CHARACTERIZATION OF THE ELECTRON BEAM VISUALIZATION STATIONS OF THE ThomX ACCELERATOR*

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Abstract

We present an overview of the diagnostics screens stations - named SSTs - of the ThomX compact Compton source. ThomX is a compact light source based on Compton backscattering. It features a linac and a storage ring in which the electrons have an energy of 50 MeV. Each SST is composed of three screens, a YAG:Ce screen and an Optical Transition Radiation (OTR) screen for transverse measurements and a calibration target for magnification and resolution characterisation. The optical system is based on commercial lenses that have been reverse-engineered. An Arduino is used to control both the aperture and the focus remotely, while the magnification must be modified using an external motor. We report on the overall performance of the station as measured during the first steps of beam commissioning and on the optical system remote operations.

OVERVIEW OF THE OPTICAL DIAGNOSTICS AT THOMX

The ThomX Compact Compton source is a novel accelerator which is being commissioned in Orsay [2, 3]. We report here on the optical diagnostics used in this accelerator.

The overall diagnostics layout is shown in Fig. 1. There are five screens stations. They are located near the RF Gun, at the end of the linac, in the transfer line (twice) and in the extraction line. The current operation permit from the Nuclear Safety Authority only allows commissioning of the straight part of the accelerator after the photo-cathode (upper part of the drawing), hence this paper will focus on the two first screens stations, named LI/DG/SST.01 and TL/DG/SST.01.

Each screens station is made of a vacuum vessel with a UHV-compatible actuator to move the screens in vacuum. The visualisation is made using a Basler scA640-70gm CCD camera equipped with a commercial lens. A drawing of these diagnostic stations can be seen in Fig. 2. There are three types of screen for each station: a YAG:Ce screen, an Optical Transition Radiation (OTR) screen and a calibration target. Those screens are at a 45° from both the beam trajectory and the camera axis. Each screen is separately described in the following sections.

The TL/DG/SST.01 has also a sapphire screen used to generate Cerenkov light and allow longitudinal length measurement. This feature is not yet commissioned and will not be mentioned further in this paper.

COMMERCIAL LENS REVERSE-ENGINEERING

Lens Characteristics

The lens used in both SSTs is a Tamron : 18-400mm F/3.5-6.3 Di II VC HLD. Those lens have a focal length of 18 mm to 400 mm and an aperture going from f/3.5 (f/6.3) to f/22 (f/40) at a focal length of 18 mm (400 mm).

Reverse-engineering

This kind of lens allows auto-focus and aperture control by photographer's cameras, but the ThomX cameras do not have the required outputs. To remotely control both those parameters, an Arduino Uno circuit controlled by a web interface has been developed [4].

A 3D printed structure is under test to remotely control the magnification by adding an external motor.

CALIBRATION TARGET

Before using a scintillation screen to evaluate beam size, some calibrations must be done. For that purpose, a specific calibration target, named USAF1951 calibration chart, is used (see Fig. 3). Nine identical calibrated targets allow the measurement of the magnification and resolution at each target position. Two numbers - group and element - are use to characterise each triplet of vertical and horizontal lines [5]. The width of a line - or a fifth of its length - may be computed using Eq. (1).

$$d[\mathrm{mm}] = 2^{-1\times(1+group+(element-1)/6)} \tag{1}$$

From the size of the largest element, one may compute the pixel/millimetre ratio needed to compute the beam size - hence the magnification - while the resolution comes out from the smallest element's triplet of lines that one can discriminate. Table 1 show the resolution and magnification computed for both images of Fig. 3. The magnification computation give a 2x2 matrix used to compute, from horizontal (h) and vertical (v) pixel length on the image, the horizontal (x) and vertical (y) physical length of the beam (in mm) as show un Eq. (2).

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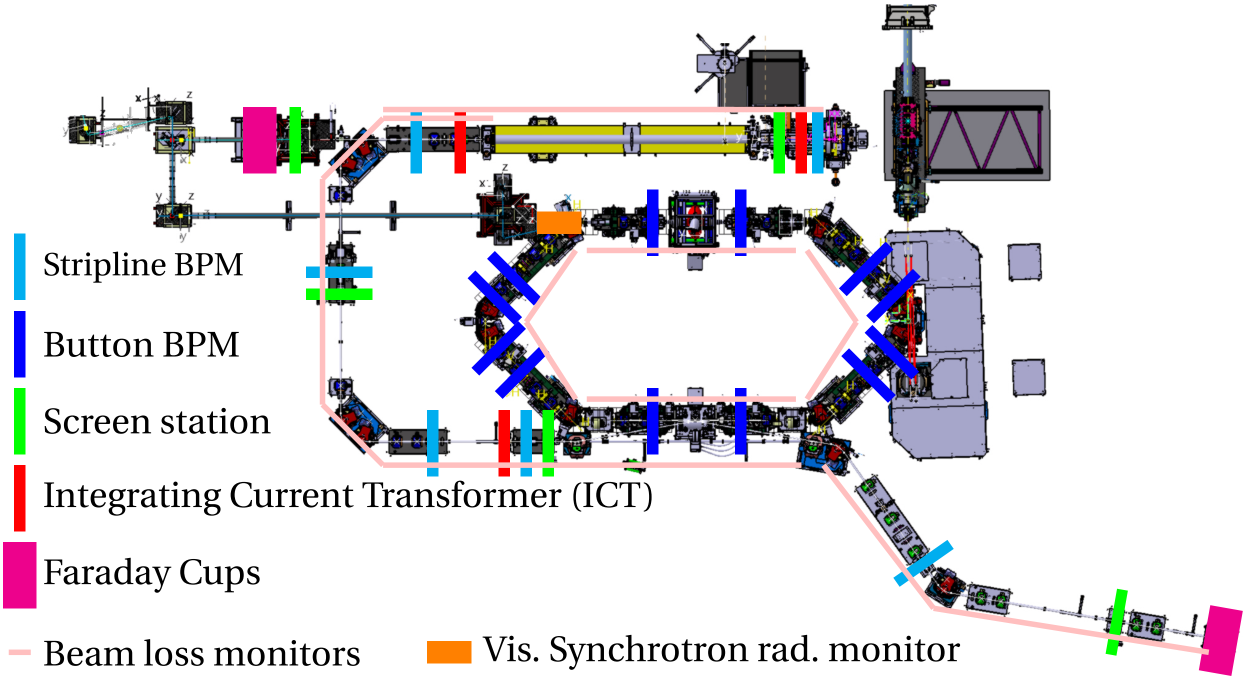

Figure 1: Location of the optical diagnostics on the ThomX accelerator. The beam is produced at the top of the drawing and propagates counter-clockwise. The green dashes show the location of the screens stations.

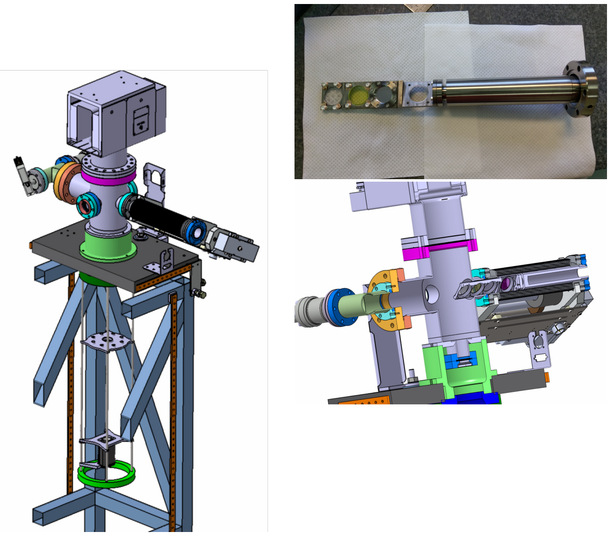

Figure 2: Left: CAD 3D view of one of the diagnostic stations. The beam travels from the front left to the back right on the image. The screen is inserted by the motorized UHV-actuator on the right. The observation camera is located below the station. On some stations such as the one depicted here, a vacuum pump can be inserted on top of the station. Right: Photo (top) and drawing (bottom) of the screens mechanical arm. Three to four screens can be inserted via these mechanical arms. In this example, the 4th screen is the Cerenkov screen and it has a slightly different angle.

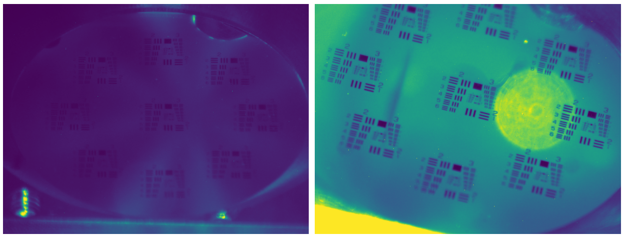

Figure 3: USAF1951 test chart on Li/DG/SST.01 (left) and on TL/DG/SST.01 (right). Nine calibrated targets allow the measurement of magnification and resolution. The bottom and top part of the screen are blurry because of the 45° rotation of the screens and the short depth of field. The illumination and exposure is adapted to allow automatic computation.

Table 1: Calibration parameters computed for images of Fig. 3. Resolution is given for the upper target while over parameters are the mean for all target detected by the analysis's code.

	Resolution [μm]		**Magnification** [μm/px]			
	Horz	**Vert**	**HX**	**VX**	**HY**	**VY**
Li/DG/SST.01	125	99	36	0	1	−36
TL/DG/SST.01	79	79	28	10	−5	27

$$\begin{pmatrix} x[\mu\mathrm{m}] \\ y[\mu\mathrm{m}] \end{pmatrix} = \begin{pmatrix} HX & VX \\ HY & VY \end{pmatrix} \times \begin{pmatrix} h[pixel] \\ v[pixel] \end{pmatrix} \tag{2}$$

One may notice reflections on Fig. 3. It comes from the LEDs used to light the screen. To avoid too much reflection preventing from reading the target, several LEDs have been tested. The less directional the LED light, the better the image. The actual configuration is not perfect but allows nevertheless the use of a python script to automatically compute the calibration of the screens. A dedicated paper about this computation has been presented at IBIC2020 [4].

YAG:CE SCREEN

A YAG:Ce screen is used on ThomX to visualise the transverse projection of the beam. This kind of screen is particularly efficient during commissioning as the yield of photo generated is considerable, which allows visualisation of a small charge beam (around tenth of pC) or dark current. Those screens are also used to measure the beam energy with a steerer magnet. While the operation permit does not allow the use of the bending dipoles, this is the main method for energy measurement. Figure 4 shows one of those energy measurements on LI/DG/SST.01.

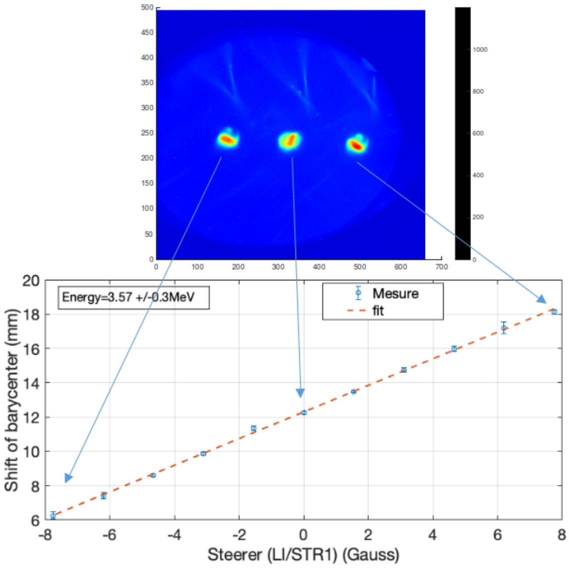

Figure 4: Energy measurement on the YAG:Ce screen of LI/DG/SST.01 using a steerer to deflect the beam. Each spot correspond to the beam position at three different values of the steerer's strength : ≈ -8 G, 0 G, ≈ 8 G. The measured energy was 3.6 ± 0.3 MeV at the exit of the photo-gun.

OTR SCREEN

The optical transition radiation (OTR) is another way to measure transverse beam characteristics. Beam size measurements are more precise than with YAG:Ce screens as no blooming occurs, but the yield of photon generated is much smaller. Figure 5 shows this yield difference as one 30 pC, 50 MeV beam alone can be clearly identified on the YAG:Ce screen's image (top) whereas to see the OTR light, an image of one hundred beams and a background noise subtraction is needed. A preliminary computation of OTR light collection by the camera give a better visualisation than those measured. Hence some measurement of the transmittance of the optical system is under process as well as a verification of potential misalignment of the camera to try to increase the OTR light collection.

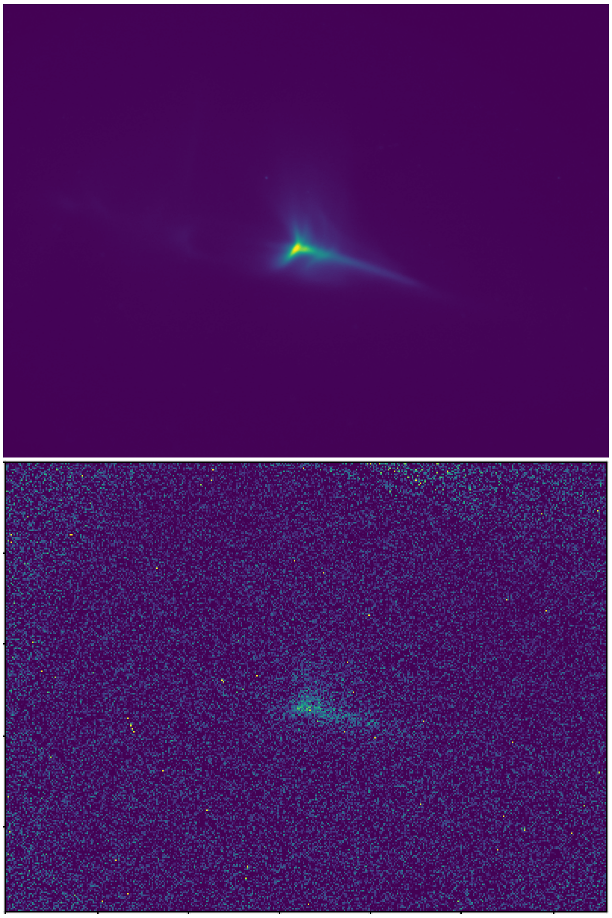

Figure 5: ThomX beam at 30 pC, 50 MeV on TL/DG/SST.01. The top image is one beam taken with a 1 ms exposition time on the YAG:Ce screen. The bottom image is the subtraction of two images of the OTR screen with a 10 s exposition time at 10 Hz, one with and one without the photo-emitted beam.

CONCLUSION

The ThomX accelerator is under commissioning since June 2021. Screens stations are one of the first electron diagnostics used, as even during the RF commissioning YAG:Ce screen allows to visualise the dark current. Those screens are used every day to visualise the beam and to measure its size and energy thanks to calibration targets. Optical radiation transition has been visualised but the very low yield has yet to be completely understood. The reverse engineering on commercial lens provides a better adjustment of the optics and remote control.

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