BI feedbacks

SY-BI: D. Louro Alves, L. Grech, S. Jackson
Beam-Based Feedback introduction

- Fast feedback loop with FESA class
  - Beam Feedback Controller (BFC)
  - Developed by SY-BI
- Keep orbit & tune @ reference
  - Orbit Feedback (OFB)
  - Tune Feedback (QFB)
- Critical LHC system
  - Especially during dynamic phases (e.g. Ramp)
System overview

- BBQ
- BPMs
- FGCs
- RF
- BFC (FESA)
- RDA
- UDP
- JAPC
- NXCALS
- LSA
- LumiServer
- YASP
- Dashboard / Expert App
- DB Config App
- HW Config App
- LHC Seq.
HW & FESA API renovation

- Significantly faster HW
  - 64-core CPU & 200 GB RAM
  - Operational + spare (testbed) machines
- Major architecture refactoring, of note
  - Eradicated initial Root obj. initialization
  - Removed internal Ethernet link
  - Merged Service Unit & Controller
- New architecture based on FESA3
  ✓ Simpler and more maintainable

[1] TESTING FRAMEWORK FOR THE LHC BEAM-BASED FEEDBACK SYSTEM (S. Jackson et al.)
HW & FESA API renovation

● New features
  ○ Function-driven behavior
  ○ Reimplemented optics (twiss) handling
  ○ Faster and parallelized Response Matrices calculations
  ○ Better integration with LHC control system

● Studies and prototypes (L. Grech et al.)
  ○ “Feasibility of Hardware Acceleration in the LHC Orbit Feedback Controller”
  ○ “An Alternative Processing Algorithm for the Tune Measurement System in the LHC”
  ○ “A Machine Learning Approach for the Tune Estimation in the LHC”
Operational-side improvements

- Settings were a bit spread out ...
  - LSA, Sequences and BFC init values
  - Confusion & inconsistencies
- Consolidation and simplification
  - LSA as source of truth
    - Make Rules & Value Generators
  - References from operational settings
    - Orbit ref. from BPM ref.
    - Tune ref. from new TUNE_TARGET knob
- Nominal operations via LHC Sequencer
Operational-side improvements

- Operational apps & projects zoo …
  - Requirements evolved with experience
- New & heavily refactored apps
  - HW Configuration app
    - Mapping files & Tune RM generation
  - DB Configuration app
    - LSA Trims, Optic & Ref. Orbit management
  - Dashboard & Expert GUI
    - Dashboards & tools for MDs/commissioning
- Simplified YASP-OFB integration
OP API renovation

- Java API on top of BFC FESA class
  - Integration with CCC ecosystem
  - Ensure correct usage of FESA API
  - Move complexity away from apps
    - *E.g. LHC Seq. agent from 3k+ loc to ~600*
  - Flexible abstraction layer for OP
- Extends BFC API
  - *E.g. “load LSA orbit as reference”*
- Opens the door to testing
  - New specific testing framework
Automatic testing

- Goals
  - Peace of mind when refactoring
  - Reduce commissioning time
  - Requirement validation
  - Encourage “good programming practices”

- Reproducible environment
  - Gitlab CI
  - Testbed machine in simulation

- Closed loop simulation tests
  - Behavior verification (“Does it converge?”)

```java
@Test
public void whenRunning_sendingPauseAndResume_shouldPauseAndResume() {
    ensureRunningFor(Duration.ofSeconds(15), () -> {
        sendFunctionPlayerEvent(PAUSE);
        awaitState(functionPlayerState(), PAUSED);
        sendFunctionPlayerEvent(RESUME);
        awaitState(functionPlayerState(), RUNNING);
    });
}
```
Orbit closed loop simulation

New orbit as BPM UDP Packets

Testing framework

\[ \Delta \text{Position} = \text{RM} \cdot \Delta K \]

OP API (Java)

RefOrbit

Optic

BFC (FESA)

Deflections (\(\Delta K\))

ΔPosition = RM \cdot ΔK
Tune closed loop simulation

New Tune reading RDA publication

BBQ Simulation Class
(Java RDA Server)

Q = ΔQ

OP API
(Java)

RefTune

Tune gain

BFC
(FESA)

Tune Trims (ΔQ)
Continuous integration

- Automatic full-stack validation
  - Run on commit and daily
  - Based on Gitlab CI Pipelines
  - Currently ~100 unit tests
  - Report in case of errors
- Detailed history of issues
  - “This happened before…”
- Better development cycle
  - “It worked on my machine…”
Beam test results

- Successfully commissioned!
  - New BFC FESA class
  - OP API + applications
  - LSA settings + sequencer tasks
  - Trim orchestration (e.g. lumi levelling)
- Some issues ironed out on the way
  - Mostly only discoverable with beam ...
- Excellent behavior during ramp @ 3.5 TeV
- Invaluable feedback and experience
  ➔ Smooth start of Run3
Beam test results

Orbit RMS evolution during ramp

... only 200 Ev
Beam test results

Tune error evolution during ramp

... some coupling
Conclusions

● Beam test was very important!
  ○ Minor issues fixed
  ○ Invaluable feedback
  ○ Significant head-start for 2022

● Success recipe
  ○ **Collaborations** & synergies are paramount
  ○ **Testing** & simulation are a MUST
  ○ Embrace change & **best-practices**

● No impact of 1-year extension of Run3
Extra
Coupling abs evolution during ramp

- Coupling B1
- Coupling B2
**Container ??**

- Isolated environment
  - Apps have their own OS* and environment
  - No dependency on host OS
- Reproducible
  - Work on any OCI-compliant** container engine
- Resource optimization
  - Many heterogeneous app can share HW
- Many more features…
  - … orchestration, scaling, blue/green updates, …
  - … not in the scope of this project

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* Host OS kernel is shared → low performance impact vs full VM
** Open Container Initiative → makes containers portable
Another test example

```java
@Test
public void arm_validRefOrbitTimeEvolution_shouldPlay() {
    RefOrbitTimeEvolution refOrbitTimeEvolution = ...
    sendRefOrbitTimeEvolution(refOrbitTimeEvolution);
    ...
    sendFunctionPlayerEvent(ARM);
    awaitState(functionPlayerState(), ARMED);
    ...
    runWhileSendingOrbitTriggersEvery(Duration.ofMillis(80), () -> {
        sendFunctionPlayerEvent(TRIGGER);
        awaitState(functionPlayerState(), RUNNING);
        awaitState(functionPlayerState(), IDLE);
    });
    assertThat(referenceOrbit().get()).isEqualTo(refOrbitT2);
}
```
References

• Testing Framework for the LHC Beam-based Feedback System
  Jackson, Stephen (CERN) ; Alves, Diogo (CERN) ; Di Giulio, Letizia (CERN) ; Fuchsberger, Kajetan (CERN) ; Kolad, Blazej (CERN) ; Pedersen, Jens (CERN)

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