A NEW TOOL FOR AUTOMATED ORBIT AND SPIN MOTION ANALYSIS

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Abstract

There are a lot of tools to simulate beam dynamics in accelerators of various types. Many of them are intended to use for specific purposes, and there are universal codes that can simulate both orbit and spin motion in magnetic and electrostatic structures. To start using these codes beam physicist first should have learn syntax, know features and methods how to describe lattice and beams in this particular code. Output data structures of different simulation programs are also vary and depend on peculiarities of each program. This paper proposes a new tool for automated generation and execution of input files for simulation programs and for data analysis of output data. The developed tool allows to describe a lattice, calculate different lattice parameters (like tunes) using simulation program, track particles inside the lattice and analyze various parameters of output data (like beam depolarization). Simulations and analysis can be done in parallel using built-in parallelization mechanisms, and all results can be stored in the database and can be easily fetched when needed. The tool is used to simulate beam and spin dynamics in different lattices to increase spin coherence time.

INTRODUCTION

Search of electric dipole moment (EDM) of elementary particles is a problem for a lot of experimental researches. In 2004 was proposed a method to measure proton's EDM called "frozen spin" method [1]. The proposed experiment will reach sensitivity in measurement of proton's EDM in level $10^{-29} e \cdot$cm, which is significantly higher than previous experiments. For EDM measurement in storage ring one needs to conserve beam polarization during the long time (more than 1000 seconds or $\sim 10^9$ beam turns in the accelerator). To design such accelerator one needs to evaluate polarized beam dynamics during the long time [2].

COSY INFINITY

Differential algebra methods allow to simulate beam dynamics in the particle accelerators with high efficiency There are several programs which use differential algebra methods for beam dynamics, like, ZLIB, MARYLIE, COSY Infinity [3]. COSY Infinity program was developed in the Michigan State University and designed for mathematical modeling of beam motion in the particle accelerators. For beam dynamics studies COSY Infinity allows to create maps arbitrary orders of non-linearities. FOX programming language is a dynamically typed with support of real and complex numbers, intervals, vectors, differential algebras and Taylor models. Module for particle physics, called cosy.fox, intended for charged particles motion in the electromagnetic fields modeling. This module is used for particle tracking in the electromagnetic elements, particle dynamics modeling, modeling of non-linear effects in the accelerators, storage rings parameters computing, like tunes and chromaticities.

COSY Infinity supports both magnetic and electric elements. Modeling is possible with fringe fields influence.

Experience with COSY Infinity in the Institute for Nuclear Physics in Juelich showed the validity of the results obtained with the program [2]. Comparison of the results, obtained using COSY Infinity and a simple integrating program performed [4, 5].

This article describes a software tool called RSX developed for spin-orbit dynamics modeling in the storage rings [6]. RSX provides a convenient graphical user interface (GUI) for COSY Infinity.

SOFTWARE PACKAGE STRUCTURE

With COSY Infinity each accelerator element could be represented as a map, which is an operator acting on a phase space. Map obtained using COSY Infinity could be used for numerical parameters of the accelerator, like betatron tunes, chromaticities, momentum compaction factors and so on. Also map representations used for particle tracking, which could be done on multiprocessor computing clusters.

After tracking usually data analysis is required. For example, to construct electrostatic storage ring for EDM searches one needs to calculate spin frequencies and spin coherence time after each change in the accelerator structure.

To provide access to the beam modeling software was created software package RSX which allows the user to use the computational core, prepare source codes for COSY Infinity, parallel execution of modeling tasks, data analysis, results processing and storing in the database.

VIRTUAL EXPERIMENT SCHEME

To automate virtual experiments the developed software tool allows to define an accelerator lattice, save it to the database and calculate lattice parameters in the linear approach. When the obtained lattice parameters satisfy user's needs the system allows to study beam dynamics in details, using particle tracking and data analysis. Experimenter can choose initial particle distribution (normal or uniform particle distribution in the phase space), initial polarization, number of turns to track, symplectification method and the order of calculations. Depending on the initial distribution and created lattice, the software tool creates source file in FOX programming language for COSY Infinity and adds it to the run queue. Task manager selects ready-to-run tasks from the run queue and sends to computing node for execution; after successful execution data are saved in the database.

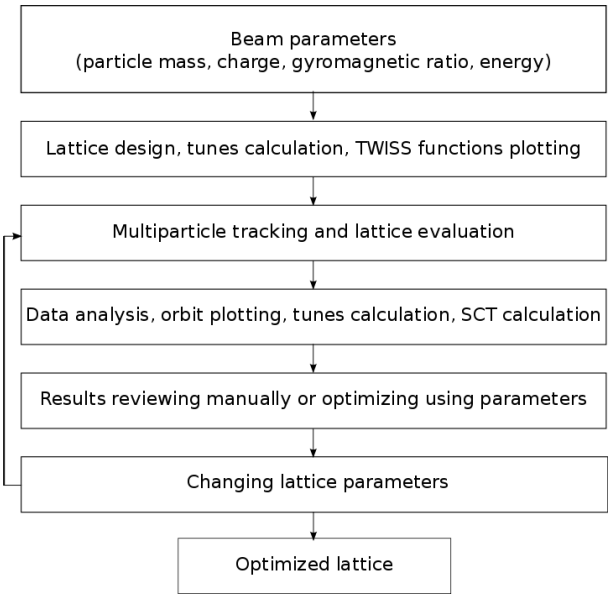

Figure 1: Virtual experiment scheme

After modeling of beam motion in the accelerator, RSX system allows to analyze data, particle trajectories could be graphically represented as phase portrait, also Fourier analysis for frequencies determination. The user, after evaluating of analyzed data, can change some accelerator parameters (change quadrupoles or sextupoles strength, RF-cavity frequency and others) and repeat the experiment. Also the RSX system allows to change accelerator parameters and analyze data automatically, graphically representing obtained data dependency on the changed parameters. Auto changing parameters is used to optimize lattices, maximization or minimization required values. Virtual experiment scheme is represented on Fig. 1.

RSX SYSTEM STRUCTURE

The user interacts with the system using web-browser via graphical web-interface. Web-interfaces was developed using modern technologies, such as Django, XHTML, CSS, AJAX, jQuery. Any web-server with WSGI support, like lighttpd, can be used to host the application.

System core consists of task manager, data analysis module and file distribution service. All executed tasks are stored for processing and could be found by user request. If the virtual experiment was done earlier, its results would be fetched from the database, without repeated calculation.

After computer modeling is done, result data could be processed. Data processing consists of data filtration and analysis. Filtration is required to expel unstable particles with trajectories not fit to the physical accelerator aperture from further evaluation. After data filtration data are analyzed in required way depending on experiment, for example frequency analysis could be made to find orbit or spin frequencies. Data processing and numerical modeling could be done simultaneously.

RSX SYSTEM INTERFACE

Web-interface was developed for user access, allowing user to use RSX system via modern web-browsers. This approach allows to support all operating systems, including Microsoft Windows, GNU/Linux, Apple MacOS, with a web-browser with XHTML and JavaScript support.

Fig. 2 shows system interface where creating or changing previously created lattices could be done.

After logging in the user should specify the reference particle parameters, i. e. mass, energy, charge, anomalous magnetic moment. After specifying reference particle user creates an accelerator lattice using lattice description lattice similar to COSY Infinity language. For user convenience lattice code input supports syntax highlighting using CodeMirror library. Defining lattice structure allows using free parameters, for example quadrupole potential can be called Q_STRENGTH which would be a free parameter. Free parameter values assigned separately.

When the lattice is defined, the RSX system allows to calculate accelerator parameters in linear approach, such as length, betatron, synchrotron and spin frequencies, chromaticities and other values. Dependency of some accelerator parameter on varying free parameter can be plotted, like betatron frequencies ν_x, ν_y dependency on focusing quadrupoles strength. These plots can be used for optimal lattice selection.

PARALLEL PROCESSING

COSY Infinity allows to save maps into the file and load maps from the file when necessary. Thus modeling of beam with different initial distributions could be done without map recalculation. For spin-orbit motion modeling software package saves all maps into the database and use it when necessary, and the speed of calculation is much higher, especially when simulations are made with high non-linearities order. COSY Infinity also supports parallel execution on clusters with MPI (Message Passing Interface) architectures.

COSY Infinity contains PLOOP...END PLOOP command for multiple cycle execution on several MPI processes. This command can be used for parallel map computation. To calculate map in parallel one needs to split the lattice into small pieces which will be computed on different processes and concatenate obtained maps into a single map of whole ring. The RSX system allows to generate codes for MPI versions of COSY Infinity.

After map calculation usually is required to study beam motion in the lattice. Particle trajectory calculation during N turns consists in consequent applying of map to initial particle coordinates N times. To study long beam evolution with no in-beam particle interaction (tasks with no space charge), it is possible to parallelize computing tasks in natural way, and different parts of beam are calculated by different processes. For large beam modeling the RSX system creates several computing tasks.

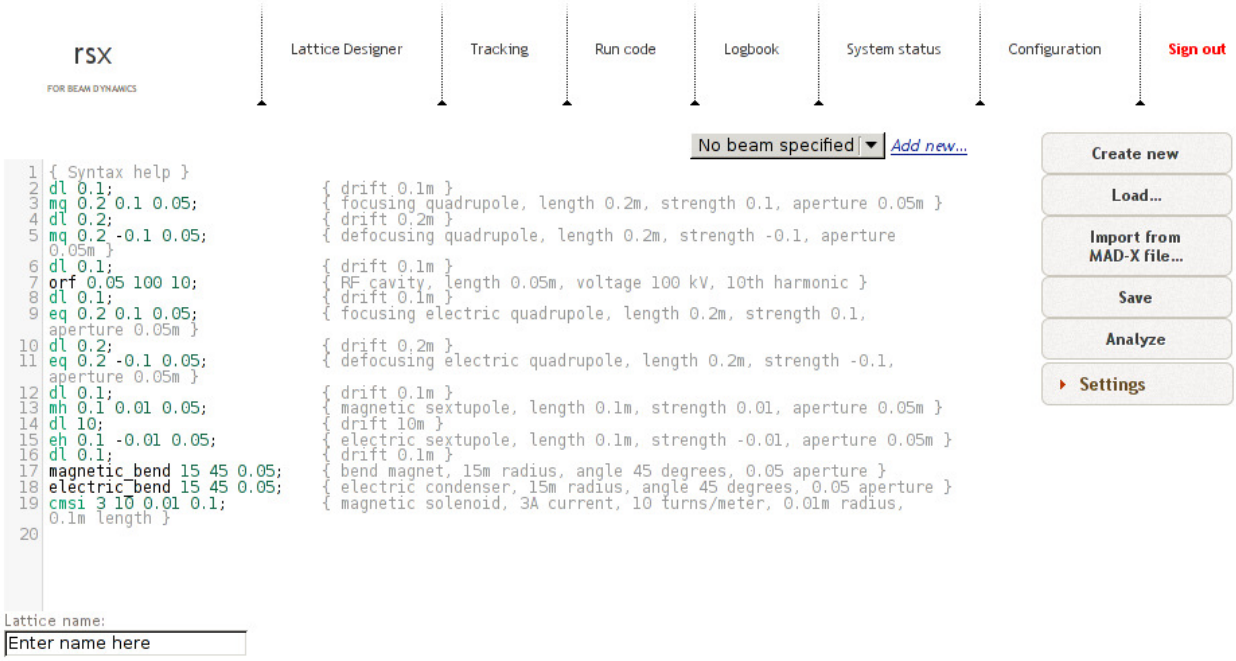

Figure 2: Graphical interface

DATA PROCESSING

After full-scale simulation, data could take a lot of disk space. Processing of data, obtained by computer modeling of beam motion in the storage ring, consists of data filtration, validation, analysis and visualization. COSY Infinity creates tracking file with some auxiliary data and warnings. RSX software package automatically filters the modeling results and after the filtration data file consists of only meaningful strings. Furthermore, COSY Infinity uses separate files for orbit and spin motion output, and RSX joins files into one to simplify further processing.

Some particles in the bunch are not stable, after several turns their coordinates become larger, than physical aperture of accelerator. RSX compares particle coordinates in the tracking data file and limits defined by user and, in case of exceeding the limits, particles are excluded from the processing.

Simulation data usually need to be graphically represented to user; RSX uses Gnuplot for plotting, which allows to plot large amount of data very fast.

SUMMARY

In the article the new software tool RSX for polarized beam dynamics modeling in storage rings presented. COSY Infinity is used as a computing core for creating maps of storage rings. The developed software package allows to significantly simplify to numerical experiments conducting during the electrostatic storage ring development for the experiment to search the proton EDM. The developed software tool is used in the Institute for Nuclear Physics in Juelich, Germany.

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