Beam Current Monitoring with ICT and BPM Electronics

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Motivation

- Energy Recovery Linacs are expected to operate with high current (hundreds of mA) and high energy (up to few GeV) electron beam. The used beam is decelerated to few MeV and dumped.
- That means that unlike in the storage ring the beam itself can easily destroy the vacuum chamber (1 MW power is available).
- There is need for the fast (few microseconds) and accurate (few μA) system monitoring beam current in few locations (at least leaving the injector and entering the gun)
- There is also need for a single instrument covering wide range of beam intensities

Existing Solutions

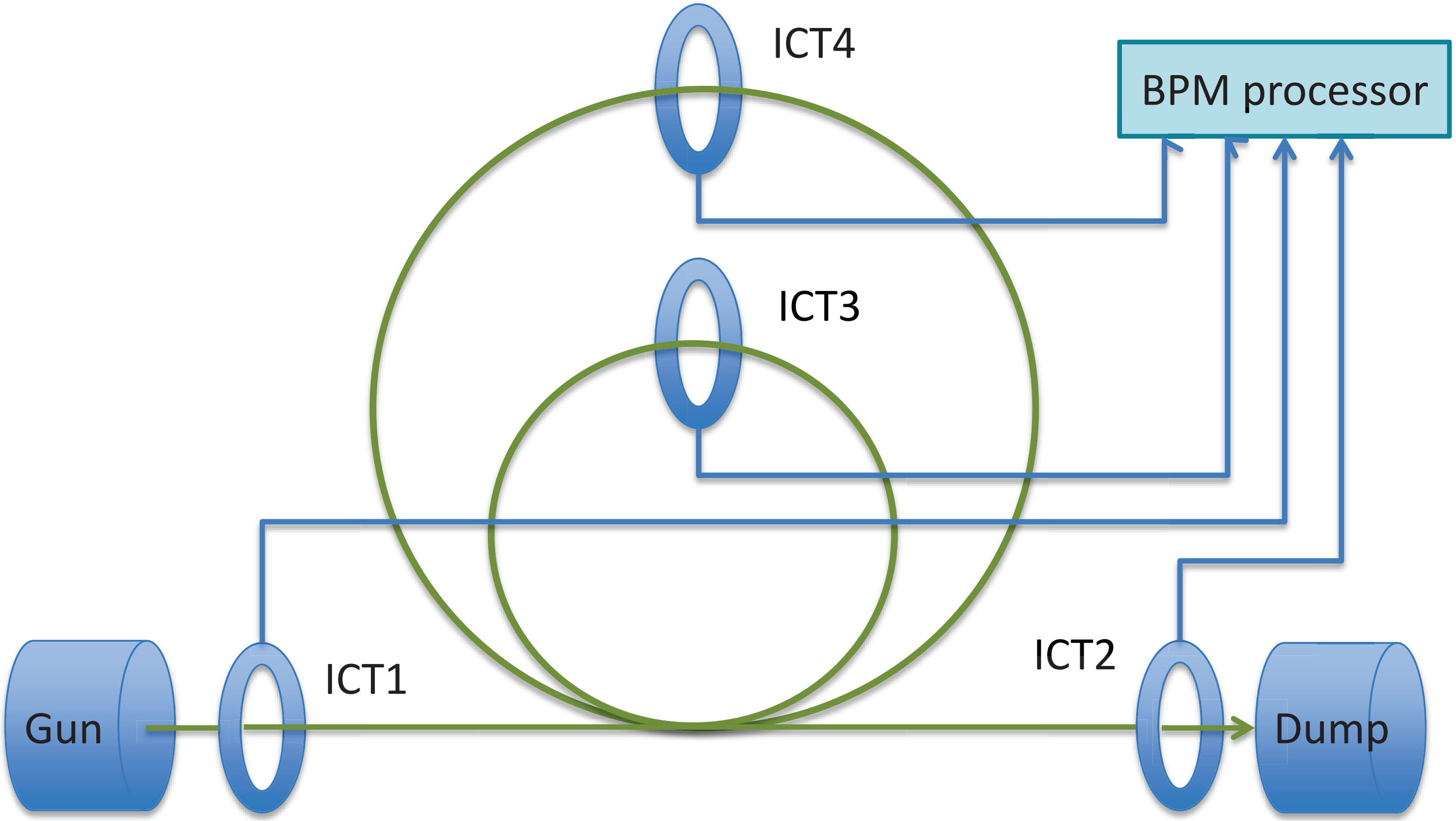
Integrating Current Transformer with BCM

- Can monitor beam from single pulses to 10 kHz repetition rate
- Not sensitive to beam position (variation less than 10^{-4} with 10 mm beam displacement)
- No integrated comparison of two beams

DCCT

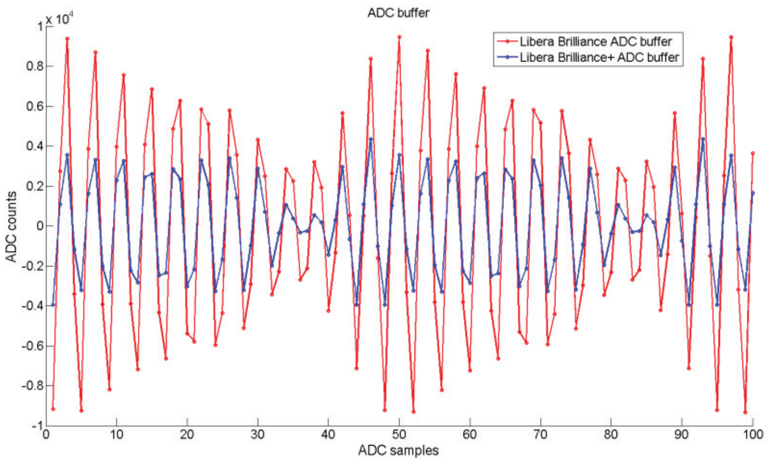
- Can monitor only CW beams
- Frequency response up to 10 kHz (response time 50 μs @90%)
- Sensitive to external magnetic field
- The highest resolution model has noise level of 0.5 $\mu A/Hz^{1/2}$ (50 μA with full bandwidth)
- No integrated comparison of two beams

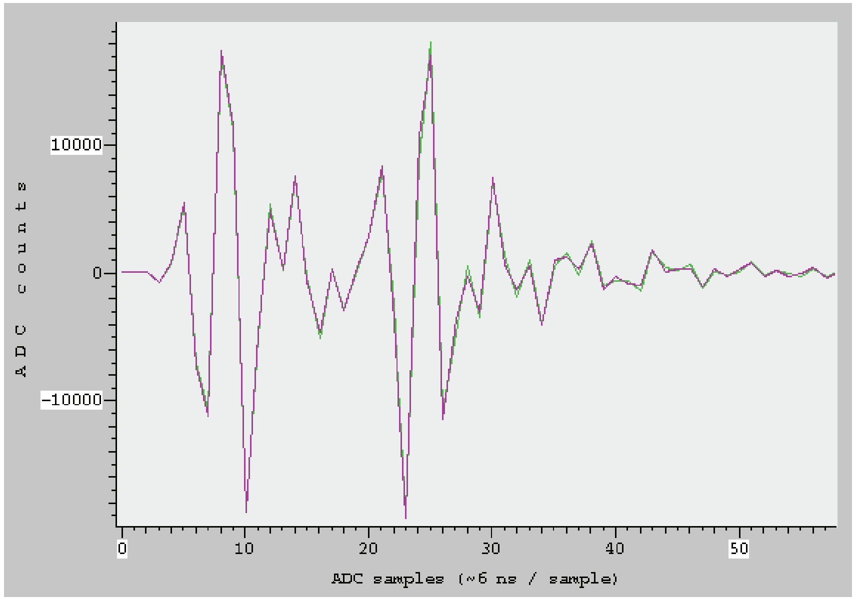
Proposed Solution



Connect the outputs of the ICT to the input of the BPM receiver. Signal levels for each channel can be used for monitoring current in the desired location. Built-in “position interlock” can be utilized as beam loss interlock.

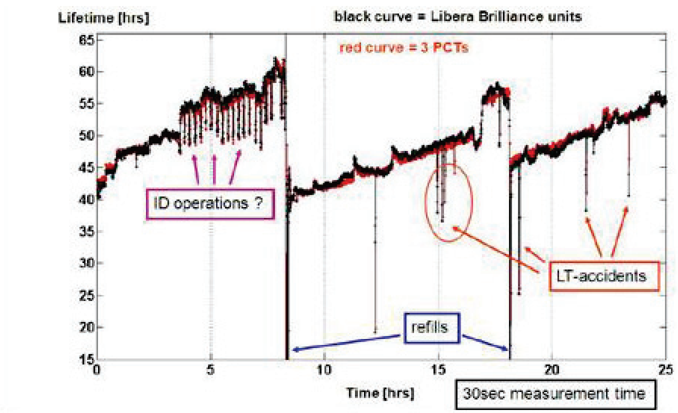
Signal Acquisition in BPM Receiver

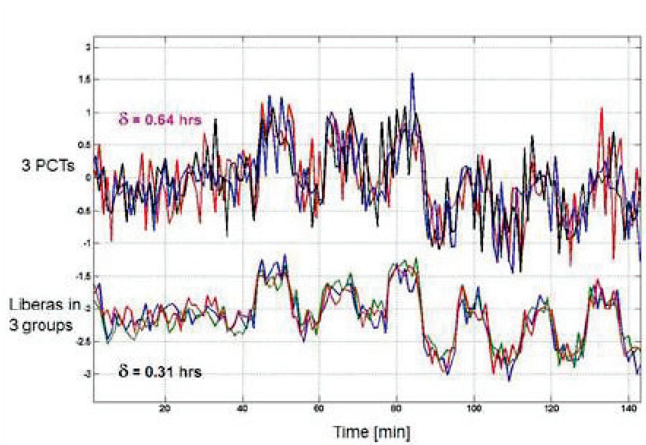




Signal from a pick-up electrode excites the bandpass filter. The ringing of the filter is amplified and sampled by fast ADC. Digitized signal is processed by FPGA in real time.

Usage of BPM for Current Monitoring





In 2009 K. B. Scheidt from ESRF proposed to monitor beam lifetime at ESRF using SUM signal from BPM receiver. The idea was further elaborated to study instant beam losses and injection efficiency.

However, the SUM signal substantially depends on the beam position. Attenuation in the cables also need to be accounted for.

A. Kosicek, P. Leban, K.B. Scheidt, Beam Lifetime Measurements with Libera Brilliance, BIW10.
B.K. Scheidt, F. Ewald, B. Joly, High Quality Measurements of Beam Lifetime, Instant Partial Beam Losses and Charge-accumulation with the New ESRF BPM System, DIPAC2011
M. Znidarcic, A. Kosicek, K.B. Scheidt, Injection Efficiency Monitor with Libera Brilliance Single Pass, IPAC'10

Data Processing: “Energy Meter”

Libera Single Pass sums the squares of the ADC data in the processing window and finds the associated signal levels V_a, V_b, V_c, V_d.

$$V = \sqrt{\left(\square \, A_i^2 \right)}$$

However, we want to measure without recalibrations from single pulse to continuous beam. The “signal energy” is non-linear and has “interference” term when ringing of closely spaced bunches overlap.

$$V = \sqrt{\left(\square \left(A_i + B_i \right)^2 \right)} = \sqrt{\square \left(A_i^2 + B_i^2 + 2 A_i B_i \right)}$$

Data Processing: Single Frequency Fourier Transformation

We can utilize single frequency Fourier transformation (analogous to lock-in amplifier operation) realized in the Libera Brilliance for the storage rings

$$I = \sum \left(A_i \cos \omega t_i \right)$$

$$Q = \sum \left(A_i \sin \omega t_i \right)$$

Such algorithm is linear and is easily expandable from single pulse to continuous current. It also allows further digital filtering improving signal-to-noise ratio by reducing bandwidth.

Expected Performance

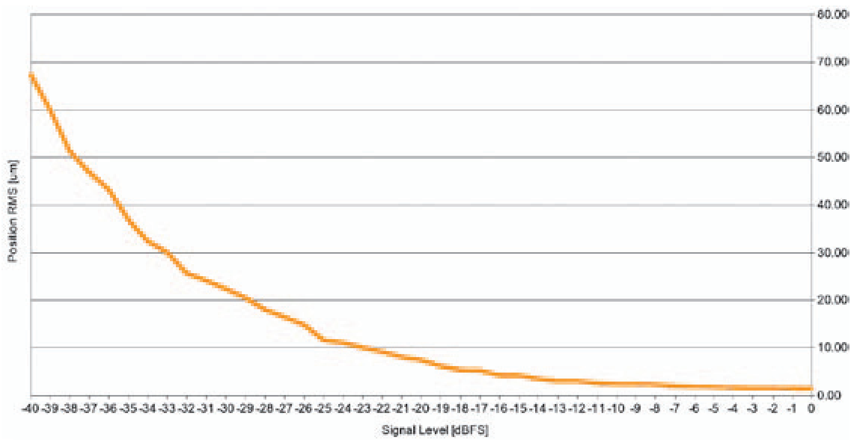


Figure courtesy of Instrumentation Technologies. Libera Single Pass E has ultimate measurement accuracy better than 1 micron for 10 mm scaling factor. That means that signal-to-noise accuracy for single bunch can have 80 dB level.

The expected performance can be evaluated from the performance of the BPM receivers. The single pulse might already be sufficient. The further increase might be achieved by further filtering at the expense of the response time, so balance should be kept.

Possible Error Sources

- Losses in the cables (30 m of LMr240 0.75 dB @ 10 MHz and 5.4 dB @ 500 MHz)
- Unmatched impedances in the connectors
- Amplifier gain drift (mostly temperature)
- High repetition rate – use FCT
- ICT can be not sensitive to the dark current from the gun (advantage?)

Summary

- The proposed method of monitoring current utilizes readily available components and is capable to cover wide range of beam intensities
- The signal processing technique is already developed
- Absolute calibration can be performed either using beam charge monitor or DCCT
- We are currently working on the prototype system