BEAM-BASED FEEDBACKS FOR THE FERMI@Elettra FREE ELECTRON LASER*

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Abstract

FERMI@Elettra is a new 4th-generation light source based on a single pass Free Electron Laser (FEL) providing high peak-power photon pulses. It consists of a 1.5-GeV normal-conducting linac working at 50 Hz repetition rate and two chains of undulators where the photon beams are produced with a seeded laser multistage mechanism. A number of control loops, some of them working on a shot-by-shot basis, are required to stabilize the crucial parameters of the beams. For this purpose, a generalized real-time framework integrated in the control system has been designed to flexibly and easily implement feedback loops using several monitoring and control variables. The paper discusses the requirements of the control loops and the implementation of the feedback framework. A slow feedback system developed to support the commissioning operations is also presented.

INTRODUCTION

FERMI@Elettra is a user facility under construction in Trieste, Italy [1]. The accelerator is made of a high-brightness RF photocathode gun producing an electron beam with single-bunch structure at 50 Hz repetition rate and a 1.5 GeV S-band linac. Two FEL cascades (FEL1 and FEL2) with a total of 22 undulators provide the beamlines with tunable output over a range from ~100 nm to ~4 nm. In order to ensure the feasibility of the free electron lasing and the quality of the produced photon beams, a high degree of stability is required for the main parameters of the electron and laser beams. According to the experience of similar accelerators [2] and the FERMI@Elettra beam stability requirements [3], a number of beam-based feedback control loops are necessary.

The main beam instabilities to counteract are slow drifts due to temperature fluctuations and properties changes of the accelerator components. Possible instabilities are also expected due to mechanical vibration of quadrupole magnets, ripple of the magnet power supplies and jittering of the RF accelerating fields.

Being still unknown the characteristics of the perturbation sources, a comprehensive and flexible design using all the available sensors and actuators has been adopted for the feedback system, which is required to allow for fast bunch-by-bunch correction.

STABILITY REQUIREMENTS

Trajectory

The electron beam trajectory in the linac must be kept stable within ±30 μm with respect to a reference trajectory. Special attention is given to L3 and L4 linac sections (see Fig. 1) where the effect of the transverse wake-fields on the beam is higher. The trajectory has to be stable also in the laser-heater where the electron beam is superimposed to a laser beam inside an undulator to increase the energy spread and thus reduce micro-bunch instabilities.

In the FEL area where the seed-laser interacts with the electron beam to drive the free electron lasing, the electron trajectory must be preserved both at the entrance and inside the undulator chains with a relative accuracy of 2 μm.

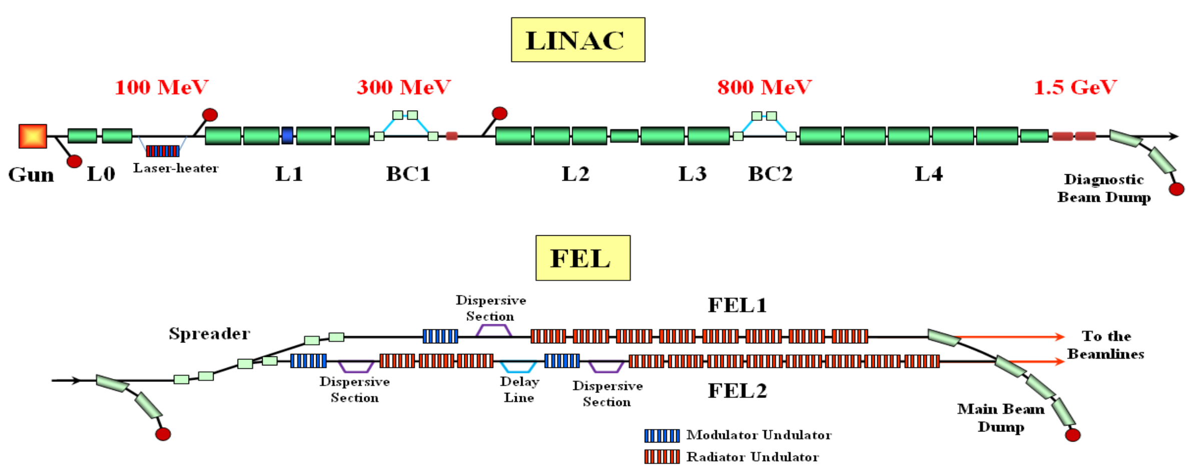

Figure 1: Layout of the FERMI@Elettra linac and Free Electron Laser (FEL).

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The feedback relies on 54 stripline (linac) and 20 cavity (spreader and FELs) BPMs providing a resolution of 5 and 1 μm respectively. The actuators are 73 corrector magnets of two different types: air-cored, used in the low energy part of the linac, and a more efficient iron-cored type in the rest of the machine. Additionally, two air-cored correctors are placed upstream each of the two undulator chains to allow for fast trajectory control. Both BPM detectors and corrector power supplies feature a suitable interface to the control system for shot-by-shot reading and setting of the values.

Energy and Peak Current

A maximum *rms* energy and peak-current variation of 0.1% and 10% respectively has been specified for the electron bunches in order to guarantee the requested FEL performance. These parameters are measured in three locations of the accelerator, Bunch Compressor 1 and 2 (BC1, BC2) and spreader (only energy), and corrected using the linac klystron phases.

The bunch compressors are made of eight-meter long four-dipole chicanes where the electron bunches are longitudinally compressed by a factor of ten in total. One BPM in the center of the chicane, where the dispersion is in the range 0.1-0.3 m, is used for the energy measurement. Assuming that the bunch charge is almost constant, the peak current is controlled by measuring the bunch length. For this purpose a Coherent Synchrotron Radiation (CSR) monitor at the end of each bunch compressor providing a relative accuracy of at least 5% is used. The energy measurement in the spreader region where the electron beam is deviated towards one of the two FEL undulator chains is provided by combining the readings of two BPMs located in positions with high absolute dispersion (0.1 m) and opposite signs.

Bunch Charge

The measured shot-to-shot *rms* variation of the photo-injector laser intensity is below the specified maximum variation of the electron bunch charge (2%). However, slow drifts and aging may affect the photo-cathode quantum efficiency. In order to preserve the specified charge stability, a slow correction feedback is envisaged that reads the bunch charge using a toroid and varies the laser intensity by using a variable attenuator in the UV range.

Laser Beams

The beam trajectory of the different lasers used at FERMI@Elettra (photo-injector, laser heater and seeding lasers) will be stabilized by slow feedbacks acting both on the IR and UV beams. The feedbacks use CCD cameras (requiring some image processing) and mirrors moved by piezo or stepper motors. In the case of the photo-injector, in particular, a virtual photocathode is created to measure the final laser beam properties. The requested position stability on the photocathode is 2% of the beam size.

Slow variations in the intensity of the laser beams will also be corrected by feedback loops. Energy meters and photodiodes can be used as sensors, while variable attenuators are adopted as actuators.

FEEDBACK LOOPS

The stability requirements described above involve several types of feedbacks each using a number of sensors and actuators. Although it is possible in principle to run one local feedback loop for each of the parameters to control (ex. trajectory at the entrance of L0), the effect of the correction performed by one loop on the downstream ones (ex. trajectory at the entrance of L1) can cause control problems and reduction of the closed loop efficiency. Cascaded local feedbacks where the upstream loops communicate the correction to the downstream ones have also been considered, as well as the global approach with many sensors and actuators used at the same time. The preliminary experience gained with the operation of slow global control loops developed in Matlab suggests that the global approach is more efficient and easier to implement. If this is the choice, a number of global feedbacks could be considered: e.g. trajectory feedback, longitudinal feedback (energy and peak current), etc.

The FERMI@Elettra fast feedback system has a centralized architecture where all sensors and actuators can be controlled in real-time from one single computer, with the advantage that any of the above control schemes can be easily implemented. Each of the feedbacks will be realized by one control loop using the appropriate inverted response matrix. Moreover, in case of significant coupling effects between different feedback loops (e.g. trajectory and energy of the beam could be reciprocally dependent) they can be taken into account using a combined response matrix considering also off-diagonal coupling terms.

FAST FEEDBACK SYSTEM

The fast feedback system is tightly integrated into the FERMI@Elettra control system [4]. The feedback architecture is shown in Fig 2. All of the sensors/actuators involved in the feedback are connected to the frontend computers (Equipment Controllers) with appropriate real-time interfaces allowing reading/setting of the values on a shot-by-shot basis at 50 Hz. An in-house developed software communication protocol (Network Reflective Memory, NRM) using broadcast UDP packets on a dedicated Ethernet network, allows the control system computers running Linux and the Xenomai real-time extension to easily exchange data with low latency.

A dedicated computer (fast feedback server) is in charge of running multiple feedback loops, which read sensors and set actuators through the real-time network and the equipment controllers at the bunch repetition frequency. Readings and settings are recorded in circular buffers and used for offline data processing and visualization. The same real-time communication framework based on the NRM is also used to distribute the bunch number to the equipment controllers, which is used as time stamp for data acquisition. The feedback loops can be configured and monitored from the control room through the Tango control system software using Matlab or graphical interfaces.

The basic control algorithm is a PID controller preceded by a low pass filter. With an inherent sampling frequency equal to the bunch repetition frequency (50 Hz), a maximum closed-loop attenuation bandwidth of a few Hz is achievable. Therefore, only slow drifts and low frequency instabilities can be addressed if the noise has a stochastic nature. Better performance can be expected if the noise is periodic and more sophisticated control algorithms such as notch filters or predictors can be employed.

Each control loop can be completely configured at runtime. Through the Tango interface it is possible to set the list of sensors and actuators to include in the loop, the repetition frequency, the set points, the control parameters and the inverted response matrix, which can be measured on the accelerator or calculated from the model.

The feedback system will also have additional features to manage anomalous situations, such as actuator saturation or temporary absence of the beam due, for example, to arcs in the accelerating structures. A tool based on the readings of the BPMs pickup sum-signal will provide in real-time information of the point in the accelerator where the beam is stopped, so that only a part of the feedbacks will be suspended while the rest will continue running.

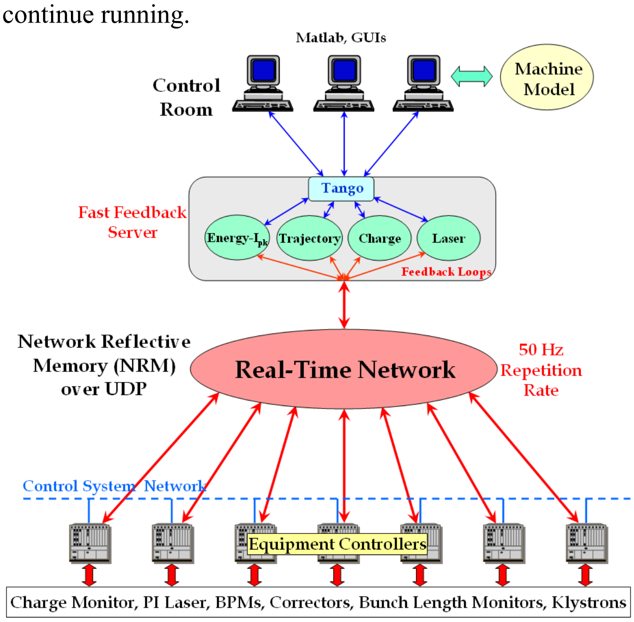

Figure 2: Fast feedback architecture.

SLOW FEEDBACK IMPLEMENTATION

The commissioning of the accelerator requires a software application to maintain some beam properties while performing measurements or optimization of other beam parameters. Given that the fast feedback loops are still under development, a slow feedback system based on Matlab has been developed meanwhile. It relies on the underlying Tango control system to access the accelerator devices. Similarly to the fast feedback philosophy, the slow feedback is flexible and simple to use, and can be easily operated by non-expert people through its graphical interface.

The core of the slow feedback is a Matlab script implementing a scheduler able to execute multiple concurrent feedback loops. Each loop can be individually configured by defining its repetition frequency, the type of input filter (average or median), the list of sensors and actuators to use and the control parameters. An additional functionality allows measuring the response matrix that can also be saved/loaded to/from a file together with the other feedback parameters.

So far three feedback loops have been tested: trajectory, bunch charge and energy. The trajectory feedback, in particular, represents an essential tool for the commissioning operations. Physicists use to configure it online according to the particular operation they have to carry out during a shift and consequently which part of the trajectory must be maintained stable.

CONCLUSION AND OUTLOOK

The commissioning of FERMI@Elettra has started in August 2009 with the setting-up of the photo-injector. The machine is presently in shut-down to complete the installation of the second part of the linac, which will be commissioned starting from June 2010.

An analysis of the real beam instabilities has to be carried out to identify the noise sources and undertake any possible action to eliminate or reduce them with passive cures. The residual perturbations will be addressed by the feedback system.

A slow feedback running in Matlab is currently used to support the commissioning operations, while a prototype of a fast trajectory feedback has been developed and will be tested during the next commissioning period.

The architecture of the fast feedback system enables the flexible implementation of different correction schemes and control algorithms. A number of feedback loops to stabilize some important electron and laser beam parameters have already been identified. Other loops will be considered depending on the necessities that will arise, including feedbacks to stabilize the photon beams in the beamlines.

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