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

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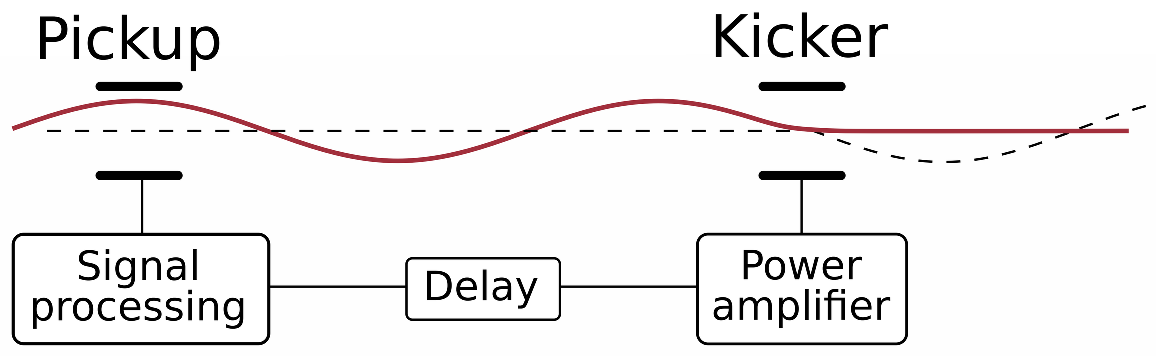
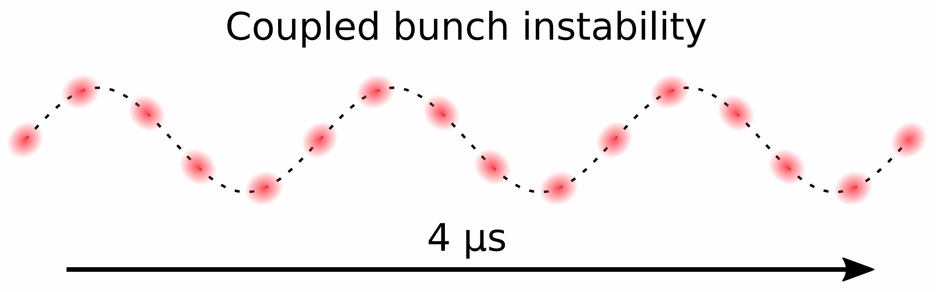
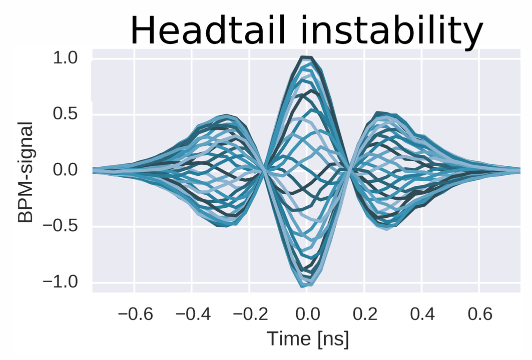
Transverse feedback system



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)





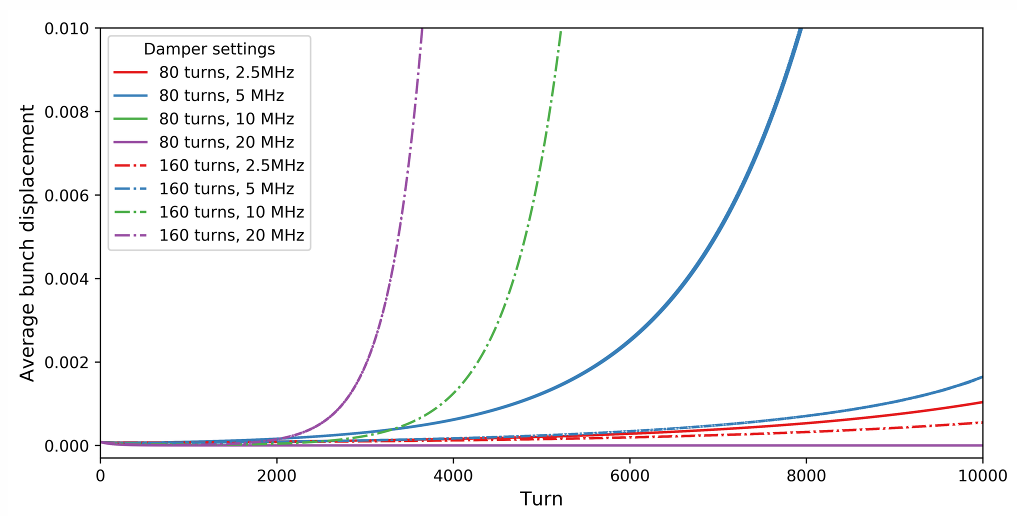
Scaling toward FCC-hh

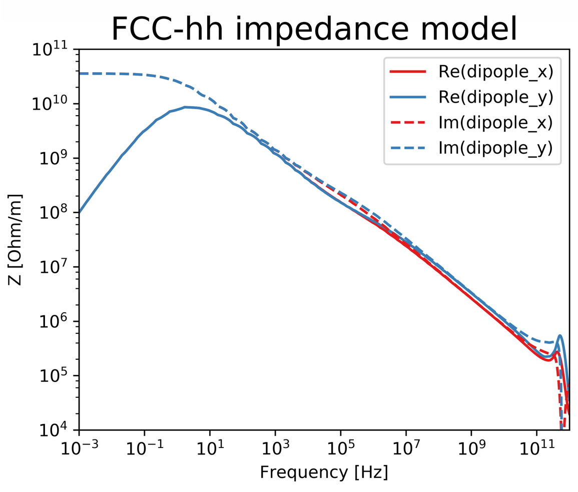
	LHC	FCC-hh		
Injection beam energy	0.45	3.3	3.3	TeV
Circumference	26.7	97.7	97.7	km
Bunch Spacing	25	25	5	ns
Number of bunch slots	3564	13068	65340	
RMS bunch length	0.3	0.27	0.27	ns
LHC transverse damper [1]				
Static injection error	2	0.5	0.5	mm
Injection error riple	2	0.5	0.5	mm
Batch spacing	0.95	0.3	0.3	µs
Coupled bunch instability growth rate	310	80	80	turns
Lowest frequency to damp	2	1	1	kHz
Highest frequency to damp	20	20	100	MHz
Nominal pass band voltage	7.5	2.5	2.5	kV
Number of kickers per beam and plane	4	22	22	
Kicker plate length	1.5	1.5	1.5	m
Total kick per turn at injection	2	0.5	0.5	µrad
Damping time (<1 MHz)	<13	20	20	turns

In the above it is assumed that the FCC-hh will use a system similar to the LHC (kicker plates driven by tetrode power amplifiers). Note that bandwidth can be traded for kick strength and the optimum is yet to be found by simulation. The FCC-hh option with 5 ns bunch spacing requires additional strip-line kickers to cover the frequency range of 20 MHz to 100 MHz. The coupled bunch feedback system can be complemented by an intra-bunch feedback using different kicker structures to cure oscillations occurring within the bunch with frequencies up to several GHz [2].

Studied challenges from the beam dynamics point of view

Coupled bunch instabilities during injection and ramp

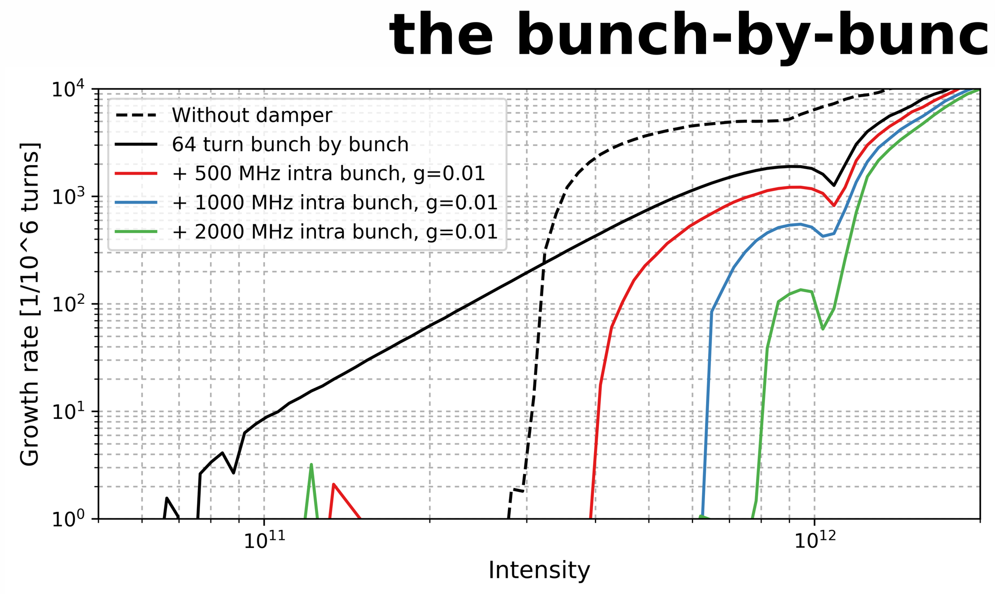




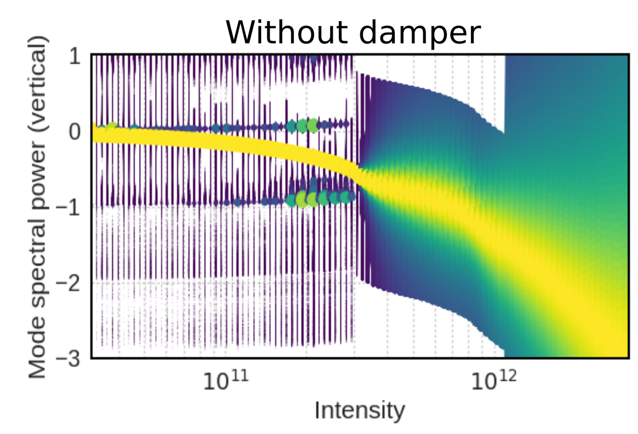
Between the injections and during the ramp it is required that the transverse feedback system suppresses coupled bunch instabilities. Preliminary simulations show that at least 10 MHz bandwidth (f_c of a Gaussian filter) and 100 turn damping time are required. The required damping time is consistent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

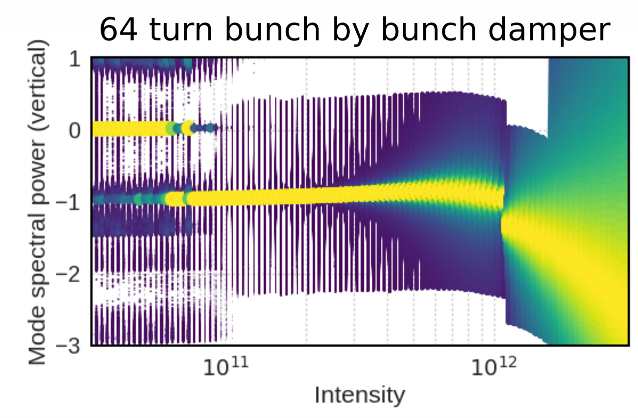
These preliminary coupled bunch instability simulations have been performed in time domain using the FCC-hh impedance model and a point-like bunch. The bandwidth of the feedback system was limited by using a Gaussian filter and the vector sum based correction algorithm was used with a one turn delay.

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



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 simulation techniques and impedance models. One method to stabilize these oscillations is to use a 1-2 GHz wideband feed-back system.



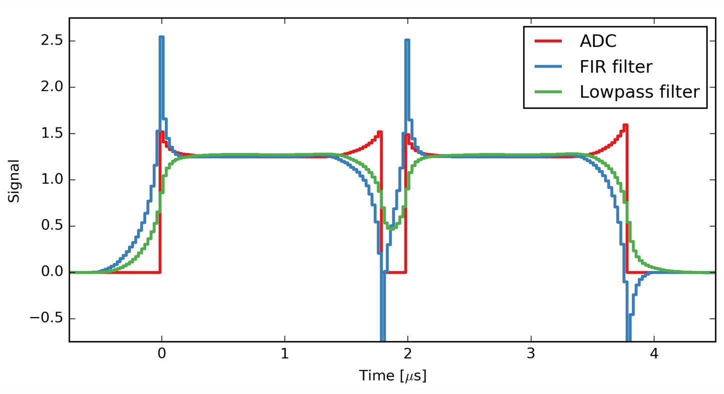


Developed simulation tools

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

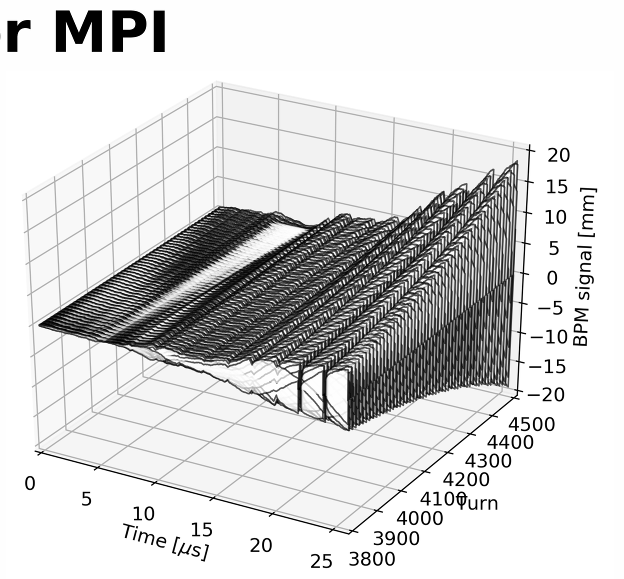
Framework for finite length signal processing

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_c 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

[1] *LHC Design Report, CERN-2004-003 (2004)*

[2] *J. D. Fox et al, "Control of Intra-Bunch Vertical Instabilities at the SPS - Measurements and Technology Demonstration," TUPIK119, IPAC 2017, Copenhagen, Denmark, May 2017*

[3] *J. Komppula, W. Hofle and K. Li, "Simulation tools for the design and performance evaluation of transverse feedback systems," TUPIK091, IPAC 2017, Copenhagen, Denmark, May 2017*

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