ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPA123

DEVELOPMENT OF A NEW ONLINE MODEL APPLICATION FOR THE HIGH-ENERGY BEAM TRANSFER LINES AT GSI

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Abstract

The high-energy beam transfer lines at GSI serve numerous experimental stations such as HADES, HTC and HTD as well as the fragment separator FRS and the storage rings ESR and CRYRING@ESR with a wide range of different heavy ion beams from the SIS18 synchrotron. The large amount of experiments carried out during beam times under different beam conditions require frequent changes of beam optics and beam steering in the transfer lines. In the past, the online model tool MIRKO-Expert was available for this purpose, which however is not compatible with the new control system infrastructure. Therefore, a new online model application based on the MAD-X beam dynamics simulation code and the JMad programming interface is under development in Java. This paper presents the concept and features of the new online model application, as well as possible future extensions. Efforts to overcome discrepancies in the present MIRKO and MAD-X optics models are also discussed.

INTRODUCTION

The beam operation at GSI is organized in such a way, that beam is delivered to several experiments in parallel. Some experiments run over a period of several weeks, but many only a couple of days. Therefore, a large number of different experiments is served with beam in each beamtime. The beam requirements of the experiments differ strongly with respect to ion species, charge state, beam energy and intensity, time structure, stability, beam size and beam divergence. Hence, frequent changes of the settings and beam tuning according to the needs of the experiments are required.

Therefore, state-of-the-art control applications are crucial for an efficient beam setup and operation. For the high-energy beam transfer lines (HEBT), which serve the experiments and storage rings downstream SIS18 with beam, the online-model application MIRKO-Expert [1] was used in the past for this purpose. It was a special version of the MIRKO beam dynamics simulation code [2] integrated into the old control system. It computed the beam envelope according to the actual magnet settings and had comfortable beam steering functions. For example, it allowed the change of the beam envelope by mouse click.

Despite of some advanced functionality as provided e.g. by MIRKO-Expert, the old control system had limitations making it necessary to develop a new control system for FAIR [3]. The new system is based on the LHC Software Architecture (LSA) [4] and Front-End Software Architecture (FESA) [5] from CERN. LSA provides a high-level layer for settings management and generation using top-level physics parameters for modelling the machine like e.g. bending angles, from which the hardware parameters like e.g. magnet currents are derived and send to FESA. FESA is running on front-end computers and its task is device control and data acquisition.

The new FAIR control system is being deployed step by step to GSI accelerators. SIS18, ESR, CRYRING@ESR and HEBT are already equipped with the new system. As a consequence, MIRKO-Expert is not usable anymore, since it is not compatible with the new controls infrastructure. The efforts to porting the Fortran-based MIRKO-Expert application to the new control system have been estimated to be enormous. Therefore, the decision had been taken to develop a completely new online model application called **B**eam **EN**velope i**N**teractive **O**ptimiser (BENNO) based on modern technology.

ARCHITECTURE

BENNO is written in Java and it is fully integrated into the new GSI controls environment. BENNO is not just another self-contained beam dynamics simulation code. Instead, it uses the well-known MAD-X software [6] from CERN for the simulations. The communication between BENNO and MAD-X takes place via the JMad programming interface [7, 8]. A schematic diagram of the architecture of BENNO and its integration into the controls environment is presented in Fig. 1. Only the most important parts are shown.

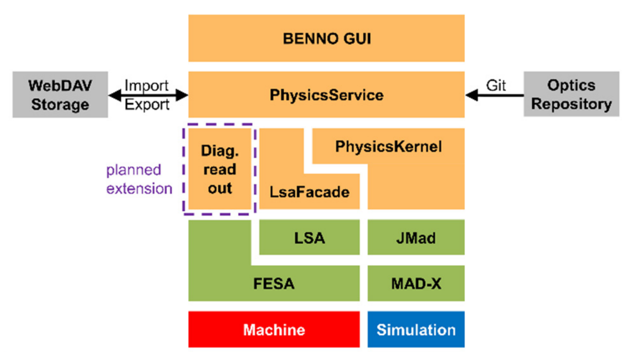

Figure 1: Simplified architecture of the BENNO application within the control system. Parts belonging to BENNO are displayed in orange colour, other software components with which BENNO interacts in green.

The user interacts with BENNO via a graphical user interface (GUI), which is implemented using the JavaFX framework [9]. For displaying the simulated curves, the ChartFx library [10] developed at GSI is used. BENNO is designed in such a way that GUI specific code is clearly separated from the code which manages all aspects concer-

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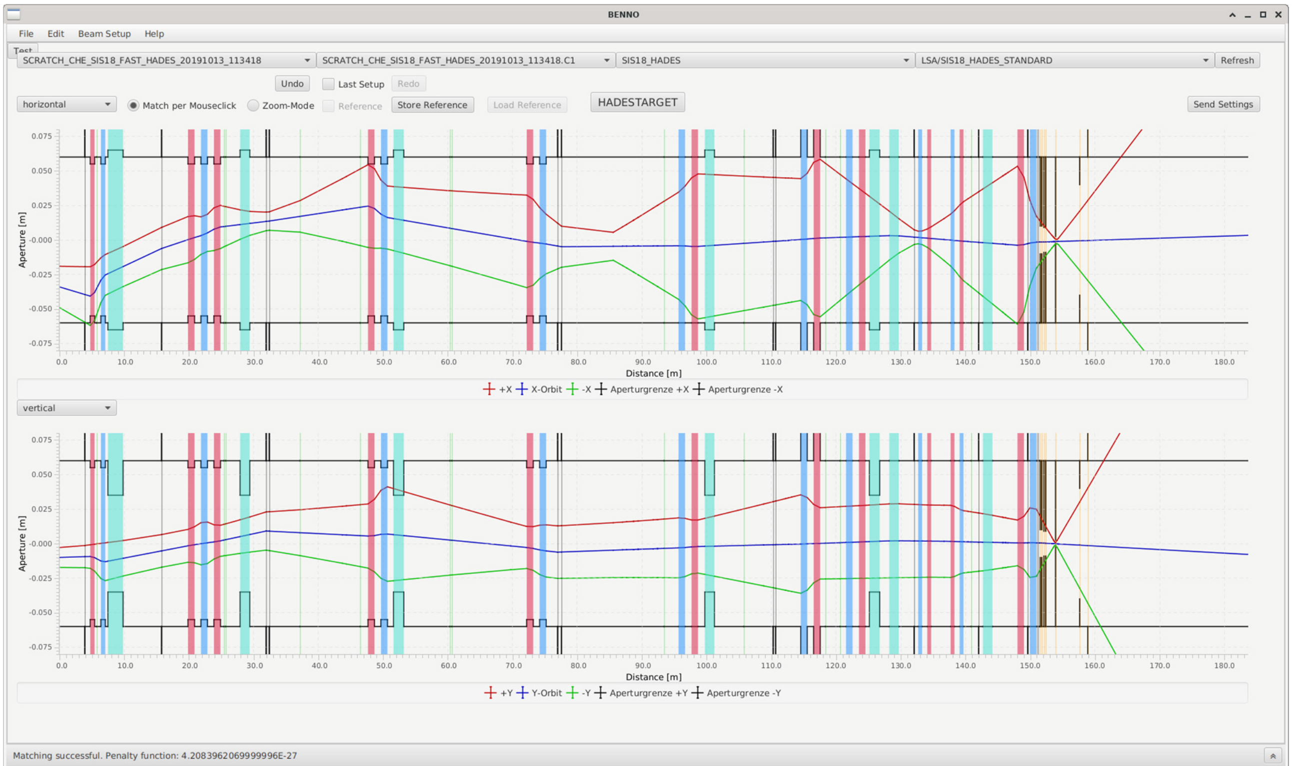

Figure 2: Screenshot of the BENNO application, displaying as an example the beamline towards HADES cave.

ning the computation of the online model, the so-called physics part. With this separation, an upgrade to new GUI technologies would be possible, if required in the future.

The GUI communicates with the physics part via the PhysicsService class. This class retrieves the model information from a Git [11] optics repository and magnet settings from LSA via the LsaFacade class. With this information, PhysicsService calls methods of the PhysicsKernel class to compute and manipulate the beam envelopes. PhysicsService also provides the functionality to send new settings to the hardware via LsaFacade and LSA.

The PhysicsKernel class contains the methods to handle and manipulate the optics model. Several high-level functions are implemented for the features to manipulate the beam envelope, presented in the next section. These methods launch MAD-X simulations whenever needed and compute the resulting magnet settings.

The communication with the power converter hardware of the magnets is done via LSA and FESA. The LsaFacade class provides high-level functions for BENNO for the interaction with LSA. Furthermore, access to beam position and beam size data measured with profile grids, luminescent screens and beam position monitors is planned for the future. For this purpose, a new class has to be developed, which will interact with the corresponding FESA classes of the beam diagnostic devices.

FEATURES

The main window of BENNO (Fig. 2) consist of two graphs, which can each display the following physical quantities:

- Horizontal or vertical beam position including the 3σ beam envelopes;
- Combined view of the horizontal (positive y axis) and vertical (negative y axis) 3σ beam size;
- Betatron function;
- Dispersion.

The main goal of BENNO is to provide an easy and comfortable way to change the position of the beam and the shape of the beam envelope, e.g. in order to steer the beam onto a target with a specific beam size.

Match by Mouse Click

The key functionality to achieve this is the possibility to change either the beam position or the beam size at a certain longitudinal position in the beamline by clicking at the corresponding position in the graph. This click launches a MAD-X matching procedure to match the beam position or beam size to the desired value, using the upstream corrector / main bending magnet or the two upstream quadrupoles. In case of matching the beam size, the beam size in the other plane is kept as constant as possible. Since the number of variation variables and the number of constraints are the same, the matching is quite fast and the user does not experience a disturbing delay.

Beam Steering onto Axis

This function performs the steering of the beam centrally on-axis through two selected monitors (either profile grids or screens), using the selected corrector or main bending magnets. The beam position values measured at these monitors must currently be entered manually, however, a direct read-in of the measurement data is planned for the future.

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Target Steering

This function allows the steering of the beam on the target or another special device, like e.g. a detector, to a specified position under a specified incident angle. The correctors or bending magnets for the steering can be chosen by the user. The precision of the steering depends on the quality of the optics model. However, even if the model is not optimal, the differences between two settings agree well with the reality.

Target Focusing

A precise tuning of the beam size at the experiment is often required. With this function, the longitudinal position of the beam focus can be moved by a given value.

Initial Beam Position and Angle

The initial beam position and angle at the SIS18 or ESR extraction point, which is used as input for the simulation, is not always precisely known and might change according to the settings in the ring. Therefore, a function has been added, which computes the initial beam position and angle at the SIS18 or ESR extraction point from the beam positions measured at two selected profile grids or screens.

ADAPTION OF MIRKO OPTICS FOR MAD-X

Online model applications rely heavily on the quality of the used optics models. Therefore, it is important that the optics used in BENNO describe well the reality. The model and the optics of the HEBT have originally been designed using MIRKO and further refined over many years. Because MAD-X has also been used as a general simulation tool for the HEBT for a few years, MAD-X optics were available for some HEBT beamlines, but did not have the

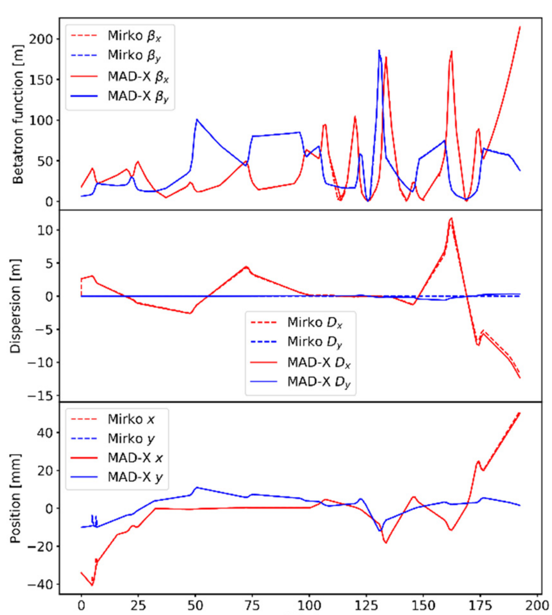

Figure 3: Comparison of the MIRKO and MAD-X optics for the beamline from SIS18 towards cave A.

maturity of the MIRKO optics. Therefore, significant efforts have been made within the scope of the BENNO project to improve the MAD-X optics models. For this purpose, a Python script has been developed, which generates automatically all required MAD-X input files from a MIRKO-MIX-file and a MIRKO-generated Twiss-file.

The MAD-X and MIRKO optics of the beamlines from SIS18 to cave A, and from ESR to CRYRING@ESR are compered in Figs. 3 and 4 as examples. The MAD-X optics have been converted from the MIRKO optics using the above-mentioned script. The plots of the Betatron functions, dispersion and trajectory agree well between these two simulation codes. The conversion script also supports tilted or misaligned beamline elements as well as dipole magnets with rotated pole faces.

During this study, also several bugs have been fixed in the Twiss export function of MIRKO. In some cases, still some discrepancies occur between MAD-X and MIRKO optics, which require further investigations.

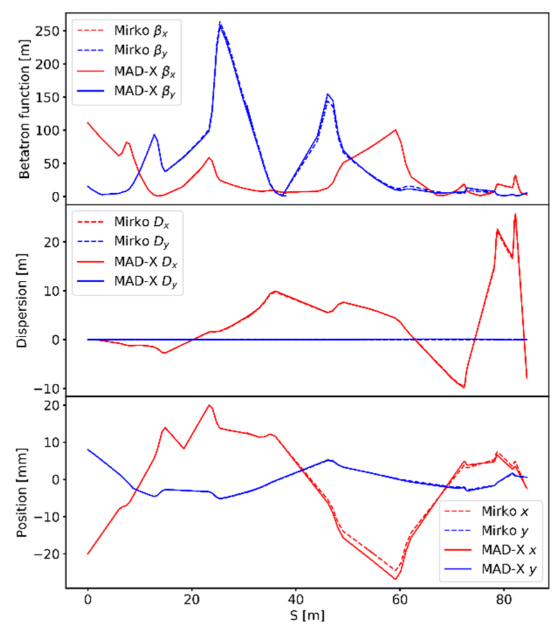

Figure 4: Comparison of the MIRKO and MAD-X optics for the beamline from ESR towards CRYRING@ESR.

CONCLUSION AND OUTLOOK

With BENNO, there is now a powerful successor of the MIRKO-Expert application available, which has been regularly used by the operators for a few years. During beamtime 2022, even some experimenters received instructions to use the BENNO target steering function, which increased the efficiency for fine tuning of the beam to the target substantially. The development of BENNO continues and several new features and improvements are planned. As mentioned, a direct read-in of measured beam position and beam size data is planned. In addition, further steering functions will be implemented. And last but not least, the application will be extended for the high-energy beam transfer lines of FAIR, once this new accelerator is modelled in LSA.

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