NON DESTRUCTIVE DETERMINATION OF BEAM EMITTANCE FOR LOW ENERGY ION BEAMS USING CCD CAMERA MEASUREMENTS

J. Pozimski, O. Meusel, A. Jakob, A. Lakatos, H. Klein, Institut für Angewandte Physik der Johann Wolfgang Goethe-Universität, Robert Mayer Str. 2-4, 60054 Frankfurt, Germany

Abstract

The determination of the beam emittance using conventional destructive methods suffers from two main disadvantages. The interaction between the ion beam and the measurement device produces a high amount of secondary particles. Those particles interact with the beam and can change the transport properties of the accelerator. Particularly in the low energy section of high current accelerators like proposed for IFMIF, heavy ion inertial fusion devices (HIDIF) and spallation sources (ESS, SNS) the power deposited on the emittance measurement device can lead to extensive heat on the detector itself and can destruct or at least dejust the device (slit or grit for example).

CCD camera measurements of the incident light emitted from interaction of beam ions with residual gas are commonly used for determination of the beam emittance. Fast data acquisition and high time resolution are additional features of such a method. Therefore a matrix formalism is used to derive the emittance from the measured profile of the beam [1,2] which does not take space charge effects and emittance growth into account.

A new method to derive the phase space distribution of the beam from a single CCD camera image using statistical numerical methods will be presented together with measurements. The results will be compared with measurements gained from a conventional Allison type (slit-slit) emittance measurement device.

1 THEORY

To derive the emittance of a particle beam from profile measurements at least 6 parameters have to be determined. This can be done by measurements of the beam profile at 3 different z positions along the beam path, or by varying the focusing strength of a lens in front of the profile measurement. Both methods assume an elliptical formed, homogeneous filled phase space distribution and neglecting emittance growth. Both assumptions are critical for high perveance, low energy ion beams. Space charge forces and field errors of the lenses lead to extensive aberrations and emittance growth. A CCD camera for beam profile determination [3,4] can deliver up to several hundred profiles simultaneously over a very short distance of a few centimetres. Due to the short distance space charge and emittance growth effects are minimised. Additionally the high number of profiles and the use of the intensity drastically enhances the available information on the beam. Therefrom it can be assumed that a more detailed determination of the phase space distribution and information on space charge forces can be derived from a single CCD camera image. Therefore a numerical simulation code (CCDEMI) was written. After loading the transversal and longitudinal intensity function from the CCD chip (see fig. 3 & 5) the data has to be prepared for the calculation by removing the underground and noise. The center of gravity (C) of the distribution is then determined by the use of :

$$C(z) = \frac{\sum_{x=1}^{x_{end}} x \cdot I(x)}{\sum_{x=1}^{x_{end}} I(x)} \qquad \forall z \qquad (1)$$

The beam radius X as a function of the fractional intensities (e.g. 1-99 %)is determined by:

$$X(I_{frac.}, z) = f(x(I_{frac.}, z) - c(z)) \quad \forall I_{frac.} \qquad (2)$$

Then the centre of gravity of beam angle is for each beam current fraction determined by an RMS formalism giving the slope of the fractional envelope using all data in the chosen longitudinal interval. Variations on the slope using a subset of the longitudinal interval can be interpreted as the influence of space charge and emittance.

$$\bar{x}'(X, \forall z) = x' + \frac{1}{(n_0 - n_1)} \sum_{Z=n_0}^{n_1} \Delta x'_{sc} + \Delta x'_{\varepsilon} \qquad (3)$$

The constant fraction of the variation is then interpreted as the result of the space charge forces the statistical variations as the angular derivation of particles in the phase space.

2 EXPERIMENTAL SET UP

A compact low energy beam transport (**LEBT**) section was used to compare measurement using a conventional destructive Allison type emittance scanner with the results gained from CCD camera measurements. The experimental set up is shown in figure 1. A volume source was used to deliver 4.4 mA of He^+ at 11 keV. The beam was focused by a solenoid into the diagnostics chamber. To control the degree of compensation a circular electrode at the entrance of the solenoid was used. In the diagnostic chamber a Faraday cup, the Allison type emittance scanner the CCD camera (512 x 512 pixel LN_2 cooled) and an absorber tank for reduction

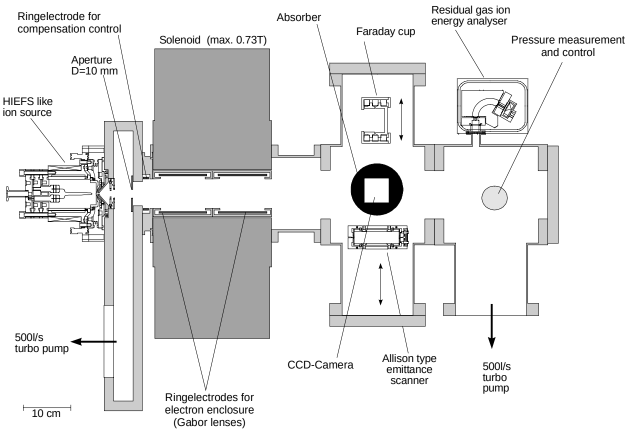

Figure 1: Schematic drawing of the experimental set up.

of reflected light where installed perpendicular to each other at the same longitudinal beam position. Due to the length of the emittance scanner the first slit defining the position of the emittance measurement is 38 mm in front of the common centreline (see fig. 1). App. 200 mm behind the main diagnostics a residual gas ion energy analyser [5] was installed to determine the degree of compensation. Additionally a residual gas pressure measurement and control device was installed. The solenoid (0.002 T/A; 360 A max.) was able to transport 3.7 mA of He^+ at 11 keV (85 % transmission) at 235 A.

3 EXPERIMENTAL RESULTS

Figure 2 shows the result of an emittance measurement using the Allison type measurement device. The solenoidal field was 0.44 T (220 A), the beam current into the Faraday cup 3.4 mA. The potential depression inside the beam was determined to be 9.9 V or ~80 % compensation degree. The beam is convergent and the envelope radius is app. 6.5 mm, the convergence angle +-30 mrad and the normalised beam emittance (rms, 100%) is 0.011 πmmmrad.

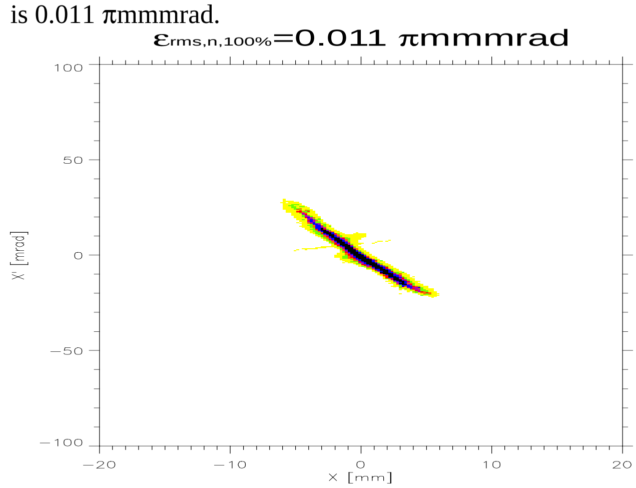

Figure 2: Beam emittance measured by the use of an Allison type measurement device (see text for more information).

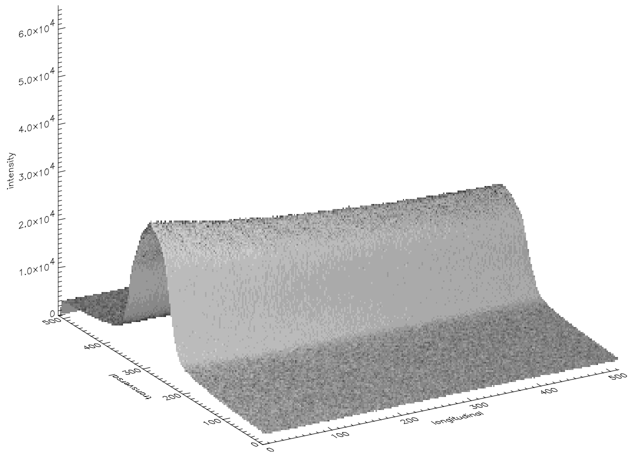

Figure 3: Intensity of incident light detected by a CCD camera as a function of transversal and longitudinal position (see text).

The corresponding CCD camera measurement is shown in figure 3 (1 Pixel=0.081 mm). The beam was drifting from left to right, therefore the higher intensity on the right side already indicates a convergent beam. The signal to noise ratio is app. 8. For comparison figure 4 shows the result of an emittance determination by calculation using the data of the CCD measurement (fig. 3). The envelope radius is app. 7 mm the convergence angle +-35 mrad, the normalised beam emittance (rms, 100%) is 0.020 πmmmrad. The compensation degree can be estimated from the calculations to be 80 %.

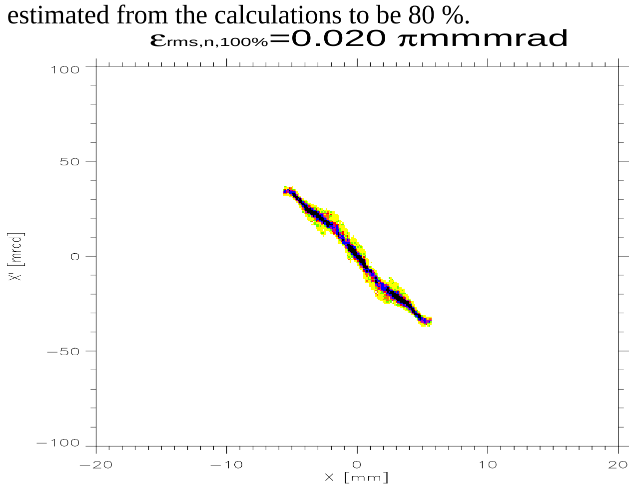

Figure 4: Emittance determined by calculation using an CCD camera measurement.

The result of an other conventional emittance measurement using a solenoidal field of 0.47 T (235 A) is shown in figure 5. The beam current into the Faraday cup was 3.7 mA. The potential depression inside the beam was 16.7 V and therefrom a compensation degree of ~70 % can be estimated. The focus of the convergent beam is just behind the point of measurements. The envelope radius is app. 2.5 mm the convergence angle +- 35 mrad

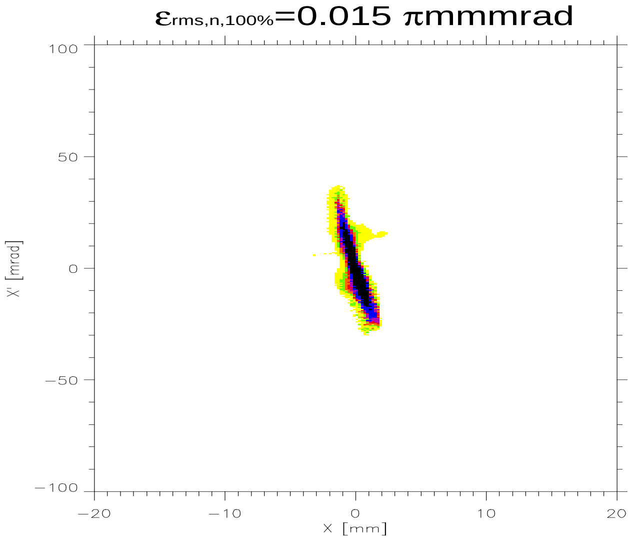

Figure 5 : Beam emittance measured by the use of an Allison type measurement device (see text for more information).

and the normalised beam emittance (rms, 100%) is 0.015 πmmmrad. The corresponding CCD camera measurement is shown in figure 6. The signal to noise ratio is app. 20. In Figure 7 the result of an emittance determination by calculation using the data gained from the CCD measurement (fig. 6) is shown. The envelope radius is app. 3 mm the convergence angle +- 55 mrad the normalised beam emittance (rms, 100%) is 0.014 πmmmrad. From the gained data an compensation degree of app. 75 % can be derived.

4 DISCUSSION

Comparison of emittances gained from conventional destructive measurements and from CCD camera measurements show an overall good agreement concerning the orientation of the emittance in phase space. The values given by the calculation have slightly higher beam radius and angle (10-20 % deviation).

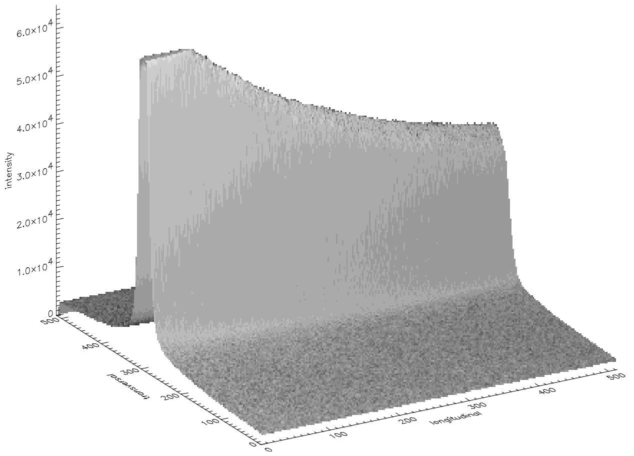

Figure 6 : Intensity of incident light detected by a CCD camera as a function of transversal and longitudinal position (see text).

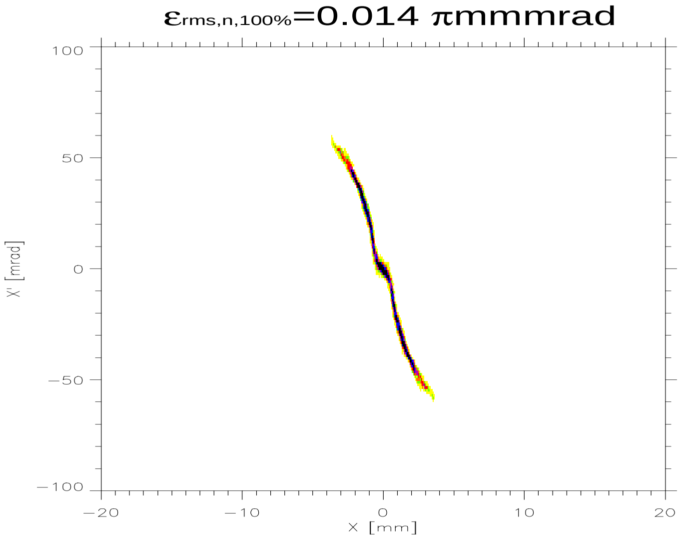

Figure 7 : Emittance determined by calculation using an CCD camera measurement.

This might be caused by the higher resolution of the CCD chip compared with the conventional detector. Therefrom it was estimated that the RMS values are greater too. This is not generally the case and might be caused by the lower thickness of the pattern. The values concerning the compensation degree are in good agreement with the measurements too. The lower values might be explained by improper separation of space charge and emittance effects and are also explaining the smaller pattern.

5 CONCLUSION

The shown encouraging results proof that the use of a CCD camera for the determination of beam emittance is an alternative to conventional devices at high beam power. Mathematical methods can derive most of the relevant parameters needed for beam transport using a single CCD camera image. Improvements of the used computer codes and the use of tomographic methods are planned for the future.

REFERENCES

[1] K. Ebihara et al, Nucl. Instr. And Meth. 202, 403-409 (1982)

[2] P. Strehl, Beam diagnostics, Proc. Of CAS, CERN accelerator school, CERN 87-10 (1987)

[3] F. Sittinger, “Untersuchungen zu optischen Profil- und Emittanzmessungen an niederenergetischen intensiven Ionenstrahlen, Dissertation IAP, University of Frankfurt, Germany (1995)

[4] L. Wicke, “Untersuchungen zu Strahlprofilmessungen intensiver Ionenstrahlen mit optischen Methoden” Diploma Thesis IAP, University of Frankfurt, Germany (1998)

[5] R. Dölling, “Raumladungskompensation driftender intensiver Strahlen niederenergetischer Ionen und Techniken zu ihrer Vermessung” Dissertation IAP, University of Frankfurt, Germany (1994)