A PRELIMINARY STUDY OF A CURRENT TRANSFORMER BASED ON TMR SENSOR*

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Abstract

As Tunnel Magneto Resistance (TMR) sensor reaches high resolution and low noise, a new principle CT based on TMR sensor is developed. Simulations and other methods for improving the resolution and accuracy are done .The linearity and bandwidth of the sensor are test in the lab.

INTRODUCTION

A TMR (Tunnel Magneto Resistance) is a new generation of magnetic sensor devices after Holzer devices, AMR (anisotropic magneto resistance) and GMR (giant magneto resistance). TMR has low power consumption; high sensitivity and temperature drift characteristics. In the current sensor, the use of TMR instead of Holzer device can significantly improve the sensitivity of the current sensor, which can significantly improve the sensitivity and temperature characteristics of the current sensor.

Dowaytech has developed a TMR sensor, which has better temperature stability compared with higher sensitivity, lower power consumption and better linearity [1].

Based on the GSI's experiment [1], a new current transformer has been developed in IHEP.

BASIC DESIGN

The basic design of the TMR current transformer is something like clamp ammeter. Beam pass through a magnetic ring with a gap, a TMR sensor is put in a gap of the ring. The output of the sensor changes with the beam current.

A TMR's principle is based on tunnel effect of MTJs (magnetic tunnelling junctions). General MTJs is like a sandwich that consists of ferromagnetic layer, nonmagnetic insulating layer and ferromagnetic layer. The magnetization direction of the two ferromagnetic layer changes when the external magnetic field varies, which cause the tunnelling resistance changes. The resistances' change breaks the balance of the MJTs Bridge, and the bridge's output is linear relation with the magnetic field.

Early TMR sensor performance is limited by the sensitivity and background noise, Figure 1. As the advance of manufacture, the sensor now can measure very low field and reach high resolution for the background noise can be reduced to Pico Tesla. The typical parameter and spectral curve of the background noise with frequency of the sensors is shown in Table 1 [2].

Table 1: TMR9002 Parameter(temperature 25°C)

Parameter	Data
sensitivity	100mV/V/Oe
nonlinearity	1%Fs
noise	150pt/√Hz
V_{offset}	15mV/V
hysteresis	0.1Oe
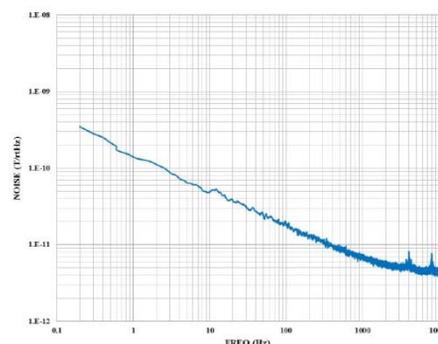
Figure 1: Background noise of TMR9002.

A high permeability nanocrystal soft material is chosen for the magnetic core, the primary μ_r is about 2e+5 and the coercive force is low. When the air gap meets the following requirements：g/a<0.2,g/b<0.2, Figure 2, the filled in the gap is approximate uniform [3].The B_g and H_g of the gap can be calculated as follow:

$$B = I/r[(2\pi - \theta)/\mu_r + \theta/\mu_0]$$

$$B \approx \mu_0 I/d$$
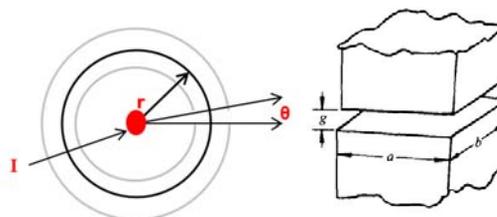
Figure 2: Calculate the B_g of the gap.

B is proportional to μ_0 and inversely proportional to the gap length when μ_r is much greater than μ_0. The dynamic range of TMR can be pre-estimated.

In this case, TMR9002 is chosen for the first prototype. For the extra power supply is needed and it is related to the sensitivity of the sensor. In first type of the electron-

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ics, the ps and output are integrated for stale and minimum the noise. .The structure of current transformer and the electronics is shown as below in Figure 3.
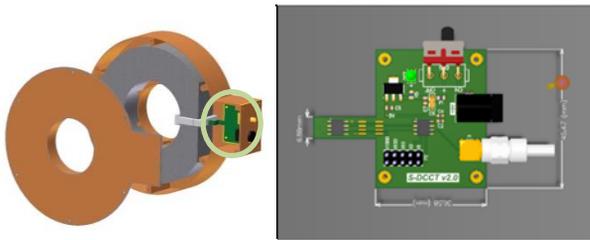
Figure 3: The structure of current transformer (right) and electronics of the TMR (left).

SIMULATION

Different from common magneto resistive device, TMR9002 is X axial sensitivity and SOP8 package, Figure 4. The effective area is quite small and the sensor's position in the gap is important for the measurement accu-racy. So simulation of the magnetic field in the gap has been done first.
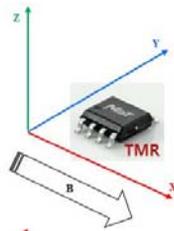
Figure 4: Sensitivity axial of TMR9002.

The CST [4] is used for the gap field simulation. From 0.1mA to 10mA DC current is set in the model as the beam current. In the first type of the core, the gap sectional area is a rectangle, as the result shows that smaller gap gives better distribution of field, but most of the magnetic lines of flux are at the edge of the gap. It makes poor efficiency of the magnetism gathering and the TMR sensor's position becomes critical. Lots of methods have been discussed. One of these is cutting off part of the sectional area. The simulation results are in Figure 5 and Table 5. The results shows that the thickness of the core is not involved too much of the gap field. The gap's width is one of the reasons of the inhomogeneous distribution of the gap field. All the cores without cut shows the deformed edge and weak field. The #4 core is cut off a regular part from the gap side, shows stronger and better field distribution in the gap.

Table2: The Parameter of the Simulation Core

No.	OD mm	ID mm	GAP mm	Specific
1	80	120	10	NA
2	80	120	8	NA
3	80	160	8	NA
4	80	160	8	cut
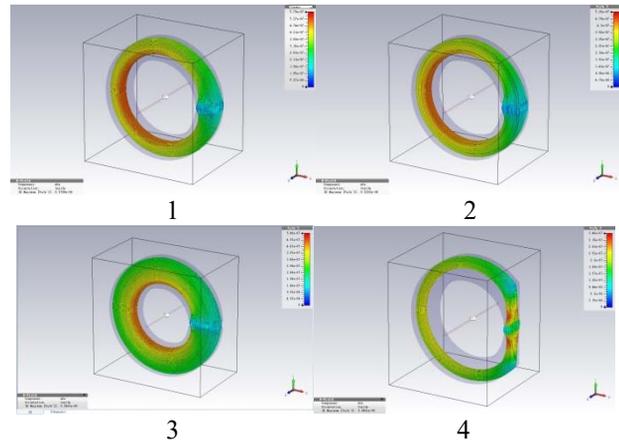
Figure 5: The simulation results.

TEST RESULTS

The first version of TMR current sensor has been test in the lab. The test plan is: a copper wire on a platform which used to fix the magnetic core and sensor is connected to the signal source and an oscilloscope or a voltmeter. Take the wire which is passing through the core as the beam. Different core is used in this experiment for finding a proper one. As the manufacture of the cut-off core is hard, it does not include in the first test.

The results shows, when gap is 8mm, the linearity of the sensor is satisfy and the coefficient of determination is $R^2=0.9997$ while the gap is 10mm, the $R^2= 0.997$ with some measurement point has greater deviation, Figure 6. The results trend fit the simulation.

During the test, one of the cores shows hysteresis effect that makes the offset is big. The difference may cause by the manufacture of these cores should be notice.

Gap=8mm

Gap=10mm
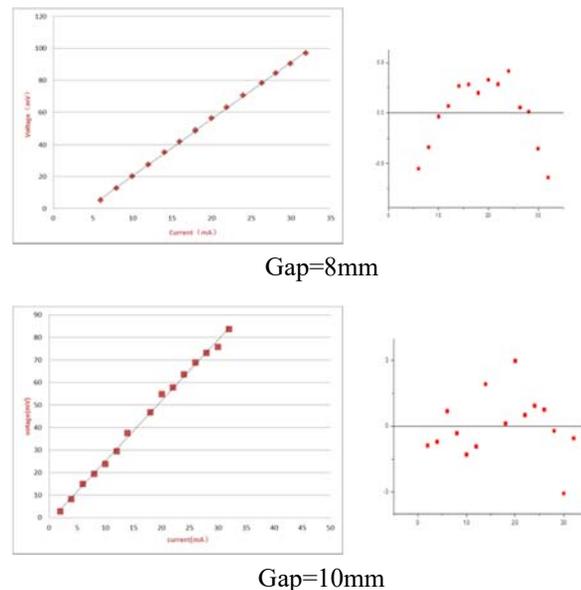
Figure 6: Different cores .linearity test result (left) and standard deviation (right).

The system bandwidth is related to the TMR's bandwidth, output circuit and the magnetic core. For the TMR is a magnetic device, the response is in tens of microsec-onds even milliseconds. A typical response of the stand-ard square wave shows about 50μs rise time, Figure 7.
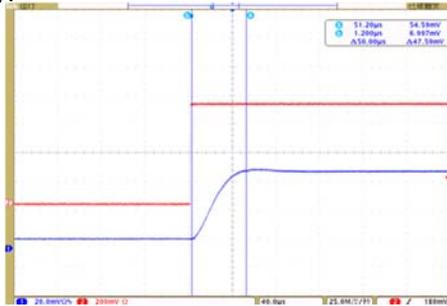
Figure 7: TMR current sensor's response (blue) of standard square wave (red).

CONCLUSION AND NEXT TO DO

The TMR current sensor preliminary test shows good linearity, but the shielding and mechanical support needs to be improved.

The dynamic measurement range of TMR is restricted by the saturation field. In this test, beyond 40mA the sensor works in a bad region. If the magnetic field is beyond a certain value, the TMR sensor will work in a nonlinear region. Limited by the manufacturing process, enlarge the good working region and keep the good resolution at the same time is quite difficult. That's the key point limit the current sensor's range. Two TMR sensors can reach the demand, but the details should be carefully considered.

Although the temperature drift is better than other magnetic sensor devices, the influence of the ambient temperature should be notice too. As the drift of the output induced by temperature is calculate. The chip impedance change from 6300 to 6000Ohm when the temperature changes and the shift of output signal is 0-0.5mV. So the complex environment needs further consideration.

REFERENCES

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