# HIGH DYNAMIC MAGNETIC BEAM CURRENT MEASUREMENTS BY MEANS OF OPTIMISED MAGNETO-RESISTANCE (MR) SENSOR ENGINEERING

Markus Häpe, Wolf-Jürgen Becker, Werner Ricken, University of Kassel (UNIK), Germany Andreas Peters, Hansjörg Reeg, Piotr Kowina, GSI Darmstadt, Germany

## Abstract

A new sensor for the beam current measurement is under design at the department of Measurement Engineering at University of Kassel and GSI Darmstadt. An overview of the commercial available magnetic sensors like AMR- (<u>anisotropic magneto-resistance</u>) and GMR- (<u>giant magneto-resistance</u>) sensors and also the new magnetic GMI-effect (<u>giant magneto-impedance</u>) is given. These sensors have been investigated for their suitability for the clip-on ampere-meter. The results will be discussed and an outlook for further development will be presented.

## **BASIC IDEA**

The GSI-FAIR project (facility for antiprotons and ion research) will comprehend DC currents up to around 1.2 A in the SIS 100 synchrotron and after bunch compression down to 30 ns pulse length the peak currents will reach up to 200 A.

The current measurement device itself will be designed in form of a clip-on ampere-meter, see Figure 1.



Figure 1: The open loop sensor

This configuration would have big advantages in contrast to a normal DCCT, because it can be dismounted without opening the vacuum due to its separable core. An alternative to a DCCT was looked for because of their problems with the high peak current in the bunch structure of 1 MHz up to 5 MHz. This difficulty was discussed at the 2<sup>nd</sup> CARE-HHH-ABI-meeting in Lyon end of last year, see Ref. [9] for more details.

To meet the challenging demands of beam current measurements – high dynamics, large current peaks – at the SIS100 new sensor techniques are foreseen, which will be reviewed in this paper.

# SIMULATION OF THE MAGNETIC FLUX CONCENTRATOR

The flux concentrator consists of soft-magnetic VITROVAC 6025F. The air gap of the flux concentrator is assumed to be around 5 mm, the inner diameter to be 200 mm (cf. Figure 1). The contour plot of the absolute values of the magnetic flux for an excitation current of 10 A is shown in Figure 2. The simulation has been carried out at GSI.



Figure 2: Contour plot of the magnetic flux

The estimated maximal field in the gap is derived to be around 27.4 mT for a beam current of 200 A peak, whereas the magnetic field in the core still keeps away from saturation. The resolution of this device is aimed to be 1 mA (corresponding to only 137 nT in the gap) in beam current, corresponding to a system dynamic of around 106 dB ( $2*10^5$ ). The results of the magnetic flux simulation deliver the input data for the sensor parameters – the range of the detectable fields can only be influenced by the material choice and geometry optimisation.

# PRINCIPLE INVESTIGATIONS ON MR-SENSORS

The characteristics like hysteresis, linearity and sensitivity of commercial AMR- and GMR-sensors as well as a GMI prototype sensor have been measured within the magnetic field of Helmholtz coils in a range of +/-4 mT at UNIK (see Figure 9).

The lowest detectable value (S/N) must be determined. Therefore the 1/f-noise, the Barkhausen noise and the thermal noise from the different sensors and the flux concentrator need to be investigated.

# AMR-AND GMR-SENSOR **CHARACTERISTICS**

Five AMR-sensors have been tested, integrated within different external electrical circuits. Modern sensors from Honeywell and HL PLANAR use a set- or reset-pulse to measure correctly. The sensors from Philips use a stabilisation field. The investigated AMR-sensors are:

HMC1001 Honeywell: HL PLANAR: KMY20S, KMY20M Philips: KMZ10A, KMZ43T

All these AMR-sensors were based on AMR-stripes with barber pole structure (Figure 3).



Figure 3: AMR-stripe with barber pole structure [3]

The measured characteristic for the HMC1001 is shown in Figure 4.



Figure 4: Measurement characteristics of HMC1001

Until now, one GMR-sensor, type NVE AA002 was measured. The multip-layer-structure of such a device is shown in Figure 5, the measurement of its characteristics in Figure 6.



Figure 5: Structure of a GMR-multi-layer sensor [5]

The reproducibility of the measured characteristics in Figure 4 and Figure 6 as well as comparable results in comparison to the data sheets was given. Nevertheless, some measurement problems can occur when using the sensors. The usage of the stabilisation fields, set- and reset-pulses and the needed precision of the orientation in the gap of the clip-on ampere-meter can have effects on the reproducibility of the measured values.



Figure 6: Measurement characteristics of AA002

The measuring range, sensitivity and hysteresis of the investigated sensors were nearly the same as from the datasheet. Therefore only the results of one AMR- and one GMR-sensor are shown:

Sensor	Measuring range	Sensitivity	Nonlinearity	Hysteresis
HMC1001 AMR [1]	±0,2 mT	$2540 \frac{V / V}{T}$	1%	0,05%
AA002 GMR [2]	1,05 mT	$3042 \frac{V/V}{T}$	2%	4%

Table 1: Table technical data from data sheets [1, 2]

The bandwidth and the dynamics of the commercial sensors are not well published from the manufacturers. Therefore we have to investigate these parameters with a special simulator in the next step.

#### **GMI-PROTOTYPE SENSOR**

Up to now commercial giant magneto-impedance (GMI)-sensors are not available. Therefore a GMIprototype sensor was constructed at UNIK (Figure 8).

GMI is another magneto-inductive effect observed in soft ferromagnetic metals. The ac impedance in a GMIelement has a strong dependence on the applied magnetic field [6 - 8]. This is shown in Figure 7. The effect occurs at high frequencies and can be explained by classical electrodynamics.



Figure 7: Measurement characteristics of GMI [7], the impedance  $|Z_0| = 24.3 \Omega$ .

Radio frequency (RF) current is not homogeneous over the cross section of a conductor (skin effect). The skin depth  $\delta = \sqrt{(2 \cdot \rho)/(\omega \cdot \mu)}$  describes the exponential decay of the current density from the surface towards the interior of the conductor. It depends on the circular frequency of the RF current  $\omega$ , the resistivity  $\rho$ , and the permeability  $\mu$ . In ferromagnetic materials the permeability depends on the orientation of a bias dc magnetic field, the amplitude of the ac magnetic field and the frequency. The high permeability of the soft magnetic metal and its strong dependence on the bias magnetic field are the origin of the GMI effect. At frequencies above 1 MHz, eddy currents heavily damp the domain wall movements, and only magnetization rotations are responsible for magnetic permeability [8].

The prototype sensor itself is a magnetic controlled oscillator that uses the GMI-effect to tune the oscillator's frequency. It is shown in Figure 8.



Figure 8: Principle structure of the sensor [6, 7]

The frequency components of the oscillator were measured with a spectrum analyser in the simulation device with Helmholtz coils (Figure 9).



Figure 9: Principle structure of the measuring system with the MCO and spectrum analyser

The measurement characteristics for the GMI-prototype sensor is shown in Figure 10. This investigations have shown that the GMI-stripe is suitable for measurements within a range of  $\pm 1$  mT. The frequency modulation caused by GMI achieves a peak frequency deviation of 1 MHz, resulting in a measured slope of around 2 GHz/T. The oscillator frequency is 113.1 MHz for this special set-up.

The curve progression from the measurement characteristics of the GMI-prototype sensor (Figure 10) and the GMI-element (Figure 7) are proportional inverted. This effect is given by the formula of the resonant frequency. If the impedance grows it reduces the oscillator frequency.



Figure 10: Measurement characteristics of the GMIprototype sensor

### **CONCLUSION AND OUTLOOK**

The measuring range of all investigated sensors is yet too small, while the resolution of all the investigated sensors is small enough to measure the required beam current of 1 mA. Furthermore other sensors with enhanced parameters must be looked for. Another possibility is to build the clip-on ampere-meter based on a compensation system.

The next steps will be investigations of the sensor parameters in high-dynamic magnetic fields. Therefore a simulation device will be constructed and intensive measurements will be carried out in the next months. In parallel, a first core arrangement will be set up.

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