Presentation of Master's Thesis

Investigation of Control Approaches for a High Precision, Piezo-actuated Rotational Stage

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August 30, 2016

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Introduction

CERN

The Large Hadron Collider (LHC) at CERN.

Source: [1].

Collimation

Collimation system used in the LHC.

Source: [1].

Crystal Collimation

The UA9 collaboration at CERN investigates how bent crystals can be used to extract halo particles.

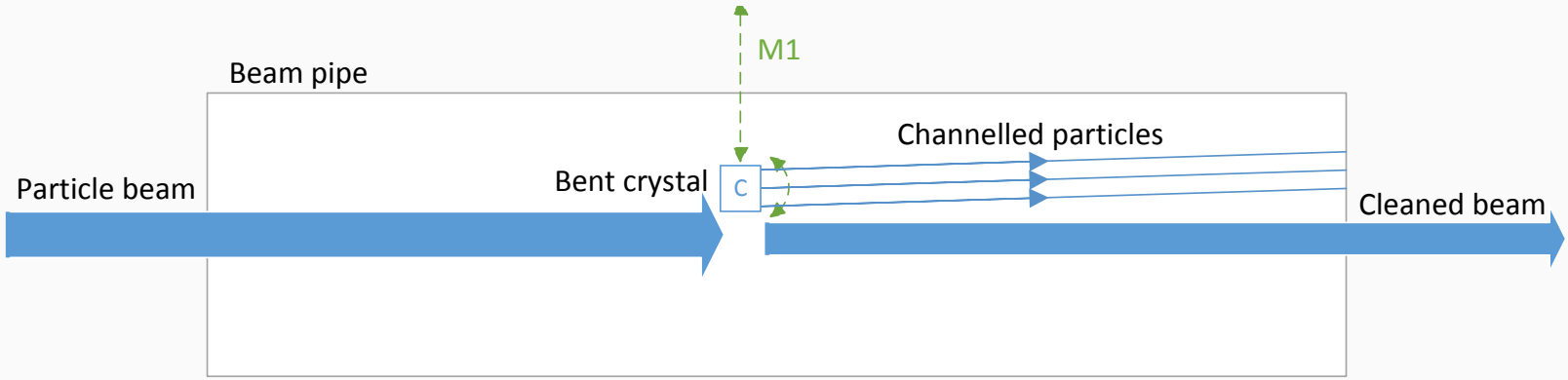


Figure 1: Illustration of the crystal collimation principle.

Implies in a more efficient cleaning, a less complex system and a reduction of the machine impedance.

Purpose and Goal

The **higher the energy** of the particle the **lower the angular acceptance** for channeling.

- have a total range of $20\ \mathrm{mrad}$
- be able to track reference trajectories at ramp rates of $100\ \mu\mathrm{rad/s}$
- reject external disturbances to maintain a maximum tracking error of $\pm 1\ \mu\mathrm{rad}$ even when the linear axis is moving

Challenges

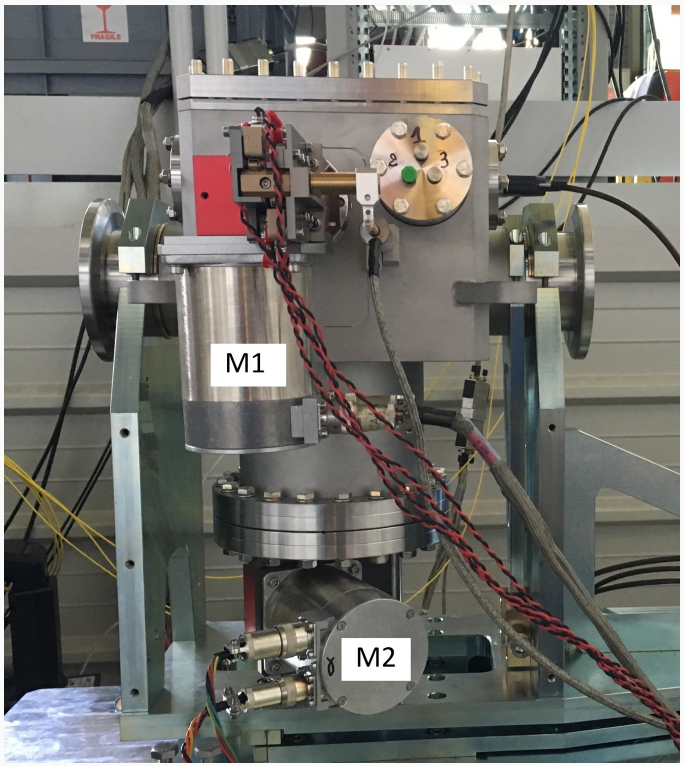
- Nonlinear effect such as hysteresis and creep
- Highly resonant structure
- The linear movement adds additional perturbation
- System changes due to rotational and linear position, moving center of rotation.

Method

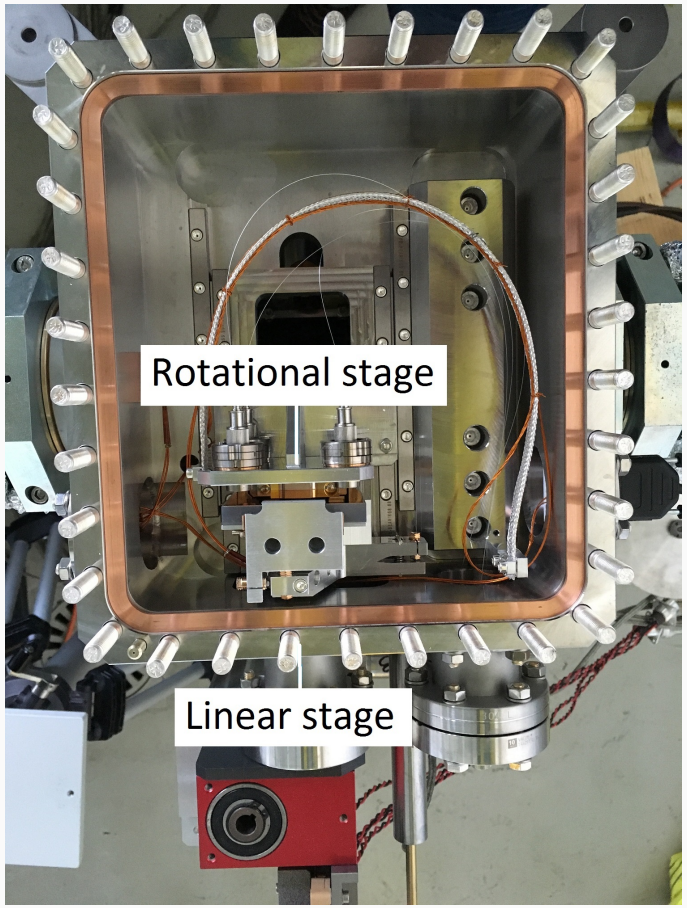
- Literature study
- Further investigation of selected control approaches
- Benchmarking tests of selected control approaches in simulations
- Implementation of the most promising approach
- Proposal of controller

System Overview

Crystal Collimator



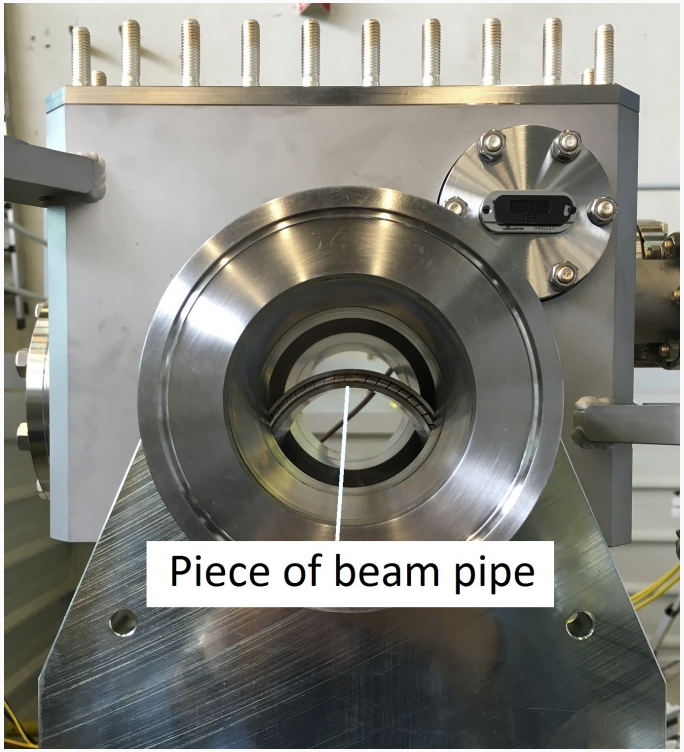
(a) Side view



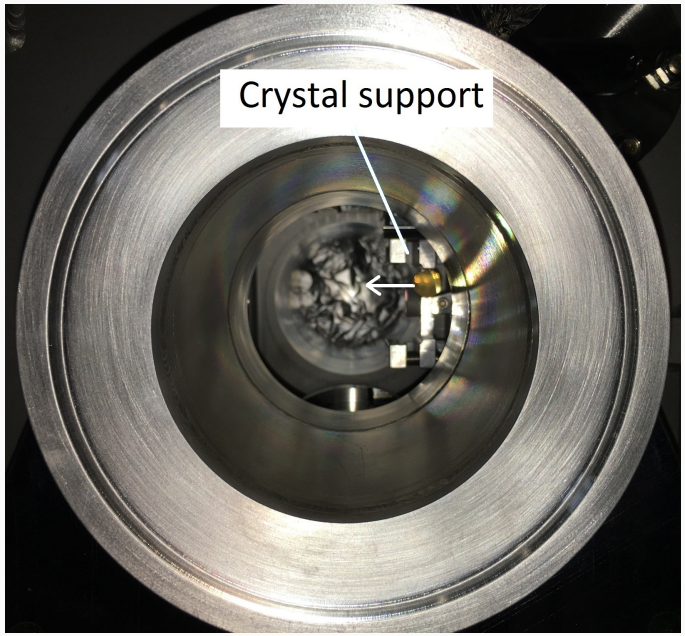
(b) Top view

Figure 2: The new collimator from the side (a) and the top (b).

Crystal Collimator



(a) Giving access



(b) Insertion of crystal

Figure 3: The new collimator with the beam pipe piece half-way out (a) and the crystal inserted into the beam pipe (b).

Rotational Stage

Displacement: 0 to $30\ \mu\mathrm{m}$ (-20 and +150 V) $\Longrightarrow$ 0 to 20 mrad.

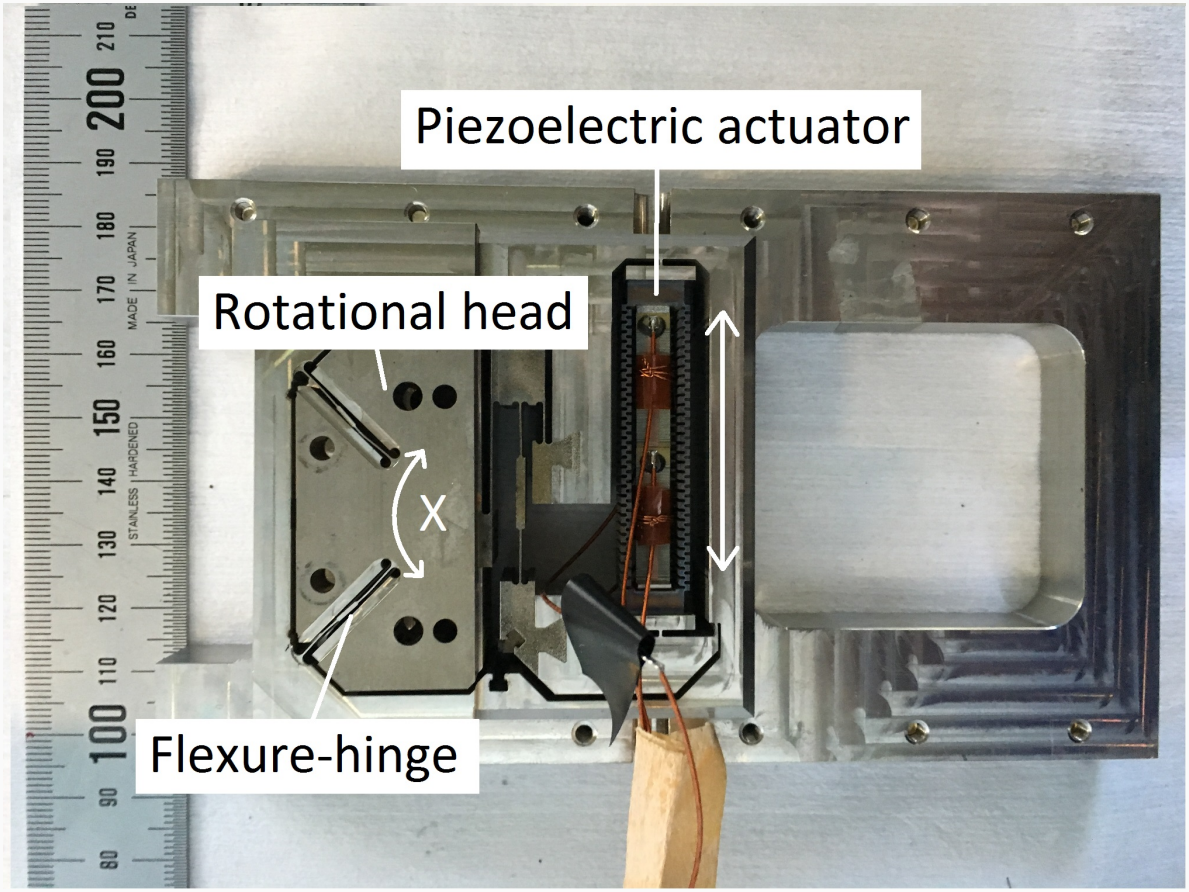


Figure 4: Piezo-actuated rotational stage used in the new collimator.

Rotational Stage

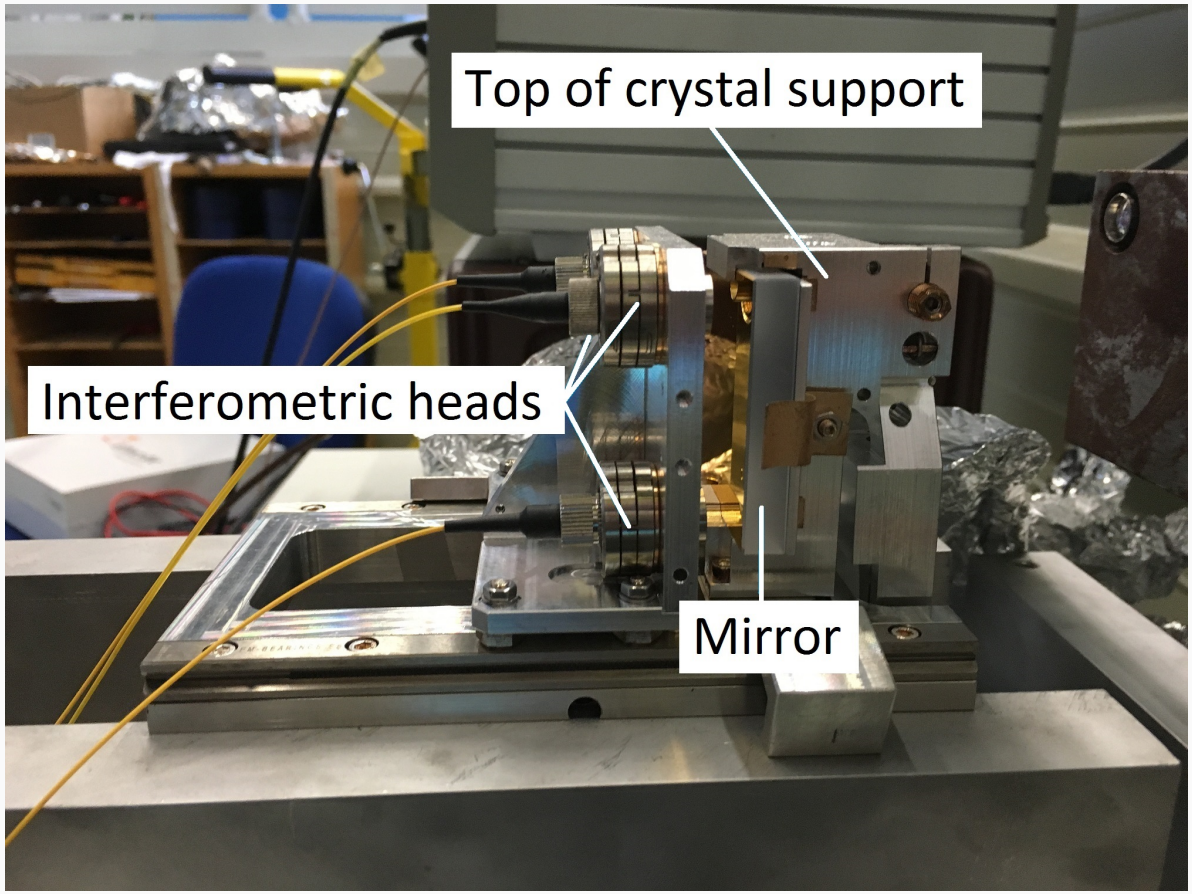
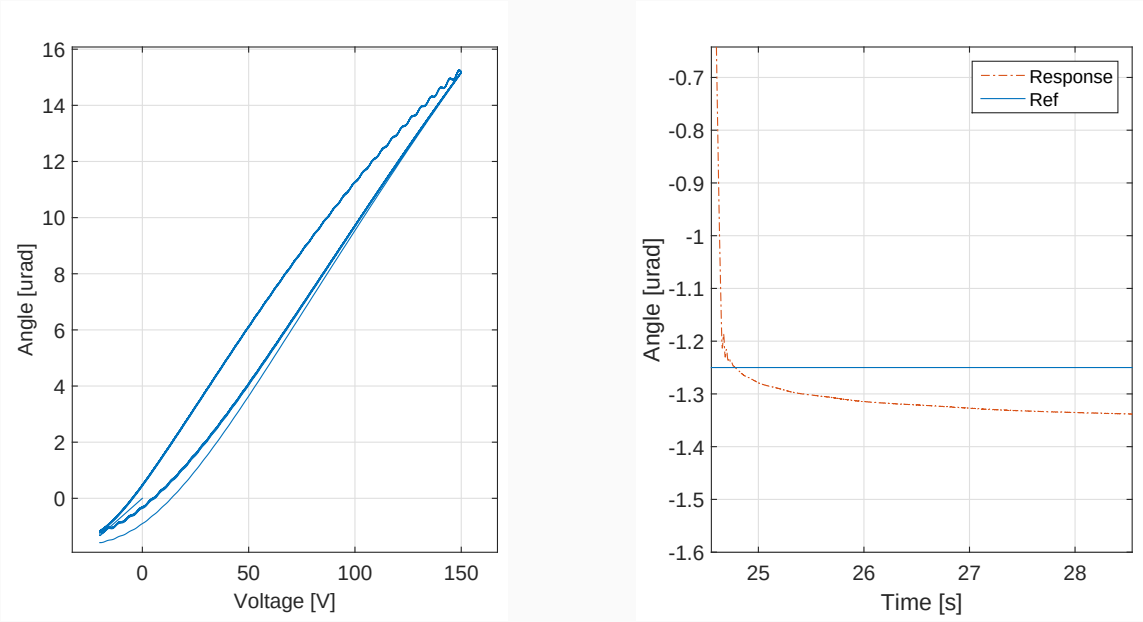


Figure 5: Rotational stage with the crystal support and the interferometric system mounted on top.

Piezoelectric stack actuators

- Piezoelectric effect
- Many thin electro-active ceramic disks connected in parallel
- Provides high stiffness and long displacement ranges
- Nonlinear effects



(a) Hysteresis loop **(b)** Creep effect

Figure 6: Illustration of the hysteresis effect (a) and creep effect (b).

Modeling

- Hysteresis effect - Modeled by a Maxwell slip model
- Creep effect - Efficiently eliminated in closed loop
- Rotational stage - modeled as a Hammerstein structure

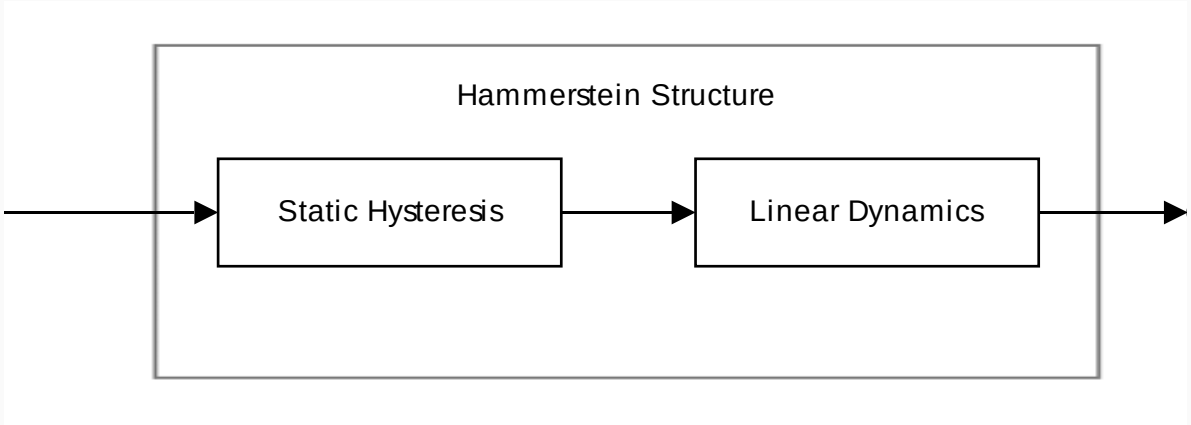


Figure 7: Block diagram of a Hammerstein structure, consisting of two blocks in series, modeling the static hysteresis and the linear dynamics, respectively.

Linear System Identification

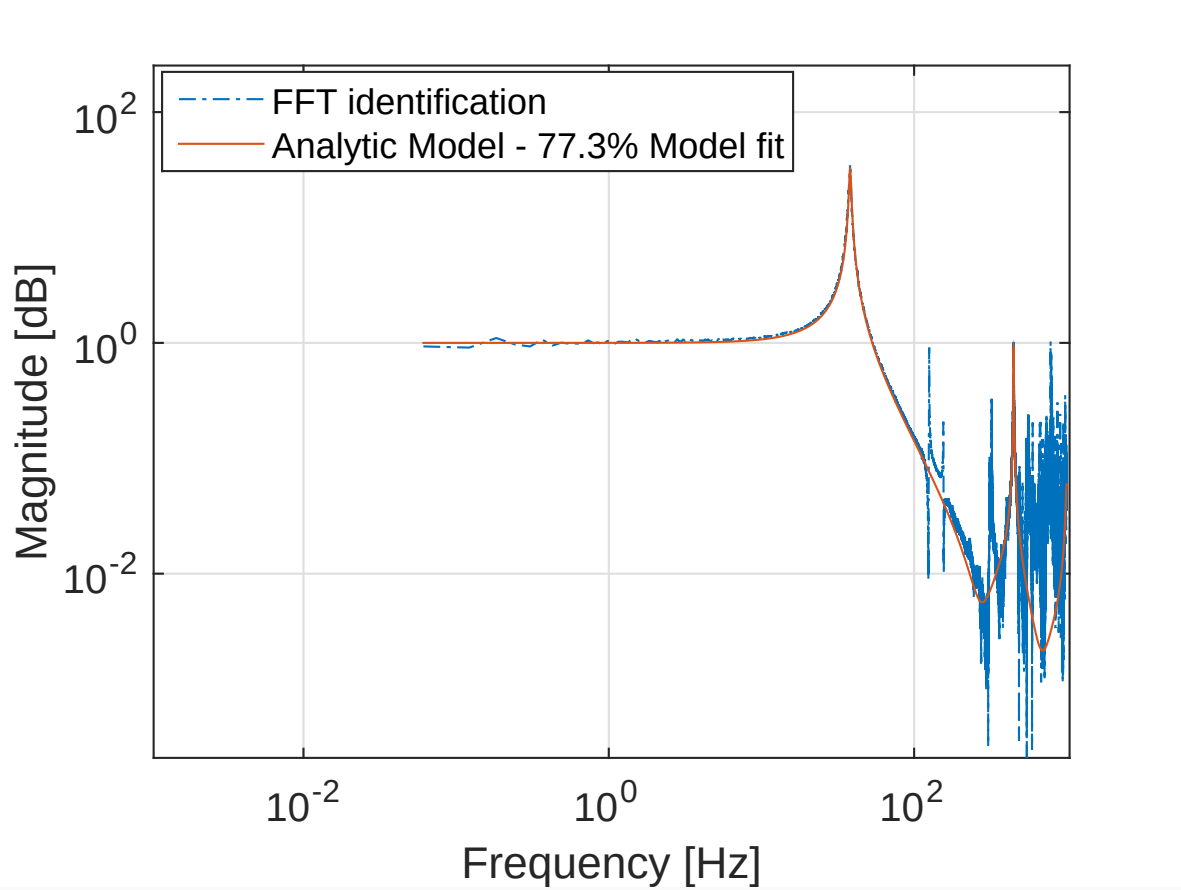
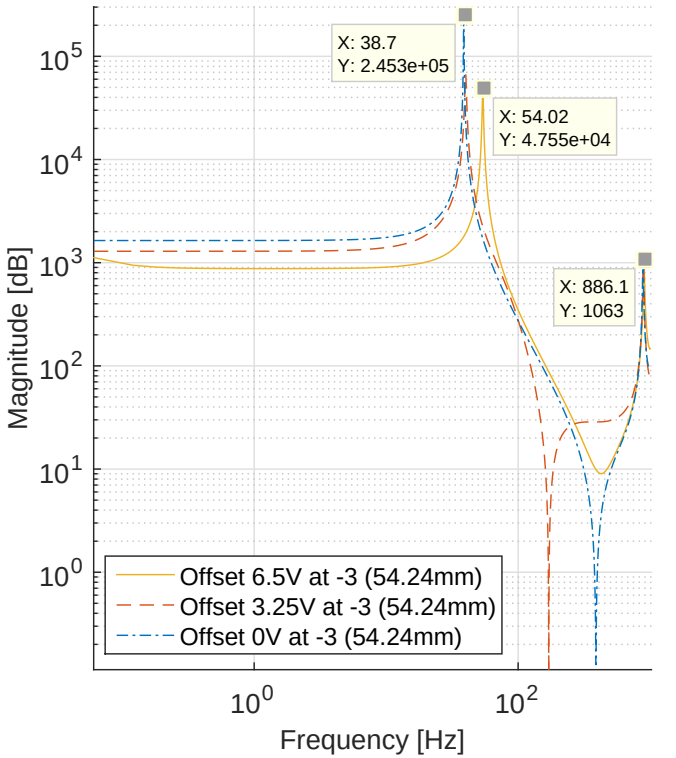
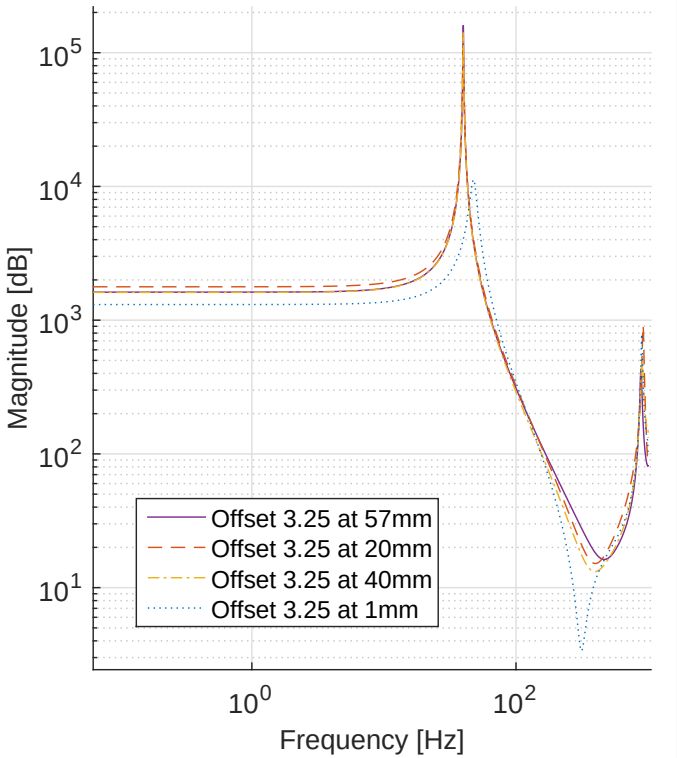


Figure 8: Model fit of the system model with 5 zeros and 6 poles to the FFT of the acquired data.

Linear System Identification



(a) Different rotational head positions



(b) Different linear axis positions

Figure 9: Identified models with different rotational positions (linear axis in 54.24 mm) is shown in (a) and with different linear axis positions (rotational position corresponding to 3.25 V) is shown in (b).

Present Control Approach

$$e = \lim_{n \to \infty} \left(1 + \frac{1}{n}\right)^n$$

Approaches and Simulation Results

Integral Resonance Control

Model Reference Adaptive Controller

Harmonic Cancellation

Comparison

Implementation

Setup

Experimental Results

Conclusion

Simulation Results

Experimental Results

Summary

Questions?

References I

H. G. Morales.
opac hector garcia morales - lhc collimation system optimization, 2015.
Available at https://www.youtube.com/watch?v=h2-ocLjUhTU.