A NEW FAST ACQUISITION PROFILE FOR THE LHC AND THE SPS

S. Burger, E. Bravin, A. Boccardi, A. Rabiller, R. Sautier, CERN, Geneva, Switzerland

Abstract

The beam profile is an important parameter for the tuning of particle accelerators. These profiles are often obtained by imaging optical transition radiation from a radiator to a CCD camera. This technique works well for slow acquisitions, but in some cases it is necessary to acquire profiles with higher rates where such standard cameras are no longer suitable.

In our case the aim is to sample the profiles on a turn-by-turn basis which, for the CERN-SPS, corresponds to ~44 kHz. For this reason we have developed a fast detector based on a recent Hamamatsu linear CCD and an optical system using cylindrical lenses.

The readout electronics is based on CERN developed, radiation tolerant components and the digital data is transmitted to an acquisition board outside of the tunnel by mean of optical fibres. This contribution describes the system and shows the performance obtained on a test bench.

INTRODUCTION

When 2 dimensional detectors like standard CCD cameras are used to make profile measurements, readout and data processing are time consuming, imposing limitations on the measurement rate. Fast cameras are well suited for this application but are very expensive and do not adapt well to the harsh environment of an accelerator (radiation).

The alternative to the 2D detectors is to sample the profile directly. The Optical Transition Radiation (OTR) image of the beam is focused and compressed by mean of cylindrical lenses in order to fit onto a linear CCD. The beam profile is obtained directly from the readout of the single pixel array.

DESCRIPTION OF THE NEW FAST ACQUSITION PROFILE SYSTEM

Figure 1 shows the layout of the new fast acquisition profile system.

The light, emitted in the interaction of the proton beam with the OTR screen (aluminized Mylar in the SPS and Ti in the LHC and SPS) is focused with different magnification factors for H and V using a set of cylindrical lenses. The resulting intermediate image is then observed with a standard camera lens in order to obtain the desired magnification. This profile monitor has been designed around a CMOS linear chip that is able to acquire turn by turn profiles in the LHC and the SPS. A front-end electronics has also been developed which conditions the analogue signal of the detector, digitalizes it and sends it to the acquisition card using an optical gigabit link (GOL hybrid). Finally, the signal is memorized in the acquisition board holding a serial receiver and an FPGA that will process the data. The communication with this last board is made, for the prototype, with a standalone PC using a USB link.

Optics

The optical line has been designed in order to meet the requirements related to the light source, the sensor format and the mechanical constraints:

- Light angle emission: 0.2° for LHC
- Minimum field of view: 10x10mm
- Image format: 6x0.025mm
- Resolution in H plane: < 80um
- Maximum length of the line: 1m

The system is made of three optical elements: two cylindrical lenses of focal length equal respectively to

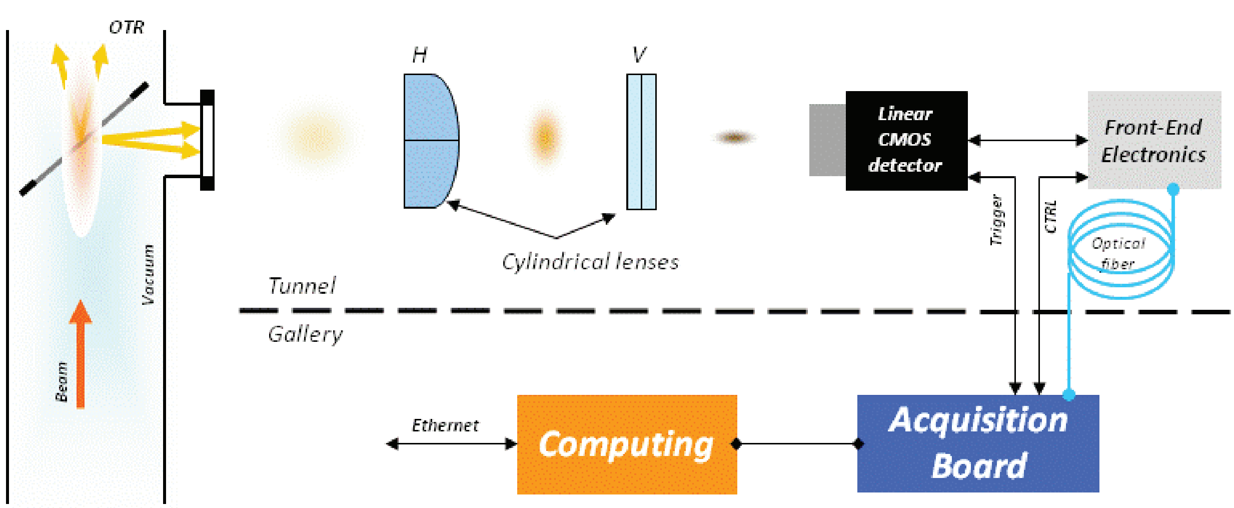

Figure 1: Layout of the fast beam profile detector with its cylindrical optics.

200mm and 75 mm for H and V, and a 35mm camera lens which creates the final image on the sensor. The cylindrical lenses give an intermediate image magnification of 1.06 and 0.12 in H and V respectively and the camera lens gives an additional image magnification of 0.165 in both planes. Figure 2 shows a 12x12mm grid, the relative intermediate image (after H and V cylindrical lenses) and the final size on the linear detector. The field of view is 12x12 mm with 100% light efficiency (cone angle emission) with a 50um resolution in the H plane.

The main aberration is chromatic and is important only in the V plane (about 200um), due to the strong demagnification. Lenses corrected for chromatic and spherical aberrations will be used, which will improve the image quality.

The system has been simulated with Zemax and tested in the lab with standard cylindrical and camera lenses.

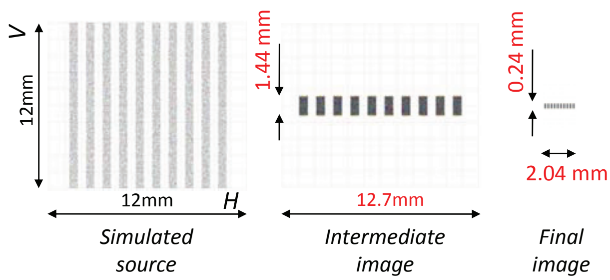

Figure 2: Simulated source and optical results using Zemax simulator.

Detector

This detector relies on (see Fig. 3) the performances of the Hamamatsu CMOS chip S11105 [1]. Its main features are the data video rate up to 50MHz, pixel number of 512 and pixel size of $12.5x250um^2$. The integration time is also adjustable down to 1.38us which permits limitations of the noise level when acquiring fast beam images. Its sensitivity has been compared to a common CCD camera (SANYO VCB-3385B) which has already proven its efficiency in OTR measurements in machines like the SPS and the LHC at CERN. The plot in Fig. 4 shows a factor 10 less sensitivity of the CMOS chip.

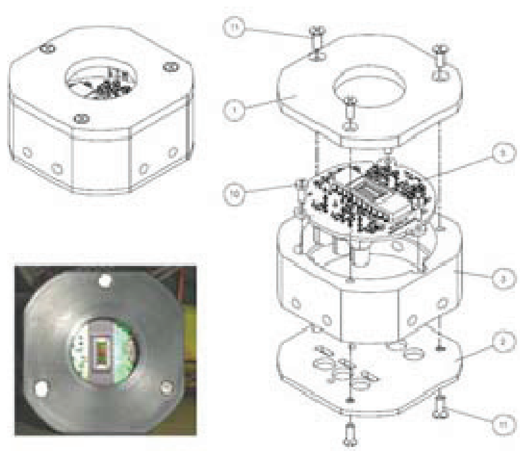

Figure 3: Exploded view and first prototype of the new matching detector using the S11105 linear CMOS chip.

This is still inside the specifications for the LHC; whereas a solution has to be found for the SPS (one can think of a different alignment in order to optimize the light collection due to larger emission angle at the SPS injection energy, already done for low energy electrons [2])

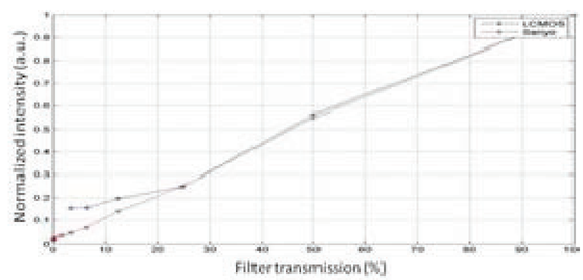

Figure 4: Comparison of the sensitivity of a CCD SANYO camera and CMOS HAMAMATSU linear chip.

Front End Electronics

The front end electronics feeds the detector module with power and timings and receives the video signal and the End-Of-Scan pulse. After levelling and conditioning, the signal is digitized and the Gigabit Optical Link Hybrid (GOH) transfers it to the acquisition card.

Most of the components of that card have been chosen for their high tolerance to radiations (ADC, LVDS receiver, GOH) since this module will be close to the detector in the tunnel. An exploded view is shown if Fig. 5 together with the first prototype.

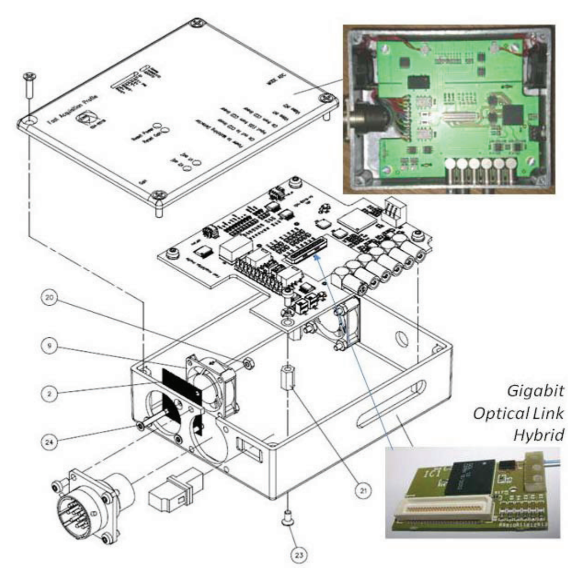

Figure 5: Exploded view and first prototype of the front end electronics using radiation tolerant components.

Acquisition Board

For the prototype, we use an existing card which is compatible with the modules mentioned above i.e. optical fibre receiver, deserializer, FPGA, IO for external commands, memory, etc... It is named Multi chip module Production Test (MPT) and is controlled through USB by a standalone PC. The (verilog) code in the FPGA was adapted to this new application and manages settings, synchronisations and memorization of up to 2000 profiles if needed.

For the final version, it is foreseen to have this card replaced by the new VME FMC Carrier (VFC) developed at CERN.

RESULTS

Horizontal and vertical magnifications have been tested and are in agreement with the simulations. The horizontal resolution is the key parameter which will allow the observation of the beam fluctuations needed in matching studies. Figure 6 shows the aperture of a movable slit versus the FWHM of the profile measured with the new detector. The linearity is rather good. Below 75um the slits is not very precise (few sets of measurements done for statistics shown in detail in Fig. 6), but nevertheless changes in width are still observable while closing the slit down to 38um. The conclusion is that the horizontal resolution is below 75um well inside our needs.

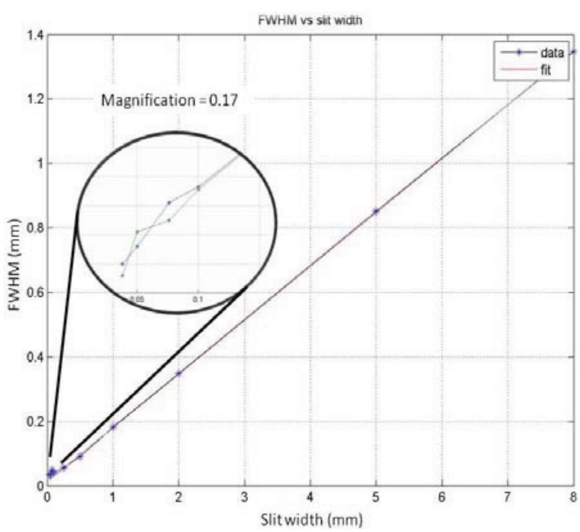

Figure 6: Calibration curve used to obtain the horizontal resolution of the system.

The field of view has been measured and compared to the simulations. In Fig. 7 it is shown that the 12mm x 12mm can be imaged although light collection is not uniform over the full range. Only an area of ±2.5mm around the centre collects more than 90% of the light. Then the collection decrease down to 50% at ±6mm. This will be improved by using larger lenses.

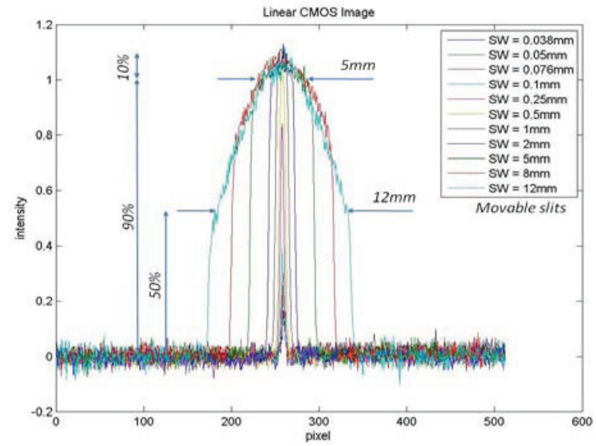

Figure 7: Measure of the optical acceptance of the new fast acquisition profile with an isotropic light source.

CONCLUSION

A new fast acquisition profile has been developed and tested in the lab at CERN. The detector, optics and front-end electronics have been characterized and fulfil the requirements.

We plan to test a first prototype in the LHC for horizontal monitoring. Once validated, we plan to build a system with 2 detectors, rotated 90 degrees with respect to each other, splitting the OTR light with a beam splitter for simultaneous measurement of the horizontal and vertical profiles. The installations in point 4 of the LHC and BA5 of the SPS will be dedicated to betatron mismatch measurement, while another installation in point 3 of the LHC will be dedicated to dispersion mismatch measurement.

Still to be done is the software application and a dedicated mechanical design for easy alignment of the optics and of the whole system in the machine.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Hamamatsu. http://www.hamamatsu.com/.
[2] Egger *et al.*, The Status of the Design of the PHIN Spectrometer Line Diagnostics for Time Resolved Energy Measurements and First Results from 09 D. CTF3-Note-099.
[3] C.Bovet *et al.* “The OTR screen betatron matching monitor of the CERN SPS, Proc DIPAC’99 – Chester, UK.
[4] C. Bovet and R. Jung “A new diagnostic for betatron phase space matching at injection into a circular accelerator”, Proc. EPAC’96, Sitgès, Spain, 10-14 June 1996, pp. 1597-9.