# Magnet Sorting along the Ring of the 1-st Stage of the UNK

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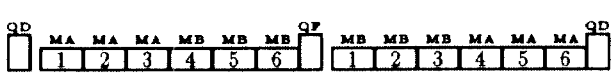
*Abstract*

The effect of random and systematic errors of the dipole effective lengths on the closed-orbit distortion is discussed. The practical technique of the dipole sorting along the ring which is based on the known values of their effective lengths is presented. This technique is aimed at the minimization of the closed-orbit distortion.

## 1 INTRODUCTION

The first stage of the UNK is intended to accelerate protons from 65 to 600 GeV, and would be operated, mainly, as a 400 GeV-booster for the 3000 GeV superconducting accelerator [1]. Magnetic measurements of a sufficiently large batch of conventional dipoles [2] have shown the r.m.s. spread of field non-linearities at the reference radius of 35 mm to be less than $1 \cdot 10^{-4}$. Therefore, while sorting and arranging magnets along the ring, it makes no sense to minimize the effect of non-linearities on stability of betatron oscillations. Rather, of interest are the sorting algorithms which decrease the initial closed-orbit distortion caused by a relatively large spread in dipole's effective lengths. Such a minimization would simplify the commissioning of the accelerator.

The first stage of the UNK employs two types of dipole magnets with different pole gaps, MA and MB. Most of these dipoles (88.5%) are to be installed in 160 regular cells of the magnetic structure. The layout of dipoles and quadrupoles (QD,QF) in a cell is shown in a sketch below. The rest of dipoles are to be installed in special insertions intended for the dispersion-function suppression, and for the orbit-length equalization of the UNK stages. The dipole arrangement in these insertions does not show such a regular pattern as in a normal cell. However, in between quadrupoles the sequence of MA, MA, MB, MB often takes place. Each octant of the accelerator has 20 cells followed by a special insertion where the number of dipoles of either type does not exceed $J = 16$.




An unit cell of the UNK.

Magnetic measurements determine a deviation of effective length of each dipole with respect to that of a standard one. This deviation is characterized by the quantity

$$\frac{\Delta H}{H} = \frac{\int_{-\infty}^{\infty} H_z(0,0,s)ds}{\left(\int_{-\infty}^{\infty} H_z(0,0,s)ds\right)_{std}} - 1.$$

Fig.1 shows systematic values of $(\overline{\Delta H}/H)_A \cdot 10^4$ (curve 1) and $(\overline{\Delta H}/H)_B \cdot 10^4$ (curve 2) for MA and MB dipoles against the values of excitation current $I$, or against the relevant energy $E$ of particles. The same figure plots the r.m.s. spread $\langle \Delta H/H \rangle \cdot 10^4$ (curve 3) which is, up to accuracy $(1 \cdot 10^{-4})$ of magnetic measurements, approximately the same for both types of dipoles. Equalization of systematic values of effective lengths of MA and MB is carried out at the energy of 400 GeV, the latter being the injection energy of the superconducting accelerator.

The closed-orbit distortion $\Delta x = x_{max} - x_{min}$, as introduced by a systematic mismatch of MA and MB lengths, does not exceed 5.7 mm at injection (65 GeV), and 3.4 mm at the maximum energy.

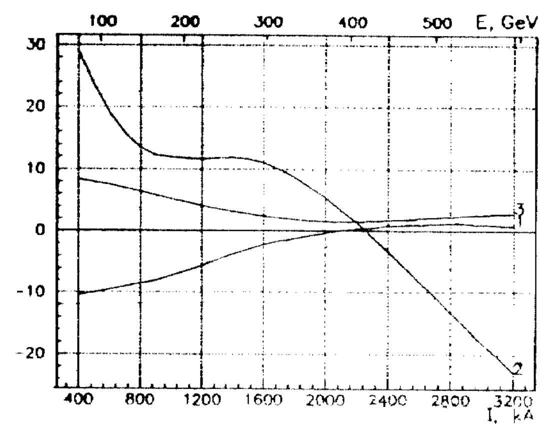



Figure 1: Dipole effective lengths.

## 2 ALGORITHMS OF SORTING

The influence of spread in lengths on horizontal orbit distortion has been studied numerically. For each type of magnets in question, a random deviation value of

$$\varepsilon = \Delta H/H - \overline{\Delta H}/H$$

is given by a Gauss distribution with a zero mean value, and the variance of $1 \cdot 10^{-3}$ corresponding to the value of

$(\Delta H/H)$ as shown in Fig.1 for injection. Allowing for the tolerances on the length spread in the dipole manufacturing, these distributions have been cut off at the level of $\pm 2 \cdot 10^{-3}$ for calculations. For either complete arrangement of dipoles over the ring the values of $\Delta x$ are calculated. After a sufficiently large number of such lattice realizations (not less than 300) the distribution of random quantity $\Delta x$ is reconstructed. The 95%-threshold of this distribution has been taken as a quantitative measure of the quality of the sorting algorithm used.

Given an arbitrary magnet installation over the ring, the numerical results yield the maximum addition to the orbit distortion of $\Delta x = 33$ mm. It can well complicate the accelerator commissioning.

Hence, it makes sense to decrease such a perturbation by applying a special procedure of magnet sorting and arrangement. The problem at issue can be solved easily provided the values of $\varepsilon$ for all the magnets are known prior to their installation. The following situation seems to be realistic. In a course of the dipole manufacturing, a batch of them, with small $\varepsilon$, is sorted out in a special store with $2J$-capacity ($J$ dipoles of each type). These are used for installation in the special insertions. The rest dipoles are accumulated in the main store with $2N$-capacity ($N$ dipoles of each type) for the successive filling in of regular cells. The values of $N = 24$, 48, 96 were taken for simulations. The location of dipoles in two stores is conventional: magnets are just registered in one of them.

The installation of dipoles is supposed to be started by filling in of the accelerator octant cells. The sorting procedure begins by accumulation of $(N + J)$ dipoles of either type, and by evaluation of systematic value of $\bar{\varepsilon}_{N+J}$. Then, $J$ dipoles with the smallest $|\varepsilon - \bar{\varepsilon}_{N+J}|$ are registered in a special store wherein the range $[\varepsilon_{\min}, \varepsilon_{\max}]$ and $\bar{\varepsilon}_J$ are determined. The rest $N$ dipoles are registered in the main store. Supplement of new magnets to replace those sent to the ring is carried out in the following way. After magnetic measurement a new dipole with $\varepsilon^* \notin [\varepsilon_{\min}, \varepsilon_{\max}]$ is registered in the main store. In the case of $\varepsilon^* \in [\varepsilon_{\min}, \varepsilon_{\max}]$ such a dipole is registered in the special store from which the dipole with $|\varepsilon - \bar{\varepsilon}_J|_{\max}$ is sent in the main one. Thus, in course of filling in of the whole octant of regular cells (120 MA and 120 MB dipoles) $J$ magnets of either type with small spread in their lengths are selected in the special store.

The simplest algorithm of magnet arrangement in the regular structure is to choose $k$ dipoles from the main store so as to avoide a stretching of an additional orbit distortion introduced by dipoles beyond their position along the ring. In this case the effective lengths of these dipoles must obey the conditions [4]:

$$\sum_{n=1}^{k} \varepsilon_n = 0, \qquad \sum_{n=1}^{k} n\varepsilon_n = 0 \tag{1}$$

The UNK cell allows dipole grouping into sets of three ($k = 3$), or of six ($k = 6$) ones. In case of $k = 3$, a magnet from the main store with the maximum $|\varepsilon|$ is put into the center of three dipoles of each type. Two other dipoles are selected so as to meet conditions of eq.1 as exactly as possible:

$$\varepsilon_1 = -\varepsilon_2/2 \quad \text{and} \quad \varepsilon_3 = -\varepsilon_2/2, \tag{2}$$

or

$$\varepsilon_1 = -\varepsilon_2/2 \quad \text{and then} \quad \varepsilon_3 = -\varepsilon_1 - \varepsilon_2. \tag{3}$$

In case of $k = 6$ (three MA and three MB dipoles), magnets from the main store with the greatest (by modulus) negative $\varepsilon$ are installed at the second and fifth positions in a half-cell, and dipoles with the greatest positive $\varepsilon$ are located at the third and fourth ones. Two remaining magnets of the hexad are selected so as to meet condition of eq.1 with a maximum accuracy, i.e.

$$\varepsilon_1 = \sum_{n=2}^{5} \varepsilon_n (n-6)/5 \quad \text{and then} \quad \varepsilon_6 = -\sum_{n=1}^{5} \varepsilon_n. \tag{4}$$

Nevertheless, given a sufficiently large $|\bar{\varepsilon}_N|$ in the main store, the employment of eqs.2,3,4 can prove to be difficult. Therefore, it is more convenient to select $k$ dipoles by putting into in these equations the quantities $(\varepsilon_i - \bar{\varepsilon}_N)$ rather than $\varepsilon_i$. In this case, on installing 24 dipoles of each type in the ring and on filling up the main store by the same number of new magnets, it is necessary to re-evaluate $\bar{\varepsilon}_N$. Twenty four dipoles of each type are required to fill in four cells whose total length is close to the UNK betatron oscillation wave-length. A constant perturbation $\bar{\varepsilon}_N$ along a section of such a length brings about practically zero orbit distortion beyond this section.

A pair-wise arrangement algorithm is used in the special insertions. That is, two magnets with maximum and minimum values of $\varepsilon$ from the special store are selected, and installed successively into the insertion.

## 3 RESULTS OF SIMULATIONS

Table 1 presents the values of orbit distortion $\Delta x$ for the dipole sorting and arrangement by triplets (algorithms 1,2,3), and by hexads (algorithm 4). Algorithm 1 relies on eq.2, while algorithms 2,3,4 employ, respectively, eqs.2,3,4 with substitution $(\varepsilon_i - \bar{\varepsilon}_N)$ for $\varepsilon_i$.

This Table shows the minimum orbit distortions to occur for the dipole arrangement by hexads. In which case the employment of the procedure of incomplete extraction $(M < N)$ from the main store would not result in an appreciable decrease of $\Delta x$. This procedure provides a valuable effect only in applying algorithm 1.

Computer simulations have else shown that an absence of a special store along with an arbitrary magnet arrangement resulted in the orbit distortion of 11.0 mm caused solely by dipoles in insertions. Employment of a special store decreases this value down to 1.8 mm given an arbitrary arrangement, and down to 1.5 mm given the pair-wise one. Thus, an algorithm of dipole arrangement in insertions is not of a crucial importance, provided a special store is created in which magnets with a small spread of $\varepsilon$ are accumulated.

Table 1: Closed-orbit distortions $\Delta x$/mm.

| | | Algorithms | | | |
|---|---|---|---|---|---|
| $N$ | $M$ | 1 | 2 | 3 | 4 |
| 24 | 24 | 22.6 | 10.0 | 7.1 | 6.9 |
| | 12 | 11.8 | 10.9 | 9.9 | 6.4 |
| | 6 | 10.9 | 10.5 | 10.0 | 6.1 |
| 48 | 48 | 16.8 | 10.3 | 6.0 | 6.5 |
| | 24 | 12.4 | 7.6 | 4.7 | 4.4 |
| | 12 | 9.0 | 8.2 | 7.1 | 4.3 |
| | 6 | 8.9 | 8.4 | 8.1 | 4.2 |
| 96 | 96 | 13.3 | 9.6 | 5.9 | 6.7 |
| | 48 | 7.7 | 7.4 | 4.7 | 4.7 |
| | 24 | 8.4 | 7.6 | 4.4 | 4.4 |
| | 12 | 7.7 | 7.5 | 6.2 | 3.8 |
| | 6 | 7.8 | 7.3 | 6.8 | 3.8 |

## 4 CONCLUSION

Numerical calculations performed show the creation of two stores, in which dipoles are accumulated to be installed separately in regular cells and in special insertions, to be reasonable. The choice of optimum $N$ is governed by a compromise between the decrease rate of the orbit distortion and the store area available. In the UNK it is quite reasonable to take $N = 24$. It requires a total capacity of two stores to be $2(N + J) = 80$. In this case the orbit distortion for dipole arrangement by hexads (algorithm 4) decreases more than five-fold as compared to an arbitrary installation.

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## 5 REFERENCES


[1] V.I. Balbekov et al."The UNK Magnetic Structure", in Proceedings of 8 All-Union Conference on Particle Accelerator, Dubna, 1983, p.187.

[2] Yu.M. Nosochkov et al."The Magnetic Field Performances of the Dipoles and Quadrupoles for the 1-st Stage of UNK", IHEP 91-65, Protvino, 1991.

[3] V.I. Balbekov and Yu.M. Nosochkov,"Analysis of Special Section in the UNK Magnetic Lattice", IHEP 83-191, Serpukhov, 1983.

[4] R. Billinge,"Magnetic Mixing to Reduce the High Field Closed Orbit Distortion", CERN LAB II-MA/74-1, Geneva, 1974.