Commissioning of the Fermi@ELETTRA Fast Trajectory Feedback

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Outline

- Feedback layout
  - Network
  - Frontend computers
  - Beam position monitors
  - Correctors

- Time schedule

- Algorithms

- Operative results
Feedback network layout

- **NRM**
  - distributed shared memory across cpus (Gigabit)
  - star topology, broadcast
  - max. propagation time: 1ms

- Trajectory feedback data payload: 3Kb x shot (150Kb/s)
CPU: Frontend Computers

- **Operating system**: Linux, kernel 2.6.25
- **Control system**: Tango

In order to support a 50Hz feedback, sensor acquisitions, processing and actuator settings have to be performed in just a few ms.

- **Worst jitter** case for a “simple application” running in userspace (plain Linux): 37 ms

- **Real-time patch**: Xenomai 2.4.8
- **Best jitter** case for a “small” piece of code executed in an interrupt handler (Xenomai): 23μs

Data acquisition and calculations are executed in the interrupt handlers of Gigabit, VME, and programmable timers.

Kernel module (xx.ko)

Tango Server

Shared memory
Stripline BPM

- 55 sBPM installed
- 6 VME PPC Crates
- Up to 15 sBPM x CPU

sBPM
- Libera Single Pass (I-Tech)
- 100 Mbit/s port for monitoring
- 1 Gbit/s port for data transmission
  - Each sBPM generates 1100 bytes (UDP) per shot (position + 4 raw waveforms)

CPU
- Data collected in the CPU ethernet
- sBPM positions acquired in about 140 μs

- Measured resolution: 10 μm rms
- Resolution goal: 5 μm rms
Cavity BPM

- 25 cBPM installed
- 3 VME PPC Crates
- Up to 12 cBPM x CPU

**cBPM**

- Two (ADC/DAC) uTCA boards (manufactured by Elettra):
  - ADO: get signals from cBPM frontend
  - ADA: drive calibration signal
- 100 Mbit/s ethernet port for monitoring and data transmission
- Each cBPM system generates 6.3 KB each shot (4 signal waveforms + 4 calibration waveforms)

**CPU**

- Position calculation and supervision performed on the CPU (ethernet ISR)
- Current max rep. rate: 10 Hz

- May 2011 measured resolution: 4 µm rms
- Sep 2011 measured resolution: 2 µm rms
- Resolution goal: 1 µm rms
Correctors

- 390 fast Power Supplies (cors,quads)
  - 146 of them are correctors
- 11 VME PPC crates
- Up to 40 PS x CPU

**PS**
- 2 Models: A2605 (5Amp), A2620 (20Amp) (manufactured by Elettra)
- 100 Mbit/s ethernet port
- Up to 200 Hz maximum current setting rate (UDP)

**CPU**
- 6 ms after the beam shot, a timer (10kHz) triggers a realtime process to send current settings (round robin scheme) to each of the PS
- correctors PS set in 2 ms

- A2605 stability (8h):
  - 50 ppm (full scale)
- A2620 stability (8h):
  - 50 ppm (full scale)
- Max. ripple (resistive load):
  - 30 ppm
- Max. settling time:
  - 9 ms
Feedback time schedule

0 ms: bunch number start propagation on NRM (1 ms)

1.2 ms: Fermi shot; acquired beam position from bpms (0.14 ms)

1.34 ms: bpm position values propagating on the NRM (1 ms)

3.0 ms: feedback calculations (0.6 ms)

3.6 ms: corrector values propagating on the NRM (1 ms)

7 ms: corrector ps set (2 ms)

9 ms: corrector current settling time (9 ms)

50 Hz mains

Processing + data transm. = 5.7 ms
Power supply = 9 ms
Idle time = 5.3 ms

Idle time = 5.3 ms
Power supply = 9 ms
Processing + data transm. = 5.7 ms
Feedback algorithms

- Since all feedback operations are performed in the intra-shot period, the closed loop dynamics is only dominated by one sample delay.

- Selectable input filters:
  - IIR
  - Median
  - Heuristic despiking rules

- PID controller + harmonic suppressors (notch filters)

- Developed a tool in Matlab to simulate the closed loop model

- Validated the real system (repetition rate 10Hz) with the model (beam excited with a set of sinusoids)

- MIMO: SVD to invert the Response Matrix
Feedback layout

Linac Fast Trajectory Feedback (FTF0)

100 MeV 300 MeV 800 MeV 1.5 GeV

Laser-heater L0 BC1 L1 L2 L3 BC2 L4 Diagnostic Beam Dump

Linac

200m

Linac Fast Trajectory Feedback: 34 BPM x 34 COR

Undulator Fast Trajectory Feedback: 8 BPM x 8 COR
Feedback configuration

- Feedback configured through Tango Devices (BPM, correctors)
- Feedback configuration (filters, matrices, weights) saved and loaded from it++ workspace files
Response matrix calculation

Shot to shot matrix calculation integrated in the feedback

- The power supplies are driven sequentially with multiple *programmable current ramps*

- In the meanwhile the BPMs are acquired *synchronously* to the corrector excitation

- If a corrector strength is so high to kick off the beam, ramp amplitude automatically is decreased and measure is repeated

- Algorithm calculates the response matrix correlating ramped kicks and trajectory distortions (linear regression)

- Calculation performed at the same time on *both planes* (option)
**Response matrix calculation**

- **Shot to shot matrix calculation integrated in the feedback**

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Response matrix calculation
Response matrix calculation
- a minimum of **4 shots** per corrector to get a reliable response matrix
- **20 s** to get the response matrix of both feedbacks at 10Hz linac repetition (4 s at 50Hz)
Closed loop data

Transverse beam stability specifications:
- $\leq 20 \, \mu m$ rms (hor/ver) in Linac area (avoid wakefields effects)
- $\leq 10 \, \mu m$ rms in Undulator area (to preserve FEL)

Noise sources (mainly in Linac):
- Thermal drifts
- Performance drifts of accelerators components
- Discharges in RF plants (spikes) and erratic trips of RF/Timing

Loop OFF
- Hor. avg. rms: 19 $\mu m$
- Ver. avg. rms: 10 $\mu m$

Loop ON
- Hor. avg. rms: 18 $\mu m$
- Ver. avg. rms: 11 $\mu m$

BPM resolution: 10 $\mu m$
Feedback operations

Feedback is used to:

- **Stabilize the trajectory** during experimental shifts.

- Perform **trajectory scans** into accelerating structures to find the trajectory which minimizes beam emittance: this is done with feedback ON by changing the setpoints.

- **Restore a golden trajectory**

- Decouple operations during machine commissioning shifts; keep the beam trajectory stable when:
  - **Change beam energy**:
    - Change RF phases
    - Switch off accelerating structures
  - **Change of machine optics**
GUI (provisional) configured on the fly by reading the list of bpms and correctors from the feedback Tango device

**Main commands**

- **On/ Off / Standby**
- **Goto Reference Trajectory**
- **SlowMode**
  - true: slow controller (\(k_i = 0.01\))
  - false: fast controller (\(k_i = 0.2\))
- **SteerMode**
  - true: no SVD regularization
  - false: Tikhonov regularization
- **ZposMin, ZposMax**
  Apply the feedback only on a part of the machine (meters from the gun)
Many thanks for your attention!!!