# An integrating current transformer for fast extraction from the HIRFL-CSR main ring*

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**Abstract** For any experiment that uses the beam of an accelerator, monitoring the beam intensity is always an important concern. It is particularly useful if one can continuously measure the beam current without disturbing the beam. We report here on test experiments for an Integrating Current Transformer (ICT) used to measure fast extraction beams from the HIRFL-CSR main ring (CSRm). The laboratory tests and beam intensity measurement results are presented in this paper. The influence of the kicker noise is also analyzed.

**Key words** ICT, fast extraction, CSRm

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## 1 Introduction

In the HIRFL-CSR [1] main ring (CSRm), ions from C to U can be accelerated to the energy range of 100 MeV/u–1 GeV/u and extracted by using slow or fast extraction. The number of stored particles is in the range of $10^5$–$10^9$. After fast extraction from CSRm and passing through RIBLL2, the beam is injected into the experiment ring CSRe. The supercycle of the beam is about 20 s and the pulse length is about several hundred ns. An ICT [2] produced by the Bergoz company is used to measure the beam intensity during the fast extraction. It is installed at the exit of the CSRm. In this way one can get the fast extraction beam intensity and extraction efficiency.

The ICT is a passive transformer designed to measure the charge in a very fast pulse with high accuracy. It can be used to measure a pulse with a risetime of the order of ps with no significant loss. The principle of the ICT is shown in Fig. 1. It consists of a capacitively shorted transformer coupled to a fast readout transformer in a common magnetic circuit. The ICT integrates the signal with a time constant of 1 to 20 ns, depending on the model and is independent of the beam pulse risetime. Its output pulse charge is in exact proportion to the beam pulse charge. Its only drawback is that the original shape of the signal is lost. As our beams are weak, we choose the highest sensitivity model with a 5:1 turn ratio which gives 5 V·s/C in a 50 Ω termination. The bandwidth is 9 kHz–10 MHz. The risetime is 32.6 ns and the droop is 5.7%/μs.

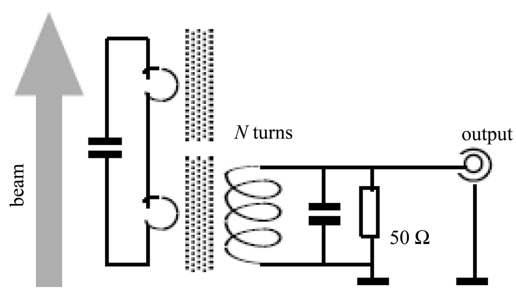


Fig. 1. Scheme of the ICT.

The electronic unit of the ICT is called a Beam Charge Monitor (BCM). Its output is a voltage of up to ±7 V, proportional to the beam charge. The ICT signal is amplified and integrated by the BCM. It has two integrators and the pulse must fall in one of the integrators. The pulse charge is obtained by summing the two integrators: the first with negative sign and the second with positive sign. This particular combination of sampling window integrators gives a high

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degree of noise suppression. The BCM has different full scales corresponding to different gains. The most sensitive configuration with a gain of 40 dB has a full scale of ±800 pC and sensitivity of 10 mV/pC.

## 2 Laboratory test

To test the ICT in the laboratory, a short pulse must be passed through the ICT aperture to mimic a beam passing through the aperture. It is difficult to send a short pulse through a wire, firstly because the generator output impedance is 50 Ω, but the wire impedance in air is much higher，secondly the pulse passing through the ICT aperture creates eddy currents in the ICT stainless steel. The beam charge (an infinite impedance source) is not affected by the eddy current load, but the 50 Ω generator is greatly affected. The eddy currents behave like a leakage inductance. For these reasons it is not easy to pass a calibrated charge through the ICT aperture. A self-made device (shown in Fig. 2), therefore, is used to feed the pulse into the ICT. The purpose of this device is that it should let all the pulse charge pass through the ICT. Therefore, it must act like a 50 Ω termination when the ICT is inside the device. It is similar to a coaxial cable. Ten non-inductive resistances of 500 Ω are soldered between the copper cylinder and the copper baseplate to form a 50 Ω termination. The wall thickness of the copper cylinder is nearly 1 mm and the upper side was tapered to minimize the capacitance. The whole copper cylinder is supported by a polytetrafluorethylene-made cylinder. We connected a vector network analyzer to the device and observed that below 100 MHz frequency, its load impedance in S11 mode is 50 Ω.

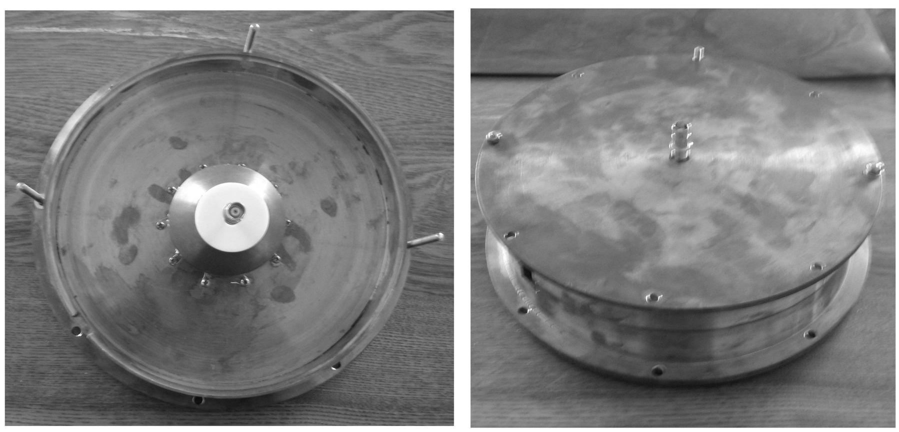

Fig. 2. ICT test device.

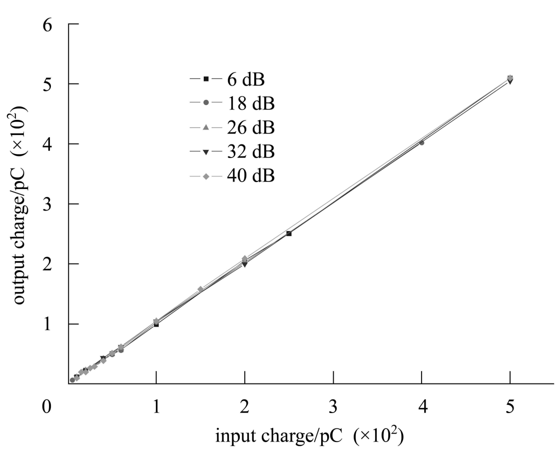


Fig. 3. ICT input versus BCM output.

Then we sent a generated short pulse through the ICT and the device, and read the BCM output. The measurement results are shown in Fig. 3 for different scales corresponding to different gains. Here the input pulse charge is calculated using $q=\dfrac{U\times\Delta t}{50\Omega}$, $U$ and $\Delta t$ are the pulse amplitude and width, respectively. The linear fitting ($y=A+B*x$) results are shown in Table 1. Because in our case the particle number of each spill is less than a few times $10^9$, the measurements were made in the range of 10–500 pC, and at each point the measurements were made many times. From the results we can see that the output is nearly equal to the input. The error is caused by

Table 1. Linear fitting results.

| $G$/dB | $N$ | $A$ | $B$ | $SD$ |
|---|---|---|---|---|
| 6 | 9 | −0.16425 | 1.01738 | 2.65076 |
| 18 | 9 | 0.24814 | 1.00539 | 1.986 |
| 26 | 6 | 1.51808 | 1.01835 | 1.65472 |
| 32 | 7 | 2.56965 | 1.00324 | 1.87557 |
| 40 | 12 | 1.12689 | 1.02226 | 2.61603 |

Note: $G$ is the gain, $N$ is the number of measured points, and $SD$ is the rms of the standard deviations.

unavoidable noise.

## 3 Beam intensity measurement results

NI5105 is used to acquire data and NI6280 is used to control the gain and calibration sources of the BCM. Software routines written with LABVIEW are used for sending commands, receiving digitized data, processing the signals and displaying the results.

Figure 4 is one of the ICT measurement results of the beam intensity during fast extraction from the CSRm. The signal view represents the ICT signal without integration and the BCM output represents the measured result of the beam charge. In this figure the gain was 40 dB and the beam was $C^{4+}$ with a revolution frequency of 1.012 MHz. So the particle number of the spill was $5.5738\times10^8$. The reading of the DC current transformer (DCCT) in the CSRm was 357 μA at that time, i.e. the particle number is $5.5067\times10^8$ in the ring. So the extraction efficiency is nearly 100%.

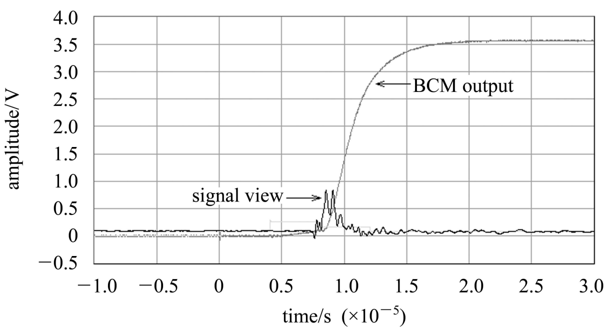


Fig. 4. The beam intensity measurement of fast extraction.

We also tested ICT without the beam and one of the results is shown in Fig. 5. The result of the kicker noise level was about $\pm1.5\times10^7$ (the equal particle number to produce the same ICT output voltage as ICT noise output voltage). It influenced the measurement result very much. We made many measurements and found that the kicker noise was almost the same. If the relative position of the kicker noise in the integration window was fixed, then the integration result of the kicker noise was nearly constant and we could deal with that. But in our machine BCM has the same trigger signal as the kicker. When the kicker is triggered and coincides with the RF signal, the kicker is discharged and the beam is kicked out of the ring. So the time delay between the kicker discharging and the trigger signal changes all along. The range of the kicker noise movement related to the integration window is ±15 μs, therefore, it hardly falls in the integration window. For this we used some mathematical techniques to handle the ICT signal instead of using the BCM integrators. Once the kicker noise alone and the beam pulse with kicker noise was coming, we began to integrate the ICT signal. Fig. 6 is an offline analysis for beam on and beam off. The upper curves are integrated results with beam on and the lower curves are integrated results with beam off, i.e. only kicker noise. So we see that with this method the influence of the pulse movement can be solved and the influence of the kicker noise is also small.

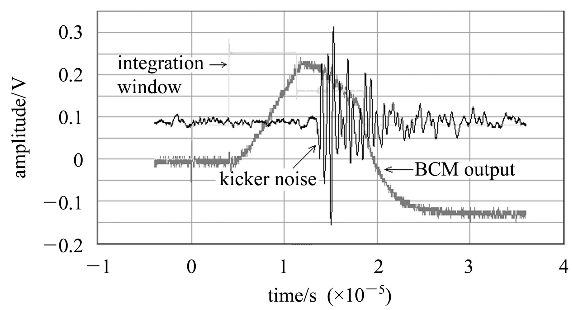


Fig. 5. Kicker noise measurement.

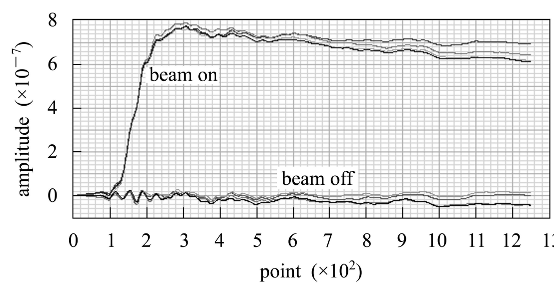


Fig. 6. Mathematical analysis result with beam on and beam off.

If we use the ICT to measure the particle number in the range of $10^6$–$10^7$, it is necessary to do some improvements because the influence of the kicker noise is too large. First one has to fix the kicker noise position in the integration window from the control system. Second the kicker has to be shielded.

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## References

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