There exist two design approaches to the problem of measuring the deuteron Electric Dipole Moment (dEDM) inside a storage ring: the Frozen Spin (FS) lattice, and the Quasi-Frozen Spin (QFS) lattice.

The FS ring design concept's main objective is the maximization of the EDM signal. In the case of a single particle, this can be accomplished if its spin is continuously aligned with the momentum vector in the horizontal plane: the so-called Frozen Spin condition. The continuous fullfilment of this condition, required by the FS method, is problematic for the following reasons:

- since the spin precession frequency $\vec{\Omega} = -\frac{q}{m}\left[G\vec{B} + \left(\frac{1}{\gamma^2-1} - G\right)\vec{\beta}\times\vec{E}\right]$, [1] the EDM of particles with a negative magnetic anomaly $G = (g-2)/2$ (such as the deuteron) cannot be measured using either a purely electrostatic or a purely magnetic ring, and so requires the use of combined E+B field elements, placed inside the accelerator arcs;
- even so, for the given values of E- and B-fields, there exists a unique γ, for which the FS condition holds strictly, meaning that for the majority of the beam particles that condition is fulfilled only approximately in any case.

This last point is the major motivation for the use of a Quasi-Frozen Spin ring design.

The Quasi-Frozen Spin design concept consists in correcting the necessarily occurring MDM spin rotation in the magnetic arcs by a reverse rotation in the straight sections. The ring can be implemented in two versions: one in which the E- and B-field elements are separated, and another in which the combined E+B elements are located in the straight sections of the lattice. [2]

In the first option, the ring is made up of two types of arcs: magnetic, in each of which the closed orbit is bent by an angle $\Phi^B_{co} = \pi + 2\alpha$, and the spin is rotated, accordingly, by $\Phi^B_{spin} = \nu^B_s \cdot \Phi^B_{co}$, and electrostatic, with the closed orbit bend angle $\Phi^E_{co} = -2\alpha$, and $\Phi^E_{spin} = \nu^E_s \cdot \Phi^E_{co}$. The Quasi-Frozen Spin condition in this case can be formulated simply as $\Phi^E_{spin} + \Phi^B_{spin} = 0$. One drawback of this lattice is the use of cylindrical electrostatic deflectors, and the non-linearities involved.

In the second option, straight E+B spin rotators (placed in the straight sections) are used to compensate the arc MDM rotation.

If the spin vector oscillates in the horizontal plane with an amplitude Φ, the EDM signal is reduced by a factor $1 - \frac{\Phi^2}{4}$. In a QFS ring with n-periodicity, the spin oscillates relative to the momentum vector within half the value of the advanced spin phase $\gamma G \cdot \frac{\pi}{2n}$. [2] In our designs, with the accelerator length approximately 150 meters, $\Phi \approx 0.25$, and hence the signal is reduced by no more than 2%.

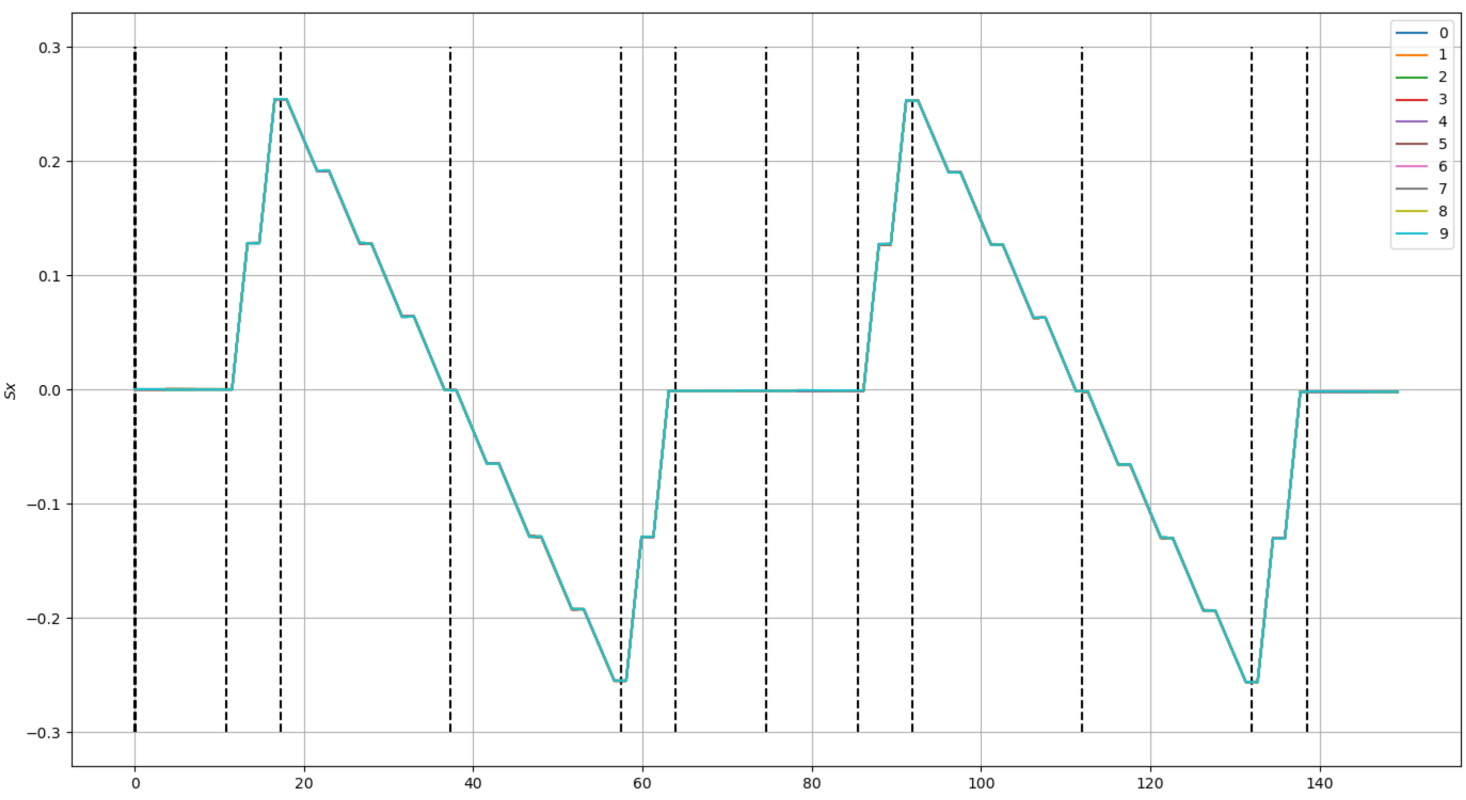

Figure 1: Spin precession in the horizontal plane in a QFS lattice. Dashed vertical lines mark the ends of sections of the lattice.

References

[1] Saleev A, Nikolaev NN, Rathmann F, Augustyniak W, Bagdasarian Z, Bai M, et al. Spin tune mapping as a novel tool to probe the spin dynamics in storage rings. Physical Review Accelerators and Beams [Internet]. 2017 Jul 7 [cited 2018 Oct 8];20(7). Available from: http://arxiv.org/abs/1703.01295

[2] Senichev Y, Andrianov S, Ivanov A, Chekmenev S, Berz M, Valetov E 2015 Investigation of lattice for deuteron EDM ring. Proc. ICAP2015 (Shanghai, China). http://accelconf.web.cern.ch/AccelConf/ICAP2015/papers/modbc4.pdf

[3] D. Anastassopoulos, V. Anastassopoulos, D. Babusci. AGS Proposal: Search for a permanent electric dipole moment of the deuteron nucleus at the 10^{29} $e \cdot cm$ level. [Internet]. BNL; 2008 [cited 2016 Nov 25]. Available from: https://www.bnl.gov/edm/files/pdf/deuteron_proposal_080423_final.pdf

[4] S. R. Mane. Spin Wheel. arXiv:150901167 [physics] [Internet]. 2015 Sep 3 [cited 2018 Sep 28]; Available from: http://arxiv.org/abs/1509.01167

[5] Frequency domain method of the search for the deuteron electric dipole moment in a storage ring with imperfections

[6] Yurij Senichev. Search for the Charged Particle Electric Dipole Moments in Storage Rings. In: 25th Russian Particle Accelerator Conference (RuPAC16), St Petersburg, Russia, November 21-25, 2016 [Internet]. JACOW, Geneva, Switzerland; 2017 [cited 2017 Apr 5]. p. 610. Available from: http://accelconf.web.cern.ch/AccelConf/rupac2016/papers/mozmh03.pdf

[7] Senichev Y, Zyuzin D. SPIN TUNE DECOHERENCE EFFECTS IN ELECTRO- AND MAGNETOSTATIC STRUCTURES. In: Beam Dynamics and Electromagnetic Fields [Internet]. Changhai, China: JACoW; 2013 [cited 2017 Jul 31]. p. 2579–2581. Available from: https://accelconf.web.cern.ch/accelconf/IPAC2013/papers/wepea036.pdf