PEPPER-POT EMITTANCE MEASUREMENTS

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Abstract

The pepper-pot emittance measuring device was developed to determine the parameters of the ion source beam. It includes a "pepper-pot" mask, a scintillation screen, a charge-coupled device (CCD) recorder, a personal computer (PC), software for data processing, calculation of beam profile and emittance. Measurements of emittance by pepper-pot method have been successfully carried out on several ion sources, at ITEP and JINR. The pepper-pot measurement method, the emittance meter design, and the emittance calculation technics are presented.

PRINCIPLES OF PEPPER-POT MEASUREMENTS

The measurement of emittance by the pepper-pot method consists of processing an image from a scintillator excited by an investigated beam passing through a mask with a rectangular grid of holes [1].

The copper mask takes the investigated beam, and round holes in the mask break the beam into several beamlets, which hit the scintillator and cause a flash of light from it. The scintillation pattern consists of a rectangular set of spots. This pattern is recorded and stored by the recorder and then processed by the software package for emittance calculation.

The process of emittance calculation from the registered image of the scintillator consists in plotting the beam image on the phase spaces x-x' and y-y' and then calculating the area occupied by the beam in these phase spaces. Images of the investigated beam in the phase spaces x-x' and y-y' are constructed by folding the graphs of the total radiation intensity for each column or row of spots and, respectively, for each column or row of holes in the mask. From the beam images on the phase planes, the areas occupied by the beam in the phase space, i.e. emittances are calculated. The most common method for calculating emittance is the statistical method. This method consists in constructing an envelope of the ellipse of the beam image on the phase planes, and calculating the characteristics of this ellipse, namely the area (this is emittance) and the ratio of the lengths of the ellipse's axes and the angle of their inclination with respect to the coordinate axes (these are TWISS parameters) [2].

The process of constructing a beam profile from an image of scintillation radiation consists in summing the radiation intensity for each spot in the image and, respectively, for each hole in the mask.

EMITTANCE METER

The emittance meter was used for several emittance measurements, in particular in [3] and [4]. It is a pepper-pot meter device. Its main parts are a copper mask with a pattern of holes, and a scintillator behind it (Fig.1).

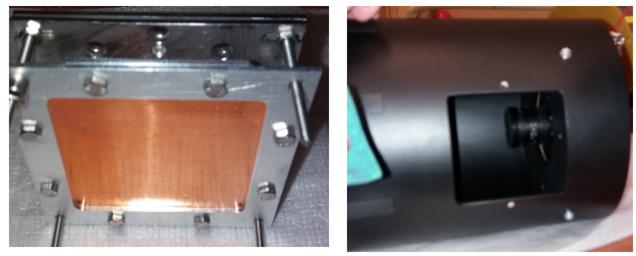

Figure 1: Emittance meter equipment.

The copper mask has a thickness of 100 µm. It contains a rectangular pattern of 20x20 holes with an average diameter of about 0.19 mm and a distance between the holes of 2.5 mm along the horizontal and vertical axes. It is mounted in a mandrel with external dimensions of 80x80 mm and with an internal window size for the passing a beam through an array of holes in a mask equal to 56x56 mm.

In this emittance meter equipment, several types of scintillators can be used. The first type is the standard P43 (Gd_2O_2S:Tb) round (52 mm diameter) scintillator from ProxyVision manufacture. Since scintillators are consumables that need to be replaced after each measurement, we need a relatively cheap scintillator. The second is a homemade $Y_2O_3:Eu$ [5] scintillator, which manufactured in ITEP on 56 mm round glass, and more frequently is used in measurements. The scintillator is mounted in a mandrel with external dimensions of 80x80 mm and an inner window with a diameter of 48 mm, which is mounted together with the mask holder. The distance between the mask and the scintillator is adjustable from 8 to 45 mm.

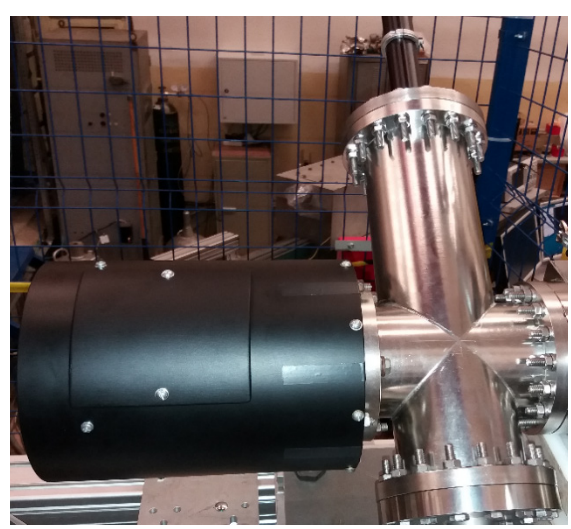

Figure 2: Emittance meter.

ISBN 978-3-95450-197-7

Both the mask and the scintillator are mounted together within a vacuum chamber (Fig.2) on a rod of linear vacuum feedthrough. The light emission emitted by the scintillator is recorded by the SDU-415 digital video camera through the output glass window of the vacuum chamber. The CCD-based digital video camera detector (VCD) is mounted on the beam axis outside the vacuum chamber inside the enclosures, which protects from external illumination (Fig. 1 and Fig. 2). The CCD sensor is the SONY ICX415AL, the frame size is 768x576 pixels, the pixel size is 8.3x 8.3 µm, and the output ADC resolution is 12 bits. The VCD camera records the scintillator image on the arrival of the synchronization pulse from the external timer system and transfers the recorded images to a personal computer (PC) via a serial interface in manual or automatic mode. The VCD camera is equipped with a Vega-7 lens with a constant focal length of 20 mm, aperture from f /2.0 to f /16, MDF 0.4 m, the distance from the CCD matrix to the edge of the lens is 16 mm. The distance from the CCD detector inside the chamber to the scintillator was chosen so that the frame size was about 55 mm on the short side, and it was 310 mm.

MEASUREMENT SEQUENCE

Before the beginning of a series of measurements of the beam being studied, it is necessary to carry out preliminary calibrations such as:

- The size and location of all the holes on the mask.
- CCD matrix distortion calibration – background image pattern and each pixel amplification calibration.
- Calibration of camcorder lens distortions.
- Calculation of the calibration curve to compensate for non-zero hole size.

The input images for emittance calculation are the following:

- The image of the scintillator mandrel, for the calibration of the scale and the angle of rotation of the images by means of calibration marks on the scintillator mandrel.
- Set of dark frames for background level calibration - a series of measurements of a dark image is mandatory, because the background image from the CCD array is not flat, but has some pattern.
- Images of the scintillator excited by the beam, at least one, better than a few dozen for each beam mode.

Since the distance from the VCD camera to the scintillator is fixed, we can make all the calibration measurements earlier, but it is additionally desirable to do this immediately before the current series of measurements on the beam. Note that the precise focusing of the lens before the measurements on the investigating beam is very necessary for correct calculations of the emittance. After receiving the first working images and before starting a series of measurements, it is necessary to examine the first images. The first goal is to adjust the intensity of the image by adjusting the exposure time and the gain value of the VCD camera. The second is to study the size of the spots. Admissible are the sizes of spots from 2 to 6 times the size of the holes on the mask. In another case, it is required to change the distance between the mask and the scintillator.

EMITTANCE CALCULATION SEQUENCE AND RESULTS

Data is processed by a set of Matlab scripts. Sequence of operations is semi-automatic, with little operator intervention. The emittance calculation consists of a set of steps with intermediate results after each and with short configuration procedures during the first stage of tuning, usually necessary for each measurement mode. After the configuration is completed, the recalculations for the current measurement mode are fully automatic. Simplified emittance calculation sequence is:

- The location of the holes in the mask on the image, and the construction of a grid of holes on top of the working images, by processing the calibration images (Fig. 3).
- Determining the background image pattern by averaging a set of background images.
- Cutting out the mask area from the full picture.
- Cutting out the region with a beam from the mask area; building a grid of spots.
- Determination of the location and size of each beam spot, approximating them by Gaussian with background pattern calibration; checking fitting correctness; correcting this with the help of preliminary calibrations for the size and location of the holes, nonzero hole size correction (Fig. 4), and several others corrections.
- The building of a beam images on phase spaces by folding the intensity distribution of the beam along the axis of angles for all columns and rows of spots.
- Calculation of statistical emittances, usually 4π rms, and TWISS parameters; drawing of envelopes of ellipses on images of a beam on phase planes.
- Building and drawing of beam profiles; calculating beam's size and position.

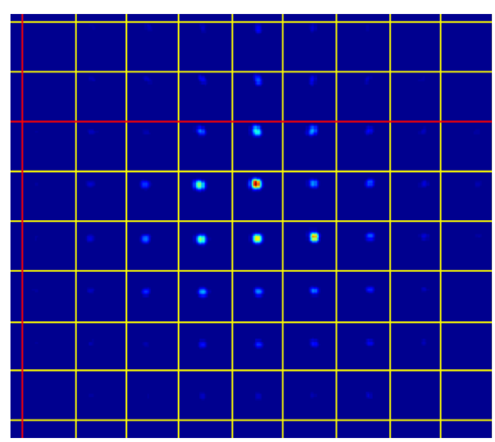

Figure 3: Spot grid above spots images.

ISBN 978-3-95450-197-7

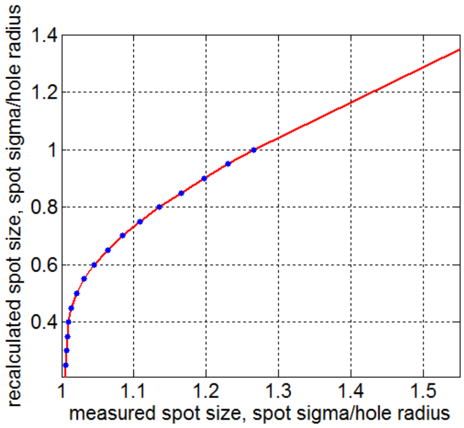

Figure 4: Unzero hole size calibration.

CONCLUSION. PEPPER-POT METHOD PROS AND CONS

Finally, we will make a few remarks on the advantages and disadvantages of the pepper-pot method as compared to the more general methods for measuring emittance, such as slit-grid.

First, the essential advantage of the pepper pot method is its simplicity. Easy to set of the necessary equipment - the right mask with holes is the most critical, but it can be made simple and cheap; scintillator and VCD camera are standard production equipment. Moreover, simple for measurements - in the minimum case, only one photographic measurement is required for this.

Secondly, this is a fast and descriptive measurement method. The first measurement results can be seen very quickly, using single-shot measurements, for example, the beam profile is visible directly from the raw scintillator image. In addition, beam emittance, and TWISS parameters can be pre-estimated in the intermediate picture of scintillation images with a grid of holes on mask (Fig. 3). This basic raw data estimation is important to verify the results accuracy.

The pepper-pot method makes it possible to carry out additional studies of the parameters of the beams, which are not acceptable for the conventional slit-grid method. The single-shot measurement possibilities makes it possible to calculate both single-pulse and multi-pulse emittances, which makes it possible to determine the influence of beam instability from pulse to pulse on the emittance value. Another additional possibility is an opportunity to evaluate the effect of nonoptimality of the beam transport optic on increasing the emittance value. This is possible by mathematically correcting these distortions in the emittance calculation procedure.

The first disadvantage of the pepper-pot method is the relatively low resolution of the beam images on the x-x' and y-y' phase spaces along the x and y axis, respectively. This resolution is strictly determined by the distance between the holes on the mask, which is 2.5 mm on reviewed emittance meter. This distance is difficult to reduce significantly, since in this case, respectively, the size of the holes in the mask should decrease, which complicates the requirements for production a mask and will lead to a quadratic decrease in the intensity of the radiation intensity for each spot. Another way to improve the resolution is to measure the emittance in several pulses, shifting the mask between the pulses by part of the distance between the holes in both horizontal and vertical directions.

The next drawback, and perhaps the main one, is the following: the correspondence of the pattern of the intensity distribution of the scintillator radiation to the beam distribution along the plane of the scintillator requires additional investigations. In part, this drawback can be reduced by optimally choosing the distance between the mask and the scintillator to optimize the spot size, where this uncertainty should be minimized. Another attempt to compensate for the uncertainty of the spots size is presented in [3].

Another disadvantages and restrictions are mainly related to the presented emittance meter device, and not to the pepper-pot method itself. First, the need to change the distance between the mask and the scintillator in order to optimize the spots sizes requires a repeated vacuum pumping out of the emittance meter, and, sometimes, of the entire beam transport system. This disadvantage is solved by redesigning of the emittance meter, adding the possibility of changing the distance between the mask and the scintillator through a linear vacuum feedthrough.

Then it is very desirable to redesign the emittance meter by adding a beam current meter. Often it is sufficient to use current meters installed at the source or in the beam transport system, but sometimes this is not the case.

In addition, it is desirable to add the ability to supply a high bias voltage to the mask and a scintillator to exclude the effect of secondary electrons from the mask. This disadvantage lead to the addition of a flat pedestal to the registered scintillation pattern and is reviewed as uncritical, since it can be compensated for in the procedure for determining the parameters of the spots. In any case, in order to make the measurement results more clear, it is desirable to remove from them all possible distortions.

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ISBN 978-3-95450-197-7