Differential Current Transformer for Beam Charge Monitoring in Noisy Environments

TUP32

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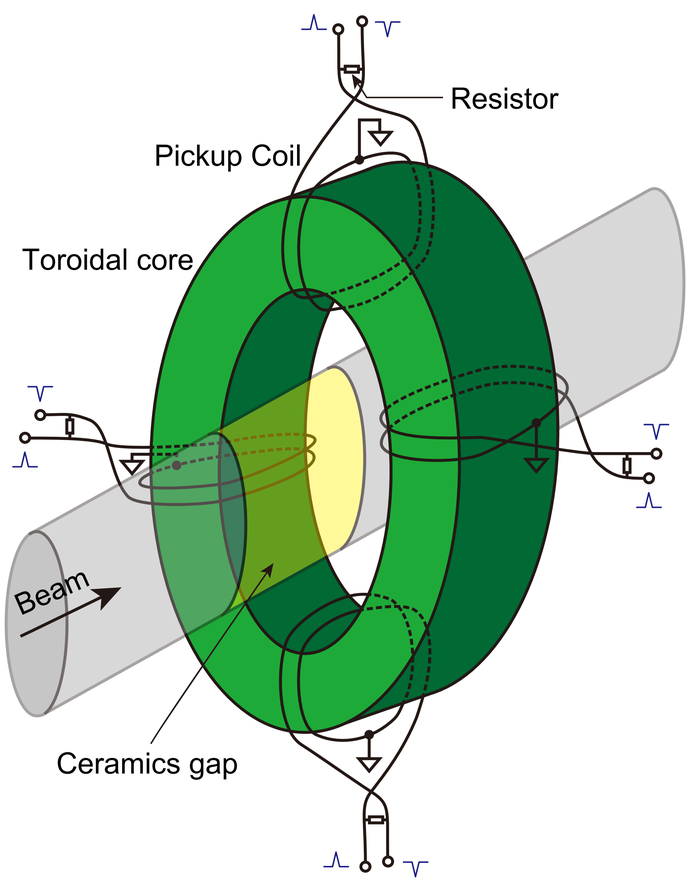
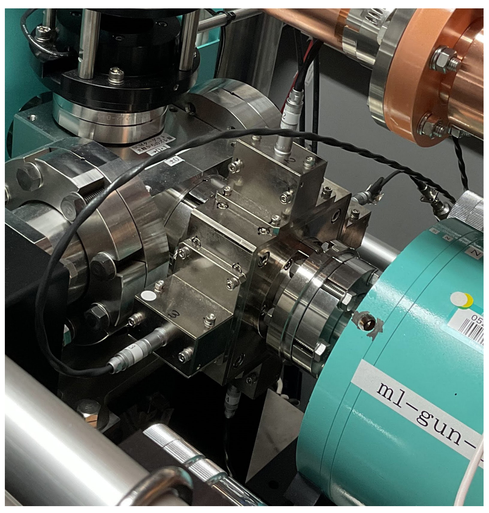
Introduction

- A conventional single-ended current transformer (CT) is susceptible to common-mode noise from a high-power pulse component.
- A diffential CT was proposed and utilized in the XFEL facility, SACLA [1, 2].
  - To mitigate the noise from the high-power component.
  - It has four single-turn coils around a toroidal core, where two coils generate positive signals and the other two generate negative signals.
  - A common-mode noise can be canceled out by subtracting the positive and negative signals.
  - A preamplifier or balun near the differential CT is required to transform two differential single-ended signals into a balanced differential line for long signal transmission.
- A new 3 GeV light source, NanoTerasu [3, 4], was proposed and now being constructed.
  - A new injector linac for NewSUBARU [5] was constructed as a prototype of the NanoTerasu linac [6].
- For low-cost and easy maintainability, we designed a new differential CT that did not need a pre-amplifier or balun near the CT.

Design

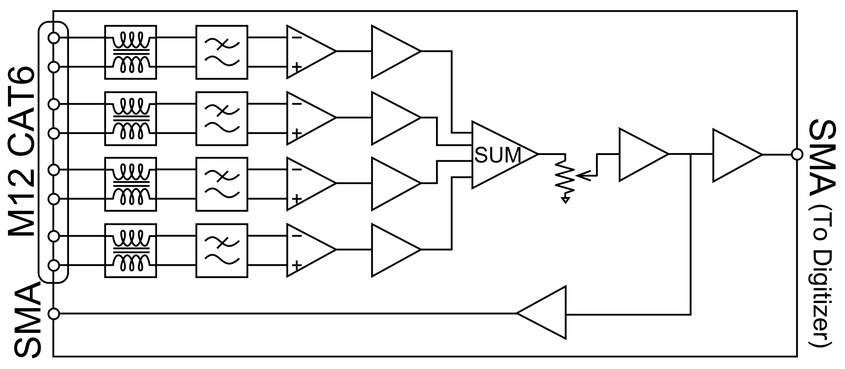
- Two-turn pickup coils are wound on a toroidal core and the midpoint is grounded.
- Four pickup coils are attached to a toroidal core at equal intervals (90 degrees).
- An 11 Ω resistor is attached to each coil in parallel to attenuate a beam signal.
- Toroidal core: Finemet FT-3KM F7555G (Hitachi Metals).
- Output connector: LEMO 0S302 series 2-pin connectors.
- Sensitivity: 1.24 V/A





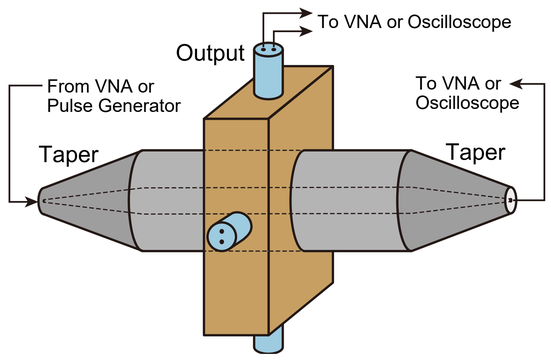
Readout Electronics

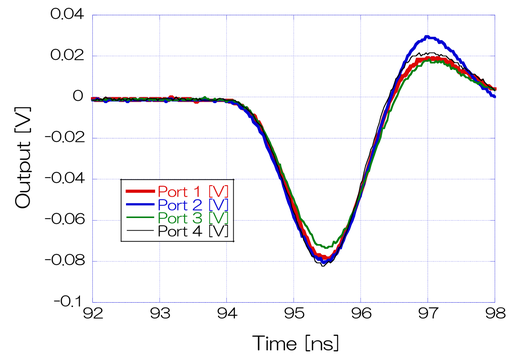
- Signal cable from CT to electronics: CAT6 S/FTP cable (M12 X-coded connector)
  - Reasonable price and sufficient high-speed transmission characteristics.
- Amplifier unit.
  - Common-mode noise in each balanced differential signal is suppressed by a common-mode choke filter.
  - A high-frequency component is blocked by a low-pass filter having a cutoff frequency of 10 MHz.
  - The differential signals are converted to single-ended signals by a differential amplifier.
  - The four signals are summed and output from SMA connectors.
- High-speed Digitizer.
  - Struck SIS8325 [7] (250 MSPS, 16bit), etc.



Laboratory Test Results

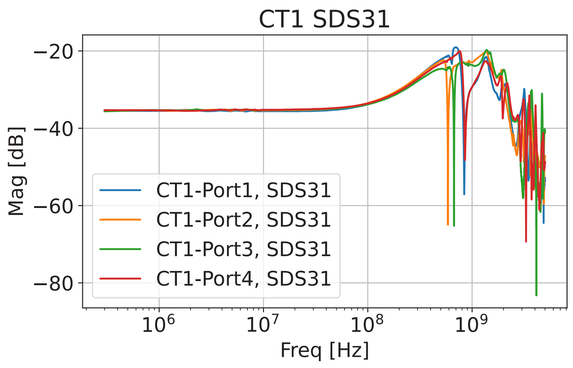
- An electron beam was simulated by a rod in the beam pipe and two taper lines.
- The pulse response was tested by using a fast pulse generator.
  - Input: A rectangular pulse of 5 V height and 1 ns width (Beam current: 100 mA, charge: 100 pC).
- The pulse width is 1.4 ns FWHM, which is fast enough for our application.



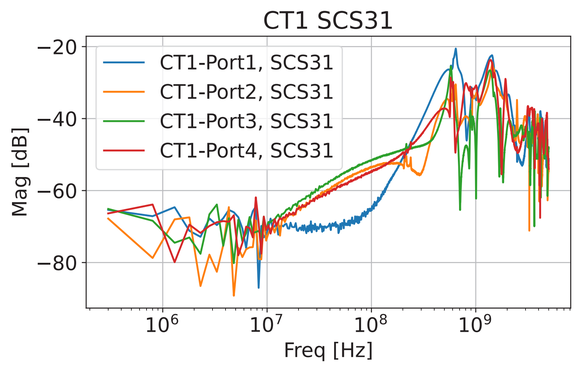


- The frequency response was measured by a 4-port vector network analyzer (VNA).
  - Two ports are connected to both ends of the taper lines.
  - The other two were connected to one of the four differential outputs.
  - (one port for the positive pin and the other for the negative).
  - The unused three outputs were terminated by 100 Ω resistors.
- The responses of the four outputs were almost flat and identical up to 100 MHz.
  - The insertion loss was –36 dB in the low-frequency region, which was consistent with the design .
- The transmission from the beam to the common mode is suppressed by approximately 30 dB compared to the normal mode up to 10 MHz.

Beam → Normal-mode



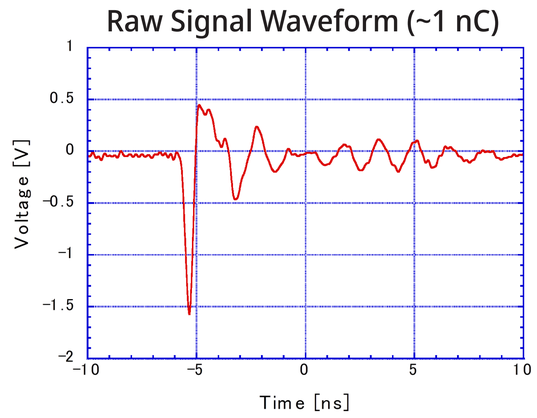
Beam → Common-mode



Beam Test Results

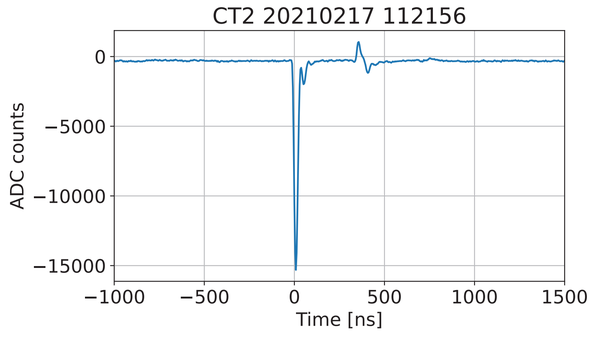
- The differential CT was tested at the new linac for NewSUBARU.
- A short pulse width of less than 1 ns FWHM was observed.
- The pedestal level was not affected by common-mode noise from high-power components near the CT.

Raw Signal Waveform (~1 nC)

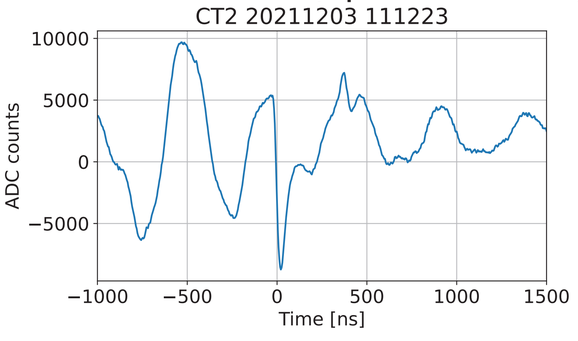


- The pulse width of the amplifier output is ~20 ns FWHM.
  - The waveform was taken by a SIS8325 MTCA.4 digitizer.
- The peak value is used for calculating the beam charge.
- The beam charge data have been stably recorded to the database system of NewSUBARU and utilized for the stable operation of the injector linac.
- Large common-mode noise was observed if one of the signal wires was disconnected.

Normal ADC Waveform (~0.5 nC)



Abnormal Waveform (1 pin disconnected)



References

[1] A. Higashiya, H. Maesaka, and Y. Otake, Proc. of FEL'07, WEPPH051, pp. 464-467 (2007).
[2] Y. Otake et al., Phys. Rev. ST Accel. Beams **16**, p. 042802 (2013).
[3] Accelerator design report for 3-GeV Next-Generation Synchrotron Radiation Facility, edited by QST and PhoSIC, https://www.qst.go.jp/uploaded/attachment/18596.pdf
[4] N. Nishimori, Proc. of IPAC'22, THIXSP1, pp. 2402-2406 (2022).
[5] A. Ando et al., J. Synchrotron Rad. **5**, pp. 342-344 (1998).
[6] T. Inagaki et al., Proc. of IPAC'21, WEPAB039, pp. 2687-2689 (2021).
[7] SIS8325 MTCA.4 Digitizer, Struck Innovative Systeme, https://www.struck.de/sis8325.html

Summary

- We designed a new low-cost differential CT to monitor the current and charge of an electron beam without common-mode noise from high-power components.
- This differential CT has a toroidal core with four two-turn pickup coils and the midpoint of each coil is grounded to generate a balanced differential signal.
- The differential CT was tested in the laboratory and then with an actual beam and sufficient performance was confirmed.