HIGH QUALITY MEASUREMENTS OF BEAM LIFETIME, INSTANT-PARTIAL-BEAMLOSSES AND CHARGE-ACCUMULATION WITH THE NEW ESRF BPM SYSTEM

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Abstract

The BPM system of the ESRF Storage Ring, that was entirely replaced by 224 units of the Libera-Brilliance system in 2009 [1], is now also being used for precise and fast measurements of the Beam Lifetime and so-called Instant-Partial-BeamLosses. This is possible by the use of the Sum signal of the four BPM buttons on each of the 224 BPM stations in the Ring. This paper describes the strong advantages in terms of response time, but also the precautions and the limitations of this particular use. Results will show the ultimate attainable performances and a comparison with that of three independent DC current transformers also installed in the Ring. The same Sum signal is also usable for precise measurement of Accumulated Charge during the injection process and results of this are also presented.

THE STABILITY OF THE SUM SIGNAL OF THE FOUR BPM BUTTONS

The 4 signals of each BPM block are transmitted, via RF cables (RG223) of ~20m length, and through 40 MHz wide bandpass filter, into the 4 inputs of the Libera unit. These 4 signals are digitized and decimated to an output rate of 10Hz (SA continuous data flow), and the associated device-server calculates the Sum signal by a simple addition of these four. This at that same 10Hz rate and simultaneously for all 224 BPM stations.

However, the absolute value of this Sum signal is not only determined by the (DC) beam current in the Ring: the bunch filling pattern and the exact signal gains and losses for each BPM and Libera unit have a strong impact. However, for a given filling pattern and for Libera units that are kept at a fixed gain it was observed that this Sum signal is proportional to the beam current and with an excellent stability.

Since this corresponds to the normal operation conditions of the ESRF it thereby allows the precise measurement of the relative decrease of the beam current (called lifetime) during a typical decay from 200 to 170mA. This beam lifetime at the ESRF is typically around 60hrs but can be well above 100hrs at special studies. A value of 100hrs corresponds to a relative loss per second of only 2.78 E-6. Most lifetime measurements in Storage Rings are based on a current transformer device, but the correct measurement of a 100hrs lifetime with such device requires long measurement times, exceeding several minutes. The new BPM system has in addition to an intrinsic good stability per BPM station a 2nd considerable advantage: The 224 stations in the Ring can be combined and their number offers a further improvement of the stability by a factor 15.

LIMITATIONS, INTER-DEPENDENCES AND PRECAUTIONS TO BE TAKEN

However, while this system has proven its superior performance as shown in the results further below, a number of limitations exist:

* The Sum of the 4 buttons is not fully independent of the transverse beam position in the BPM block. For normal beam operation (with very stable transverse position) this effect is fully negligible. But on the other extreme, e.g. by examining the Sum signal at a Turn-by-Turn rate at the moment of 1rst Injection into the Ring, this dependence is of such extent (due to large position fluctuations) that the localisation (in the Ring circumference) of any losses in these first turns is not possible unless well above 1%.

The pick-up buttons & their blocks have the same geometry for all stations: 10mm diameter and a horizontal separation of 20mm and a vertical separation of 33mm.

* The thermal stability of a Libera unit is of utmost importance. Arrangements have been made in the 32 cabinets that hold 7 units to improve this stability, and we operate the Liberas now with fixed ventilator speeds. But despite this, it is not avoidable that a limited number of units may occasionally show an excessive drift.

* If a simple average of the 224 values was calculated then these units would impair the stability & quality of the overall measurement. Instead, the lifetime calculation algorithm analyses first the individual Sum values provided by each unit, and then rejects those units that diverge (often temporarily) too much from the others. The rejection criteria are optimized to obtain the best result in terms of stability which means that on average ~20 units out of 224 are rejected per measurement cycle that can run at 1Hz rate.

* The amplitude of the RF component (352MHz) from any button is also dependent on the bunch length. A shorter bunch length produces an increase of the level of all RF harmonics, including that of the 1rst RF frequency that is detected by the Libera, e.g. a reduction of bunch length from 31 to 30ps (fwhm) is calculated to give an increase of 27E-6 for this 1rst RF harmonic. While this can be a nuisance (when this occurs which is rare) to its potential of an accurate, fast and reliable beam lifetime measurement, it is at the same time an asset for precisely analysing such tiny bunch length fluctuations and linking them to the RF cavity & RF Transmitter system and their associated control loops.

FASTER AND MORE ACCURATE BEAM LIFETIME MEASUREMENT

The relative stability of any current measurement device in a Ring that has a sufficiently high and stable lifetime can be assessed by redressing the (flat) decay slope of a recording and subsequently calculating the rms value. In comparative measurements this must be done simultaneously and at the same bandwidth, sample rate and recording length. Doing this at 1sec rate for 180 seconds on the 3 available PCTs in the Ring and on the BPM-Libera system (for a Ring current at 91mA and a 15hrs lifetime in 16 bunch filling) yields results shown in Fig. 1 that clearly demonstrate the strong stability of the BPM-Libera system (green curve). The main advantage of the latter system is (much) less noise in the 0.05 to 1Hz bandwidth which now allows its use as an improved lifetime measurement with a faster response time [2].

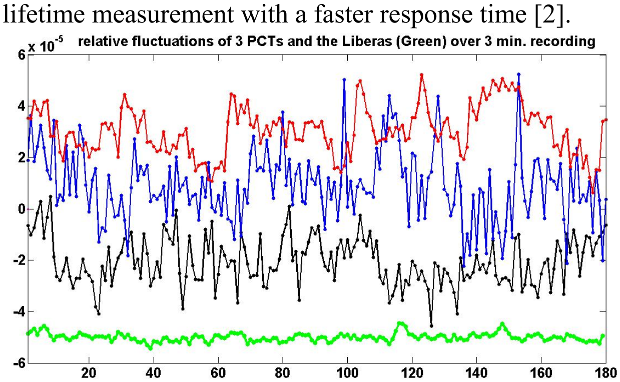

Figure 1: Comparative stability of current measurements between the 3 PCTs and the BPM-Liberas (in green).

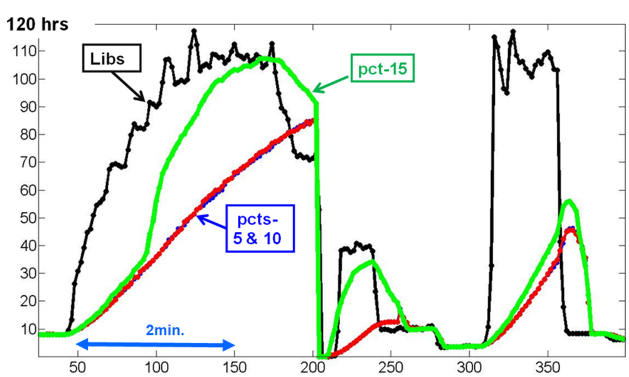

Figure 2: Comparative lifetime results between the 3 PCTs and the BPM-Libera devices at high lifetime values during specific beam dynamics studies over ~7minutes.

In particular when the beam lifetime is high (>50hrs) and thus the beam current decay slope very shallow, the PCTs need a long interval to measure the dI/dt value in the order of several minutes. This has 2 major practical inconveniences : During normal User operation, for a change of lifetime or a so-called “lifetime-accident” the response of the PCTs is (very) slow and misleading : if the change (or accident) lasted shorter than the duration of the measurement interval then the real value will never be reached. The second problem is at dedicated accelerator studies for beam dynamics that push the beam to very high lifetime values: at each new measurement point in such campaign the new lifetime value provided by the PCTs is by far the slowest device and slows down considerably the whole study and its efficiency. This can be seen if Fig. 2 with the 3 PCTs (in cells 5, 10 and 15) compared to the BPM-Libera system (black curve). Note that the PCT of cell 15 is equipped with a different algorithm for optimizing its measurement interval.

INSTANT PARTIAL BEAMLOSSES

Unlike many others synchrotron light sources the ESRF operates in “decay” mode with a high beam lifetime: the re-injection of electrons is between only 2 or 3 times per 24 hrs and typical lifetime is above 50hrs. Also the ESRF has an ambitious program of implementing long (6m) ID chambers with narrow vertical gap (10mm) and no other pumping facilities than that provided by in-house applied NEG coating inside these ID chambers. This combination means that the quality of the UHV in the Ring is of paramount importance.

With the new BPM-Libera system we can now detect cases of “instant-partial-beamlosses” of amplitudes as low as 10ppm and reaction times as low as 100millisec (see Fig. 3). These losses appear irregularly but of an average frequency of ~10 per day and with a typical signature of the speed of the event: most losses are instant, i.e. they happen within a fraction of a second, and often close to 100millisec (time-resolution from the used output rate of 10Hz).

These losses are being monitored quasi permanently and simultaneously with other devices sensitive to UHV incidents like the BeamLoss Detectors (BLDs, 64 units around the Ring) and the pressure gauges available from the UHV vacuum system. There is an excellent correlation between these devices at each incident. Also the frequency and amplitude of such events decreases with time as the UHV quality in newly installed ID chambers improves because of vacuum conditioning.

While the distribution of the 64 BLDs around the Ring often allows to pin-point the location of the ID chamber that causes these losses, they do not allow to assess the exact amplitude of the instant loss, neither its time characteristic, which is now fully possible using the BPM-Libera system.

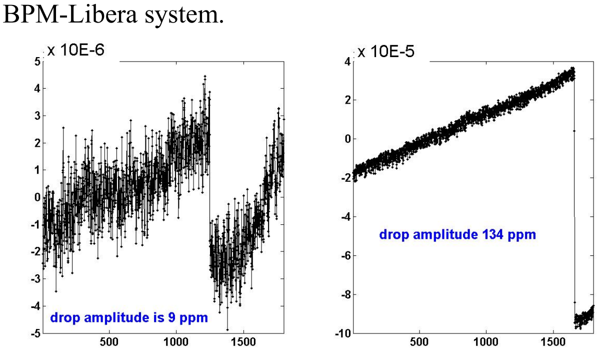

Figure 3: Examples (180sec at 10Hz) of instant-partial-beamdrops of only 9ppm (<2uA) and 134ppm. The normal beam lifetime slope is redressed in these curves.

CHARGE ACCUMULATION

The same Sum signal at 10Hz is easily used to measure at each 1Hz injection shot the accumulated charge. For a 10Hz injection rate the DD-64 buffer (samples at 5.5KHz) is used. Again, the use all 224 units is extremely beneficial to obtain an excellent stability & reproducibility of this measurement. It is also possible to assess precisely the relative deviation between the 224 values. This was done by analysing 50 injection shots at 1Hz with an average accumulated current of ~600uA per shot (1us long-pulse with ~350 RF-structured bunches). This deviation was 2.1uA rms (=0.35%) (see Fig. 4). By averaging the 224 values the reproducibility can be improved by a factor 15 to 0.023%. For injection at lower currents and with (multiple-) single bunches from the Injector this reproducibility is less but still much better than available with fast current transformer devices.

Moreover, for detailed studies of injection efficiency [3] and electron capture efficiency the system can give details of various loss processes of the Storage Ring in a time domain down to the Turn-by-Turn rate.

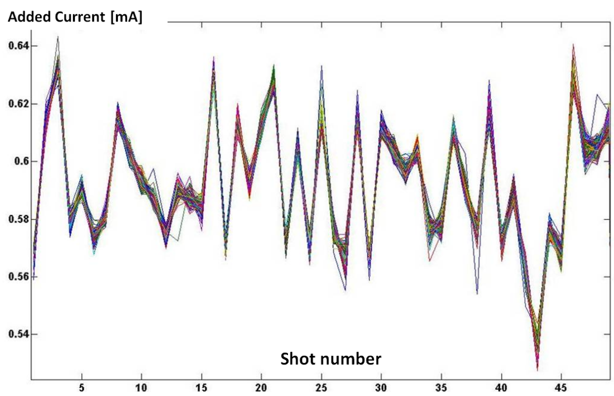

Figure 4: The 'normalized-subtracted' Sum signals of all BPM units in 224 curves over 50 injection shots. The average rms deviation between the 224 units is 0.35%.

SENSITIVITY TO BUNCH LENGTH AND RF CAVITY & TRANSMITTER EFFECTS

As mentioned in the first section, the RF amplitude of the button signals is dependent on the bunch length. In fact, even a tiny bunch length fluctuation creates a very noticeable and detectable variation on these 224 combined Sum signals (at 10Hz output). We tested this sensitivity by modifying our RF cavity voltage by 0.05MV on the nominal 8MV value (=0.63%) and detected a Sum variation of 14ppm. By verifying roughly (from former bunch length measurements with Streak Camera) what such cavity voltage variation should induce on the bunch length we find a good agreement.

When we examine the available Sum buffers at a 5.5KHz rate we see many strong frequencies appearing: a ~6Hz saw-tooth oscillation and its higher harmonics, and also strong amplitudes at 50Hz and 150Hz (see Figs. 5 and 6). At first & rough analysis we believe these lines to originate from the RF cavity and transmitter system where certain control loops are operating at this 6Hz frequency.

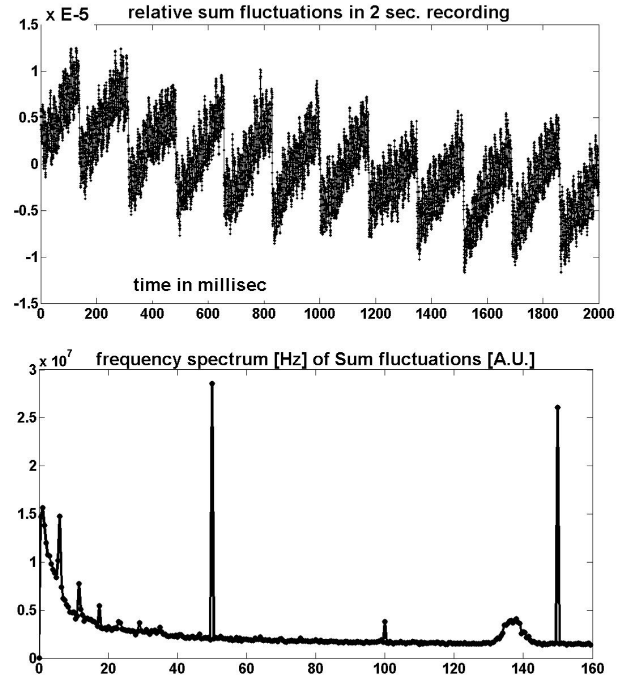

Figure 5a & 5b: Relative fluctuations of the Sum signal in a 2sec recording and its frequency spectrum.

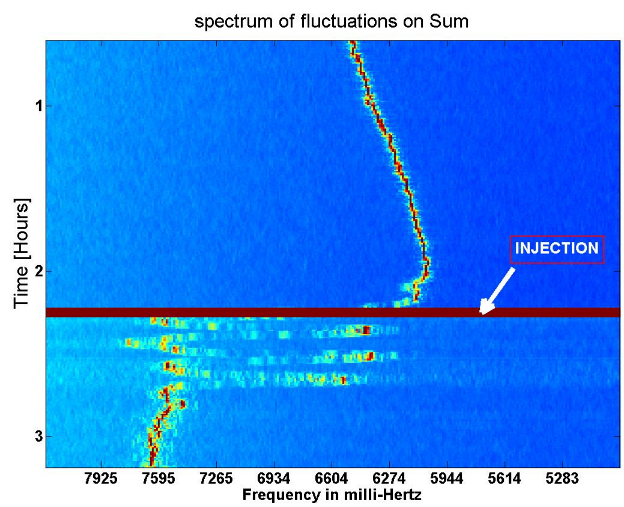

Figure 6: 3hrs monitoring at the moment of Injection of the exact frequency of the 6Hz line in the Sum spectrum.

REFERENCES

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