THE PEPPER-POT EMITTANCE MEASURING DEVICE AT THE 400 keV H-MINUS LEBT CHANNEL

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Abstract

The emittance measuring device has been developed for operational control of INR RAS linac 400 keV H-minus injector beam parameters. It includes the "pepper-pot", the quartz screen, the CCD camera, PC, the software for camera data processing and beam phase portrait formation. The device has been mounted at the first straight section extension of H-minus LEBT after 45 degree bending magnet. When the bending magnet is switched off the device is possible to measure and to represent single shot beam phase portrait. The results of the H-minus beam emittance measurements and the device performance have been discussed.

INTRODUCTION

Registration of light, received on the scintillator after passing the ion beam through mask with a set of holes ("pepper-pot"), allows, in principle, to measure the emittance of the ion beam in a single shot beam pulse.This method of measuring the emittance associated with the interception of the beam, and is usually implemented by inputting the emittance measuring device into the beamline [1-2]. The H-minus LEBT of INR RAS linac contains 45 degree bending magnet, this allowed to mount an emittance measuring device at the straight extension after bending magnet (Fig. 1). Aiming beam at device is possible to produce by switching off the bending magnet, and the parameters of beam emittance at the entrance to the bending magnet can be calculated from the experimentally obtained values by the reverse linear transformation for a drift length through the magnet.

EQUIPMENT, CALIBRATION AND EXPOSURE REDUCING

For testing of this emittance measuring device in the H-minus LEBT channel of INR RAS linac was assembled the system, which included "pepper-pot", the quartz screen and the CCD-camera type "VIDEOSCAN-415-USB".

Diagram of this emittance measuring device is shown in Fig.2 The camera uses CCD-matrix SONY ICX415AL with 780*582 pixels image format and 12-bit digitization. "Pepper-pot" had a set of holes with a diameter of 0.2 mm, arranged with a pitch of 3 mm for a field of approximately 100x100 mm^2. Distance from "pepper-pot" to the screen was 200 mm.

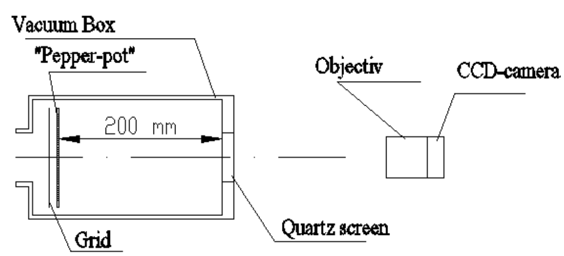

Figure 2: Diagram of emittance measuring device.

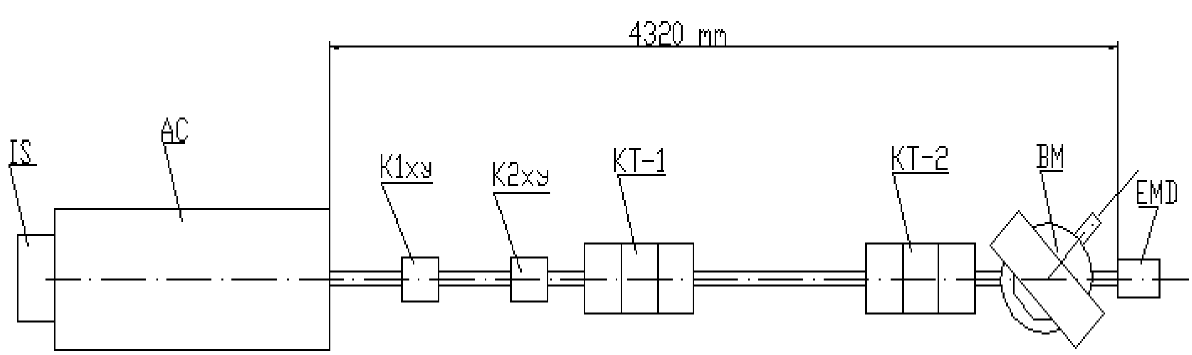

Figure 1: Scheme of the beam line channel with the emittance measuring device. IS – H-minus ion source, AC – 400 keV acceleration column, K1xy, K2xy – steering magnets, KT-1, KT-2 - quadrupole triplets, BM – bending magnet, EMD - emittance measuring device.

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A camera calibration by irradiation of "pepper-pot" with parallel beam light is performed before emittance measurement. As a result of calibration the "binding" of the image is performed, i.e. the pixel in the matrix of the camera corresponding to the center of axial hole of "pepper-pot" is located.

Figure 3: Example photo of the beamlets after "pepper-pot" on the quartz screen.

Then the calibration coefficient Kc has been determined. This coefficient Kc is the ratio of the distance between the centers of two adjacent holes of "pepper-pot" (which is equal to 3 mm for our “pepper-pot”) to the number of pixels separating this images on the camera. Kc~0.232 mm/pix has been obtained in the result of calibration.

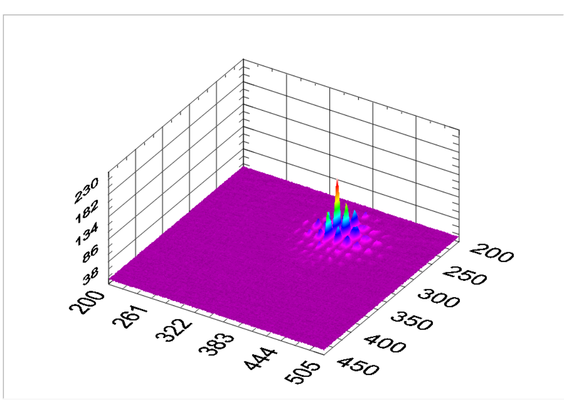

Figure 4: The intensity distribution obtained from the processing of image Fig.3 (after the subtraction of the data file without illumination by ion beam).

Fig. 3 shows an example of illumination of the screen, obtained with a beam of H-minus ions with energy of 400 keV. File of 12-bit data values from the array pixels were saved in bmp format for later processing.

A file of values pixels of CCD- matrix was recorded without ion beam to reduce the influence of background lighting of the screen. Then these values were subtracted from values obtained with the ion beam on the screen. Fig.4 shows an example of intensity distribution, obtained after this procedure of subtraction.

THE ALGORITHM OF DATA PROCESSING AND DETERMINATION OF BEAM EMITTANCE

Integrating the distribution function f(x,y), shown in Fig.4, on the Y or X direction, the resulting we get intensity distributions along the X or Y axis respectively. To exclude the effect of the remaining noise on data processing, we subtract from the obtained data of the function f(x,y) the value, equal to 0.1 of the maximum value of the function f(x,y). As a resultwe obtain intensity distribution with clearly separated " spikes", which corresponds to the holes of the "pepper-pot" (Fig. 5). Square of the "spikes" is proportional to the fraction of the beam passing through vertical or horizontal rows of "pepper-pot" holes.

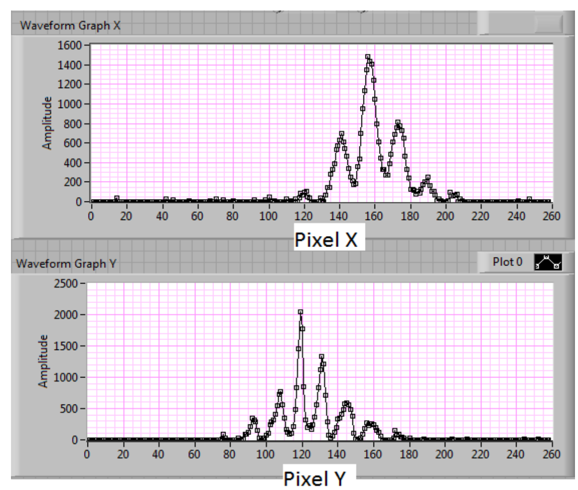

Figure 5: Intensity distributions along the X or Y axis.

Consider the intensity distribution of the beam along the X axis. Each separate n–th "spike", corresponding to the fraction of the beam that passes through an n–th vertical row of holes of "pepper-pot", has a width of N_n pixels. Each point of the n-th "spike" can be assigned in accordance the angle of the particle in a beam X'_m and the level of intensity of w_m, where $m=1,2,\ldots,N_n$. The results of the calibration of the camera were used to calculate the angles of deviation X'_m. Thus, we obtain the intensity distribution in the coordinate X and angle X' for the entire beam at the "pepper-pot". It is the input data array to determine the configuration and parameters of the beam emittance in XX' plane. First and second moments of the beam intensity distribution w(x,x') are calculated based on these data. N is the total number of points.

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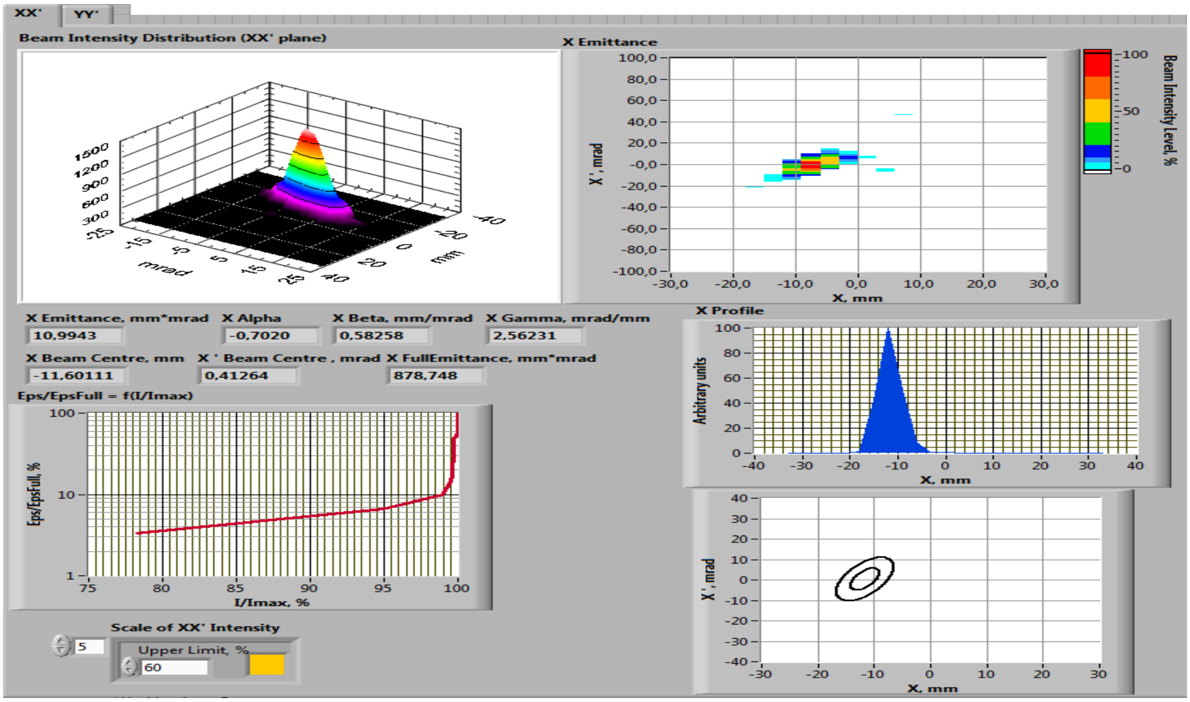

Figure 6: Data processing results.

$$\bar{x} = \frac{\sum_{i=1}^{N} x_i \cdot w_i}{\sum_{i=1}^{N} w_i} \; ; \; \bar{x}' = \frac{\sum_{i=1}^{N} x_i' \cdot w_i}{\sum_{i=1}^{N} w_i} \; ;$$

$$\langle x^2 \rangle = \frac{\sum_{i=1}^{N} (x_i - \bar{x})^2 \cdot w_i}{\sum_{i=1}^{N} w_i} \; ;$$

$$\langle x'^2 \rangle = \frac{\sum_{i=1}^{N} (x_i' - \bar{x}')^2 \cdot w_i}{\sum_{i=1}^{N} w_i} \; ;$$

$$\langle xx' \rangle = \frac{\sum_{i=1}^{N} (x_i - \bar{x})(x_i' - \bar{x}') \cdot w_i}{\sum_{i=1}^{N} w_i} \; ;$$

The value of RMS emittance is determined by:

$$\varepsilon_{Xrms} = \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2} \; ;$$

And calculated Twiss-parameters of the ellipse:

$$\alpha_X = -\frac{\langle xx' \rangle}{\varepsilon_{Xrms}} \; ; \; \beta_X = \frac{\langle x^2 \rangle}{\varepsilon_{Xrms}} \; ; \; \gamma_X = \frac{\langle x'^2 \rangle}{\varepsilon_{Xrms}}$$

Fig.6 shows the following results of the date processing: 3-dimensional beam intensity distribution, diagram of the intensity of the beam (X Emittance) at selected beam intensity level, the beam profile obtained by integrating values of the intensity distributions over the angles for each coordinate, the dependence of the beam emittance on the share of current, phase ellipses for $\varepsilon_{x\,rms}$ and for $4 \cdot \varepsilon_{x\,rms}$.

Here the parameters of the emittance obtained at the position of "pepper-pot". Parameters of the emittance at the entrance to the bending magnet prior to the "pepper-pot" on the drift distance L, can be recalculated as follows:

$$\beta_{X0} = \beta_X + 2L\alpha_X + L^2\gamma_X \; ;$$

$$\alpha_{X0} = \alpha_X + L\gamma_X \; ;$$

$$\gamma_{X0} = \gamma_X$$

For the YY' plane, all parameters are calculated similarly.

CONCLUSION

The pepper-pot emittance measuring device has been tested at the 400 keV H-minus LEBT channel of the INR RAS linac and the possibility to measure the emittance of the ion beam in a single shot beam pulse was demonstrated.

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