Bunch-by-bunch Feedback System for Hybrid Filling and Recent Topics in SPring-8


JASRI / SPring-8

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SPring-8 Storage Ring

- Energy: 8 GeV
- Revolution Period: 4.79 μs (C = 1436 m)
- RF frequency: 508.6 MHz
- Average Current: 100 mA

Transverse Feedback For Hybrid Filling
- High Bunch Current Singlet + Thin Bunch Train

Longitudinal Feedback
- New Type Energy Kicker (High Shunt Impedance/m)
- Simple Driving Circuits (No QPSK modulation)

Collective Effects
- Burst CSR by Microwave Instability

2ns 50kV Bucket-by-Bucket Injection/Extraction Kicker
- for off-axis injection for 2mm dynamic aperture
- for on-axis injection/extraction for narrower aperture
- Wide (infinite) Horizontal Physical Aperture
Hybrid Filling with High Current Singlet Bunch(es)

Singlet

5mA/bunch (25nC)

11/29 fill 95mA
~ 0.1 mA/bunch
bunch train

1.5 μs

Single-bunch Instability
Mode-coupling (H, V)
Broad-band geometrical impedance
+ Resistive-wall In-Vacuum IDs

Multi-bunch Instabilities
Cavity HOM (H)
Resistive-wall (H, V)
In-Vacuum IDs

Transverse Bunch-by-bunch Feedback System
Feedback System for Hybrid Filling

* 5mA/bunch (singlet) ⇔ 0.1 mA/bunch (train)

System saturates with large BPM signal of 5mA/bunch

* Bunch Current Sensitive Attenuator for BPM signal

* Extra Vertical Feedback Loop for Singlet(s) (> 3mA/bunch)
  Independent tuning: FIR filter, gain, kick width

* Suppression of Single-bunch instability

Installed/Tested  Light sources and Hardon rings
* SOLEIL, SSRF, KEK-PF, TLS, HLS, PLS, PLS-II, New SUBARU, Aichi Synchrotron
* 10ns/2ns **Part-by-Part Feedback** for Long Bunch/Coasting Beam
  KEK-PS (Proton long bunch, for head-tail ),
  S-LSR  (Proton coasting beam)
  (for detail, visit http://acc-web.spring8.or.jp/~nakamura)
FIR filter to produce Phase Shift
Position and Kick: -90deg at kicker

Number of Taps

FIR filter

Kick

Bunch Position
turn-by-turn History

\[ y_n = \sum_{k=1}^{N} a_k x_{n-k} \]

Bunch Position

Kick

-90 deg Phase Shift

Current Turn

Turn No

HOW?
Bunch Current Sensitive Attenuator for BPM signal

BPM

Storage Ring

Kicker

Bunch Current

SensiCon

Digital Control

Analog Control

ADC

DAC

FPGA

508MS/s

Signal Divider

Bunch Current Sensitive Attenuator

Fast variable attenuators x 1/Bunch Current

Position

Kick Signal

Singlet

Bunch train

Singlet

Bunch Current x Position

Bunch Current

5 mA/bunch

0.1 mA/bunch

A+B

A-B

A+B

A-B

A+B

A-B

A+B

A-B

A+B

A-B
Feedback for Vertical at Bunch current > 3mA/bunch

Based on SPring-8 Feedback Processor

**BPM**

- **Current**
  - $0.1\text{mA/bunch}$

- **Kicker**
  - **train**

**Feedback**

- **for Vertical at Bunch current > 3mA/bunch**

**SPring-8 Feedback Processor**

- **508MS/s**
- **FPGA**
- **PosiCon Kick ADC**
- **ADC**
- **Signal Divider**
- **Bunch Current Sensitive Attenuator**

- **Gate Generator**

**Singlet**

- **5 mA/bunch**

**Bunch Current x Position**

**Bunch Current ON/OFF**

**Digital Control**

**Analog Control**

**FPGA**

- **Bunch Current**
  - ↓ **Attenuation**

**Signal Divider**

**FPGA**

- **Position Kick**
  - ↓ **DAC 6508MS/s**

**Bunch Current ON/OFF**

**Gate Generator**
Instability Strength Monitoring

\[ G \propto \sum \frac{(ID \text{ Length})_i \langle \beta_{y,i} \rangle}{(ID \text{ gap})_i^3} \text{ for all In-vacuum IDs} \]

All In-vacuum IDs are minimum gap

Value for Stability Test Routine

Values at User operation

1 year
Suppression of Single-bunch instability by Feedback

mode-coupling (fast head-tail) for V (and H : weak)

Chromaticity = 1 ( < 3 ) for wide dynamic aperture

In-vacuum IDs **Open**

3.5 mA/bunch => 14 mA/bunch
Feedback OFF ON

~ simulation result

In-vacuum IDs **Close** (Partly ~ user operation)

2.5 mA/bunch => 6 mA/bunch
Feedback OFF ON

5 mA/bunch for User operation
Simulation

Home made code (SISR)

Wake potential

Geometrical wake : Simulation by MAFIA bellows, weldments, flanges, RF cavities, tapers, BPMs, offset

Resistive-wall wake : Theoretical Wake CSR not included

Microwave instability Threshold :

~ 3mA/bunch for CSR (theory)

Simulation based on Geometrical Wake Observation

http://accelconf.web.cern.ch/accelconf/e96/PAPERS/WEPIG/WEPI04G.PDF
Comparison with Experiment

Longitudinal

**Bunch Shape**

- Measured
- Simulation

**Energy Spread**

- Additional inductive wake ~ 40nH is required for bunch length
Comparison with Experiment

Vertical Single-Bunch Instabilities

Simulation based on Calculated Wake Function

-4.3  0.5mA/bunch (m=0 head-tail)
0.24  3.5-4mA/bunch (mode-coupling)
Vertical Beam Size Growth by ID radiation profile monitor

Injection ~50ms

Vertical Width
6.2mA → 1.3mA

Relative Vertical and Horizontal Widths

Vertical Photon Beam Size Growth

Stable Photon Beam Width = 1

Low chromaticity
- low growth rate of beam size
- low threshold bunch current

Feedback suppresses only
- CM motion chromaticity
- mixing of CM motion and head-tail motion

Indirect suppression of head-tail motion ??
High Feedback Gain for Vertical
  ~ Stability Limit of the feedback

To High Feedback Gain
  => Tune shifts to Unstable region (FIR filter phase : 0deg to 180 deg )
  => Unstable or Fragile against perturbation

Selection of FIR filters
  Vertical Fractional Tune  0.35
  3-taps
Feedback Stability and FIR filter response

\[ y_n = \sum_{k=1}^{N} a_k x_{n-k} \]

To High Feedback Gain

=> Tune shifts to Unstable region (FIR filter phase : 0deg to 180 deg )

=> Unstable or Fragile against perturbation

Feedback Output saturated by the oscillation signal

~ Fractional tune = 0.5

3gap (Red line) => 4tap (Green line) : solved
CM motion feedback
  Further improvement of the bunch current is hopeless...

Head-tail motion feedback ????
  Head-tail Kicker is designed
  Head-tail Motion detector : now trying ....

This Autumn ????

Collaborators are welcome!
Longitudinal Bunch-by-bunch Feedback

Longitudinal Instability Driven by Cavity HOM (TM011)
8 GeV: stable ~ 100mA, 6 GeV: ~ 90 mA, 4 GeV: ~ 20mA

New Shape Energy Kicker

- High Shunt Impedance / m : x3 of over damped cavity (ODC) type
- Higher Frequency 13/4 fRF = 1.65 GHz ( != 11/4 for ODC type )
- 3 waves + 1/4 ↔ 2 waves + 3/4 wave for every buckets
- => Eliminate QPSK modulator at cavity drive stage

HOM damper

10cm

1/4 part
Input port
HOM damper

20 mm
45 mm

530mm for 3 cells

**Simple Drive Circuit for Kicker** : $13/4 f_{RF}$ (Passive, No QPSK)

$T_{RF} \approx 2\text{ns}$

Feedback signal (DAC output)

Pulse Generator(81134A) -> Impulse forming network

Splitter

$2T_K$ -> 1dB

Combiner

$T_K$ -> 1dB

Phase Detector

BPM

Beam

Kicker

200W

500W
Development of New Feedback Processor

Current Processor : 2003 10 years ago
New Processor is being developed at SPring-8
  Collaborating with SOLEIL

Advances of
  FPGA (Virtex-7)
    Faster and Larger circuits
  ADC (12-bit, 500MS/s)
    1 ADC <= 4 ADC 127MS/s)

Many ADCs and DACs
Ethernet
Hardware + FPGA program until this Autumn (Hopefull)

Hardware/Software is Open and Free
Collaborators are welcome!
Faster and more Stable Feedback

One turn data => Kick
No Tune Shift by Feedback => More FB Gain

Kicker

BPM 1 → ADC → Gain → $x_1$
BPM 2 → ADC → Gain → $x_2$
BPM 3 → ADC → Gain → $x_3$
BPM 4 → ADC → Gain → $x_4$
BPM 5 → ADC → Gain → $x_5$
BPM 6 → ADC → Gain → $x_6$
BPM 7 → ADC → Gain → $x_7$
BPM 8 → ADC → Gain → $x_8$

$y = \sum_{k=1}^{8} a_k x_k$

DAC

508MS/s

€ = a_k x_k

\text{Kicker Faster and more Stable Feedback}
Hirose_U.FL connectors from/to board

DAC board (FMC on FPGA board)

FPGA board (red board)

ADC board (FMC on FPGA board)

Ethernet port (not connected. intelligent GbE board (FMC) will be installed this FSY)

DAC output ports

SD for parameter file

mini SD for configuration

DAC on/off indicators

ADC overflow indicators
50kV Variable Field Fast Kicker for 2ns Bucket-by-bucket Injection/Extraction

Dipole Kick
11 MeV/m (+50kV,-50kV)

Quadrupole Kick at 2mm
4 MeV/m (+50kV,+50kV)

50kV test at Bench
No discharge
good pulse response
Beam test at Linac with
1 pulse generator
=> Consistent with design
kick width ~ 4ns : OK

Field Strength Distribution in Horizontal

Dipole Kick
11 MeV/m (+50kV, -50kV)

Quadrupole Kick at 2mm
4 MeV/m (+50kV, +50 kV)

Electric Field [V/m]
Horizontal Position [mm]

On-axis Injected
Off-axis Injected
Stored
High Transverse Impedance (Horizontal) !!

Loss Factor
Horizontal value ($k_x$) is $\times 70$ of our Bunch-by-bunch kicker

Gap Dependence of Quadrupole Field Strength
Quadrupole $\sim 1/(\text{gap})^2$
(Dipole $\sim 1/\text{gap}$)