SENSOR STUDIES FOR DC CURRENT TRANSFORMER APPLICATION*

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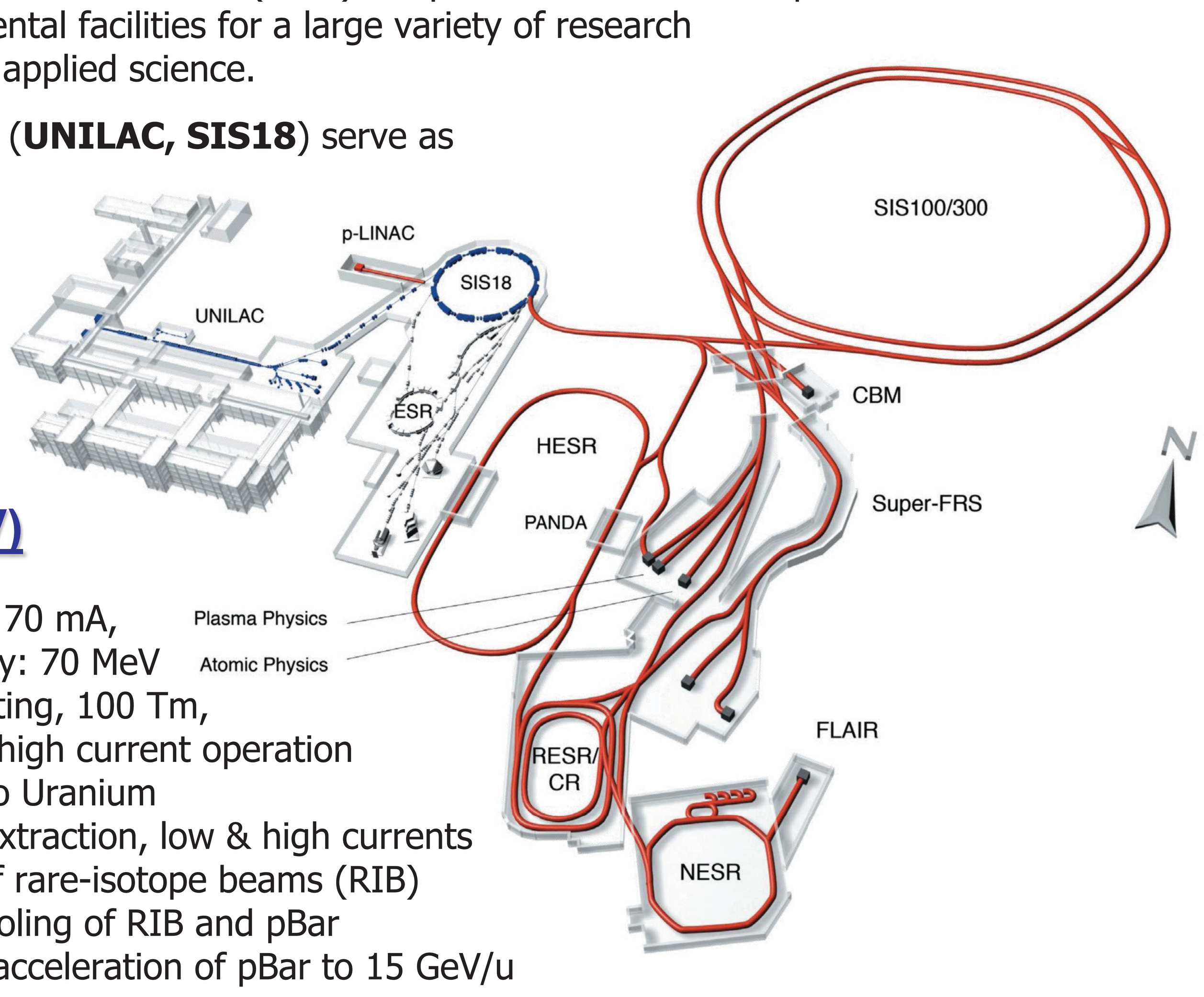
International Beam Instrumentation Conference
Monterey, California, USA September 14–18, 2014

Abstract

DC Current Transformers (DCCTs) are known since decades as non-intercepting standard tools for online beam current measurement in synchrotrons and storage rings. In general, the measurement principle of commonly used DCCTs is to introduce a modulating AC signal for a pair of ferromagnetic toroid, a passing DC ion beam leads to an asymmetric shift of the hysteresis curve of the toroid pair. However, a drawback for this measurement principle is found at certain revolution frequencies in ring accelerators, when interference caused by the modulating frequency and its harmonics leads to inaccurate readings by the DCCT. Recent developments of magnetic field sensors allow for new approaches towards a DCCT design without using the modulation principle. This paper shows a review of different kinds of usable magnetic sensors, their characteristics and how they could be used in novel DCCT (NDCCT) devices.

FAIR Facility & Requirements

- Facility for Antiproton and Ion Research (FAIR) will provide worldwide unique accelerator and experimental facilities for a large variety of research programs in physics and applied science.
- existing GSI accelerators (**UNILAC, SIS18**) serve as **injectors for FAIR**



Modularized Start Version (FAIR-MSV)

- **p-LINAC:** high current: 70 mA, proton energy: 70 MeV
- **SIS100:** superconducting, 100 Tm, 1-29 GeV/u, high current operation for protons to Uranium
- **HEBT:** fast & slow extraction, low & high currents
- **S-FRS:** production of rare-isotope beams (RIB)
- **CR:** stochastic cooling of RIB and pBar
- **HESR:** storage and acceleration of pBar to 15 GeV/u

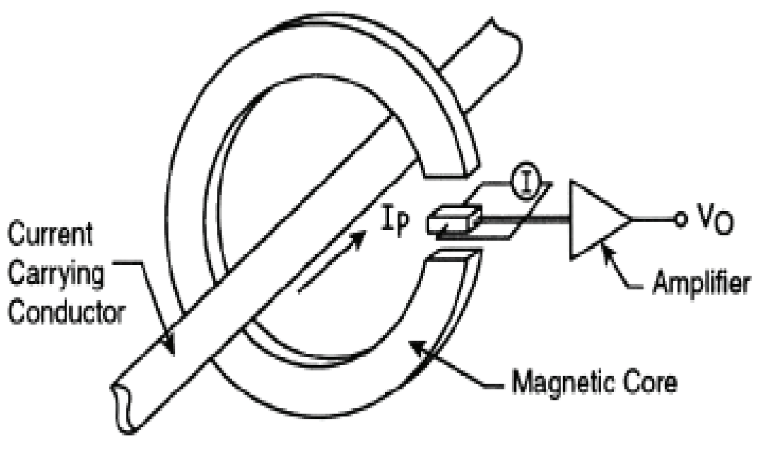
Requirements for Beam Current Monitors

- **SIS100, HEBT:** wide range of beam intensities with special requirements for diagnostic devices at each installation location
- **Novel DCCT:** measurement of mid-range to high beam intensities inside SIS100 with high input bandwidth from dc to several kHz current signal.
- **Cryogenic Current Comparator:** high-precision measurement of slowly extracted beams in nanoampere region, bandwidth dc up to few kHz
- **Resonant Beam Charge Transformer:** precise pulse charge measurement of fast extracted beams with high accuracy for online transmission control.

Novel DC Current Transformer

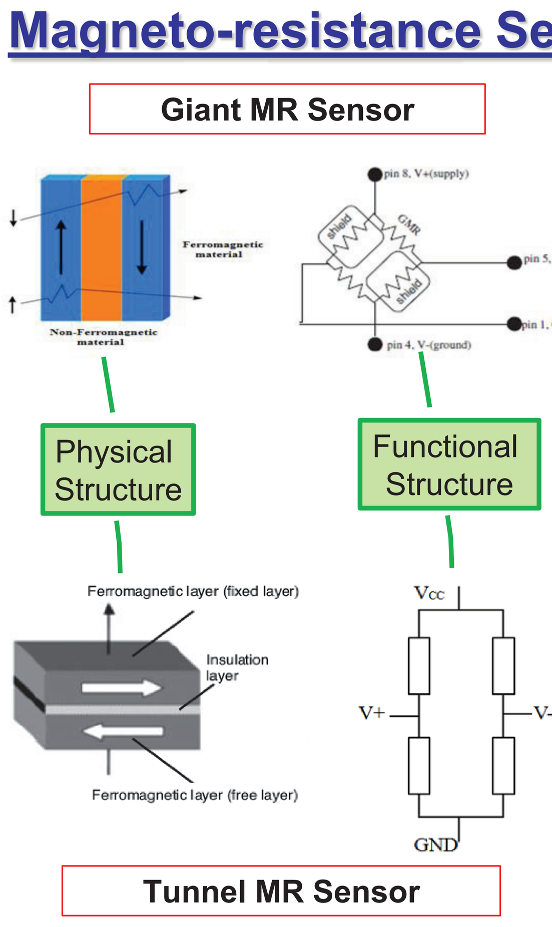
Design Concept:

- The NDCCT consists of a high permittivity slotted flux concentrator
- A magnetic field sensor is placed inside the air gap of the flux concentrator
- The magnetic sensor output voltage is proportional to the magnetic field inside the air gap 'B_{gap}'
- The sensitivity of the NDCCT is inversely proportional to the air gap width 'd'
- An amplifier is implemented on the sensor PCB to amplify the output signal to increase sensitivity.
- Different types of magneto-resistance (MR) sensors integrated circuits are available as magnetic field sensors



$$B_{gap} = \mu_o \frac{I}{d}$$

Magneto-resistance Sensors

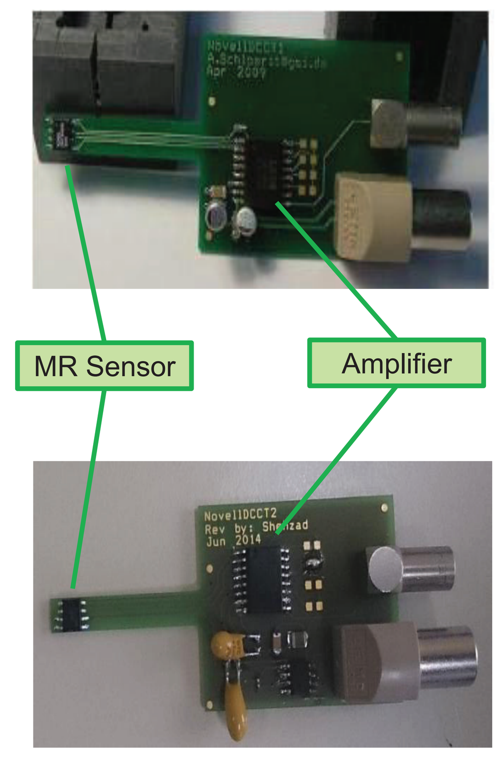


- MR sensors are based on a quantum mechanical magneto-resistance effect
- The MR effect refers to the change of the material's electrical resistivity in response to a change of an external magnetic field
- The change in the material's resistance could be enhanced significantly in thin film multilayer structures of alternating ferromagnetic/non-magnetic materials
- Two main types of MR sensors Giant Magneto-Resistance (GMR) and Tunnel Magneto-Resistance (TMR) sensors
- The functional structure is identical for all MR sensors. Four thin film resistors form a Wheatstone bridge.
- If an external magnetic field is applied the resistor's value changes and consequently the voltage of the bridge changes as well
- GMR has two shielded resistors in the bridge and this causes unipolar output voltage in contrast to the bipolar output voltage of the TMR.

MR sensors study for NDCCT

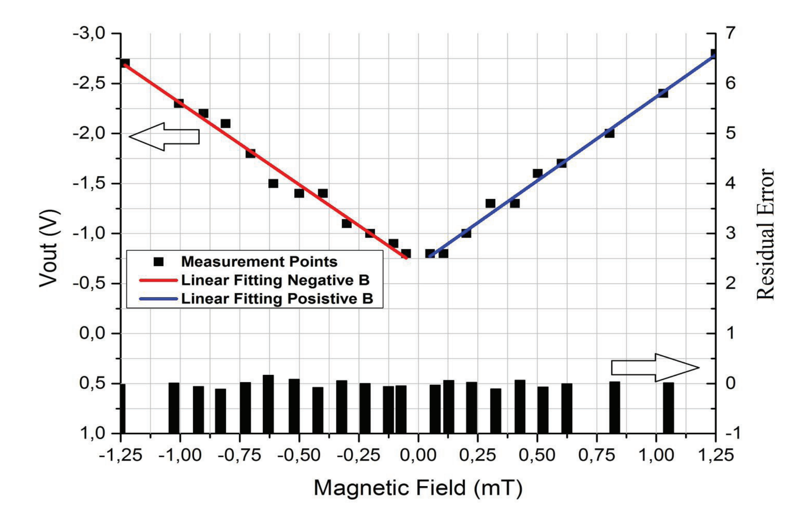
Testing MR sensors:

- Two PCBs were fabricated by GSI to compare the performance of GMR and TMR sensors
- The PCB contains a MR sensor and an operational amplifier to amplify the output signal of the sensor
- The GMR sensor is from NVE type AA002 and the TMR sensors are available in two types MMLH45F and MMLP57FP
- A test of the sensors functionality using a permanent magnet was done
- The value of the magnetic field at the sensor was measured using a Hall probe
- The DC output voltage of the PCB is measured versus the magnetic field by varying the distance between the permanent magnet and the magnetic sensor PCB

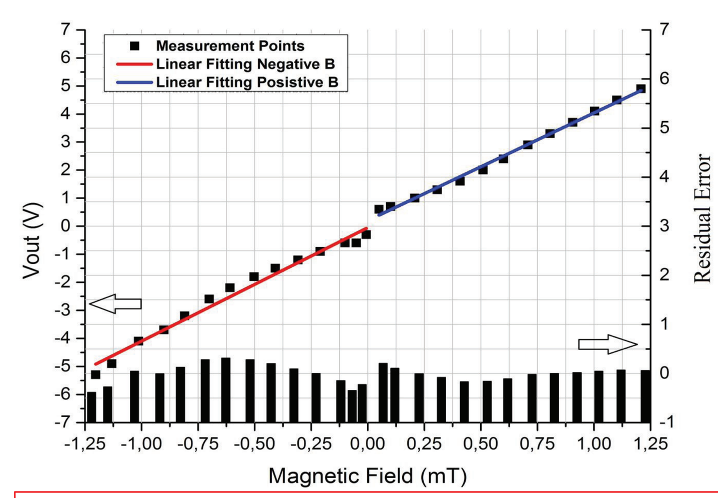


Experimental Results

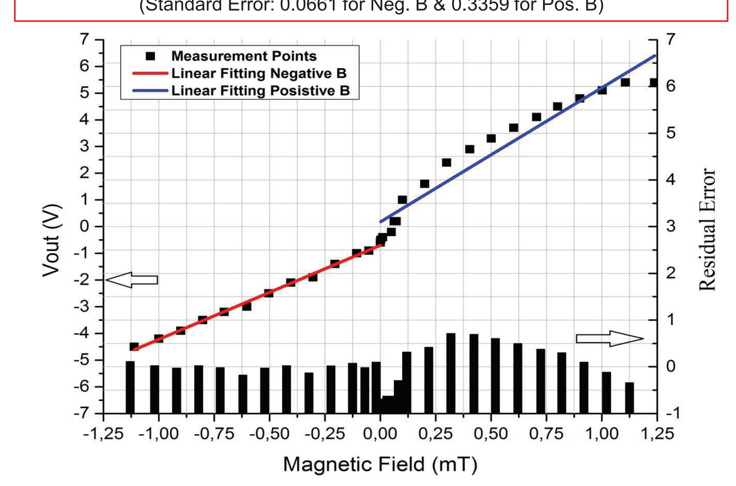
GMR Sensor NVE AA002 (Standard Error: 0.0492 for Neg. B & 0.0652 for Pos. B)



TMR Sensor Dowaytech MMLH45F (Standard Error: 0.1697 for Neg. B & 0.0842 for Pos. B)



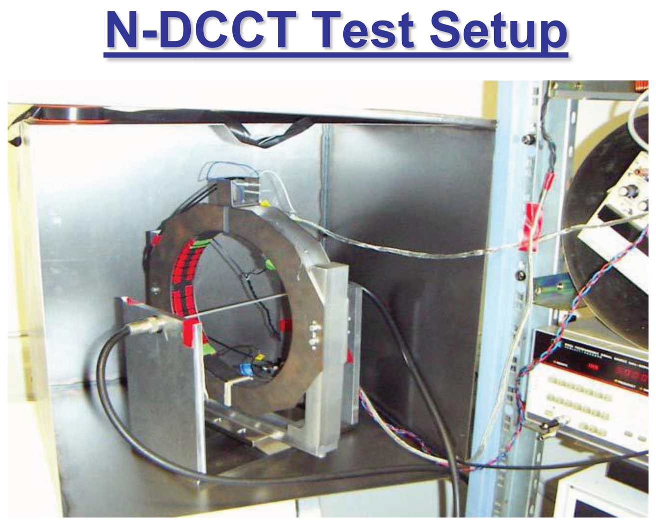
TMR Sensor Dowaytech MMLP57FP (Standard Error: 0.0661 for Neg. B & 0.3359 for Pos. B)



- Both TMR sensors have bipolar transfer characteristics in contrast to the GMR sensor
- TMR sensors have higher sensitivity compared to the GMR
- Also with the use of the op-amp both types of TMR sensors display a comparable sensitivity
- the DC current needed to have a magnetic field value of ±1.25mT in a 10mm air gap width, then the current value will be ±10A

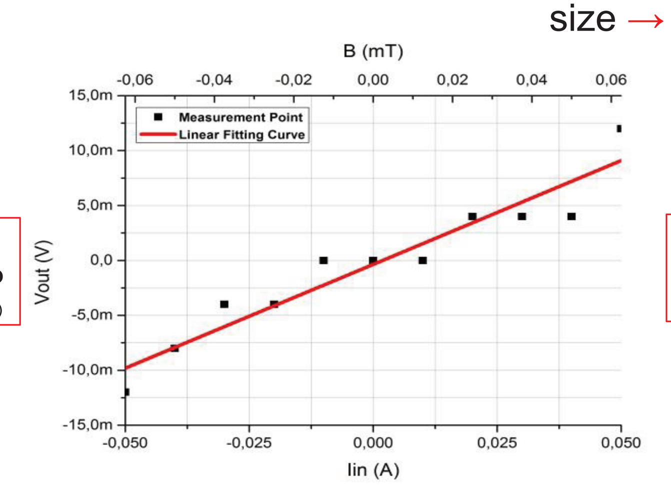
NDCCT DC wire test

N-DCCT Test Setup

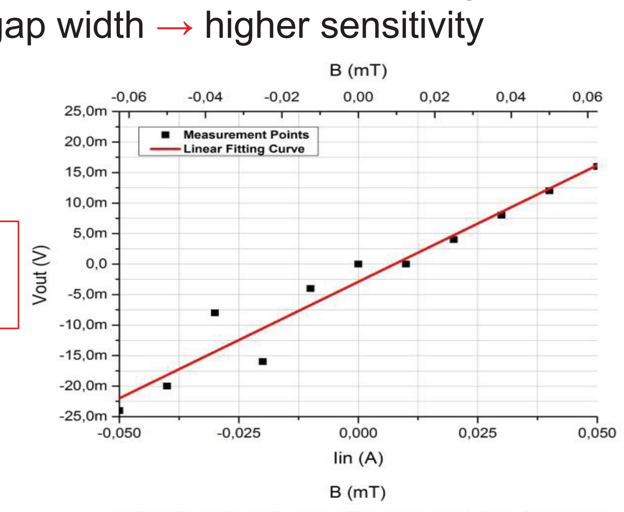


- A ring core flux concentrator from Vitrovac Company '6025F' is used
- The width of the air gap is 10 mm for MMLP57FP and MMLH45F sensors
- A μ-metal box for shielding covers the whole NDCCT test setup
- two types of the TMR sensors in SOP8 package were used MMLH45F and MMLP57FP
- The sensitivity of the NDCCT is given by the slope of the curves
- MMLP57FD is a TMR sensor in a DFN8 package → smaller size → smaller air gap width → higher sensitivity

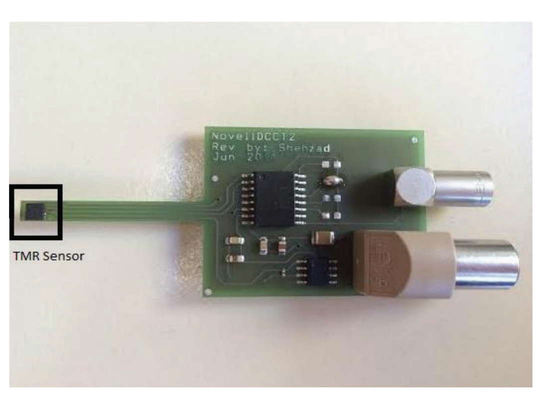
TMR MMLP57FP (Typical Error: 0.01939)



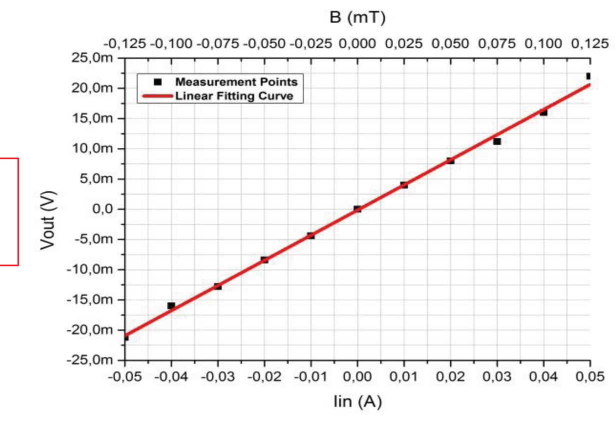
TMR MMLH45F (Typical Error: 0.03102)



MMLP57FD PCB



TMR MMLH45F (Typical Error: 0.00645)



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