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THE PEPPER-POT
**PEPPER-POT METHOD**

- Beam segmented by plate with regular array of holes
- Beamlets move in a short drift before hitting the scintillation screen and producing image
- The distance $L$ value is chosen to prevent beamlet overlapping
- CCD camera records images of lightspots

$L$ - Distance between pepper-pot plate and screen

$L \geq \Delta p/2x', \quad \Delta = 100 \, \mu m - screen spot resolution limit$

$p$ – number of holes
PEPPER-POT METHOD
• First standard step – the subtraction of the background (for every position of the mask)

• The problem of readout noise from CCD or pixel illuminated by stray radiation

• The idea is to mask parts of the image which are not related to the beam (removing noise contributions from these regions)

• Masking procedure is controlled by threshold parameter, which determines the size of the mask

• The average pixel intensity of the masked region is subtracted from the whole image to remove remaining offsets and then all masked parts are set to zero

The color map is adjusted to increase the visibility of the noise
The determination of threshold parameter is crucial since the emittance value depends on it.

The fluctuations will be large with a strong dependence on the threshold parameter if the CCD noise dominates or is relatively small and constant in case the beam jitter dominates.

The criterion for the choice of threshold parameter is in selecting the lowest threshold value for which the statistical error is still stable.

Higher values would cut parts of the beamlet spot, thus leading to an underestimation of the measured emittance.
A smoothing process along all pixels in each line of the image should be performed.

Detecting and distinguishing each spot, assuming no overlap (algorithm starts at the position of the center hole).

The vertical and horizontal size of each spot must be determined.

For further processing, two projections (vertical and horizontal) of one spot are needed.

Mathematical expression:

\[ I(x) = \sum_{k=0}^{m} c_k \cdot L_k(x), \quad [x_0, x_n] \]
IMAGE PROCESSING ALGORITHMS

- For further processing two projections (vertical and horizontal) of one spot are needed.
- Approximation of the projected spot curves by Gaussian functions
Each spot will be described by 4 Gaussian functions, maximum intensity $I_0$ and $\Delta x$, $\Delta y$ describe the relation to the corresponding hole position. Then, it will be possible to determine the divergences for different fractions of the maximum intensity. From the formula

$$I(x) = I_0 \cdot \exp\left(-\frac{(x-x_0)^2}{2\sigma^2}\right)$$

The linear deviation is determined by

$$\Delta x = \sigma \cdot \sqrt{2 \cdot \ln \frac{I_0}{I(x)}}.$$
As an example, divergences given by:

\[
XR' = \left( \frac{dx + \Delta xr}{L} \right) \cdot h \\
XL' = \left( \frac{-dx + \Delta xl}{L} \right) \cdot h
\]

With \( dx = x_0 - x_{\text{hole}} \)

\( x_0 \) - position of the maximum intensity in the spot

\( x_{\text{hole}} \) - the coordinate of the corresponding hole

And \( h = \Delta h / N_p \)

\( \Delta h \) - spacing between two holes

\( N_p \) - the number of pixels between two holes
Then

\[ \Delta x \sigma = \sigma \sqrt{2 \ln \left( \frac{IN_m}{PR} \right)} \]

**PR** - fraction, \([0 \leq PR \leq 1]\),  \(IN_m\) - normalized intensity

- 5 matrices should be formed for describing divergence in the directions left, right, up, down and one matrix for total spot intensities.

- To determine 2-dimensional emittance in the horizontal plane the averages for each vertical column must be calculated.

- Determination of Twiss parameters
EMITTANCE

\[ \epsilon_x^2 = \langle x^2 \rangle - \langle x \rangle^2 - \langle x x' \rangle^2 \]

\[ \approx \frac{1}{N^2} \left\{ \left[ \sum_{j=1}^{P} n_j (x_{sj} - \bar{x})^2 \right] \left[ \sum_{j=1}^{P} [n_j \sigma_{x_j'}^2 + n_j (x'_j - \bar{x}')^2] \right] - \left[ \sum_{j=1}^{P} n_j x_{sj} x'_j - N \bar{x} \bar{x}' \right]^2 \right\} . \quad (30) \]

This is the final slit emittance formula. All the terms in the formula are expressed by slit positions and beamlet spots parameters on the screen. Specifically, they are:

- \( x_{sj} \) – j-th slit’s position;
- \( P \) – total number of slits;
- \( n_j \) – number of particles passing through j-th slit and hitting the screen. Practically it is a weighting of spot intensity;
- \( \bar{x} \) – mean position of all beamlets
- \( x'_j \) – mean divergence of j-th beamlet
- \( \bar{x}' \) – mean divergence of all beamlets
- \( \sigma_{x_j}' \) – rms divergence of j-th beamlet

The generalization of the above slit emittance formula to the pepper-pot case is straightforward. Instead of projecting slit image lines to the x axis, we sum up all pepper-pot spot images in y direction for \( \epsilon_x \) and in x direction for \( \epsilon_y \).
OUR PEPPER-POT
Initial data for calculation:
• Particle energy – 5 MeV
• Mask diameter – 5 mm
• Mask thickness – 0.5 mm
• Hole diameter – 20 μm
• Hole spacing – 150 μm
• Distance between pepper-pot plate and screen – L
Thank You
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