MEASURING SYSTEM FOR FLNR CYCLOTRONS MAGNETIC FIELD FORMATION

I.A. Ivanenko, G.N. Ivanov, V.V. Aleinikov, V.V. Konstantinov, FLNR, JINR, Dubna, 141980, Russia

Abstract

Since beginning of millennium, three new heavy-ion isochronous cyclotrons, DC72, DC60 and DC110, were created in FLNR, JINR. At the present time the activities on creation of the new cyclotron DC280 for Super Heavy Facility are carried out. The one of the main problem of cyclotron creation is a formation of the isochronous magnetic field. The FLNR measuring system bases on Hall probes and provide the measuring accuracy 10^{-4}. The paper presents the features, measuring and exploitation results of FLNR cyclotrons magnetic field formation.

INTRODUCTION

During the last twenty years the series of magnetic field measurements for FLNR new and operated cyclotrons were carried out. The purpose of these measurements were the increasing of the efficiency of operated cyclotrons U400, MC400 and IC100 and magnetic field formation for new cyclotrons DC72, DC60 and DC110 [1, 2]. This experience formed a general approach to mapping system creation and measurement philosophy. The common feature is a measuring in a polar coordinate system with the several, 8 or 14, Hall probes. The probes number depends on the cyclotron pole radius and extremely decreases the measuring time. The another feature is a usage of a toothed belt around the pole for azimuthal moving. For radial and azimuthal stepping motion of the magnetometer bar the pneumatic engines are used. Because presented cyclotrons have different parameters of the magnetic structures, such as pole diameter, sectors and pole gaps, the magnetometer bar is created separately for each cyclotron. The magnetometer electronics and pneumatic system of bar stepping motion are unificated and stay the same with minimal changing.

MECHANICAL SYSTEM

For magnetic field measurements at FLNR cyclotrons the polar coordinate mapping system was chosen. The mechanical part of magnetometers consists of the bar for radial motion of Hall probes and the system of bar azimuthal motion. Hall probes are placed at the plank that is moved radially along bar with a step 10mm. The usage of several probes decreases the number of radial steps of the plank and, as a result, a time of mapping. At the table 1 the number of probes - Nh, number of plank steps - Ns, the radiuses of mapping Rb and pole Rpole for FLNR new cyclotrons are presented. To control the coherence of the measuring data between the probes, the additional radial step is used. Then the total plank steps equal Ns+1. At the additional step the previous probe at its last position stands at the first position of the next probe. As a rule this difference is very small, some gausses, and can be corrected numerically in the processing program.

Figure 1: DC72 magnetometer with gear wheel.

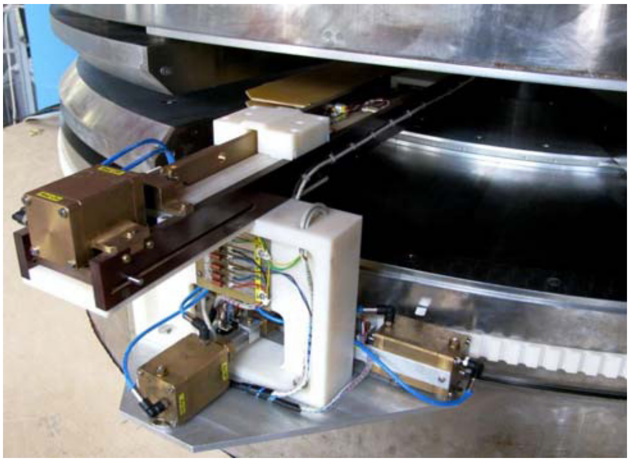

Figure 2: DC110 magnetometer with toothed belt.

The earlier versions of FLNR magnetometers used gear wheel for azimuthal motion, figure 1. The problem was that for each cyclotron the individual gear wheel must be created. It increase the price of magnetometer manufacturing dramatically. For DC110 and DC280 cyclotrons we refused to use the wheel and replaced it by a toothed belt, figure 2.

Table 1: Mapping System Radial Parameters

cyclotron	Nh	Ns	Rb	Rpole
DC280	14	16	2240mm	2000mm
DC110	8	16	1280mm	1000mm
DC60	8	14	1120mm	810mm
DC72	8	20	1600mm	1300mm

ISBN 978-3-95450-181-6

As radial and azimuthal motions are carried by the pneumatic engines, figures 2 and 3. It exclude the engines dependence on magnetic field. The air pressure provides by compressor with receiver and supplied to engines by a thin ∅4-6mm polyurethane tubes. Each step is controlled by optical probes and is counted by control program.

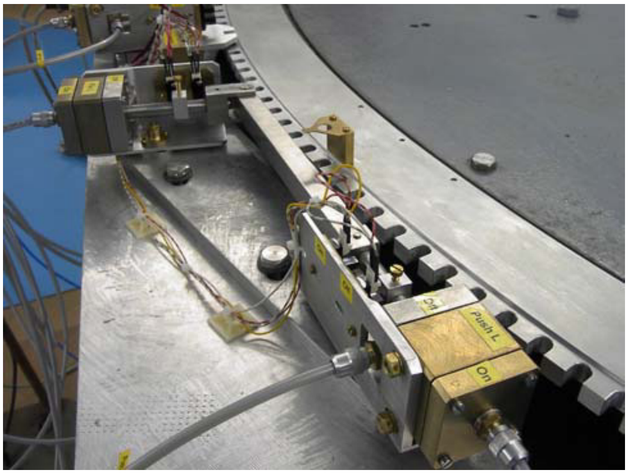

Figure 3: DC72 azimuthal step pneumatic engines.

The mechanical system of FLNR magnetometers, as with gear wheel and with toothed belt, provides the accuracy of probes positioning in radial direction ±0.02mm and in azimuthal direction ±0.01°. At this case the measuring errors, caused by mechanical inaccuracy, are no more than $\Delta B/B=10^{-4}$.

HALL PROBES

FLNR magnetometers use the series of InSb Hall probes with approximately the same parameters:

- Dimension of crystal 3x3x0.6mm.
- Dimension of working area 1.5x0.5mm.
- Nominal current 100mA.
- Magnetic sensitivity 90mkV/mT.
- Temperature coefficient -10^{-5} V/K.
- Upper level of magnetic field 10T.

Because the temperature variation during a map is not more then a few degrees and probes temperature coefficients are very small, so voltage correction due to temperature variations are negligible.

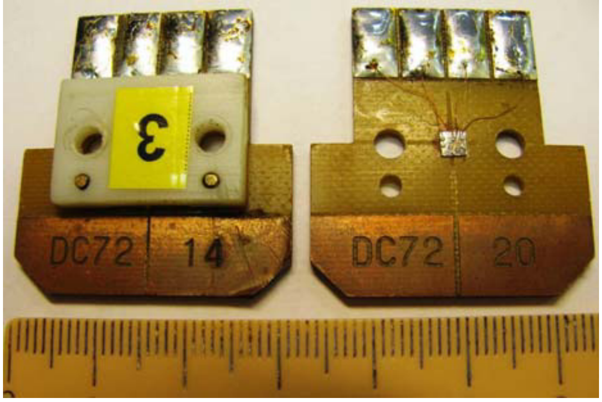

Figure 4: Hall probe at the substrate.

The crystals are placed at the substrate with the markers for correct placing at the magnetometer bar, figure 4.

All Hall probes were calibrated at the range 0.2 – 2.8T. The result of calibration of each probe are submitted by third-degree polynomial.

CONTROL SYSTEM

FLNR magnetometers control system is unified and consists of standard measuring and motion control parts. SPLC type controller provides the control of radial and azimuthal motions. Keithley 2701 multichannel voltmeter reads Hall probes voltages. The communication between apparatuses drivers and control program is based on Publish-Subscribe Protocol and uses Ethernet and RS-485 interface. The reading of Hall probes voltages takes about 2 seconds. Control program writes the voltages data to output file and in parallel demonstrates it in a form of graphics on monitor, figure 5. Each step of radial and azimuthal motions is controlled during the measuring. At the case of accidence the program stops the mapping and show the error message.

Figure 5: DC60 magnetometer control program interface.

Control program provides different mapping options:

- 360° or 90° of azimuthal range.
- 1° or 2° of azimuthal steps.
- 10mm or 20mm of radial steps.

Optionally one radius or one azimuth modes can be used. It is convenient for a quick testing of a magnetic field level and for a local area mapping.

The different mapping options lets to decrease the measuring time. The mapping of 90° azimuthal range with 2° and 20mm steps is taken for a quick analysis of average magnetic field of 4-sector magnetic structure and takes about 40 minutes. The mapping of 360° azimuthal range with 1° and 10mm steps is taken for field harmonic analysis and for final measuring, and takes more than 6 hours.

Control program provides as program and hand managing of magnetometer motion. The hand managing is used for calibration of magnetometer mechanism.

The magnetometer uses the monitor Hall probe. The monitor probe is placed stationary at the mapping area, usually on the pole surface between the sectors, and collect the information about the main field stability during the measuring process. This data is shown

ISBN 978-3-95450-181-6

graphically at the control program interface, as well as the time distribution of current of Hall probes power supply.

FIELD MEASHUREMENTS

The stability of magnetic field, temperature variation, stability of current of Hall probes power supply are important factors for accuracy of the magnetic field measurements. At the figure 6 the relative readings of the monitor probe during 6 hours of DC110 cyclotron mapping are presented. The absolute readings of the monitor probe for the present case was about 1.23T. The probe noise is about ±0.05Gs and the field instability during the measurements no more than 0.15Gs which are under the specified measurement accuracy.

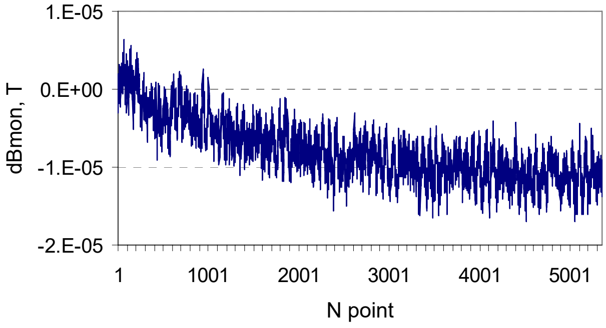

Figure 6: The relative readings of the monitor probe

The main topics of magnetic field formation are the average magnetic field for a range of levels, the compensation of parasitic field harmonics, radial and azimuthal correcting coils operation modes. The total time The results of magnetic field measuring are processed by a handle made program BCalc [3]. The program presents the main parameters of cyclotron magnetic field in a form of 2D and 3D graphics, figure 7.

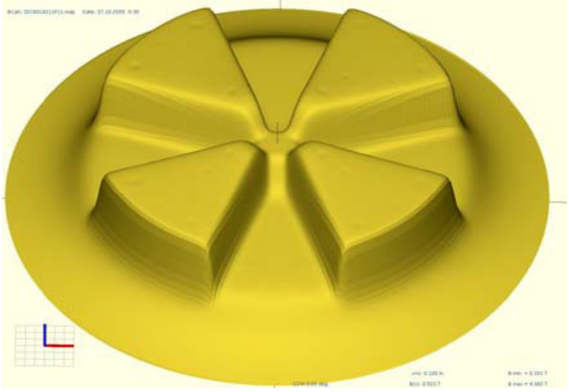

Figure 7: 3D visualisation of the measured field map.

As an example of measurements and formation of the magnetic field, the comparison of calculations and results of final measurements at three levels of DC 60 cyclotron magnetic field are presented at figure 8. The difference between calculations and measurements no more than 4 Gauss for the main acceleration area and about 10 Gauss for the areas of sector screws positions. Finally, the cyclotron commissioning shows the efficiency of the beam transition during acceleration up to 98%, that is a criteria of a quality of field mapping and formation [1]. Figure 9 demonstrates the experimental resonance characteristics, the dependence of beam current at different radiuses on the changing of magnetic field level. The concentric position of resonances shows the minimum deviation of magnetic field from isochronous. Similar results were obtained for other FLNR new cyclotrons, DC72 and DC110 [2].

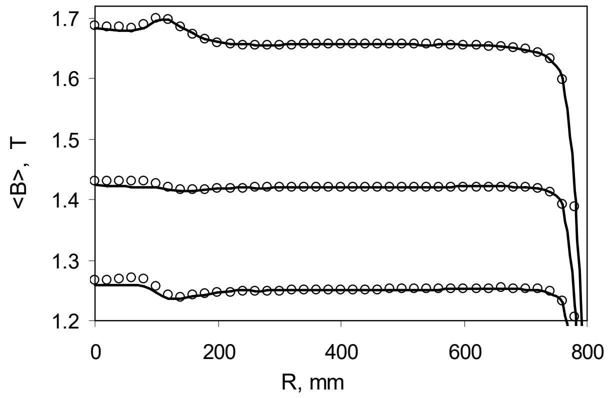

Figure 8: DC60 magnetic field calculations (circles) and results of final measurements (lines).

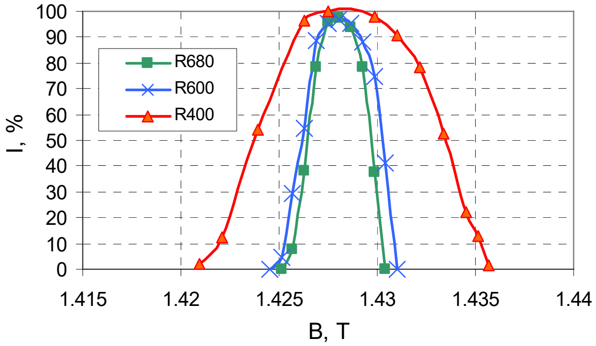

Figure 9: DC60 magnetic field resonance characteristic for 14N^{2+} acceleration mode.

REFERENCES

[1] B.N.Gikal, et al., ”The method and results of formation of the DC-60 cyclotron magnetic field”, In: Proceedings of the 18th Conference on Cyclotrons and Their Applications, 1 – 5 October 2007, Giardini Naxos, Italy, p.p. 432 - 434.

[2] E.V.Samsonov, et al., ”Numerical simulation of Ion Acceleration and Extraction in Cyclotron DC110”, Part. Nucl. Lett. 11, 2(186),2014, p.p.264 - 276.

[3] I.A.Ivanenko, et al., “BCalc – Software for Analysis and Vizualization of the Results of Measured Isochronous Cyclotron Magnetic Field“, P9-2003-162, JINR, Dubna, 2003.

ISBN 978-3-95450-181-6