METROLOGY FOR THE BEAM EMITTANCE MEASUREMENT OF THE SOLEIL INJECTOR

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Abstract

The injector system of SOLEIL is composed of a 100 MeV electron Linac pre-accelerator followed by a full energy 2.75 GeV Booster synchrotron, operating at 3 Hz. Dedicated diagnostics such as emittance monitors are installed on the two transfer lines between the Linac and the Booster and between the Booster and the Storage Ring. The measurement is performed using the gradient method, relying on YAG screens and high resolution CCD cameras. This paper presents the metrology of the emittance measurements which were performed for the HELIOS (THALES) Linac beam (total emittance in the range of 1 µm.rad). Error sources are identified and specific corrections are shown. Additional analysis of the dynamics of the injection into the booster is made for a deeper characterization.

INTRODUCTION

The 100 MeV electron Linac pre-injector of SOLEIL, the new French SR facility, has been built by THALES. It is a turn-key system based on SOLEIL design and it has been commissioned in October 2005 [1]. Two operation modes are available: a Long Pulse Mode (pulse train of 1.4 ns during 300 ns@ 352 MHz – 8 nC) for filling one quarter of the Storage Ring and a Short Pulse Mode (up to four pulses of 2 ns – 0.5 nC each) for time resolved operation. Then, the current at the gun may vary from a few tenths to a few hundreds of mA. In consequence, we expected transverse emittance variations at the entrance of the Booster. Specification of these has been set to 200 π µmrad (normalized, 90 % of particles) together with a +/- 1.5 % maximal energy spread to insure an optimal injection efficiency and Booster ramping.

MONITOR DESCRIPTION

System overview

A profile monitor (figure 1) is installed in the straight branch situated just after the first TL1 bending magnet and before the beam dump. Four quadrupoles placed in the upstream matching section and powered by bipolar power supplies enable the emittance measurement using the three gradient method. A drawback of this method is the necessary minimum distance between the last quadrupole and the monitor, in accordance with the camera resolution. With 4.2 m, that distance was barely sufficient for some TL1 quadrupole tunes because the minimum beam size has been measured at 0.16 mm rms, close to the resolution of the monitor.

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Hardware description

The monitor is composed of an insertable cerium doped YAG screen positioned at 45° (∅ 42 mm, 0.2 mm thick), an optical zoom with 5 lenses (tunable magnification from 0.5 to 0.18), a lead glass to shield the CCD, and a SONY XC55 CCD camera. The electronic shutter of this latter eliminates most of the noise out of the signal time window. Its sensitivity has been measured as being in a mean range (0.5 nC beam over 10mm^2 was the under limit), and it is externally triggered. A tilt mirror switches the image to a calibration grid situated in a 90° branch. The grid is 45° inclined like the YAG screen. A 15 cm thick lead shielding surrounding the camera was efficient for protecting the CCD from 100 MeV scattered particles coming from the nearby TL1 energy slit.

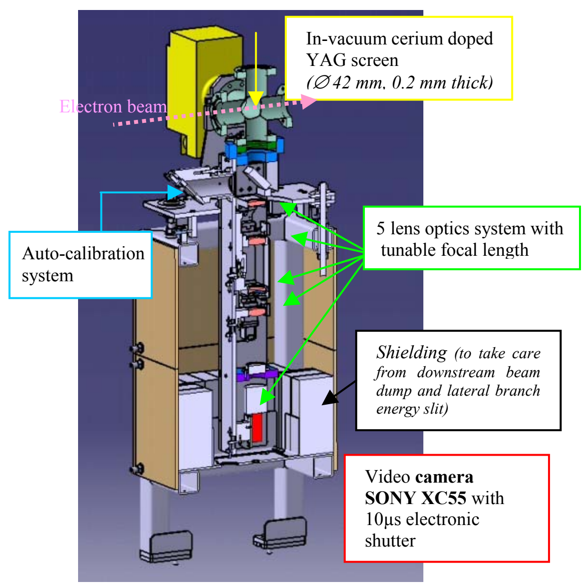

Figure 1: Emittance monitor.

Software description

As the SOLEIL control system is based on the object oriented TANGO framework [2], each equipment is individually controlled by a dedicated server object called “device”. Each device represents its associated hardware and hides all the details behind an easy to use interface. On the client side, the so-called TANGO binding for Matlab, provides a generic access to any device within the control system. In addition, on top of the TANGO binding, the Matlab Middle Layer (MML) [3] adds a degree of abstraction in the accelerator control.

The matlab interface shown in the figure 2 details the successive measurement stages: adjustment of the optical bench and calibration through the dedicated National

Instrument software, tuning of the quadrupolar TL1 optic, projected beam profile measurement (second moment of the distribution) and emittance calculation from a specific least square fitting (three gradient method). MML allows an easy control and gradient conversion of magnets, and transport calculation using measured emittance and theoretical line in order to display phase ellipses at TL1 screen locations.

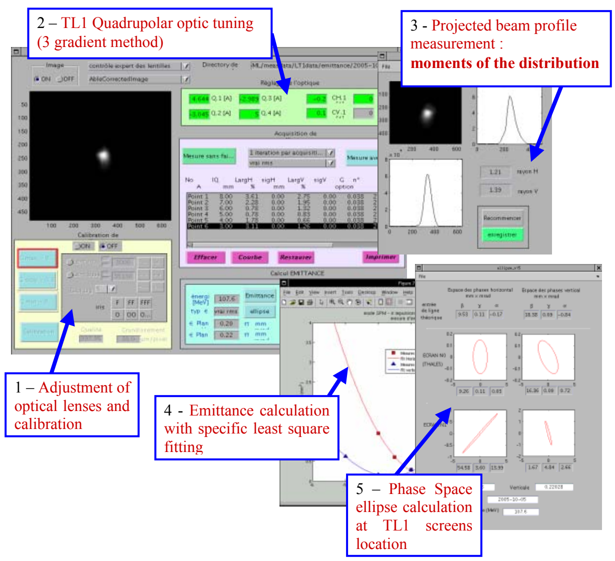

Figure 2: Matlab high level control application.

MEASUREMENT ERROR SOURCES

Quadrupole cycling default / Beam position and size jitter

These sources of error have been measured by repeating the measurements at short and long time intervals for a same Linac and TL1 setting. The Linac energy instabilities of 5.10^{-3} (peak) do not affect the beam position and size in the dispersion free branch, and quadrupole cycling was not even necessary to get a good reproducibility of the beam size measurement over two days (maximum deviation of 2 pixels that is less than 80 µm).

YAG screen: Induced default in vertical plane

Thickness of the YAG screen has been chosen as thin as possible (0.2 mm) in order to minimize the resolution in the vertical plane. In that plane, a 0.16 mm measured size corresponds to a 0.13 real size.

Linearity default and noise from camera

The SONY camera has been chosen for its linear coefficient γ=1 option. Tests with beam showed a discrepancy of 20% between size measurements done around maximum output signal level, and at a middle level. However, a systematic study in the lab of the second camera used for TL2 transfer line showed on the contrary an excellent linearity (1% discrepancy). The CCD thermal noise appeared to be significant for a few random pixels (15 % of the saturation level). It affects the projected profile for small beam sizes. Therefore a systematic treatment is done by ignoring the points below 1% of the maximum value in the projected profiles before RMS calculation. An example of emittance sensitivity to the noise is shown in figure 3.

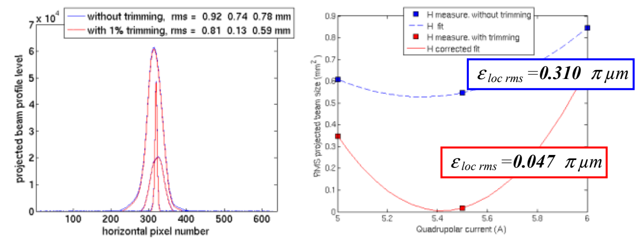

Figure 3: Emittance value and CCD noise.

Background noise is systematically treated by subtracting a "dark" image obtained with a camera trigger shift.

Perspective correction of the image- Chromatic and geometric aberrations

National Instrument software has perspective correction capabilities. Actual aberrations were difficult to evaluate because the diaphragm aperture was manually adjusted for each shot with no possible readout. Nevertheless we checked that they always stayed well under the measured sizes for each aperture range.

Effect of the quadrupole focusing

A strong focusing TL1 quadrupole setting leading to small beam sizes in one plane is undesirable: we evaluated the corresponding error on the measured emittance in inverting the quadrupole polarity. Figure 4 shows a good measurement in vertical plane (blue curve) and a bad one in horizontal plane (red curve), even with an optimized fit. Table 1 details the error done.

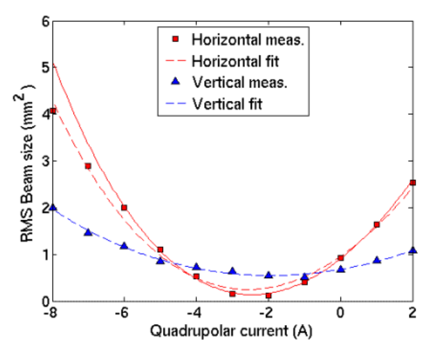

Figure 4: Fits with strong TL1 quad focusing conditions in H plane.

Table 1: Effect of the Quad focusing on measured emittance and Twiss parameters.

curve	*data*	$\varepsilon_{x,norm}$ *[πµmrad]*	β_x *[m]*	α_x *[-]*
- - - - (dashed red)	Raw data	75	19	0.77
—— (solid red)	Raw data with 3 points excluded	64	24	0.74
not presented	Weak focusing	51	35	0.90

RESULTS AND COMPARISON WITH THE SIMULATIONS

Figure 5 shows multiple emittance measurements made along the 3 months of commissioning and under various quadrupole focusing conditions. A mean transverse normalized (4 $\gamma\varepsilon_{rms}$) emittance of 55 $\pi\mu$mrad is found with a rms dispersion of +/- 10 for the multibunch mode. With a same TL1 setting, the emittance has been measured for various gun currents, and it increases with the current as predicted. The comparison is made with the PARMELA code simulation [4] for 90% of the particle and for 4 $\gamma\varepsilon_{rms}$ and also with the THALES code [5] for 4 $\gamma\varepsilon_{rms}$.

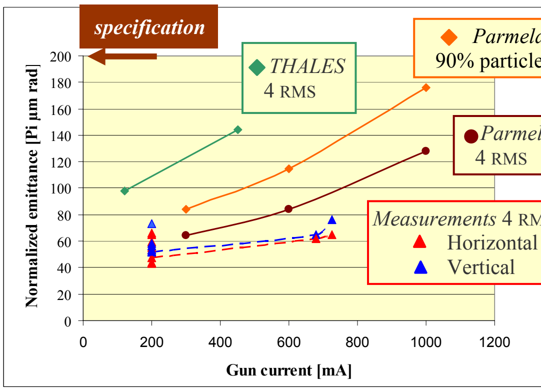

Figure 5: Comparison simulation – measurements

The measurements are slightly lower than the simulations. It can be due to the beam profile treatment: trimming the projected profiles by 1% has excluded real particles at large amplitudes which would have increased the RMS value of the emittance.

DATA ANALYSIS OF THE INJECTION INTO THE BOOSTER

Measurements have been cross-checked against injection performances into the Booster. A first point was that errors around 1mm on the Booster BPMs have led to a mis-correction of the vertical orbit, and then to a reduction of the global vertical acceptance [6]. Another surprise was that decreasing by 10% the TL1 defocusing quadrupole Q2 with respect to the theoretical value increased the injection efficiency from 50% up to 80%.

We looked for the Twiss parameters at the exit of the Linac which could explain this effect, associated with the measured emittance value mentioned above. Figure 6 shows the BETA code simulation results: with the setting $(4\ \gamma\varepsilon_{RMS\ z},\ \beta_z,\ \alpha_z)_{output}$ = (50 $\pi\mu$mrad, 35 m, 2.5) the change in the TL1 Q2 current reduces by a factor of 2 the injected beam emittance, and moreover, fits it to the Booster vertical acceptance.

Then we compared this result to the measured sets of Twiss parameters in the vertical plane. A mean value of 38.9 +/- 7 m for β_z, and 1.7 +/- 0.35 for α_z were found. Figure 7 shows that this region leads to a favourable reduction of the injected emittance between 0.8 and 0.6 when tuning the TL1 Q2 by 10%.

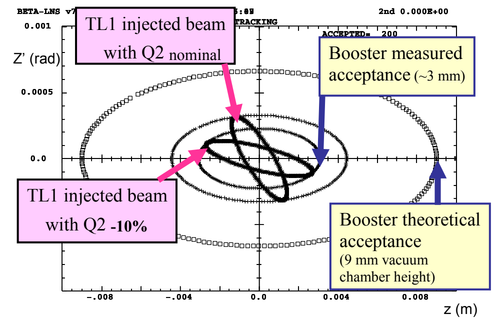

Figure 6: BETA simulation of injection in the first defocusing Booster quadrupole

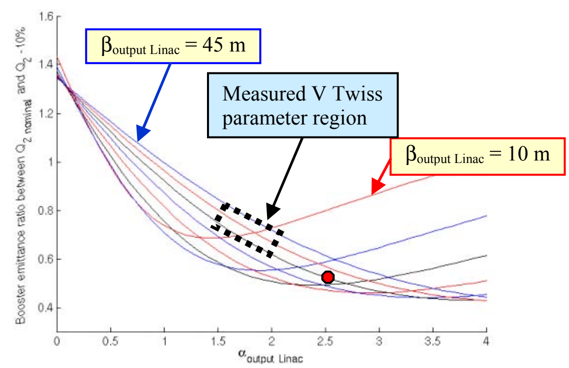

Figure 7: Analytical relation between Twiss parameters at Linac exit and injected emittance reduction in the Booster with TL1 Q2 [-10%]

CONCLUSION

Emittance measurements gave satisfying results for the 100 MeV Linac HELIOS: cross-check has been made with the simulation and with the injection efficiency into the Booster. The relative error seems to stay beyond +/- 20 %. Nevertheless, the fine tuning of the first transfer line was made by varying each quadrupole individually. The accuracy actually required in the Twiss parameter measurements to match the injection is more demanding. In order to be able to predict the best tuning for injection (as we want to do it for the Storage Ring in top up mode), improvement of the method has still to be done.

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