REVIEW OF RECENT UPGRADES & MODERNIZATIONS ON DIAGNOSTICS IN THE ESRF STORAGE RING AND INJECTOR

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Abstract

Over the last two years a number of upgrades and modernizations have been implemented on diagnostic tools in both the Injector system and the Storage Ring. Brand new diagnostic tools have also been added. In the Injector, a new Transfer Line current monitor has been installed, as well as four new ¼ λ Striplines equipped with **S**ingle-**P**ass Libera electronics. In the Storage Ring, a new Visible Light Mirror (VLM) system has replaced the original system that had been in place for more than 15 years. Also, the acquisition system for the DC Current Transformers has been upgraded with new hardware. Descriptions and results are presented on the improved reliability, sensitivity and resolution of these systems.

BEAM-CHARGE MEASUREMENTS IN THE INJECTOR

A Beam-Charge measurement is done on four identical ¼ λ Striplines and an equal number of the **S**ingle-**P**ass Liberas. Each Stripline has four strips at 90° distribution around the cross-section of the 36mm circular chamber. The SP-Liberas, with respect to ordinary Brilliance-Liberas, have an increased sensitivity (analog) and an increased ADC buffer size (8k instead of 1k). In terms of firmware and internal software they are very different. There is no more **S**low **A**cquisition (10 Hz) or **F**ast **A**cquisition (10 kHz) outputs, no more DD (i.e. 355 kHz) and PM buffers. Another essential difference is that there is no internal calibration with the RF-switching and the associated DSC (Digital-Signal-Conditioning). The SP-Libera is simply a 4-channel ADC with an RF module in front of each channel.

The ADC outputs sample the RF signal at 108MHz. With an ADC buffer of 8192 (~8k) samples long we can therefore monitor up to 75 orbit turns in our Booster (1µs orbit time). In the Booster, at 10Hz, a 1µs long pulse or a series of one to five pulses of 1ns are accelerated in 50ms from 200MeV to 6GeV.

The Striplines are located in the **T**ransfer **L**ine **1** between the Linac and the Booster, in the Booster, and in the **T**ransfer **L**ine **2,** between the Booster and the Storage Ring. When precisely measuring the charge, at each injection and at each of these four points, we can determine the transfer efficiency from one part of the Injector complex to the next.

The charge measurement (from the server point of view) consists of reading (at each injection trigger) these four ADC buffers and doing a simple treatment on the data. This is presently done in Matlab code. First, an RMS calculation is done on the electrode signal. Then we do a convolution with the data in order to smooth the signal pulse. The combination of a Stripline (instead of a BPM button) and the highly sensitive SP-Liberas allows optimization of the transfer efficiency at very low beam currents and therefore greatly reduces the associated radiation and activation doses. The system can handle currents as low as 10µA (while the nominal Booster current for a 1µs long pulse is 5mA).

An important issue is the stability and reproducibility of the charge measurements. By having four independent devices, with two units in the Booster measuring the beam charge in 75 Turns, the possibility of verifying the output results against each other allows assessing directly the reproducibility of the measurement systems. This reproducibility is excellent and at least two orders of magnitude below the fluctuations in beam-charge and transfer-efficiency that are intrinsic to the fluctuations of the Injector complex itself.

The system offers some additional features like beam position measurements, with the same quality of sensitivity and reproducibility. The time resolution is much shorter than the typical 1µs orbit turn since the ADC sampling rate is 108MHz (9.3ns). While this implies under-sampling of the RF frequency, it still allows distinguishing and measuring (charge and position) up to 5 short pulses in one 1µs burst.

Some synchronisation problems are still under investigation on the data acquisition of the system, but some promising results have been obtained combining the four Booster-SP-Liberas (Striplines) and the SR-Brilliance-Liberas (BPM buttons).

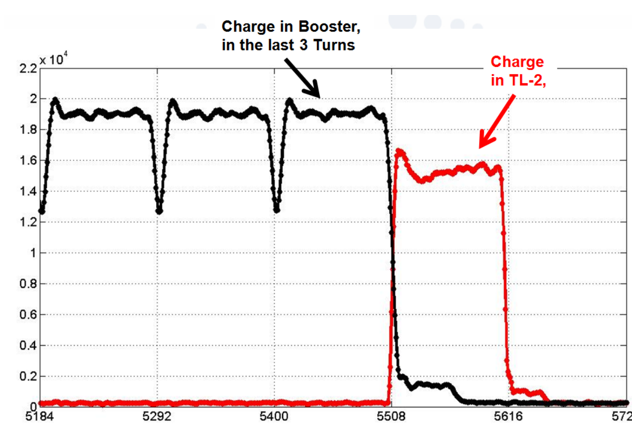

Figure 1: Charge outputs of two devices, showing 3 turns of 1µs long pulse in the Booster (black) and the subsequent extracted beam in the TL2 (red).

In addition to the four Striplines, we recently installed an In-Flange **I**ntegrating **C**urrent **T**ransformer on the TL1. In-Flange current transformers are directly installed on the vacuum chamber without any mechanical design. This has several key advantages since it saves valuable space in the accelerator and it is a simple installation between two flanges. There is therefore no need for bellows, mechanical holders or wall current bypasses. It also integrates a ceramic **U**ltra **H**igh **V**acuum gap [1]. The In-Flange ICT can also be used to measure the beam charge in TL1 using Surface Integral measurement with a high bandwidth oscilloscope on the ICT output signal.

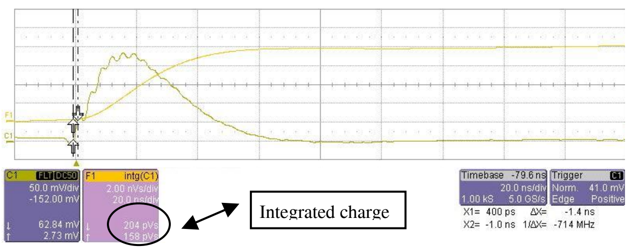

Figure 2: LINAC Short Pulse - Green: ICT output pulse Yellow: Surface integral of ICT output pulse.

The integration of the main pulse (Figure 2) leads to 158pVs, which gives an integration charge of:

$$(158pVs\ /\ 50\Omega)\ x\ 40 = 0.13nC$$

40: ICT ratio in 50Ω load

This measurement is coherent with what has been previously measured during the commissioning of the new LINAC gun in April 2010 (0.18nC at the gun exit and 0.105nC stored in the booster [2]).

STORAGE RING DCCT UPGRADE

Selecting a better Instrument Control Bus was part of the upgrade made to our DC **C**urrent **T**ransformers. The DCCTs are used to monitor the beam current in the Storage Ring and in the Injector. Nevertheless, only SR DCCTs have been upgraded. The upgrade of the Injector DCCT is still under development and will be presented later.

First, in order to harmonize equipment control at the ESRF, and also because high resolution measurements for smart diagnostics generate more raw data, a Fast Ethernet control bus has been implemented on the **P**arametric **C**urrent **T**ransformer of the Storage Ring.

Ethernet, with its higher bandwidth and ubiquitous usage, seems a natural alternative to the market-leading GPIB instrument control bus for automating instruments. Fast Ethernet, operating at 100Mb/s, is the most common implementation for both PCs and instruments available today. The maximum bandwidth for GPIB is 61.6Mb/s for high speed IEEE 488.1. This gives Ethernet a 7x bandwidth advantage over GPIB. GPIB, however, has a shorter latency than Ethernet and should be better suited for short data transfers [3].

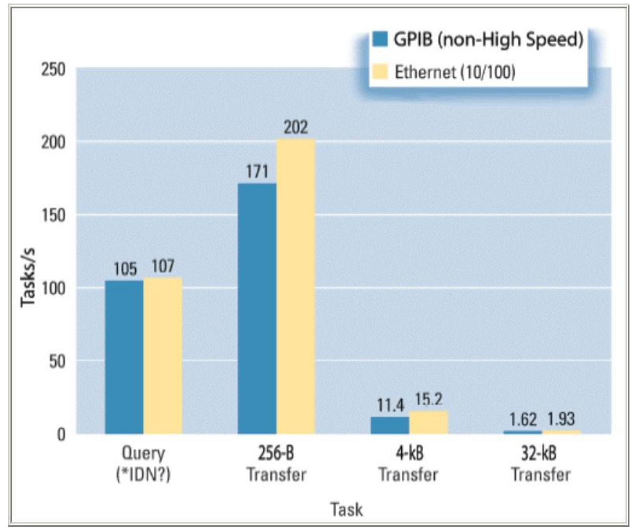

Figure 3: Ethernet 2% to 34 % faster than GPIB for queries and transfers [3].

This Fast Ethernet control bus implementation has been done using a Keithley model 2701 Ethernet-Based DMM and a plug-in model 7706 I/O module connected on the PCT output instead of the good old Hewlett-Packard 34401 GPIB-Based DMM. The main task here was to re-write a brand new server in order to cope with the new acquisition structure of the Keithley DMM.

Over the control harmonisation that brings the Ethernet-based DMM, the Keithley set also offers the possibility to store a 450k data buffer at a rate of 1 kHz (normal acquisition for the PCT is 10Hz), which we were not able to do with the HP34401 DMM. This buffer can be triggered by an event (post-triggering) and the time-stamped data then allow analyses directly on the DMM for smart diagnostics, beam lifetime accidents or beam drops, using Matlab programs.

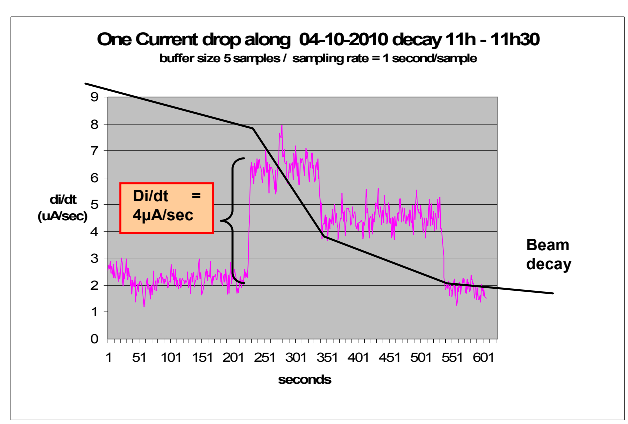

Figure 4: Diagnostics from Ethernet-Based DMM Keithley using post triggering data buffer.

NEW DESIGN FOR THE VISIBLE LIGHT MIRROR (VLM)

Since 1996, UV and visible light have been extracted from a 0.86 Tesla dipole in the Storage Ring using a light extraction system consisting of a vertically movable mirror and a thermal probe in a feedback loop. This system, which is installed in **U**ltra **H**igh **V**acuum, avoids mirror surface deformation by the thermal load of 1.5kW from the X-ray source by operating as a "half-mirror". I.e. only the top part out of the vertical light emission cone (less than 50% of ~4mrad) is extracted and the powerful heart of the beam passes just underneath the mirror edge [4].

During the last ESRF shut-down (March 2011) the old VLM was replaced by a new design and a new mirror piece. This served several purposes: remedying a poor-vacuum problem due to a leaking thermo-couple feedthrough, simplifying the mechanical design so that the UHV bellows are less solicited and improving the mirror quality that suffered from some astigmatism. Good vacuum quality is important since we know that surface-blackening on the (Aluminium) mirror is favoured by poor local vacuum. Also, this new design allows easy access to maintenance on the motorisation that is exposed to X-ray radiation in the vicinity of the beam absorber and suffers from breaking limit switches and/or wires. It makes the VLM more robust and reliable.

In the new design the water cooling system has been completely omitted. While this greatly simplifies the design it also means that for safe and reliable operation at the nominal SR current of 200mA, the operation point of the mirror is a little bit higher than before. This implies that only 25% of the vertical light cone is effectively extracted and available. While this produces an increased diffraction effect for the image spot, it is of minor concern, since for nominal vertical emittance values of the ESRF Storage Ring (<10pm.rad), the visible light imaging is not capable of approaching the corresponding electron beam-size measurements that are done elsewhere in the Ring in the In-air X-ray domain.

However, at low currents (<1mA), i.e. for injection studies, the mirror can be fully inserted into the full cone of the synchrotron light without risk of heat load damage. The mirror piece (10mm-thick Aluminium without coating) allows to precisely measure the beam dimension of the injected beam in a single orbit turn.

The pictures in Figure 5 show the projected light cone on a screen at nearly 8m from the dipole source point. The right part of the upper image shows the light shape originating from the flat 0.86T field of the nearest dipole. The intense ring-like structure in the lower image results from interference of the fringe-fields of the main (nearest) dipole and the second dipole which is further upstream.

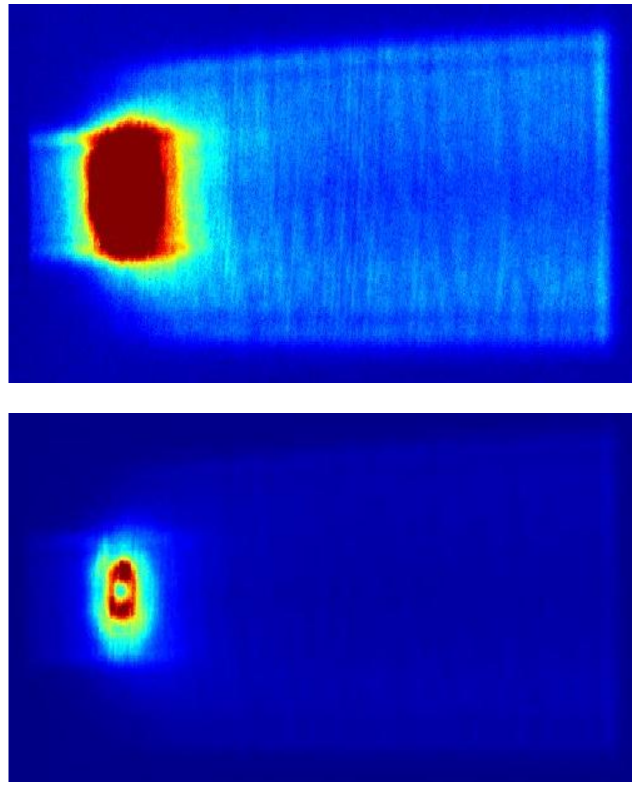

Figure 5: Image of the projected visible light (no colour filters) onto a screen at 8m from the dipole source.

The commissioning of the new VLM was completed by taking images with the mirror fully inserted in the synchrotron beam path at 1mA beam current (to avoid heat load deformation). This yielded results that confirm the good quality of the new system.

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