MATCHING OF MAGNETIC FIELD WITH ENERGY OF ELECTRONS IN 2 MeV COSY COOLER

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Abstract

In the high energy electron cooler for COSY the beam energy range is wide (24keV- 2MeV). Maximal guiding magnetic fields are 0.5kG in accelerating tube, 1kG in transport channels and 2kG in cooling solenoid and 45° toroids. As result we have two sections with longitudinal gradient of field, three 90°bends and 45° toroid before beam pass to solenoid.

Transition of beam energy to transverse degrees of freedom is possible in such conditions. Chances to minimize this transition (named further “heating“) are discussed. Also the results of using of correctors and pick-up system are considered.

MATCHING OF GUIDING & BENDING FIELDS

The magnetic measurements on the assemblies of cooler magnetic elements are shown good agreement with calculated magnetic fields for such assemblies [1]. Therefore optimization of magnetic fields B_S and B_B for different electron energy was produced by trajectories computations. Computations were done for fragments of system (see Fig. 1). Each fragment includes potential “heating” element (bend, matching section and etc.). Field along of magnetic system are constructed from such fragments

Functionally five high-current power supplies are used in system.

- cooling solenoid – PS-1, (566)
- 45° toroids – PS-2, (173).
- guiding field of bends and lines-17 – PS-3, (349, 331)
- lines-05 and lines-10 – PS-4, (358, 348).
- all bending coils – PS-5, (17βγ).

Fields at currents 100A are recorded in brackets.

PS currents for series values of electron energy are contained in Table 1. Currents correspond with optimal fields for these energies.

Table 1: Electron Energy and PS Current Correspond with Optimal Fields

T MeV	PS – 1 A	PS – 2 A	PS – 3 A	PS – 4 A	PS – 5 A
0.5	286.0	792.0	302.0	302.0	115.0
1.0	260.0	720.0	265.0	265.0	187.0
1.5	251.0	714.5	281.0	279.3	255.6
2.0	246.9	565.0	254.1	250.0	323.0
2.0	317.3	933.0	254.1	250.0	323.0

Currents for others energies may be converted from these as γβ relations. Geometric parameters (bend’s radii, number of turns around field B_S on bend length and etc.) keep in this case

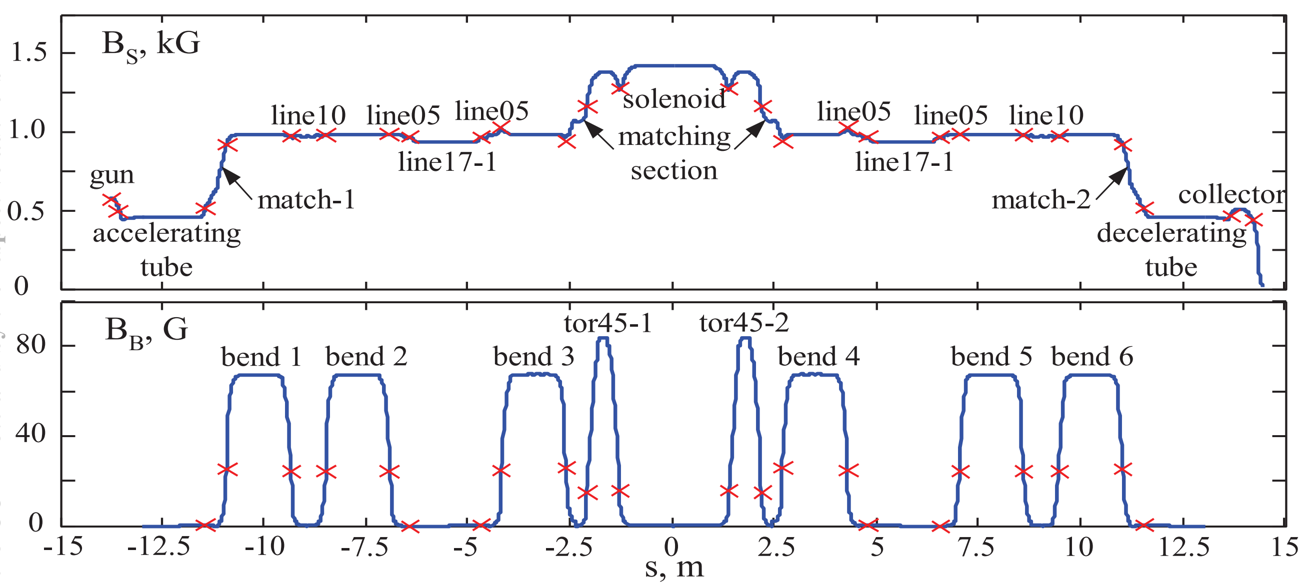

Figure 1: Calculated guiding magnetic field B_S and transverse bending magnetic field B_B along axis of magnetic system of cooler. Fields are optimal for 1.5MeV electrons. Junctions of magnetic element are marked by symbol ×.

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LAYOUT OF PICK-UPS & CORRECTORS

Beam orbits are tracked by pick-up system. Pick-up positions along magnetic system are shown on Fig. 2. They are placed in transition sections (line-05 and line-10), in matching sections and also in cooling solenoid ends. Pick- up numeration is ***1 – 10*** along the beam. Coordinate frame of pick- up is: Z – along the beam, Y – up⁻ vertical and X ⁻ outside cooler ring.

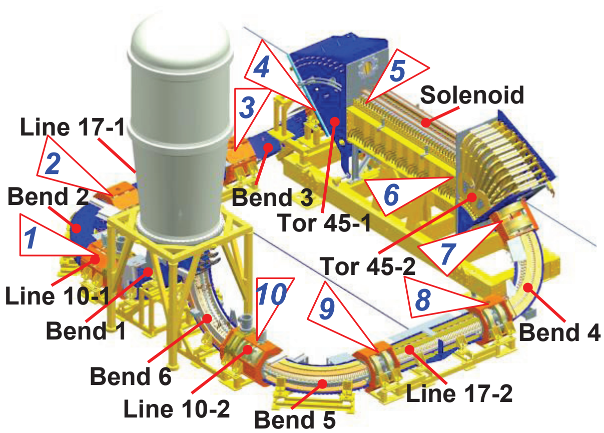

Figure 2: Pick-up positions are marked as ***1 – 10***. Magnetic elements with correctors are denoted.

Also elements of magnetic system with correctors are denoted on Fig. 2. Solenoid, line17-1 and line17-2 have long correctors both in horizontal and in vertical. Line10's have short horizontal and vertical dipoles.

RESPONSES MEASUREMENTS

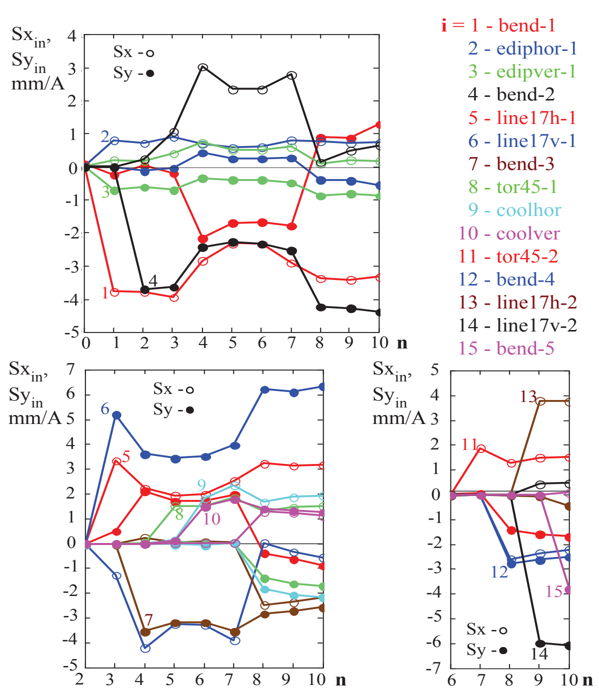

Figure 3: Measured responses $Sx_{i,n}$ and $Sy_{i,n}$ in each pick-ups (**n** from ***1*** to ***10***). Index **i** – corrector number.

Corrector's responses (Sx, Sy) were measured in each from 10 pick-ups. Beam shifts are linear in corrector currents J_i. All measurements were done at optimal fields for electron energy 150keV.

Required PS currents were re-counted from currents for 0.5MeV. So, solenoid field B_S≈0.8kG, tor-45° field B_{TOR} ≈0.7kG and transport channels field B_{CH}≈0.5kG.

You can see features of beam shifts by different correctors. For example dominating beam shifts by corrector 4 (bend2) are straight down (at J_4>0) in pick-ups *2*, *3*, ***8*** *–**10*** and angularly 45° in pick-ups *4 –7*.

"HEATING" MEASUREMENTS

Feature of these measurements is ramp-up change of solenoid field B_S in range of optimal value. Lead of helix ρ_S changed accordingly. Here $\rho_S = 2\pi\beta c/\omega_B \approx 1.7\cdot10^3\cdot2\pi\beta\gamma/B$, ω_B cyclotron frequency. As result phase change arose on the solenoid length. It should be detected by pick-ups with **n** ≥*6* if ρ_S in pick-ups is larger than its length of measuring Lz ≈10cm.

Thus two beam orbits were tracked by pick-ups at parameters of responses measurements. Field B_S = 735 – 820G. Corrector's currents were the same except current J_3 of edipver-1. Orbits $Xs_n=X1_n+Sx_{3,n}\cdot J2_3$ and $Ys_n=Y1_n+Sy_{3,n}\cdot J2_3$ are got with use of responses data.

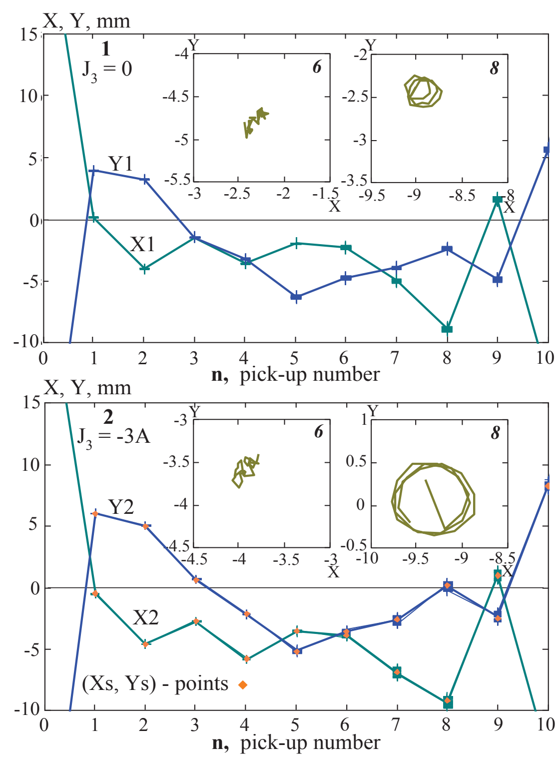

Figure 4: Beam orbits of 150keV electrons: (X1, Y1) and (X2, Y2) – measured; (Xs, Ys) – restored orbit.

Two pair of beam centre trajectories in transversal X-Y plane are shown on Fig. 4 also. Results in pick-up ***6*** (solenoid end) and in pick-up ***8*** (line05) are cited. Sizes of frames are the same 1.5×1.5mm. So ρ_S varied in solenoid from 11.9 to 10.7cm and phase change near 5π appeared on the solenoid end. But ρ_S here is near Lz and pick-up ***6***

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didn't detected phase change. Line05 field is 0.52kG and ρ_S is 17cm. As result near 2.5turns were registered here.

Next two orbits were measured in ramp-up field B_S at 500keV and are shown on Fig. 5. Required PS currents were re-counted from optimal currents for 1MeV

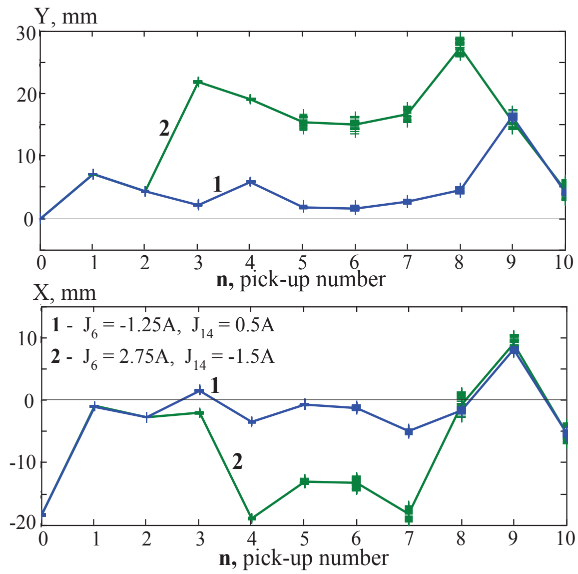

Figure 5: Orbits at different currents of line17v-1 corrector.

Trajectories of beam centre in X-Y plane are shown on Fig. 6. Here n = ***2*** – ***9*** for both orbits. Frames are 5×5mm.

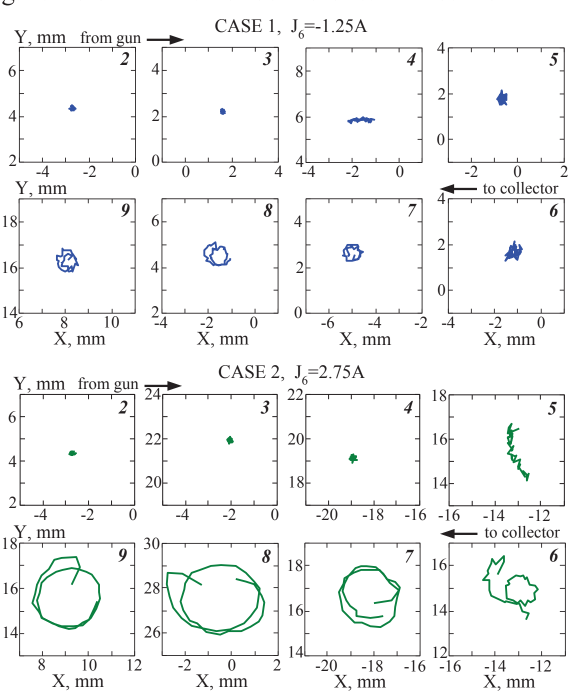

Figure 6: Trajectories of beam centre in X-Y plane.

Solenoid field B_S varied from 700 to 800G (ρ_S = 27 - 23cm, phase change ≈3.5π). Transport channels field B_{CH} was ~550G ($\rho_S \approx$ 33cm). Therefore trajectories of beam centre in X-Y plane detected by pick-ups ***6*** – ***10*** in ramp-up field B_S. Corrector currents here were the same except current J_6 of line17v-1 and J_{14} of line17v-2 correctors.

Probably in case **2** "heating" arose from strong shift of beam in regard to axis of matching section (**n**=***4***). Field increases along axis from 570 to 780G. Here grade of matching [2] is acceptable in case **1** (shift 6.3mm) but it unacceptable in case **2** (shift 26.9mm). Besides "heating" in both line17v is low-probability since integer number of ρ_S places on theirs length (5).

"HEATING" CALCULATIONS

Represented fragment included accelerating tube, match-1, bend1, line10-1 (see Fig.1) and added testing solenoid with uniform field. Thus computer simulations were done for shifted beam entrance in match-1 and shifted entrance with subsequent dipole kick in line10-1. Necessary parameters of simulations are the same as in responses measurements, electron energy 150keV. Except is current J_3 of edipver-1 corrector. Beam was simulated by nine trajectories. Results are shown on Fig. 7. Guiding field B_S along axial force line is cited.

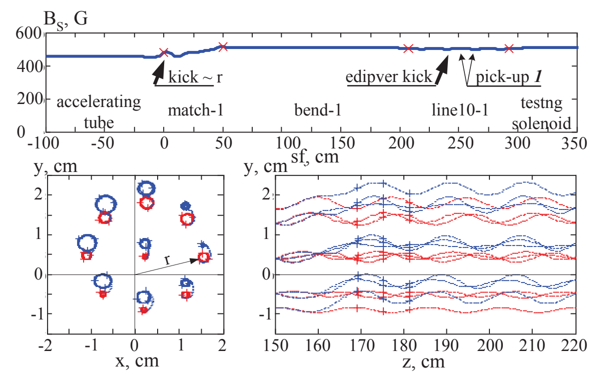

Figure 7: Calculated trajectories in line10-1 and testing solenoid at edipver-1 off and at edipver-1 on (J_3=-3A).

In-phase cyclotron rotation in transversal section of beam is typical at dipole kick. Antiphase rotation is typical for axis beam in field with longitudinal gradient. It is seen that nature of rotation is upset in analyzed cases.

CONCLUSION

Pick-up tracking in ramp-up solenoid field B_S allows detecting of "heating" and even though to measure it at dipole kicks only. Strong beam shift in regard to axis is inadmissible in sections with longitudinal gradient of field. Corrector's responses may be used for alignment of orbit. Gun with four-sector control electrode is additional tool for definition of "heating" nature.

REFERENCES

[1] M. Bryzgunov, A. Bubley, V. Gosteev, et al. "Magnetic system of electron cooler for COSY", Proceedings of COOL'11, Alushta, Ukraine TUPS10

[2] 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.

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