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LOW ENERGY "PEPPER-POT" EMITTANCE MEASURING DEVICE

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Abstract

The device which includes the "pepper-pot" mask, the quartz screen, and the CCD camera was used for measure the transverse emittances of beam at the exit of H-minus ion source for 7-15 keV beam energy. Emittance measuring at such low ions energy required low-level signals from quartz screen to be recorded and processed, while the intense glow of the gas discharge plasma created a spurious illumination of the quartz screen. The issues of obtaining sufficient signal level at such low ions energy, methods of subtracting the signal of non-ion-beam illumination of quartz screen from the full amplitude of the signal as well as issues of data processing and presentation of phase portraits are discussed.

INTRODUCTION

The advantage of "pepper-pot" emittance measuring device is that the device allows, in principle, to get the phase portraits simultaneously in XX' and YY' planes in a single shot or a small number of pulses of beam current in quasi real time mode.

This type device which includes the "pepper-pot" mask, the quartz screen, the CCD camera, PC, the software for camera data processing and beam phase portrait formation was implemented 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 [1]. However, when measuring the emittance close to the output of an ion source for a beam with an energy of about 15 keV, the level of the useful signal from the quartz screen is much lower, and the spurious illumination of the CCD-matrix by the radiation of the gas discharge plasma from the ion source may be much higher than the useful signal. Direct light illumination from gas discharge plasma is the most critical when measuring the emittance of a source with "direct" ion beam extraction without the use of a bending magnet. It is for this geometry of the ion source that measurements were made, which are discussed later in the report.

EQUIPMENT SELECTION

The disadvantage of the "pepper-pot" method is the need for constructive selection of the measurement step (step between holes) and this step cannot be changed during the measurement. The choice of the "pepper-pot" mask parameters was determined by the expected characteristics of the measured ion beam – its sizes and angular divergences as well as the distance to the screen and the intensity of the screen glow.

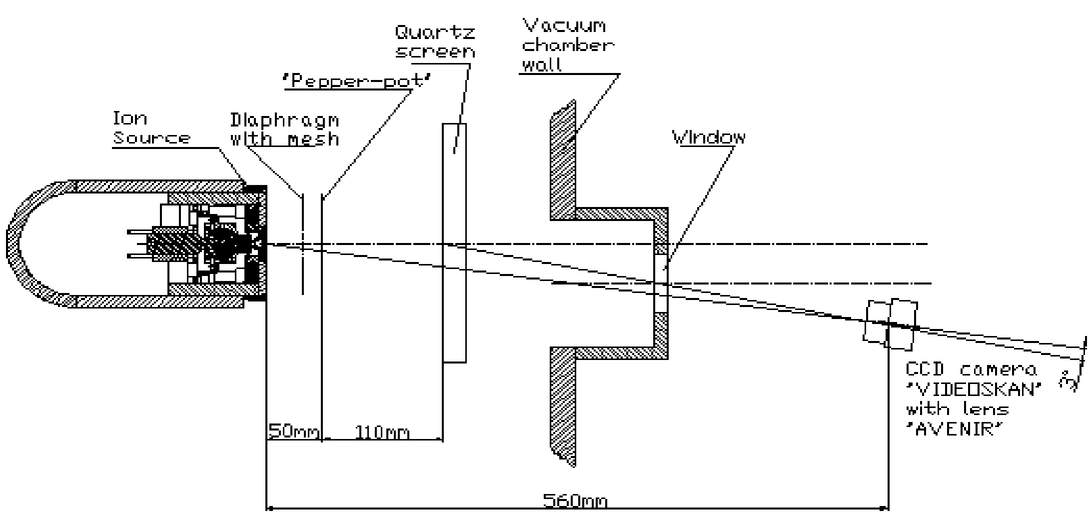

Figure 1: Scheme of the emittance measuring device.

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In this case - measurements close to the output of the extraction gap - it was expected that the beam has a large angular divergence and large size on the “pepper-pot” mask is due to this divergence. Based on this, the following parameters were selected: the size between the holes of the “pepper-pot” mask in X and Y coordinates - 3 mm, the distance from the mask to the screen-110 mm. Hole diameters were chosen 0.6 mm, as the sizes of the beamlets images on the mask was expected to be large enough, much larger than this value. Before the mask, which is a collector of the full beam current, a grid is installed to which a voltage of up to -300 V could be applied to suppress secondary electrons. A quartz screen was chosen as a scintillation screen due to its availability and stability of the luminescence parameters in the expected range of beam intensities. CCD-camera type "VIDEOSCAN-415-USB" with matrix SONY ICX415AL 12-bit monochrome, pixel size – 8.3×8.3 μm×μm, image format 780×582, shutter speed – adjustable from 3.5 μs to ~10 min was used. Scheme of this emittance measuring device is shown in Fig. 1

Camera calibration in visible light is performed before emittance measurement. Then the calibration coefficient K_c has been determined. This coefficient K_c is the ratio of distance between the centers of two neighbour holes of "pepper-pot" (which is equal to 3 mm for our “pepper-pot”) to the number of pixels separating these images on the camera. K_c~0.2 mm/pix have been obtained as a result of calibration. Linear distortions due to the displacement of the CCD-camera relative to the beam axis should be taken into account in data processing.

ACQUIRING DATA FOR PROCESSING

To obtain an array of data suitable for further processing in order to obtain phase portraits on the XX’ and YY’ planes it is necessary to separate the signal, received on the matrix pixels by the beam illumination, from the total illumination. Two methods were applied to distinguish the useful signal.

The first method for selection of useful signals is geometric one. To do this, the camera was shifted from the beam axis by a certain distance, as shown in Fig. 1, which made it possible to obtain a spatial shift between the image of the beam axis on the quartz screen and the direct image of the emission hole.

The second method for selection of useful signals is digital subtraction from the total signal the component of signal from illumination of the matrix by direct radiation of gas discharge and other spurious light without ion beam. For this purpose frame of illumination with the beam was recorded, then the trigger of extractor voltage generator was disabled with gas discharge generator creating plasma in the gas-discharge chamber was enabled, and a frame of background light from the plasma gas discharge was recorded. The software for data processing subtracted second file from the first file and resulted data obtained after subtraction were used for beam phase portrait formation.

To obtain at low (less than 15 keV) ion energy sufficient value of the useful signal for further processing, it was necessary to integrate the signal amplitude over several beam pulses. The CCD-camera allows to change the shutter speed in the range from 3 μs up to ~10 minutes. Frames with exposures from 1 s to 20 s at a beam pulse repetition rate of 5 Hz were used for further processing. The illumination from the beam on the quartz screen was usually placed in the size not more than 55×55 mm^2, so the area of 260×260 pixels was chosen for further processing.

As a result, the signal distribution file from the matrix pixels f(x,y) after subtracting the background values file was obtained, an example of which for the number of beam pulses N=10 and the energy of ions 12 keV is shown in Fig. 2.

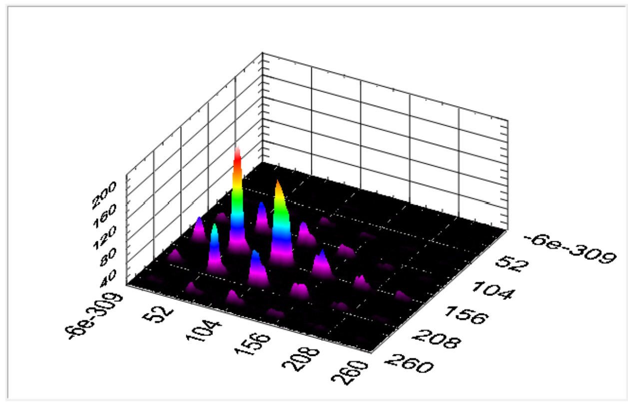

Figure 2: The signals distribution from the pixels of the matrix after the background subtraction.

A grayscale bitmap file from CCD camera was loaded for subsequent processing of the image, but it is possible only if it has 8-bit amplitude resolution (256 channels). So, the exposure was chosen that the maximum values of the signal amplitude from the pixel did not reach 2^8 (=256), while the amplitude of the signals from the pixels outside the beam illuminated zone after subtraction of the background equals 0 or 1.

DATA PROCESSING AND BEAM PHASE PORTRAIT FORMATION

At the output of the extraction gap, the beam in both planes has a large divergence, so in our case, all the images of the beamlets are well localized and do not overlap. This makes it simple to integrate the distribution function on the Y or X direction, as a result 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 result we obtain intensity distributions with clearly separated "spikes", which corresponds to the rows (or columns) of holes of the "pepper-pot" (Fig. 3). Square of the "spikes" is proportional to the fraction of the beam passing through vertical or horizontal rows of "pepper-pot" holes. The

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algorithm of data processing, formation of phase portrait of the beam, determination its RMS emittance and Twiss parameters of the phase ellipse is described in detail earlier [1] taking into account the results of work [2].

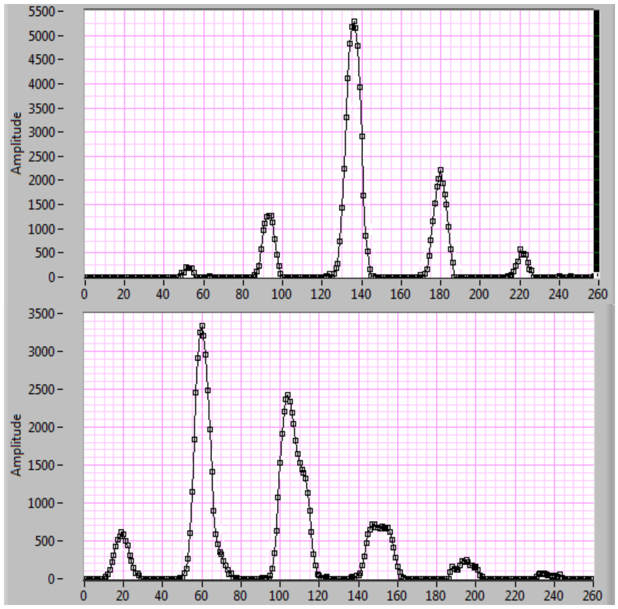

Figure 3: Intensity distribution after integration of the distribution function f(x,y) along X or Y axis.

RESULTS AND DISCUSSION

The emittance measurements were carried out for a beam of H-minus ions from a source with a penning geometry of a discharge chamber with an axisymmetric geometry of the emission hole and extraction gap. The magnetic field is created by permanent Sm-Co magnets with a length of the pole tip along the beam of 12 mm, while the maximum amplitude of the magnetic induction is located in the center of the gas-discharge chamber and has a value of about 100 mT.

The emission hole has a diameter of 2.5 mm, the length of the extraction gap of 1.5 mm, the diameter of the hole in the extraction gap of 3 mm. All measurements were carried out in pure hydrogen discharge mode without applying cesium to the discharge. The glow of the quartz screen, sufficient for reliable selection of a useful signal, took place at decrease in energy of ions to 7 keV, the maximum ion energy in the measurements was 15 keV. The current of the ion beam on the mask of the "pepper-pot" was in these regimes from 4 to 9 mA.

The emittance values in the XX' and YY' planes are very close to each other, as one would expect for an axisymmetric case, in contrast to the case with the slit geometry of emission aperture [3]. However, there is a noticeable effect of the magnetic field on the beam in the YY' plane. The example of the data processing in XX' plane for beam energy 12 keV is shown in Fig. 4.

The parameters of rms emittances are calculated. Non-normalized emittances are equal to 19 mm×mrad for the plane XX' and 29 mm×mrad for the plane YY', beam divergence (full) is ±100 mrad in both planes, the beam dimensions are 15 mm in the X direction and 18 mm in the Y direction (along the magnetic field).

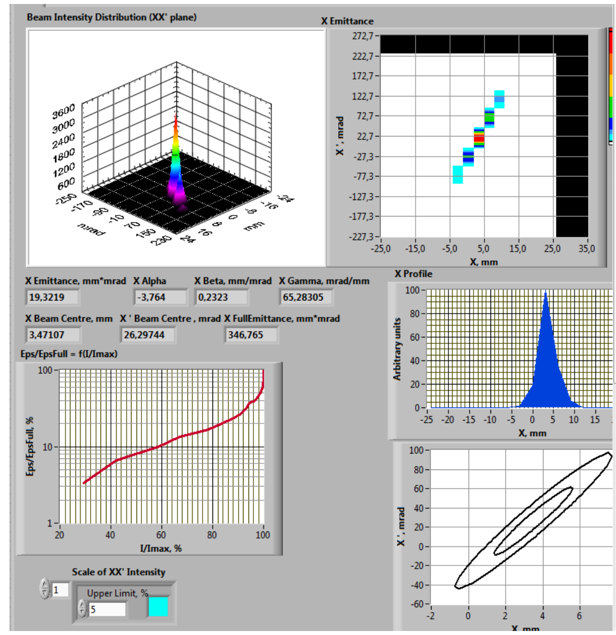

Figure 4: Results of the data processing in XX' plane.

Such a large beam divergence at the output of the extraction gap is in qualitative agreement with the numerical calculations of an axisymmetric ion optical system with similar parameters [4].

CONCLUSION

The emittance measuring device which includes the "pepper-pot" mask, the quartz screen, the CCD camera, to control the transverse emittances at the exit of H-minus ion source for 7…15 keV beam energy was applied. The possibility to measure the emittance of the ion beam at such low ions energy in single shot or small number of pulses of beam current in quasi real time mode was demonstrated. Preliminary results of the emittance for a beam from a source with an axisymmetric extraction system were obtained.

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