WIRE SCANNER CONTROL AND DISPLAY SOFTWARE

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Abstract

Wire scanners are diagnostic devices to measure the transverse beam profile. By moving a thin wire across the path of the electron beam while monitoring the secondary particles, the transverse beam charge distribution can be obtained. The primary application of wire scans is the determination of beam emittance and optics match quality.

At DESYs VUV-FEL Linac [1] emittance scans should be fully automated and easily accessible to all operators. For this reason a wire scanner control and display software is developed as an integral part of the control system DOOCS [2]. The main component of this software is a middle-layer server, which uses the shared memory of a data acquisition system (DAQ) [3] for fast data exchange. This server controls the wire scans and calculates the emittance and Twiss parameters using MATLAB routines. After each scan a set of relevant data is written back to the DAQ and is then accessible for further investigations.

The general concept of wire scanner software using the shared memory facilities for fast access to the central DAQ will be described.

TTF VUV-FEL

In a collaboration of 52 institutes from 12 different countries the TESLA Test Facility (TTF) is extended to a new Free Electron Laser facility (VUV-FEL). In the current stage, the second phase of TTF (TTF2), five accelerating modules, each having eight 9-cell superconducting cavities, are installed (see Fig. 1). Electron beam energies up to 1 GeV, corresponding to 6 nm FEL wavelength, can be achieved. The following table gives an overview of the TTF2 design parameters.

Table 1: Parameters of TTF2 electron beam

bunch charge	=	1 nC
max. electron Energy	=	1 GeV
transverse beam size (σ)	=	50 μm
bunch length (σ_z)	=	50 μm
peak current	=	2.5 kA
max. bunch train length	=	800 μs
max. number of bunches per train	=	7200
max. repetition rate	=	10 Hz

MOTIVATION

Optimal accelerator perfermance critically depends on the ability to measure and control the properties of particle beams. Emittance and Twiss parameters are the most important parameters needed for beam optics optimization.

At TTF there are two possible methods of measuring the emittance and Twiss parameters: a four (or multi) monitor method and a quadrupole scan. In the first case, the beam optics is fixed and the beam size is measured at different locations along the beam line. In the second case, the beam optics is varied by changing the focusing strength of one or more quadrupoles and the beam size is measured at a fixed position downstream of the quadrupole.

We concentrate on emittance measurements using the four monitor method. The server is designed for the TTF section downstream of the first bunch compressor, called DBC2, and for the undulator section (see Fig. 1). In the DBC2 section four beam size monitors (optical transition radiation screens and wire scanners) are mounted in a lattice of three Focusing-Defocusing quadrupole pairs (FODO cells) with 45° phase advance between the monitors (see Fig. 2). The undulator section is equipped with seven wire scanners.

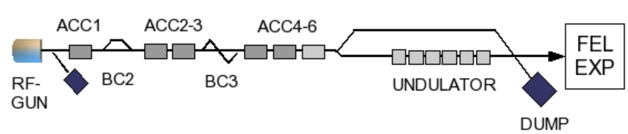

Figure 1: Sketch of the Linac, BC refers to a bunch compressor and ACC to an accelerating module.

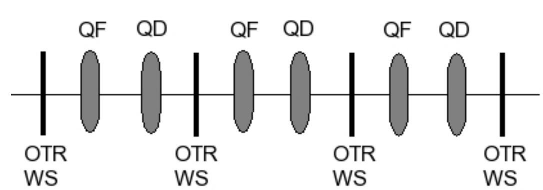

Figure 2: Sketch of FODO lattice in section DBC2, OTR refers to an optical transition radiation screen, WS to a wire scanner, QF to a horizontally focusing quadrupole and QD to a horizontally defocusing quadrupole.

EMITTANCE CALCULATION

To determine the emittance at least three beam profiles with a proper phase advance need to be measured. A fourth profile provides a better error estimation. Let x_i be the wire position and y_i the photomultiplier reading. Assuming Gaussian beam profiles, the following algorithm is used for rms calculation:

$$\sigma = \sqrt{\frac{\sum_{i=0}^{n} y_i \cdot (x_i - \mu)^2}{\sum_{i=0}^{n} y_i}} \quad (1)$$

$$\text{with } \mu = \sum_{i=0}^{n} x_i \cdot y_i \quad (2)$$

Let σ_i be the rms beam size at different locations i along the electron beam line, $m_{11,i}$ and $m_{12,i}$ the elements of the transfer matrix between the first and the last measurement point, α, β and $\gamma = (1 + \alpha^2)/\beta$ the Twiss parameters. Solving the equations 3 and 4 the beam emittance and the Twiss parameters can be calculated.

$$\sigma_i^2 = m_{11,i}^2(\beta\epsilon) - 2m_{11,i}m_{12,i}(\alpha\epsilon) + m_{12,i}^2(\gamma\epsilon) \quad (3)$$

$$\epsilon = \sqrt{(\beta\epsilon)(\gamma\epsilon) - (\alpha\epsilon)^2} \quad (4)$$

Usually one is interested in the normalized emittance:

$$\epsilon_N = \gamma_{rel}\epsilon \text{ with } \gamma_{rel} = \frac{E}{mc^2} \quad (5)$$

A description of basic accelerator beam optics can be found in Ref. [4].

DAQ TECHNOLOGY

The TTF2 data acqusition system (DAQ) is developed in a collaboration with Cornell, Ohio State University, DESY Hamburg and DESY Zeuthen [3]. The goal of this system is to record all beam relevant data and to better understand, improve and maintain the Linac.

The data from the ADCs are accumulated from two types of collectors, one for fast signals as BPM readings and one for slow signals as magnet readings. The data are packed in ”Server Blocks” with variable length and are written by multicast to the shared memory of the DAQ-server. From the shared memory the data are provided to middle-layer server programs for feedback, measurement and monitoring tools. The data are also written to a storage device.

A so called run control process configures DAQ and Linac parameters according to the Linac run mode.

WIRE SCANNER EMITTANCE MEASUREMENTS

Wire scanner types

At TTF2 there are two types of wire scanners (see Fig. 3) [5]:

1. In the DBC2 section the wire scanners have 3 wires in X,Y and diagonal direction.

2. In the undulator section the wire scanners have 3 parallel wires with different thickness. Always two wire scanners, one in x- and one in y-direction, are mounted in a row.

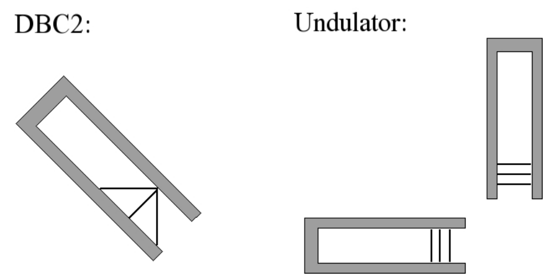

Figure 3: Wire scanner types used at TTF2.

Concept

A sketch of the software architecture for wire scanner emittance measurements is shown in Fig. 4.

All wire scanners are directly controlled by a wire scanner device server. Following scan parameters can be set: used wire, start position, scan speed and scan length. During a scan process the wire is moved through the beam with a constant speed. Each electron bunch hitting the wire creates one pair of data consististing of wire position [μm] and photomultiplier reading. The measured beam profiles of up to 30 micro pulses in a bunch train are written to xy-array properties of this server.

Each measured pair of data is also sent to the shared memory in real time.

The main component of the automated wire scanner emittance measurements is a DOOCS middle-layer server, referred as WS.FSM in Fig. 4. This server is designed for horizontal and vertical emittance measurements in the DBC2 and undulator section. It consists of several state machines for measuring the emittance with different sets of wire scanners.

General procedure of wire scanner emittance measurements: The WS.FSM server subscribes to the shared memory of the DAQ-server. For the emittance measurements it starts the wire scans consecutively, reads out the data from the shared memory of the DAQ-server and calculates the rms beam widths, emittance and Twiss parameters using MATLAB routines [6]. The beam energy used for emittance calculation is an estimated value. After the measurements all calculated data of the WS.FSM are written to an ASCI-file.

The beta function in DBC2 and the phase space ellipse can be examined with a ROOT emittance display.

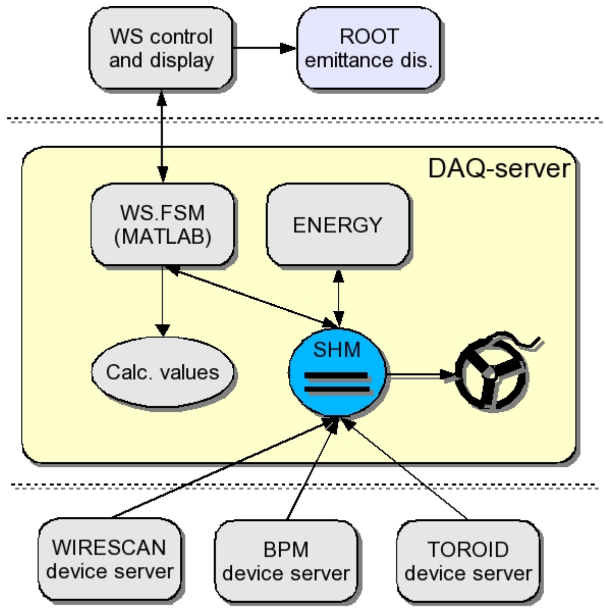

Figure 4: Software architecture.

The new DAQ technology allows to correct the data on a bunch-to-bunch basis: The measured beam position is corrected with corresponding BPM-data and the photomultiplier signal with Toroid-data. In the next step this correction will be included in the WS.FSM server. Further improvements will be: 1. using not the estimated beam energy for emittance calculation, but a calculated value from a new energy middle-layer server. 2. writing all calculated data of the WS.FSM to the shared memory for further analysis.

Display

To start and control the wire scanner measurements a DOOCS [2] data display is used. A screenshot of this display is shown in Fig. 5. All relevant settings for emittance measurements are shown on this display. The user has the possibility to change following parameters for each wire scanner: used wire, start position, scan speed and scan length. When pressing the START button automatically four wire scans are executed consecutively. The rms beam widths are calculated for each scan. Taking into account γ_{rel}, the rms beam widths, rms errors and the field strength of all quadrupoles located between the wire scanners the emittance, normalized emittance and the Twiss Parameters alpha and beta are calculated.

Each emittance measurement doing 4 scans with an acceptable amount of measured data points takes about 2 minutes.

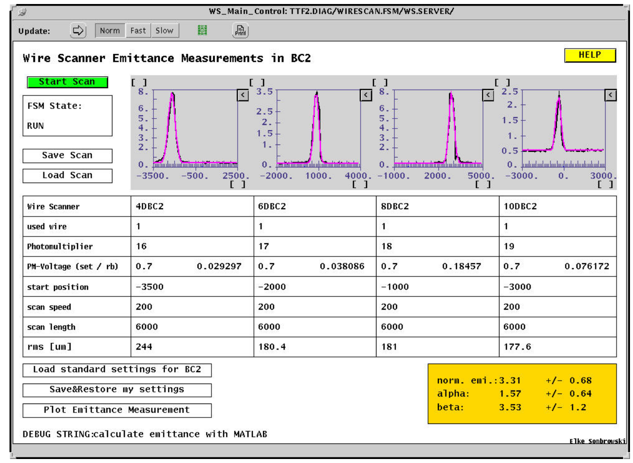

Figure 5: Wire Scanner display for DBC2.

CONCLUSION

The complete project is now ready to be released to the operators. The wire scanner middle-layer server program in combination with the wire scanner DOOCS data display offers a fast and easy to use interface for automated emittance measurements.

The DAQ technology easily allows to correct raw data bunch-by-bunch. This enhances the quality of the emittance measurements. The new approach to keep the data of one macro pulse in a central shared memory has proven to be a useful concept for middle-layer servers.

REFERENCES

[1] VUV-FEL Vacuum Ultraviolet Free Electron Laser http://xfel.desy.de.

[2] DOOCS Distributed Object Oriented Control System http://doocs.desy.de.

[3] V. Rybnikov, *Data Acquisition System for TTF VUV-FEL Linac*, this conference.

[4] H.Widemann, *Particle Accelerator Physics*, Springer-Verlag, 1993.

[5] M. Werner, K. Wittenburg, *A new Wirescanner Control Unit*, DIPAC 2001.

[6] F. Loehl, *Measurements of the Transverse Emittance at the VUV-FEL*, diploma thesis, to be published.