DEVELOPMENT OF A PEPPER POT EMITTANCE MEASUREMENT DEVICE FOR FRANZ*

B. Klump#, U. Ratzinger, W. Schweizer and K. Volk,
Institute of Applied Physics, Goethe-University Frankfurt,
60438 Frankfurt am Main, Germany

Abstract

Within the FRANZ project on the Institute of Applied Physics, University Frankfurt, a robust and simple pepper pot emittance measurement device for high beam power densities is developed. To use the device directly behind the ion source, a high robustness against HV breakdowns is necessary. This paper gives an overview on experimental setup, on the analysis method and on imaging properties of the screen. Furthermore, the implemented software-based evaluation method is shown. It concludes with a preliminary emittance measurement on the high current ion source for FRANZ.

INTRODUCTION

For emittance measurements directly behind an ion source a measuring system is required that is insensitive against high voltage breakdowns. Therefore, a robust, high voltage insensitive and simple measuring device for high beam power densities has been developed within the FRANZ project (Frankfurt-Neutron-Source at the Stern-Gerlach-Center) [1]. The basis is the pepper pot measurement method.

EXPERIMENTAL SETUP

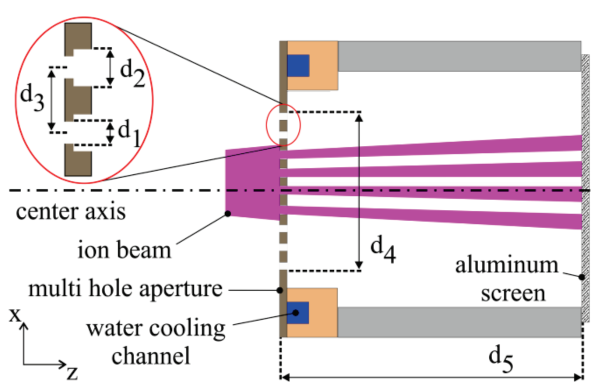

Figure 1: Collector setup.

Fig. 1 shows the schematic setup of the pepper pot emittance measurement system. The ion beam penetrates from the left side through a multi hole aperture plate with more than 700 holes with a diameter of $d_1 = 0.3$ mm, which are arranged grid-like inside a diameter of $d_4 = 60$ mm. The plate is made of wolfram-copper and is water cooled. Partial beams hit after $d_5 = 70.5$ mm a pretreated aluminum screen. The maximum measurable divergence angle is limited to 200 mrad by the contour of the boreholes. The center distance between holes on the

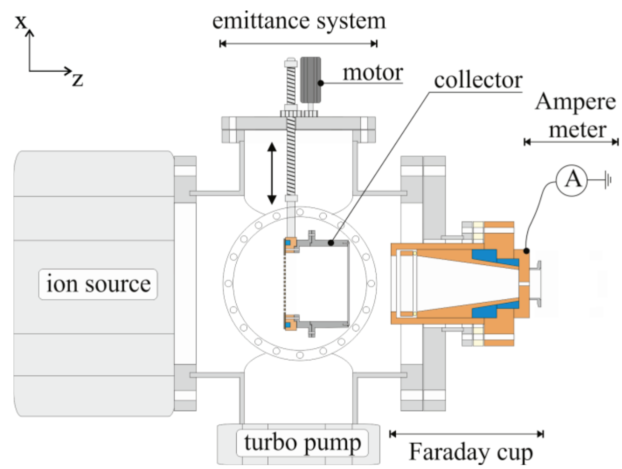

Figure 2: Experimental setup [2].

multi hole aperture d_3 is 2 mm, which ensures no overlap of the partial beams. To investigate this concept, a prototype was build and installed in a diagnostic chamber, which also contains a Faraday cup, the vacuum system and a view window. The system can be moved into the beam by a motor drive. For the investigations, the ion beam of the FRANZ ion source was used. The ion source was mounted directly on the diagnostic chamber (Fig. 2). The FRANZ ion source is a filament driven high current arc discharge volume source [2].

Beam currents and beam energies are variable in the range of 30 mA to 200 mA protons and 20 keV to 60 keV beam energy. To reduce the mean beam power on the multi hole aperture, the source discharge was pulsed with 80 Hz and 1 ms pulse length. Due to the hole diameter a spatial resolution of 0.3 mm results. The angle resolution is 0.6 mrad because of the digitalization (see below).

MEASUREMENT METHOD

Pepper Pot Principle

The ion beam is split into several partial beams due to the multi hole aperture. Those hit the pretreated surface of

*Work supported by HGS-HIRE
#klump@physik.uni-frankfurt.de

ISBN 978-3-95450-142-7

the aluminum screen. Due to the power deposition carbon footprints are generated. The phase space distribution and the 4D-emittance can be calculated from the analysis of

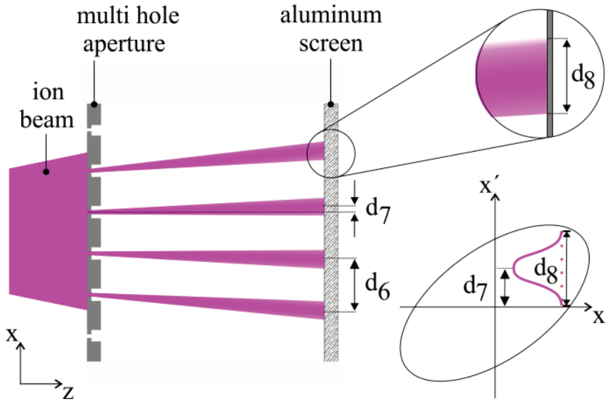

Figure 3: Pepper pot measurement principle.

the center of mass position of the intensity distribution d_7, the expansion d_8 and the intensity distribution itself (Fig. 3). Furthermore, all information is available after one exposure. Demounting of the irradiated screen and the analyzing of the screen pattern takes about 1 hour.

Numerical Analytic

Using Matlab [3], an analysis software to calculate the phase space distribution in the two dimensional subspace and the corresponding emittances from the carbon footprints was developed. For the digitalization process of the screen pattern a 600x600 dpi scanner is used. Thereby follows a digital resolution of 0.042 mm / pixel resp. 0.6 mrad / pixel with a color depth of 8 bit. To increase the signal-to-noise ratio the Canny algorithm [4] was used for the edge detection. Therefore the footprints were separated from the background and the background value was set to zero.

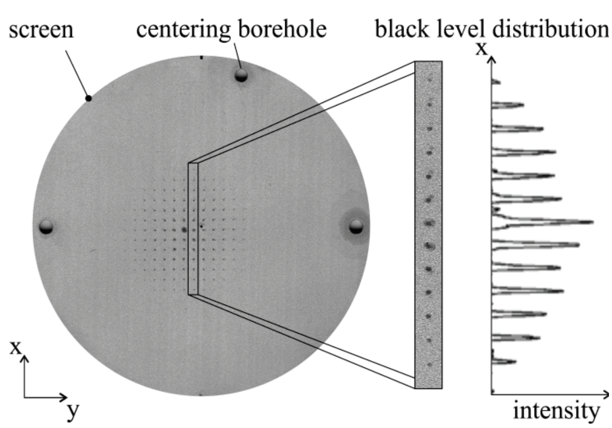

Figure 4: Aluminum screen with carbon footprints.

In order to calculate the two dimensional phase space projection, the black level values of each phase space cell are added along one direction. Position and value of the peak-maxima of the resulting black level distribution (Fig. 4) are compared with the position of the corresponding hole position on the multi hole aperture and serve as a basis for the calculation of the phase space position. The intensities are transferred into the corresponding phase space cells. The phase space cell width is limited by the spatial resolution. This depends on the borehole diameter (0.3 mm in our case). The cell height is limited by the digitalization resolution and amounts to 0.6 mrad. Thus, the cell area is 0.18 mm mrad. Due to the center distance between holes d_3 of 2 mm, the phase space is measured partially and the phase space is not complete covered (Fig. 8).

RESULTS

Black Level Calibration

In order to calculate the emittance on the basis of the carbon footprints, it is necessary to prove that the black level distribution is correlated to the beam current density distribution. Due to the small dimension of one footprint it was not possible to measure the current density distribution inside one footprint electrically. Hence the currents of 15 boreholes in one direction on the multi hole aperture were measured using 15 individual Faraday cups directly behind the multi hole aperture. The current through each borehole was compared with the maximum black level value of the corresponding footprint. Fig. 5 shows the black level distribution depending on the location and the corresponding beam current density. Both distributions show a good agreement, which demonstrates that the emittance calculation based on the black level distribution of the carbon footprint is feasible.

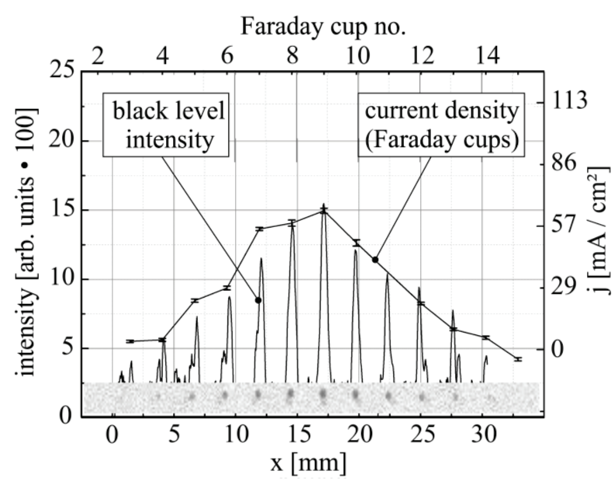

Figure 5: Footprints and current density distribution comparison.

Further investigations have shown, that a longer exposure time can compensate a minor black level to rise the signal-to-noise ratio and to ensure comparability between different measurements.

Emittance Measurements

The FRANZ ion source was used to generate the ion beam during the first test measurements of the pepper pot emittance device. The dynamics of the extraction system has an essential meaning for the FRANZ-LEBT due to the ion source emittance has been matched in the acceptance of the LEBT. For this reason the dependence of the emittance from the normalized beam current resp. from the plasma density at 52 keV beam energy was investigated. The normalized current I_{norm} describes the

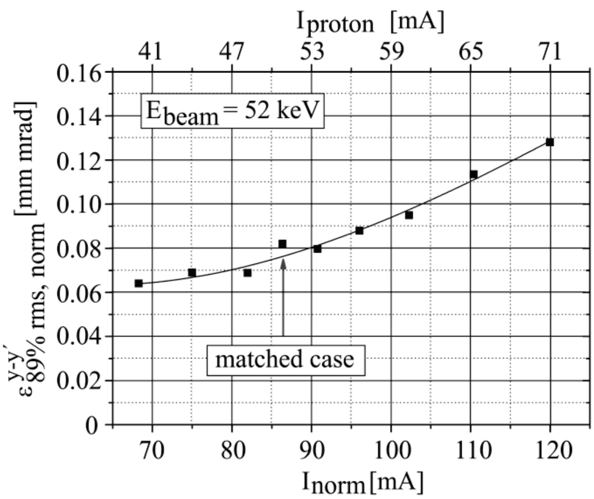

Figure 6: Measured 89% rms emittance depending on normilized beam current.

space charge equivalent proton current. Fig. 6 shows that the emittance rises with increasing beam current. The deflection of the beam is changed by 160 mrad in y`-direction at the investigated range. This influences the beam forming process in the extraction system causes an emittance growth against the theoretical prediction through the simulation code IGUN [5].

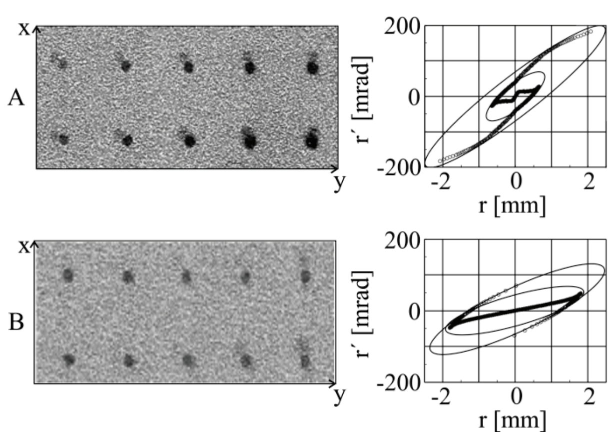

Figure 7: Footprints and IGUN phase space distribution for low plasma density (I_{norm}=68 mA, above) and high plasma density (I_{norm}=120 mA, below).

From these measurements it became evident, that at lower plasma density two footprints per pepper pot hole are generated (Fig. 7, top), while at high plasma densities the footprints merge into one spot (Fig. 7, below). This corresponds to the beam simulations, shown in Fig. 7, right side: For the low intensity case, two angle distibutions per one borehole at a given radius are transported to the screen, causing two separated spots. The comparison of the calculated beam parameters (divergence angle and radius) with the measured ones confirms the above mentioned thesis of two partial beams. Further, the divergent partial beam merges with the core beam by increasing plasma density. For this reason, the operation of the ion source with a slightly higher plasma density as the plasma density in the matched case, is recommended. Finally, Fig. 8 shows the result of one of the first emittance measurements at 52 keV beam energy with 86 mA normalized beam current. The 89 % normalized rms emittance is 0.08 mm mrad, correlated to the normalized 89 % effective emittance, which is shown as an ellipse and amounts to 0.54 mm mrad.

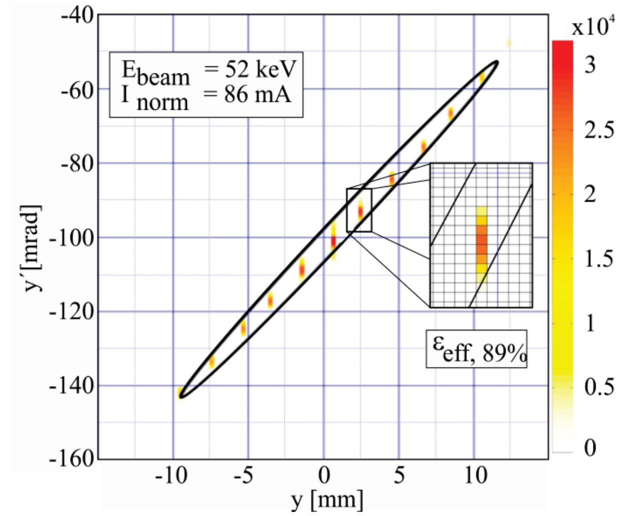

Figure 8: 89% y-y´ rms emittance (52 keV@I_{norm}=86 mA).

CONCLUSION

The presented pepper pot measurement system is in this critical area (high voltage, high current) a promising emittance measurement device. Further measurements in the context of FRANZ are in preparation.

REFERENCES

[1] U. Ratzinger et al., “Intense Pulsed Neutron SourceFRANZ in the 1-500 keV Range”, Proc. ICANS-XVIII, Dongguan, p.210 (2007).

[2] W. Schweizer, U. Ratzinger, B. Klump, and K. Volk, “A High Intensity 200 mA Proton Source for the FRANZ-Project (Frankfurt-Neutron-Source at the Stern-Gerlach-Center)”, Rev. Sci. Instrum. Vol. 85 No. 2, p. 02A743-1 (2014).

[3] MATLAB and Image Processing Toolbox Release 2013a, The MathWorks, Inc., United States.

[4] John Canny, “A Computational Approach to Edge Detection”, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. PAMI-8, No. 6, pp. 679 (1986).

[5] R. Becker and W. Herrmannsfeldt, Rev. Sci. Instrum. Vol. 63, 2756 (1992).

ISBN 978-3-95450-142-7