OPTIMIZATION OF THE MAGNET SYSTEM FOR LOW ENERGY COOLERS

A. Bubley, V. Panasyuk, V. Parkhomchuk ,V. Reva, Budker INP, Novosibirsk, 630090, Russia

Abstract

Aspects of magnet design and field measurements are discussed in the view of low energy coolers construction. The paper describes some engineering solutions for the magnetic field improvement which provides appropriate conditions for the cooling process as well as electron and ion beams motion.

INTRODUCTION

In installations of electron cooling, the electron beam passes from the cathode of an electron gun then through bending section to cooling solenoid and then up to absorbing collector in a continuous longitudinal magnetic field. Requirements of quality of a magnetic field are various for various parts of installation. Most they are high for cooling section - the central solenoid. Efficiency of the cooling process strongly depends on quality of the guiding magnetic field produced by the solenoid. Acceptable of cooling rate can be achieved, if non-parallelism of the field force lines, in relation to an axis of the solenoid $B_{\perp}/B_{\parallel}$ in a vicinity of ion trajectories does not exceed size of angular spread of the ion beam. The aspiration to achieve extreme high cooling rate produces rigid requirements to straightforwardness of the field force lines - from 10^{-4} for low energy electrons up to 10^{-5} and even less - for high energy. For achievement of these high requirements the special designs of the central solenoid, as well as a technique of correction of heterogeneity of a magnetic field and precision system of its measurement were developed.

CORRECTION OF THE MAGNETIC FIELD AT COOLING SECTION

Asymmetry of the magnetic system leads to inhomogeneous magnetic field rise at the cooling section. This effect can be eliminated by the inclination of the solenoid coils. As a step of a commissioning such a procedure was performed for EC-300 cooler (IMP China) at 0.75 kG longitudinal field. Also small-scale disturbances of the transverse field were minimized those originated from imperfectness of the coils alignment. Data obtained is shown in fig.1 – curve 1,[1].

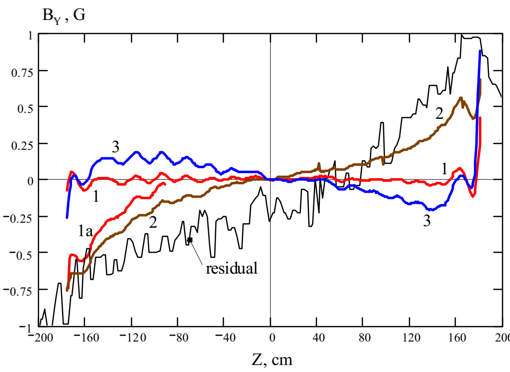

Figure 1: Vertical fields at cooling section of EX-300 measured at longitudinal field: curve 1: 0.75 kG, curve 2: 0.5 kG, curve 3: 1 kG. Curve 1a: 1-st switching on after return to a field of 0.75 kG. “Residual” – result of Hall probe measurements of the residual field.

However non-uniform vertical fields appeared to show up again at a change of the longitudinal field. Plots of the vertical field distribution are shown in Fig.1 (curves 1,2,3). It can be easily estimated that these fields have linear and cubic components. It is visible, that small-scale disturbances are proportional to a field. On the other hand horizontal component kept stably small independent on longitudinal field.

It appears, that (curve 1) at return from *1kG* to *0.75kG* the achieved field slickness is restored only after several turning on and off of the magnet system (normalization cycle). After 1-st turning on the vertical component is restored only in the central part of the solenoid (curve 1a). After normalization cycle in the solenoid it is formed rather steady and about a linear vertical residual field (curve ‘residual’ in Fig.1). Apparently, a course of curves 2 and 3, is determined by this residual field especially in the central part of the solenoid namely, inclination of the coils overcompensate the residual field at *1kG* an under compensate at *0.5kG*.

So, the technique of alignment of the field by coils inclination [2], [3] suits only for a fixed longitudinal field. Therefore special correctors of a linear and cubic field should be used for operative reaction to a change of a longitudinal field.

Measures to Enlarge Good Field Region

According to design requirements, effective length of cooling section has to be as close as possible to the mechanical length of the solenoid. Therefore effort should be made to enlarge good field region.

EC-40 (LEIR, CERN) was designed as a cooler with changeable longitudinal field, so its magnet system contains various corrections installed on the cooling solenoid [4].

Curve 1 in Fig.2 shows result of Hall-probe measurements performed at cooling solenoid after rough alignment of the coils [3]. Then couple of coils on both ends of the solenoid was inclined outwards by higher angles in comparison with regular part (curve 2). This distribution has expressed linear component which can be compensated with linear field corrector. Result of the improvement is shown in Fig.2 (curve 3).

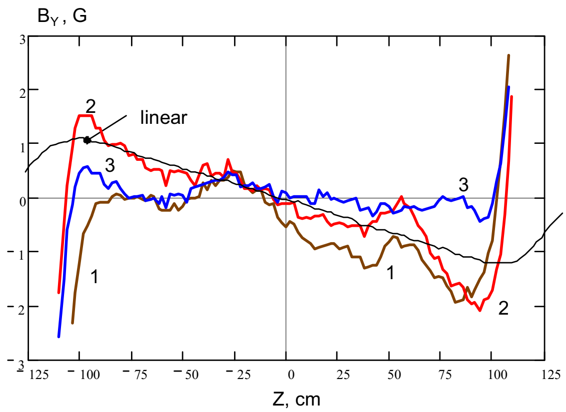

Figure 2: Vertical field before inclination of margin coils - 1, and after - 2, compensation with linear corrector; linear - a field of the linear corrector with an opposite current.

The results of Hall probe measurements are important from the point of view of further field adjustment because compass-based measurement system [5] has rather narrow dynamic range. Obtained amplitude of ±0.8G of transverse field components is sufficient for operation of the compass system in automatic mode. The laser beam of the measurement system was aligned on a geometrical axis of the solenoid. Some regular errors could arise due to misalignment between the beam and a magnetic axis, as well as the beam and a magnetic moment of the compass. Those errors can be eliminated with the help of vertical and horizontal steering coils with homogeneous field. With the help of techniques described transverse field components were reduced down to *±0.05G* at longitudinal field of *1kG* [4].

As a result the effective length of cooling section increased on *15-20 см*.

Magnetic Diaphragms

One of the methods to increase area of a good field inside the central solenoid is use of the magnetic diaphragms on joints of the solenoid and toroids. Figure 3 shows vertical components of a field on one of edges of the solenoid for two cases: 1 -with magnetic diaphragm and 2 - without it.

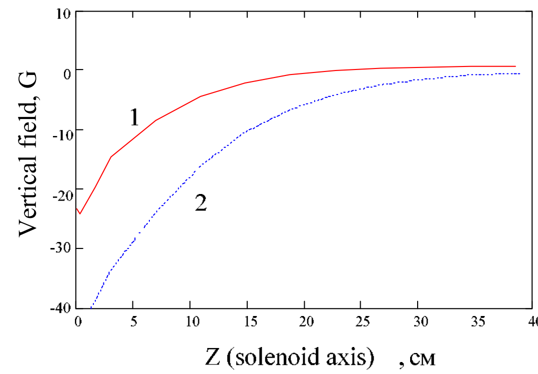

Figure 3: Vertical field distribution at solenoid and toroid junction: 1 - with magnetic diaphragm, 2 - without it.

Although diaphragms (so-called “magnetic mirrors”) provide significant improvement of uniformity of the field at the solenoid their use is complicated for several reasons. First, practically there is no enough room for their installation due to space required for installation of the vacuum chamber, heating jackets and thermal screen. On the other hand presence of the magnetic diaphragms increases influence of a residual field, which is strongly dependent on the sequence of switching on different sections of the magnet system.

ELECTRON TRAJECTORY CORRECTION AT BENDING SECTION

As well as the central solenoid, bending magnets (toroids) and solenoids of the gun and collector are constructed from flat, connected in series, coils. Mmagnetic yoke, serving as a mechanical skeleton for all units of magnetic system, weakly influences on the conducting field, closes a return magnetic flux. Magnetic diaphragms also are used on the transitions between the gun (or collector) solenoids and bending toroids. In this case is possible to correct a trajectory of movement of the electronic beam in ben.

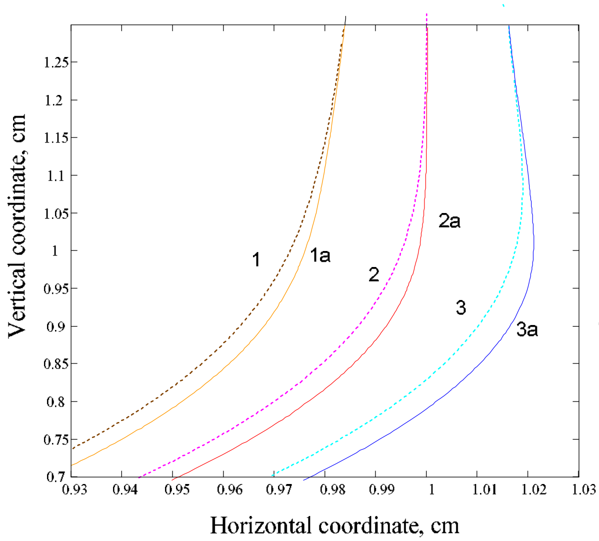

Figure: 4 Results of simulations of electron beam trajectory. 1,2,3 - without diaphragm 1a, 2a, 3a with diaphragm.

The matter is that the solenoid of a gun has small length, in comparison with diameter, and radial component of the field in the toroid displaces a beam practically right after its exit from the gun. As a result the electrons appreciably deviate from an axis of a bending toroid. Magnetic diaphragms significantly (Fig.4), correct the electrons orbit, reducing current load on correctors those area are rather weak because of remoteness from the axis.

However, when we deal with optimization of magnetic structure for installations on medium or high energy, it is important to take into account possible negative effects. Sharp change of curvature of the longitudinal magnetic field inevitably resulted from use of diaphragms, can result in increase of electrons transverse velocity, that is inadmissible from the point of view of cooling.

CORRECTION OF THE ION BEAM ORBIT

Passing through the magnetic system of electron cooler, an ion beam experiences impact due to strong vertical components of a magnetic field in bending toroids. Special dipoles are used for ion orbit correction. Magnets are designed under classical scheme; however their arrangement is a little bit unusual. Magnet yoke is introduced into bending toroid as shown in Fig.5.

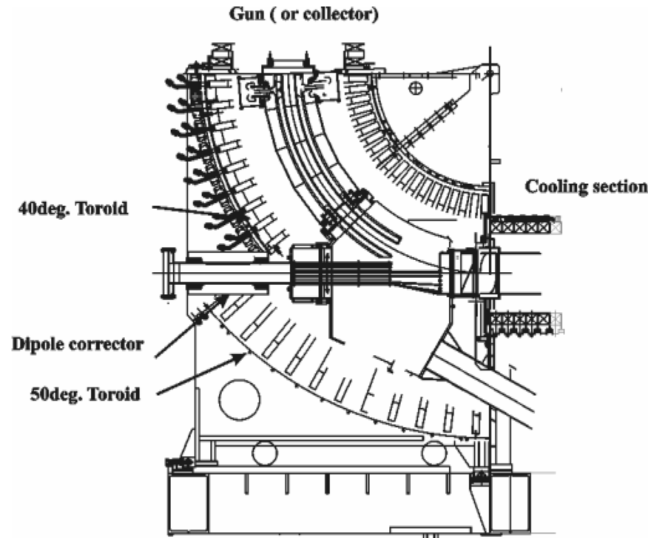

Figure 5: Dipole corrector inserted into 50 deg. bending section.

It allows reducing the cross-section of the vacuum chamber as well as mechanical length of the magnet system

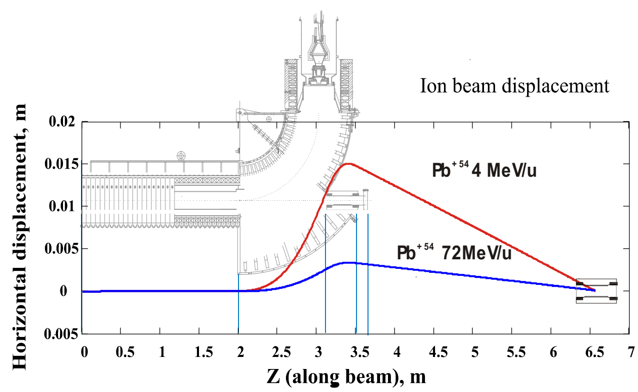

Figure 6: Scheme of correction of ion beam orbit.

The scheme of ion orbit correction of EC-40 cooler is shown in Fig.6. Plots represent horizontal displacement of ions at passage of magnet system of installation for energy of injection 4.2 MeV/nucleon (upper curve) and extraction 72 MeV/nucleon (lower curve). Having received displacement, the ion gets in dipole magnet where it is displaced in an opposite direction. The field of the dipole corrector is chosen so that particles have a small angle (10^{-3} rad.) on an exit from installation to return them into a stationary orbit by means of the additional correction established on a ring (it is schematically represented in the right part of figure 6).

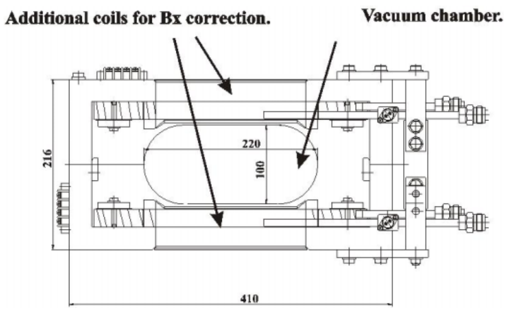

Figure 7: Design of the dipole corrector.

Passing the bending toroids, the ion beam experiences action of rather strong longitudinal and vertical field. It results in occurrence not only horizontal, but also vertical displacement. Actually, for a considered case it quite small (only 2 mm on energy of injection) so that can be compensated with the help of additional low-current coils wound over the of poles of the dipole corrector, as shown in Fig.7.

REFERENCES

[1] E. Behtenev et al., “Commissioning of Electron Cooler EC-300 for HIRFL-CSR”, AIP 0-7354-0314-7/06/, p334.
[2] A.V. Bublei et al., “New Technology for Production of Precision Solenoid for Electron Cooling System”, Proceedings of MEEC-98, Dubna, 1998, Russia.
[3] V. Bocharov et al., “Precise Measurements of a Magnetic field at the Solenoids for Low Energy Coolers”, AIP 0-7354-0314-7/06/, p360.
[4] V. Bocharov et al., “First Tests of LEIR-Cooler at BINP”, AIP 0-7354-0314-7/06/, p355.
[5] V.N. Bocharov et al., “The precise magnetic field sensor for solenoid for coolin section”, Proceedings of the XVII Workshop on Particle Accelerators, Protvino, Russia, October 17-20, 2000.