MAGNETIC SYSTEM OF ELECTRON COOLER FOR COSY

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Abstract

The magnetic system for the COSY cooler is presented. Electron beam energy range is wide (24keV-2MeV), typical bend's radii of electrons track are near to 1 m, typical magnetic fields are 0.5 – 2kG. Transport channels with guiding magnetic fields for motion of electrons from high voltage terminal of cascade transformer into cooling section and their return for recuperation under such conditions are discussed. Results of Hall sensors measurements are compared with corresponding computations. Also some steps were taken for improvement of the magnetic field lines straightness in the cooling section.

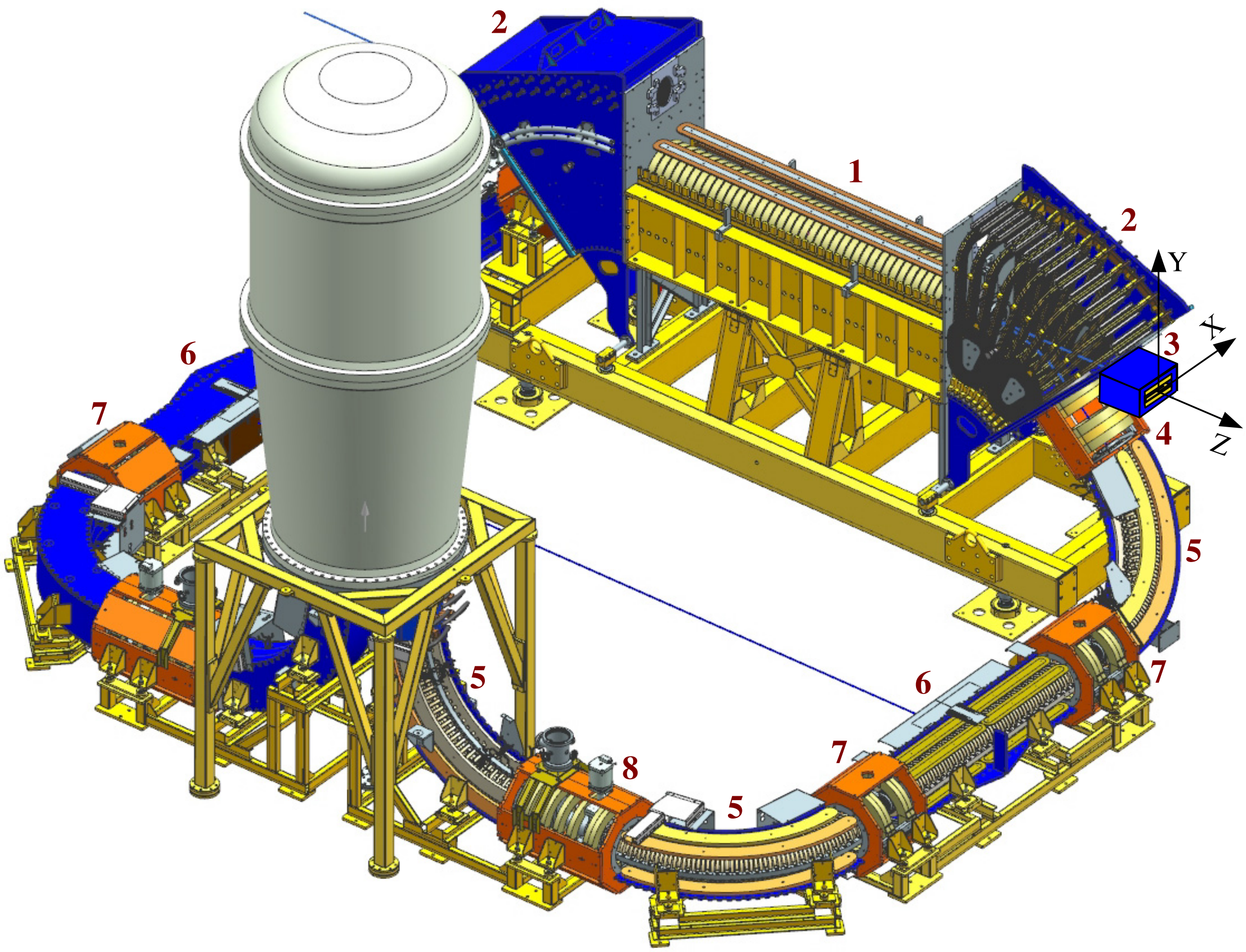

Figure 1: Cooler magnetic system layout: 1 – solenoid and transverse correctors of cooling section, 2 – toroidal and bending coils of 45° toroid, 3 – dipole corrector, 4 – two coil groups of matching section, 5 – toroidal and bending coils of 90° bend, 6 – solenoid and transverse correctors, 7 – coils of short transition section, 8 – coils of long transition section, 9 – coil group of matching section.

DESCRIPTION

Solenoid consists of 40 pancake moveble coils [1]. Half the coils have right-handed winding, the rest – left-handed winding. Interleaving of such coils minimize field inhomogeneities which arise at commutation of coils. Since cooling by magnetized electrons is used, high straightness of the magnetic field line is required: $\Delta B_{\perp} / B = \theta < 10^{-5}$. Coils are installed on ball bearings for adequate correction of position. Magnetic field is aligned by tilting or slewing the coils. Necessary displacements of control screws were found by mathematical treatment of previous compass measurements [2]. Displacements of ~0.01mm were needed in final stage. In addition magnetized electron beam may be tilted by horizontal and vertical correctors of cooling section (B_X=B_Y≤±15G). The values of longitudinal magnetic fields of solenoid B_{Zsol} and guiding magnetic fields of toroids B_{Stor} amount to 2kG. Usually B_{Zsol}≈B_{Stor}.

High-voltage tank magnetic system includes two solenoids around accelerating and decelerating tubes[1]. The nominal value of the magnetic field is 0.5kG. Electron beam moves from tank to cooling section and comes back for recuperation by identical transport channels. Each channel consists of three 90° bends, two short and one long transition sections and a solenoid with transverse correctors. Guiding magnetic field of channels B_S amounts to 1kG. Two matching sections are situated at the ends of each channel. These sections ensure passage of electrons through longitudinal gradient of field without heating [3].

Transverse bending field is created by bending coils of bends and toroids. Field index (~0.5) is ensured by coils positioned on the walls of magnetic conductors.

Functionally five power supplies are used for water-cooled coils.

Table 1: Fields and Supplies parameters

Series connection coils	**Fields kG**	**Current A**	**Power kW**
Coils of cooling solenoid	2	330	110
Toroidal coils of 45° toroids	2	1040	180
Toroidal coils of 90° bends	1	320	130
Coils of transition sections	1	300	70
All bending coils	0.1	350	45

Two dipoles are situated on the axis of cooling solenoid outside of toroids. Their vertical field coils may be connected in series with coils of 45° toroids. Two coils of matching section (**4**) connected in series with coils of cooling solenoid and other three are connected in series with coils of 90° bends.

HALL SENSORS MEASUREMENTS

Calibrated set of Hall sensors was used for magnetic measurements. Twelve devices are placed on a precise Cross-support so that 3-d components of field are measured, where every component is measured in four points around cross axis. The Cross is installed on a Carriage.

The Carriage moved along rails in one-step operation. Special rigid rails installed in the magnetic system elements ensured movement of the Cross center along the axis in straight sections, or along the arc of 1m radius in bends and toroids. The position of the Cross center along the track was considered as longitudinal coordinate **s**.

General assembly consisted of cooling section, toroid, dipole and matching section (**1–2–3–4** in Fig. 1). Other eight elements were measured in triads. Each triad consisted of one bend (one of the six 90° bends (**5**)) in the center with two neighboring transition straight sections, or one of the two solenoids (**6**) in the center with corresponding straight sections on sides (**7–6–7**, **7–5–8** etc). Measurements were carried out with various combinations of four power supplies for the triads' elements.

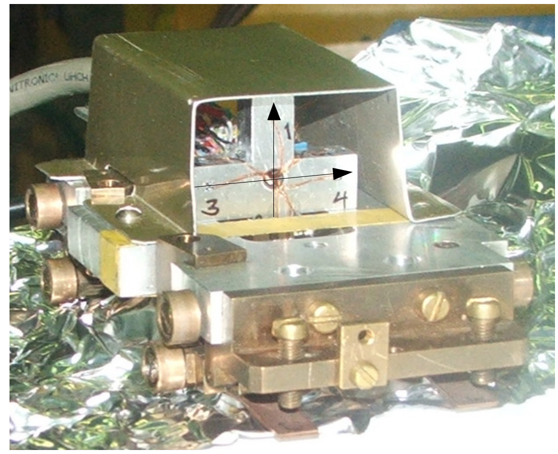

Figure 2: The Cross with Hall sensors on the Carriage.

MEASUREMENT RESULTS

Results of measurements (dot curves) and results of corresponding computations (solid curves) are presented in next figures.

Measurements on the assembly **1–2–3–4** along straight axis are represented below in Fig. 3 (i.e. measurements in the path of ion beam). The **z** origin is fixed in the centre of the cooling solenoid.

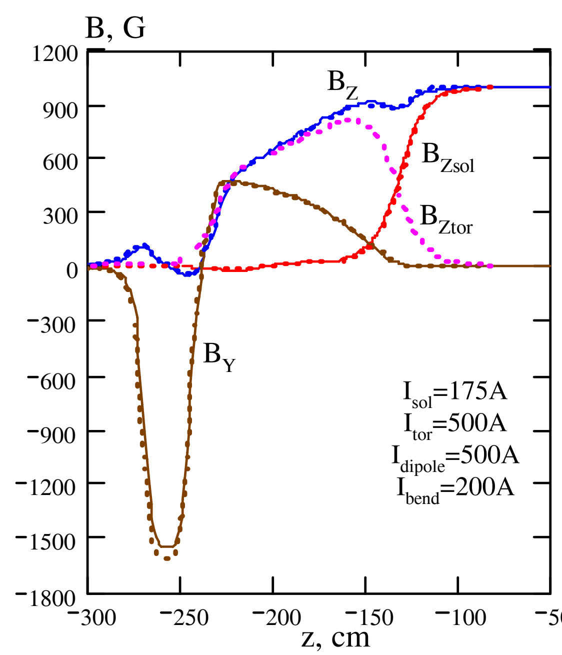

Figure 3: Longitudinal component B_Z and its constituents B_{Zsol} and B_{Ztor} and vertical component B_Y along the axis. Dot – measured curves, solid – computed curves.

Here and farther each constituent is powered by its own supply.

Measurements of assembly **1–2–3–4** along travel line (axis–45°arc–straight line) are represented below (i.e. measurements on the path of electron beam). The **s** origin is fixed also in centre of cooling solenoid.

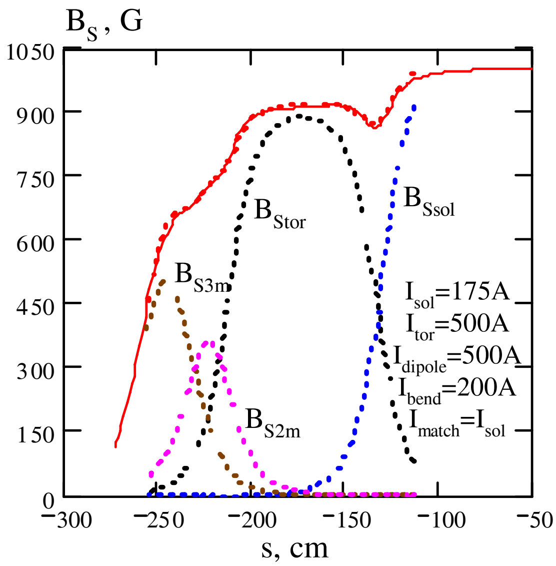

Figure 4: Longitudinal field B_S and its main constituents B_{Ssol}, B_{Stor}, B_{S2m} and B_{S3m} along travel line s. Dot – measured curves, solid – computed curve.

Measurements of assembly **8–5–7** along travel line (axis–90°arc–axis) are presented below (i.e. one from six bends measurements). The **s** origin is fixed here in centre of the bend.

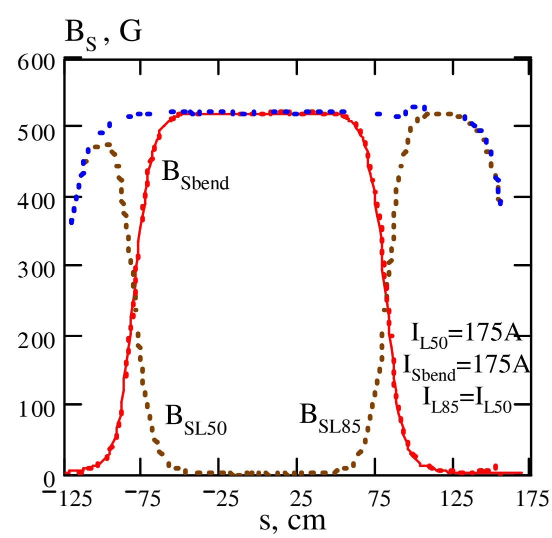

Figure 5: Longitudinal field B_S and its main constituents B_{Sbend}, B_{SL50} and B_{SL85} along travel line s.

Thus:

- Field measurements coincide with field computations.
- Full field equals to its constituents sum, i.e. influence of ferromagnetic nonlinearity is small at stated currents.
- This allows constructing of field by variation of the constituent currents, for example, constructing the optimal field for electron transit without 'heating'.

COMPUTATION OF ELECTRON TRANSIT THROUGH TOROIDS AND BENDS

Profiles of guiding field curvature (cur(s)) and bending field $B_B(s)$ do not coincide. So, the Lorentz force $F_L(s) = e\cdot\beta\cdot B_B(s)$ counteracts with centrifugal force $F_C(s) = mc^2\gamma\beta^2\cdot cur(s)$ only on average [4]. Normalized profiles are shown in Fig. 6.

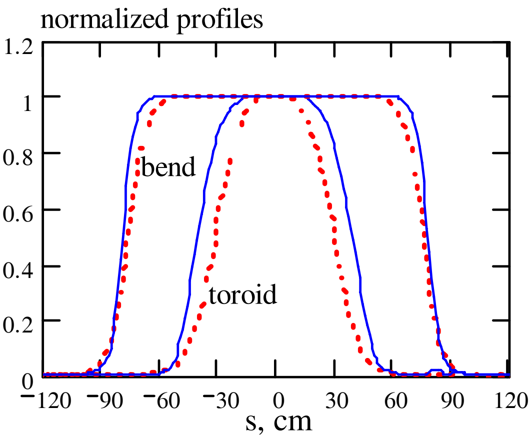

Figure 6: Solid – curvature: max(curv)=0.01cm^{-1}. Dot – profiles of bending field.

Electron beam energy range is wide (24keV- 2MeV). Non-adiabatic electrons of major energies are 'heating' in such bends and toroids. If electrons make integer number of turns (nω) around magnetic field B_S during transit, they leave bend or toroid without 'heating'.

Since diverging profiles are present, fitting of coils current for B_S and B_B is needed. For the beginning we can choose B_S corresponding to integer number of Larmor's turns on the bend transit and $B_B \approx 17\gamma\beta$ (from $F_L=F_C$).

Computations of electron transit through channel fragment **8–5–7–6** are presented on the Fig.7, 8 and 9.

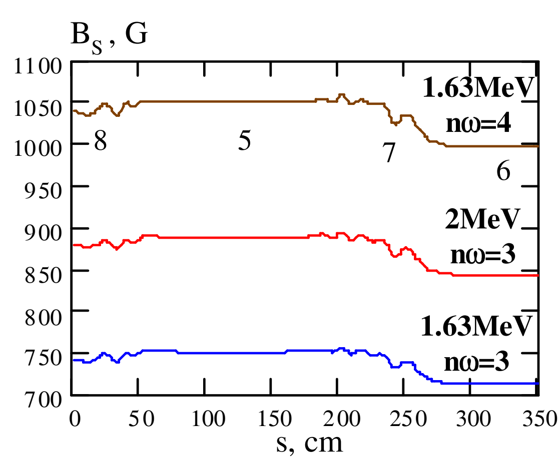

Figure 7. Optimal fields for electron transit through channel fragment **8–5–7–6** without 'heating'

Electron oscillations relative to central force line are shown below. Here δr is radial displacement in the bend and x is displacement across bend plane.

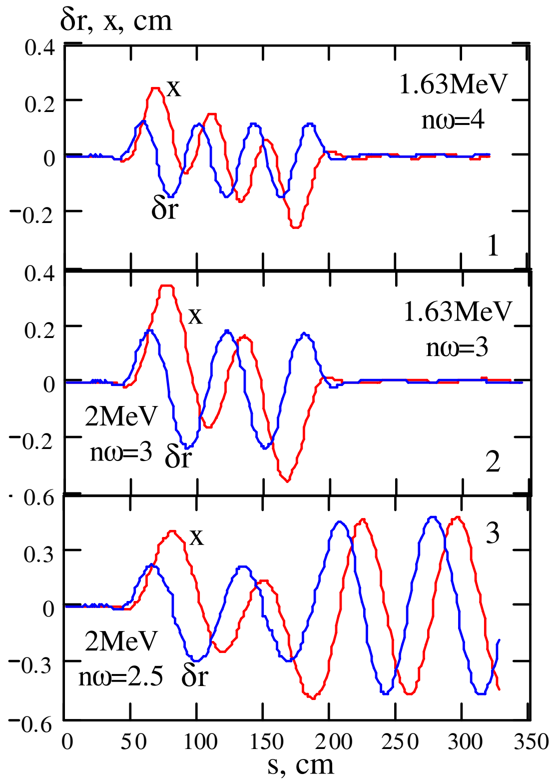

Figure 8: Electron oscillation in optimal fields – **1**, **2** and electrons with T_e=2MeV in field for T_e=1.63MeV – **3**.

Larmor's turns of 2MeV electrons into solenoid **6** (i.e. after bend transit) are shown below for different cases.

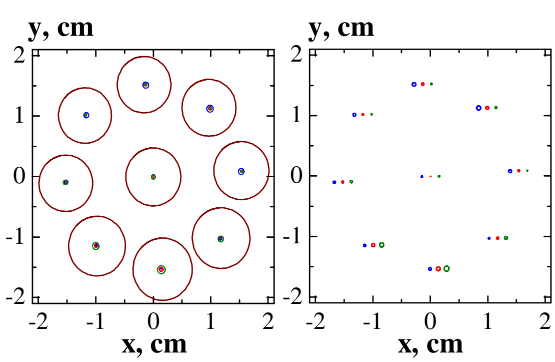

Figure 9: Left graph – Larmor's turns in optimal B_S, ±2% varying relative to optimal B_S and non-optimal (nω=2.5). Right graph – Larmor's turns in optimal B_B and ±2% varying relative to optimal B_B.

Optimal fields B_S at T_e=2MeV, nω=3 and at T_e=1.63MeV, nω=4 got by fitting. At fixed nω optimal B_S value varies on energy as γβ. At T_e=1.63MeV conversion nω from 4 to 3 decreases optimal field by 0.71 instead of 0.75. At electron energy T_e=2MeV max(B_{Bbend})=84G (max(B_{Btor})=104.6G) and varies on energy as γβ.

Variation of optimal guiding field B_S on ±2% increase 'heating' slightly. Variation of optimal bending field B_B on ±2% substantially shifts the beam axis across bend plane on ±2mm.

Computations were done by MAG3D code [5] in maximal approximation to real design. Steel grade of magnetic conductors is ST10.

CONCLUSION

The magnet measurement of magnetic elements: cooling section, toroid, bending solenoid and matching section shows good agreement with calculated magnet fields. Beginning of the electron beam orbit optimization for different energy will made according results of B_S and B_B computations.

Naturally final positioning of electron beam orbit will made according results of diagnostic measurement. Tools for optimisation exist: system of pick-up and set of the correctors.

REFERENCES

[1] Bubley, V. Panasyuk, V. Parkhomchuk ,V. Reva, Budker INP, Novosibirsk, 630090, Russia, Optimization of the magnet system for low energy coolers, http://accelconf.web.cern.ch/AccelConf/cl07/PAPERS/THAP04

[2] A. Bubley, V. Bocharov, S. Konstantinov, V. Panasyuk, V. Parkhomchuk. Precision Measurements and Compensation for the Transversal Components of the Solenoids' Magnetic Field. Instrum. Exper. Techn. Vol. 48, № 6, 2005, pp.772-779

[3] M.I. Bryzgunov, V.M. Panasyuk, V.B. Reva. Calculation of electron beam motion in electron cooling system for COSY. Proceeding COOL-09 Conference Lanzhou, China, August 31-September 4, 2009.

[4] A.V.Ivanov, V.M.Panasyuk, V.V.Parkhomchuk, V.B.Reva, M.A.Tiunov, "Simulation of electron beam dynamics in a high-energy electron cooler", Nuclear Instruments and Methods in Physics Research A 558 (2006) 227-234.

[5] B. Fomel, M. Tiunov, M. Karliner, "3D simulation of magnets with taking into account the effect of nonlinearity", preprint BINP 83-15, 1983.