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RR note

Modified procedure of dipole field adjustment in the cooling section of the Recycler electron cooler

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Introduction

Effectiveness of the electron cooling drops with an increase of dipole field components in the field of the cooling section (CS). The current assumption is that such deterioration occurs in the Recycler electron cooler over time due to mechanical tilting of the section's solenoidal modules caused by a tunnel motion. Magnetic field of an inclined solenoid is equivalent to the non-perturbed field plus a constant dipole field proportional to the angle. Such component of X or Y magnetic field can be compensated by adding equal current in all of 8 dipole correctors, which are evenly placed along each module. The paper discussed the present way of optimization these currents and introduces an alternative procedure.

Present procedure

Presently, the values of these corrections are found in the procedure reported in Ref. [1] and describe below. The main idea is to align separately the first module (#0) to provide at its exit a trajectory parallel to the CS axis.

1. A low-intensity (several 10^{10} particles), coasting antiproton beam is cooled with electron beam on axis and transverse stochastic cooling to an equilibrium. That provides reproducibility of the initial beam conditions.
2. Currents in all 8 correctors in the first module (X or Y) are change by the same amount. The software feedback loop, so-called Autotune, adjust 4 dipole correctors upstream of the cooling section to keep the beam centered in the first and the second BPMs, C00 and C10, positioned, correspondingly, at the entrances of the CS and the second module.
3. The electron beam is deflected out axis immediately after the first module, so that it does not interact with antiproton downstream of the BPM C10 (Fig. 1).

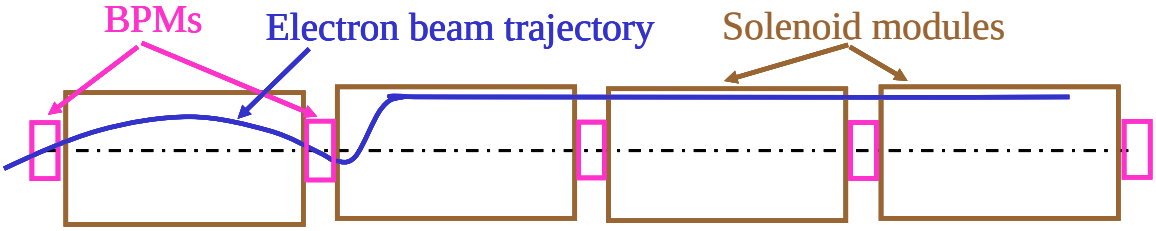

Figure 1. Illustration of the present procedure of adjustment of the dipole fields in the cooling section.

4. Electron energy is changed by 2 kV.
5. The time derivative of the average antiproton momentum is recorded and interpreted as a drag force by the electron beam in the first module.

6. The energy is moved back, the trajectory deflection is removed, and currents in the first module's correctors are restored to standard values to once more cool the beam to equilibrium.

7. Steps 2- 6 are repeated for several steps in both directions, and the drag force is plotted as a function of the current in X and Y correctors of the first module. The corrector currents are set to value providing the maximum drag force.

8. Corrector currents in the second module are adjusted by changing all 8 X – correctors by the same amount and then all 8 Y-correctors by another amount to center the beam in the BPM at the entrance of the next module, C20.

9. The step 8 is repeated for all downstream modules.

This procedure has been used for several times, and typically was improving the cooling rate. However, its resolution corresponds to the electron angle of 0.1 – 0.15 mrad, and, therefore, reliably helps only if the initial perturbation is large; otherwise, it is rather a question of luck.

Possible reasons for a poor resolution could be twofold. First, the drag force with one module should be 10 times lower than with the entire cooling section. As a result, statistical errors are significant. Second, the observed maximum of the drag rate in the first solenoid was always lower than this predicted 0.1 of the drag rate recorded with the same beam current, 0.1A, for all 10 modules in normal configuration. It may mean that dipole field variation over the first module, remained after 2004 magnetic measurements [2], is higher than the average over CS. In this case, the maximum drag rate in the first module may be at settings still leaving a significant angle of the electron beam trajectory at the exit of the first module, defeating the purpose of its separate alignment. This angle would propagate through the entire cooling section, and the gain of the cooling strength in the first module would be overwhelmed by the loss in other modules.

Idea of the alternative procedure

Optimization can be more straightforward and robust if one adjusts all correctors involved into the procedure described above at the same time and records the drag rate produced by the entire cooling section. In this case, currents in each pack of 8 correctors are changed by the same amount, proportional to a change of the current in the first module's pack of X or Y correctors. With the Autotune running, there is a proportion between corrector currents that keeps the beam in centers of all BPMs at all these variations (Fig.2).

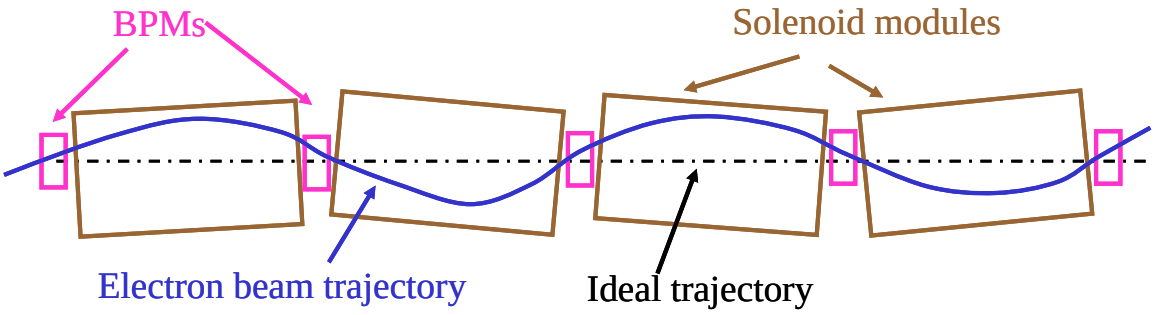

Figure 2. Beam trajectory during alignment according to the proposed procedure.

This procedure may give better results than the present one. First, from the very beginning we optimize the value that we really need, the drag rate with the entire CS. Second, the drag rate is by ~10 larger, which decreases contribution of statistical errors.

Calculation

The first step is a generation of coefficients relating dipole currents, or a MULTs in the Fermilab's jargon.

The system is supposed to be linear, so that a shift in the i-th BPM, $\Delta r_i = \begin{pmatrix} \Delta x_i \\ \Delta y_i \end{pmatrix}$, is proportional to changes in corrector currents, $\Delta I_k = \begin{pmatrix} \Delta Ix_k \\ \Delta Iy_k \end{pmatrix}$:

$$\Delta r_i = \sum_{k=0}^{i-1} m_{ik} \cdot \Delta I_k \quad , \tag{1}$$

In a module, the changes in all 8 correctors are the same. The 2 X 2 matrixes m_{ik} represent motion of electrons in the solenoidal field. Notation assumes that all BPMs are numbered from 0 to 10 and have the same number as the module, at which enter they positioned.

The Autotune keeps the beam centered in the first two BPMs; therefore, the shifts in other BPMs caused by the Autotune correctors can be interpreted as functions of the change in the first module's corrector currents, ΔI_0. Response of the BPMs to a change ΔI_0 with Autotune running can be described by 18X2 matrix L:

$$\Delta R_a = \begin{pmatrix} \Delta x_2 \\ \Delta y_2 \\ .... \\ \Delta x_{10} \\ \Delta y_{10} \end{pmatrix} = L \cdot \Delta I_0 . \tag{2}$$

The goal is to calculate coefficients of MULTs showing dependence of ΔI_k, k = 1 – 9, on ΔI_0, or a 18X2 matrix N,

$$\Delta J = N \cdot \Delta I_0 \, , \; \Delta J = \begin{pmatrix} \Delta Ix_1 \\ \Delta Iy_1 \\ .... \\ \Delta Ix_9 \\ \Delta Iy_9 \end{pmatrix}, \tag{3}$$

that keeps all BPMs at zero,

$$\Delta R = \begin{pmatrix} \Delta x_2 \\ \Delta y_2 \\ .... \\ \Delta x_{10} \\ \Delta y_{10} \end{pmatrix} = 0 \,. \tag{4}$$

Let's denote M a matrix of 9X9 stacked matrixes m_{ik} :

$$M = \begin{pmatrix} m_{2,1} & ... & m_{2,9} \\ ... & ... & ... \\ m_{10,1} & ... & m_{10,9} \end{pmatrix}. \tag{5}$$

Then the equation to solve is

$$\Delta R = L \cdot \Delta I_0 + M \cdot \Delta J = 0 \,, \tag{6}$$

and

$$N = -M^{-1} \cdot L \,. \tag{7}$$

The simplest approach is to assume that all dipole correctors and all solenoids are identical. In this case,

$$m_{ik} = \begin{cases} 0, & i \le k \\ m_{i-k+2,2}, & i > k \end{cases} . \tag{8}$$

Technical details of possible implementation

The preparation measurements can be done at any number of antiprotons, because with the electron beam close to the axis, the image charge contribution is small, and the measurements can be done at 0.1 A. Autotune is running all the time. BPMs are recorded with the EXCEL macro and averaged over 20 readings at each setting.

1. CXC01 – CXC08 are changed in steps of 0.05 A; several settings.
2. Step 1 is repeated for Y.
3. CXC11 – CXC18 are changed in steps of 0.05 A; several settings.
4. Step 3 is repeated for Y.
5. Data are read into MathCad.
6. Linear fits to the data from steps 1 and 2 generate coefficients of the matrix *L* according to Eq.(2).
7. Linear fits to the data from steps 3 and 4 generate coefficients of the matrixes $m_{i,2}$ according to Eq.(1).
8. Matrix *M* is composed according to Eq. (8).
9. Matrix *N* is calculated according to Eq. (7).
10. Two rows of the matrix *N* are transferred to two EXCEL files for generating X and Y data sets.

11. The files create output text files for the WaveGenerator in the manner similar to the present procedure: change of all dipole correctors; time for Autotune to settle down; 2 kV voltage jump; 5 min for the measurement; voltage is back; correctors are back.
12. Otherwise, the procedure is identical to the present one.

References

1. Beam-based Field Alignment of the Cooling Solenoids for Fermilab's Electron Cooler, by L. R. Prost and A. Shemyakin, in Proc. of COOL'07, Bad Kreuznach, Germany, September 10-14, 2007, THAP09, also available as FERMILAB-CONF-07-446-AD
2. Magnetic Field Measurement and Compensation in Recycler Electron Cooler, by V.Tupikov, G..Kazakevich, T.K.Kroc, S.Nagaitsev, L.Prost, A.Shemyakin, C.W.Shmidt, M.Sutherland, A.Warner, Proc. of COOL'05, Galena, USA, September 19-23, 2005, p. 375, also available as FERMILAB-CONF-05-397-AD