A DC Current Transformer for TRIUMF

Yan Yin
TRIUMF, University of British Columbia
4004 Wesbrook Mall, Vancouver, V6T 2A3, Canada

ABSTRACT

A DC current transformer (DCCT) has been designed to operate over the current range of ± 20 mA, with a resolution and accuracy of 2 μA. The long term drift has been measured at less than 3 μA over 30 hours.

A test has been done using H^- beam CRM 2" cusp ion source to compare the readings of DCCT and the Faraday Cup. The test shows that they both agree within 3 μA.

1. The Principle of the DCCT

The DCCT consists of 2 toroids which are wound with 1 mil supermalloy tape. The diameter is 8.5" O.D, 7.875" I.D, the height is 0.313". The two toroids are matched with each other. The permeability is as high as 60000.

There are 5 coils. Each toroid has a 30 turn drive-coil driving it to saturation. The two drive coils are connected in series but with opposite polarity. So the two toroids will be driven into saturation in opposite directions. A 100 turns sense coil is wound around the two toroids. The DCCT measures the magnetic field of the beam. When there is no current going through the toroids, the sense coil will sense nothing. But when there is current going through the toroids, the current will bias the saturation of the toroids, the difference of them is proportional to the current to be measured. A feedback coil is used to balance the sense signal, so that the current going through the feedback coil will build up a voltage on the standard resistors to be readout.

The circuit is a modification of the CERN[1] type DCCT circuit. The circuit consists of Drive, Receiver, De-modulator, Feedback, Calibration and Output. The driving signal is a 1.7 KHz square wave.

2. A Test with ion source

The device was installed in the injection line of the Central Region Model cyclotron and its output compared with the current read by a Faraday cup equipped with ring plates biased to repel stripped and secondary electrons, The DCCT was inserted into the beam pipe with an nylon pipe spacer to cut off the wall current which flowed through wires bridging the gap and outside the DCCT. With this arrangement, the DCCT will be able to detect the beam signal. Fig.1. A 2" cusp ion source delivered a steady current of H^- or D^- ions accelerated to 15 KeV.

Three tests have been done. The first one compared the DCCT reading with the Faraday cup reading with H^- beam. The vacuum close to the the Faraday cup was 4×10^{-7}. Due to current limit of the ion source, the measurement was only done up to 950 μA. The measurement showed that the DCCT read a current 5% smaller than the Faraday Cup did, Fig.2, where " □ " represents H^-, "+" represents D^-.

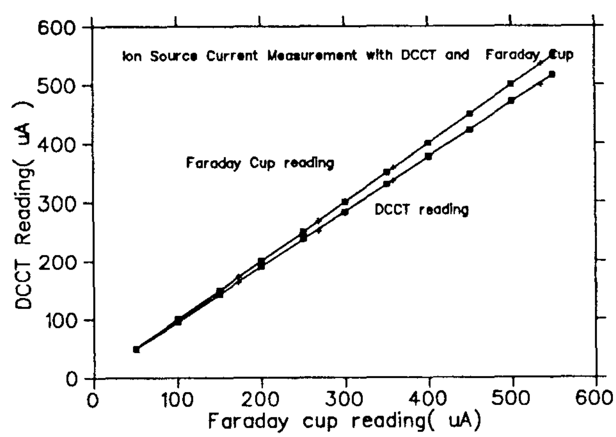

Fig.2. Ion current measured by Faraday Cup and DCCT

To understand the discrepancy of the two readings, the second and the third tests were done. The second test measured the currents from Faraday Cup and the Bias while keeping the voltage of the bias at -300 volts but changing the beam current. This test was done with D^- beam due to the ion source set-up at the time. The test showed that the current on the bias was increasing when the beam current was increasing. The difference between the Faraday Cup and the bias current is just the reading of DCCT, see Fig.3, symbol "+". Although the DCCT was not installed at the second and third test, by interpolating from the Faraday Cup reading, , the corresponding data which fitted the the DCCT reading curve obtained from the first test, can be gotten. The difference is less than 3 μA as following table shows.

$I_{Faraday}$	$I_{Faraday}$-I_{bias}	$I_{interpolated}$=DCCT
173	165	164.62
268	253.5	254.56
301	283.4	284.92
358	337.2	337.52
400	377.1	377
536	500.7	503.4

The current unit in above table is μA.

The third test measured the currents from Faraday Cup and the Bias while keeping the beam constant and changing the voltage of the bias from 0 to -350 V. The vacuum in the beam pipe before the Faraday Cup was 2.6×10^{-7}. This test showed that the difference between both was constant although both readings were changing, Fig.3. But when the voltage was higher than 10 volts, the change was very small.

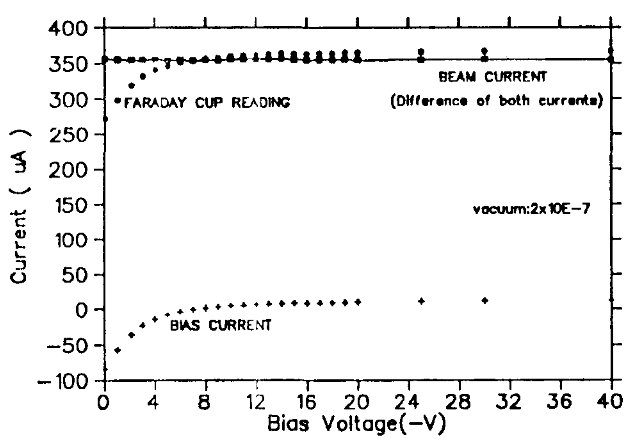

Fig. 3. The Bias, Faraday cup and DCCT

This phenomenon is related to secondary emission and backscattering. When the voltage of the bias is higher than -8 volts, the electrons due to secondary emission or gas stripping were repelled and can not reach the bias plate, but when the voltage is lower than -8 volts, the electrons will be able to hit the bias plate to form the negative current. When the bias voltage is higher than 8 volts, there is a positive current going through the bias plates, this is because the bias with negative voltage will attract the positive charges due to ion stripping and the backscattering. If the beam current is increasing, this part will be also increasing proportionally to the beam current.

3. The drift and sensitivity to the magnetic field of the DCCT

The DCCT was tracked over several days to measure the drift. The DCCT was placed in Trailer GG for a long weekend and the zero reading was collected by the computer.

The measurement started on Nov.8, Friday, 5:30 PM, ended on Nov.11, Monday, which was a long weekend. On Nov.10th 7:00 AM, the main magnet was turned on, the DCCT detected the magnetic field change, Fig.4. Each division of Y is equivalent to 10 μA. during the first 7 hours, DCCT drifted about 10 μA; it then stayed at $\pm2\mu$A. If the temperature change in the room was about 5°C, the drift related to temperature is 0.8 μA/°C. The DCCT reads current by measuring the magnetic field of the current. The μ of the toroid is 60000, so every mA current will produce 1.2 Gauss magnetic field in the toroid, which will be converted to the DC current reading. So the sensitivity to the magnetic field is about 0.83 mA/Gauss. This is consistent to the observation of the DCCT reading change when it was on the roof of the Proton Hall with the main magnet turned on.

4. The wall current influence to the DCCT

Although the DCCT measures the beam current by detecting the magnetic field, the non-metal material spacer is still needed nearby. Since when the beam goes through the pipe, the wall current will go along the pipe on the opposite direction, cancelling each other, and the DCCT will not be able to detect beam signal. Also because the beam pipe is like a long antenna, with many interference induced in it, this gives DCCT a big false reading. A test has been done to prove this. Even without the beam, the DCCT read about 4 mA which was jumping and could not be set to zero.

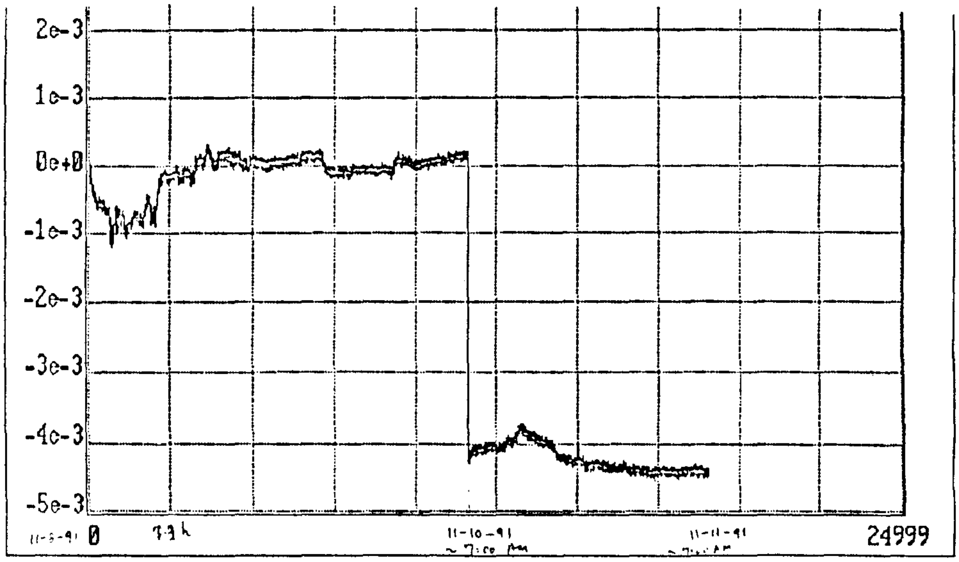

Fig.4. The drifting test and the influnce of the magnetic field

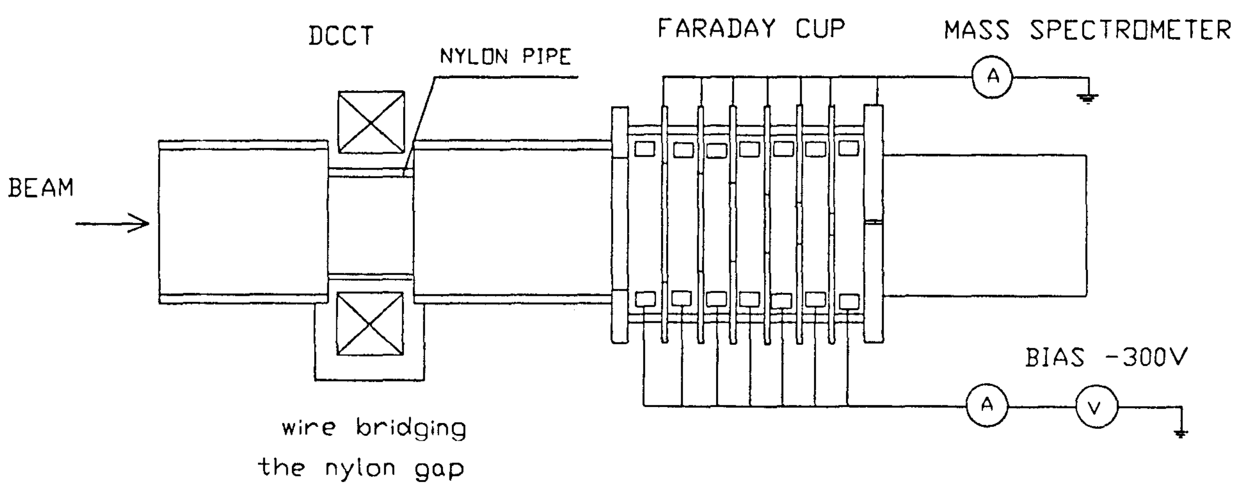

Fig. 1. IRM 2" cups ion source set up for DCCT test

5. Acknowledgments

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6. REFERENCES

1) K.B.Unser, *Beam Current Transformer with DC to 200 MHz Range*, IEEE ,NS-16, p.934-938, June 1969