CONTROL AND DATA ANALYSIS FOR EMITTANCE MEASURING DEVICES

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Abstract

Due to the wide range of heavy ion beam intensities and energies in the GSI linac and the associated transfer channel to the synchrotron, several different types of emittance measurement systems have been established. Many common devices such as slit/grid or dipole-sweep systems are integrated into the GSI control system. Other systems like the single shot pepper pot method using CCD-cameras or stand-alone slit/grid set-ups are connected to personal computers. An overview is given about the various systems and their software integration. Main interest is directed on the software development for emittance front-end control and data analysis such as evaluation algorithms or graphical presentation of the results. In addition, special features for improved usability of the software such as data export, project databases and automatic report generation will be presented. An outlook on a unified evaluation procedure for all different types of emittance measurement is given.

1. INTRODUCTION

The GSI linear accelerator provides ion acceleration of all chemical elements from p up to U and allows various energies in a range from 120 keV/u to 15 MeV/u[1]. Therefore in ion source development, ion type changing activities, regular beam optimisation and for commissioning purposes emittance measurement is required. Since the foundation of the GSI facility in 1970 a lot of different types of emittance measurement devices have been installed. Slit/grid systems, dipole-sweep systems but also slit/sandwich systems, a special type of detector using 32 isolated layers with a thickness of 0.15 mm are operated with the GSI control system. However, different types of control software are used within the control system leading to manifold data outputs and evaluation processes. Newer emittance measurement systems like the pepper pot [2,3] or the stand-alone slit/grid device are operated with personal computers and are based on various types of Windows and DOS control and evaluation software. All types of the emittance soft- and hardware components are working properly but reorganisation to a unitary graphical user interface (GUI) and evaluation procedure is mandatory due to improved usability and comparability of the results.

2. STRUCTURE OF THE SOFTWARE

The new designed control and evaluation software, first used for pepper pot emittance measurement, is a bundle of subprograms, which are combined together using unified data structures and Windows Component Object Model (COM) technology. Due to this not only pepper pot emittance measurement devices but also other types could

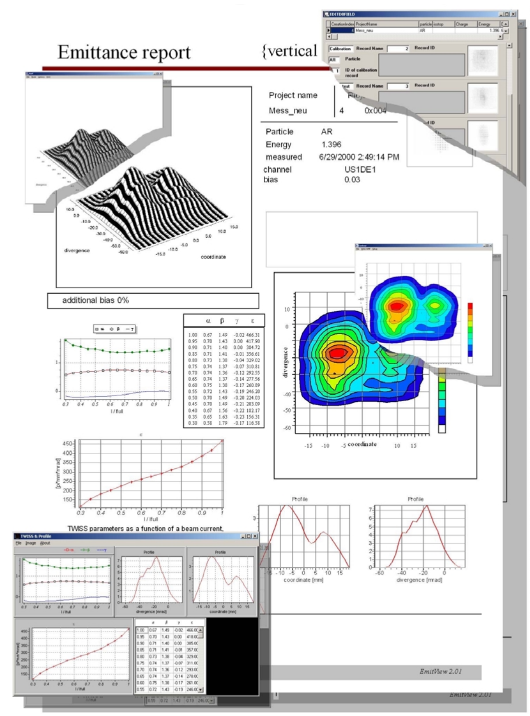

Fig.1. All ‘independent’ software parts are merged into the hardcopy report generation.

be connected without code recompilation. To provide flexibility in data computation few output data formats are realized. Independent data analysis algorithms may be used if they are available as special dynamic libraries.

The software consists of data acquisition, evaluation and visualization tools.

An extensive description of the software on the basis of the pepper pot method is given in [2]. The possibilities of the visualisation part of the software are shown in fig.1. The calculated emittance data is illustrated with various visualisation tools such as contour plot and three-

[1] ITEP-Moscow, work done at GSI.

dimensional surfaces. These tools are implemented as autonomous subprograms and may be run independently. The data like images, tables and graphs produced by these tools are merged into the final printable report.

3. SPECIAL ALGORITHMS

The software includes a set of algorithms. Most of the mathematical routines as grid placement algorithm, data re-sampling, coordinate system recalculating etc. has been evaluated and tested in MATLAB environment before they were implemented in C++ code. Some of them, like grid placement, are used specifically for the pepper pot system, others (noise cancellation, data re-sampling) are necessary to solve common problems. For instance two procedures are briefly described below.

One plane data analysis.

RMS parameter calculation. The root-mean-square phase space distribution parameters are calculated as a normalized sum of matrices elements.

$$V = \sum_{ix}\sum_{iy}\hat{E}; \qquad \hat{e} = \hat{E}\cdot 1/V$$

$$x_0 = \sum\left\{\hat{e}\bullet\vec{X}\right\} \qquad y_0 = \sum\left\{\hat{e}^T\bullet\vec{Y}\right\}$$

$$\sigma_x = \sqrt{\sum_{ix}\sum_{iy}\left\{e_{ix,iy}\cdot(x_{ix}-x_0)^2\right\}}$$

$$\sigma_y = \sqrt{\sum_{ix}\sum_{iy}\left\{e_{ix,iy}\cdot(y_{iy}-y_0)^2\right\}}$$

E and e are original and normalized rectangular intensity matrices in the space-divergence coordinate system.

Obtained statistical values are used for rms twiss coefficients calculation.

To improve accuracy the initial data set may be re-sampled. The improvement is achieved due to the fact that the summation means rectangular rule integration while the re-sampling uses cubic interpolation method.

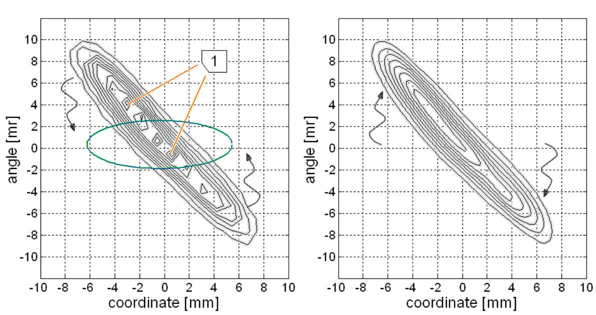

Fig.2. Re-sampling in canonical coordinates allows removing the 'islands' (1) on experimental data.

Geometric emittance. The contour data is used to calculate the geometric emittance dependence of the current. The contours are being calculated using linear data approximation, which leads to better results rather than simple summation. Data re-sampling also improves accuracy of this algorithm.

Re-sampling. To improve accuracy of calculations the data may be re-sampled with smaller steps in both x and x' directions. If usual interpolating routines are applied to convergent or divergent beam data, 'islands' may be produced. To remove these 'islands' the re-sampling is executed in rms emittance ellipse canonical coordinate system. The result of this operation is shown in fig.2.

Data reduction

One of the disadvantages of the pepper pot measurement method is the limited number of beam slices. The number of the slices depends on spot sizes and CCD matrix resolution. When the spacing of the pepper pot mask holes is too small or drift length from the mask to the scintillation screen is too large the spots may overlap each other. Then a different technique can be used

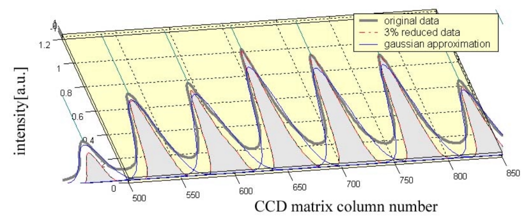

Fig.3. Plot of real profile data evaluated with approximation and offset applying methods.

to improve the device performance. Typical measured two-dimensional emittance data is shown on fig.3. This data is obtained as the integral of a two-dimensional data array along vertical direction (horizontal profile). Each peak represents one slice of the two-dimensional emittance or compared with the slit/grid method every peak would correspond to one slit position.

As it can be seen in fig. 3, the peaks from adjacent 'slits' are significantly overlapped. There are two possibilities for effective peak separation. The first is the data approximation by Gaussian (normal) distribution. In fig. 3 this case is shown thin lined. This variant should be used for noisy data, but some information may be lost. The data acquisition software supports the opportunity to apply an offset value to the initial 2D data and not only to the profile. The result of applying a 3% offset is shown in fig. 3 as a grey highlighted graph. A significant difference between the approximation and the offset applying method is recognizable. It was found that the second method leads to results, which are much closer to the slit-grid measurement than the first one.

4. VISUALIZATION POSSIBILITIES

The results of measurements may be presented in different ways. Due to human mind limitation it is more native to have a few parameters, which values can be easily compared with the others. As a basis the rms TWISS parameters were chosen. To give additional possibilities in beam analysis the contour plot and 3D

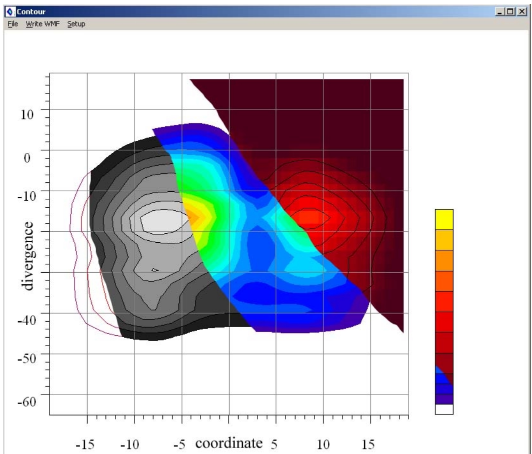

Fig.4. Different types of contour plots are available.

graph are also available for analysing purposes. The operator has several alternatives in selecting the shape of the graphs: contours, bricks or filled contours with different colour palettes in two-dimensional graphs, surfaces, bars or wire frames and standard OpenGL effects like the fog and lighting in three-dimensional case. The twiss parameters are given in table style and as graphs as a function of beam percentage. On the same window the beam profiles in space and angular directions are shown. Each image or graph may be saved in form of Windows bitmap or metafile.

5. DATA IMPORT

The data evaluation part of the software was initially developed to manage the pepper pot system. Meanwhile, this part of software may be used independently to calculate data obtained by other emittance measurement devices.

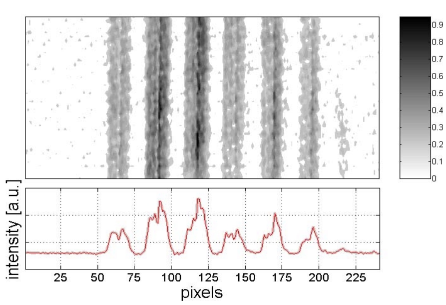

Fig.5. Data from the TWAC injector emittance measurement device had been calculated with the presented evaluation tools.

For example this tool is used with data from a one plane multislit CCD based device, which is used in emittance measurements for ITEP's ISTRA (protons) and TWAC (heavy ions) projects [4], see fig. 5.

6. DATA EXPORT

The software provides the possibility to export raw or evaluated data. The export may be executed on different stages of data evaluation:

- Original data, obtained from CCD camera, or parts to be stored as bitmap file or as a text table in ASCII format.
- ASCII or binary file with vertical and horizontal profiles of modulated beam.
- Beam density distribution in two dimensional phase spaces.
- Four-dimensional beam density distribution as a set of equal charged macro particles.

Data presentation as a row of randomly scattered particles gives possibility to realize the advantages of the pepper pot method due to real four dimensional emittance measurement, which is not available for slit-grid techniques. An obtained array of macro particles can be natively used in beam dynamics simulation programs. A simple real measured data evaluation over a drift space executed and painted in MATLAB is shown on fig.6.

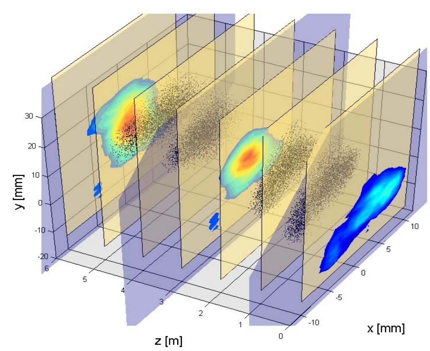

Fig.6. Data, exported as random distributed macro particles allow realizing advantages of the pepper pot method.

7. REFERENCES

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