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**DESIGNING BYPASS CHANNELS IN NICA ACCELERATOR COMPLEX FOR POLARIZED BEAM EXPERIMENTS FOR EDM SEARCH**

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Experiments with polarized beams for electric dipole moment search in the NICA accelerator complex implies the design of an additional ByPass channels. Such alternative channels will make it possible to use NICA as a storage ring and collect enough statistical data.

*Keywords*: *magneto-optical structure, ByPass channels, storage ring, electric dipole moment*.

# INTRODUCTION

NICA (Nuclotron-based Ion Collider fAcility) is an accelerator complex, located in Dubna, Russia. The main ring is designed for collision experiments with heavy ions at 4,5 GeV to study properties of dense baryonic matter as well as for polarized proton beams at 13 GeV. For these purposes, appropriate SPD and MPD detectors and other necessary implements are installed on the straight sections [1].

In Electric Dipole Moment (EDM) experiments the main feature is to maintain high value of Spin Coherence Time (SCT) at about 1000 s. During this time coherent polarized beam stores in ring. For these needs is necessary to operate the main NICA ring as a Storage Ring, and not in a collider mode. To do this, it is proposed to install ByPass channels. Thus, it is possible to create a completely new alternative regular structure in a straight section, parallel to original one. Creating ByPass channels is a big adventure, don’t require significant restructuring of the complex and costs and will make it possible to engage NICA in various experiments at once.

1. PREREQUISITES FOR NICA MAIN RING MODERNIZATION

To measure EDM, it is necessary to develop spin control methods. Spin-vector evolution is described by T-BMT equations [2]:

As it can be seen from Equation 1, the main features are the experiment energy, and particle type.

The EDM research experiment does not require special detector, only polarimeter. Cross section at polarimeter with carbon target achieve the highest value for protons and deutrons at energy about 270 MeV. This requirement determines the experiment energy, only by polarimeter needs.

In addition, stable spin motion is required. The consequence of equations is the «Frozen Spin» concept. [2]. This method involves zeroing the term associated with the magnetic dipole moment (MDM) during the entire time of beam retention. This method is valid for both protons and deuterons, but has significant differences. For a deuteron magnetic moment anomaly is negative , which is an order of magnitude less than for the proton . For protons at a certain energy, called "magic", MDM term takes zero value in a purely electric ring, without magnetic elements. While for deuterons, due to the negative value of the magnetic anomaly, the necessary magneto-optical structure involves the use of deflectors with both electric and magnetic fields. In this case, spin rotation in a magnetic field is compensated by an electric one in each element. Thus, the rotation retains its orientation during the entire rotation time in the ring. However, the dipoles in the arcs of the NICA main ring have only a magnetic field component. Thus, the implementation of the "frozen spin" concept in the NICA ring is impossible without a corresponding significant modernization and reconstruction.

To carry out EDM search experiment, it becomes necessary to use an alternative spin control method – the concept of «Quasi-Frozen Spin» [3]. Unlike the «Frozen Spin» method, here the spin does not retain orientation throughout the entire period of circulation, but restores orientation on a straight section. This is possible by using elements with both electric and magnetic fields, which are called Wien Filters. The rotation of the spin in the arc by a certain angle is compensated by the corresponding rotation in the Wien Filter. Also, fields can be chosen to make zero-Lorentz force and do not disturb orbit. For this reason, polarimeter can be installed on straight sections. Thus, polarimeters located after Wien Filters will detect the same orientation of the spin-vector and for them it will be "frozen".

There are two main reasons for magneto-optical structure modernization. Firstly, the space lack for Wien Filters in already existing straight sections. Secondly, the available magneto-optics assumes NICA ring in the collider mode. But EDM search experiments involve long-term retention and preservation of polarized coherent beam at a time about s. Therefore, proposed the modernization by introduction of ByPass channels to create an alternative straight section, parallel to the original one (Fig. 1). Thus, NICA can be used as a Storage Ring. Such rings can carry out EDM experiments with polarized deuterons and axion search at QFS regime.

# 2. MAGNETO-OPTICAL STRUCTURE WITH BYPASS CHANNELS

The features given in the previous chapter are crucial for choosing the experiment energy and particle type. In the future, all proposed magneto-optics will be considered for deuterons at energy It is worth noting that the calculations show the main parameters of the dipole magnetic field , as well as magnetic rigidity . (Table 1)

Designing ByPass NICA Storage Ring, the geometry of arcs is planned to remain unchanged. It is possible to change fields in already installed elements. So that it is possible to use NICA for various experiments.

In NICA ring, arc is a place with a non-zero dispersion. At the edges, both dispersion and

its derivative suppressed to zero. Straight section has zero dispersion throughout.

The total length of original NICA m. Each arc length is m. So, there is m available.

**ByPass** is a channel for beam deflection into alternative straight section. Dipole magnets chosen to make a deviation by angle . Dipole strength Т with length sm. Alternative straight section is at a distance of 1 meter from the original ones, so ByPass section length . Schematic diagram of ByPass channels shown on Fig.1.

Defector magnets distort dispersion function. Thus, needed to use at least 2 focusing quadrupoles on ByPass channel to suppress dispersion at the end. This will help to provide zero dispersion throughout the straight section. To ensure periodicity and symmetry of beta-functions, it can be used 1 or 3 defocusing quadrupoles at ByPass.

Two cases will be considered, adopted straight sections is fully identical to arcs but without magnets. This is done for simplicity and ideal regular modelling. Lastly, we consider real case of magneto-optical structure with fully regular FODO straight section.

# *3 Quadruple ByPass scheme*

In this case, ByPass consist of minimal possible 3 quadrupoles (Fig. 2). The matching of the arc with the ByPass is provided by three quadrupoles QM1, QM2, QM3 (M1 section). And the matching of the ByPass with a straight section (M2), which is identical by virtue of symmetry, and consist of 3 quadrupoles QM1, QM2, QM3 to ensure beta-function periodicity (Fig.3). Total length of the whole accelerator is then m.

Figure 3 shows the Twiss-functions, the black lines indicate the boundaries of the ByPass channel. Beta-function maximum is located in the center of the ByPass channel. And may take on more significant value, compared to . For this reason, we can consider the case with 5 quadrupoles in the ByPass channel.

# *5 Quadruple ByPass scheme*

Compared to the previous case, the ByPass channel consists of 5 quadrupoles, which are represented by 2 families: focusing QBP1 and defocusing QBP2. It's getting longer m and is deflected by m (Fig. 4). Now, matching sections M1 and M2 are still identical, but they are represented by two quadrupoles QM1 and QM2 to ensure the regularity of Twiss-functions. However, the full length of the accelerator becomes longer, NICA m. Figure 5 shows that the maximum getting smaller in the center. It is worth noting that the maximum of the dispersion function has increased from till . Thus, this case should be adapted to the real one.

# *Real case scheme*

Based on the considered cases, we can finally get the structure closely adopted to reality. Now, straight section is fully regular and become shorter m (Fig. 6). ByPass consist from 5 quadrupoles and deflect beam by 1,46 m. But for matching used different sections M1 and M2 to compensate non-symmetry between arc and straight section. Finally, Twiss-function of half of NICA ByPass represented on Fig. 7. At the center of straight section located Wien Filters.

All calculations of Twiss-functions made with OptiM [4] and COSY Infinity [5].

# 3. CONCLUSION

For EDM experiments it is necessary to use NICA as a Storage Ring. For this reason, modernization was considered by creation of an alternative straight sections parallel to the original ones by using ByPass channels. Also, straight sections have the ability to place special elements – Wien Filters to compensate spin rotation in the arcs. As arcs remain unchanged, this allows to use NICA in various experiments.

Considered 2 principal schemes of ByPass channel. And finally got the most realistic case, where straight section is fully regular. Final structure satisfies all necessary magneto-optics requirements. Spin-tracking research with optimized Wien-filters made and simulations shows that spin restore orientation at the straight sections. «Quasi-Frozen Spin» method can be implemented in ByPass NICA.

# ACKNOWLEDGEMENT

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CONFLICT OF INTEREST

The authors confirm that they have no conflict of interest.

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**Table 1**. Basic parameters of the structure and experiment.

|  |  |
| --- | --- |
| Magnetic field of dipoles |  |
| Magnetic rigidity |  |
| The full length of the accelerator |  |
| The energy of the experiment | MeV |

**Table 2**. Lengths and parameters of the considered magneto-optical structures.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Structure | Full length, m | Straight section length, m | ByPass channel length, m | Matching section length, m | Working point |
| NICA | 503.04 | 109.6 | – | - |  |
| 3 Quadrupoles | 503.46 | 83.97 | 6.41 | 3.198 |  |
| 5 Quadrupoles | 510.0 | 83.97 | 9.35 | 2.548 |  |
| Real | 503.5 | 80.70 | 9.35 | 2.548 |  |

Fig. 1. Schematic diagram of ByPass channels in the existing NICA complex.

Fig. 2. Schematic diagram of ByPass with three quadrupoles.

Fig. 3. Twiss-parameters for ByPass with three quadrupoles. The black lines show the location of the deflectors.

Fig. 4. Schematic diagram of ByPass with five quadrupoles.

Fig. 5. Twiss-parameters for ByPass with five quadrupoles. The black lines show the location of the deflectors.

Fig. 6. Schematic diagram of a real ByPass.

Fig. 7. Twiss-functions for half of the ByPass NICA ring. Wien-filters located on a straight section.