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UPGRADE AND IMPROVEMENT OF CT BASED ON TMR

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Abstract

The CT based on TMR sensor has been developed in the lab. For Improving the accuracy and linearity, reducing the influence of sensor position, a series simulation and calculation have been done which conduct an upgrade both in the mechanical structure and electronics design. Lab test shows good results and test on beam will be carried on soon.

INTRODUCTION

The CT based on TMR sensor's principle is like hall 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 [1]. The a principle diagram and the whole profile are shown in Figure 1. First test indicate that the resolution and linearity error could not meet the demand, improvement of the magnetic core and electronics design has been done, most details are present in this paper.

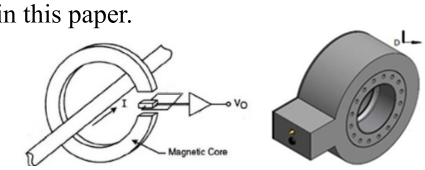

Figure 1: Principle and profile of TMR CT.

STUDY AND IMPROVEMENT OF CORE DESIGN

One of the key parameter that involves the resolution are the core with a cutoff section. The soft alloy which has been processed is used as the magnetic core.The initial permeability is changed, so does other characteristic.

The cutoff section is an air gap,for an toroid core with air gap and ignore the edge flux,a equivalent permeability μ_e can be calculate as below.

$$I_{beam} = \frac{B_{core}}{\mu_0\mu_r} l_{core} + \frac{B_{gap}}{\mu_0} l_{gap} = \frac{B_{core} l_{core}}{\mu_0\mu_r}(1 + \frac{\mu_r l_{gap}}{l_{core}})$$

$$\mu_e = \frac{1}{\frac{1}{\mu_r} + \frac{l_{gap}}{l_{core}}}$$

l_{core} is average core circumference $2\pi r_{core}$ (r_{core}=(r_{out}+ r_{in})/2, r_{out} and r_{in} are outer and inner radius of the core), l_{gap} is length of the air gap. When μ_r is large enough, the μ_e is related to the l_{gap} and l_{core}. It means the core magnetic permeability is decreased and linearized.

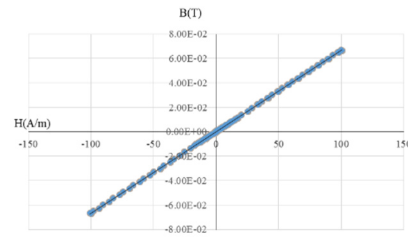

Figure 2: Magnetization curve test result of the core with air gap.

The magnetization curve of the core with air gap is test in the lab as shown in Figure 2. The magnetization curve with air gap can be seen as the synthesis of magnetization characteristic of the core and air gap. The air gap reduces the remanence and the core saturation.It also means most of the loss is garthered in the gap instead of the core.

High frequency signal brings hysteresis loss. If the magnetic core cross section area is A_{core},, the exciting signal are u(t) and i(t). As indicate in Figure 3, the area A_1 of $-B_r$ ->S -> B_m -> - B_r, means the exciting signal varies from zero to the maximum, in the half period T/2 ,the total energy can be calculate below:

$$\int_{\alpha}^{\alpha+\frac{T}{2}} u(t)i(t)dt = \int_{-B_r}^{B_r} A_{core}\frac{dB}{dt} \cdot Hl_{core}dt$$

The area A_2 from S to B_m is the part of recoverable energy. The energy of the core loss is proportional to the area around the hysteresis loop, is related to the area of A_1-A_2. With air gap the A_1-A_2 is small enough to be ignored.[2]

$$A_{core}l_c(\int_{-B_r}^{B_s} HdB - \int_{B_s}^{B_r} HdB) = A_{core}l_c(A_1 - A_2)$$

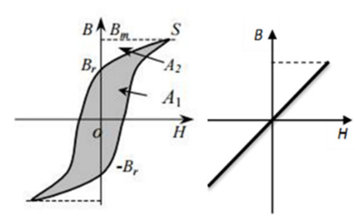

Figure 3: Magnetization curve without (left) and with (right) air gap.

Primary design and test result shows that output resolution is influenced by sensor's position and angle in the gap. Focusing on how to uniform the magnetic field distribution doesn't show effective improvement. As the sensing area is 2mm much smaller than the gap section area 20mm x 20mm, gathering the magnetic field is a feasible option. A perpendicular cutoff is made to reduce the cross section as shown in the Figure 4. The gap section area is 10mm x 20mm after this improvement.

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Figure 4: Sketch of the perpendicular cutoff.

One of the side-effect of perpendicular cutoff is the increasing of edge flux. Basic knowledge, magnetic fields are not insulated, the space around the air gap can be also seen as part of the magnetic circuit, so does the side section.The edge flux and gap flux are in parallel, it equivalent to enlarge the air gap section area, and leading the increase of the inductance L of the core.A simulation result also shows that the field in the air is concentrated and the edge flux is more obvious in Figure 5[2]. Another aspect concerned is the edge flux that may impact the eletronics nearby which so far do not observed in the test.

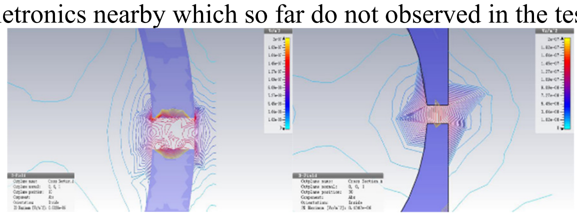


Figure 5: Simulation resluts of before(left) and (after)perpendicular cutoff.

ELECTRONICS DESIGN

The electronis has two simple main function : power supply for the TMR sensor and processing the output signal.The TMR rated operational voltage determin the output sensitivty *S* mV/V/Gauss. Choosing of operational voltage focus on the high enough sensitivity and flat stable work area. Temperature drift at different working voltage as shown in the figure. From 1 to 6 volt to driving,[3] A 14 hours continuous electronics temperature drift test form 18-27˚C has been record, reslut shows less dependence,for large scale of temperture test should be done in the future.

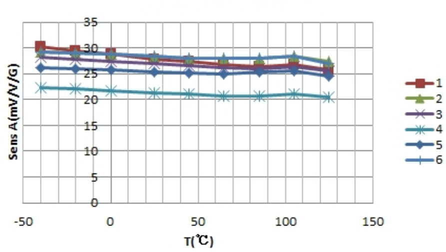


Figure 6: Sensitivity drift with temperature at different working voltage.

One of the aspects that involved the sensing area is the stress between the TMR board and the main electronics board. The vibration conduct to the TMR board lead the sensitivity change. The flat cabale is chosen to connect the two board shows much improved. A FFC (Flexible Flat Cable) is also a proper one. Range control protects the TMR sensor's saturation, it is integrate on the board which may change to remote control in the future. Figure 7 shows the component of the electronics.

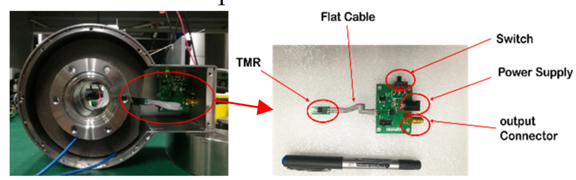


Figure 7: CT structure and the eletronics.

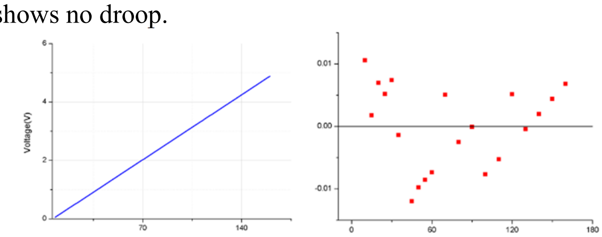
MECANICAL DESIGN

Mechanical structure design aims to be easy installed and stable. Two layer of low permeability steel and copper are used for shielding and conduct the wall current. In the first design, a vacuum chamber with ceramic gap and flange is made integral with the core and eletronics. Further plan is making two semicircle core and clip on the beamline for do not need to break the vacuum. The structure is shown in Figure 7.

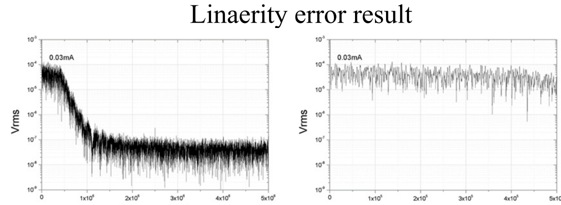
TEST RESULTS

In the Lab, the CT's performance has been test using 30 meters long transmission cable,include : 1.DC linearity and resolution test,using transmille 3041 calibration and keithley 34401A DC current meters.NI PCI 4070 (DC) with external trigger [2]. Square signal responds and bandwidth test, using leCroy oscilloscope 6GHz 40GS/s, Agilent 33250A waveform generator.

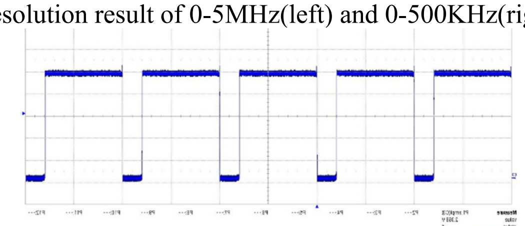
The 200mA range test results is shown in Figure 8. The linearity error of full scale is less than 0.2%. For TMR's bandwidth is DC-5MHz[3], the step at 1MHz of resoluton result is because of the electron component's bandwidth limit which can be increased in the next version. The CT's bandwidth is low enough as the square signal responds shows no droop.



Linaerity error result



Resolution result of 0-5MHz(left) and 0-500KHz(right)



Square signal responds

Figure 8: Test results of 200mA range.

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CONCLUSION

The improvement and upgrade study shows good results in the performance, especially amend of core structure. An extra calibration winding and electronics are plan to complete the function. For further online test, vacuum need to be promote, shielding from disturb and noise are the key issue should be concerned.

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