# Feedbacks and Automation at the Free Electron Laser in Hamburg (FLASH)

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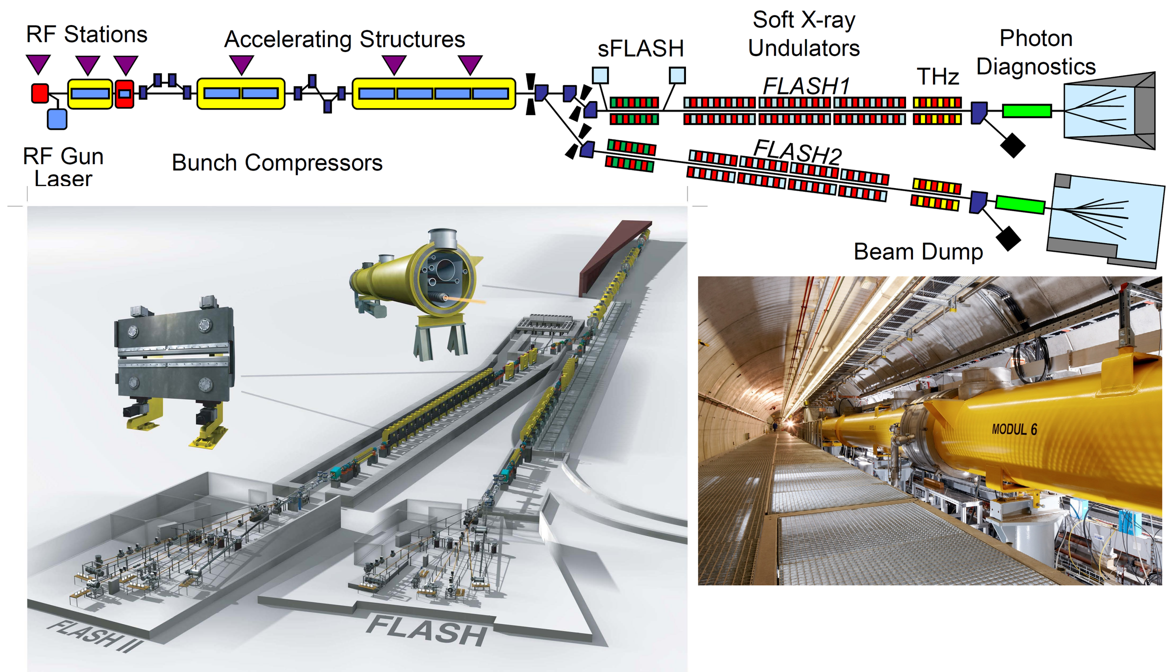
## Introduction

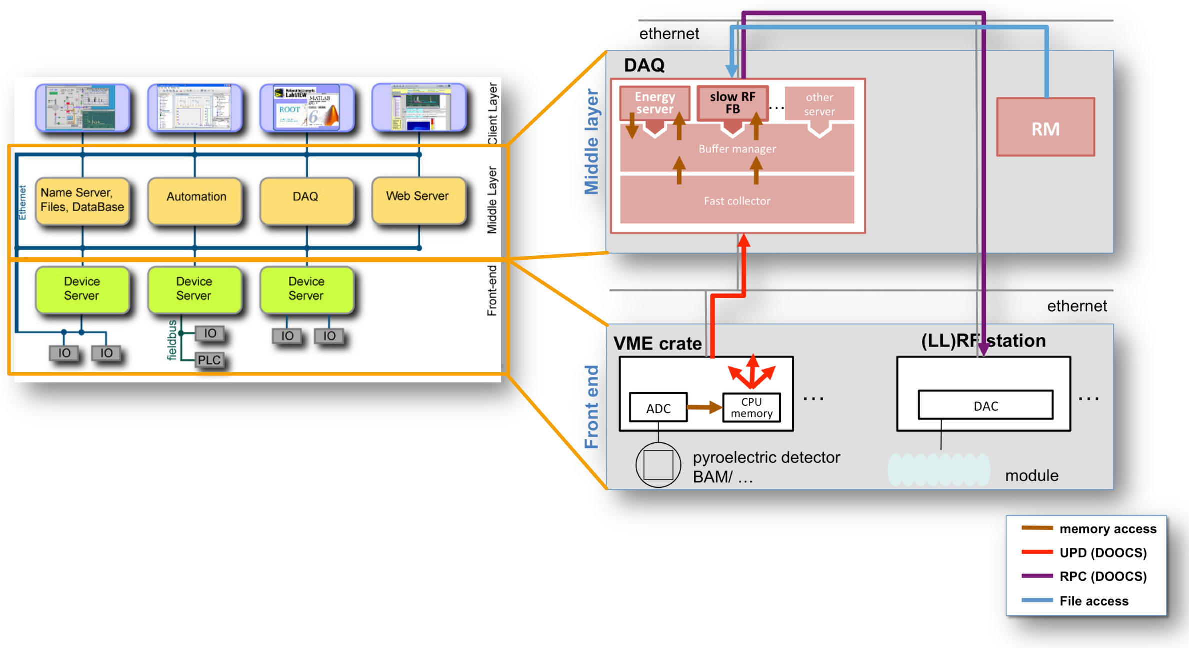
### The FLASH Facility

The Free electron Laser in Hamburg (FLASH) has been the world's first soft X-ray free-electron laser (FEL). It is available to the photon science user community for experiments since 2005. The main Linac is driven by seven superconducting accelerator modules. Many of the technologies in use have been further developed to adopt it at the European XFEL project (see e.g. **THCOBB02**). At the moment FLASH is extended by a second undulator line (FLASH 2) providing multiple photon users with beam at the same time.




### Control System Infrastructure at FLASH

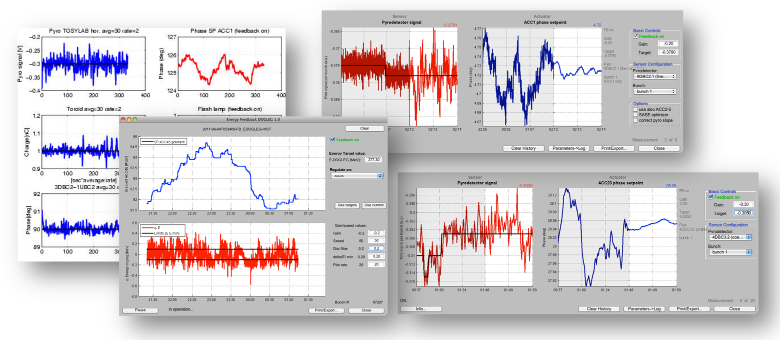
The prominent control system used at FLASH is DOOCS (Distributed Object Oriented Control System). A key concept of the here shown feedback loops is to use the central data acquisition service (DAQ – see [1]) for synchronizing all data of a single machine shot. This synchronized data can be used within so called *middle layer* servers to compute higher level monitoring data like e.g. beam energy (derived from beam position monitors plus optics data) or be used for feedback within the machine.




Data flow for a typical DAQ based middle layer server – here for the slow longitudinal feedback.

## Evolution of Feedbacks at FLASH

In the beginning most of the automation got its origin in simple processing scripts to ease operation "put together during a shift". At FLASH these where mostly Matlab scripts with rudimentary GUIs without or only poor exception handling.



Some examples of Matlab based feedback programs.

If such a tool has proven to be needed for standard operation it is good practice to turn it into a *server* properly integrated into the control system infrastructure.

As an example (and since it is an essential tool for standard operation of a FEL) the *slow longitudinal feedback* (also called *slow RF feedback*) will be discussed here in more detail.

## The Slow Longitudinal Feedback – Flexibility and Robustness

The feedback algorithm assumes that for a small change of the actuators ($\delta\mathbf{a}$) one can expect a linear response on the monitors ($\delta\mathbf{m}$). This very common and robust approach has been covered extensively in literature. Thus one can use the inverse of the response of all monitors ($\mathbf{R}$) to evaluate a global correction in one step as follows:

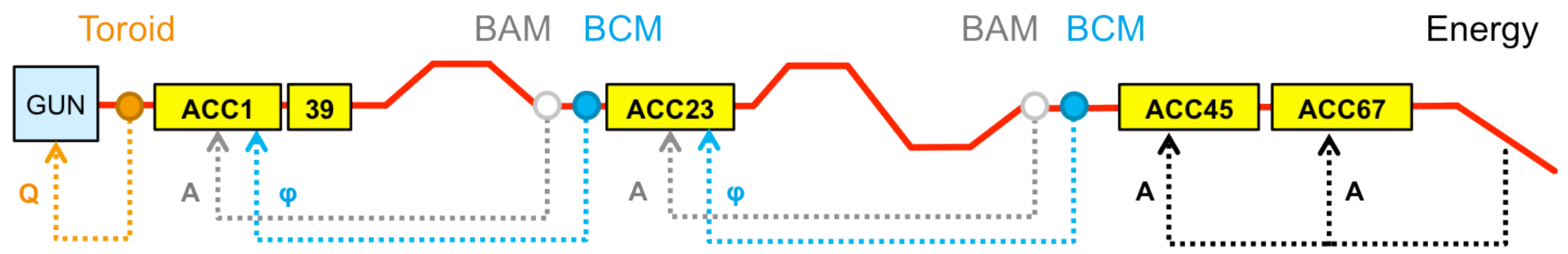
$$\delta\mathbf{a} = \mathbf{R}^{-1} \cdot \delta\mathbf{m}$$

$$\begin{pmatrix} \delta ampl_{ACC1} \\ \delta phase_{ACC1} \\ \delta ampl_{ACC39} \\ \delta phase_{ACC39} \\ \delta ampl_{ACC23} \\ \delta phase_{ACC23} \\ \delta ampl_{ACC45} \\ \delta phase_{ACC45} \\ \delta ampl_{ACC67} \\ \delta phase_{ACC67} \end{pmatrix} = \begin{bmatrix} R_{11} & R_{12} & \cdots & \cdots & R_{91} \\ & \ddots & & & \\ & & \ddots & & \\ & & & \ddots & \\ & 0 & & & \vdots \\ & & & & R_{99} \\ & & & & R_{910} \end{bmatrix} \begin{pmatrix} \delta BAM_{1UBC2} \\ \delta BAM_{BC2} \\ \delta BCM_{BC2}(fine) \\ \delta BCM_{BC2}(coarse) \\ \delta BAM_{BC3} \\ \delta BCM_{BC3}(fine) \\ \delta BCM_{BC3}(coarse) \\ \delta BAM_{1ACC7} \\ \delta Energy_{Dogleg} \end{pmatrix}$$

Here both the monitor and the actuator vectors include redundant entries so that one needs to do the proper wiping of columns and rows to select between the monitors/actuators of choice. The implementation of this matrix operations can be seen in the GUI showing the colored table (*Expert/configuration panel*).

## The Slow Longitudinal Feedback Loops at FLASH

In the current layout there are up to **six feedbacks loops** active along the electron beam-line to preserve the longitudinal phase space properties.




**Charge FB**
**Monitor**: Toroid directly behind the laser driven photo injector (GUN)
**Actuator**: rotatable **λ/2** plate in laser beam line

**Compression FBs**
**Monitor**: pyro-electric detector (BCM)
Actuator: RF phase of nearby module

**Beam arrival FBs**
**Monitor**: beam arrival time monitor (BAM)
**Actuator**: RF amplitude of nearby module

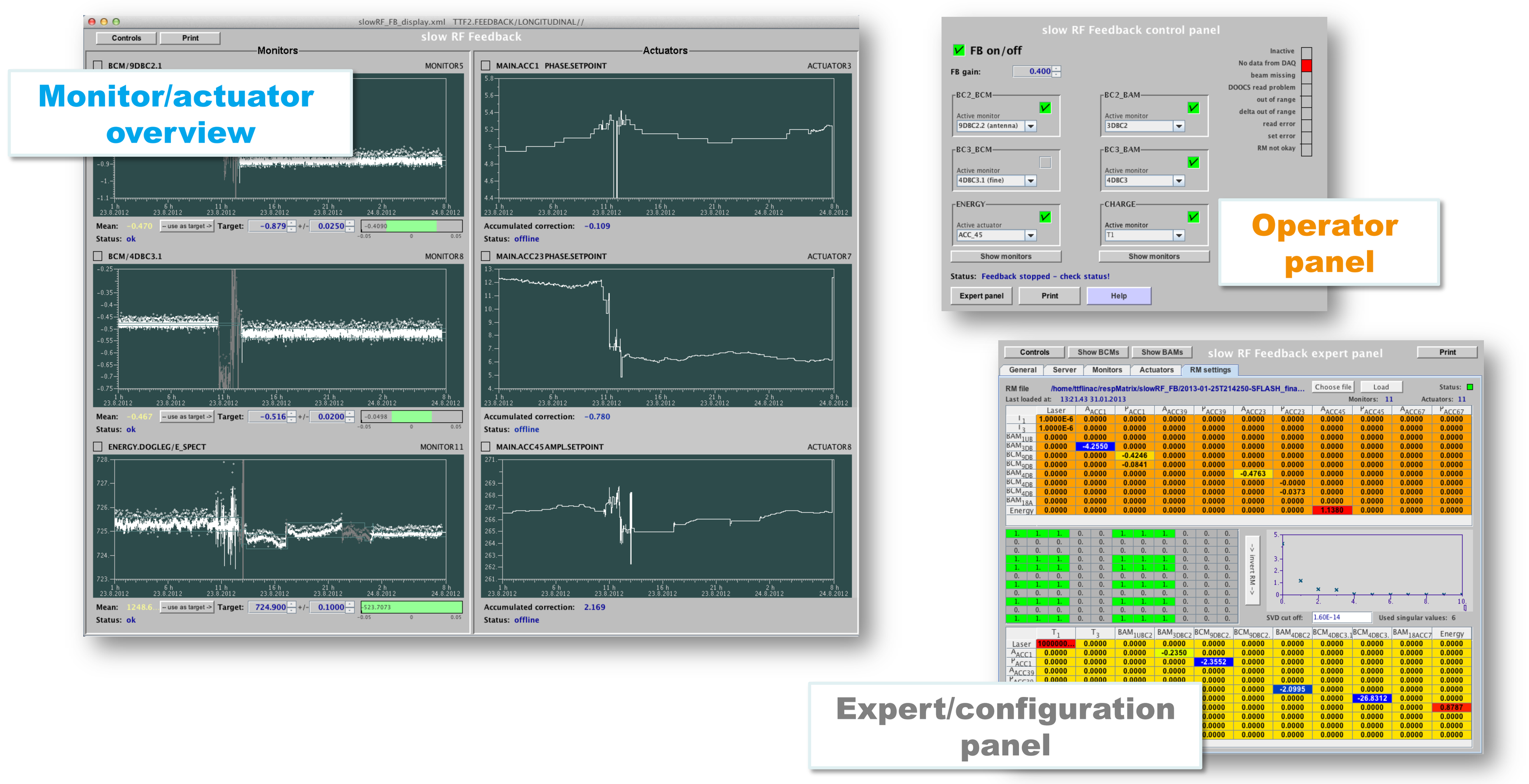
**Energy FB**
**Monitor**: Energy measurement in dispersive section
**Actuator**: RF amplitude of last modules

### Monitors, Actuators and the reality

While the charge can easily be measured using a standard toroid, the beam energy is determined using a spectrometric orbit measurement in a dispersive section using a middle layer server (see e.g. [2]). Technical details of the beam arrival time and bunch compression monitors have been discussed in e.g. [3].

The wide operation range of FLASH (bunch charges from 0.06 nC up to nC level, energies from 0.37 – 1.25 GeV corresponding to 45 – 4 nm) can causes the monitors to show nonlinear response. To get proper response of the FB loops for this wide range of operation, one can a) choose between different monitors and b) needs to measure the response matrix for each (strongly) differing operation point. Switching between different monitors is nicely integrated into the standard operation panels. Measuring of a response matrix is done using a Matlab GUI.

## The Slow Longitudinal Feedback – Operators' View




The operation of the slow longitudinal feedback is monitored and controlled using a set of panels created with the graphical control system editor *jddd* – see **TUPPC104**.

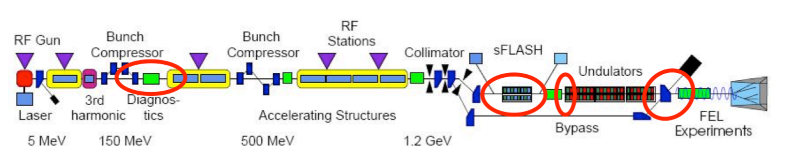
There are three levels/scopes of operation offering different complexity:

- **Operator panel**: **basic operation** e.g. to open/close individual loops (charge, BCMs, BAM, energy), overall FB status
- **Monitor/actuator overview**: **show FB performance** to monitor/actuator traces, set targets, monitor/actuator status
- **Expert/configuration panel**: **full expert view** which offers full access to response matrix, monitor/actuator details/configuration and much more

## Other (Slow) Feedbacks

### Orbit FB

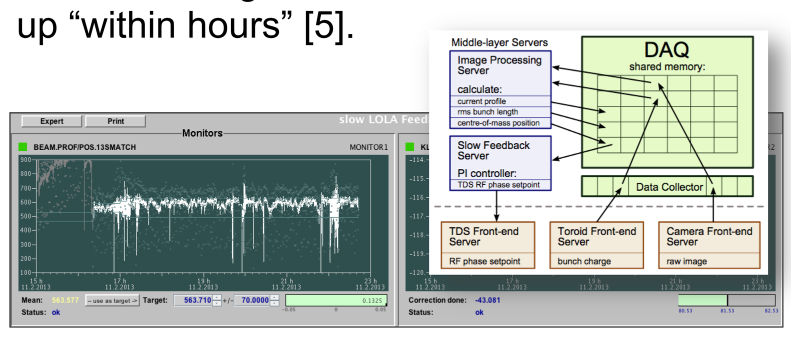
The orbit FB designed for standard operation at FLASH has been discussed on the PCaPAC 2010 [4] already. The schematic diagram below shows the locations where the orbit FB has been running successfully along the machine.




Sections where the orbit FB is used at FLASH.

### TDS RF FB

By simple cloning the slow longitudinal FB and proper configuration, a slow FB loop controlling the RF phase for a transverse deflecting cavity (TDS), which is being used for bunch length measurements, could be set up "within hours" [5].




A clone of the slow longitudinal FB used for stabilizing the streaked beam on an off-axis screen.

## Summary and Conclusion

Preserving the longitudinal properties of the electron bunches is essential for a FEL running as a user facility.

The daily routine operation of the shown server-based FB implementation has been proven to offer a robust, well maintainable and flexible solution to this common problem of automation and control for such complex machines as FLASH and will be well suited for the European XFEL purposes.

### References

[1] K. Rehlich et al., „*Multi-Processor Based Fast Data Acquisition for a Free Electron Laser and Experiments*", IEEE Transactions on Nuclear Science, vol. 55, no. 1, February 2008, pp. 256-260

[2] R. Kammering et al., „*DAQ based high level software applications using MATLAB*", PCaPAC 2006, Newport News

[3] W. Koprek et al. „*Intra-train longitudinal feedback for beam stabilization at FLASH*", FEL2010, Malmö, THOAI2

[4] R. Kammering, J. Carwardine, „*An orbit feedback for the Free Electron Laser in Hamburg (FLASH)*", PCaPAC 2010, Saskatoon, Saskatchewan 2013, WEPL015

[5] M. Yan et al., „*First Realization and Performance Study of a Single-Shot Longitudinal Bunch Profile Monitor Utilizing a Transverse Deflecting Structure*", BIC13, Oxford, 2013, TUPC36

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