Design considerations for the LCLS profile monitors

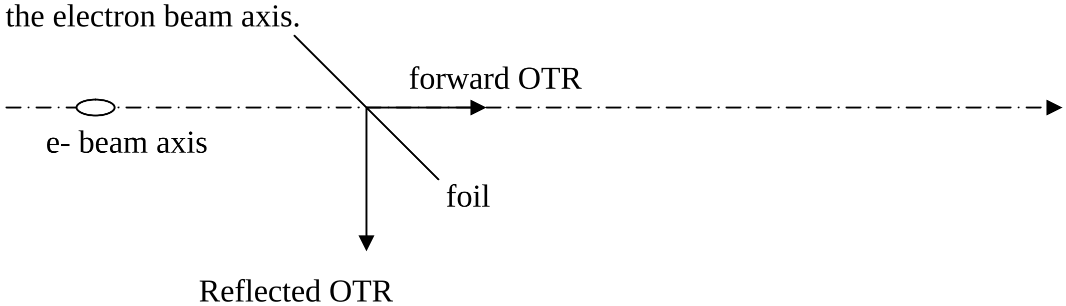
March 18, 2004

The LCLS profile monitors will be used to make high resolution measurements of the transverse beam profile at numerous locations along the linac. The common design features are listed here so that a uniform design can be adopted for most locations. The existing SLAC designs do not, in general, satisfy the LCLS design requirements because they typically use phosphor screens and the view port is too far away from the screen. Both of these aspects spoil the resolving power.

The LCLS will therefore rely on the optical transition radiation (OTR) from a metal foil inserted into the beam path. Since the light output is related to the beam energy it will be necessary to use YAG screens in the off-axis injector beam line. It should be possible to use the OTR profile monitor design and substitute a different screen. This document will therefore concentrate on the OTR requirements.

1. Geometry

The light path follows the specular reflection path from the surface of the foil, so that if the foil is inserted at 45° to the electron beam axis the OTR light will be emitted at 90° to the electron beam axis.



2. Invasiveness to the electron beam

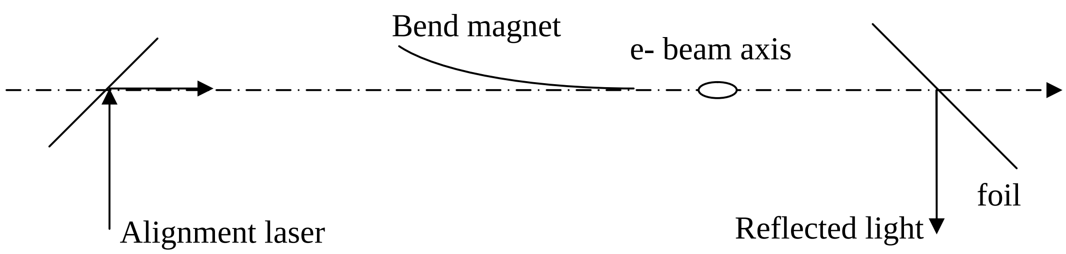
Inserting the metal foil into the beam path will increase the emittance of the electron beam making it unusable for FEL operation in the undulator. However, if the foil is kept thin enough the degradation to the electron beam is small enough that the electron beam will remain contained in the vacuum envelope and will be transported cleanly to the electron beam dump with out any beam loss so that the accelerator can continue operation without any further action.
This requires that the foil be made of a low Z material and have a thickness of the order of a micron. This is based on experience in the FFTB where 1 um Ti foils have been successfully used. The 25 um Ti foils showed appreciable beam loss in the FFTB.
The foil holder is made of much thicker material like stainless steel and should not be allowed to intercept the beam. If possible the foil holder should have a gap at the location where it crosses the beam axis. If this is not possible the control system will have to actively suppress the beam every time the foils are inserted or extracted, and this would be more invasive to the LCLS operation.

3. Resolution

Beam sizes down to the order of 10 um are expected on the profile monitor screens. This pushes us to the limits of achievable optical resolution.
Surface quality of the foil is important and requires that thin foils be stretched over a frame to remove wrinkles. The foil should also be free of tooling indentations.
The magnification ratio of the external optics is determined by the closeness of the first objective lens. The vacuum window should be as close to the electron beam axis as the electron beam stay clear allows.
Provision should be made for fine focus adjustment to the optics during the pre-beam setup of the apparatus.

4. Alignment

Unlike the diffuse light from a phosphor screen the light from an OTR screen is emitted in a very narrow cone. The camera optics need to be precisely aligned to this axis.
The screen should be insertable into the beam line axis with good angular positioning reproducibility.
One method of finding the optical axis is to insert an alignment laser some distance upstream which can be centered on the OTR screen and will reflect at the same angle as the OTR light. The alignment laser light can be brought on axis with an insertable upstream mirror. If the OTR screen is just downstream of a beamline bend then the alignment laser can be operated simultaneously with the electron beam.



5. Illumination and graticules

A fluorescent screen such as a phosphor or a YAG screen can printed with a graticule scale which is useful for beam size calibration and for focusing the camera. The profile monitor can then be equipped with an illuminating lamp with remote brightness control. When the lamp is off no stray light should reach the screen in order to achieve the best contrast of the beam image. Printing a graticule on a micron thick foil may not be possible so alternatives need to be considered. An untested idea is to position a fine wire grid close to the foil surface to serve as a graticule.

6. Chamber wakefields

In order to minimize disruption of the beam by wakefields the profile monitor chamber should be smooth and without any large step changes in bore diameter. In extreme cases, and only if further studies warrant it, we may ask for a sleeve to position itself in the chamber when the screen is in the out position to ensure a smooth beam pipe. RF fingers would be required between the sleeve and the chamber wall.

7. Actuators

The screen is to be remotely insertable and should reproducibly come to the rest in the same position and angle with respect to the beam. The motion should be soft enough not to damage the fragile foils or YAG crystals, but should not take more than a few seconds to cycle. Air actuators have been used for profile monitors at SLAC. The mechanical stops for the actuators should be equipped with micro-switches to indicate the position status of the screen.

8. External optics

The optics to the recording camera need to have sufficient resolution to measure 10 um spots and should have adequate light gathering power for the image from the foil, even at low charge operation of 0.2 nC where only 1/5th as many photons will be produced as in nominal operation.

An achromatic objective lens need to be mounted close to the vacuum window.

An additional requirement for profile monitors located close to a bend magnet such as the bunch compressors and the dog-legs is the ability to selectively filter out the synchrotron radiation illumination. This can be done with remotely adjustable polarizing filters.

If a remotely operable iris is used to control image brightness it needs to be positioned in the optics at the correct location to avoid vignetting of the image intensity. A better solution is to use cross-polarized filters to reduce the light intensity to avoid vignetting altogether. The cross-polarizers can be mechanically combined with the polarizing filter for suppressing synchrotron radiation.

In many cases the camera can be located in the accelerator housing to simplify the optics. However, this raises the issue of accessibility for maintenance.

In some linac applications there is a further risk of radiation damage to the camera, particularly during the non-LCLS operation of high current beams for end station experiments. This requires the cameras to be removed prior to such operation and then re-aligned for LCLS operation. A preferable solution is to have the camera optics relayed out of the accelerator housing with high quality optical mirrors. This has been done for SLC operation and requires careful design with regard to alignment, vibration, air currents, cleanliness and aperture restrictions in the optical layout.

The field of view should be large enough to find the beam even if it is steered off-axis. In order to maintain sufficient optical magnification a zoom lens should be used to vary the field of view.

The profile monitors used in conjunction with the RF transverse deflecting cavity bunch length measurements need a larger field of view than other monitors in order to accommodate the beam centroid motion of a few mm during the bunch length calibration procedure.

9. Controls requirements summary

The screen actuator will use a switch to control an air solenoid for either “in” or “out” commands. Limit switches at the two extreme positions will confirm the status of the actuator position.

A remotely dimmable lamp will be used in some cases to illuminate the screen.

In other cases an alignment laser beam should be remotely switchable on or off. The alignment laser may be combined with another insertable screen device to reflect the laser light into the beam line, which will need a second set of the actuator controls above. A pair of remote rotational movers will control two polarizing filters placed somewhere between the vacuum window and the camera.
The camera will be a remotely triggerable digital video camera with typically >12 bit intensity resolution and several megapixels of spatial resolution. Since camera technology is rapidly advancing we will allow this specification to evolve. This is also true of the camera interface which today could be USB2 or ethernet compatible.