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# The adaptive-modular technique for pre-project simulation the transportation channels of the relativistic charged-particle beams

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**Abstract.** Considered the numerical simulation technique which providing optimum beam parameters at the transport channel output of electron accelerator. The KATRAN channels design environment used for this purpose has a modular structure includes the basic beam focusing blocks. This allows enabling create and configure the optical system of the accelerator fast and efficiently if a given topology of the transport channel.

## 1. Introduction

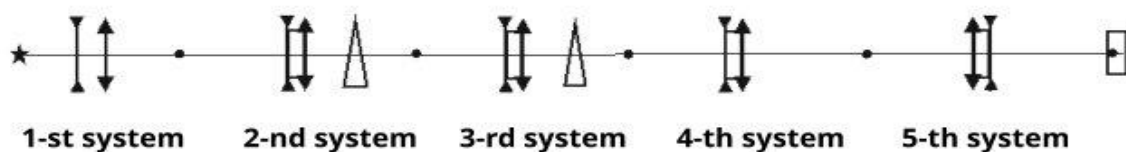
Total effect of the beam intensity loss during transporting depends on many factors. Numerical simulation of the dynamics of charged particles makes it possible to identify the contribution of single factors to the loss of beam intensity.

The Adaptive-Modular technique implements a preliminary optimization of parameters for a sequence of single focusing systems (modules) based on the requirements imposed both on the modules individually and on the channel as a whole. Then based on the results obtained the channel parameters are finally optimized.

## 2. The technique of optimization transportation channel parameters

### 2.1. Basic analysis algorithms

For example, consider the optimizing process for a transport channel in the real operating synchrotron. Need to adapt the transport channel to the dimensions of accelerator hall and experimental hall with the available focusing devices: - quadrupole lenses, quadrupole lens doublets and magnets (figure 1).



**Figure 1.** The transportation channel scheme (single quadrupole lenses, doublets of quadrupole lenses and bending magnets).



Particles dynamics in the transportation channel are described by transformation matrices in the horizontal and vertical plane ( $[m_{ij}]$ ,  $[n_{ij}]$ ). Relationship between parameters of the beam (linear dimensions— $x, z$  and divergence— $x', z'$ ) at the channel output (or at single element) with the input parameters is written as:

$$\begin{bmatrix} x_{output} \\ x'_{output} \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \begin{bmatrix} x_{input} \\ x'_{input} \end{bmatrix} \dots \dots \begin{bmatrix} z_{output} \\ z'_{output} \end{bmatrix} = \begin{bmatrix} n_{11} & n_{12} \\ n_{21} & n_{22} \end{bmatrix} \begin{bmatrix} z_{input} \\ z'_{input} \end{bmatrix} \quad (1)$$

The required parameters of the particle beam are provided by obtaining the corresponding values of the elements of the transformation matrices, both at intermediate points and at the channel output. The minimum beam linear size in vertical and horizontal planes of the channel output is achieved when the condition stigmatic of image— $m_{12} \rightarrow 0$ ,  $n_{12} \rightarrow 0$  and unit limit conversion—( $m_{11} \rightarrow 1$ ,  $n_{11} \rightarrow 1$ ) are met. Divergence minimum of the electron beam define by basic condition ( $m_{21} \rightarrow 0$ ,  $n_{21} \rightarrow 0$ ).

Based the values of elements the conversion matrix we can be formed target function:

$$Ft = \sqrt{\sum^n a_i ((\varphi_i(x) - x_i^c)/x_i^{norm})^2} \quad (2)$$

In equation (2):  $\varphi_i(x)$ —the current parameter value;  $x_i^c$ —the target value of the parameter;  $x^{norm}$ —vector of normalization coefficients;  $a_j$ —the weights coefficients of the parameter;  $x$ —the search space vector of parameters.

The channel parameters optimization is based on the following conditions:

- The length of the transport channel and the location of bending magnets remains unchanged.
- Only fixed set structural elements can be used (single quadrupole lenses, doublets of quadrupole lenses and bending magnets).
- Can be vary only the values of the magnetic fields in the lenses and their location along the length of the channel.

The formation of the transport channel begins with a preliminary analysis of the focusing properties of individual focusing systems (with different sequences of focusing and defocusing lenses) to determine the optimal structure of the final channel structure for each selected lens sequence.

For a horizontal plane the transport channel structure can be described by symbolic descriptors:

- **O**—is a free gap.
- **F**—a focusing quadrupole lens.
- **D**—a defocusing lens.
- **(F: O: D)**—a doublet of quadrupole lenses.
- **(WM: M: WM)**—a bending magnet with wedge magnets on the boundaries.

## 2.2. Systems optimization procedure

### 2.2.1. First system

Lens orientation: **(O: D: O: F: O)**—a stigmatic image is formed at the output of the system, as the elements of the transformation matrices tend: ( $m_{12} \rightarrow 0$ ,  $n_{12} \rightarrow 0$ ). The beam at the input to the transport channel has an elliptical profile.

### 2.2.2. Second system

We select **(O: F: O: D: O: WM: M: WM)** for further analysis because the transverse size of the beam for it much smaller than the transverse size of the beam for system **(O: D: O: F: O: WM: M: WM)**.

### 2.2.3. Third system

From the analysis of two variants of the third focusing system, we choose the alternation of lenses as the basis **(O: D: O: F: O: WM: M: WM)**, since at the system output the transverse size of the beam are significantly smaller than in the other variant, which is essential for further optimization.

#### 2.2.4. Fourth and fifth systems

These two systems are the same—doublet systems with the orientation of the lenses in the horizontal plane (**O:D:O:F:O**).

#### 2.2.5. Whole transportation channel

Based on a preliminary analysis of the single systems of the electrons transportation channel, the following lens layout was chosen:

**O:D:O:F:O:O:F:O:D:O:WM:M:WM:O:D:O:F:O:WM:M:WM:O:F:O:D:O:O:F:O:D:O**

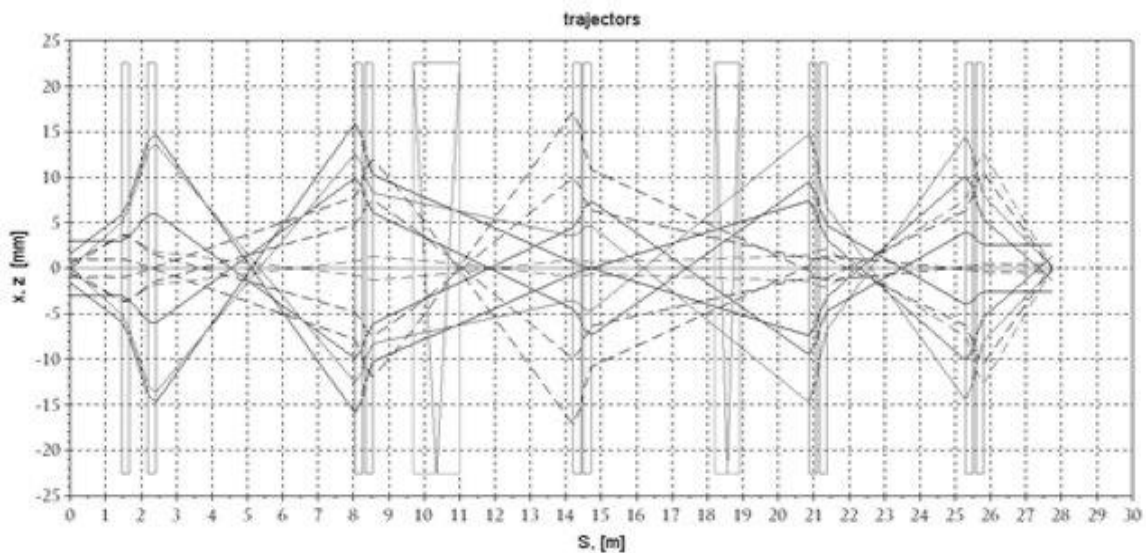
Complete optimization of the transportation channel parameters is implemented from the condition stigmatic of beam image at the channel output ( $m_{12} \rightarrow 0$ ,  $n_{12} \rightarrow 0$ ) and approximately unit transformation ( $m_{11} \rightarrow 1$ ,  $n_{11} \rightarrow 1$ ) and ( $m_{21} \rightarrow 0$ ,  $n_{21} \rightarrow 0$ ).

As can be seen from table 1, the optimized version of the channel allows you to skip most of the electron beam from the accelerator output.

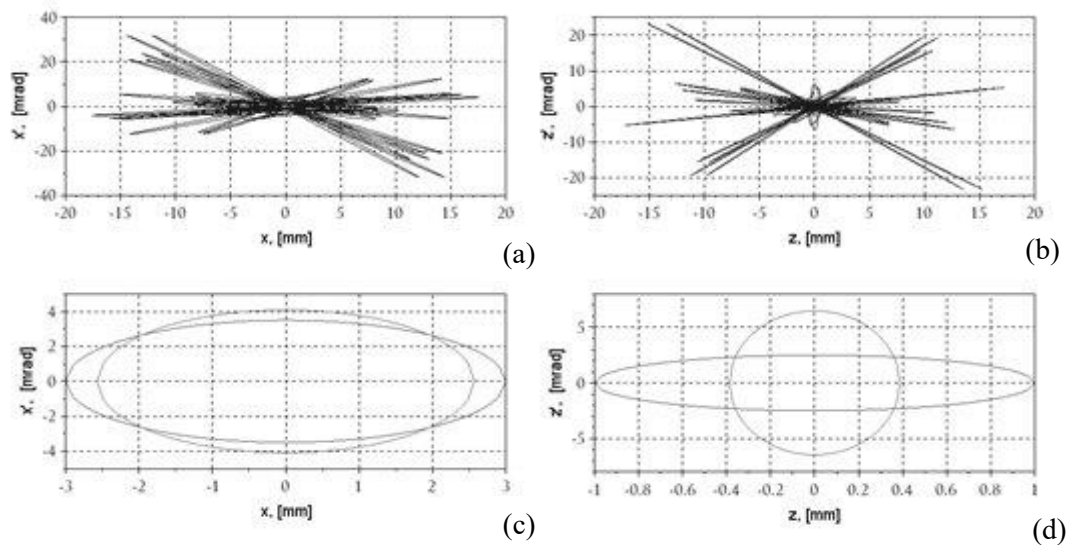
**Table 1.** The beam parameters at the input/output of the transportation channel.

	Input beam parameters	Output beam parameters
Horizontal beam size (diameter) (mm)	4	6
Horizontal beam divergence (mrad)	$\pm 1.6$	$\pm 3.5$
Vertical beam size (diameter) (mm)	2	2
Vertical beam divergence (mrad)	$\pm 3.0$	$\pm 3.0$

In figures 2 and 3 show particle trajectories and phase portraits of the beam in an optimized version of the transport channel.



**Figure 2.** The particle trajectories in the horizontal (solid lines) and vertical plane (dashed line).



**Figure 3.** Phase portraits of the beam at the inputs (a) and (b) and at the outputs (c) and (d) of the elements of the transport channel.

### 3. Conclusion

The most important advantage of an optimized transport channel is that the beam at the channel exit has significantly smaller transverse dimensions and divergence.

The graphic means of the medium display the trajectories of individual particles, envelopes and phase portraits of the beam in the horizontal and vertical plane. This information allows you to quickly analyze and adjust the geometric and field parameters of the transport channel.

### References

- [1] Averyanov G P *et al.* 2014 *The Interactive Computer Environment for Designing and Tuning of Charged Particle Beams Transport Channels* (Proceedings of RuPAC , Obninsk, Kaluga Region, Russia) pp 63–5
- [2] Averyanov G P *et al.* 2014 *Prob. of At. Sci. and Tech.* **3** 138–42
- [3] Averyanov G P *et al.* 2015 (in Russian) *Modeling the transport path of the electron beam output from "Pakhra" synchrotron* (International conference “Stability and Control Processes”) pp 165–6 (Original Russian title: Modelirovanie kanala transportirovki vyvedennogo jelektronnogo puchka sinhrotrona «Pahra». Saint Petersburg: Saint Petersburg State University)