THE DESIGN OF TRANSVERSE EMITTANCE MEASUREMENT AT HIRFL-CSR

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Abstract

HIRFL-CSR is a multi-purpose heavy ion storage ring in Lanzhou. In order to measure the transverse emittance of the injected beam on the transfer channel to the HIRFL-CSR, two kinds of emittance measurement devices which included pepper- pot and slit-grid were proposed. The pepper-pot is unique in providing an instantaneous measurement of the two-dimensional emittance of a beam. The data acquired by this method is only an image. The slit-grid is a one dimensional emittance measurement device. During the measurement, the slit, driven by the stepper motor is moved stepwise across the beam, and then the signal induced on the grid will be stored in the computer for further analysis. Because slit-grid is one dimensional device, two sets of this device are needed for transverse measurement. In this paper, we introduce the design, parameters, data acquisition and analysis of these two methods. Especially the software integration is given in this paper. Main interest is directed on the software development for emittance front-end control and data analysis such as evaluation algorithms.

INTRODUCTION

HIRFL-CSR (Heavy Ion Research Facility in Lanzhou-Cooling Storage Ring) is a multi-purpose heavy ion storage ring that consists of a main ring (CSRm), an experimental ring (CSRe) and a radioactive beam line (RIBLL2) to connect the two rings [1]. As part of the development program and to provide necessary information for HIRFL-CSR beam dynamic simulation and experiments, high quality emittance measurement are required. So in order to measure the transverse emittance of the injected beam on the transfer channel to the HIRFL-CSR, two kinds of emittance measurement devices which included pepper- pot and slit-grid were proposed. The chamber will be installed in the injection line of HIRFL-CSR which is shown as figure 1. The pepper-pot and two sets of grid-slit devices can be seen in figure 2. Two systems have already been installed in the chamber. There are also some other equipments for measurement such as CCD camera and mirror which are used for alignment in pepper-pot systems. In slit-grid system, I/U converter and DAQ card acquire beam current data for analysis.

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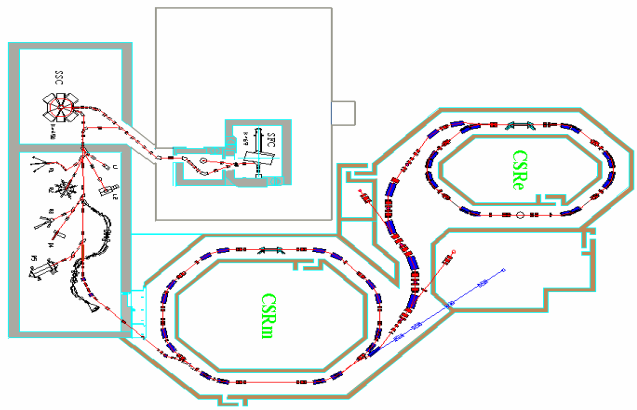

Figure 1: The layout of HIRFL-CSR

Figure 2: The chamber

SLIT-GRID SYSTEM

The slit-grid is a very popular method used for protons/heavy ions emittance measurement. The classical scheme is shown schematically in figure 3[2]. Two sets of slit-grid system with the same parameters are designed for measuring the horizontal and vertical emittance respectively. A narrow slit, driven by the stepper motor, is moved stepwise across the beam. In our slit-grid system, the width of the slit is 0.5mm. The distance between slit and grid is 300mm. There are 49 wires of which the width is 0.2mm and the spacing is 1mm in one dimension. The gird device can be seen in figure 4. During the measurement, we need two coordinates to locate the beamlets: one for the slits(x), the other for the grid(X) [3]. The wire currents are converted into reasonable voltages U using I/U converter. DAQ card is used to acquire data.

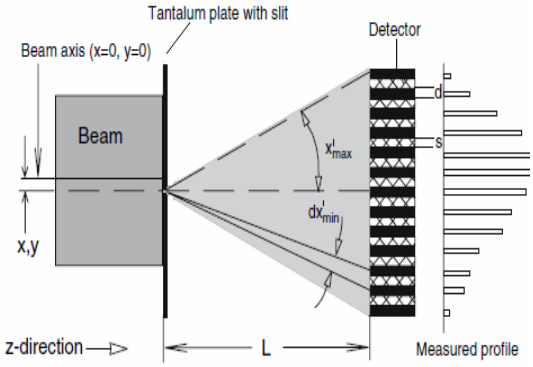

Figure 3: Scheme of slit-grid system

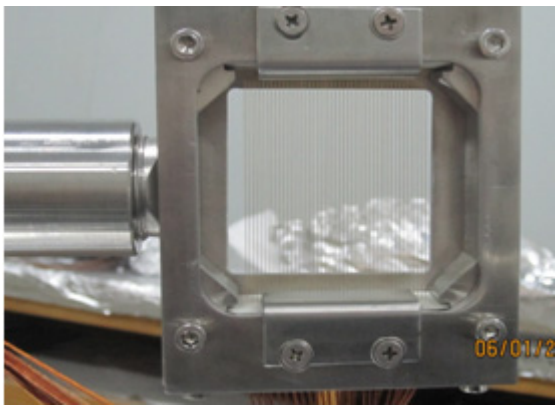

Figure 4: The grid device

PEPPER-POT SYSTEM

Due to the relatively slow movement of slit-grid systems through the beam, the measuring time becomes rather long. Although this time will be of the order some 10s up to about 5 minute for dc-beams, this can extend to some minutes for pulsed beams. The coupling effects between both transverse phase planes cannot be observed in the slit-grid system. Those drawbacks of the slit-grid system can be solved by another method called pepper-pot measurement way. The scheme of this method is shown in figure 5[2]. The beam come from left and then hit a plate with a number of small holes, arranged in the x, y-plane like the elements of lines and columns in a matrix. The sample beamlets fall on the viewing screen, where the light spots are observed by a fast PC-controlled CCD-camera system [4]. The pepper-pot screen is a 0.1mm thick tungsten foil with a square array of 27×27 holes, each 0.2mm in diameter, on a 1.5mm pitch. The beam is imaged with a quartz scintillator, 150mm from the tungsten screen, and a 1024×1344 pixel high speed camera. Data is recorded from the camera direct to a multi-image TIF file or excel file and analyzed with Matlab.

SOFTWARE SYSTEM

Two programs are used to control measurement as well as evaluate and visualize data for the two systems. Since the system may be operated by scientists and operators, who can be more or less familiar with the system parameters, the control software must be designed based graphical user interface (GUI). The software designed with Matlab consists of data acquisition, evaluation and visualization tools.

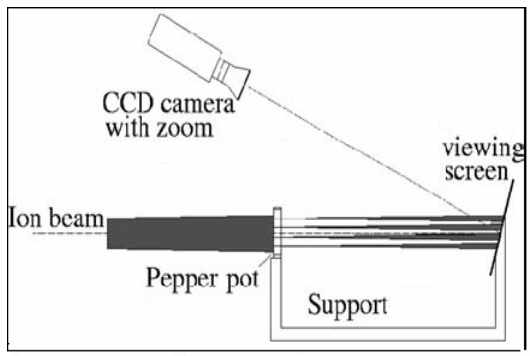

Figure 5: The scheme of the pepper-pot system

Data Acquisition

In pepper-pot system, the data is only an image acquired by a CCD-camera. The measurement process can be seen in figure 5[2]. Meanwhile accurate calibration data is crucial in converting the pepper-pot images into emittance data. The calibration data would be stored in the computer before analysis.

In slit-grid system, the data acquisition is more complicated. Because this method is a one-dimensional way to measure emittance, two slit-grid devices are needed to obtain the horizontal and vertical data. Four stepper motor are used to control the position of the slit and grid. The stepper motor is connected with the computer by RS-232 port. Meanwhile, the measured grid currents have to be converted into reasonable voltages U for digitization. The digital data is acquired by the DAQ card of NI 6224. All the data would be stored in the computer for the further analysis. Figure 6 is the scheme of measurement process in slit-grid system [2].

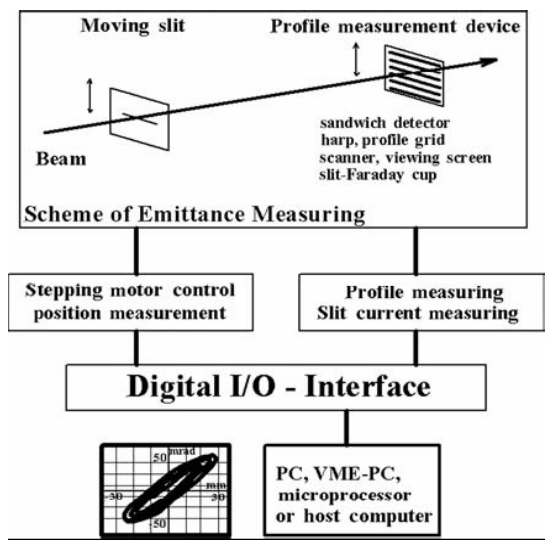

Figure 6: The scheme of measurement in slit-grid system.

Data Analysis

The root-mean-square phase space distribution parameters are calculated as a normalized sum of matrices elements. The data gathered from the pepper-pot systems is more difficult to analyse than from the slit-grid systems. But the RMS emittance can also be calculated by the following formula [5].

For one dimension:

$$V = \sum_{ix}\sum_{ix'} U$$

$$e = U / V$$

$$x_{mean} = \sum_{ix}(e_{ix,ix'} \cdot x_{ix})$$

$$x'_{mean} = \sum_{ix'}(e_{ix,ix'} \cdot x'_{ix})$$

$$\sigma_x = \sum_{ix}\sum_{ix'}(e_{ix,ix'} \cdot (x_{ix} - x_{mean})^2)$$

$$\sigma_{x'} = \sum_{ix}\sum_{ix'}(e_{ix,ix'} \cdot (x'_{ix'} - x'_{mean})^2)$$

$$M_{x,x'} = \sum_{ix}\sum_{ix'}(e_{ix,ix'} \cdot (x_{ix} - x_{mean}) \cdot (x'_{ix'} - x'_{mean}))$$

$$\varepsilon_{RMS} = \sqrt{\sigma_x \sigma_{x'} - M_{x,x'}}$$

U and e are original and normalized beam intensity. x and x' are the position and angular in horizontal dimension. Sometimes in order to improve accuracy the initial data set may be resampled. The re-sampling can use linear or cubic interpolation method [6]. Twiss parameters can be calculated according to the RMS emittance and the profile of the beam.

Geometric Emittance

The data can also be used to calculate the geometric emittance. There are many emittance subtraction modes for calculating emittance. For example, summing up all intensities $U_{x,x'}$ of the corrected data matrix defines the maximum intensity $U_{\max}$, taken as reference to calculate the percentages. Therefore, to calculate, for example, the so-called 80% emittance, a value of S = $0.2U_{\max} / n_x n_{x'}$ (n_x = number of rows, $n_{x'}$ = number of columns) has to be subtracted from each element with $U_{x,x'}$ > 0 in the data matrix. No subtraction takes places if $U_{x,x'}$ = 0. The subtraction has to be performed successively in much smaller steps as defined by S (for example S/100). Elements below zero are set to zero. Then we use the unit area $dxdx'$ and the subtracted elements to calculate the geometric emittance.

Visualization

Having finished the calculation mentioned above, the result especially the geometric emittance can be seen in an image. There is also a tool bar to adjust the contrast ratio to make a clear visualization. Furthermore, the phase space ellipses can be plotted by the RMS emittance and the Twiss parameters.

CONCLUSIONS

There are both advantages and disadvantages respectively in the two systems. The data analysis for slit-grid system is much easier than the analysis in pepper-pot system. But the measurement time in slit-grid system is longer. We can use the two systems to measure the beam parameters at the same time, and do the comparisons between the two results. The hardware and software have been designed and finished. The systems will be tested as soon as they are installed on the transfer line.

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