BDO-RFQ Program Complex of Modelling and Optimization of Charged Particle Dynamics

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Abstract. The article is dedicated to BDO Code program complex used for modelling and optimization of charged particle dynamics with consideration of interaction in RFQ accelerating structures. The structure of the program complex and its functionality are described; mathematical models of charged particle dynamics, interaction models and methods of optimization are given.

1. Introduction
When an accelerator of the charged particles is being developed an important task is an optimization of charged particle dynamics in order to improve the quality of the output beam. Different mathematical models of beams dynamic, models of particles interaction and methods of optimization are used for optimization problem solving in accelerator structures. BDO Code is a program complex, which has a developed graphic interface and different sets of instruments, methods and algorithms and allows researcher to concentrate time on implementation of the model. BDO RFQ project is included into this complex and it’s general description is given in this article.

2. Program Complex
BDO Code Program Complex consists of managing program, models and libraries (Fig. 1):
- BDO Shell – managing program, which has developed graphic interface, libraries of the parameters of the model and system functions. The specialties of this product are a possibility to divide into the stages of the calculation process with setting of your own group of input and output data files; a possibility of automatization of the modelling process for the given parameters ranges; usage of the scenarios with setting of the determined parameters, input and output data files, setting up of the calculation stages.
- BDO RFQ – project for modelling and optimization of charged particle dynamics in RFQ structure [1]. The project contains several models, which allow to perform a step-by-step optimization on “from easy to hard” basis, and library of the consideration of the particle interaction and library of optimization methods.

3. Models
Consider in details the models realized in BDO-RFQ project [2-7]:

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3.1. **BDO RFQ TW (Travelling wave)**

This model was proposed in works [5,6] and successfully used for modelling and optimization of the longitudinal motion of the beam of charged particles in the field of equivalent travelling wave in RFQ structure [5-8]. The functional realized in this model allow modelling the beam dynamic with interaction of particles, to perform the optimization with usage of the gradient method. Main window BDO RFQ TW is presented on Figure 2.

![Structure of BDO Code Program Complex](image)

**Figure 1.** Structure of BDO Code Program Complex

The advantages of this model are the following:

- The consideration of the particle interaction is performed by the method of macro particles for conventional and periodic cases;
- The joint optimization for program and perturbed motions is performed;
- Different quality functionals are used for characteristics at the exit of the accelerator and also for along the structure;
- Recalculation of the managing parameters of the model after optimization for the model of the dynamics in stationary wave.

3.2. **BDO RFQ SW (Stationary wave)**

This model is used for modelling and optimization of the longitudinal and transversal motion of the beam of charged particles in the field of stationary wave in RFQ structure. The realized functional of this model allows to calculate acceptance of the channel, to model and optimize the matcher, to model the dynamic of the beam for the envelopes with the interaction of particles, to optimize by different methods.

The advantages of this model are the following:

- The consideration of the particle interaction is performed with cylindrical models;
- The joint optimization for longitudinal and transversal motion of the beam is performed;
- Optimization of a radial matching section.

3.3. **BDO RFQ 3D**

The results of the optimization are checked with the current 3D dynamic model. The consideration of the particles interaction is performed by the method of the pair interaction or by the grid method. There is also a possibility of comparison of the coulomb field on the axis of accelerator calculated with the different models of the particle interaction.
4. Interaction models toolbox
In modelling of the dynamic of the charged particles beams with particle interaction in BDO Code program complex the following calculation methods of the coulomb field of the beam are realized:

- Method of thin discs – for calculation of the coulomb field, the beam is a set of infinitely thin and proportionally charged discs with the same radius.
- Method of thick discs – for calculation of the coulomb field, the beam is a set of proportionally charged discs with the finite thickness of the same radius.

These methods allow to calculate approximately only longitudinal component of the coulomb field of the beam and are used for modelling of the longitudinal beam dynamic and also for comparison of the calculation results of longitudinal component of the coulomb field on the axis of accelerator by other methods.

- Cylindrical model – for calculation of the coulomb field the beam is a cylinder with a constant radius, proportionally charged in each transversal section with heterogeneous distribution of the charge along the axis of accelerator.
- Method of nested circular cylinders [9] – for calculation of the coulomb field the beam is a set of embed cylinders with constant radius. Each cylinder is proportionally charged in each transversal section with heterogeneous distribution of the charge along the axis of accelerator.
- Pair interaction method - for calculation of the coulomb field the beam is a set of proportionally charged balls with the same radius. The coulomb field of the beam is calculated as a vector sum of the fields, made by each ball.
- Grid method - the coulomb field the beam is calculated by the grid method, boundary value problem for Poisson equation is solved.

5. Optimization toolbox
For optimization of charged particle dynamics in BDO-RFQ system, various optimization methods have been developed [7,10-14]. In directed optimization methods of charged particle dynamics external accelerating and focusing fields in the accelerator and internal coulomb field of the beam are calculated with analytic approximate expressions. Analytic models of the external and internal fields allow using analytic expressions for the gradient of the optimized functional. In optimization with analytic formulas for functional gradient in BDO-RFQ system there are two optimization methods
realized: gradient descent method (method of steepest descent) and ravine method. Along with directed optimization techniques and other methods of numerical optimization are used. There are two numerical optimization methods used: genetic algorithm and Box-Wilson method. When genetic algorithm is used the system user defines the parameters of the crossing, mutation and population size.

In conclusion we would like to mention, that there is a possibility to exchange files of BDO-RFQ program complex with files of LIDOS.RFQ program complex [6].

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