GSI

TECHNISCHE
UNIVERSITÄT
DARMSTADT

DAMPING OF LONGITUDINAL DIPOLE OSCILLATIONS WITH THE BUNCH-BY-BUNCH LONGITUDINAL FEEDBACK SYSTEM DURING ACCELERATION

01.12.2025

CONTENTS

1. INTRODUCTION

BUNCH-BY-BUNCH LONGITUDINAL FEEDBACK SYSTEM

- Feedback system to damp arbitrary longitudinal beam oscillations.
- Independent feedback for each bunch allowing independent phase and amplitude manipulations.
- No dependency on specific oscillation modes.

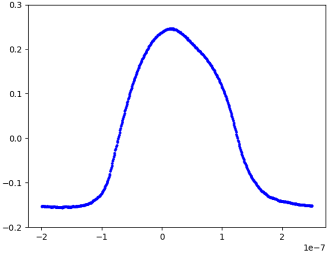

Figure: Example for measured longitudinal beam oscillations during a machine experiment at SIS18 on the 22nd of November 2023.

1. INTRODUCTION

COLLABORATIVE PROJECT:
BUNCH-BY-BUNCH LONGITUDINAL FEEDBACK SYSTEM FOR SIS100

- Collaboration between GSI and the chair for accelerator technology at the Technical University of Darmstadt financed by GSI.
- Start of associated PhD project: December 2024.
- PhD project aims to support further development of the system for SIS100.
- MDEs with the prototype at SIS18 provide crucial insights, e.g verification of the concepts of the feedback and of hardware developed for SIS100.

1. INTRODUCTION

CONCEPT OF THE BUNCH-BY-BUNCH LONGITUDINAL FEEDBACK SYSTEM

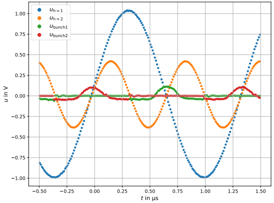

Figure: Measurement dated 10th of July 2025 showing the Demultiplexing of the beam current signal.

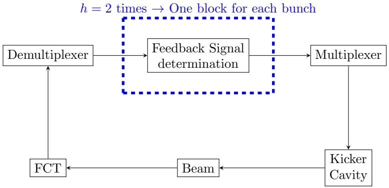

Figure: Simplified topology of the Longitudinal Feedback System Prototype.

- Demultiplexing of beam current signal.
- Obtain beam current signal to each bunch.
- Calculate separate feedback signals.
- Act on beam via a kicker cavity.

1. INTRODUCTION

GOAL OF THE MACHINE EXPERIMENT ON THE 10TH OF JULY 2025

Previous Experiments: Successful damping of longitudinal dipole and quadrupole oscillations for constant revolution frequencies.
Goals of this experiment:

- Demonstrate operability of the Feedback System during acceleration without manual interference.
- Focus on longitudinal dipole oscillations.
- Damp the oscillation of only one bunch to demonstrate Bunch-By-Bunch characteristic.

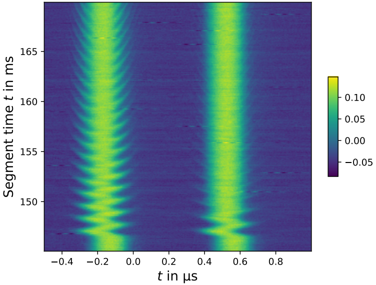

Figure: Measured in-phase dipole oscillation of two bunches with the right one being damped using the Longitudinal Feedback System (10th of July 2025).

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2. SETUP FOR THE MACHINE EXPERIMENT

TOPOLOGY OF THE LONGITUDINAL FEEDBACK SYSTEM DURING THE MDE

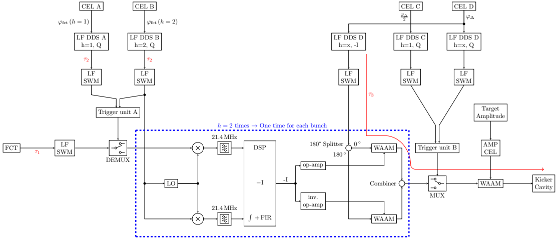

Figure: Block diagram of the Longitudinal Feedback System prototype during the MDE on the 10th of July 2025.

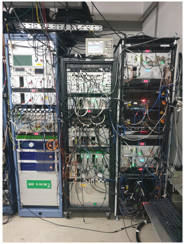

Figure: Hardware for the Prototype.

Synchronization using calibration electronics; Separate signal processing paths for each bunch; Local RF reference signal generation;...

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2. SETUP FOR THE MACHINE EXPERIMENT

SYNCHRONIZATION OF BEAM CURRENT SIGNAL MEASUREMENT

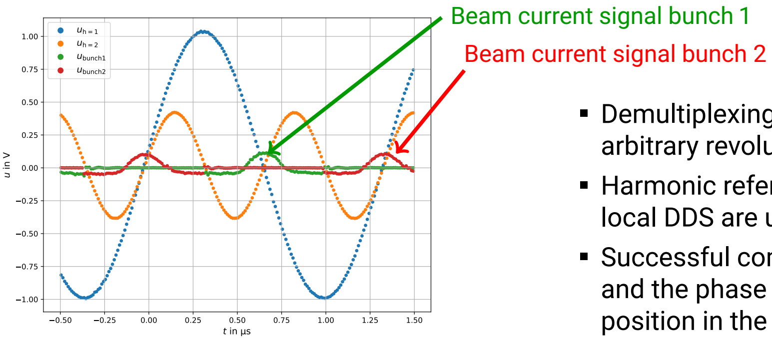

Figure: Measurement showing the Demultiplexing of the beam current signal (10th of July 2025).

- Demultiplexing of beam current signal for arbitrary revolution frequencies.
- Harmonic reference signals provided by local DDS are used to control timing.
- Successful compensation of signal delays and the phase shift introduced by the FCT position in the ring.

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2. SETUP FOR THE MACHINE EXPERIMENT

SYNCHRONIZATION OF FEEDBACK KICKER SIGNALS

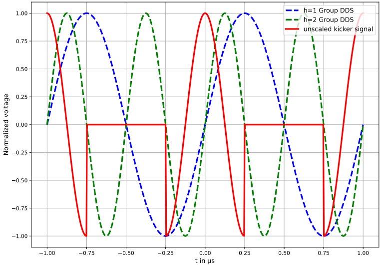

Figure: Schematic of RF feedback kicker signals.

- Individual kicker signal to each bunch/bucket.
- Multiplexing of the sequence of kicker signals into one signal.
- Calibration to ensure a correct phase of the kicker signals at the kicker cavity for arbitrary revolution frequencies.

2. SETUP FOR THE MACHINE EXPERIMENT

BEAM PATTERN

- Beam pattern provided by Holger Liebermann.
- Very slow ramp rate as current setup still requires modifications to account for fast acceleration. Main goal is the operation during acceleration without manual interference.

Parameters	**Values**
Ion species	$^{238}\mathrm{U}^{73+}$
Injection energy	11.13 $\frac{\mathrm{MeV}}{\mathrm{u}}$
Revolution frequency f_R during injection	212.68 kHz
Energy at flattop	979.20 $\frac{\mathrm{MeV}}{\mathrm{u}}$
Revolution frequency f_R during flattop	1211.82 kHz
Ramping rate	0.125 $\frac{\mathrm{T}}{\mathrm{s}}$
Harmonic number h	2

3. PROCEDURE DURING THE MACHINE EXPERIMENT

- Activate feedback right after injection to test stability during the whole cycle.
- Intentionally excite an in-phase dipole oscillation of both bunches using a 20° phase jump of the cavity voltage.
- Much larger oscillation amplitudes than expected in standard operation.
- Damp only the oscillation of the right bunch and the other must not be influenced.

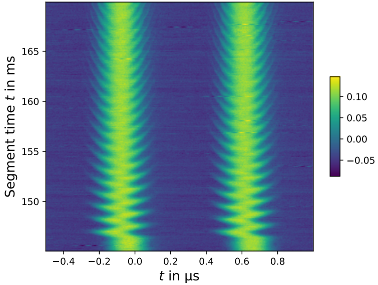

Figure: Measured in-phase, intentionally excited dipole oscillation of two bunches (10th of July 2025).

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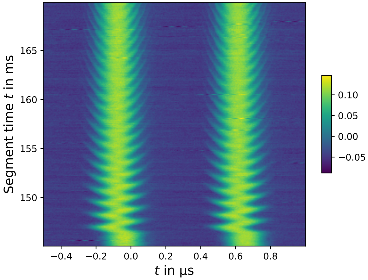
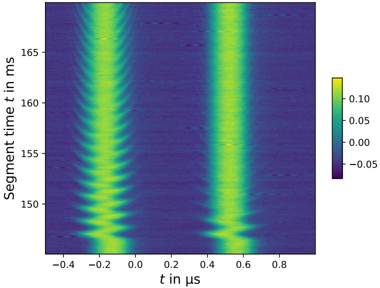
4. RESULTS OF THE MACHINE EXPERIMENT

Excitation at $f_{\mathrm{R}} = 723.589\,\mathrm{kHz}$, $E_{\mathrm{kin}} = 160.08\,\frac{\mathrm{MeV}}{\mathrm{u}}$, $f_{\mathrm{s}} \approx 800\,\mathrm{Hz}$.



(a) Feedback for both bunches off.



(b) Selective Feedback for right bunch on.

4. RESULTS OF THE MACHINE EXPERIMENT

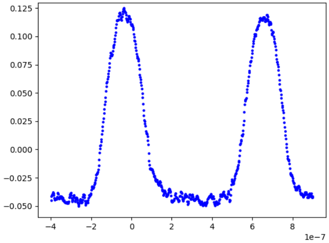


Figure: Measurement result showing the intentionally excited in-phase dipole oscillation of two bunches.

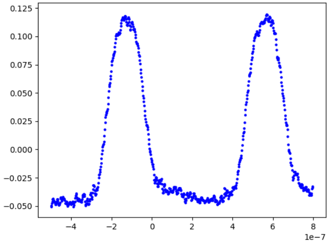
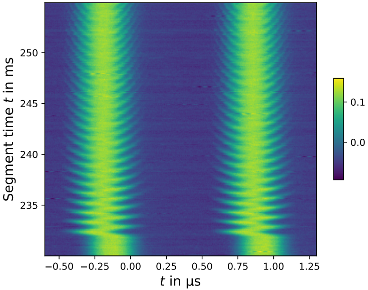


Figure: Measurement result showing the selective damping. Feedback only for the right bunch on!

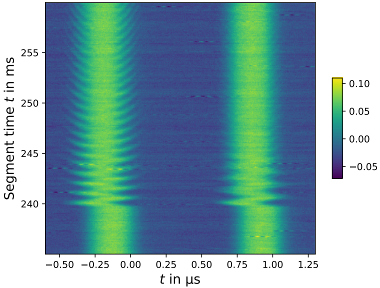
As desired, only the dipole oscillation of the right bunch is damped if the Longitudinal Feedback for it is active!

4. RESULTS OF THE MACHINE EXPERIMENT

Excitation at $f_{\mathrm{R}} = 477.555\,\mathrm{kHz}$, $E_{\mathrm{kin}} = 60.57\,\frac{\mathrm{MeV}}{\mathrm{u}}$, $f_{\mathrm{s}} \approx 1060\,\mathrm{Hz}$.



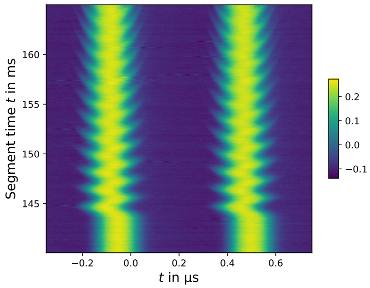
(a) Feedback for both bunches off.



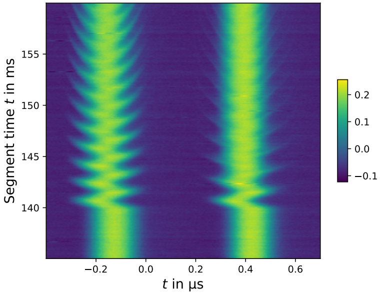
(b) Selective Feedback for right bunch on.

4. RESULTS OF THE MACHINE EXPERIMENT

Excitation at $f_{\mathrm{R}} = 907.523\,\mathrm{kHz}$, $E_{\mathrm{kin}} = 299.65\,\frac{\mathrm{MeV}}{\mathrm{u}}$, $f_{\mathrm{s}} \approx 570\,\mathrm{Hz}$.



(a) Feedback for both bunches off.



(b) Selective Feedback for right bunch on.

5. ACHIEVED PROGRESS

- First operation of the Longitudinal Feedback System prototype during acceleration without manual interference after initial setup.
- Successful synchronization of the beam current signal measurement and the feedback kicker signals.
- Successful damping of dipole oscillations during acceleration even with comparably small bandwidth of MA cavities.

6. FUTURE DEVELOPMENT STEPS

- Extension of the theoretical analysis of the Longitudinal Feedback System for broader applications.
- Continue Development of Hardware, e.g. digital multiplexing of feedback kicker signals.
- Continue development of SIS100 broadband feedback cavity systems.
- Development of adaptive gain control for the beam current signal in order to deal with dynamic range expected for SIS100.

$\rightarrow$ Future modifications have to be verified in similar, further machine experiments!

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CONTRIBUTIONS

K. Groß, M. Hardieck, H. Klingbeil, D. Lens, H. Liebermann, D. Penza, C. Thielmann, G. Thomin, J. Wegmann, D. Ziegelmann, B. Zipfel and many more by participating in the machine experiment, providing hard- and software for the system itself or by contributing to the feedback design, ... etc.