Distributed Hall measuring system
Распределённая Холловская система для измерения магнитных полей

O. Volkova[a,b,1], *D. Chernovskiy*[a,b], *K. Shtro*[a,b]

О. А. Волкова[a,b,1], *Д.П. Черновский*[a,b], *К.С. Штро*[a,b]

[a] Laboratory 6-1, BINP SB RAS, Russian Federation, Novosibirsk, 630090, 11, Acad. Lavrentieva Pr.

[a] Лаборатория 6-1, ИЯФ имени Г. И. Будкера СО РАН, РФ, Новосибирск, 630090, пр-кт Академика Лаврентьева 11

[b] Novosibirsk State University, Russian Federation, Novosibirsk, 1, Pirogova street, 630090

[b] Новосибирский национальный исследовательский государственный университет, РФ, г. Новосибирск, Пирогова 1, 630090

Через перепускной канал инжекционного комплекса ВЭПП5, находящегося в ИЯФ им. Г. И. Будкера СО РАН проходят электроны и позитроны. Необходимо менять направление и значение магнитного поля в поворотных магнитах для таких разнополярных частиц, как электроны и позитроны. Из-за физических явлений в электромагните для точной установки поля важно измерять не только ток в катушках, но и непосредственно поле в канале. Целью работы является разработка установки, измеряющей магнитное поле в канале перепуска инжекционного комплекса с точностью лучше 10^{-3}. Для измерений выбран метод на основе эффекта Холла. Проведены испытания датчиков Холла на устойчивость к радиации. Разработан, собран и протестирован прототип устройства для этого эксперимента. Зарегистрировано изменение параметров Холла в зависимости от времени нахождения в радиационном поле. Эксперимент успешно продемонстрировал, что датчики Холла работают в инжекционном комплексе.

VEPP-5 injection complex located at BINP SB RAS delivers electron and positron beams through transportation channels to the VEPP-4M and VEPP-2000 colliders. It is necessary to change magnetic field vectors in dipole magnets to deliver particles which have different charges, such as positrons and electrons. Because of some physics effects in order to achieve precise adjustment of field, it is better to register not only current in magnet coils, but also the field in the transportation channel of the injection complex itself. The aim of the work is development of the device which would measure a magnetic field in the injection complex transportation channel with an accuracy better than 10^{-3}. Hall effect method is chosen. The tests on Hall sensors resistance to radiation are conducted. The device prototype for this experiment is created, assembled and tested. The change of Hall parameters due to time spent in radiation is registered. The experiment successfully demonstrated that the hall sensors operate in conditions of the injection complex radiation.

PACS: 44.25.+f; 44.90.+c

[1] E-mail: O.A.Volkova@inp.nsk.su, o.volkova2@g.nsu.ru

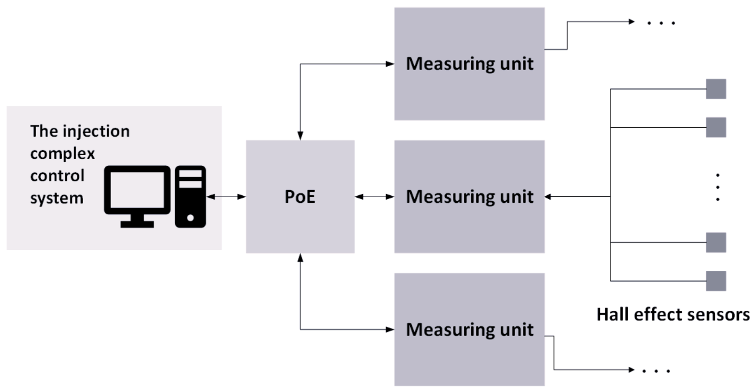

Fig. 1. Distributed Hall measuring system

Introduction

The injection complex VEPP-5 located at BINP (Novosibirsk) accumulates and delivers electrons and positrons to VEPP-2000 and VEPP-4M [1]. Since electrons and positrons delivered by the complex have opposite charges and different energies, the magnetic field inside the binding dipole magnets must change with error that is less than 10^{-3} when the complex switches from one type of particles to another. Binding magnet field dependence of current depends also on previous stages of magnet and current which leads to hysteresis phenomenon. Because of that it is better not only to rely on current measurement, but also to measure magnetic field itself.

1. Measurement system requirements

The aim of the work is development of the device which measures constant magnetic field around 1 T inside the injection complex binding magnets with an inaccuracy less than 10^{-3}. The device must operate remotely (in $20-30$ m) in order to avoid irradiation. Because the gap between magnet coil and vacuum tube is about 1.5 mm, field sensor has to be thin. Hall effect sensors are thin (< 10 μm), Hall plate size usually is around 100 μm; such sensors can achieve an accuracy around 100 ppm at the 1 T field [2]; also they can be measured remotely. The disadvantage of this method is Hall effect gain and offset sensitivity to temperature fluctuations.

The distributed Hall measuring system is in development (fig. 1). It has at least one measuring unit. Every unit can be plugged independently. Every unit connects several Hall effect sensors. The unit is controlled by a PC.

2. Measuring unit prototype

The measuring unit prototype is developed in order to test the system using calibration magnet and reveal the system weaknesses. There is measuring unit prototype includes Hall probe boards with sensors on them, Demo board with analog-to-digital converter ADS1216 and Crossboard V0 which is developed specially for this prototype.

Hall and temperature signals come through multiplexer placed on the Crossboard to ADC inputs. A microcontroller contains measurements and sends them to a PC. Software is written for the microcontroller and for a computer in order to control measuring process.

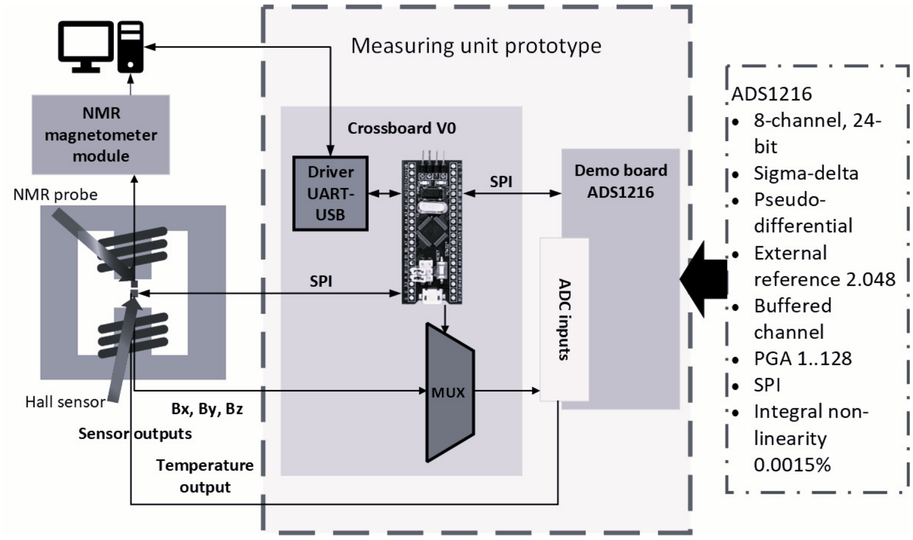

Fig. 2. Measuring unit prototype

3. Measuring prototype tests

The offset and gain of the measuring unit prototype were tested for 6 days (table 1).

Table 1. Measuring unit prototype test results

Offset, μV	Peak-to-peak offset, μV	Gain, bit/V	Gain error, ppm	Estimated error for $0.1V$ signal, ppm
25	0.6	$4 \cdot 10^6$	< 3	3

The beam emits x-rays when passing through the injection complex binding magnets. Hall effect sensors placed near the vacuum tube must deplete because of radiation effects [3]. It influences Hall effect gain and offset. Several Hall effect sensors are tested in the injection complex for 2 or 6 weeks in order to reveal the one most resistant to radiation. Two three-dimensional sensors SenM3Dx, MV2 (table 2) with internal amplifiers and current sources are chosen for the experiment; one-dimensional HE144 and ИМ103Ф1-1 (table 3) were also exposed to the radioactivity. 2 weeks correspond to the dose of 500 rad. Before and after radioactivity test Hall effect sensors were placed into calibration magnet (fig. 2). NMR probes were used in order to compare NMR and Hall measurements [4]. According to tables 2 and 3 all sensors has depleted too fast, but HE144 has depleted less.

Table 2. Hall parameters change after irradiation, the dose is 500 rad

Sensor	SenM3Dx 1	SenM3Dx 2	MV2
Signal at 1T, V	0.6	0.6	0.7
Offset change, V	10^{-4}	10^{-4}	$5 \cdot 10^{-5}$
Signal at 1T change, %	0.06	0.07	0.04

Table 3. Hall parameters change. Sensors placed into irradiation twice. 2 weeks correspond to the dose of 500 rad

Sensor	HE144		ИМ103A1-1	
Signal at 1T, V	0.17	0.17	0.12	0.12
Meas. repeatability,%	< 0.001	< 0.001	0.04	0.04
Offset change, V	$4 \cdot 10^{-5}$	$4.3 \cdot 10^{-5}$	$1.6 \cdot 10^{-6}$	$1.9 \cdot 10^{-6}$
Signal at 1T change,%	0.025	0.25	< 0.1	-0.5 (depleted)
Time spent at the injection complex, weeks	2	6	2	6

4. Measuring unit

The measuring unit structure is based on the prototype structure. (fig. 3). The measuring unit can connect up to eight Hall probes. The unit contains eight measuring channels: every channel is related to one sensor. Every channel has a multiplexer and a programmable gain amplifier in order to Hall voltage, temperature signal and current could be measured by the one pair of ADC inputs. The channel has two independent adjustable current sources for Hall effect sensor and for thermistor which is also placed to Hall probe in order to cope with sensor temperature drift. Therefore, each of eight sensors is powered by an independent current source, which allows for an increase in the distance between the measuring channel and the sensor. It also contains microcontroller aimed to control measurement process and to send data by Ethernet.

Table 4. Measuring unit parameters expected

Number of channels	Field range, T	$E_{noise} = \sqrt{\Sigma E_i^2}$, μV	Offset temp. drift, $\mu V/C^\circ$	Gain temp. drift, ppm/C°
8	± 1	1.5	0.09	2.5

The value of measuring channel inaccuracy is estimated based on ADC and PGA characteristics (table 4). A calibration device is incorporated into the system in order to reduce the impact of long-term and temperature fluctuations. Furthermore, the system of measuring unit and sensors will be calibrated, which will reduce non-linearity and temperature non-stability contribution to measurements.

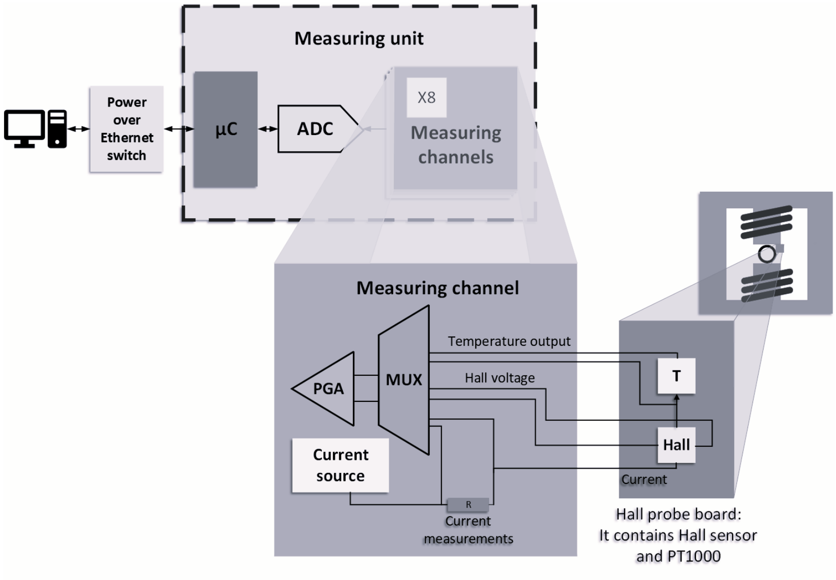

Fig. 3. Measuring unit channel

5. Conclusion

The Hall measuring system has been developed, the measuring unit prototype has been developed and tested, and sensors have been tested at the injection complex. The measuring unit project will be developed and tested. Hall effect sensors radioactivity resistance tests will be continued.

Acknowledgement

I would like to thank I. Okunev for his assistance during the calibration process.

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