DIPOLE LIGHT MONITOR SYSTEM FOR THE ESRF INJECTOR

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Abstract

The visible part of the synchrotron radiation produced in a total of 9 dipoles of the ESRF injector is now extracted to obtain simultaneously images of the electron beam profile at these locations. This at each injection and in a non-destructive way to the electron beam. The first transferline (180MeV) contains three monitors on the 2 dipoles (0.38T) and the injection septum magnet. The Booster accelerator has one monitor that allows the profile measurement at any moment in its 50ms acceleration cycle by timing the internal camera shutter. In order to equip each of the 5 dipoles (0.9T) in the 2nd transferline (6GeV) with such a monitor, a compact and low-cost light extraction system was added at the end of the (non-modified) dipole vacuum chamber. All systems use low-cost commercial CCD cameras, sufficient light is produced at beam-currents a factor ~100 below nominal values. The video images are displayed to the control room operator at each injection, giving a quick & complete view of injection conditions all along the injector path. This paper describes the mechanics and optics of light extraction and collection, and the results obtained since mid-2004.

OVERVIEW AND TL-1 MONITORS

The position of the total of 9 Dipole light monitors in the injector complex (TL-1, SY, TL-2) is shown in fig.1.

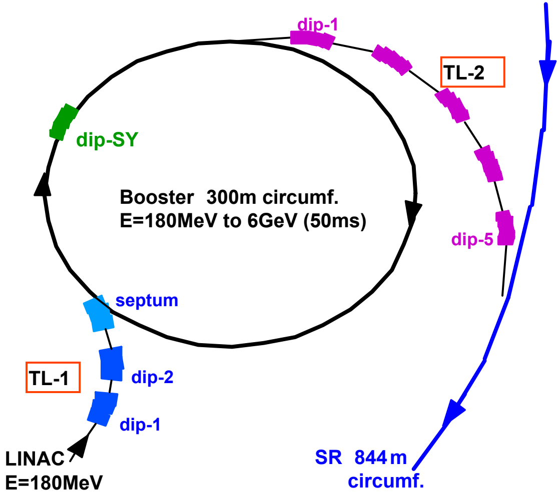


Figure 1: The location of the 9 dipole light monitors.

The 2 dipoles in the TL-1 transferline are of 40cm length with a deflection radius of 1.5m (E~180MeV, B=0.38T). This relative short length and the strong deflection angle (15deg.) permits to equip the simple vacuum chamber with 2 separate vacuum flanges : one for the electron beam exit and another one for the extraction of synchrotron light. The latter, strait aligned on the dipole entrance, uses a sapphire UHV vacuum window (W) to let the visible light through. An aperture directly after the window selects the light from a source point inside the nominal dipole field. A commercial achromat lens of 200mm focal length projects an image on the ½” CCD with a de-magnification factor of 3.1 (fig.2 left).

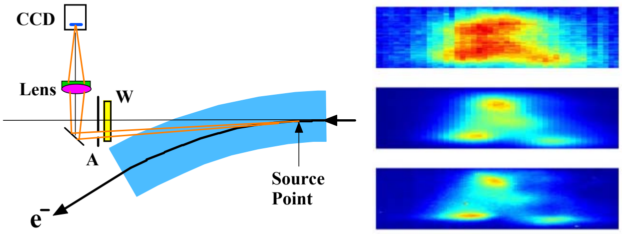


Figure 2: TL-1 dipole light extraction principle and results obtained with it, compared to that of screen monitors.

An existing screen monitor just in front of the 1rst dipole allowed to compare the obtained images from three different devices (fig.2 right): a former screen monitor with an alumina (AF-995-R) screen in air (upper image), a new screen monitor in vacuum (middle), and the dipole light monitor (lower image). [1] The images show several spots that are caused by the emission characteristics of the Linac Gun. The spatial resolution of the dipole light monitor is of superior quality and estimated at <100um, mainly determined by diffraction for 500nm wavelength and 6mrad hor. aperture. The vertical emission angle is ~8mrad. The collected light flux is enough to attain sufficient image quality down to 0.1mA (compared to 5mA nominal TL-1 current).

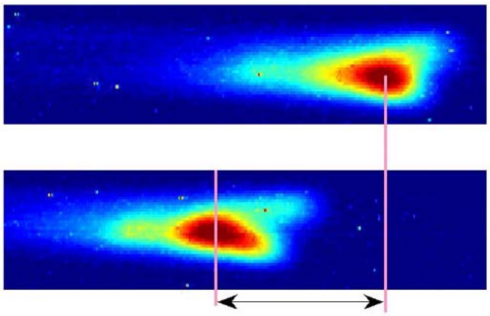


Figure 3: Results from 2nd Dipole Light Monitor in TL-1

The 2nd TL-1 dipole monitor is of similar design, with a 150mm lens offering a larger view area (24x18mm, HxV) so to cover the full excursion of the beamspot. Being at a location of high dispersion it serves the measurement of energy variation & fluctuations from the Linac as shown in the 2 (zoomed) images in fig.3 with a 4mm shift.

For the imaging of the injected beam inside the Septum magnet (injection TL-1 to SY), an 75cm long vacuum chamber had to be added directly after the Septum Tank with an in-vacuum aluminium mirror. Its edge is at 15mm horizontal distance to let the circulation SY beam un-obstructed under all circumstances. The so extracted light fan is emitted from about 10cm before the septum exit. The fig.4 shows the extraction scheme with two (zoomed) images of same scale (7.3x5.6mm, HxV) : To the right the image of the injected beam, to the left the same image under identical beam condition but of higher sensitivity showing now (to the left of the saturated beam image) the faint light deflected of the septum sheet. In fact this parasitic signal allows to determine the septum position and hence the distance of the beam to it.

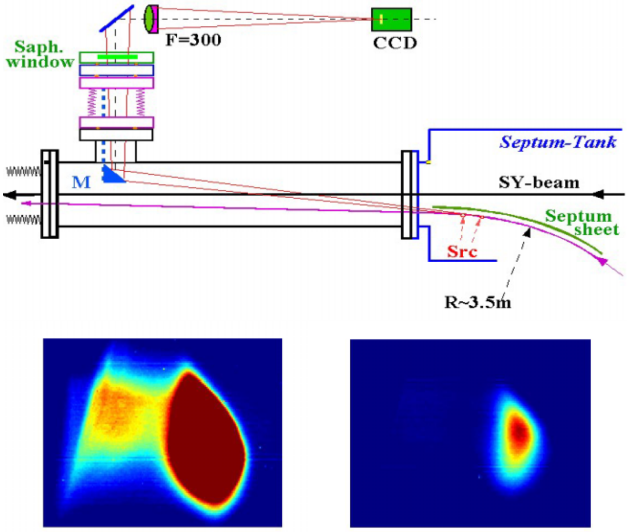


Figure 4: The extraction scheme for the Septum Magnet with images obtained showing the beam, and also the septum sheet.

SY-BOOSTER MONITOR

In contrast to all other monitors, that are compact and inaccessible inside the accelerator, only the SY-Booster system has a permanently accessible laboratory in which the achromat, attenuation filters and camera are installed. The edge of the in-vacuum aluminium extraction mirror has a 13mm horizontal offset to the beam, the light source point lays 70cm ahead of the dipole exit and the achromat (F=1185mm) is at 5.6m distance from this which yields convenient field coverage of 18x13mm (HxV) for the 1/3" CCD camera.

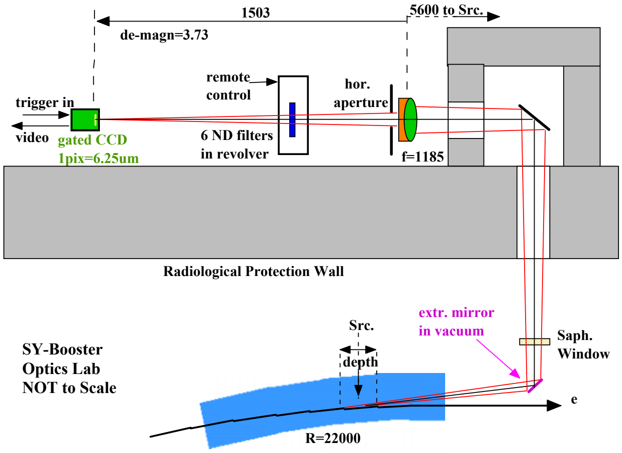


Figure 5: Topview of the SY light extraction to its optics lab

By triggering the internal shutter of this camera with a pulse of variable delay and width, an image at any point in the 50ms acceleration cycle can be obtained.

The light flux at the injection point (E=180MeV B=25mT) is a factor ~100 lower than that from the rest of the 50ms period but still enough to yield good quality images. The minimum shutter-open time of the used camera being 130us means that each image is integration over 130 turns in the 300m SY-Booster. This is of no limitation or disadvantage for its practical use : The two left images here below show the beam-shape at 2ms (both) after injection, the two small ones at the right at respect. 30 and 50ms. The strong fluctuations at 2ms are due to energy fluctuations of the injected Linac beam. The decreasing vertical dimension is consistent with decreasing emittance of the injector, while the horizontal size reaches a minimum at ~30ms before increasing again afterwards, also conform with theoretical predictions [2].

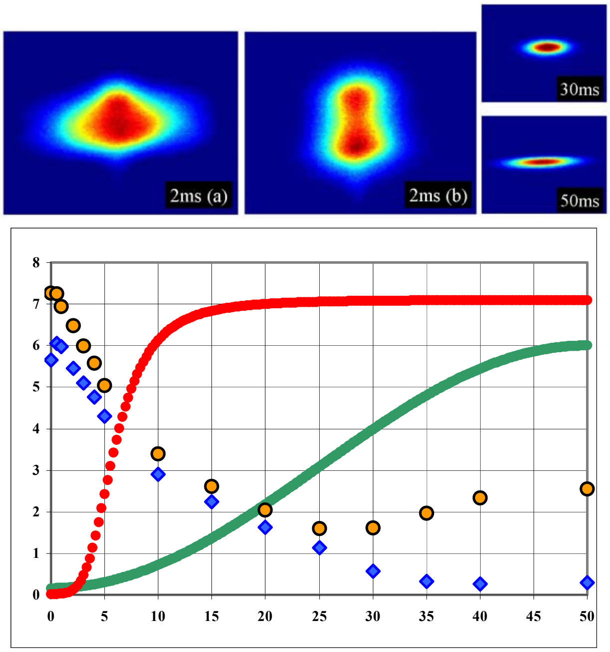


Figure 6: images and beamsize results [mm fhwm] along the 50ms acceleration cycle hor.=orange, vert=blue, red = flux[A.U] , green = Energy[GeV]

TRANSFER-LINE 2 MONITORS

The existing TL-2 dipole chambers are of 2.4m length and could not be modified for practical and cost reasons. The solution was to make place in the drift sections behind each dipole chamber for a small chamber that holds the extraction mirror, sapphire window and optics in a well-aligned position. (see fig.7 for views from 3 sides).

The mirror has a 18mm offset to the chamber centre, this equals the horizontal aperture for the beam imposed by the overall 36mm wide TL-2 vacuum chamber. The mirror deflects the light downwards for reasons of restricted space. An U-bar, rigidly attached to the chamber, provides a support rail for the mounts of the lens, filter and camera. This assembly is pre-aligned in laboratory before installation to ensure that the optical system will collect & image the light of its theoretical source-point. This point lies 1015mm ahead of the mirror and 1100 from the achromat lens (f=300mm). The ½" CCD covers a 17x12.5mm at the source. The total dimensions of the lightweight assembly measures only 18cm length, 14cm width and 65cm height.

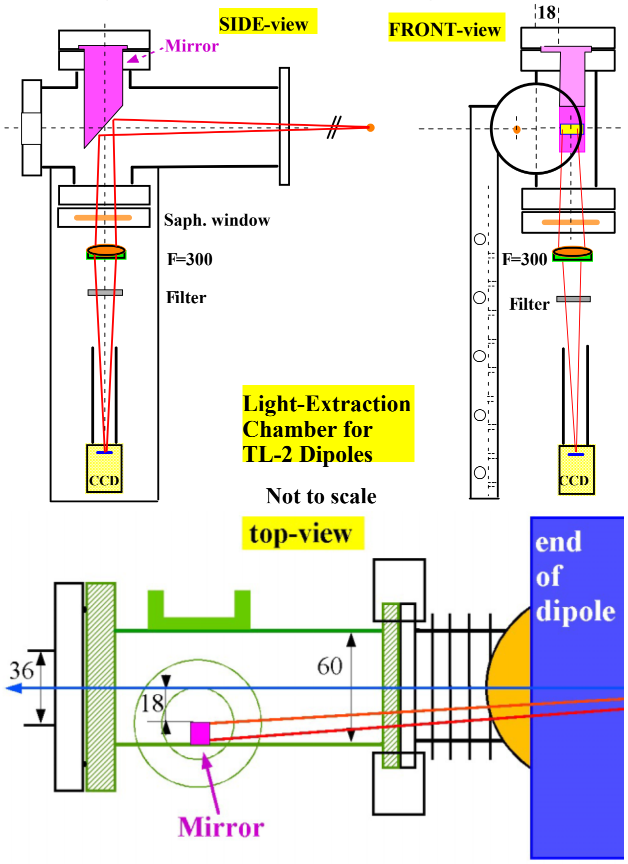
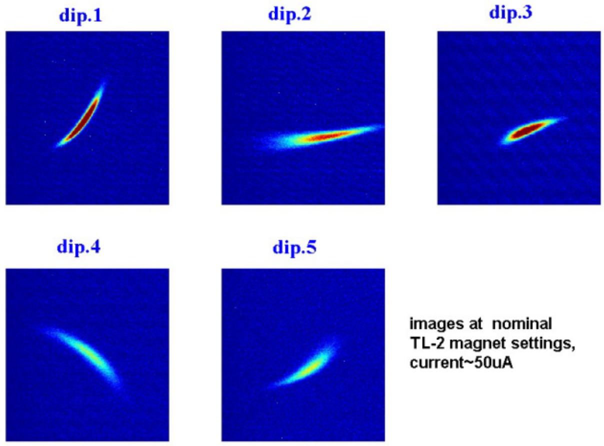


Figure 7: Special light extraction chamber for TL-2 Dipoles.



images at nominal
TL-2 magnet settings,
current~50uA

Figure 8: The 5 TL-2 Dipole images (17x12.5mm,HxV)

The obtained images in each of the 5 monitors show, under nominal TL-2 magnet settings, a shape indicative of strong coupling and non-linear distortion. This is caused by a large deviation of the SY beam orbit in the last quadrupole just before extraction. By adjusting the local quadrupoles and steerers in TL-2 it was possible to reduce the beamsize in each dipole individually and so to test the resolution of the whole imaging system. The vertical emission angle is ~4mrad which defines the ultimate resolution at ~120um. For each system the CCD camera is on a single translation stage with remote control for the verification of optimal focussing. This is the only remote control in the system, and has only served once at commissioning.

IMAGE TRANSPORT, ACQUISITION, DISPLAY FOR DAILY APPLICATION

The long distances (up to 200m from camera to acquisition card) and the already available image frame grabbers (incl. software) at the ESRF for the CCIR interlaced 75ohm video standard have determined the choice of the CCD cameras, with the Sony-ST50 (1/2" or 1/3") used for all devices. The NI-1409 frame-grabbers (6 in total) are used in 3 rackable PCs with the 3 output monitor screens directly to the Control Room. The associated timing of the TL-1 and TL-2 system is of great simplicity : only the frame-grabber is triggered with the injection pulse or respectively the extraction pulse. All the TL-1 & TL-2 systems are equipped with a single attenuation filter to select between nominal injector current (5mA) or low current.

CONCLUSION

The injector complex now benefits from a complete system to survey and measure to required precision the transverse beam-shape and dimensions in a routine and reliable way. Being totally non-destructive to the electron beam it is permanently active and thereby giving to the operator a quick & comprehensive view of injection conditions all along the injector path at each injection.

In comparison to traditional screen monitors this non-destructive feature does not only allow this simultaneous data acquisition but also avoids the local generation of radiation from beam interception. In terms of sensitivity and resolution the system is also of superior performance. No effects of degradation on either component have been observed after nearly 18months of operation. The technical simplicity of the light extraction (i.e. no mechanical motion in vacuum) and the system in general is a major advantage in terms of costs and reliability.

The author expresses thanks for the professional help in the realisation of the system, to J.Pasquaud for the mechanical designs, to F.Epaud for the image acquisition, and to the vacuum group colleagues for installation.

REFERENCES

[1] B.K.Scheidt, "Upgrade of the ESRF Fluorescent Screen Monitors", DIPAC'03, Mainz, May 2003.

[2] Y.Papaphilipou et al, "Operational Improvements in the ESRF Injection Complex", EPAC'04, Lucern, July 2004.