BCM System Optimization for ESS Beam Commissioning through the DTL Tank4

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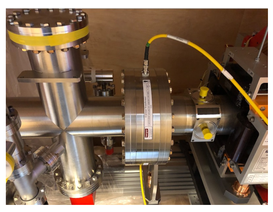
Introduction

The ESS BCM system is not only used for beam measurement but it also plays an important role for machine protection particularly in the normal-conducting part of the linac. During the previous beam commissionings to the MEBT and DTL1 FCs and before the cavities were fully conditioned, RF breakdowns and other types of discharges in the cavities had a major impact on beam availability due to the Fast machine protection functions of the BCM. Following an investigation on the root cause of the beam trips, the configuration of the machine protection functions was modified to improve beam availability in the more recent beam commissioning to the DTL4 FC. In addition to this, some optimizations were made in the BCM system to improve beam measurement, and a few more functions were added based on new requirements. Here, we report on these improvements and the results obtained during the beam commissioning through the DTL4.

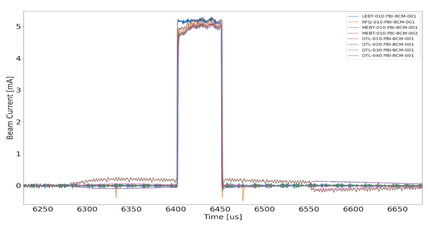
BCM System Overview

- 19 Bergoz ACCTs: 9 in the normal-conducting and 10 in the superconducting part of the linac.
- One Fast BCM in the MEBT.
- Wall-mount FE unit including Bergoz ACCT-E.
- Rack-mount BE unit including customized electronics for signal filtering, fanout, voltage/impedance matching, ACCT auto calibration, network connection etc.
- uTCA crate including:
  - NAT Power supply
  - NAT MCH
  - Concurrent Technologies CPU
  - Struck SIS8900/SIS8300-KU
  - MRF Timing
  - AMC for RS485/optical interface
- Customized BCM FW for beam measurement and machine protection.
- EPICS IOC

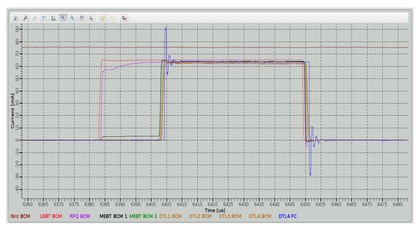




BCM Measurements

- Measurement noise: < 50 µA peak-peak
- Accuracy: < 0.1 mA
- Bandwidth = 1 MHz
- Per-pulse measurements:
  - Average beam current over a ROI
  - Pulse charge
  - Pulse width
  - Pulse frequency
  - Beam pulse presence with the ISrc, LEBT and MEBT BCMs
- Voltage of the ISrc platform (using a voltage divider).
- Supplied current to the ISrc (ACCT on the HVPS cable to the platform)



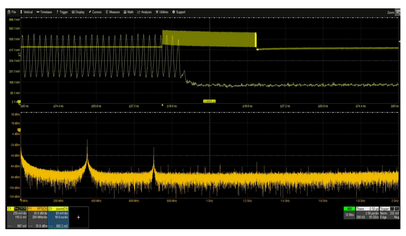
A low current beam pulse measured by 8 BCMs from the LEBT to the DTL4



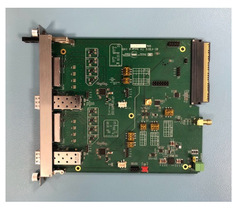
A high current beam pulse measured by 9 BCMs from the ISrc to the DTL4, and a FC at the end of DTL4.

Other improvements

- A Fast BCM (i.e. FCT) with BW=700 MHz at the MEBT end measures:
  - 10 ns rise/fall time of the beam pulse
  - Individual proton bunches
- New RS485/optical AMC (collaboration with WUT-Poland) for improving the BCM-FBIS interface.
- A special BCM channel with sub-µA accuracy was tested and verified with beam.



FCT signal measured by a fast oscilloscope



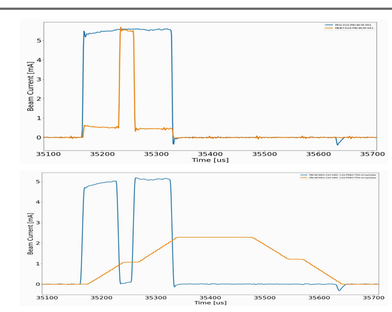
LVDS to RS485/optical converter AMC

20-h history of the charge-per-pulse and the 1-hour average beam current

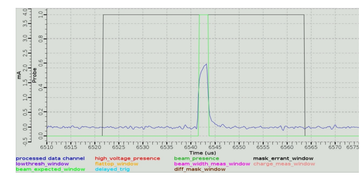
BCM Machine Protection Suite

Beam-mode-dependant thresholds on:
- Pulse amplitude
- Pulse length
- Trigger length
- Trigger frequency

Beam-mode-independent thresholds on:
- Errant beams
- Beam exist
- Differential beams:
  - Fast
  - Medium-speed
  - Slow



Absolut (above) and differential (below) beams with the RFQ-MEBT1 differential pair

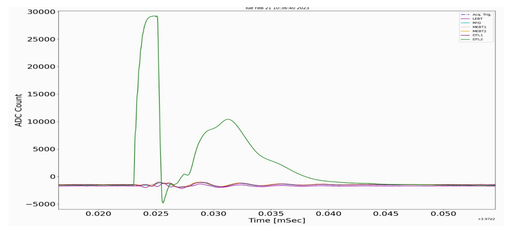


Beam expected and errant mask windows

Beam Availability Issues/Solutions

Spike/disturbance summary:

- EMI in the ISRC:
  - HVPS
  - High power contactors
  - Safety (i.e. ground) relay
- RF breakdowns in the DTL
- RF/vacuum breakdowns in the MEBT buncher 3 cavity
- Broken insulator around the LEBT repeller ring causing sparks
- Induced current in the series-connected ACCT calibration windings due to DTL RF breakdowns



An RF breakdown in the DTL2 causing ringing with the other BCMs (with cal. windings being connected)

Action items for fixing the beam availability issues:

- The ISrc EMI issues were resolved through:
  - Grounding of the ISrc cage and the electronics racks was improved.
  - Additional shielding (i.e. flexible conduits) was installed on the ACCT cables to the ISrc/LEBT ACCT FEs.
  - EMI filters were added to the input power of the ACCT-E power supplies.
  - Surge protectors and filters were installed on the cable from the ISrc voltage divider.
- The Fast upper/errant interlocks in the DTL were replaced by Medium-speed differential interlocks.
- Calibration windings of the DTL ACCTs were disconnected after the in-site tests/verifications were completed and before starting with beam.

Summary and outlook

During the ESS beam commissioning through the DTL tank 4, nine BCM channels were successfully used for beam measurement, machine protection and timing synchronizations. At the start of the commissioning, the beam availability was impacted by a large number of beam trips due to spikes on the BCM readouts. An investigation then showed that the spikes were partly due to EMI and other types of external disturbances, and partly due to RF / vacuum breakdowns particularly in the DTL section. The issue was then resolved by addressing the EMI issues and reconfiguring part of the BCM protection functions to make them less sensitive to the spikes but sensitive enough to beam losses that pose a damage potential. During the same commissioning run, a Fast BCM, a Medium-speed differential interlock and a special BCM channel with sub-µA measurement accuracy were successfully tested and verified with beam as well. It is planned to continue with the BCM activities in 2023-2024 by installing in total ten new BCMs in the DTL tank 5 and the superconducting part of the linac as well as three BCMs in a new ISrc-LEBT Test Stand that is under construction. It is also planned to make the BCM-FBIS interface more robust by deploying a newly developed RS-485/optical interface module. The other parts of the system including the electronics, FPGA firmware, software and the operator interfaces have already become mature following a few rounds of improvements, hence no major changes are planned in the near future.