

AN EMITTANCE EVALUATION TOOLBOX

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Abstract

A long-time experience in emittance measurements and result evaluation at GSI were transformed into a set of numerical instruments to perform basic and advanced data analysis for data obtained in various emittance measurement systems. The common problems and differences between slit-grid-, pepper-pot- and longitudinal emittance data analysis are discussed. Some aspects of non-linear algorithms particularly for the case of non-zero slit width and pepper-pot holes diameter are presented.

TOOLBOX APPLICATIONS

Historically the emittance evaluation software development has been started as a part of control and evaluation software developed for a new pepper-pot emittance measurement device [1]. The data evaluation software was designed as a standalone application providing a Component Object Model (COM) interface to data mining software. The main requirement at that time was a maximum compatibility with the existing algorithms used for classical slit-grid measurements. With the time and with new emittance control techniques new demands were issued to finally produce an idea of the Toolbox which is both, conservative, to provide trusted results, and flexible, to be adapted to different devices and data structures.

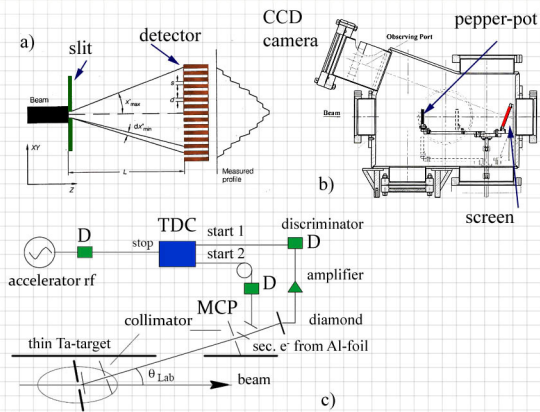


Figure 1: The Toolbox is used for various emittance measurement methods and systems.

Fig. 1 schematically shows three emittance measurement systems for which the Toolbox is used on regular basis: the classical slit-grid device a), a high performance pepper-pot system b) [2] and TOF-based longitudinal emittance measurement system c) [3].

BASIC FUNCTIONALITY

The Toolbox core is a library of MATLAB scripts, which are covering emittance data import, export, evaluation and presentation. Included extensions provide a Microsoft Word interface for report production and interactive tools for batch calculations and interactive digital experiments. In the simplest case the Toolbox provides basic procedures to present most common data related to the accelerated beam. Fig. 2 shows the main page printed by Toolbox using MATLAB Word interface. One can see the phase space, beam profile, statistical data and marginal emittance as a function of threshold level. Very often the original data includes a significant amount of noise or measurement system artefacts. Therefore some basic data reduction procedures are normally executed before the data is finally processed.

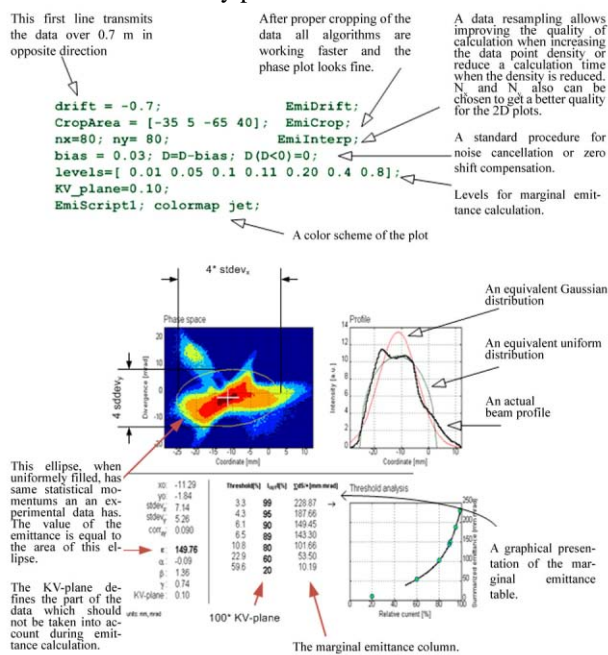


Figure 2: The standard graphical output of evaluated data.

The data pre-evaluation script is also printed within the graphical output, so afterwards one can see the applied procedures.

DATA EDITOR

In addition to the standard region-of-interest (ROI) selection procedure the Toolbox allows another reasonable data modification which could be specific for each particular measurement system. Fig. 3 shows the data consisting of different fractions of particles. A polygonal ROI is used for removing non-interesting

fractions from further analysis. The polygon can be defined by typing the vertices coordinates in the script file or by using a GUI and storing the data in the file for further usage or for batch data processing.

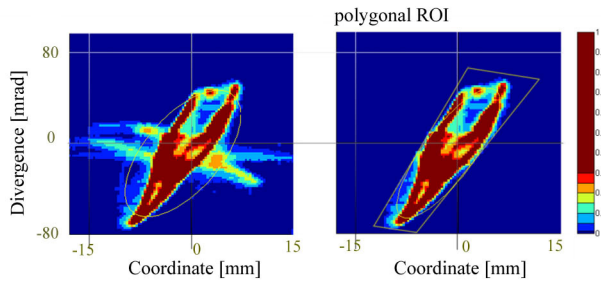


Figure 3: Foreign fractions can be removed by using a polygonal ROI and empiric rules.

To increase a reliability of measurement systems some algorithms were added to allow a proper operation in the case of particular failure of the system. As an example Fig. 4 shows the operation of a classical slit-grid emittance measurement device having a broken current measurement channel.

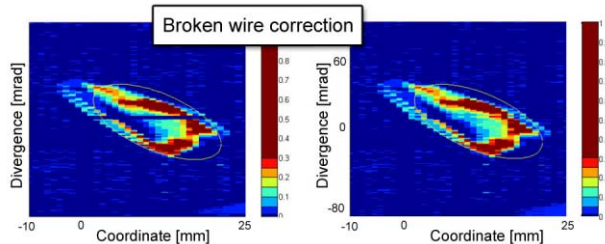


Figure 4: In some cases it is required to perform a data repair as it is shown for the case of the broken wire of the slit-grid device.

DATA INPUT FILTERS

Different applications produce different data structures which are most native for used hardware. Often the data format is chosen to minimize data loss due to pre-evaluation procedures and to keep all features provided by certain measurement system. Slit-grid output is a set of slit and grid coordinates combined with the measured wire current. A file header includes also all required information related to further data evaluation like drift length, grid spacing, slit width etc. Despite the original data X-X' coordinates do not fit in the nodes of rectangular 2D-grid in the phase space, the dedicated input data filter take an advantage of regular wire-grid spacing. A pepper-pot measurement data has sufficient information for four-dimensional emittance analysis. The input filter preserves this data for advanced analysis and for the emittance translation tool. Because of some pepper-pot devices provides a few-step pepper-pot positioning to get a better resolution in spatial and angular dimensions the filter could combine the measured data from several mask positions. Significant improvements of pepper-pot data import algorithms were made to support "cost efficient" systems supplied by budgetary CCD cameras and optics. A certain effort was made to

provide an enhancing quality of the measurements. The Toolbox includes an optic distortion correction option and the CCD matrix sensitivity calibration. The non-ideal pepper-pot mask is taken into account by another kind of calibration. A form-factor table is used then for hole-by-hole intensity correction. A usage of the form-factor correction table requires an identification of holes. This can be done by simple key-hole placing in the exposed region. In a more interesting case one can use a non-rectangular pepper-pot mask. A special pattern recognition algorithm was developed to identify a position of the mask with predefined randomly distributed holes. The question whether the non-regular mask is able to provide a better data pattern for the emittance calculations is still under investigation.

Another data import filter is used for the data provided by the longitudinal emittance measurements system [3]. The original time-of-flight data is a mixture of timestamps from two time-of-flight detectors and thinned down RF reference pulses. A dedicated time-to-digital converter (TDC) provides 25ps resolution and ~ 35 ps rms timing error. The input filter separates the timestamps by detectors and then classifies obtained data by belongs to the certain event. Figure 5 shows an example of a phase space density distribution. In this particular case the region of interest was extended to show an interesting 'longitudinal halo' effect.

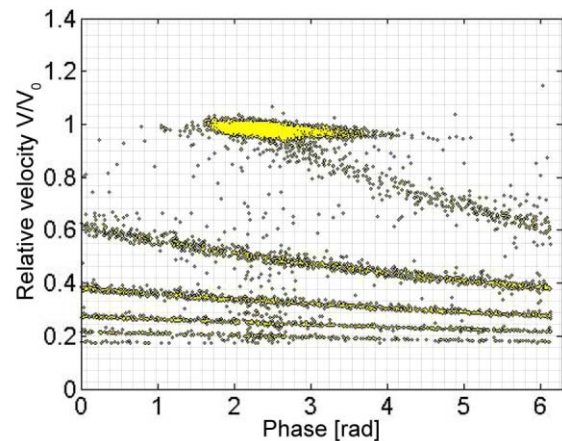


Figure 5: TOF data is used for building a longitudinal phase space distribution. One can see the "halo" consisting up to 20% of the beam current.

There are also several data import filters which were developed to maintain compatibility of the Toolbox with the data obtained with the old "classical" data acquisition software for the slit-grid system.

ADVANCED DATA PROCESSING ALGORITHMS

In addition to the common emittance data algorithms the Toolbox implements some advanced analysis features. The low energy beams on the ion source output often has a complex geometry and therefore the Gaussian or KV-distribution does not describe the beam properly. On the

other hand there is only one number which really matters – the amount of accepted particles. Following this idea the Toolbox allows to compare the measured raw data with a given acceptance. When the acceptance has a certain degrees of freedom due to possible tuning elements the Toolbox looks for the optimal data-acceptance matching as it is shown in Fig. 6. Depending on data smoothness a gradient- or random walk method can be used for optimum finding. The simplest case assumes the goal function of optimization as an integral current inside of the acceptance ellipse. The Toolbox provides as well a stochastic and their deterministic substitute problems [4] reflecting the uncertainties related to projection of the 4-dimensional distribution into the horizontal or vertical plane.

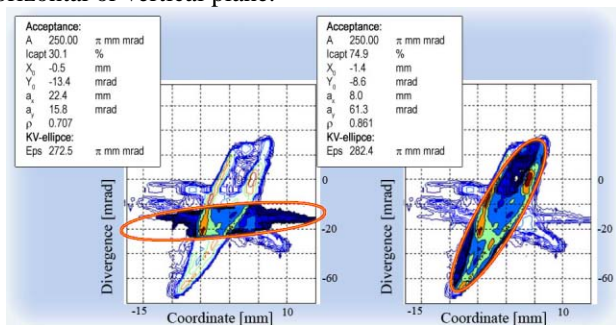


Figure 6: Finding the matching position of acceptance using two (left) and four (right) parameters for optimization.

ERROR ESTIMATION AND CORRECTION ALGORITHMS

There is another important part of the Toolbox related to the estimation of the efficiency of the emittance measurements. The error handling section is a developing part of the system. The present analysis is based on statistical methods using an estimator distribution function and numerical models for measurements processing.

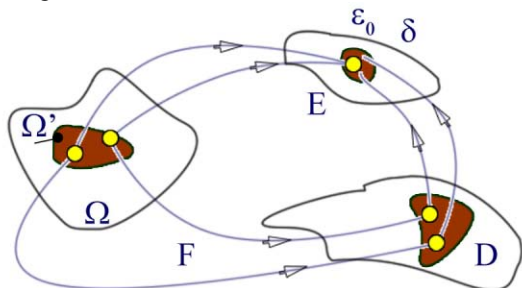


Figure 7: Emittance error estimation by stochastic simulation.

Assume that Ω is a class of functions which describe a density distribution in the phase space. The Ω' is a subset which is mapped to a sole point ϵ_0 . The emittance measurement process is described by operator F which reflect Ω' into the measured data field D . It is important that operator F allows to simulate such elements like non-

zero width slit or pepper-pot holes. A chosen data evaluation algorithm produces a result in the near of ϵ_0 in the region of δ which is the final subject of interest. In the deterministic case the Ω is a parameterized function like normal or uniform distribution and the Ω' is realized by its parameters modification. In the most comprehensive case the analysis is taking into account a stochastic element $\epsilon(x)$ describing real beam fluctuation, system noise or uncertainties in distribution definition like in the formula:

$$G' = A_o e^{-|\bar{x}|^2} + \epsilon(\bar{x});$$

$$\bar{x} = \sum_i a_i (x_i - x_{oi}) \bar{n}_i; \|\bar{x}\|^2 = |M \bar{x}|^2;$$

OUTPUT DATA FORMATS

The toolbox is a complete and independent instrument for emittance data evaluation. Nevertheless the data exchange possibility is required especially in the case of comparison of the measurements with simulated beam dynamics or using the measured data for more realistic simulations. For those purposes one can store the output as a matrix data set in ASCII or binary format. The macro-particles set with proper phase space density distribution is also possible. In the case of pepper-pot the resulting data could be presented in 4-dimensional space.

GRAPHICS AND PRESENTATION

The standard output of the Toolbox is shown in Fig. 2. The Toolbox includes a set of graphical elements and templates which could be used for building complex and comprehensive presentations with application dependent highlighted features.

CONCLUSION

The Toolbox is a permanently developed utility collection for basic, advanced and device specific emittance evaluation. It combines high flexibility and computational power available for numerous non-standard ideas with clear and user friendly interface. A custom measurement evaluation and matching the toolbox to a certain application require expert skills.

REFERENCES

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