Functional requirements, design and performance of the transverse damping system for FCC-hh

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**Transverse feedback system**

- **Pickup**
- **Kicker**

Transverse feedback systems are used for damping transverse oscillations of the beam. These oscillations together with nonlinear imperfections of the accelerator lead to emittance growth, beam quality reduction and potential beam losses.

The main sources for the transverse beam oscillations in FCC-hh are injection errors and wakefields caused by impedances and electron could effects. The transverse feedback systems can be designed as a bunch by bunch system for injection errors and coupled bunch instabilities or a wideband system for intrabunch oscillations (headtail instabilities).

![Coupled bunch instability](image1)

**Headtail instability**

- **Signal processing**
- **Delay**
- **Power amplifier**

- **RMS bunch length**
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These preliminary coupled bunch instability simulations have been performed in time domain using the FCC-hh impedance model and a point-like bunch. The bandwidth of the feedback system was limited by using a Gaussian filter and the vector sum based correction algorithm was used with a one turn delay.

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**Scaling toward FCC-hh**

<table>
<thead>
<tr>
<th>LHC</th>
<th>FCC-hh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection beam energy</td>
<td>0.45</td>
</tr>
<tr>
<td>Circumference</td>
<td>26.7</td>
</tr>
<tr>
<td>Bunch Spacing</td>
<td>25</td>
</tr>
<tr>
<td>Number of bunch slots</td>
<td>3564</td>
</tr>
<tr>
<td>RMS bunch length</td>
<td>0.3</td>
</tr>
</tbody>
</table>

- **LHC transverse damper**

  - **Static injection error**
  - **Injection error ripple**
  - **Batch spacing**
  - **Coupled bunch instability growth rate**
  - **Lowest frequency to damp**
  - **Highest frequency to damp**
  - **Nominal pass band voltage**
  - **Number of kickers per beam and plane**
  - **Kicker plate length**
  - **Total kick per turn at injection**
  - **Damping time (<1 MHz)**

- **TTPK109, IPAC 2017, Copenhagen, Denmark, May 2017**

**Studied challenges from the beam dynamics point of view**

**Coupled bunch instabilities during injection and ramp**

**FCC-hh impedance model**

Between the injections and during the ramp it is required that the transverse feedback system suppresses coupled bunch instabilities. Preliminary simulations show that at least 10 MHz bandwidth (f, of a Gaussian filter) and 100 turn damping time are required. The required damping time is consistent with the earlier estimations of the growth rates.

Single bunch simulations with the FCC-hh impedance model at zero chromaticity show that the bunch by bunch damper induces intra-bunch oscillations even below the TMCI threshold. An accurate theoretical treatment is under investigation, but the phenomenon has been observed using different feedback techniques and impedance models. One method to stabilize these oscillations is to use a 1-2 GHz wideband feed-back system.

**Intra bunch oscillations induced by the bunch-by-bunch damper**

**Developed simulation tools**

In order to study the requirements and technological solutions for the transverse feedback systems of the FCC-hh, new simulation tools have been developed.

**Framework for finite length signal processing**

A new framework for the finite length signal processing was developed in Python [3]. The framework can be used as a PyHEADTAIL module or as a separate tool for technological optimization of feedback systems. The single bunch version of the framework has been used since summer 2016 and the next, multibunch version is currently being benchmarked.

**PyHEADTAIL parallelization for MPI**

PyHEADTAIL was originally developed for single bunch instabilities. In order to get reliable results for the FCC-hh requirements and technological solutions, multibunch simulations are required. Thus, PyHEADTAIL has been parallelized by using MPI. The first version of the code is tested and currently under optimization toward simulations including the full filling scheme.

**Discussion**

New simulation tools have been developed for the conceptual design of the FCC-hh transverse feedback system. Preliminary simulations show that the main challenges for the transverse feedback systems are set by the coupled bunch instabilities and the intra-bunch oscillations induced by the bunch-by-bunch damper system. Specific requirements and technological solutions for these challenges will be studied more carefully by using PyHEADTAIL simulations including the detailed models for the accelerator and the feedback systems. However, the first results imply that damping the coupled bunch instabilities requires at least 10 MHz bandwidth (f, of a Gaussian filter) and below 100 turn damping time. Damping of the injection errors might set additional requirements for the damping time. One method to suppress the intra-bunch oscillations induced by the bunch by bunch damper is to use a 1-2 GHz wideband feedback system.

**References**


**Acknowledgement**

The authors would like to thank members of the CERN BE/RF/FB and RF/ABP/HSC for fruitful discussions.