BEAM EMITTANCE MEASUREMENT TOOL FOR CEBAF OPERATIONS

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Abstract

A new software tool was created at Jefferson Lab to measure the emittance of the CEBAF electron beams. The tool consists of device control and data analysis applications. The device control application handles the work of wire scanners and writes their measurement results as well as the information about accelerator settings during these measurements into wire scanner data files. The data analysis application reads these files and calculates the beam emittance on the basis of a wire scanner data processing model. Both applications are computer platform independent but are mostly used on LINUX PCs recently installed in the accelerator control room. The new tool significantly simplifies beam emittance measurement procedures for accelerator operations and contributes to a very high availability of the CEBAF machine for the nuclear physics program at Jefferson Lab.

INTRODUCTION

Advanced nuclear physics experiments at Jefferson Lab require a very small ($\sim 2.5 \cdot 10^{-5}$) relative beam energy spread $\delta_p = \sigma_p / p$. The energy spread is continuously monitored by two Synchrotron Light Interferometers (SLI) installed in high dispersion locations of the Hall A and C beam extraction lines [1]. The SLI data processing software estimates the energy spread based on the RMS beam size σ_b calculated from the SLI interferograms. The transverse beam size in dispersion areas has betatron ("native") and dispersion sources:

$$\sigma_b^2 = \beta \varepsilon + (D \delta_p)^2 \qquad (1)$$

where β is a beta function and D is a dispersion function at a measurement point, ε is the transverse beam emittance. Thus in order to estimate δ_p, one must know the value of ε.

Jefferson Lab routinely uses the method of quadrupole scans to calculate the beam emittance. If non-dispersive ($D=0$) optics between a quadrupole lens and a beam size monitor doesn't change and is described by the transfer matrix $S=\{s_{ij}\}$, then the square of the beam size measured by the monitor is a quadratic (parabolic) function of the quadrupole strength K [2]:

$$\sigma_b^2 = A \cdot (K - B)^2 + C \qquad (2)$$

The coefficients *A, B*, and *C* are estimated by fitting function (2) to measurement data. Assuming that σ_b is a horizontal (X) beam size, a horizontal beam emittance is calculated as

$$\varepsilon = \frac{\sqrt{AC}}{s_{12}^2} \qquad (3)$$

The most used beam size measurement devices at Jefferson Lab are wire scanners (WS). A stepper-motor moves a set of thin (tungsten or carbon) wires through the beam. The amount of the beam particles intercepting a wire changes depending on the shape of the beam. A typical WS consists of at least two wires to measure vertical and horizontal beam profiles. The beam profile is defined by the level of the signal generated by the interaction of the beam with a wire as the function of the position of the wire. The signal can be either an induced voltage on the wire or the amount of scattered electrons registered by Cherenkov detectors. A basic WS hardware configuration at Jefferson Lab consists of a stepper motor with its controller and a set of synchronized ADC boards giving the positions of the wires and beam profile related signals.

WS OPERATIONS AND CONTROLS

The main operational mode of the WS at Jefferson Lab is trivial and is called automatic. A stepper-motor moves the WS into a beam pipe with a specified speed until an installed limit switch latches and then immediately moves it back in the original or home position. Each scan takes about one minute to perform.

Another operational mode of WS is semi-automatic. In this mode, the WS can continuously move back and force between any two specified stepper-motor positions in the beam pipe, with different speeds and accelerations.

Beam emittance measurement procedures mostly use the semi-automatic WS mode because it significantly reduces total time these procedures take.

WS operations are automated with the use of WS control software [3]. The software handles WS hardware components and collects measurement data, which can be written into WS data files on user requests. The structure of these files is simple. They consist of data blocks corresponding to WS scans. Each block begins with a header, which is followed by three columns of data containing the measurement point numbers, the corresponding wire coordinates in the beam pipe and wire signals. The header has a WS scan timestamp and quadrupole settings *K*.

The WS control software runs on accelerator control computers (IOCs) and communicates with the external

world via the EPICS Channel Access (CA) and Remote Procedure Call (RPC) protocols.

Two WS control screens (EPICS MEDM screens, one for each operational mode, see Fig. 1) provide users with WS status information and available control functions.
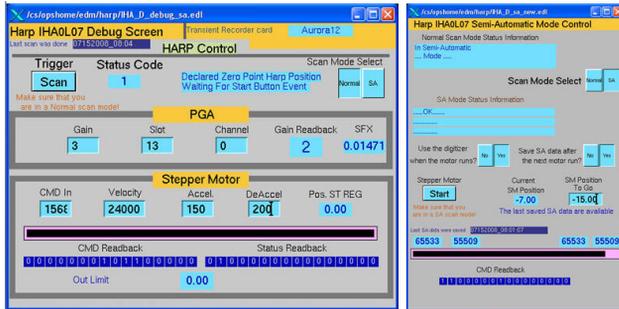
Figure 1: WS control screens for automatic (left) and semi-automatic (right) operation modes.

BEAM EMITTANCE MEASUREMENT TOOL

The user control of wire scanners and all WS data processing functions are provided by a Beam Emittance Measurement Tool (BEMT). The tool consists of WS device control and data analysis applications. Both applications are written in C++. The mathematical part of the BEMT is based on the GNU Scientific Library (GSL) [4]. The tool graphics is implemented with the use of the QT package [5] and its QWT extension [6].

The WS control application allows users to efficiently operate WS and manage WS data on the basis of a variety of WS control (GUI) screens.

The main task of the BEMT data analysis application is to calculate the beam emittance with the use of the information collected during quadrupole scans. When the application starts, it provides a user with the main BEMT control screen, which is shown in Fig. 2. The user can simultaneously work with data of up to 3 wire scanners. When the wire scanner is selected and the corresponding button "SELECT" is pushed, a Wire Scan Data Selecting screen pops up (the right snapshot in Fig. 2).
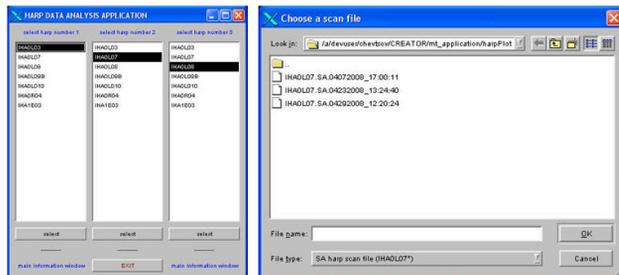
Figure 2: Main BEMT control and Wire Scan Data Selecting screens.

One can now use any WS data file created by the WS control application and press the "OK" button. The data

selecting screen immediately disappears and two new graphical objects pop up: a WS Data Information screen with a WS Data Control window (Fig. 3).
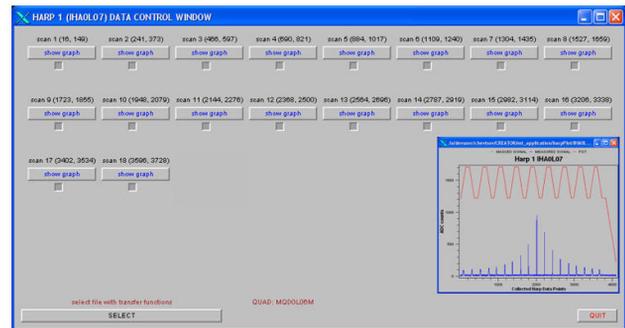
Figure 3: WS Data Control window and Data Information screen.

At this moment, the BEMT software has already finished data processing for the selected WS data file. For each quadrupole (MQD0L06 in our case) scan or WS move (we note that the red curve in the data information window above shows 18 such scans done before the WS was completely retracted from the beam pipe), it has analyzed the WS signal (the blue curve), and estimated the beam position and size σ_b based on a standard Gaussian fit. All these data can be seen by pushing "show graph" buttons on the WS data control screen after which a WS data fit window pops up (Fig. 4) allowing one to examine raw data (the blue curve) and data fit (the red curve) quality. If the quality of data for any of the scans is not acceptable (which usually means that raw WS data are very noisy or do not show a typical bell-like shape), then such data can be excluded from all further calculations by checking a box right below the "show plot" button for this scan.
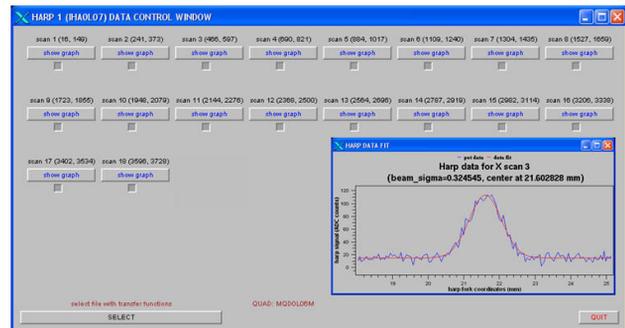
Figure 4: WS Data Control window and WS Data Fit screens.

At this point, to calculate the beam emittance, the BEMT software has to know element s_{12} of the transfer matrix S between the used quadrupole and wire scanner in accordance with equations (2) and (3). We note that in most cases only a drift space separates the quadrupole and the wire scanner, and s_{12} is simply equal to the length of this drift.

All transfer matrices for BEMT are kept in data files. This information is retrieved by pushing the "SELECT"

button below the line "select file with transfer functions" in the WS Data Control Window. This pops up a transfer function file selecting screen with a list of all available files containing WS transfer functions (see Fig. 5 below).

Figure 5: WS Data Control window with transfer function file selecting screen.

If the file is chosen and the "OK" button is pressed, the file selecting screen disappears and the WS Data Control window changes. The "SELECT" button disappears, the line "select file with transfer functions" is replaced with the line consisting "transfer function file:" and the name of the chosen file, as well as new three control buttons appear at the bottom (Fig. 6). If now one presses the "calculate emittance" button, then the BEMT software begins beam emittance calculations. When the results of these calculations become available, the BEMT pops up a WS Data Fit screen (Fig. 6).
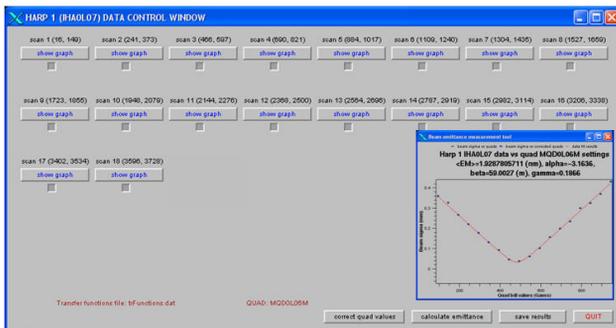
Figure 6: WS Data Control window with WS Data Fit screen.

The Data Fit screen shows the results of the calculations (the beam emittance together with Twiss parameters) as well as a set of WS σ_b values as a function of quadrupole BDL settings (blue points) and the results of the fit (1) for this function (the red curve). By pressing the "save results" button all these results can be saved in a file for the off-line data analysis.

CONCLUSION

The new tool described in this paper significantly simplifies beam emittance measurement procedures for accelerator operations and contributes to a very high availability of the CEBAF machine for the nuclear physics program at Jefferson Lab. Tool software is computer platform independent but is mostly used on LINUX PCs recently installed in the accelerator control room.

REFERENCES

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