EMITTANCE MEASUREMENTS AT THE EXIT OF INR LINAC

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Abstract

Emittance measurements at the exit of INR linac are of importance for proper beam matching with the beam line of the downstream experimental facility. Emittance ellipses are reconstructed from beam profile data obtained with three wire scanners and one ionization beam cross section monitor (BCSM). A possibility of quadrupole gradients adjustment not only increases the reconstruction accuracy but also enables to find emittances with BCSM data only. The latter provides completely transparent measurements and can be done within a wide range of beam currents. The results of measurements by wire scanners and BCSM are presented and compared, the reconstruction procedure features are discussed.

INTRODUCTION

Accelerated proton beam of INR linac is used on the experimental facility of Neutron Studies Laboratory, proton therapy complex of Medical Physics Laboratory, facility for dibaryon resonances study and on other experimental targets.

Neutron Studies Laboratory experiments are carried out on the beams of 0.3 to 200 µs duration at repetition rate of 1 to 50 Hz with a pulse current up to 15mA, i.e., the average current can be as high as 150 µA, while for the proton therapy complex one should apply an average current of about 10 nA. The beam energy can be varied from 70 to 209 MeV. So each experiment requires specific values of beam energy, intensity, duration, and matching of these parameters with the characteristics of beam channels at INR experimental complex.

For INR proton linac operation in wide dynamic range of beam parameters one has to carry out proper retuning and matching procedures according to the features of the experiments. This in turn requires more attention to the dynamic range of the beam measuring system to ensure reliable diagnostic abilities for different beams.

Last years the linac diagnostics has been supplemented and upgraded. In particular, the system of wire scanners (WS) was developed. Besides the ionization beam cross section monitor was installed [1], which allows to measure transverse beam profiles at the linac exit.

Beam cross section monitor (BCSM) of accelerated protons provides possibility to observe the following beam parameters during adjustment and operation of the linac: protons distribution in beam cross section (BCS), beam centre position and its displacement relative to linac axis. The transverse beam profiles can be obtained from the beam cross section distribution too.

In process of linac tuning various interactive procedures are used [2]. They give the possibility to carry out transverse matching of the beam, centre correction and minimization of beam losses. Description of the equipment at the linac exit is presented. The emittance measurement procedures, as well as a comparison of the results obtained by different methods are discussed.

BEAM INSTRUMENTS AT LINAC EXIT

The measuring area at the linac exit for transverse beam matching and centre correction is shown in Fig.1a. The following equipment is installed at this area:

- 8 quadrupole magnetic doublets D106 ÷ D113. Their windings are supplied from a common current source;
- beam current transformer;
- 4 quadrupole magnetic doublets D114 ÷ D117. Their windings are supplied from different current sources;
- 3 wire scanners. They are installed downstream the doublets D113, D114, D115. Each scanner consists of two mutually perpendicular wires of 0.1 mm, which are parallel to horizontal and vertical axes.
- BCSM is installed upstream the doublet D114.

Procedures of transverse beam matching and correction are realized using the profiles obtained by WS at the same time with BCSM.

High sensitivity of BCSM allows to extract profiles from beam cross-sections measurements in very wide dynamic range of beam intensities for high- and low-current beams, while WS measurements are effective only in limited range of beam pulse currents due to noises induced on electronics and cables.

PROFILE AND EMITTANCE MEASUREMENTS

Linac tuning is performed strictly with 1 Hz pulse frequency to avoid excessive equipment activation and damage due to overheating of linac equipment in the point of significant beam losses.

Profile measurement with BCSM during linac tuning is also executed with 1 Hz beam frequency. Single pulse of 100 µA÷10 mA with 100 µs duration is sufficient to obtain profile. However, it is possible to measure beam profiles with pulse current lower than 100 µA using higher beam frequency e.g. 10÷50 Hz. In former case average proton beam current would be smaller than 10 mA of 100 µs pulse current with 1 Hz repetition rate. Low current beam Profiles are generally measured by BCSM using averaging over multiple pulses.

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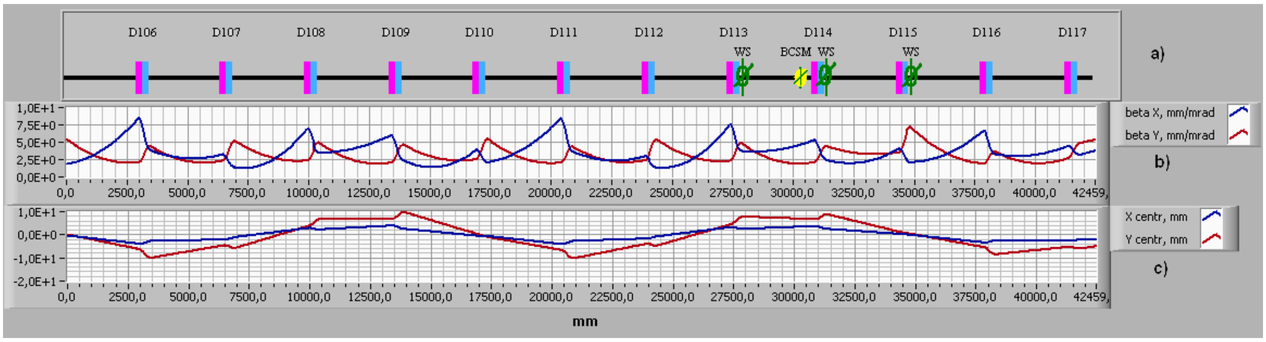
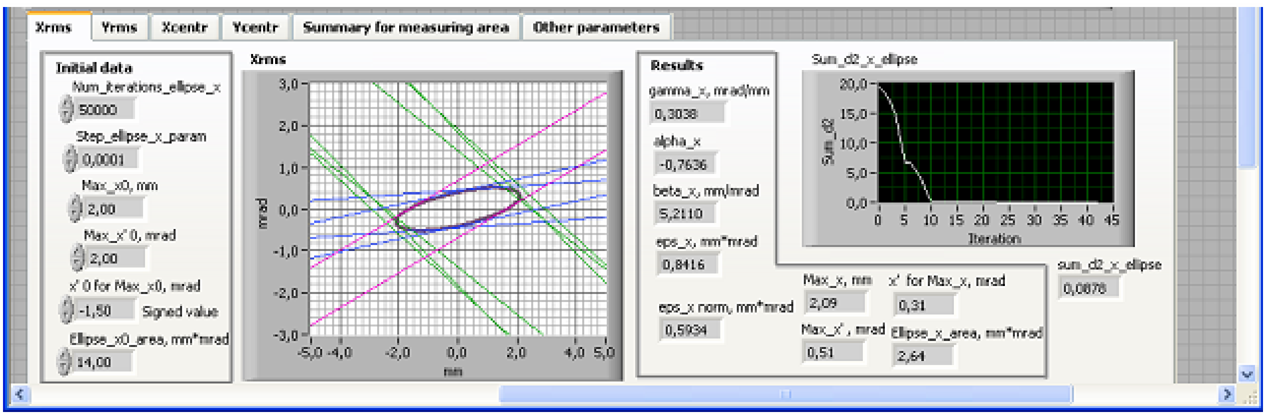


a)



b)

Fig. 1. BCSM and Wire Scanners locations on beam line; beam envelope and beam centre at the linac exit (a), example of beam emittance measurement by WS(b).

Linac tuning procedure [2] is used to define the coincidence of beam parameters obtained by WS and BCSM. The results of beam center position and RMS size measurements at WS location are represented with lines for each transverse phase plane. These lines can be transformed to any location along beam line with magnetic optics transmission matrices.

There are several methods for emittance measurement at exit of the linac:

- Three WS located along beam transport line after three quadrupoles with constant magnetic field gradient. Measurements are processed with above mentioned matrix method. It takes 3 minutes to make a scan with 3 WS simultaneously.

Wire scanners (WS) are driven with stepper motors. The scan of single profile with WS takes 3 minutes. Actuators of WS's can be driven either individually or simultaneously.

- One WS measurement where multiple profiles are obtained by varying fileds of 8 quadrupoles. The scan takes 10 minutes.

- Multiple profile measurement with BCSM by varying fields of 8 quadrupoles. Scan time is determined by settling time of fields in the quadrupoles. Typical time necessary for BCSM to measure single profile is 140 ms for high intensity beam, and 1 s for low intensity beam average profile.

EXPERIMENTAL RESULTS

Procedure to define the coincidence of beam parameters obtained by WS and BCSM is carried out after linac preliminary tuning to minimize beam losses at the linac exit.

Beam of 209 and 127 MeV with 1 Hz repetition rate, 170 µs pulse width and 10 mA pulse current is used for measurement and comparison.

Comparison measurements are carried out by varying fields of 8 quadrupoles in the range of ±20 A with 5 A steps around the optimal current value. These variations provide enough slope changing of the lines bounding the beam profiles to calculate the inscribed ellipse of the emittance. The results of emittance measurement (Fig. 2) for 209 MeV beam are shown in green for BCSM and in red for WS. Bottom figure shows overall picture with overlapped ellipses.

Measurements for 127 MeV beam are shown on Fig. 3. Currents in quadrupoles were varied with the same varying and comparison results are also carried out.

Measured RMS beam size non-coincidence between WS and BCSM is within few percent.

The comparative results of emittance measurements by WS and BCSM shown on Fig. 2 and Fig. 3 are satisfactory too.

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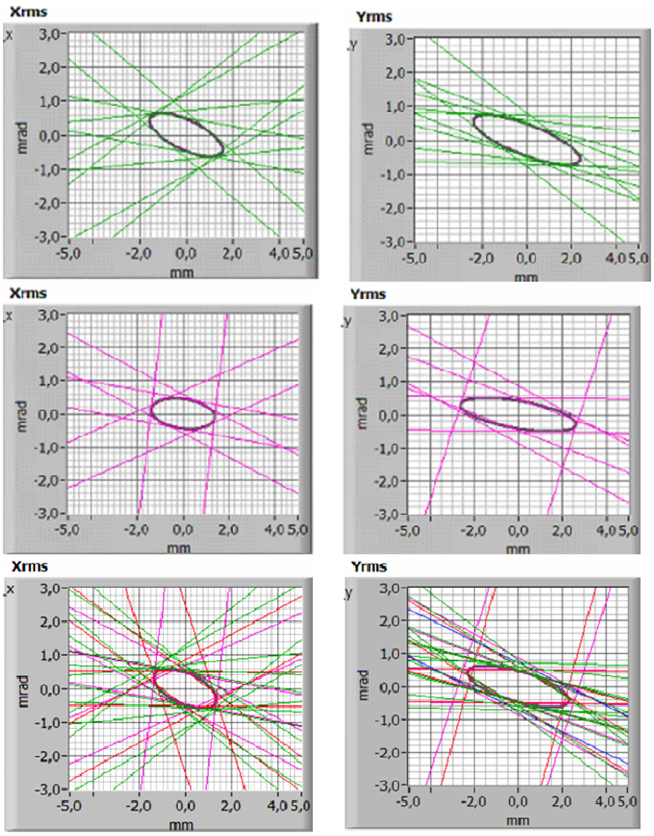

Fig. 2. Emittance comparison for WS (red line) and BCSM (green line) of 209 MeV beam.

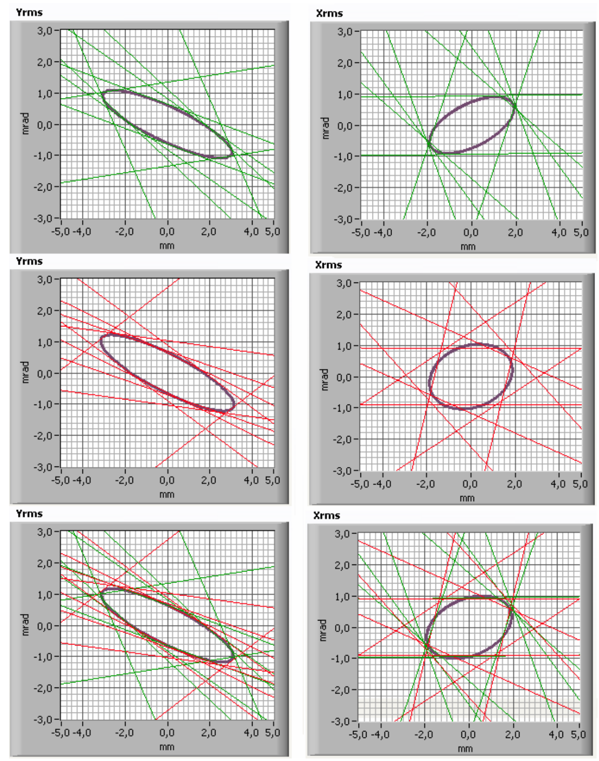

Fig. 3. Emittance comparison for WS (red line) and BCSM (green line) of 127 MeV beam.

CONCLUSION

There are two possibilities to measure the proton beam tranverse parameters at the exit of INR linac using either wire scanners or BCSM. These procedures includes emittance and beam position measurement, the optimization of beam size and correction of beam position to minimize beam losses at the linac exit and to match these parameters with the experimental complex beam channels. The result of emittance measurements by these two methods shows satisfactory coincidence. But transverse beam measurement procedure carried out by BCSM has two advantages over wire scanners: this method does not violate the beam and can be used for low intensity beams. This method expands beam monitoring and control for wide range of beam intensities. That is particularly very important for medical physics beam formation.

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