RESEARCH FACILITY FOR AUTOMATED MEASUREMENTS OF THE CYCLOTRON MAGNETIC FIELD TOPOGRAPHY

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Abstract

The field topography is measured in the polar system of coordinates using 40 Hall sensors installed on a radial line as detecting elements.

A set of instrumentation includes: an electric drive, automated meters for angles and linear movements built on the basis of a 16-bit absolute encoder; detecting elements for measuring the field in the axial channels of the magnet.

The electronics used for the acquisition and processing of the information comprises: a source of control current for the Hall sensors, a power supply for temperature probes, a multiplexer to alternately connect signal electrodes of all the sensors to a signal meter; an ADC or a computer-controlled voltmeter to measure and record signals of a sensor.

When measuring the field, the attained accuracy was $2{\cdot}10^{-4}$. The source of the stabilized magnet excitation current installed on our facility allows measurements with an accuracy of $3{\cdot}10^{-4}$ to be carried out.

A research facility for automated measurements of the cyclotron magnetic field topography has been constructed in NPK LUTS, the D.V. Efremov Institute (NIIEFA). This facility is intended to form a field in the main magnet and to measure fields in the magnets of the external injection and ion beam transport channels at the CC-30/15, CC-18/9 and CC-12 [1, 2, 3] cyclotrons designed and manufactured in NPK LUTS.

A necessary field configuration (the isochronous induction distribution) is formed in the main magnet by measuring the field topography and subsequent mechanical correction of the profile of correcting plates in the hills of the pole sectors.

On this research facility in addition to standard equipment we used designed and manufactured in NPK LUTS novel automated devices for angular and axial movements of sensors and an equipment for automated acquisition and computer processing of data, which is a significant advantage.

The facility consists of a constant current supply for 120 V, 100 A with a long-term current stability of $1.5{\cdot}10^{-4}$ (during 3 hours), a closed water cooling system with distilled water under a pressure of 5 atm, a system for magnetic measurements; a system for measuring elements’ calibration and an equipment for acquisition, processing and visualization of the data obtained.

The system for magnetic measurements comprises: a coordinate device to measure the field topography in the median plane of the magnet, a system for turning the movable element of the coordinate device to a specified angle by a motor, a device to determine the actual coordinates of sensors, an adjusting device for sensors’ calibration, a device for sensors’ verification, a coordinate device with measuring rods to measure the distribution of the magnetic field induction components in axial holes of the magnet, a probe head with the Hall sensors to make measurements in the beam injection and transport channels.

In addition to mechanical devices, the system for magnetic measurements includes an electronics ensuring the controlled movement of measuring elements: a device for automatic angle reading (an absolute encoder) and a meter of axial movements (a linear coder).

The equipment for data acquisition and processing consists of two 75 mA current supplies of high stability, a 42-channel analog switch commutator, a voltmeter with a 0.1 μV resolution and electronic devices interfacing the computer with measuring elements. The computer-controlled analog switch commutator allows signals from 40 sensors to be measured by one integrating voltmeter during 20 seconds, which ensures the noise immunity of the measuring circuit.

The coordinate devices are designed to operate in the shielding-type magnet with the central opening in the yoke of not less than 20 mm, through which movements of the field probes are controlled and measuring terminals are brought out. The coordinate devices work in the polar system of coordinates with the center in the center of the magnet. The line with 40 stationary fixed Hall sensors is moved by a motor in the median plane of the magnet working area, and in accordance with a computer program it can be stopped at any angular point. The absolute encoder indicates an actual angular coordinate with an error of $2{\cdot}10^{-5}$ degrees.

Radial coordinates of the sensors are defined at the stage of the line manufacturing with an accuracy of 0.05 mm; for this purpose optical means are used, for example, a KM-6 cathetometer. To do this, the line is designed so that the center of a necessary sensor can be seen and can be referred to the rotation axis of the line. The size and configuration of the line cross-section are chosen so that the bending deformation of the 1m-long glass-cloth laminate line fixed as a cantilever will be less than 0.05 mm at any rotation angle.

Measurements were carried out by using Hall sensors of the IM103B2-1 type of overall dimensions $1.5 \times 1.5 \times 0.6$ mm and with the sensitive zone 0.6×0.2 mm in size. The magnetic sensitivity of the Hall sensor is of the level of 5.3 μV/G at a control current of 75 mA; the temperature coefficient of the magnetic sensitivity is 0.001-0.003% degrees; the temperature coefficient of the residual voltage is 0.01-0.03.

The sensors with the current supplies, a voltmeter and other elements of the circuit are calibrated by MR equipment in the magnetic field set up by the SP-186 dipole magnet with a homogeneity not less than 0.02% (in the volume 20 × 20 × 20 mm). Calibration of the sensors is made simultaneously with the calibration of a working set of equipment. To install the sensors, we use a special adjusting device, which allows all 20 sensors to be installed on it and in turn to be placed to the center of the working zone of the magnet with the 15 mm gap.

The range of the magnetic induction under calibration is from -2.2 up to 2.2 T. The time instability of the field under calibration and measurements should be not less than 0.01%. The field instability is controlled by a reference sensor located in the SP-186 magnet close to the sensor calibrated. Signal from the reference sensor is recorded by the second voltmeter simultaneously with the signal from the sensor calibrated. From the readings of the reference sensor, a decision is taken if the signal of the sensor calibrated should be corrected or not and if the measurements are to be repeated. From the results of calibration, for each Hall probe we found a regression polynomial ensuring the maximum accuracy when defining a coefficient relating the signal with the magnetic field induction over the whole range. From this coefficient the measured induction in the place of the sensor location is found.

For fields of the order of 2 T the system of magnetic measurements allows the induction of the magnetic field to be measured with a relative error of $3 \cdot 10^{-4}$.

The process of the magnetic field formation includes the following:

- finding the operating current;
- measuring the induction topography in the median plane of the magnet along 40 circular orbits in the $F = 0 \div 360°$ range with a pitch of 2;
- taking the field integral $B_{av} = \frac{1}{2\pi} \cdot \int_0^{2\pi} B(R,F) \cdot dF$ for each orbit in the radii range 20-400 mm from the $B = f(R, F)$ topography;
- correcting profiles of the plates used in sector hills to obtain isochronous values of the $B_{av} = f(R, F)$ curve;
- finding the radial distribution of the induction in the center of the hill and valley of the pole piece at a nominal current;
- finding the 1st harmonic of the Fourier expansion of the $B = f(R, F)$ curve; the expansion was done for all radii of the working range (20-400 mm);
- determining the place of installation and topography of the plates correcting the 1st harmonic;
- determining the effect of the vacuum in the working volume on the magnetic induction in the gap.

When shims were located for proton acceleration, the operating current in the magnet of the CC-18/9 cyclotron was chosen by increasing current until the design induction was attained at the 440 mm radius in the middle of the valley. The used MR equipment allowed us to find out that at an induction of 0.4945 T at a given point, current was 82 A. For deuteron acceleration, current was chosen from the minimum discrepancy between theoretically obtained and measured difference in the field integral distributions for proton and deuteron acceleration, which occurs at 81 A.

Figure 1 shows the radial distribution of the average field and the isochronous curve for protons and deuterons in the magnet of the CC-18/9 accelerator. All measurements were done with the plate for correcting the 1st harmonic.

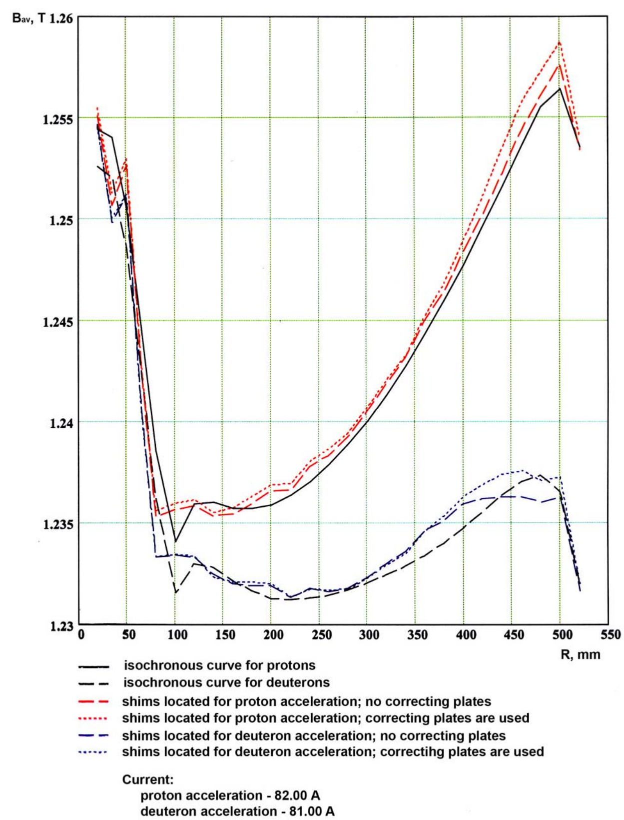

Fig.1 Field integral B_{av} as a function of radius.

Studies of the influence of the magnetic field unsymmetry on the proton's and deuteron's dynamics in the cyclotron have been carried out. Figure 2 shows components of the field 1st harmonic as a function of the radius when shims are located for proton acceleration. Four plates for correcting the field integral were installed in case of shims located for deuteron acceleration, and one plate for correcting the 1st harmonic was installed in the case of deuteron acceleration. The radial dependence of the 1st harmonic components with shims located for deuteron acceleration is similar.

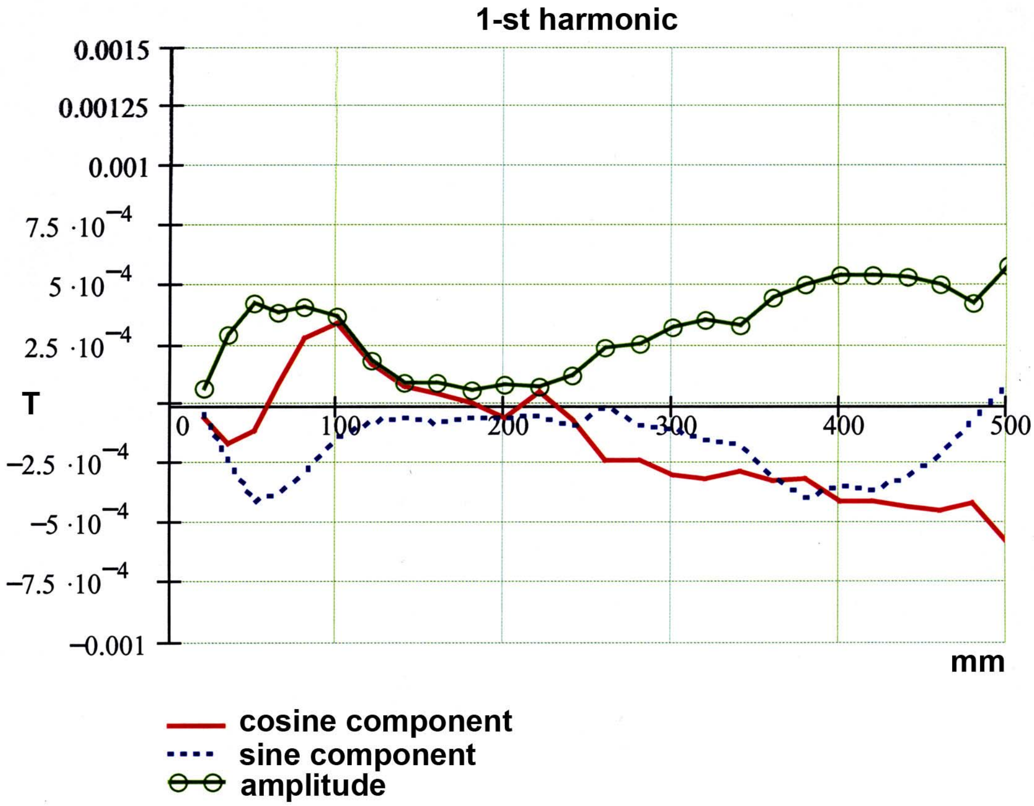

Fig.2 Components of the field 1st harmonic as a function of radius when shims are located for proton acceleration.

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