ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPTS100

THE ESR CLOSED ORBIT CALCULATION AND SIMULATION

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Abstract

The commissioning of the Experimental Storage Ring (ESR) with a new control system based on the LSA (LHC System Architecture) has started recently. The aim with these updates were that the 25-year-old control system, which was based on outdated computers and operating system, was discontinued. In addition, the front-end components of the hardware were also 25 years old and couldn't be serviced any more, they are modernized together with the control system. This new control system is under development and considers all aspects of the expected functionality to operate the GSI/FAIR accelerators and incorporates the present GSI controls infrastructure [1].

So, both the heavy ion synchrotron SIS-18 and the ESR operation from now on have to be performed with the new FAIR control system. In order to introduce an improved model to the control system change, new calculations and simulations for SIS and ESR are necessary. In this paper we summarize the results of closed orbit calculations for the ESR which are done with three different codes, namely: ELEGANT [2], MAD-X [3] and MIRKO [4]. Considering similar results between MAD-X and ELEGANT, we present ELEGANT results in the report. In fact, the simulation for the old control system had done with MIRKO which worked fine. For the new control system, we decided to use these three codes for numerical simulation, but using MIRKO values in ELEGANT did not agree well, therefore the ELEGANT input was checked and adapted for better agreement.

It is not yet clear that the details of the large aperture ESR magnets are treated in the same way in the two codes and higher order field components affect the result of the orbit calculation. This might be the origin of the difference between ELEGANT and MIRKO results.

INTRODUCTION

The ESR storage ring [5] at GSI is the core instrument for unique physics experiments. The ESR is operated for accumulation, storage and cooling of heavy ion beams in the energy range from 4-400 MeV/u. It is a symmetric ring with two arcs and two straight sections and a circumference of 108.36 meters.

The ESR consists of 6 dipole magnets (deflection angle is 60°) and 20 quadrupoles. For the second-order corrections 8 sextupoles are installed in the arcs. The ESR operates at a maximum magnetic rigidity of 10 Tm. For reducing transverse and longitudinal emittances of the stored ion beams, the ESR is equipped with an electron cooler which is installed in one of straight sections of the ring.

Beam cooling is the prominent feature of the ESR, reducing the beam phase space by a non-Liouvillean process. Stochastic and electron cooling in ESR reduce the beam size in 6-D.

In one of the two straight sections the internal gas-jet target is installed. Local orbit bumps at the target are controlled by four horizontal steerers which are placed 8 cm from each of the two edges inside the dipole magnets. The ESR has in total 12 horizontal and 8 vertical orbit correctors around the ring, the objective of the correctors is to control the beam orbit. They are labelled KX and KY in Figure 1. Four horizontal correctors that are placed in the northern and southern of ESR are used for the stochastic cooling.

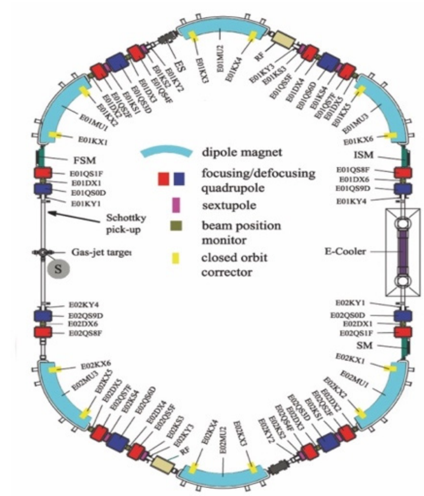

Figure 1: The ESR storage ring.

The ESR stochastic cooling system has been commissioned over the past years. An important step forward was the first stochastic cooling of hot secondary beams from the fragment separator FRS . A fragment beam was injected into the ESR and pre-cooled by the stochastic cooling system for some seconds. After turning the stochastic cooling system off, electron cooling was used to finally obtain a very well cooled beam with an excellent separation of different components of the fragment composite [6]. So, the whole range of energy can be covered: electron cooling for all energy range and stochastic cooling for hot high energy beams.

The ESR has two different ion optical modes, standard and isochronous mode. Most of the ring experiments are performed with the standard ion-optical setting of the ESR. Another setting is used for the mass measurement of extreme short-lived exotic nuclei. The calculations and simulations of in this paper are done for standard mode of the ESR.

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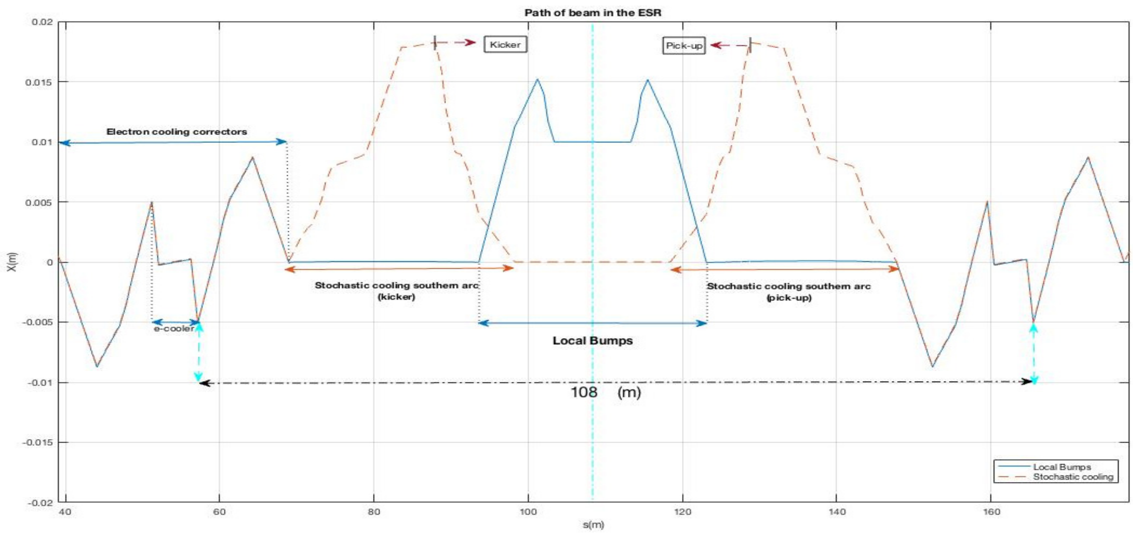

Figure 2: Path of an on-momentum particle in the ESR by simulation.

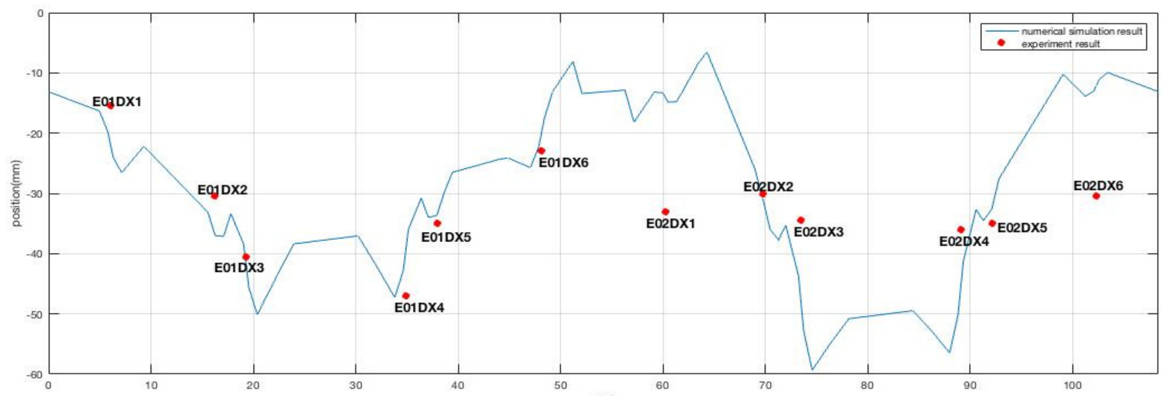

Figure 3: Numerical simulation in ELEGANT and experimental result are shown. The red points are the experimental results and the blue solid line is the ELEGANT simulation. Experiment and simulation are done for an off-momentum particle (dp/p=1%).

TARGET BUMPS

Considering the importance of local bumps and correctors, we start our calculation by local bumps. These bumps are supposed to deviate the beam locally in order to meet the internal target with a well-defined position and angle. Generally, the beam position and beam angle can be controlled by use of kicks by the orbit correctors according to experimental requirements. We calculate 10 mm bumps in MIRKO and ELEGANT, values in these codes are slightly different. In table 1 the difference between ELEGANT and MIRKO kick values for a 10 mm target bump are shown.

Table 1: Target Bumps

Name	ELEGANT values (mrad)	MIRKO Values (mrad)	$\Delta(\boldsymbol{ELEGANT}_{values} - \boldsymbol{MIRKO}_{values})$ (mrad)
E01KX1	-0.52	-0.43	-0.09
E01KX2	2.68	2.51	0.17
E02KX5	2.68	2.51	0.17
E02KX6	-0.52	-0.43	-0.09

ELECTRON-COOLING

Beam cooling is synonymous for a reduction of beam temperature which is equivalent to terms as phase space volume, emittance and momentum spread. In the ESR ion cooling is done with a beam of commoving electrons. So, in order to keep the beam parallel to the electron beam in the cooler section, 4 horizontal correctors in 2 neighboring main dipole magnets are used to correct the deflection of the ion beam in the toroid magnets of the electron cooler [7]. In Table 2 the difference between values for electron-cooler corrector in ELEGANT and MIRKO are shown.

Table 2: Correctors of E-Cooling

Name	ELEGANT values (mrad)	MIRKO values (mrad)	$\Delta(\boldsymbol{ELEGANT}_{values} - \boldsymbol{MIRKO}_{values})$ (mrad)
E01KX5	-2.06	-0.96	-1.1
E01KX6	2.61	2.31	0.3
E02KX1	-2.61	-2.31	0.3
E02KX2	2.07	0.97	1.1

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STOCHASTIC COOLING

The purpose of the stochastic precooling system at the ESR is the cooling of freshly injected beams occupying a large phase-space volume prior to subsequent electron cooling. Such beams arise typically as nuclear fragment beams from the GSI fragment separator [8].
Five horizontal orbit correctors in the northern arc (pick-up location) and five horizontal orbit correctors in the southern arc (kicker location) of the ESR are used to control the beam orbit for stochastic cooling. The differences of value between ELEGANT and MIRKO for 19 mm bumps in the pick-up location are shown in the Table 3. Same values are obtained for the kicker location.

Table 3: Stochastic Cooling

Name (pick-up)	**ELE-GANT values (mrad)**	**MIRKO values (mrad)**	$\Delta(\boldsymbol{ELEGANT}_{values} - \boldsymbol{MIRKO}_{values})$ **(mrad)**
E01KX1	0.97	0.96	0.01
E01KX2	1.97	2.01	-0.04
E01KX3	-1.77	-2.85	1.08
E01KX4	3.39	4.20	-0.81
E01KX5	0.86	0	0.86

The simulation results of particle tracking in the presence of local bumps, stochastic cooling and electron cooling, are shown in Figure 2. As mentioned before, the tracking is done for 10 (mm) beam deviation because of local bumps and 19 (mm) beam deviation because of stochastic cooling. Because of simplicity, the simulation of tracking is shown for more than one turn e.g. (from 39 m to 178 m).

MEASUREMENT

Because of technical problems and due to the necessity to implement the new control system the planned commissioning time was reduced and delayed. Also, this was a first attempt with a new measurement system and very limited time during the first commissioning period.

Based on the scheduled beamtime, the next chance to apply the BPM system will be end of this year. So, we were able to perform only a basic beam position measurement during the commissioning period in the spring of 2019. The measurement was done for the injection orbit (with an intentional momentum deviation of $\frac{dp}{p} = 0.01$ from the central orbit) and the magnetic field and the corrections of the cooler switched on. The closed orbit of the beam with the indicated properties is shown in Figure 3.

There is in general a good agreement between measurement and numerical simulation, but for two pick-ups the numerical simulation result and measurement data are different. (for knowing the place of BPMs, see Figure 1). This is most likely due to electronic offsets in the position monitor electronics. In fact, there is no alternate way to measure the orbit (beam position) close to the doubtful beam position monitors.

OUTLOOK

More detailed orbit measurements to improve the ring model will be performed after upgrades of the ring control system and the data acquisition system for the beam position monitors in the coming commissioning period at the end of 2019.

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