EXPERIENCE WITH YAG AND OTR SCREENS AT ALBA

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Abstract

One of the key diagnostics instruments during the ALBA Linac commissioning was the screen monitors that allowed the control of beam size and position. These screen monitors are equipped with a YAG and an OTR screen. This paper describes our screen monitor setup and the experience with both types of screens.

INTRODUCTION

During the ALBA Linac commissioning [1], beam transverse position and profiles are obtained using the setup named "FSOTR" (Fluorescent Screen and Optical Transition Radiation monitor). It includes a Fluorescent Screen (Cerium activated Yttrium Aluminum Garnet, named herafter "YAG", with chemical formula $Y_3Al_2O_{12}$), and a second screen that produces Optical Transition Radiation (named hereafter "OTR").

After collision with the electron beam, both screens emits light, but their nature differs: YAG screen emits light by scintillation, the OTR screen emits light by Transition Radiation. In both cases, a lens system brings the light to the CCD screen, where the image is collected.

We adopted the solution of YAG and OTR screens in the same setup to obtain a proper beam image for the cases of low and high beam charges. As shown in next Sections, the YAG usage is appropriate for low beam charges because these screens produce lots of light. Its drawback is the saturation at high charges. In these circumstances, the usage of the OTR is convenient, albeit its low photon flux production and so, dynamic range.

In the following, we describe our mechanical setup and experience during the Linac Commissioning, and compare beam images produced with both OTR and YAG screens. We would like to stress that our experience is based with low energy electron beams (up to 100 MeV), which is a relevant factor for both YAG and OTR imaging.

EXPERIMENTAL SETUP

Figure 1 (left) shows a picture of the experimental setup. Using a pneumatic system, the FSOTR monitor allows to introduce either screen into the beam's path. Once the beam collides with either screen, an optical system directs the light to the CCD camera, where the beam image is analyzed.

The optical system is bought off-the-shelf from *EHD-Imaging* with a manually controlled zoom. The working distance of this system is about 300 mm. The CCD camera is *Basler Scout* model, Ethernet controlled, 12-bit resolution, 1034x779 pixels and a square pixel size of 4.65 μm. To minimize the luminic noise, we set the CCD shutter to the minimum time aperture: 100 μs. Since the slowest light emission is the one produced by the YAG screen, and this is only 70 ns [2], this shutter is enough to collect the light produced by either screen.

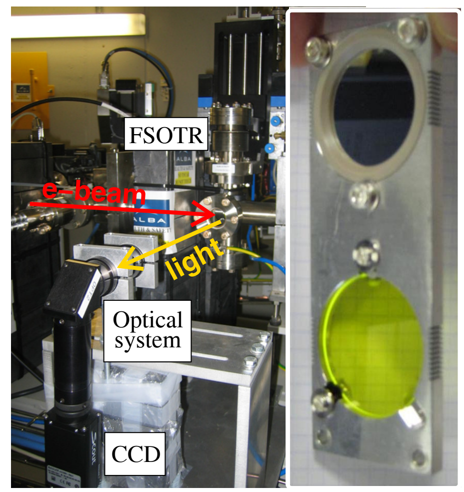

Figure 1: Picture of the FSOTR (right) installed at the Diagnostics line and screen holder with the YAG (bottom yellowish) and OTR screens (top).

Figure 1 (right) shows a picture of the screen holder with the YAG (yellowish and translucent screen) and the OTR ("mirror-like" screen). The YAG screen manufactured by Crytur [2] has a 0.5 mm thickness and 30 mm diameter. The second is a Silicon substrate of 0.3 mm with a thin layer (100 nm) of Aluminum to enhance the transition radiation. The reference marks on the holder edges are used for calibration purposes and image focusing. The calibration in the FSOTR monitors varies from one to another, but it is generally 1 pixel = 20 μm.

BEAM IMAGING WITH YAG SCREENS

The number of photons arriving at the CCD camera produced after a single electron hits the YAG screen is

$$N_{ph} = Y \times \Omega \,, \tag{1}$$

where $Y = 35 \times 10^3$ ph/e-/MeV is the YAG photon yield [2], and $\Omega = 4 \times 10^{-4}$ sr is the solid angle covered by the optical system. This means that a single electron at 100 MeV

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produces 1400 photons that arrive to the CCD sensor, assuming 100% efficiency along the optical system. Large photon fluxes are very positive, but in some cases it can has some disadvantages, which are next listed.

CCD Saturation

Pixel or CCD saturation occurs when the image sensors reach their finite charge capacity or their maximum charge transfer capacity. This occurs when the number of photons arriving to the CCD chips is larger than this maximum, which occurs for high areal beam charge densities. In our case, we find this limit at about 2 nC/mm^2.

CCD saturation is easily recognised whenever we reach the maximum pixel intensity in an area around the beam centroid. In this case, 4095 (12-bit digital CCD camera). When CCD saturation is reached, the beam profile image is distorted and so is the image analysis.

YAG Emission Saturation

Fluorescence or scintillating light by the YAG screen is emitted by the de-excitation of atomic states that were previously excited by the passage of an ionizing particle, in this case the electron beam. Above a certain areal beam charge density of the electron beam, the atomic excitation is no longer proportional to the number of electrons crossing the YAG crystal, and a saturation of the light emission is reached. When YAG saturation is reached, the image analysis is not reliable.

YAG saturation is not easily recognized when looking at one single image. This is better distinguished during the quadrupole scan performed to do emittance measurements. Figure 2 shows the horizontal sigma as a function of the quadrupole intensity. As the beam approaches the waist along both branches, the beam size decreases linearly until we enter a pseudo-plateau (between approximately -1.9 A and -1.7 A). This corresponds to a 2 nC beam, for which the charge areal density (1-sigma) at saturation is 1.5 nC/mm^2.

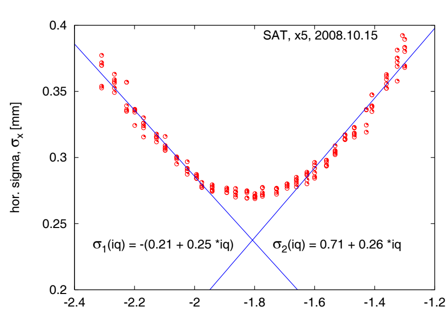

Figure 2: Beam size decreases linearly as we approach the beam waist (approximately at -1.8 A). Below 0.28 mm, the beam size enters a saturation regime. The blue line shows two linear fits to the data at each branch, and stresses the lack of linearity between -1.7 A and -1.9 A, which points the YAG saturation.

Light Reflections and Multiple Scattering

Because the YAG screen is translucent, light produced by the beam itself can be reflected in the beam chamber and distorts the beam image. In our case, since the chamber behind the YAG screen is round, it acts as a concave mirror and this effect enlarges the apparent beam size.

Moreover, due to the YAG screen thickness, multiple scattering inside the screen increases the apparent beam size [3]. Because the screen is tilted 45° in the horizontal direction (and not in the vertical), this effect is more pronounced horizontally than vertically – see Figs. 5 and 6. Figure 3 depicts the effect of the multiple scattering inside the YAG screen.

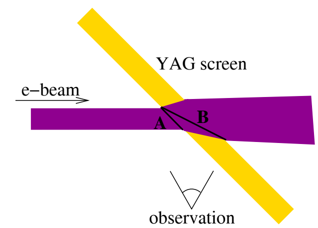

Figure 3: Beam size enlargement due to multiple scattering inside a YAG screen. The distance A appears as B.

BEAM IMAGING WITH OTR SCREENS

An OTR screen produces visible light when a relativistic charged particle crosses the interface of two media with different permittivity ϵ_r. The radiation is emitted in a cone of $\pm 1/\gamma$ towards the optical system, and so reflections inside the vacuum chamber are not an issue. The most critical point is the low photon flux produced with the ALBA Linac beams.

The number of photons N_{ph} generated when a single electron crosses a metal foil is [4]:

$$N_{\mathrm{ph}} = \frac{\alpha}{\pi}(2\ln\gamma - 1)\ln\frac{\nu_2}{\nu_1}\,, \tag{2}$$

where α is the fine structure constant, γ is the beam relativistic factor, and ν_1, ν_2 is the photon frequency region. Since the OTR light is emitted between $\pm 1/\gamma$, we consider that the same optical system captures all the OTR photons. In this case, one electron at 100 MeV produces about 0.016 photons that arrive to the CCD in the visible range. This is about 5 orders of magnitude lower than the image produced using the YAG screen.

In the first phase of the Linac commissioning, the maximum energy was 70 MeV, for which the OTR signal was too low. We could only use the OTR during the last part of the Linac commissioning, when the Linac was properly optimized and energies > 100 MeV and small emittance beams could be reached.

BEAM SIZE USING YAG AND OTR

Figure 4 compares two cases that illustrate the pros and cons of the beam imaging with YAG (top) and OTR (bottom) screens, and their profile analysis in the vertical direction. In both cases the Linac settings are the same. The effect of reflections and multiple scattering in the YAG screen produces the tails' enlargement. On the other hand, the OTR image has a larger Signal to Noise Ratio (SNR) because of the areal charge density is not very large (in this case, about 0.2 nC/mm^2).

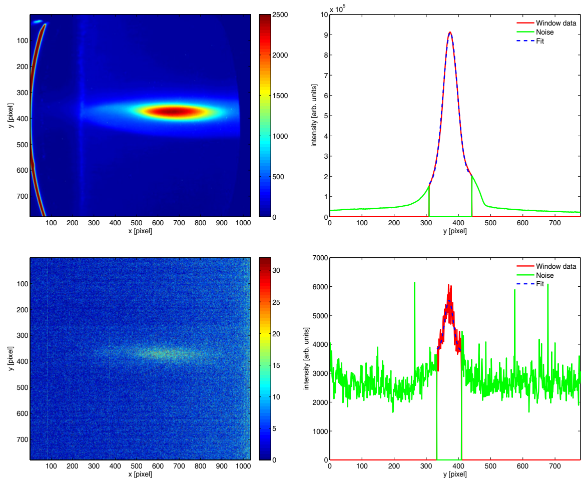

Figure 4: Two beam images and their profile analysis for the same Linac settings using the YAG (top) and OTR (bottom).

Due care shall be then taken during a beam size scan, for example, in the emittance measurements using the quadrupole scan technique. In these cases, the areal beam charge density varies by about one order of magnitude between the beam waist and the scan edges [1].

Figure 5 shows the difference between the horizontal beam size inferred using the YAG and OTR screens. The YAG screen gives a horizontal size which is a factor ~ 2 larger than the beam size inferred using the OTR screen. Note that around the beam waist, the scan is probably affected by saturation.

On the other hand, the vertical beam size (see Fig. 6) does not show such a significant difference because of the screen orientation previously mentioned decreases the effect of the reflections and multiple scattering. In both horizontal and vertical profiles, this difference is more pronounced in the beam waist.

SUMMARY AND OUTLOOK

The ALBA FSOTR monitor and the advantages and disadvantages of using YAG or OTR found during the ALBA Linac comissioning are shown. The images produced using the YAG screen have a photon flux of about 5 orders of magnitude larger than images produced using the OTR screen. However, beam imaging using YAG screens produce CCD or YAG saturation. In this case, we measure CCD saturation for charge densities above 2 nC/mm^2 and YAG saturation above 1.5 nC/mm^2. Light reflections and multiple scatterings produce a beam size overestimation using the YAG screen of about a factor of 2 (horizontally) and about 50% (vertically).

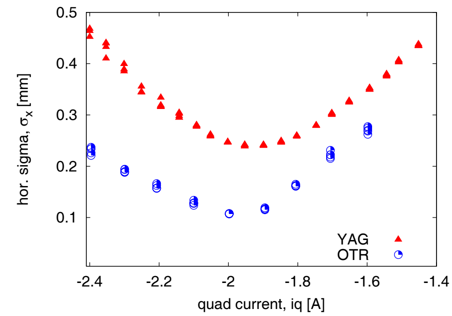

Figure 5: Hor beam sizes during a quad scan, inferred after analysis of the YAG and OTR images (MBM, 4 nC).

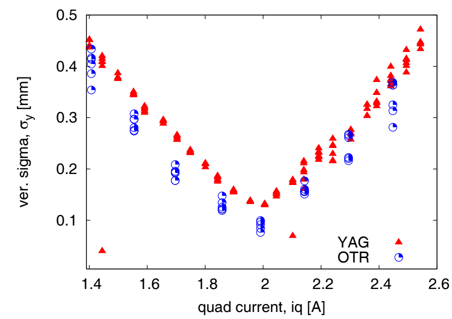

Figure 6: Ver beam size during a quad scan, inferred after analysis of the YAG and OTR images (MBM, 4 nC).

In order to avoid these reflections, it is convenient to use YAG screens optically non-transparent (i.e., with a few µm Si coating). Since ALBA already has all its YAG screens, we have designed a sandblasted stainless steel plate to avoid these reflections. Moreover, this plate has also some marks to provide in-situ calibration.

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