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EMITTANCE MEASUREMENT AND OPTICS MATCHING AT THE EUROPEAN XFEL

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Abstract

Electron beam quality described by the emittance or phase space moments are important for the operation of FEL facilities like the European XFEL [1]. For the operation these parameters need to be routinely measured. Based on such measurements machine setup can be optimized to match beam requirements. The beam parameters depend on parameters like quadrupole magnet strength or RF settings. While manual tuning is possible, we aim for highly automatized procedures to obtain such optimizations. In this paper we will present and discuss an overview of the different subsystems which are involved. These include image acquisition, analysis, and optics calculations as well as machine control user interfaces.

INTRODUCTION

An important measure of beam quality required for a FEL driver linac is the beam emittance. The machine settings, especially of the injector, needs to be tuned to optimize this parameter. In order to achieve this fast, efficient and reproducible measurement procedures are required. Related to emittance measurements is the determination of the beam optics. This optics is “matched” to the design based on such measurements using a set of upstream quadrupole magnets. These phase-space parameters are determined from beam spot-size measurements in different optics conditions, either at multiple positions or varying the magnet lattice, as described in [2]. Phase-space studies are done in a diagnostic section, which includes four-screen stations, a spectrometer arm, and a transverse deflecting RF structure (TDS) for longitudinal resolved studies. A unique feature of this diagnostics layout are fast kicker systems to kick individual bunches on off-axis screens (see Fig. 1). In this configuration individual bunches out of the train can be analysed while the remaining bunches continue eventually to the SASE user stations.

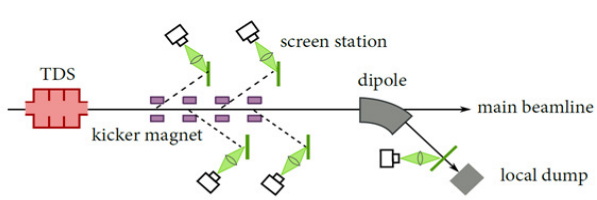

Figure 1: Overview of a diagnostic section of the European XFEL.

MEASUREMENT METHODS

There are several methods established to measure the emittance. Using the on-axis screens the full beam is intercepted by the screens and therefore prevent normal user operations. With the off-axis screens we can use individual bunches out of the full 2700 bunch train. In this measurement mode user operation is, in general, not interrupted.

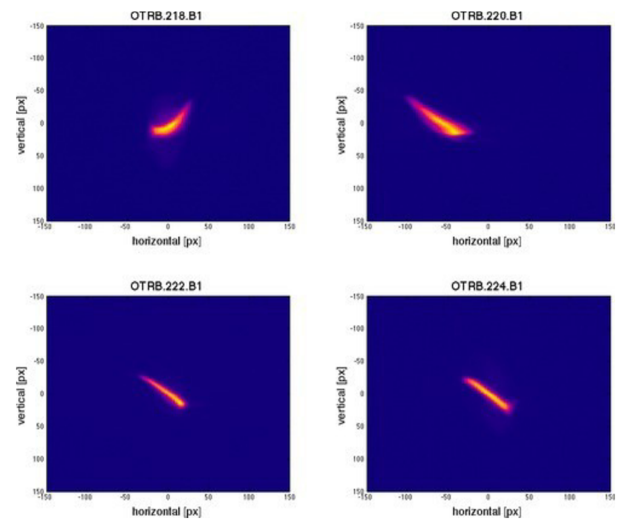

Figure 2: Example output of 4 on-axis screens.

Multi-Position Measurement

While an on-axis measurement four screens or wire scanners will be inserted into the beam one by one. In the case of screens the background noise has to be determined. After screen insertion the production of bunches will be stopped by turning off the injector laser and background images are acquired. An average of these background images are subtracted from subsequently acquired beam images. From a set of these processed images an average of beam parameters like the Gaussian width or RMS spot-size are calculated. After the successful acquisition, the screen will be moved out of the beam. This step will be done for all four screens. An example output for a measurement with four screens can be found in (Fig. 2). If wire scanners are used, each wire scanner will be moved through the beam one by one. Out of the profile of the wire scanner the beam parameters like the Gaussian width will be calculated. With the calculated beam parameters and the transport matrices from the optics model, the beam emittance at the reference point can be estimated. The outcome of this method is the machine operation is limited to one bunch due to radiation safety. While the measurement no other machine operation is possible. This methods take some time to move the screens. An overview about the screens at the European XFEL can be found in [3].

In order to speed-up the multi-position measurements the fast kicker system is used. In this configuration off-axis screens are used. These screens are installed with

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about 7mm distance to the regular beam trajectory. Four fast kicker magnets push single bunches from the bunch train onto these screens. At the European XFEL a bunch train consist of up to 2700 bunches with a 4.5MHz rate on the 600 microsecond RF pulse. While most bunches are used for the FEL user stations individual bunches are used for semi-parasitic emittance measurements. This method can be used while a user run and doesn't disturb the normal operation. Changing the time-delay of the kicker trigger each bunch of the 2700 bunch train can be selected individually. Therefore dynamics along the train can be studied, which allows for the optimization of the full train FEL performance.

Multi-Quadrupole Measurements

The measurement with multiple quadrupoles is also known as multi-quadrupole scan. This method uses a single screen as measurement device. Upstream of this screen the strength of the quadrupoles magnets will be changed according to pre-calculated tables to keep the beta functions about constant while scanning the phase advance. The beam spot-sizes are determined as discussed before. An optics model is used together with the pre-calculated quadrupole tables to determine the phase space beam moments e.g. the emittance at a reference point upstream of the first quadrupole. Due to hysteresis effects such modifications of the quadrupole current influences the beam even if the measurement is finished. To mitigate this influence the quadrupoles needs to be cycled in a time-consuming procedure.

Longitudinal Resolved Emittance Measurements

A combination of the previously discussed measurement methods with a transverse deflecting structure (TDS) enables longitudinal resolved phase-space analysis [4]. The transverse deflecting field in the TDS varies linearly along the bunch, which converts the longitudinal information on a transverse coordinate downstream of a drift. After image processing for each longitudinal slice the local spot-size is determined and the emittance is determined.

THE CONTROL SYSTEM COMPONENTS

The control system at the European XFEL uses the client-server model. In general the client side consist of several hundreds of panels who are designed and run by jddd [5]. Additionally there are some tools written in Matlab or Python. The servers are DOOCS based and written in C++ [6]. An overview is shown in (Fig. 3).

Client Interface

The client interface for emittance measurements is designed and written in Matlab. The European XFEL consists of thousands of hardware devices. While the commissioning phase of the European XFEL the server interfaces of many hardware elements were improved to proper handle the large number of elements. To reduce the load of the back-end servers a lot of new middle layer server were developed. Choosing Matlab the client interface could easily adapt to the changes on the server side (Fig. 4). To speed up the development the datagui3 library was used [7]. A server based version of the emittance measurement tool will be developed to improve the automation of the measurement and for a better integration into the standard operation interface.

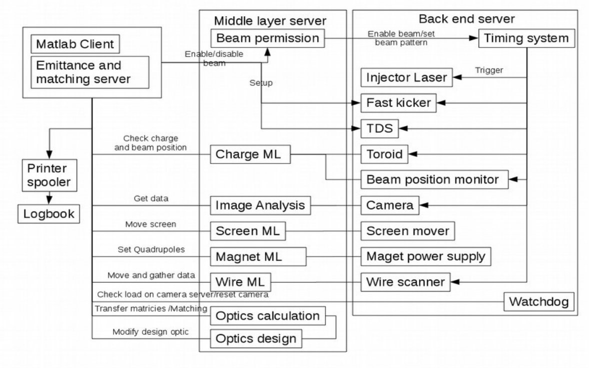

Figure 3: A rough overview of the involved servers.

Handling the Screens

The image taking part of an emittance measurement is done by the camera servers. Every screen is handled by a camera server. The server was developed for the FLASH facility and enhanced to handle the camera hardware of the European XFEL. The servers run on the racks nearby the cameras in the tunnel. The movement of the screens are done by a PLC. To integrate them a screen mover middle layer server was developed. The processing of the images is a complex process. To avoid a reimplementation in each client an image analysis server can handle the workload with machine frequency [8]. The server also runs in the tunnel to decrease the bandwidth on the network.

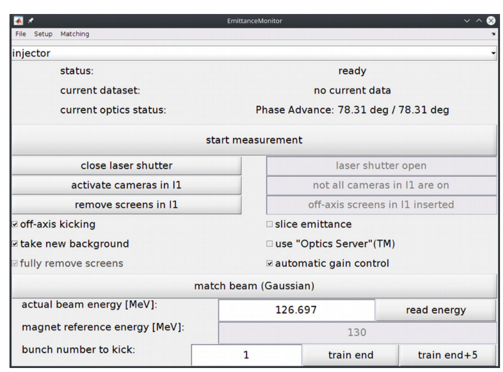

Figure 4: Current client interface of the emittance measurement tool.

Handling the Beam Production

While an emittance measurement the beam production must be prevented. Handling of the injector laser shutter is not reasonable because other software or the operator can also close or open it. The alternative is the reduction of the bunch pattern to zero in the timing interface. Modifying the bunch pattern is delicate and should be avoided by client software. To solve the problem a beam

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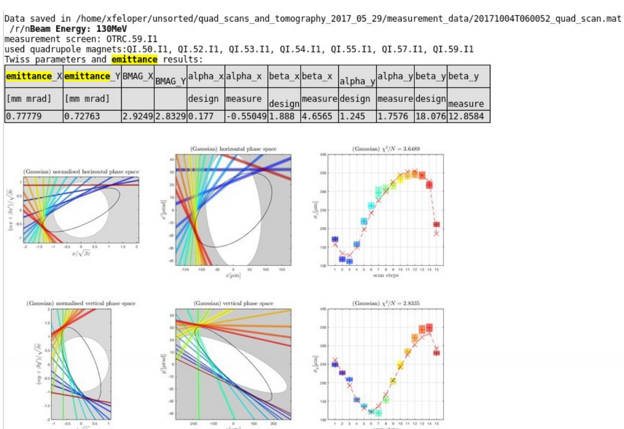
permission server was installed. Each client can get a ticket with a precise description of the beam parameters at a position in the accelerator. The server takes care to meet the conditions. For example to handle a wirescanner in the SASE3 section of the accelerator the number of bunches have to be reduced. But it is still possible to use the maximum number of bunches in a different arm of the facility.

Setting up the Fast Kickers and the TDS

The setup and timing of the fast kickers and the transverse deflecting structure is a complex procedure. The client can not directly setup the correct timing values in the front end servers. A middle layer server is handling the triggering of kicker and TDS systems and is configured by the Matlab clients. This special bunch server is in operation in the Injector of the European XFEL and under development/commissioning for the downstream diagnostics sections.

The Optics Model

To calculate the emittance one need the transfer matrices between the active devices. An optics calculation server provides these for the current machine setup and for the design setup [9]. Additionally the server offer matching routines. To specify the design optics model an optics design server was developed. These server can provide the special optics model with is needed if one is working with the TDS.


Data saved in /home/xfeloper/unsorted/quad_scans_and_tomography_2017_05_29/measurement_data/20171004T060052_quad_scan.mat
/r/n**Beam Energy: 130MeV**
measurement screen: OTRC.59.I1
used quadrupole magnets:QI.50.I1, QI.52.I1, QI.53.I1, QI.54.I1, QI.55.I1, QI.57.I1, QI.59.I1
Twiss parameters and emittance results:

emittance_X	emittance_Y	BMAG_X	BMAG_Y	alpha_x	alpha_x	beta_x	beta_x	alpha_y	alpha_y	beta_y	beta_y
[mm mrad]	[mm mrad]			design	measure	design	measure	design	measure	design	measure
0.77779	0.72763	2.9249	2.8329	0.177	-0.55049	1.888	4.6565	1.245	1.7576	18.076	12.8584

Figure 5: DESY Electronic Logbook output.

The Magnet Currents

While a quadrupoles scan the power-supply currents of the quadrupoles have to be modified. The power-supplies are behind several servers who handle the currents. At the European XFEL we always handle with kicks. A magnet middle layer takes on responsibility for the conversion between kicks and currents. The necessary coefficients are located in an Oracle database. The database also hold the complete machine layout which is used by the optics calculation server.

The Calculated Results

The calculated results were stored on the filesystem. We designed a common result structure for all our emittance measurements. The results are stored in a Matlab file format with a unique timestamp. To analyse the output we plan to store the data in our Oracle database because of the powerful report possibilities. At the European XFEL it is always a good agreement to document all important operations in the electronic logbook [10]. The common output to the logbook is a printer spooler. For the advanced formatting of the output we implemented a Matlab function which directly uses the web-server interface to create new entries in the logbook. An example output of a quadupoles scan can be found in (Fig. 5).

CONCLUSION

The emittance measurement and matching is a complex procedure which is necessary for the successful setup of the SASE process. A lot of different devices and servers are involved. Even if the European XFEL consists of such a huge number of elements we managed a successful commissioning and first user run. We gained a lot of experiences and feedback from the operators. Now we will improve the operation to get a higher level of automation.

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