Performance of various Hall generators for 3-axis magnetic field measurements

E. Kusano, K. H. Tanaka, K. Agari, M. Ieiri, Y. Katoh, Y. Sato, Y. Suzuki, M. Takasaki, H. Noumi, M. Minakawa, and Y. Yamanoi

Abstract

Now we are preparing a new 3-axis magnetic field measurement system based on Hall sensors. In this report, we would like to describe the selection of the Hall sensors for the system. Some domestic Hall sensors can be driven with low control current, high output Hall voltage, and small temperature dependence. The price of them are incredibly low. We studied their performance by using a dipole magnet whose maximum flux density is 2.4 Tesla.

1 INTRODUCTION

We have to manage a few hundreds of magnets equipped in the neutrino beam line and other external beam lines of the KEK-PS. Since the construction of the 50-GeV Proton Synchrotron at the KEK/JHF and JAERI/NSP joint accelerator project [1] has started, we will have to manage more and more magnets soon. Then we need a new 3-axis magnetic field measurement system, which is sensitive, speedy, and lower cost. Recently, Hall sensors are used widely, for example, door switches in refrigerators and washers, rotational speed sensors of motors of CDs, and so on. Since huge numbers of Hall sensors are produced and used, the prices of them are going down and their quality is being improved well. Then we checked their performances up to high magnetic field.

2 CHARACTERISTECS

The number of Hall generators researched in this paper was 11. Their electrical characteristics are listed in Table 1.

F.W. BELL [2] is a famous company for its Hall sensors for a long time. The BH-703 has been used and made a good job in the accurate measurements of our magnetic field measurement system for more than 10 years. However typical output Hall voltage is too low in spite of the relatively large operation current. In addition it is too expensive for us.

Hall generators of domestic companies of National [3] and ASAHI-Kasei [4] seem better than F.W.BELL's. Their control current is small, i.e. a few mA. Output voltage to the same magnetic field is approximately 10 times higher than F.W.BELL's. Especially, OH023's operation current is only 1.5 mA. It can be operated by a dry battery. Then we can make a portable field measurement system without using the specific power supply. Their temperature dependence also is as small as BH-703's, which is the smallest in F.W.BELL's Hall sensors.

3D-H-30-C made by GMW [5] Co. in U.S. is a novel single-chip Hall sensor, which can measure 3-axis magnetic field simultaneously. The principle or characteristic is detailed in the reference 5. The 3-D-H-30-C Hall sensor is basically a square block of low-doped silicon fitted with 8 ohmic contacts at the surface. The current runs in the surface of square block, and each face generates Hall voltage. The unique vertical Hall geometry allows the extraction of the information about the three magnetic field components simultaneously at the exactly same spot in space within a cube of 0.1mm. Since Electrical connection consists of only two energy supply contacts and only four sense contacts, it can be operated remarkably low current, i.e. 3mA, for the 3-axis.

Maker	Model	Material	Operation Current [mA]	Temp. coef. of Hall voltage [%/℃]	Typical Output voltage [mV/0.1T]
BELL	BH-703	InAs	100	-0.04	10
National	OH003	GaAs	6	-0.06	150
	OH008				150
	OH009				105
	OH010				105
	OH023		1.5		90
ASAHI-Kasei	HW105C	InSb	5	-1.8	175
	HW108C				175
	HG106A	GaAs		-0.06	170
	HG106C				130
GMW	3D-H-30-C	Si	3	0.1	X,Y:27.5 Z : 10

Table 1: Electrical Characteristics of each Hall generator.

3. MEASUREMENT

The dipole magnet used for this measurement is seen in Fig. 1. The maximum flux density is 2.3 Tesla. The stability of magnet power supply is better than 10^{-4}. The Hall sensors were mounted in a plastic plate seen in Fig. 2. This plate was inserted into the gap of the magnet and set parallel to the magnet pole face. The Hall sensors were driven by constant current mode. The stability of current supply to Hall sensors is within $\pm 0.02\%$. The output voltage was read by digital voltmeter. Each Hall sensor was directly connected to the current supply and the digital voltmeter by twisted cables. The response of the each axis of the GMW's tri-axial Hall sensor was measured independently. In order to set perpendicularly between each axis of the Hall sensor and the direction of the magnetic field, it was mounted on a plastic cube. Absolute value of the magnetic field was measured by NMR at the same time.

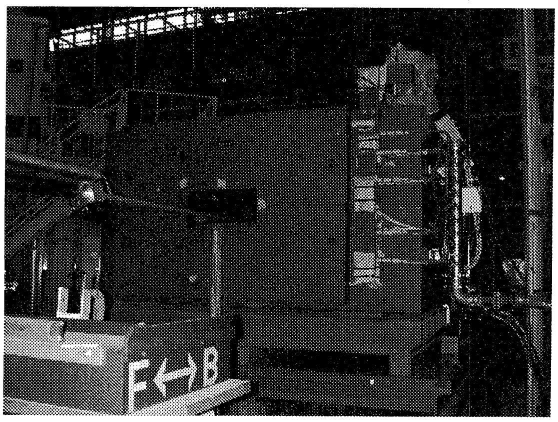

Figure. 1 The magnet used for the field measurement.

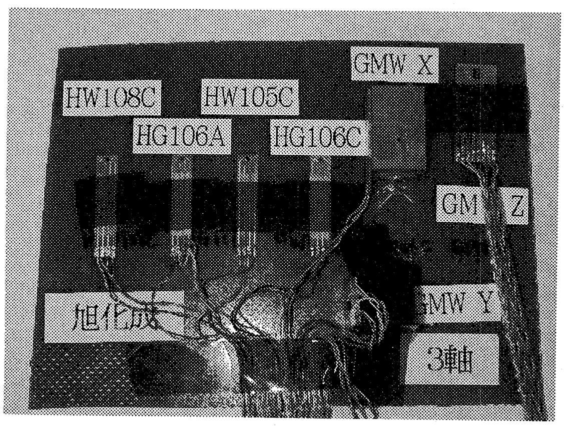

Figure. 2 The hall probes mounted on the plastic plate.

4. RESULTS

Measured output Hall voltages of National's Hall sensors are shown in Fig. 3 as a function of magnetic flux density. It is found that measured output Hall voltage can be represented by a linear function of the magnetic field. OH003 and OH023 generate approximately 2 V at 2 Tesla. OH008, OH009 and OH010 generate approximately 1.7 V at 2 Tesla. In Fig. 4 the non-linearity of them are shown as a function of the flux density. Non-linearity [%] is represented by,

$$\text{Non-linearity [\%]} = (V_{obs} - V_{exp}) \times 100 / V_{obs}.$$

Here V_{obs} is the measured Hall voltage and V_{exp} is the expected Hall voltage calculated from the fitted function. OH008, OH009 and OH010 keep their linearity within 1% between 0.15 Tesla and 2.3 Tesla. OH003 and OH023 is little worse.

Similarly, Fig. 5 and 6 illustrate magnetic field dependence of measured Hall voltage and the non-linearity of ASAHI-Kasei's Hall sensors, respectively. HG106A and HG106C generate approximately 1.8V at 2 Tesla, and linearity is good. HW108C and HW105C made from InSb reach approximately 2.5V at 2 Tesla. However their outputs are not linear as clearly seen in Fig. 5. Then a simple quadratic function was used for the fitting and for deducing the non-"linearity". Then the non-"linearity" for HW108 and for HW105C are plotted in Fig. 6 and are found to be a few percent.

The output voltage of the three independent axis of GMW's tri-axial Hall sensor is plotted in Fig. 7. The F.W. BELL's output voltage is showed in Fig. 7, too. It is found that generated voltages of F.W. BELL and GMW are very low, e.g. approximately 0.6V at 2 Tesla in the x and y axes of GMW's and approximately 0.1V at 2 Tesla in the z axis of GMW's and BELL's.

The output non-linearity of BELL's and at each axis of GMW's are plotted against the magnetic flux density and shown in Fig. 8. It is found that the linearity at x and y axes of GMW's is surprisingly good within 0.3% from 0.15 Tesla to 2.3 Tesla. Due to the device geometry, the sensitivity at two in-plane axes, x and y, is different from that at the other perpendicular axis, z. Then we fitted the output voltage at z-axis of GMW's by a simple quadratic function similar to the InSb devices. The output non-linearity of BELL's and at z axis of GMW's is approximately 2%.

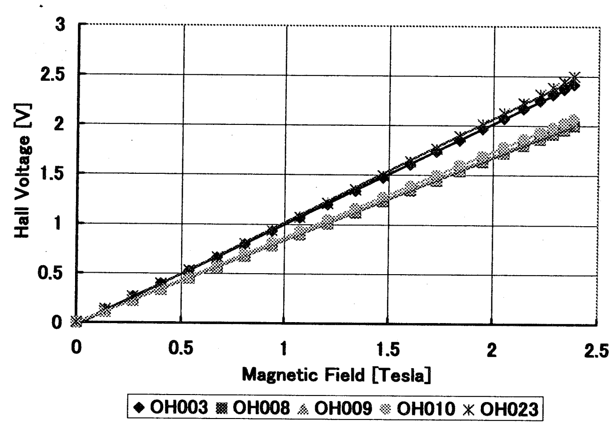

Figure 3. The output voltage of each National's Hall sensor plotted as a function of magnetic flux density.

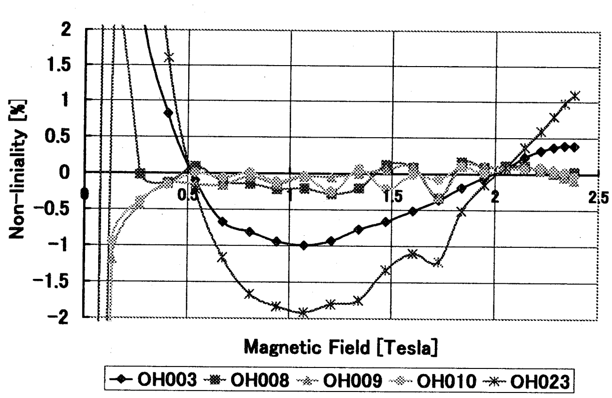

Figure 4. The non-linearity of each National's Hall sensor plotted as a function of the flux density.

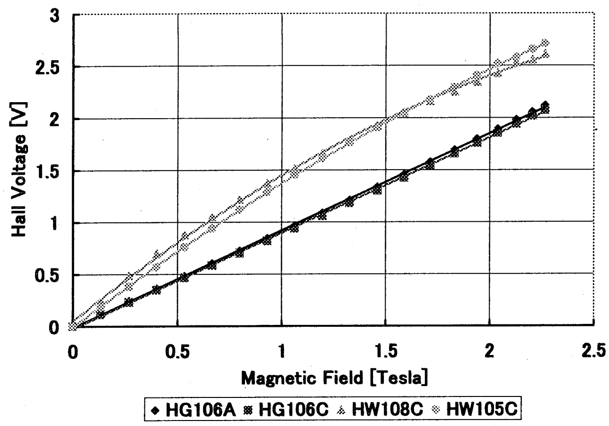

Figure 5. The output voltage of each ASAHI-Kasei's Hall sensor plotted as a function of the flux density.

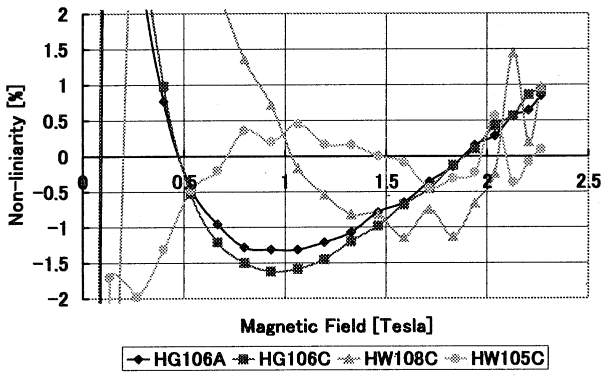

Figure. 6. The non-linearity of each ASAHI-Kasei's Hall sensor plotted as a function of the flux density.

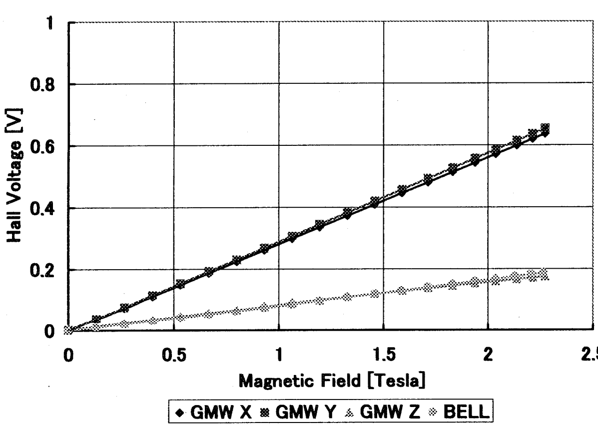

Figure. 7. The output voltage of each axis of GMW's Hall sensor, and a F.W.BELL's Hall sensor.

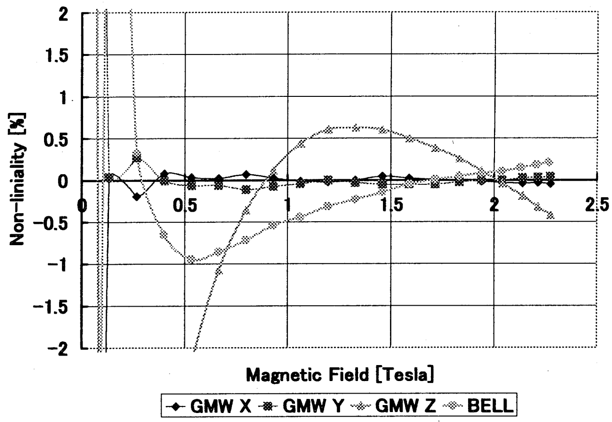

Figure. 8 The output non-linearity at each axis of GMW's Hall sensor, and a F.W.BELL's Hall sensor.

5. CONCLUSION

The output Hall voltages of various Hall sensors were measured up to high magnetic field of 2.2 Tesla. For all sensors non-linearity of the measurements is only a few percent in fields as high as 2.2 Tesla. Non-linearity of OH008, OH009, OH010 and the direction of x, y of 3D-H-30-C was approximately 1 % or less in the flux density up to 2.2 Tesla. However, due to the geometry, 3D-H-30-C has a few percent of cross-sensitivities between the three axes [5]. So it may not be appropriate for the exact magnetic field measurement system. Since OH023 or 3D-H-30-C has a feature of low power consumption, it is useful for battery-powered application, e.g. a portable polarity-checker or a portable field measurement device. We have made some portable ones, which have already been used in our beam lines. From this examination of each Hall sensor, it can be concluded that the performance of the new 3-axis magnetic field measurement system will be improved on better linearity, higher output voltage, and lower power consumption if we use either OH008, or OH009, or OH010. Our next step about the Hall sensor is to assemble 3-axis sensor complex with the temperature control within 0.1 ℃.

REFERENCES

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