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IMPLEMENTATION OF A DIAGNOSTIC PULSE FOR BEAM OPTICS STABILITY MEASUREMENTS AT FLASH

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Abstract

In order to monitor long-term stability of beam optics, simple and at the same time minimally invasive procedures are desirable. Using selectively kicked bunches, betatron phase advance, as well as potential growth of the betatron oscillation amplitude and the Twiss parameters alpha and beta can be extracted from BPM data. If done periodically, this data can be compiled into a long-term history that is accessible via the control system. This way it is possible to identify potential sources of beam optics errors. At FLASH the procedure could be implemented as a server/client tool. Since the whole procedure takes less than five seconds, operation is not disturbed significantly. In this work the possible implementation of the procedure is presented. It is also shown how the history data can be evaluated in order to infer possible beam optics error sources.

INTRODUCTION

The high-gain free-electron laser FLASH at DESY, Germany produces ultra-short X-ray pulses with a duration less than 30 fs FWHH. These pulses are generated by the SASE process using a high brightness electron beam, which can be tuned to energies between 350 MeV and 1.25 GeV. This corresponds to a photon wavelength range between roughly 52 nm and 4 nm. Electron bunches are created by a laser-driven photoinjector and then accelerated by seven 1.3 GHz superconducting accelerator modules (*TESLA-type*). X-ray pulses are then generated inside the 27 m long undulator section. [1–3]

Since FLASH is a user facility, the long-term stability of the beam optics is crucial for all connected user experiments and the operation of the new second beamline FLASH2. In addition to that the seeding experiment sFLASH also demands for high beam optics stability. In [4] a simple procedure to monitor the beam optics routinely and at the same time minimally invasive was proposed. This work presents the actual implementation of the procedure at FLASH, as it is planned to be deployed during beamtime in the second half of 2015.

METHOD

The diagnostic pulse method is based on the idea of extracting beam optics stability information by measuring kicker magnet induced betatron oscillations of selected pulses periodically. These oscillations are measured by all available beam position monitors downstream the location of the kick. An online tool then analyzes the data. This way a long-term history of beam optics stability can be compiled.

The aim of the method is to reveal the cause of beam optics errors by correlating the long-term beam optics stability history with recorded machine parameters, or other events. A detailed description of the method can be found in [4].

IMPLEMENTATION

For the implementation of the method two schemes are possible. Table 1 shows the two possible scenarios at FLASH.

Fast Kicker

The first scheme is based on fast single bunch kickers. The main advantage of this scheme is the fact that it is minimally invasive and can potentially be run in the backround without disturbing any user experiments. At FLASH an appropriate fast kicker would be a dark current kicker at the beginning of the linac ($s = 0.45$ m). This device would then act as the only betatron oscillation inducing device (*DC-Kicker Scheme*). Being a sinusoidal kicker running resonantely at 1 MHz, the kicker can only be used in *single bunch mode*. Due to space constraints the installation of a second kicker is currently not possible. Since the DC-kicker only acts on the y-plane, information about the x-plane cannot be recorded. Because of the missing second kicker data analysis must rely on the *zero-crossing method*, as described in [4].

Slow Steerers

The second scheme (*Steerer Scheme*) relies on the use of two slow steerer magnets. By choosing a suitable set of steerers ($\approx \pi/2$ phase advance distance), it is possible to perform a complete trajectory fit. This then enables the extraction of beam optics parameters (like Twiss parameters β and α - see [4] for details). If two suitable sets of steerers are chosen, both the x and y plane data can be taken. First test measurements showed that in this scheme the whole procedure takes roughly 5 seconds. Therefore this scheme must be considered invasive, which is the main disadvantage. Two implementations of the *Steerer Scheme* are possible. The first one is an easy to use control panel and the other one is the integration of the diagnostic pulse measurement into the routinely performed shift documentation. This documentation already involves running several diagnostics and documentation related scripts. The diagnostic pulse measurement would then be added as another plug-in script to be run. Because of the invasive nature of the *Steerer Scheme*, currently the control panel is the favored approach.

Software

Independent of the choice of scheme, the implemenation of the diagnostic pulse measurement and beam optics stability history is based on a server/client concept. At FLASH many of the machine components are controlled via the DOOCS control system [5]. Therefore the diagnostic pulse

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Table 1: Two possible implementation schemes for the diagnostic pulse at FLASH. See [4] for details on the extractable quantities

Scheme	Planes	Extractable quantities
DC-Kicker	y	Ψ_y
Steerer	x,y	Ψ_l, A_l, β_l, α_l, B_{mag}

measurement is carried out by a rich *DOOCS middle layer server*. The server is written in C++ and uses native DOOCS APIs. As a result it can talk directly to existing middle layer servers such as the *orbit server*, which provides the BPM data. In addition to that the server can also perform the measurement itself by talking to the front-end servers, which control the steerer power supplies. All data aquisition is carried out with full 10 Hz repetition rate. The main server structure comprises of three parts:

- Control/Measure
- Results/History
- Settings

In order for the user/operator to control the measurement, a lightweight jDDD [7] control panel is provided (see fig. 1). The panel interfaces with the control and data properties the server provides. Figure 2 shows all currently implemented properties.

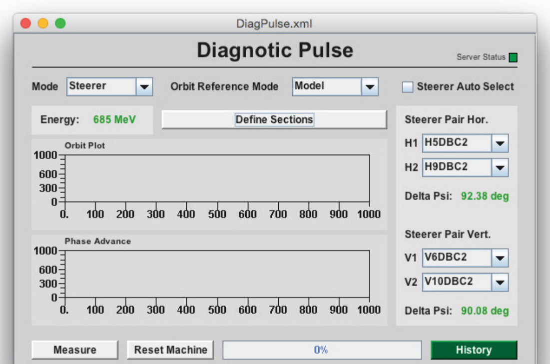

Figure 1: The jDDD-based control panel.

Control

Using the control property *Measure* the diagnostic pulse measurement procedure can be started. The server automatically disables any of the feedback systems that could interfere with the measurement. This is especially important when using the *Steerer Scheme*. By writing to the *ResetMachine* property the operator can stop the procedure and restore the machine settings to the state before the measurement was started. During the measurement the *Progress* property provides status information if needed (the measurement should be as short as possible).

Settings

The settings properties provide access to global settings. The most important are:

- Mode
- SteererAutoSelect
- OrbitReferenceMode

The property *Mode* can be used to switch between the two schemes that were discussed above (*DC-Kicker* vs. *Steerer*). If the *Steerer Scheme* is used the server can be instructed to select the two steerer pairs automatically by evaluating energy measurements (*SteererAutoSelect*). If not, the operator must provide a steerer pair setting manually (see fig. 1). The last main option *OrbitReferenceMode* defines whether the relative history data should be in reference to an ELEGANT [6] calculation, or an averaged measurement.

Results

The results part of the server provides the user with the last measurements and calculated quantities, as well as the long-term history of recorded and processed data. Since the phase advance is a beam energy dependent quantity and FLASH is run in several wavelength settings, the energy setting is recorded for every data point in the *Energy* property. In addition to that the complete orbit is saved for reference (*Orbit*). The most important part of the results section is of course the processed data part. Here - depending on the selected operation scheme - all available calculated physical quantities can be retrieved.

SIMULATION

The actual implementation of the tool at FLASH is currently planned as part of a beamtime slot in the second half of 2015. Therefore a long-term history of measured data can not be discussed here. In this section simulated long-term history data is presented. The same data processing routines as in the DOOCS server were used on the simulated ELEGANT based data. In order to test the scheme a FLASH virtual machine was setup in form of an OS X application. This tool was then used as a dummy machine for the diagnostic pulse server.

Test Cases

Figures 4 and 5 show simulated long-term history data of the phase advance difference $\Delta\Psi_y$ with respect to a previously recorded reference. For brevity only *DC-Kicker Scheme* simulations are shown. The data corresponds to the average value in four pre-defined machine sections (see fig. 3), which are defined by their end positions. From figure 4 it can be seen that all four sections show a response starting from data point 40. This is the data point where the error was applied to the virtual machine. This immediately implies an error source in the first section. The characteristic response (pattern) of the four curves matches the scenario of a phase drift in the first accelerating module (S1). Figure 5 shows

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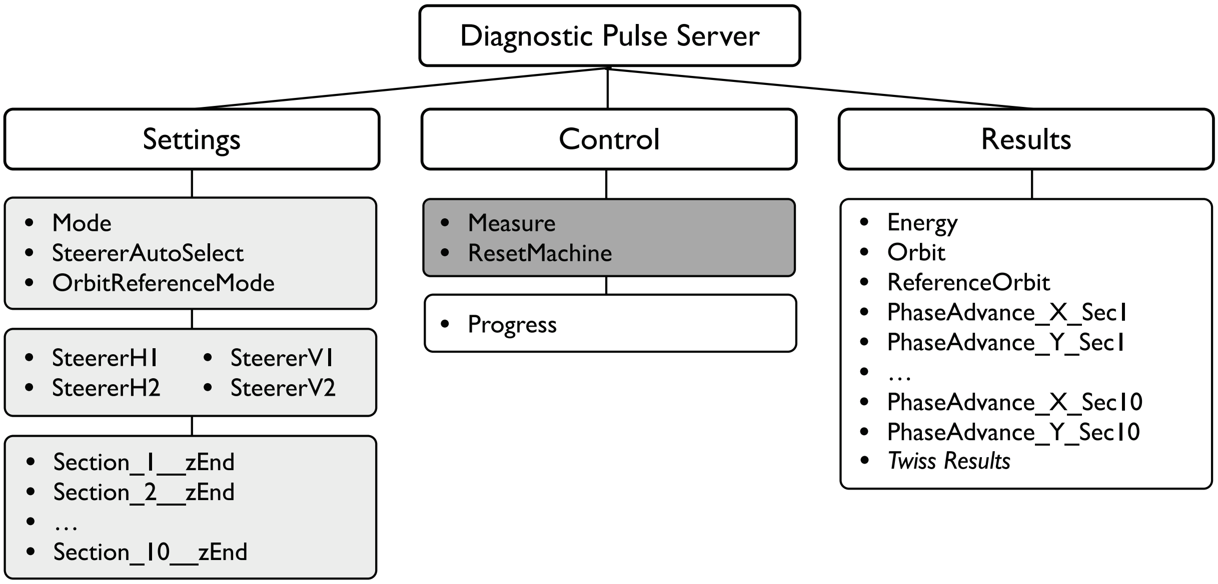

Figure 2: Structure of the rich DOOCS middle layer server.

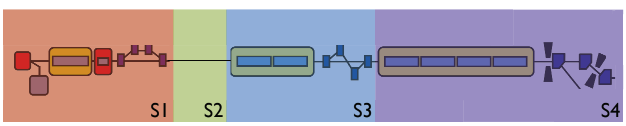

Figure 3: The four FLASH linac sections that were chosen for the test case simulations. S1: end of first bunch compressor, S2: start of 2nd accelerating module, S3: start of 4th accelerating module, S4: end of linac. The color coding corresponds to the one used in figures 4 and 5.

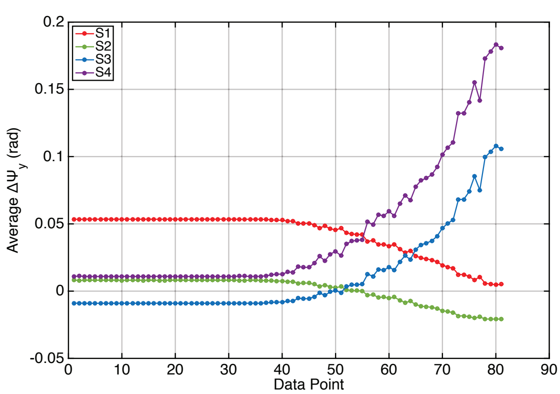

Figure 4: Test case 1: Phase drift + 1 % noise in the first accelerating module.

a scenario where quadrupole k-value errors are applied in S1 and from data point 60 a phase drift in the second accelarating module (S3). It can be seen that the errors from S1 propagate through all sections, whereas the phase drift can clearly be attributed to S3. Again a unique pattern for this accelerating structure can be seen.

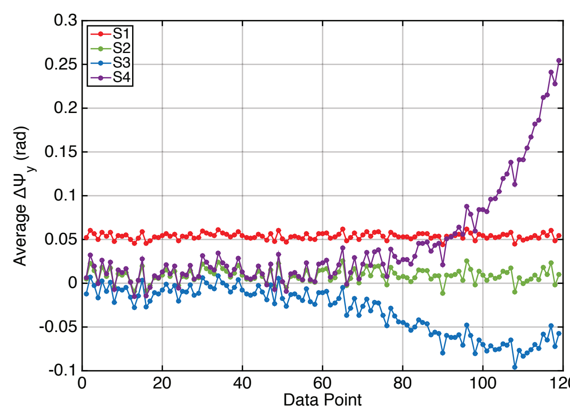

Figure 5: Test case 2: 0.5 % quadrupole k-value noise in S1 + phase drift in second accelerating module.

CONCLUSION AND OUTLOOK

The simulated data show that by analyzing long-term history data of calculated physical quantities such as the betatron phase advance beam optics errors can easily be monitored in different pre-defined machine sections. It can be seen that even from the very limited *DC-Kicker Scheme* data it is possible to extract useful information concerning beam optics stability and possible error sources. Therefore the data provide an additional diagnostic in the case of component failure. Further investigations concerning data analysis will focus on the detection of more complex error patterns from the history data.

The actual implementation of the measurement procedure and the data processing tools is planned to be carried out as part of a FLASH studies beamtime slot in the second half of 2015.

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