OPTICAL TRANSITION RADIATION BASED BEAM DIAGNOSTICS AT THE BESSY SYNCHTROTRON RADIATION SOURCE AND FEL ACCELERATORS

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Abstract

Optical Transition Radiation (OTR) based diagnostics tools are widely used in linear accelerators to measure beam parameters like transverse beam size and emittance. Design ideas for OTR stations in the linac section of the BESSY FEL facility are presented. Several key components will be tested in the transfer lines of the BESSY storage ring. Furthermore a novel type of OTR monitor is introduced which enables the measurement of the transverse overlap of seed laser and electron beam in the undulator sections of the linac based FEL facility. Here a special radiator screen will be used allowing simultaneous imaging of both beams in the same optical readout channel.

INTRODUCTION

Modern seeded FEL facilities like the proposed BESSY HGHG FEL [1] require a precise overlap of the seeding radiation with the electron beam along the undulator beamline. Furthermore the transverse size of both beams have to be controlled within tight tolerances in order to achieve efficient bunching at the desired wavelength. With screen monitors a precise characterization of the electron beam properties as well as the seed laser beam is possible. Depending on the individual setup the transverse beam size and divergence, energy and energy spread, and pulse length can be reconstructed with single shot capabilities. Screen monitors could either be based on luminescence or transition radiation. So far optical transition radiation (OTR) stations are standard tools at linac test facilities TTF [2] or CTF3 [3]. There are however concerns about the survival of the radiating aluminum foils or aluminum coated foils at high bunch charges. Therefore studies should be launched to evaluate different OTR radiators, screen substrates and crystals for high peak current applications. Furthermore the imaging properties for seed laser radiation should be investigated. In order to evaluate different technologies it is planned to design and test a novel type of beam profile monitor for application at the HGHG FEL facility. Beam tests of such a monitor at the Bessy II transfer channels and with laser beams could provide deep insights into relevant issues like resolution and applicability for laser and electron beams.

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VIEWSCREEN AND OTR MONITORS

Common to all screen monitors under evaluation is the way a beam image of the transverse charge distribution is obtained. Usually the screen is inserted by an actuator directly into the electron beam path. The electron bunch passes through the screen and the electrons interact in various ways with the screen material. Light is created by luminescence or transition radiation. The light spot on the screen is a direct measure of the transverse charge distribution in the bunch passing through the screen. A window is used to extract the light and pass it to an imaging system on a CCD camera.

Viewscreens are either made of single crystals or as a baked powder on an appropriate carrier material. Experiences are available with Thallium doped CsI and Cerium doped YAG with proton beams (see [4] and references therein). While the resolution of screens made of baked powder is typically limited by the grain size of the material to several ten μm, with single crystal screens a resolution of several μm should be achievable.

Transition radiation is emitted when charged particles pass through a thin metallic or dielectric radiator foil. Optical transition radiation (OTR) is the part of the radiation emitted in the optical spectrum between 350 and 750 nm, i.e. it is visible light, and thus can be detected by optical imaging systems (see [5]). The light output from an OTR radiator is smaller than for viewscreens (few orders of magnitude) but the time response is immediate allowing bunch-to-bunch measurements using gated cameras. OTR screens are usually aluminum coated insulating polyimide foils of several μm thickness or plain aluminum foils. The resolution of OTR screens is mainly limited by the resolution of the optical channel and CCD camera and therefore in the order of 5 μm for typical setups.

BEAM SPECIFICATIONS

The HGHG FEL electron beam is composed of bunches with several nC bunch charge and beam sizes ranging from 200 μm (injector area) to 60 μm in the collimator and undulator section. The resolution for the beam size measurements should be better than 8% for efficient emittance reconstruction. The beam parameters for the Bessy II transfer channels TC1 and TC2 are listed in Tab. 1. For laser beam tests suitable laser systems are available at BESSY. The seed lasers for the facility will be tunable between 230 nm and 460 nm with pulse energies around 10 μJ. The

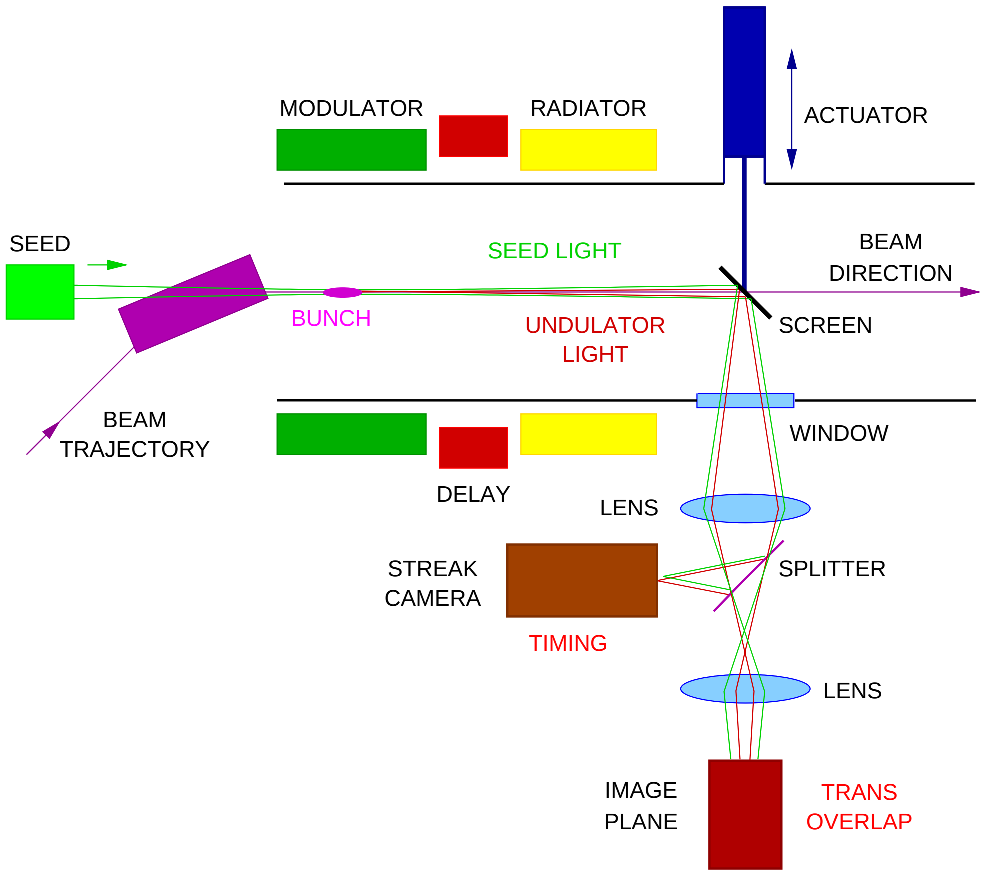

Figure 1: Extraction and analysis scheme for transverse beam size and overlap diagnostics.

Table 1: Relevant electron beam parameters for both transfer channels and HGHG FEL linac.

Parameter	**TC1**	**TC2**	**Linac**
Beam Energy/GeV	0.05	1.7	0.131 – 2.3
Bunch Charge/pC	1	12	$3 \cdot 10^3$
Bunch Length/ps	5	10 – 50	1 – 45
Trans Beam Size/mm	1 – 3	1 – 3	0.06 – 0.200

wavelength of the light output of the first modulator of the high-energy FEL is around 300 nm.

COMBINED SCREEN SYSTEM

In Fig. 1 a combined screen station for the HGHG FEL facility between undulator sections is sketched. In order to analyse the beam sizes and overlap between the seed laser, modulator radiation and electron bunches, an appropriate screen is inserted into the beam path. For the measurement of the temporal overlap, the light pulses are analyzed with a ps-resolution streak camera. For transverse size and overlap, an optical system images the source points on a CCD camera.

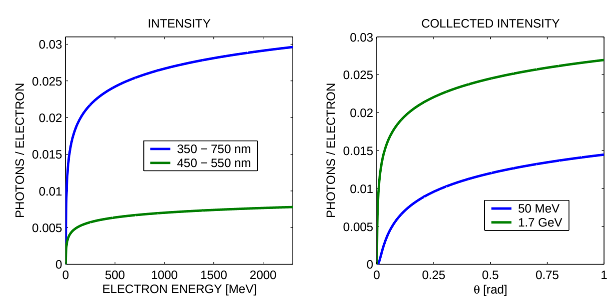

Figure 2: Number of photons per electron as a function of beam energy and acceptance angle.

LIGHT YIELD

Typical light yields for scintillators like YAG(Ce) [6] and CsI(Tl) are in the order of several ten photons per keV energy deposit. The emission spectrum usually peaks at 550 nm wavelength and is thus well suited for standard light optics and CCD cameras. The light yield for photon beams passing the scintillator can be evaluated in a similar manner.

The angular distribution of OTR is concentrated into two symmetric lobes with large tails. For the wavelength region between λ_1 and λ_2 the photon yield per electron is

$$\frac{N_\gamma}{e^-} = \frac{\alpha}{\pi}\left[\ln(1+\theta^2\gamma^2) - \frac{1}{1-\theta^{-2}\gamma^{-2}}\right]\ln\left(\frac{\lambda_1}{\lambda_2}\right) \quad (1)$$

The number of emitted photons is in the order of the fine structure constant α and scales logarithmically with the beam energy γ. In Fig. 2 the number of photons per electron at both transfer channels for two wavelength regions is plotted. Also shown is the collected intensity for different acceptance angles. For standard optical readout channels the acceptance angle is in the order of 100 mrad. For TC1 the total number of photons is $N_{VIS} = 8 \cdot 10^4$ for a wavelength interval between 350 and 750 nm and $N_{BAND} = 2.1 \cdot 10^4$ for 450 to 550 nm. At TC2 the light yield is higher due to the higher beam energy higher and $N_{VIS} = 6.32 \cdot 10^5$ and $N_{BAND} = 1.66 \cdot 10^5$. With these number of photons, intensified CCD cameras are required to provide an adequate beam image. The minimum illumination for standard CCD cameras is 0.1 Lux at F1.4 and for intensified CCDs 5 to 0.5 mLux at F1.4. These translates to roughly 2000 photons per pixel for standard and 2 photons per pixel for intensified cameras.

TEST MEASUREMENTS

In the next phase of the project a combined screen station will be built and tested with different screen and OTR materials. Tests under beam condition are planned with the Bessy II electron beam and laser beams. Properties under investigation include the light yield from laser beam at seeding and modulator wavelengths, linearity with respect to beam power, achievable resolution, and damage threshold.

CONCLUSION AND OUTLOOK

A combined viewscreen station will be set up in order to observe the transverse beam size and overlap of seed laser, undulator radiation and electron beam for the BESSY HGHG FEL. Various candidates for the screen material are identified and will be tested under electron and laser beams at BESSY.

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