

DESIGN AND IMPLEMENTATION OF AN OPTICAL DIAGNOSTIC BEAMLINE AT THE BESSY II INJECTION LINE

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Abstract

In order to improve the present LINAC injection line diagnostic system at BESSY II, a non-destructive source point imaging system is being developed. This paper presents the conceptual design, including technical requirements, simulation results, and expectations for the optical transport line and mechanical integration. The design aims to ensure beam quality during operation using synchrotron radiation emitted from the dipole magnet. The primary components of this beamline are a CCD camera and a lens system. To enable precise positioning, the optical system is equipped with a motorized linear feed through. The entire setup is designed to operate under high vacuum conditions. A basic, fixed focal length setup is initially employed to experimentally validate the simulation results, using the same CCD camera as in the final beamline setup.

MOTIVATION

To maintain and improve the injection process of the third-generation synchrotron radiation source BESSY II [1], accurate beam size measurements on exit of the linear accelerator (LINAC) are essential. Until now these measurements have mainly relied on retractable Fluorescent screens (FOMs), which are inherently destructive due to directly imaging the electrons. A non-destructive solution involves a short beamline equipped with a camera and lens system to observe synchrotron radiation.

A fixed implemented system of this kind has already been installed as shown in Fig. 1, which allows no further adjustments during machine operation. Furthermore the system lacks sufficient position accuracy and has not been fully characterized. To improve the setup it is necessary to develop a mechanical solution that allows for precise, under operational condition adjustments of the lens position and a fully characterized optical response.

LabVIEW [2] is used to process the image shown on the CCD camera as shown in Fig. 2. Such an image is readily available in the control room for live monitoring as part of the essential high-end diagnostic. The post processing in LabVIEW includes Gaussian fit of the beam intensity profile for beam position and size within the region of interest.

INITIAL DESIGN AND GENERAL REQUIREMENTS

The objective is to implement a motorized and characterized lens system with integrated Prosilica GT 1920 camera [3] for non-destructive source point imaging.

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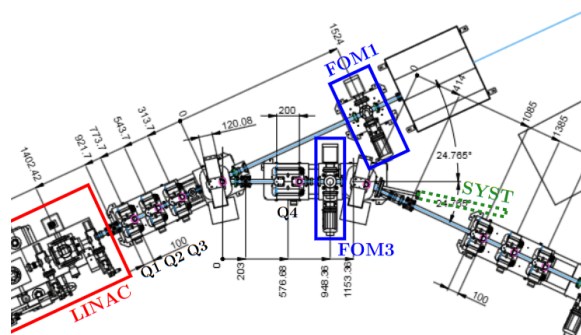


Figure 1: Technical drawing of the injection line at BESSY II with marked LINAC, FOMs and placement of new optics. Dimensions in mm.

Given the fixed lens system placement a few preconditions are already established: pipe diameter of 25.4 mm, minimal distance between lens and source of 1.3 m, non-magnetic steel 316L, focal length of 200 mm and possible implementation of a vacuum system.

For a straightforward implementation a common design is chosen: motorized paired bellows moving a lens horizontal.

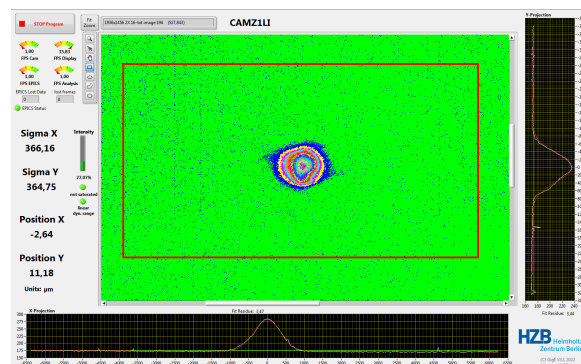


Figure 2: Typical image analysis of the present fixed lens source point system. Image taken after LINAC optimisation.

To calculate the stroke length and maximal distance between lens-source the electron beam and the emerging photon beam was simulated as documented in the following sections. The simulations resulted in maximal length of 1.6 m and stroke length of 50 mm. Given that the following setup has been designed Fig. 3.

SIMULATING ELECTRON BEAM

The beam emittance on exit of the LINAC was found through the common quadrupole scan method [4] before LINAC optimisation using Q3 and FOM1 (Fig. 1). The

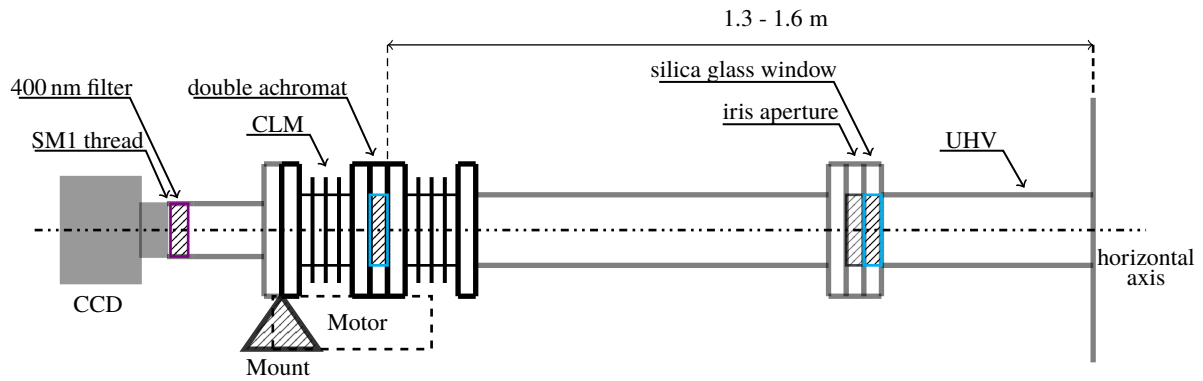


Figure 3: Schematic of the proposed adjustable source point imaging system with a Compressed Linear Mechanism (CLM).

measured Twiss parameters allows tracking of the electron beam through a series of quadrupoles and a bending magnet to the watch point located within the second bending magnet (Fig. 4). ELEGANT [5] simulation found the transverse electron beam size $\sigma_{e_{x,y}}$ to be 460 μm and 290 μm at the source point and for a typical beam energy variation it was shown that the beam size varies less than 5 μm .

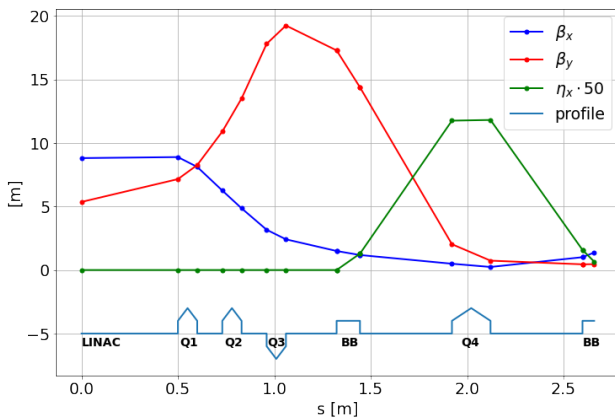


Figure 4: Tracking Twiss parameter from LINAC to source point.

SIMULATING PHOTON INTENSITY AND BEAM PARAMETERS

With the assumption that the photon source is equal the electron source point and linear optics the photon beam can be traced. A critical step in this process is the selection of the appropriate wavelength. The primary range is constrained by the quantum efficiency of the CCD sensor Sony ICX674 [3], which spans from 400 to 750 nm. To maximize the detected photon count a small opening angle θ is favourable due to aperture limitations. For the vertical plane this angle can be calculated using the critical wavelength λ_c corresponding to a beam energy of $E = 50$ MeV [6].

$$\theta = \frac{0.565}{\gamma} \left(\frac{\lambda}{\lambda_c} \right)^{0.425} \quad (1)$$

This is dependent on the electron rest energy E_0 and the bending radius ρ of the magnet where $\gamma = (E + E_0)/E_0$ and $\lambda_c =$

$(4\pi\rho)/(3\gamma^3)$. With the minimal possible distance of 1.3 m between source and lens and a tube diameter of 25.4 mm a geometric opening angle of less than 4 mrad is required to limit the 2σ Gaussian beam loss to below 5%. Based on equation Eq. (1), a wavelength of 400 nm is selected, corresponding to an opening angle of 3.6 mrad and a quantum efficiency exceeding 50% [3]. Since the radiation is in the horizontal, a geometrical acceptance angle of 8.56 mrad is considered neglecting the diffraction limit. With the possible opening angles the angular flux density over different wavelengths were calculated. The chosen wavelength is near the peak flux density as shown in Fig. 5. Using the electron

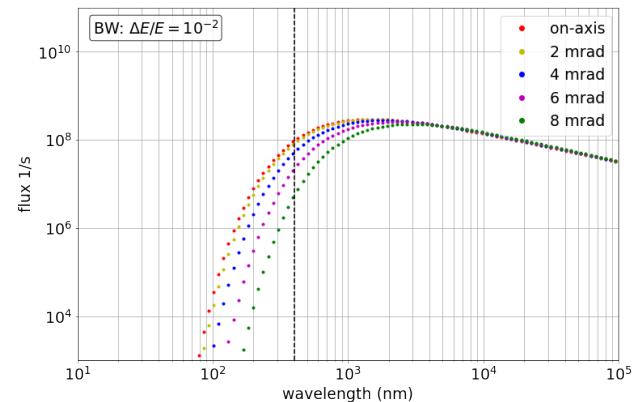


Figure 5: Angular spectral flux density depending on wavelength at 50 MeV and lens-source distance of 1.3 m

beam size at the source point and the obtained opening angles in both planes, the photon beam can be traced through linear optic. The primary objective is to find a lens position such that the beam size on the camera x_1 depends only on the source point beam size x_0 and not the divergence.

$$\begin{bmatrix} x \\ x' \end{bmatrix}_1 = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} x \\ x' \end{bmatrix}_0 \quad (2)$$

$$x_1 = Ax_0 + Bx'_0 \quad (3)$$

To achieve this, the value of the element B in the transport matrix T (Eq. (3)) tends towards zero. With this requirement a possible lens-source distance needs to be determined. To

find the required lens position and stroke length a scan of the transport matrix was undertaken with the chosen focal length of 200 mm.

Including different aberrations, diffraction limit and resolution limit, the beam size on the camera for different lens position was simulated as shown in Fig. 6. A resolution limit of $27.24 \mu\text{m}$ (six times the pixel size $4.54 \mu\text{m}$) and a diffraction limit of $22.81 \mu\text{m}$ determined by the wavelength has been assumed. This shows a transverse real image size on the CCD of $\sigma_{\gamma,x} = 91.26 \mu\text{m}$ and $\sigma_{\gamma,y} = 63.65 \mu\text{m}$. The simulation indicates a necessity of a stroke length greater than 30 mm (preferable 50 mm) and a lens position accuracy of 0.01 mm estimated for a 2 % variation in nominal beam size.

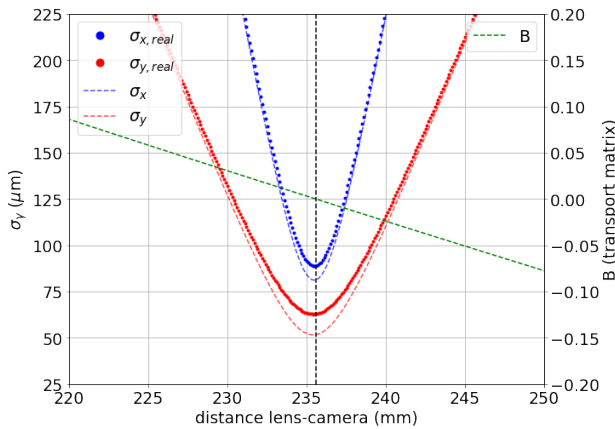


Figure 6: Image size of photon beam on CCD including diffraction and resolution limit depending on lens to CCD distance. For reference the dependence of the transport matrix element T_{11} is shown.

Now it is possible to determine the magnification factor of the adjustable system using the object and image distance.

$$M = \frac{1314 \text{ mm}}{236 \text{ mm}} \approx 5.57. \quad (4)$$

Neglecting aberrations the source point analysis system is characterized using the following equation.

$$\sigma_e = M \cdot \sigma_\gamma. \quad (5)$$

The analysis has shown a high photon flux for a large dynamic range, an image size significantly larger than resolution limit and using all dimensions within the preconditions.

FINAL DESIGN

Preferring a lighter set up a compressed bellow mechanism is chosen, CLSM38-50-SS. [7] The bellow length is 42 mm as shown in Fig. 7 and requires an extension pipe of length 142 mm attached through a SM1 thread onto the CCD. The full length of the beamline will be under 1.7 m with a source-lens distance of 1.4 m disregarding potential motorized repositioning of the lens.

The complete mechanism will be mounted to a MiniTec framework [8] and installed in the accelerator tunnel during

the summer shut down. To improve the system further the beamline will be vacuum sealed and include an iris blender to minimize internal reflection.

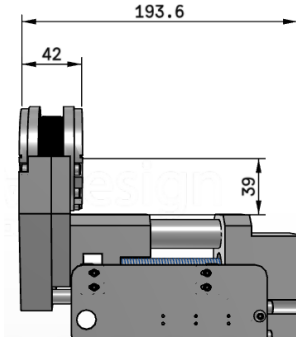


Figure 7: Compressed Linear Mechanism CLSM38-50-SS. Dimensions in mm.

OUTLOOK

In the future the system will be optimized to characterize the source point image through measurements using synchrotron radiation. Through a variety of measurements it is also possible to determine the beam energy and charge deviations. This high-end diagnostic will help optimize the injection process.

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