RECONSTRUCTION OF THE BEAM PARAMETERS AND STRUCTURE CHARACTERISTICS FOR INR ISOTOPE CHANNEL

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Abstract

The various treatments of profile measurements have been applied to estimate both the major beam parameters and structure functions for the INR isotope channel (IC). The main problem for beam dynamics reconstruction consists in the presence of a dispersion function along the beam line studied. The reliable results were obtained and used to form the beam on the target of INR isotope complex.

INTRODUCTION

Special proton beam extraction channel is used at INR linac for isotope production for the technical and medical purposes in wide energy range (100÷160 MeV) [1]. The qualitative beam behaviour control is needed to form the beam on the isotope target. The total beam line for monitoring and forming the desired beam parameters is presented in Fig.1a (linac part) and Fig.2a (isotope channel). The deflection of the proton linac beam is carried out in horizontal plane by two bending magnets BM1 and BM2 (Fig.2a) with the total bending angle 26º.

The profile measurements for linac part (Fig.1a) are made by two 2-wire scanners WS1 and WS2. In isotope channel two-coordinate multiwire profilometer MWP (Fig.2a) is used. The beam formation on the isotope target is made by all quadrupole doublets shown in Fig.1a and Fig.2a.

For simplicity the measurements and calculations will be discussed below only for the horizontal plane where the dispersion is taken place for the isotope complex beam line.

METHOD 1

This method is based on the measurements by the linac profilometers WS1 and WS2 only. Both monitors are operated simultaneously. The scanning time is ~ 3 min. For each space step multiple measurements are carried out over the beam pulse. The space step is determined by 1 Hz beam pulse repetition rate, whereas the time structure is sampled at 1 MHz frequency. Any time and space region of beam intensity distribution can be taken for further treatment [1].

For the accelerator part (Fig.1a) the method [2] was realized to determine the transverse beam phase space configuration. The current variations for doublets D15 and D16 (Fig.1a) were used. The well-known beam phase space characteristics (α, β, γ) and rms emittance ε may

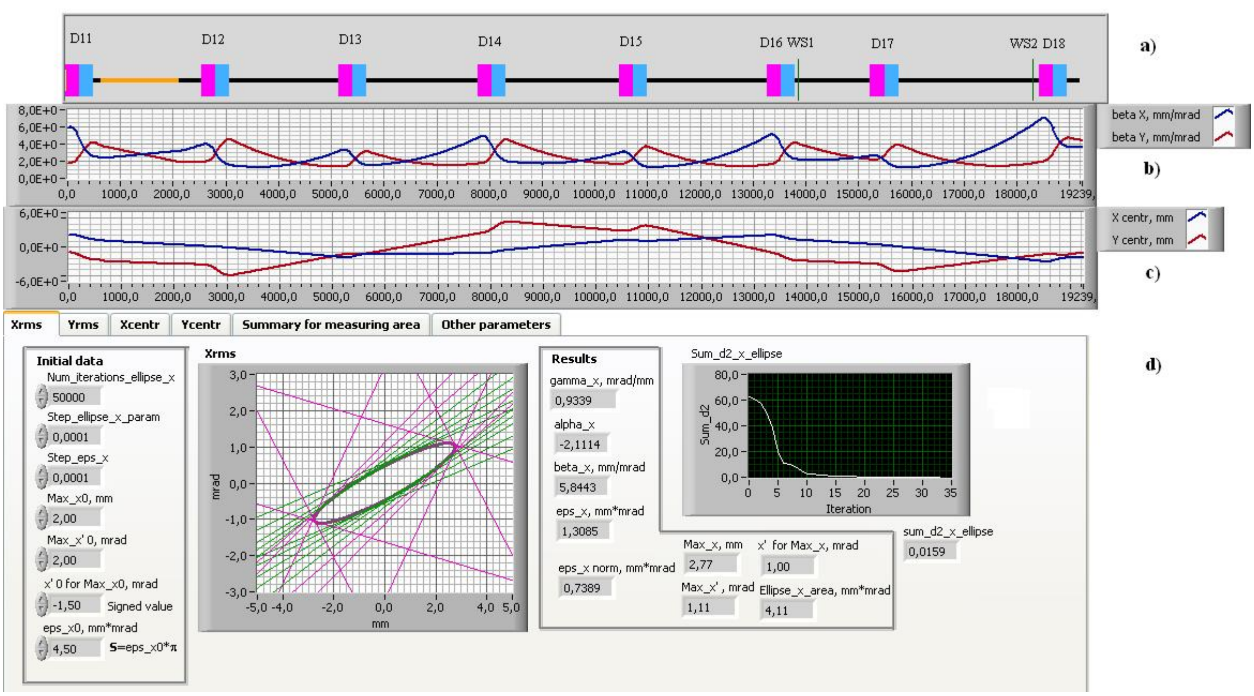

Figure 1: 160MeV beam measuring area: a) lattice: D11,…, D18 - quadrupole doublets; WS1, WS2 – 2-wire scanners; b) β-function tracing; c) beam center tracing; d) inscribing of the beam phase ellipse and main parameters.

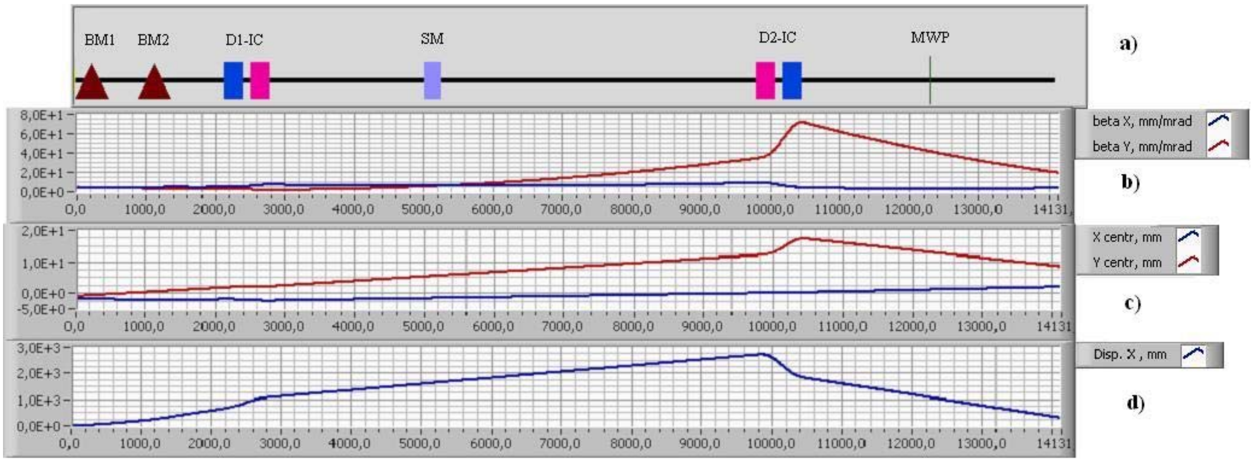

Figure 2: Isotope channel: a) lattice: BM1, BM2 – bending magnets; D1-IC, D2-IC - quadrupole doublets; SM – steering magnets; MWP – multiwire profilometer; b) **β**-function tracing ; c) beam center tracing; d) dispersion function.

be calculated at any accelerator point. In Fig.1(b, c, d) the Method 1 results are presented for the linac part. The calculated data for the beginning point (Fig.1d) permit to determine the beam phase space characteristics at any point of the accelerator (Fig.1b-Fig.1c) and isotope channel (Fig.2b-Fig.2c) by matrix formalism. The calculated results are used to predict the beam dynamics along any beam line including beam formation on the isotope target.

MEASUREMENTS IN ISOTOPE CHANNEL

The main isotope channel (IC) measurement area is presented in Fig.3. The multiwire profilometer MWP (Fig.2a) is used for the continuous beam size operation control. For the beam characteristic measurements the current variations are used in doublet D2-IC.

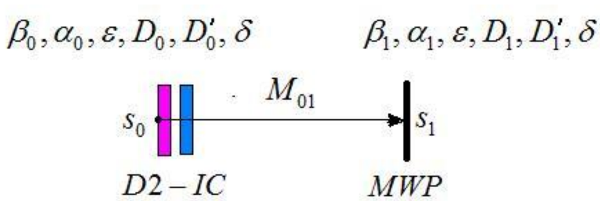

Figure 3: IC measurement area

The beam and structure parameters for proposed determination are shown in Fig.3, where δ is rms longitudinal momentum spread for the beam particles; $\beta_0, \alpha_0, \beta_1, \alpha_1$ – the beam characteristic functions at the beginning s_0 and final s_1 points for the beam particles with $\delta \cong 0$; ε – rms non-normalized beam emittance for the beam particles with $\delta \cong 0$; D_0, D_0', D_1, D_1' – dispersions and its derivations; M_{01} - varied transfer matrix for the beam particles with $\delta \cong 0$. The parameters δ and ε are constant because there are no accelerating elements in the measurement area.

Method 2

The modified Method 1 was developed [1] to treat the transverse profile measurement results for a beam lines with high dispersion. For the standard operation mode of the INR IC beam line the dispersion is ~ 2 m at MWP (Fig.2a) and ~ 3 m at D2-IC entry point. That leads to essential beam spread (~ 40 %) in a dispersion plane. It means that the ellipse presentation of a beam phase space (Method 1) is not valid. It was proposed in [1] to introduce a data correction at the measurement point with presence of high dispersion. The followed formulae were used:

$$\overline{x^2} = \overline{\xi^2} + D^2 \overline{\delta^2} \quad , \quad \bar{x} = \bar{\xi} , \qquad (1)$$

where $\overline{\delta^2}$ – is the square of a rms longitudinal momentum deviation of the beam particles; $\overline{x^2}$ – the square of a measured rms beam size; $\overline{\xi^2}$ – the square of a rms beam size for particles with $\delta \cong 0$; D – a dispersion function at the measurement point, in our case it depends on D2-IC current and is calculated numerically; $\bar{x}$ – measured beam center; $\bar{\xi}$ – beam center for particles with $\delta \cong 0$.

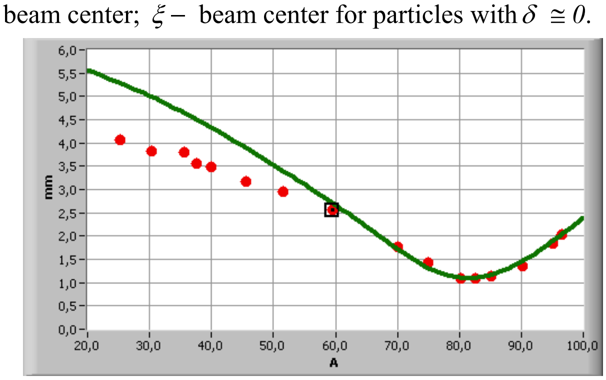

Figure 4: $\boldsymbol{x_{rms}}$ at MWP location vs. D2-IC current.

The results of Method 1 calculations for β – functions and beam sizes along the isotope channel (Fig.2a) are used to compare with MWP measurements. According to Eq.1 the value of $\overline{\delta^2}$ was chosen to equalize the rms emittances calculated by Method 1 and by Method 2 for variable ξ. The determined rms beam size according to Method 1 results and correction Eq.1 is presented in Fig.4 by solid line. The points are the experimental data and square is the operating mode of the INR isotope channel.

Proposed Method 2 permits to predict qualitatively beam dynamics for the dispersion part of the INR isotope channel and to design beam formation on the isotope target for wide range of the beam energies.

Method 3

In [3] the analytical method is proposed to calculate the phase space beam characteristics and structure functions for beam lines without accelerating elements. The input data are the measurement results, the parameters of varying elements and the beam line information. The last one may be extremely shot to reduce the structure errors and beam losses. The developed algorithm was applied to the beam line in Fig.3 of INR isotope channel. This method includes the theory of combinations and the minimizing numerical algorithms to solve the systems of linear and nonlinear equations where there are errors of the measurement data and elements of transport matrix for the beam line under study.

Eq.1 is the basic one. The calculation results are following: the characteristic phase space parameters of the beam, the structure parameters of a beam line, the rms non-normalized beam emittance ε and rms longitudinal momentum spread δ for the beam particles. These results are averaged for the solutions of more then two hundred of linear and nonlinear equations depending on number of measurements [3]. In this case the rms deviations for calculated values may be statistically determined. Moreover the proposed method permits to estimate the measurement data quality through the calculation of assumed exact measurement data values. The determination of the characteristic parameters $\beta_0, \alpha_0, D_0, D_0'$ at the beginning point of measurement area (Fig.3) permits to define these values outside this part of beam line by matrix operations.

The disadvantages of the proposed method are following [3]:

- the necessary number of measurements must be not less than five;
- there is no fast interactive data processing algorithm now;
- for treatment it is necessary to use measurement data only for the same sign of dispersion at the measuring point (two rows for Method 3 results in Table 1).

COMPARISON OF RESULSTS

In Table 1 the results for fixed measuring cycle are presented. They were obtained for the beginning point of accelerator part in Fig.3 by means of all methods discussed above.

Table 1: Calculation Results

Parameter	Method 1	Method 2	Method 3
β_0, mm/mrad	8.90	5.47	11.65±0.24
			10.79±0.15
α_0	-0.75	-0.79	-0.64±0.10
			-0.92±0.10
D_0, m	2.705	2.705	2.34±0.22
			2.42±0.22
D_0', mrad	234.7	234.7	62.9±71.03
			29.1±147.1
ε, mm·mrad	1.29	1.27	1.11±0.21
			0.98±0.29
δ, %	earlier ~0.103	0.086	0.137±0.021
			0.120±0.019
x_{centre}, mm	-0.05	14.5	14.56±2.65
x'_{centre}, mrad	0.35	0.53	0.72±0.45

The dispersion data for Method 1 and Method 2 are equal and were estimated by tracing along the total line of isotope channel. The calculations by Method 3 were carried out for small beam line (Fig.3) only.

Only Method 3 as was mentioned above permits to estimate the quality of the profile measurements. For measuring cycle presented in Table 1 the beam rms sizes were in the range of (1.3÷2.8) mm. The deviation of expected exact measurement values is less than 0.3 mm.

CONCLUSIONS

Three methods were presented to estimate the transverse beam phase space characteristics and accelerator structure functions. All methods were implemented for the accelerator part and isotope channel to extract proton beam to isotope target. An application of any method for actual problems depends on the requirements to duration of data treatment, graphical support and results quality.

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