THE INTERACTIVE COMPUTER ENVIRONMENT FOR DESIGNING AND TUNING OF CHARGED PARTICLE BEAMS TRANSPORT CHANNELS

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Abstract

This paper considers the application package that simulates transport channel of relativistic charged particles. The package provides an interactive mode for the user. It is possible to observe the main parameters of the beam crossing the channel on the PC screen such as envelope and cross-section of the beam at different sections of the channel while changing the main control parameters of the real channel. Enabling of procedures of mathematical programming provides express optimization of control parameters of the channel. The designed package is compact, has a modular structure and can be easily adapted to different software platforms. MATLAB integrated environment is used as instrumental environment, which has a freeware version of this system - SCILAB. Package testing was carried out on the electron synchrotron "Pakhra" during the recalibration of the channel of the accelerator working in different modes, which are determined by conducted experiments.

INTRODUCTION

A simulation model of the channel is created on the basis a MATLAB environment and its open-source counterpart SCILAB. One of the main advantages of these software environments is the programming efficiency of matrix operations, which are the basic mathematical tools for calculating the magneto-optical systems. In this environment is developed KATRAN representing an integrated modular open structure, adaptable to the calculation of a specific transportation channel of relativistic charged particles [2].

KATRAN STATE DIAGRAM

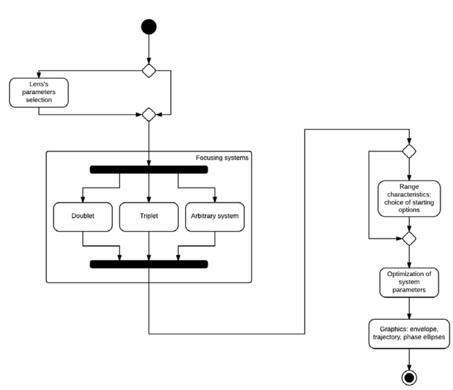

Figure 1: KATRAN state diagram.

The complete cycle of study of the properties and the calculation of the focusing system begins with the selection of the quadrupole lens. Preliminary review of its envelop characteristics will allow in further calculations to select working variant the system parameters. In general, this process is iterative by nature. You must select a variant of the system fully provide the required launch parameters, using perhaps more "weak" lenses. Module KATRAN named "Range characteristics" allows consider depending focal lengths of the system (the lens, doublet, triplet, etc.) one by one. Building a envelop characteristics provides a visual representation of the degree of influence of the individual parameters of the system on its focusing properties. Figure 2 shows, as an example, the dependence of the focal length of the triplet from the first lens's magnetic field with a parameter - the distance between the first and second lenses. As can be seen from the figure, the focus of the charged particles at the same time in the two transverse planes (vertical and horizontal) is possible in a limited range of parameters of quadrupole lenses and system as a whole (the focal lengths in both planes have positive values).

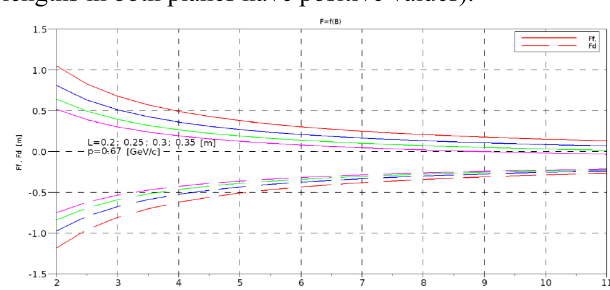

Figure 2: Dependency of focal lengths of the triplet from magnetic field of the first lens with a parameter - the distance between the first and second lenses.

KATRAN allows us to consider these characteristics of the various focusing systems. When considering the envelop characteristics of focusing systems and calculation of parameters of the transport channel numerical methods used for finding optimal solutions (search simplex method).

In general, the objective function Ft, used for the calculation of the magneto-optical system can be written as

$$\mathrm{Ft} = \sqrt{\sum_n a_i((\phi_i(\bar{x}) - x_i^c) / x_i^{norm})^2} \,. \qquad (1)$$

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where $\phi_i(\bar{x})$ - current value of the parameter, x_i^c - target value of the parameter, x_i^{norm} - normalization coefficient of the parameter, a_i- weighting coefficient of the parameter, $\bar{x}$ - vector of search parameters space.

Normalization coefficient x_i^{norm} is chosen so that the value of objective function component of this parameter was close to unity and become dimensionless. This operation is scaling of the objective function, i.e. the contribution of all components in the objective function to get about the same. Weighting factor of x_i^c parameter reflects the priorities of achievements of goal parameters of one or another component of the objective function.

Graphical tools of MATLAB (or SCILAB) allow us to show the focusing properties of the transportation channel in the form of the trajectories of individual particles, beam envelopes and phase portraits of the beam in the horizontal and vertical planes. This information is sufficient for operative channel setup to the new operating mode.

SIMULATION BY KATRAN

As an example, was considered by the transport channel of existing synchrotron "Pakhra" [1].

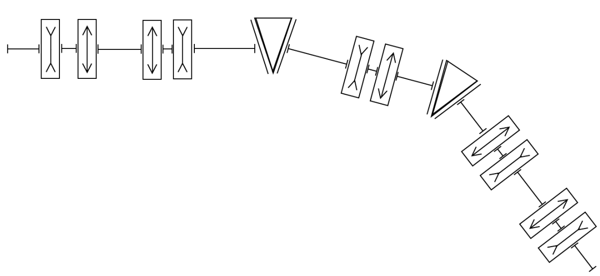

Figure 3: Scheme of transportation channel of "Pakhra" synchrotron.

Figures 4 and 5 show the graphic results of the calculation of the current channel KATRAN transportation in "Pakhra" synchrotron.

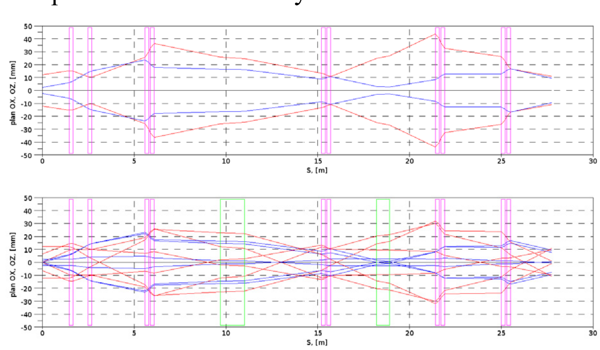

Figure 4: Envelopes (upper figure) and particle trajectories (lower figure) of existing transport channel of "Pakhra" synchrotron.

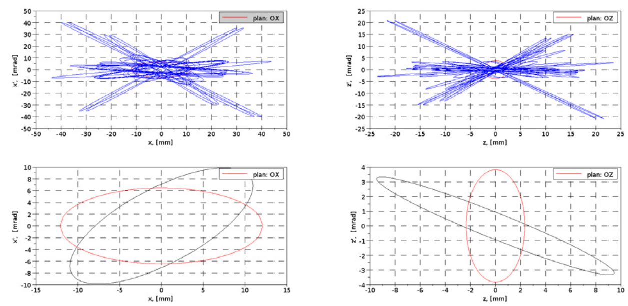

Figure 5: Upper figure - phase portraits of the beam after passing each element of the transport channel in the horizontal and vertical planes, bottom figure - phase portraits of the beam at the input (red line) and output (black line) transport channel in existing transport channel of "Pakhra" synchrotron.

Figures 6-9 presents options for optimizing the transport channel of "Pakhra" synchrotron.

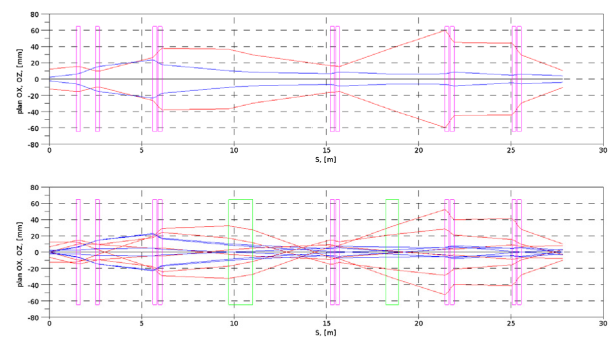

Figure 6: Envelopes (upper figure) and particle trajectories (lower figure) of existing transport channel of "Pakhra" synchrotron.

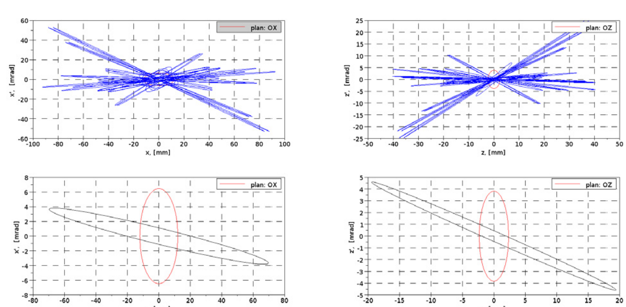

Figure 7: Upper figure - phase portraits of the beam after passing each element of the transport channel in the horizontal and vertical planes, bottom figure - phase portraits of the beam at the input (red line) and output (black line) transport channel in existing transport channel of "Pakhra" synchrotron.

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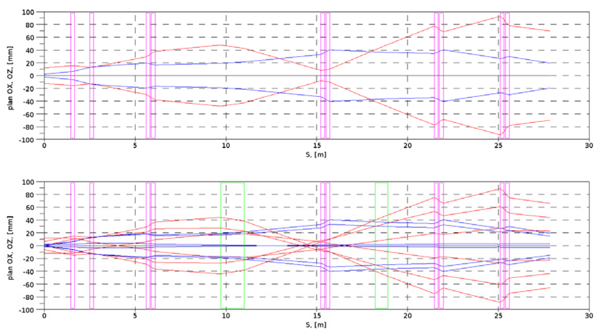

Figure 8: Envelopes (upper figure) and particle trajectories (lower figure) of existing transport channel of “Pakhra” synchrotron.

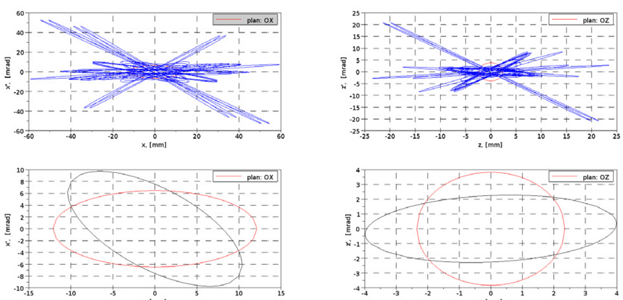

Figure 9: Upper figure - phase portraits of the beam after passing each element of the transport channel in the horizontal and vertical planes, bottom figure - phase portraits of the beam at the input (red line) and output (black line) transport channel in existing transport channel of “Pakhra” synchrotron.

The main problem of the transport channel of “Pakhra” accelerator is large particle loss during the passage of the transport channel. Increasing the size of the beam occurs due to the influence of the magnetic field (~ 4 kG) accelerator magnets and Coulomb scattering of electrons by dural plate output window of the accelerator and in the air [1]. At the inlet of the transportation channel the beam has an elliptical cross section. The semimajor axis of the ellipse is 12 cm, and a small is 4 cm. Diameter of the transportation channel is 40 mm. Small diameter leads to a significant loss of beam intensity already at the inlet of transportation channel. As can be seen, in a number of elements of the channel cross-sectional dimensions of the beam is larger than the diameter of the transportation channel. This is due not only to the large linear dimensions of the beam in the transverse plane, but with large divergence angles of the particles (6.45 mrad and 3.82 mrad) in the horizontal and vertical planes. In this regard, the current transportation channel includes two collimators that limit the size of the beam. Attempts to improve the beam parameters have shown that the optimal parameter search of the channel by changing the parameters of the field focusing elements, and their arrangement along the length of the channel leading to a change in the dynamics of the particles but do not solve the problem of the loss of particles along the channel length. This is largely due to the formulation of the problem: it is necessary to fit into the geometric dimensions of the room and only use existing lens, doublets and bending magnets.

KATRAN allows us to consider the structure of transportation channel with individual focusing systems (doublets, triplets, ect) and with the whole channel either. Necessary parameters of the particle beam is provided by specifying the respective values of the elements of the transformation matrix in the horizontal and vertical planes. To find the values of the elements of transformation matrix extreme search methods are used. The dimension of the search area is determined by the number of elements of the channel and the number of their geometry and field parameters. In our calculations the search for optimal parameters of the focusing system was considered by varying from 10 to 15 parameters.

When choosing a transportation channel focusing system, there are two main problems: providing the required size of the beam at the output of the channel and the channel transparency. The first problem is solved by using of extreme search methods, in which the objective function is based on the transformation matrix of the beam. The second problem is related to the construction of the phase space acceptance of the the channel, which is constructed on the basis of transformation matrices of individual elements of the channel in its exit plane. Transformation of the output acceptance to the input plane of transportation channel allows to evaluate the consistency of the beam parameters at the exit of the accelerator with the possibility of passing without loss along the entire length of the channel.

FINAL REMARKS

The calculations show that to improve the conductivity of the beam is necessary to build a transport channel at a more short focusing lenses. This will reduce the length of the intervals between, making the main contribution to the increase in the transverse dimensions of the beam. Due to specified size of the room, the number of lenses must be increased.

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