

# TRANSVERSE BEAM MATCHING AND CORRECTION PROCEDURES IN INR LINAC

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## Abstract

An interactive procedure for the transverse beam matching and correction has been developed and implemented in several areas of INR Linac. Profile measurements are used for determination of the main transverse beam parameters. These data are applied for calculation dipole correction currents and quadrupole gradients to transport the beam with minimum sizes and off-axis displacements. The user friendly interface and graphics support have been developed for data treatment and beam behavior presentation. The proposed algorithm of beam matching, beam steering and data treatment is discussed. Some experimental and simulation results for different INR Linac operation modes are presented.

## INTRODUCTION

The Linac of Institute for Nuclear Research of the Russian Academy of Sciences is a high intensity accelerator [1]. Therefore it is important to provide optimum beam transportation throughout the accelerator with minimum beam loss.

There are five areas in the high energy part of the accelerator (above 100 MeV) where transverse beam parameters can be measured and adjusted. Transverse beam matching and correction procedure includes the following steps:

- beam profile measurements and preliminary data treatment;
- processing of profile measurement data;
- beam matching;
- beam steering.

## INSTRUMENTATION AND PRELIMINARY DATA TREATMENT

Transverse behavior of the beam is monitored by wire scanners. From three to five wire scanners are installed in each measuring area. The scanner consists of two perpendicular wires parallel to horizontal and vertical axes. Two-wire assembly is moved across the beam by a stepper motor. Scanning is made through the whole aperture in the range of  $\pm 20$  mm with respect to the axis. A scan step is set by operator and can be equal to 0.5, 1 or 2 mm. Processing of experimental profiles (Fig.1) gives rms and maximum size of the beam as well as position of the beam centre. Two definitions of the beam centre are foreseen: the mean value of the measured distribution and the middle of beam edges. These data along with information on focusing structure of the measuring area are further used for data treatment. Below, for simplicity, the discussion will concern to rms beam size and beam centre defined as mean value.

The Ethernet TCP/IP protocol and LabVIEW are used to get profile data and to make the preliminary treatment. A detailed display of the measured beam profiles is foreseen with the aim to estimate the data reliability for further statistical treatment. For example, the cut off noise level can be introduced and the unreliable data can be excluded.

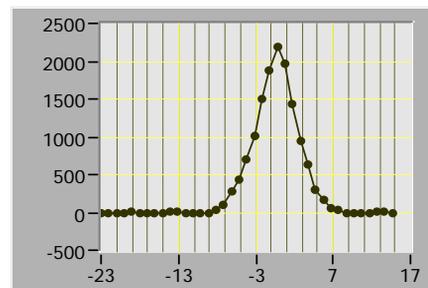


Figure 1: Example of beam profile measurement.

## TREATMENT OF PROFILE MEASUREMENT DATA

The results of rms beam size and the beam centre measurements at the point of wire scanner longitudinal location for each transverse phase plane represent vertical lines. The disposition of these lines can be transferred to arbitrary point of measuring area by matrix method.

The results of measurements with several scanners at the selected longitudinal position represent a set of lines. The phase ellipse is inscribed with the iteration algorithm in the central part of the phase space separated by the lines in such a manner that the sum of distances from all the lines to the ellipse is minimized (Fig.2). The parameters of phase ellipses  $\alpha_x, \beta_x, \gamma_x, \alpha_y, \beta_y, \gamma_y$  and the emittances  $\epsilon_x$  and  $\epsilon_y$  are calculated.

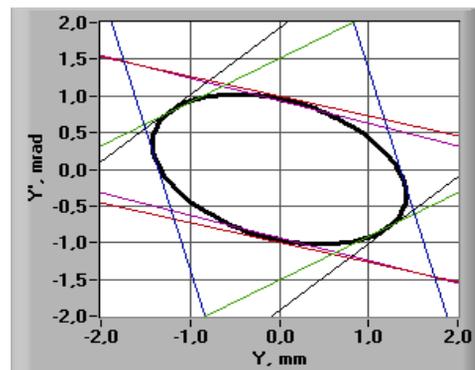


Figure 2: Example of inscribed beam phase ellipse.

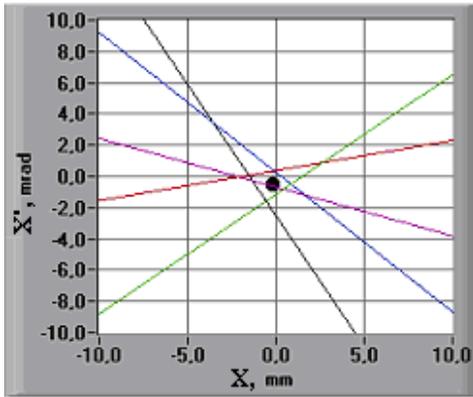


Figure 3: Example of the beam centre determination.

The method mentioned above has errors of determination of the ellipse parameters, which depend on mutual disposition of the lines because a standard matrix transformation for any transverse phase plane doesn't keep invariable the segments of the lines and the angles between the crossed lines. To decrease these errors the procedure is carried out for several points along the measuring area. Then the parameters of calculated phase space ellipses for all desired longitudinal points can be transformed to the point of interest by matrix technique and the mean values and statistics of the parameters are calculated. For example, the parameters at the entrance of the first measuring area (~100MeV) are the following:

$$\begin{aligned} \beta_x &= 2.16 \pm 0.13 \text{ mm/mrad}; & \beta_y &= 0.43 \pm 0.03 \text{ mm/mrad}; \\ \alpha_x &= -1.73 \pm 0.18; & \alpha_y &= -0.09 \pm 0.03; \\ \varepsilon_x &= 0.47 \pm 0.02 \text{ mm}\cdot\text{mrad}; & \varepsilon_y &= 0.82 \pm 0.01 \text{ mm}\cdot\text{mrad} \end{aligned}$$

The above errors represent errors of the method and are only the part of the total errors.

Similarly one can get a series of transformed straight lines for a beam centre. Ideally an intersection point of these lines is a beam centre in a phase space. Normally due to errors all the lines do not intersect in one point, therefore the point of beam centre is found by minimizing the sum of distances to all the lines (Fig. 3).

Similarly to the procedural errors for ellipse parameters there are procedural errors for centre determination and

the values related to Fig. 3 are:

$$\begin{aligned} X_{centre} &= -0.13 \pm 0.17 \text{ mm}; \\ X'_{centre} &= -0.16 \pm 0.31 \text{ mrad}. \end{aligned}$$

All the calculations are carried out in LabVIEW. The interface presenting the statistical view of simulation is shown in Fig. 4. It is possible to control the treatment process and iteration procedures with the aim to exclude unreliable data and to improve statistics.

### MATCHING PROCEDURE

Reconstruction of transverse beam phase ellipses and determination of beam centres in arbitrary longitudinal point is necessary for the subsequent procedure of beam matching and correction.

The main goal is to match different accelerator parts using the calculated averaged beam parameters without knowing of the beam "history". The parameters at the exit of the matching area are selected from the point of view of optimisation of the subsequent beam dynamics. Normally five independent parameters of focusing elements are used to adjust phase ellipse parameters and to minimize the beam size.

The elements of the focusing structure along with the wire scanners for 100 MeV measuring area are shown in Fig. 5a. The tracing of the found phase ellipse parameter  $\beta$  along the measuring area is presented in Fig. 5 before (b) and after (c) matching. The gradients of the first four quadrupoles and the following quadrupole doublet are the parameters for optimization. After setting the calculated parameters the test profile measurements are done and in case of need the procedure of matching can be repeated.

At present the matching simulation is carried out in separate FORTRAN block matched friendly with LabVIEW data.

### BEAM CENTRE CORRECTION

There are special windings in the quadrupoles to produce an additional dipole field for beam steering. Two steering elements for both transverse planes are used in each measuring area. A standard correction procedure [2]

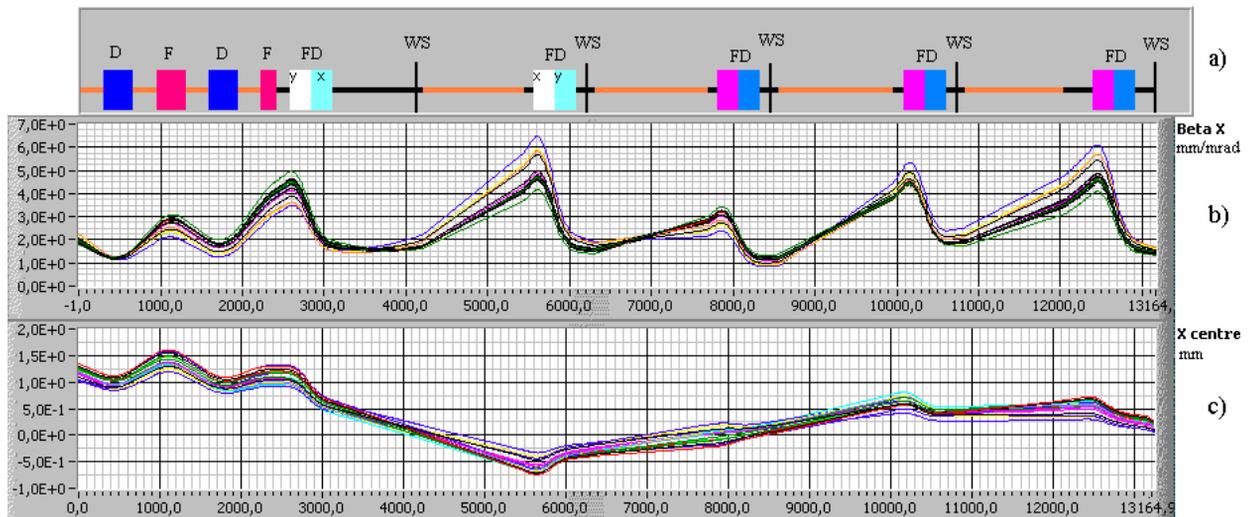


Figure 4: Lattice (a), tracing statistics of the  $\beta$ -function (b) and beam centre (c).

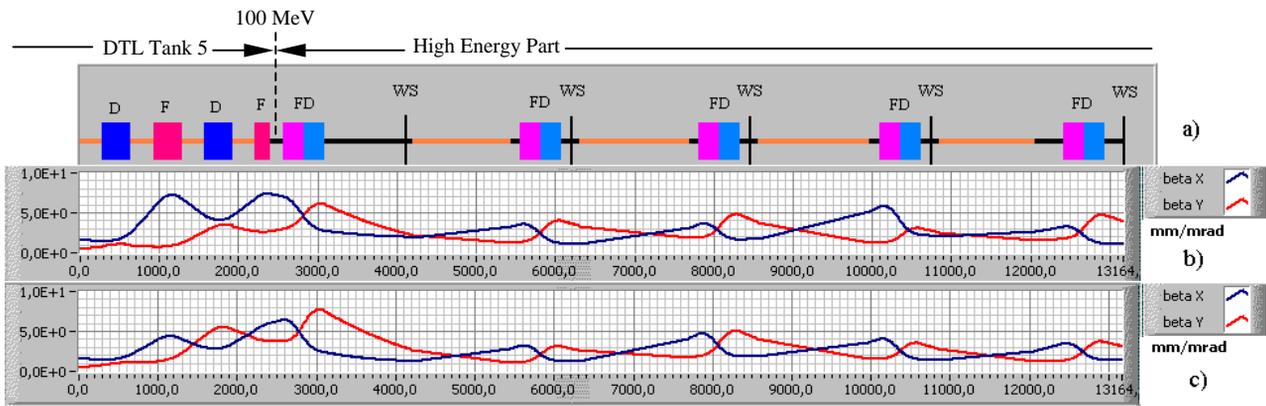


Figure 5: Lattice (a) and tracing of the  $\beta$ -function before (b) and after (c) matching procedure.

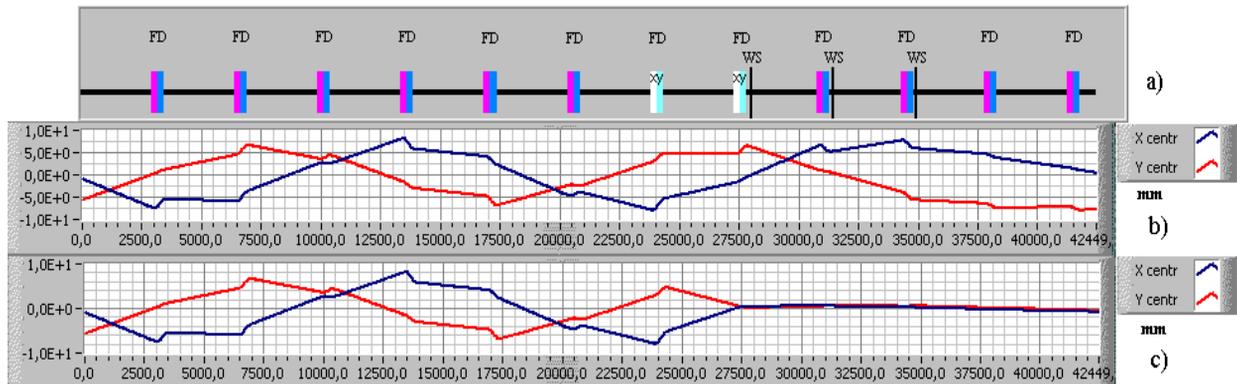


Figure 6: Lattice (a) and tracing of the beam centre before (b) and after (c) correction.

enables to suppress displacement and angle of the beam at the exit of the second steering element in both horizontal and vertical planes.

The correction procedure is carried out after completion of the procedure of beam matching.

The steering currents are calculated with a separate code. A behavior of beam centre throughout the measuring area at the accelerator exit before (b) and after (c) correction is presented in Fig. 6.

To estimate the correction efficiency a special parameter was introduced. It is defined as an rms deviation of the beam centre from the axis averaged over the measuring area downstream of last corrector. The improvement of beam behaviour after the second step of correction is demonstrated in Fig. 6. The parameters defined above are:

$$\begin{aligned} Xcen_{rms} &= 4.63 \text{ mm}, & Ycen_{rms} &= 5.50 \text{ mm} \\ Xcen_{rms} &= 0.46 \text{ mm}, & Ycen_{rms} &= 0.39 \text{ mm} \end{aligned}$$

before and after correction correspondingly.

In practice two iterations were sufficient for acceptable results.

The LabVIEW interface enables to measure and to control the corrector currents, to make all computations for determination of steering currents and to display beam centre behavior.

### CONCLUSION

All the algorithms mentioned above were included to the application package. It has been tested at two measuring areas of the INR Linac and is planned to be used throughout the whole accelerator. This application package has been developed to analyse interactively and to control transverse beam parameters in order to reduce beam loss. The effective beam matching and correction have been achieved.

### REFERENCES

- [1] B.P. Murin et al., Ion Linear Accelerators, «Atomizdat», Moscow, 1978.
- [2] I.N. Biryukov et al., Investigation of Transverse Beam Dynamics at the INR Linac, INR internal report, Moscow, 1991.