Bunch-by-bunch feedback commissioning at BESSY-II

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Outline

1. Hardware Setup
   - System Installation

2. Timing and Calibration
   - Calibration
   - Transverse Power Amplifier Setup

3. Beam Studies
   - Injection Transient
   - Longitudinal Grow/Damp Measurement
   - Transverse Grow/Damp Measurements
   - Synchronous Phase Transient
   - Steady-state Residual Motion
Work Summary

- Prepared all 4 iGp12 units for operation on the control network;
- Three baseband processors and the front/back-end are installed in the rack and connected to:
  - RF reference;
  - Fiducial;
  - BPM hybrid outputs;
  - Power amplifiers.
- Checked and adjusted power amplifier drive levels;
- Vertical plane has two combiners between iGp12 and power amp, need to recheck the drive level at some point.
Feedback Hardware

- Dimtel hardware installed in the ring;
- Fiducial signals use splitters:
  - Long transition times, significant jitter (1 ns) — need to find a sharper edge with better stability;
  - Using 6 dB attenuator to avoid magnetic saturation;
  - Try a DC block with low cut-off to eliminate the attenuator.
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Front-end Calibration: Transverse Plane

- Set up controlled orbit bumps in X and Y;
- Measure bunch signal displacement in ADC counts;
- At 1 mA per bunch ADC LSB is to 1.8 and 2.2 $\mu$m in X and Y respectively;
- To accommodate camshaft bunches had to increase X attenuation by 11 dB, Y — by 4 dB (6.4 and 3.5 $\mu$m LSB).
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Longitudinal Calibration

- Sweep phase shifter over 360°;
- Record bunch signal (average);
- Calibration factor of 9.32 counts/mA/degree;
- At 1 mA per bunch ADC LSB is 107 milli-degrees (600 fs);
- At 300 mA in nominal fill pattern the ADC range is only partially used, can lower the attenuation (18 dB now).
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Drive the single bunch at the betatron frequency;

- Adjust back-end delay;
- Record betatron oscillation magnitude;
- Optimal timing has 11.9 dB isolation;
- Can extract impulse response of the DAC/amplifier/kicker chain.
**Vertical Amplifier Response**

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**Vertical Amplifier: FIR Shaper**

- FIR shaper in iGp12 can pre-distort the kick to correct amplifier/kicker induced coupling;
- Response with shaper FIR $[-0.3 \ 1 \ 0.15]$;
- Isolation improved to 18.6 dB;
- Compare with the impulse response derived signal.
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**Vertical Amplifier: Optimized FIR Shaper**

- Using the measured impulse response, optimize shaping coefficients and timing;

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**Isolation vs. Config**

- No shaping: 11.9 dB
- Empirically optimized: 18.6 dB
- Numeric optimization: 23.4 dB
Performed empirical FIR shaper optimization in X;
Achieved the same isolation as in Y plane;
Should redo the timing to get a raw response sweep and optimize.
Injection transient captured on the waveform panel;

- Large excitation in the horizontal plane;
- Visible in the vertical plane as well.
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   - Steady-state Residual Motion
The beam is longitudinally unstable around 200 mA, stable at 300 mA;

Open-loop growth shows mode -1 (399);

Fast feedback damping;

Beating is due to mode 0 (driven motion) interference.
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Beating is due to mode 0 (driven motion) interference.
The beating can be eliminated by transforming to the true eigenmode basis;

- Assume signals in EFEM 0 and 399 are linear combinations of the true eigenmodes;
- A linear combination of these two modes can almost perfectly remove the beating.
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The beam is transversely stable at nominal chromaticity;
- Vertical grow/damp at -3.0 units, 263 mA, no camshaft;
- Modes -1 — typical resistive wall;
- Excellent fit in both open and closed loop.
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A Horizontal Grow/Damp Measurement

- Horizontal grow/damp at -3.0 units, 245 mA, no camshaft;
- Modes -1;
- Very fast damping.

BESSY II jar0513/2053521, S2=252mA, Dampq=1, ShiftGain=3, Nhumb=10000.
At Fs: G1= 52.7247, G2= 6, Ph1= 1.4513, Ph2= 0, Brkpt= 3732, Calib= 156.9839.
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Transverse Grow/Damp Measurements

**Vertical Growth Rates vs. Chromaticity**

- Automated analysis of multiple data sets;
- More or less linear growth rate increase with chromaticity;
- Not corrected for beam current variation;
- Growth rates are well within the range of the feedback system.
Transverse Grow/Damp Measurements

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Computed from a closed-loop measurement right after injection to 300 mA;
- Fill pattern estimated as 5 mA in each camshaft bunch, 278 mA in the train;
- Large transient of 26° peak-to-peak.
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Steady-state Residual Motion

Longitudinal Plane

- Filtered with 3 dB bandwidth 3.95–6.25 kHz;
- 0.013° mean, 0.016° RMS, 0.28° peak;
- Variation is consistent with the loop gain loss due to the synchronous phase transient.

BESSY II: jan0513/213910: I0= 298mA, Dsmp= 1, ShlGain= 6, Nbun= 292,
At Fs: G1= 210.6183, G2= 0, Ph1= -117.9657, Ph2= 0, Brkpt= 22434, Calib= 10.54.
BESSY-II longitudinal: mean closed-loop oscillation amplitudes

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Transversely, closed-loop data underestimates the true residual amplitudes;

Filtered with 3 dB bandwidth 174–192 kHz;

2 µm mean, 2.2 µm RMS, 8.5 µm peak;

More indicative of the ADC quantization noise floor, scaled by the bunch current.
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**Vertical Plane**

- Filtered with 3 dB bandwidth 323–341 kHz;
- 2.5 $\mu$m mean, 2.8 $\mu$m RMS, 14.7 $\mu$m peak;
- Bunch 4 stands out due to the fiducial jitter coupling.
Steady-state Residual Motion

**Vertical Plane**

- Filtered with 3 dB bandwidth 323–341 kHz;
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Summary

- Successfully commissioned bunch-by-bunch feedback in all three planes;
- Strong feedback opens possibilities for lowering chromaticities, changing fill patterns, etc.
- Expect the operating regimes and configurations to evolve with experience and machine requirements.
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