High-Resolution Optical Transition Radiation Measurements

1 Application

Optical transition radiation (OTR), Čerenkov radiation and the radiation from fluorescent screens are common diagnostics in particle accelerators. A camera is used to observe the screen. If these devices are to be used for precision diagnostics, the performance of the imaging system has to be evaluated.

To measure the properties of cameras used for the plasma wakefield acceleration experiment E-167 and for the linac coherent light source (LCLS), a joint test setup is proposed.

2 Proposed Tests of the Imaging System

The imaging system is made up of

- The lens
- The CCD chip and the connected ADC / frame grabber
- The post-processing of the image data

These can all affect the image quality: diffraction and aberrations of the lens convolute the ideal image with its point spread function (PSF). The CCD chip splits the image into discrete pixels; the digitization introduces discrete intensity steps. Artifacts such as a non-linear response or blooming may be created. The post-processing of the image may include a lossy compression, or image enhancement techniques to make up the limited resolution of the lens.

These factors affect our ability to determine the bunch shape reliably. Therefore, the following tests of the imaging system are suggested:

2.1 Resolution

- Measurement of the modulation transfer function (MTF)
- Measurement of the contrast transfer function (CTF)

- Measurement of the point spread function (PSF)

The MTF is the ratio between the contrast (modulation) of an image and the modulation of the actual object, as a function of spatial frequency; an object with a sine-like intensity distribution consists of only one spatial frequency. If the intensity distribution is rectangular (e.g. black lines on a white substrate), the imaged contrast makes up the CTF. The image of a point-like source is the PSF.

While these three functions are related mathematically and could be derived from each other in principle, an independent measurement assures that the measurements are reliable and that the image post-processing does not create spurious details.

The measurement is done by imaging a uniformly illuminated test target onto the CCD. To measure the MTF, one can image a target containing various sine patterns. One can also image an object that has equal brightness contribution at all spatial frequencies, i.e. is made up of ideal white noise. The Fourier transform of the image is the MTF.

Several standard targets are being used to measure the CTF, the USAF 1951 and the more recent ISO 12233. The latter has the advantage of being optimized for digital imaging. It contains components to test the effect of binning and image post-processing.

2.2 Depth of Field

This is important for applications where the imaged object has a certain extent along the optical axis, e.g. because a tilted OTR foil is imaged.

A resolution measurement is done with a varying distance, or using a tilted uniform ruling.

2.3 Efficiency and Linearity

Calibrate the number of photons necessary to increase the ADC by one least significant bit (LSB) and test whether this calibration is linear across the dynamic range of the CCD. This test is affected by the gain and ADC offset (called “brightness”) setting of the camera.

The efficiency has to be done with a monochromatic light source, since power meters are always calibrated for monochromatic light. It can be done at different wavelengths, using different LEDs.

Linearity can also be measured with a uniformly illuminated gray scale.

2.4 Noise and Uniformity

This is measured with a homogeneously illuminated CCD. Care has to be taken to ensure that the uniformity of the illumination is better than the expected uniformity variation of the CCD; I am not sure whether this can be achieved at all.

It has been suggested to use the morning sky (before sunrise) as an illumination source.

2.5 Timing and Shutter Efficiency

This is important because for our application, we measure typically a very short light pulse.

A measurement can be done using a very short pulse from a bright LED. The camera has to be triggered using a hardware (e.g. TTL) input.

2.6 Image Processing Artifacts

These may include JPEG artifacts (ringing at sharp intensity boundaries) and spurious details introduced by image sharpening algorithms.

A fingerprint of such artifacts is a different resolution, depending on how it is determined. JPEG artifacts can also be seen with the corresponding fields in the ISO 12233 target.

2.7 Other Measurements

Difficult to measure, and maybe not so important:

- Wavelength response
- Lens distortion
- Blooming artifacts

3 Material

- Test targets
  - USAF 1951 √ (ARDB)
    Edmund Optics, $115
  - High-resolution USAF 1951 (?)
    Edmund Optics, $850
  - ISO 12233 (LCLS)
    Sine Patterns LLC (www.sinepatterns.com),
    Standard Test Chart ISO Resolution 1/10x, 2x3.6cm, Chrome on white opal glass, $350
  - Uniform rulings √ (ARDB)
    Edmund optics
  - Pinhole (LCLS)
    - Edmund Optics (www.edmundoptics.com),
      Mounted Precision Pinhole, 2um diameter, Stock No. G56-273, $99
    - Edmund Optics (www.edmundoptics.com)
      Mounted Precision Pinhole, 5um diameter, Stock No. G56-274, $55
  - Pseudo-random target √ (ARDB)
    Al Ducharme, Univ. of Central Florida, $1000
  - Grayscale √ (ARDB)
    Keeble & Surchat, Stouffer Co. Transmission Projection Step Wedge, $33.25
- Illuminators
  - Uniform √ (ARDB)
    Keeble & Surchat, Cabin Light panel, $89.95
  - High-brightness (gooseneck lamp) √ (ARDB)
    Edmund optics, $345
  - Laser or LED, calibrated with power meter (ARDB)
    Newport, $1950
  - LED (with DG535 pulser) √ (ARDB)
    Digikey, $0.05
    Stanford Research Systems, $3995

- General
  - Optical breadboard (LCLS)
    ThorLabs Inc (www.thorlabs.com),
    Ultralight Breadboard, 1” thick, dimension: 5’x2’, Item # PBG11108, $1145.80
  - Mount for test target (LCLS)
    ThorLabs Inc (www.thorlabs.com),
    Fixed filter holder, Item # SFH3, page 152, $53.50
  - Translation stages for the test target (LCLS)
    Newport (www.newport.com),
    XY modular linear stage, page 830, Model 460P-XY, $457
    2 pieces, Vernier micrometers, page 894, Model SM-25, $2 \cdot \$89$
  - Vertical movement and rotation for the test target (LCLS)
    Lab jack with rotary platform, page 884, Model 488, $325
  - Mounts for the camera
  - Color filters / IR cutoff filters √**?**
  - Light-tight cover √ (ARDB)
  - Computer √**?** (ARDB)
  - Software √