INJECTION EFFICIENCY MONITORING WITH LIBERA BRILLIANCE SINGLE PASS

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Abstract

Libera Brilliance Single Pass is a standard device for single pass position measurements. Initially, the device was intended for beam position monitoring at injector system for the FEL machines, this was afterwards followed by the idea of using it on transfer lines on the same 3rd generation light sources. The device can be used on pickup buttons and on striplines. The measurement principles and results of Libera Brilliance Single Pass at ESRF, as beam-charge monitor and injection-efficiency monitor, are presented.

INTRODUCTION

During injection process at synchrotrons, a part of the electrons, arriving from the LINAC, is lost. The injection efficiency studies are necessary to study and optimize this process. The benefits from such optimizations are broad, from minimizing the disturbances to the stored beam during injection, to the unwanted radiation reduction. To perform these studies, Libera Brilliance Single Pass units were installed along the ESRF injection system.

The goal of the tests was to study the injection process, and to evaluate the Libera Brilliance Single Pass performance through whole dynamic range, from nominal to extremely low currents.

The beam current in booster is routinely determined using commercial electronics – DCCT current monitors. The current measurement from this device was used as a reference point in normal regime. At extremely low currents, the DCCT measurement became unreliable.

MEASUREMENT PRINCIPLE

Four identical signal processing chains on the Libera Brilliance Single Pass are in charge of analog signal processing, digitalization on fast ADCs and digital signal processing. On every external trigger event, the 8k samples of each channel in the Libera Brilliance Single Pass ADC rate buffer can be acquired. This means that ca. 75 us of data can be analyzed on each trigger event, in ESRF case this equals to ca. 75 booster turns. The acquired raw data is furthermore processed to achieve readable data in terms of bunch signal amplitudes. Various algorithms can be used for this purpose, in our case, the convolution and filtering algorithm is applied over the batch of data. We were interesting in the sum of all four channels, which is proportional to the beam current.

MEASUREMENTS

All the measurements were performed in the ESRF injection system, where 3 Libera Brilliance units are installed and used for the injection efficiency studies. The three units are connected to the striplines, which are installed on the transfer line from the linac to the booster (TL1), booster (SY) and the transfer line from the booster to the storage ring (TL2). Figure 1 depicts the setup.

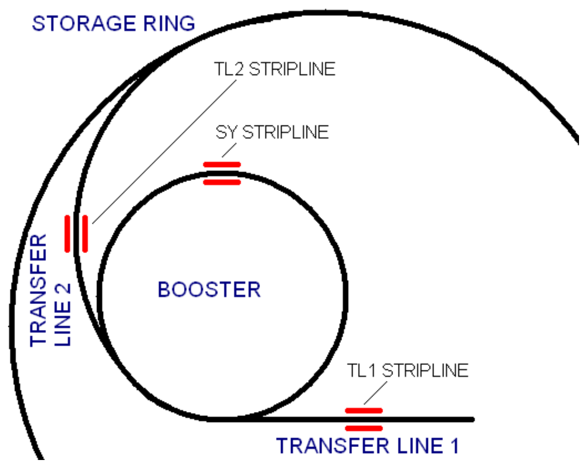

Figure 1: Injection system at ESRF lightsource

Injection at ESRF is scheduled twice a day, at 9 AM at 9 PM. The typical current in the ring is ~200 mA immediately after the injection, decreasing to a minimum value at ~150 mA before the next injection. The detailed injection procedure is dependent on current bunch fill pattern in the storage ring. In our case, with the fill pattern of 7/8 + 1, two-bunch pattern is being injected first, followed by four-bunch pattern, to fill the 7/8 of the ring with uniform fill. At the end, single bunch is being injected, to fill the single bunch in the middle of the gap. Whole process is automatic and lasts for approx. 2 minutes.

Transfer Line 1 to Booster Efficiency

To make these experiments wider and more detailed, the TL2 was closed in order to keep the users undisturbed. Beside three bunch patterns, described above, we experimented with so called "long pulse" pattern, where booster is uniformly filled during ramping. In all modes, the instrument behaved perfectly stable. Furthermore, during the measuring session we were already able to observe some phenomena which directly affect the efficiency of the injection. For example, on Fig. 2, the injected long pulse, coming from TL1, is longer (almost two times) than the revolution time of the booster. Since the gate is opened only for one turn, a good portion of the beam is lost, causing unwanted radiation and energy loss.

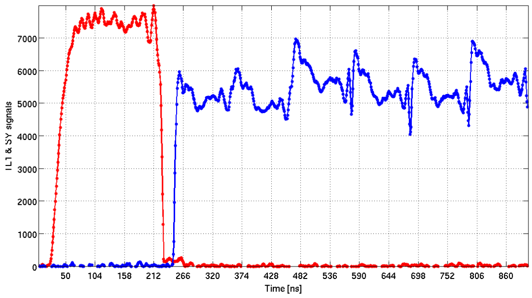

Figure 2: Injection of long bunch at 1.1 mA. The excesive length of the pulse form TL1 can be observed.

During tests, we observed interesting phenomenon during the injection of short bunches in the booster. In some cases, bunches are not completely ejected from the booster to TL2, a small fraction of them surviving until the next injection. This can be seen on Fig. 3, where the injected (red) bunches from TL1 overlap with small bunches from the previous cycle (blue). This phenomenon was randomly appearing, and needs to be further investigated.

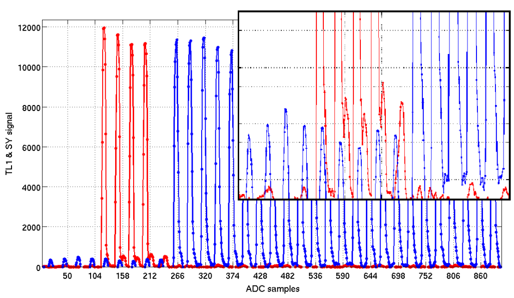

Figure 3: Injection of four bunches into the booster – signal overlapping

Comparison with Existing Current Monitors

ESRF booster is equipped with the DCCT current monitor, its performances were compared to the Libera Brilliance Single Pass. Various injections of long bunches at different beam currents were performed to evaluate absolute current measurement. The results are presented in the Table 1.

Table 1: Current readings at long bunch injection

DCCT current reading [µA]	Libera Brilliance Single Pass reading [µA] and attenuation setting [dB]	
4200	5600	31
1100	2000	31
350	790	31
300	750	16
100	310	7
25	76	7
noise	35	7
noise	30	0

The deviation in the results from two measuring devices was increasing with lowering the beam current. The current in a booster was decreased in steps, down to 25 uA, where the DCCT showed last, although very noisy, positive reading. Afterwards, the current was decreased even further down, where the DCCT started to read the negative current – noise, while the Libera Brilliance Single Pass still perfectly saw the signal, with useful S/N ratio. At the last setting, the lowest current with variable attenuators fully opened, raw ADC data shows approx 1000 counts of noise and approx 5000 counts of signal. Figure 4 depicts raw signal at this extremely low current measurement.

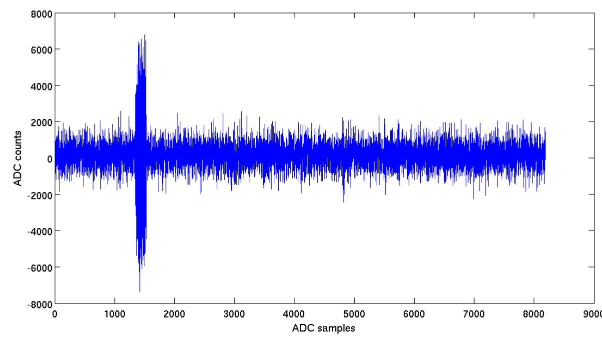

Figure 4: Signal to noise ratio at minimal booster current tested

To prove the Libera Brilliance Single Pass measurement repeatability and feasibility of measuring currents of different bunch patterns, the measurements were performed with two, four and single bunch patterns in booster at different charges and different attenuation settings. Every measurement was repeated three times, the results proving excellent repeatability. The measurements are presented in the Table 2. Here it can be observed that change of on-board attenuation slightly affects the absolute current measurement.

Table 2: Current readings at various bunch patterns

No. of injected bunches	DCCT current reading [µA]	Libera Brilliance Single Pass reading [µA] and attenuation setting [dB]	
2	200	280	31
2	90	142	31
2	90	125	22
4	360	510	31
4	180	250	31
4	180	220	22
1	100	158	31
1	50	72	31
1	50	78	22

Booster to Transfer Line 2 Efficiency

These measurements were performed as a comparison of two Libera Brilliance Single Pass readings, each connected to a stripline, one on the booster and one on the TL2. The time window was very short, as we had time to acquire the data only during one regular injection at 9:00 AM, which takes 2 minutes altogether. On Fig. 5 there is the first stage of the injection, two bunches are being injected, see lower graph. This graph is a snapshot of the injection, in blue are the two bunches circulating in the booster immediately before the injection, in red are the two bunches travelling through TL2. The two green lines show the ESRF booster revolution time. The upper graph shows calculated currents measured on the booster and TL2 during the injection procedure through ten subsequent snapshots. From the ratio of these currents the injection efficiency can be calculated, see middle graph. We can observe that the mean efficiency during the injection was slightly under 90%.

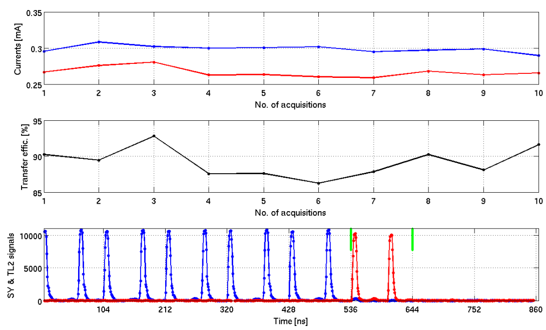

Figure 5: Injection of two bunches

On Fig. 6 one can observe the second stage of the injection procedure, where four bunches are being injected to fill the uniform 7/8 fill. The graphs are using the same logic as two bunch injection above. It can be observed also that the efficiency in this case was very stable but slightly lower than with two-bunch pattern.

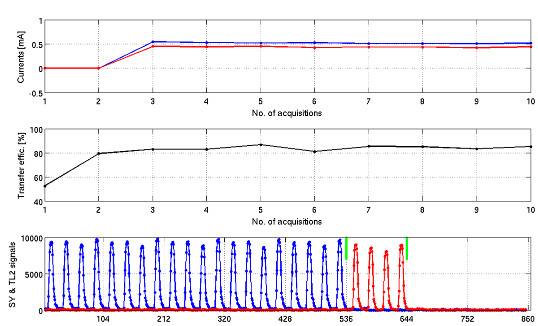

Figure 6: Injection of four bunches

The last part of the injection procedure consists of single bunch injections. On Fig. 7, Libera readings can be observed; the logic is again the same as above. It can be seen (two upper graphs) that we have observed first three injections, as the current before is zero, resulting in non valid efficiency.

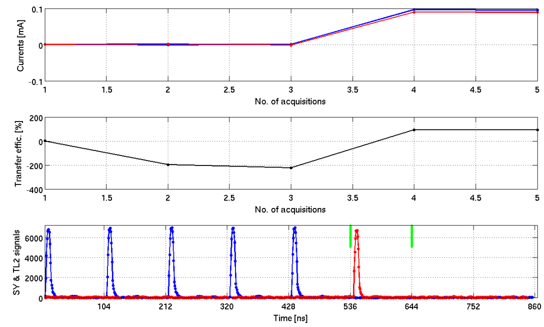

Figure 7: Injection of single bunch. The efficiency measurement is calculated for three last acquisitions only.

Transfer Line 2 to Storage Ring Efficiency

These measurements were done in one of previous sessions and the efficiency outcome is presented here to have a complete picture.

Figure 8 shows the added current of each injection, as measured on stripline of TL2. At the same time, the increase of the current after each injection was measured with regular Libera Brilliance devices, installed on pickup buttons on storage ring. The TL2 to storage ring efficiency is thus calculated in a very accurate way, with RMS of 2.7%

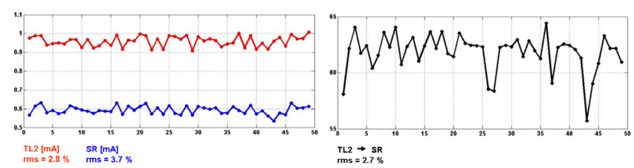

Figure 8: RMS values of the injection efficiency measurement

CONCLUSION

Libera Brilliance Single Pass has been shown to be an effective tool for monitoring the beam-charge losses during complete injection cycle (from TL1 to Storage Ring) at ESRF. The instrument provided excellent performance in terms of accuracy, resolution and reproducibility. Overall injection efficiency can easily be evaluated as a result. A significant result of the studies is that Libera Brilliance Single Pass is capable of measuring at very low beam current (below 0.05 mA stored ring in the booster), which is a factor 100 below nominal currents. It perfectly meets the requirements of the high-performance injection efficiency monitoring tool and offers better resolution and dynamic range than DCCT current monitors.

REFERENCES

[1] K. B. Scheidt, Status of ESRF BPM system, ppt presentation, Solkan, November 2009
[2] Instrumentation Technologies, Libera Brilliance Single Pass User Manual v2.00, Solkan, November 2010