# CLOSED ORBIT CORRECTION IN 2 MEV ELECTRON COOLER SECTION AT COSY-JUELICH

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*Abstract*

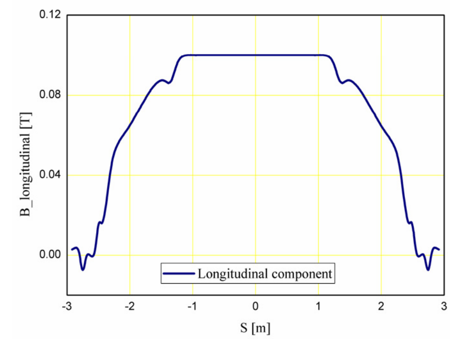
A 2 MeV magnetized electron cooling system will be installed at COSY in order to boost the luminosity for future high density internal target experiments. For an effective electron cooling, the ion beam and electron beam have to overlap coaxially, demanding a perfect orbit correction in the cooler region. Due to the U-shaped arrangement of the toroid magnets the ion beam orbit distortion is anti-symmetric in horizontal plane. With two steerers at each side of cooler the ion beam can be made coaxial in the cooler without disturbing the region outside the cooler. The distortion caused by the bending coils in the toroids is symmetric in the vertical plane. Also here a local correction is suggested for correction. Using the magnetic field data measured at BINP we calculated the orbit distortion of ion beam at injection energy and investigated the schemes for orbit corrections.

## INTRODUCTION

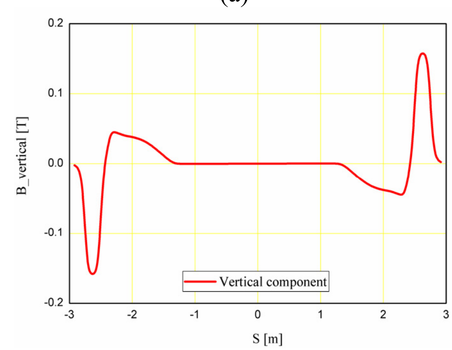
Considering the requests of high luminosity for future COSY internal target experiments, a magnetized electron cooling system up to 2 MeV was suggested to be tested and operated at COSY [1]. This device has been developed together with the Budker Institute in Novosibirsk and will be installed in COSY at the end of 2011. Basically, a strong longitudinal magnetic field is used to guide the electron beam and to magnetize the electrons. The vertical field components in the toroids cause a severe horizontal deflection of the ion beam which has to be corrected by a set of steerers around the cooler. The principles of correction schemes have been described in various articles, e.g. in [2] and [3]. Two horizontal dipole correctors already installed in the toroids and regular steerers around form a fully compensated bump on each side of cooler. A weaker but not negligible orbit distortion in the vertical plane is caused by the bending coils in the toroids which serve to compensate the centrifugal force of the electrons related to the toroid radius. Also here fully compensated bumps are considered.

## MAGNETIC FIELD DISTRIBUTION

The magnetic field map of the 2 MeV cooler produced by the cooling section drift solenoid, the toroids and the bending coils in the toroids have been measured at BINP [4]. The dipole correctors are connected in series with the toroids using the same power supply. Additional small coils mounted in the dipole correctors [5] will be used for a fine adjustment of the horizontal and vertical steering angle. The map (see Fig. 1) of magnetic field along the ion beam orbit has been measured with typical operational parameters.




(a)

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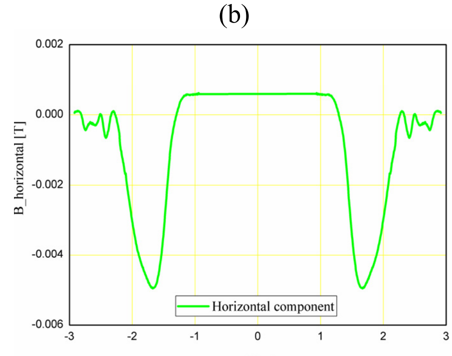


(c)

Figure 1: The magnetic field along the ion trajectory in cooler. From top down are shown the longitudinal, vertical and horizontal components. The current value of power supply is 175 A for the solenoid, 500 A for the toroids and the dipole correctors, 200 A for the bending coils. These parameters are half of design value.

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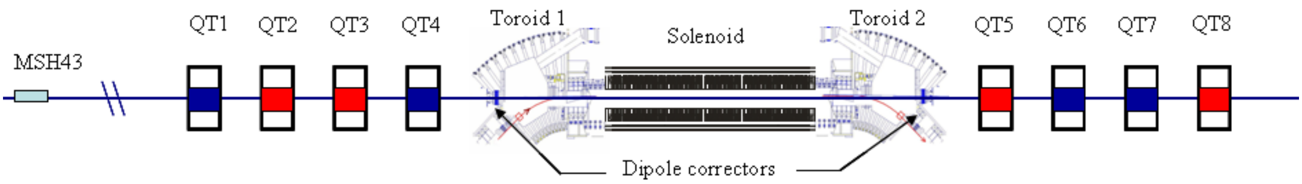


Figure 2: The COSY lattice structure in the 2 MeV electron cooler region. QT1, QT4, QT6 and QT7 are horizontally defocusing quadrupoles, QT2, QT3, QT5 and QT8 are horizontally focusing quadrupoles

## CLOSED ORBIT DISTORTION

The vertical and horizontal components of the magnetic field (see Fig. 1(b) and Fig. 1(c)) cause a horizontal and vertical deflection of the circulating ion beam, respectively. The deflection angle is given by integration:

$$\alpha_{v,h} = \frac{\sum B_{h,v} dz}{B\rho} \quad (1)$$

Here $B\rho$ is the magnetic rigidity of the ion, $B_{v,h}$ is the measurement data of magnetic field component and $dz$ is the measurement step length (5mm for BINP measurement case). As the magnetic field in cooler is fixed and not ramped with the ion energy, this formula reflects the worst case of maximum angles occurring at injection energy and maximum magnetic field. Therefore, the calculations below are performed for 45 MeV (0.98 Tm) proton beam and maximum design magnetic field value of 0.2 T. Since the horizontal magnetic field is determined by the electron energy, the vertical deflection is considered for the maximum electron energy 2.0 MeV.

In order to correct the orbit in both planes, several steerers installed in the quadrupoles near the electron cooler region are used (see Fig. 2). Two horizontal steerers have been installed in quadrupoles QT1 and QT8. Two vertical steerers have been installed in QT4 and QT5. The main parameters of these regular COSY steerers are listed in Table 1 [6]. The location value denotes the distance from centre of electron cooler. The deflection angle is calculated for 45 MeV proton beam. All calculations are made with MAD program for COSY injection optics [7].

Table 1: Main parameters of steerers

| Steerer | Location | Max. deflection angle |
|---|---|---|
| MSH43 | -12.192 m | 28.0 mrad |
| MSH_QT1 | -6.398 m | 12.0 mrad |
| MSV_QT4 | -3.538 m | 12.0 mrad |
| MSV_QT5 | 3.538 m | 12.0 mrad |
| MSH_QT8 | 6.398 m | 12.0 mrad |

## SCHEME OF CORRECTION

Fig. 3 shows the suggested correction scheme in the horizontal plane. The steerers installed in QT8 together with the toroid and the dipole corrector at the downstream side of the cooler form a three steerer bump. Upstream, due to the lattice structure (DFFD quadrupole sequence instead of FDDF sequence downstream), the strength of the steerer in QT1 is too weak. It is suggested to use the regular steerer MSH43 in addition (2.0 mrad). The accurate matching of the bumps is achieved by the fine tuning coils in the dipole correctors. The maximum displacement 41 mm is located at the dipole correctors in the cooler

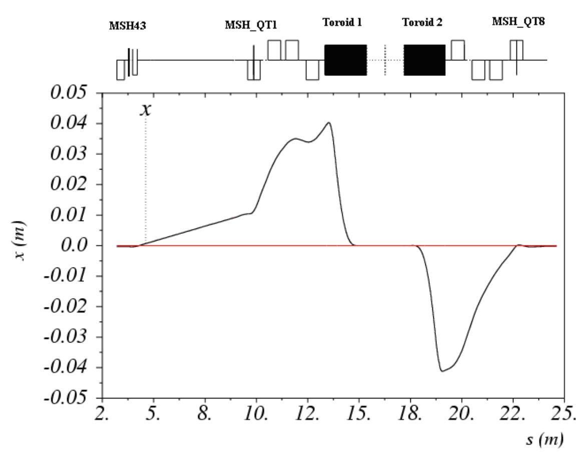


Figure 3: The closed orbit correction scheme in the horizontal plane. The regular COSY steerer magnet MSH43 and the steerers installed in QT1 and QT8 are used for correction on the both sides of cooler.

At COSY stripping injection of $H^-$ (or $D^-$) ions is applied to fill the ring with protons (or deuterons). For that purpose the COSY orbit is horizontally bumped for a few milliseconds to the edge of the stripping foil which is located in a distance of 16.3 m upstream the centre of the 2 MeV cooler. The last one of the three injection bumper magnets is located just behind QT4. Fig. 4 shows the horizontal orbit during the injection period and how the short term injection bump is superimposed on the steady state cooler bump.

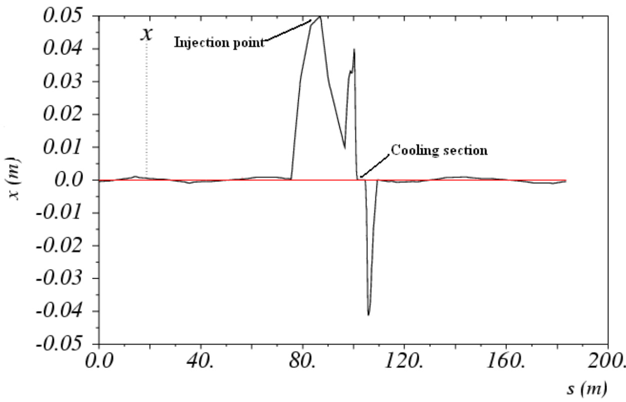


Figure 4: The proton beam trajectory during injection.

Vertically, the deflection due to the electron beam bending field is symmetric. The coils in the dipole correctors and the bending coils in the toroids can be used to form a matched four steerer bump. However will make a remaining offset of about 5 mm in the cooling section (see Fig. 5 (a)). Alternatively, a three steerers bump scheme at each side of the cooler can be applied too when the vertical steerers in QT4 and QT5 are activated (see Fig. 5 (b)). Here, the collinearity with the electron beam is as perfect as in the horizontal plane. The maximum displacement of orbit 5 mm again occurs in the dipole correctors. At higher ion beam energies, all orbit excursions are shrinking proportional to the increasing beam momentum.

The parameters of the closed orbit correction in both planes are listed in Table 2. The steerers EC_V1 and EC_V2 are the vertical coils in the dipole correctors upstream and downstream, respectively. The steerers EC_H1 and EC_H2 are the horizontal coils in dipole correctors. The values in parenthesises are the parameter of the four bump scheme in vertical plane, as shown in Fig. 5(a).

Table 2: Correction scheme in cooler region

| Steerer | Deflection angle /mrad | plane |
|---|---|---|
| MSH43 | 2.00 | x |
| MSH_QT1 | 11.16 | x |
| MSV_QT4 | 0 (5.06) | y |
| EC_V1 | 5.61 (-10.53) | y |
| EC_H1 | 10.15 | x |
| EC_V2 | 5.61 (-10.60) | y |
| EC_H2 | -16.31 | x |
| MSV_QT5 | 0 (4.82) | y |
| MSH_QT8 | -8.80 | x |

## CONCLUSION

The closed orbit correction for the new 2 MeV cooler at COSY is investigated. The local bump method is used to correct the orbit distortion due to the cooler magnetic system. The schemes have been performed by MAD program.

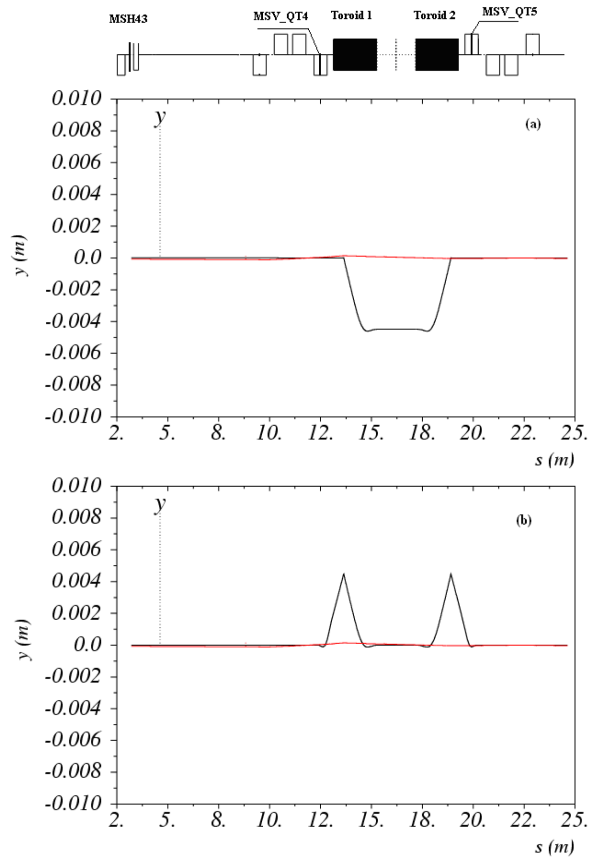


Figure 5: The orbit correction schemes in the vertical plane. (a) Only steerer coils belonging to the cooler are used. (b) The best collinearity is achieved by additionally using the vertical steerers in QT4 and QT5.

## ACKNOWLEDGMENTS

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