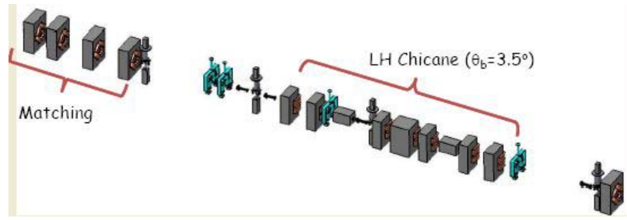

Figure 2: 100 MeV diagnostic section.

EMITTANCE MEASUREMENT AND OPTICS MATCHING

Low transverse emittance is one of the peculiar feature of an electron beam driving a single pass VUV, X-ray Free Electron Laser (FEL). The FERMI low emittance beam is provided by the photoinjector operating according to the emittance compensation scheme [3,4].

Many parameters have to be optimized in the photoinjector to reach the required normalised emittance value (<2 μm mm for FERMI). A precise emittance measurement is then an important topic for this kind of machine.

Emittance will be measured with an emittance-meter [5] during the gun commissioning and then this diagnostics will be removed. After that, multi-screens technique [6] will be implemented to measure the beam emittance and the beam Twiss parameters at the end of the photoinjector. The screens are placed at a betatron phase advance of 60 degree one from the other, in both x and y plane. The second screen is in the laser heater chicane, just after the laser heater undulator, in correspondence of the beam waist. The measurement of the beam size will be performed with the chicane dipoles switched off. Then, they will be switched on for the machine operation. Simulations have demonstrated that the small bending angle does not perturb the lattice optics more than a few percent.

To avoid emittance degradation, the incoming electron beam optics has to be matched to the linac optics; the matching will be performed by the four quadrupoles at the beginning of the diagnostic section.

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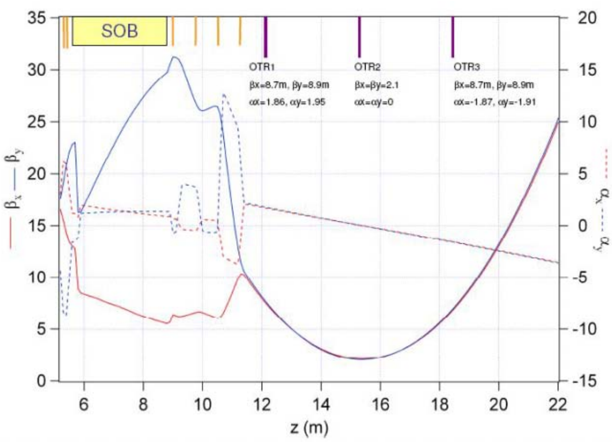
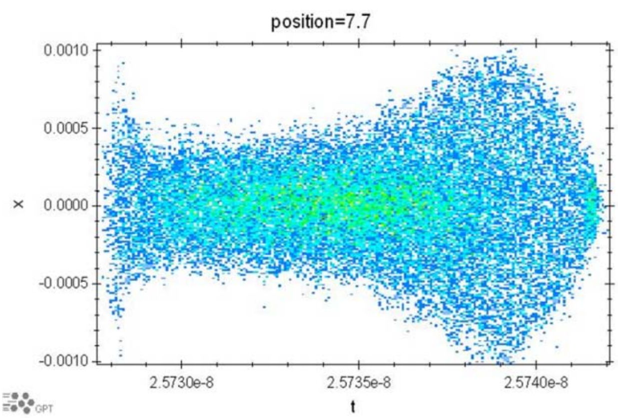
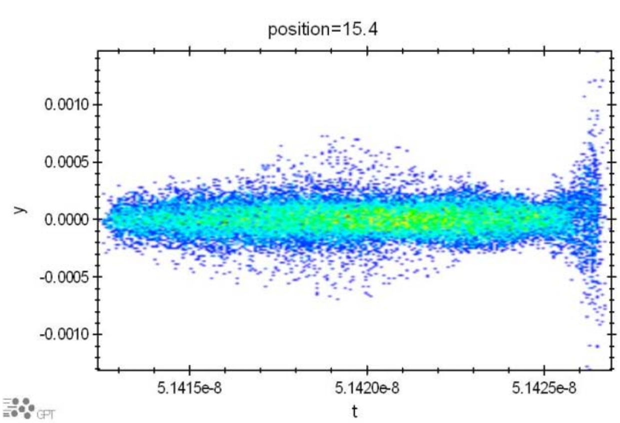


Figure 3: evolution of the betatron functions in the low energy diagnostic section.

Simulations of the beam transport through this section have been performed to investigate the beam dynamics in the presence of space charge, which can be important at this energy. Figure 3 shows the optics functions evolution in the low energy diagnostic station. Figure 4 shows the top view, in the x-z plane, of the beam particles at three different positions along the diagnostic station.





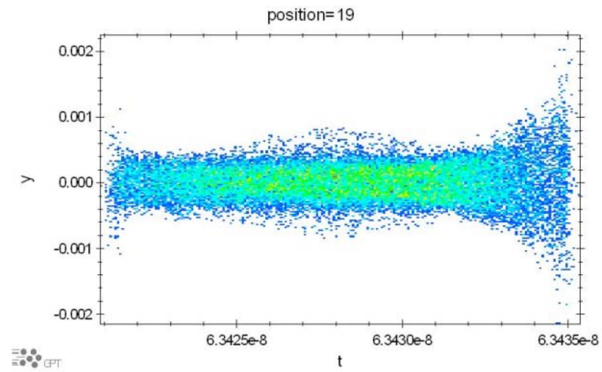


Figure 4: top view in the x-z plane of the beam particles at three different locations along the emittance diagnostic section: the distance from the cathode is respectively 7.5 m 15.5 m and 19.5 m, from the top to the bottom plot. Bunch head is on the left.

ALIGNMENT

Alignment and transverse matching between the laser and the electron beam is very important in order to have the correct interaction between the two beams and therefore the desired heating. The relative alignment between the photon and electron beam has to be better than 50 micron. To achieve this, two YAG screens, capable of recording the image of the two beams, are placed in the laser heater chicane before and after the undulator.

SPECTROMETER

The last part of the low energy diagnostic line is represented by a spectrometer. The knowledge of the beam energy at this point is required to satisfy the resonance condition in the laser heater undulator to the laser wavelength and to optimize the injection into the linac. For this purpose, the beam average energy has to be known with an accuracy of 100 keV rms. The maximum dispersion in the centre of the laser heater chicane is 3.1 cm. Thus, a BPM with < 5 micron rms resolution placed there will permit to resolve a shot-to-shot relative energy variation of 0.1%. This BPM will be part of the FERMI longitudinal feedback system.

The correlated beam energy spread in the laser heater chicane is mainly due to the off-crest acceleration provided by the upstream injector. Then, a scan of the beam mean energy and beam energy spread as function of the injector RF phase and voltage will be performed to characterize the longitudinal beam dynamic into the injector booster cavities.

ADDITIONAL DIAGNOSTICS

The layout of the laser heater chicane foresees some space for the future integration of an optical replica synthesizer [7]. The most important goal of this device could be the beam current profile measurement with 10 fs rms resolution of the bunch duration. A dispersive section and an additional undulator are needed for this diagnostics.

Even if further study of this diagnostic are needed to know their feasibility and resolution, it is clear that an additional dispersive section and an Optical Transition Radiation (OTR) screen are sufficient to detect the beam energy modulation provided by the laser/electron interaction. The energy modulation induced at the laser wavelength is converted into a density modulation with the same wavelength. The beam density is modulated even on the harmonic of the laser wavelength. Then, the OTR screen emits coherent radiation [8] at the laser wavelength and at its harmonics. This radiation will be a clear sign of the reached energy modulation. Figure 5 reproduces the expected spectrum of the second harmonic of the seeding laser wavelength. For the moment space charge in the dispersive section and near field effects are neglected. The large bandwidth is mainly due to the RF curvature that imposes a quadratic energy chirp to the longitudinal phase space of the electron beam.

The basic diagnostics foresees a power-meter to analyze the power of the coherent emission. The required energy to allow a study of the longitudinal propriety of the coherent emission is quite high. Further studies will check the possibility to go up from this information to the longitudinal electron beam distribution.

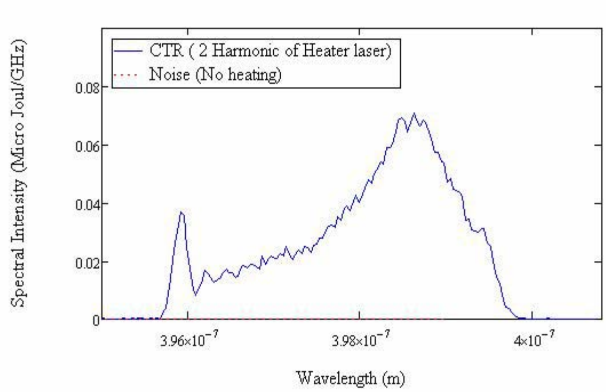


Figure 5: spectrum of the emitted coherent transition radiation at the second harmonic of the seeding laser wavelength.

CONCLUSIONS

We have presented the design and the main features of the low energy FERMI@Elettra diagnostic station. It will permit to optimize the beam injection into the main linac by measuring the beam projected emittance, Twiss parameters, average energy and energy spread.

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