Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Final Presentation

Vibrating Wire Control System

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IN SUPREMÆ DIGNITATIS 1343

Outline

Overview

Understanding The Problem

Control Design and Results

Overview

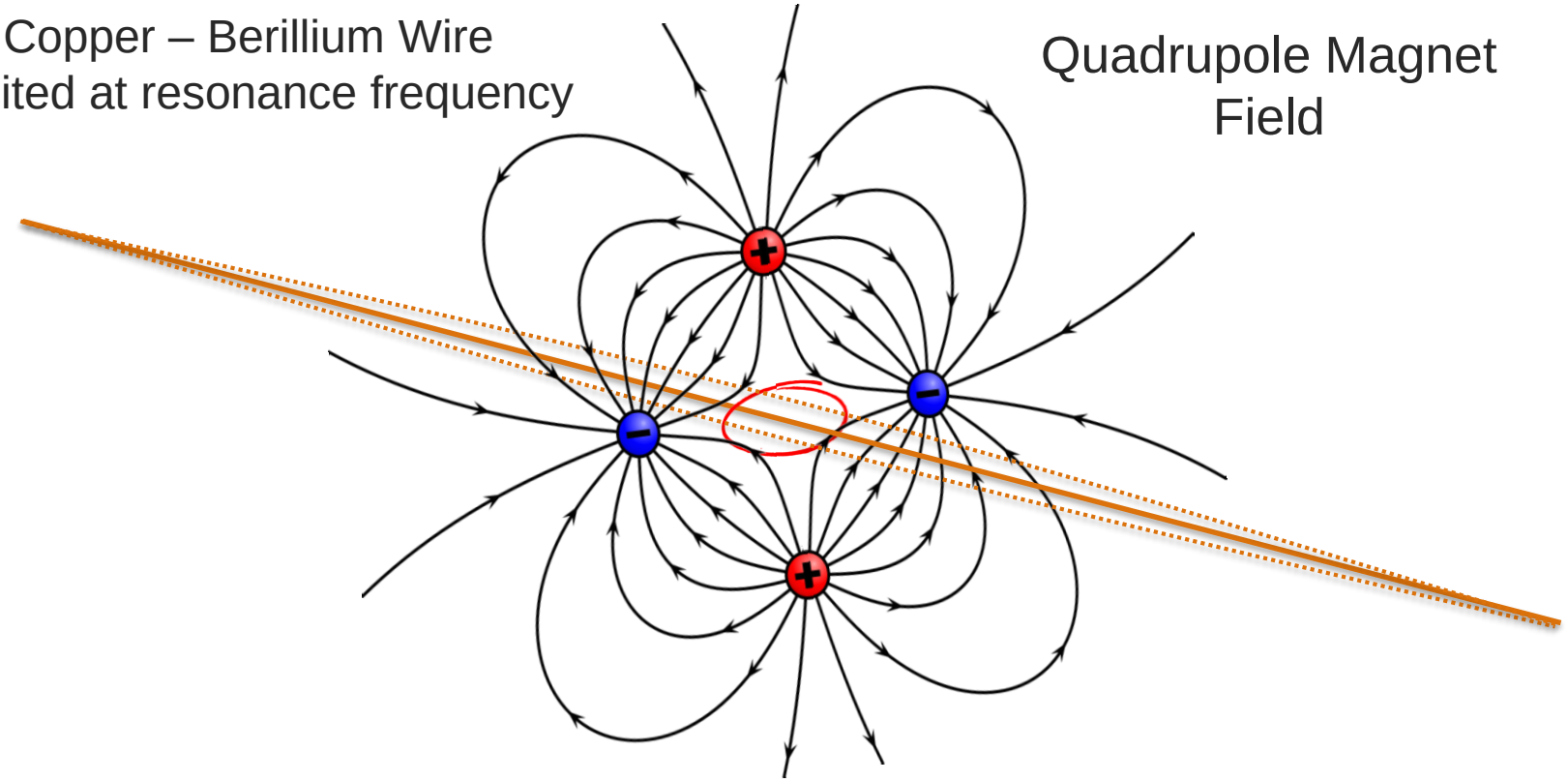
Understanding The Problem

Control Design and Results

Vibrating Wire System
Working Principle

Copper – Berillium Wire
Excited at resonance frequency

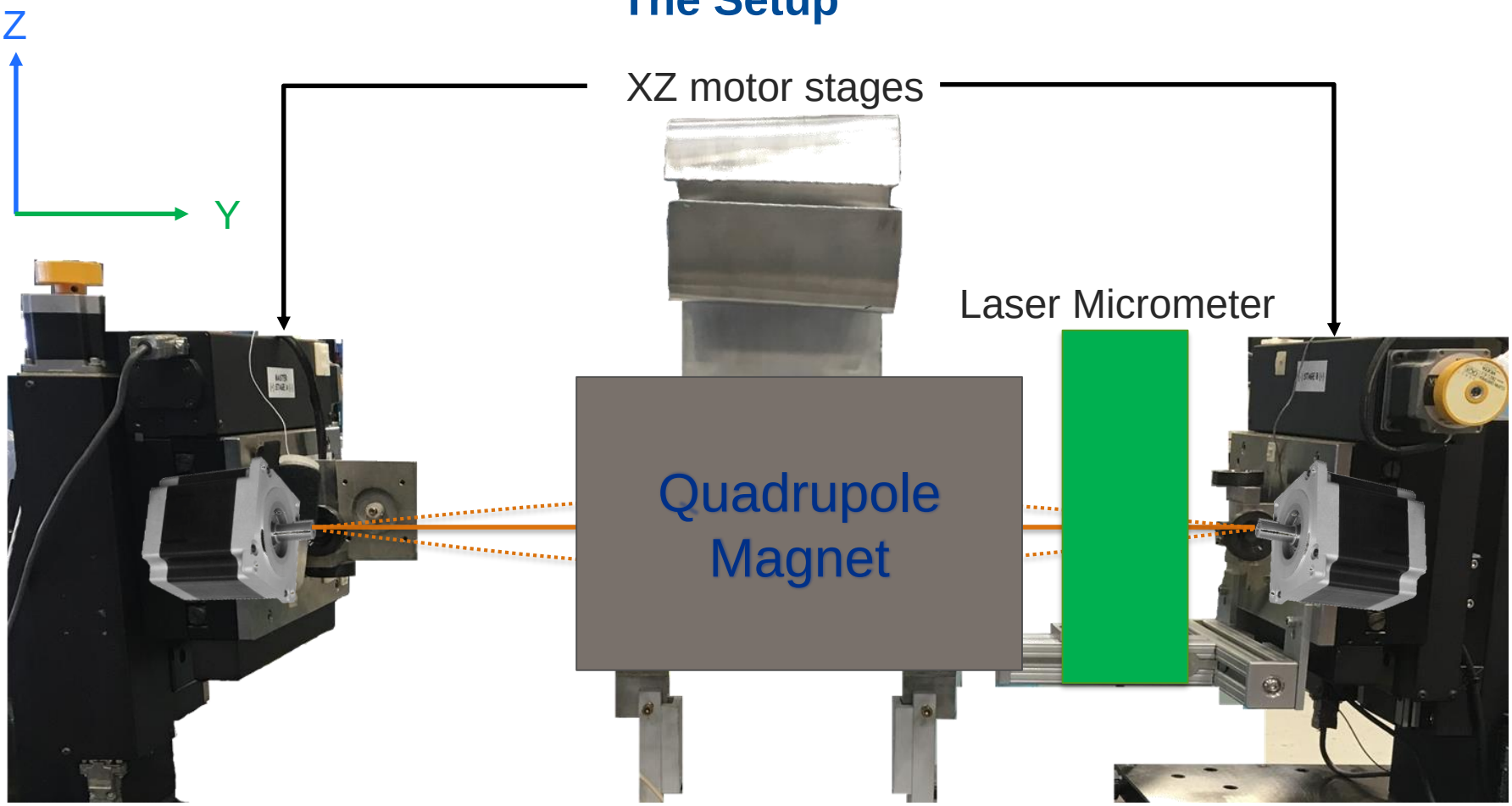
Quadrupole Magnet Field



GOAL: To minimize the oscillation amplitude of the wire, that means finding the Zero Field Line

Vibrating Wire System

The Setup



At the moment the search for Zero Field Line is done by hand.
Goal of the project is to automate the process.

Overview

Understanding The Problem

Control Design and Results

Understanding the Problem

- **Current “by hand” Procedure**
  - **Set the Resonance Frequency**
  - **Find the Minimum Oscillation**

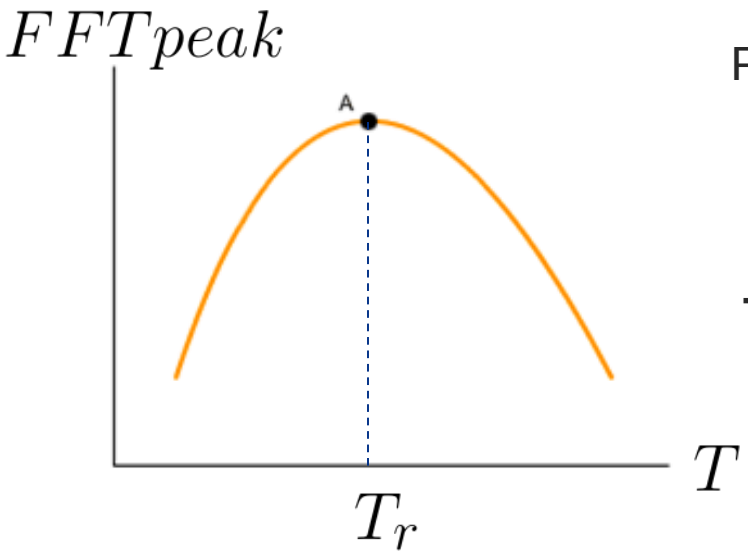
Understanding the Problem
Resonance Frequency Search

$$f_r = \frac{1}{2L}\sqrt{\frac{T}{w}}$$

To be Set

Imposed

Known



Presence of a **Torque motor**, but no Torque sensor

Torque sweep and search for maximum FFT peak

At the moment, problems with Torque motor

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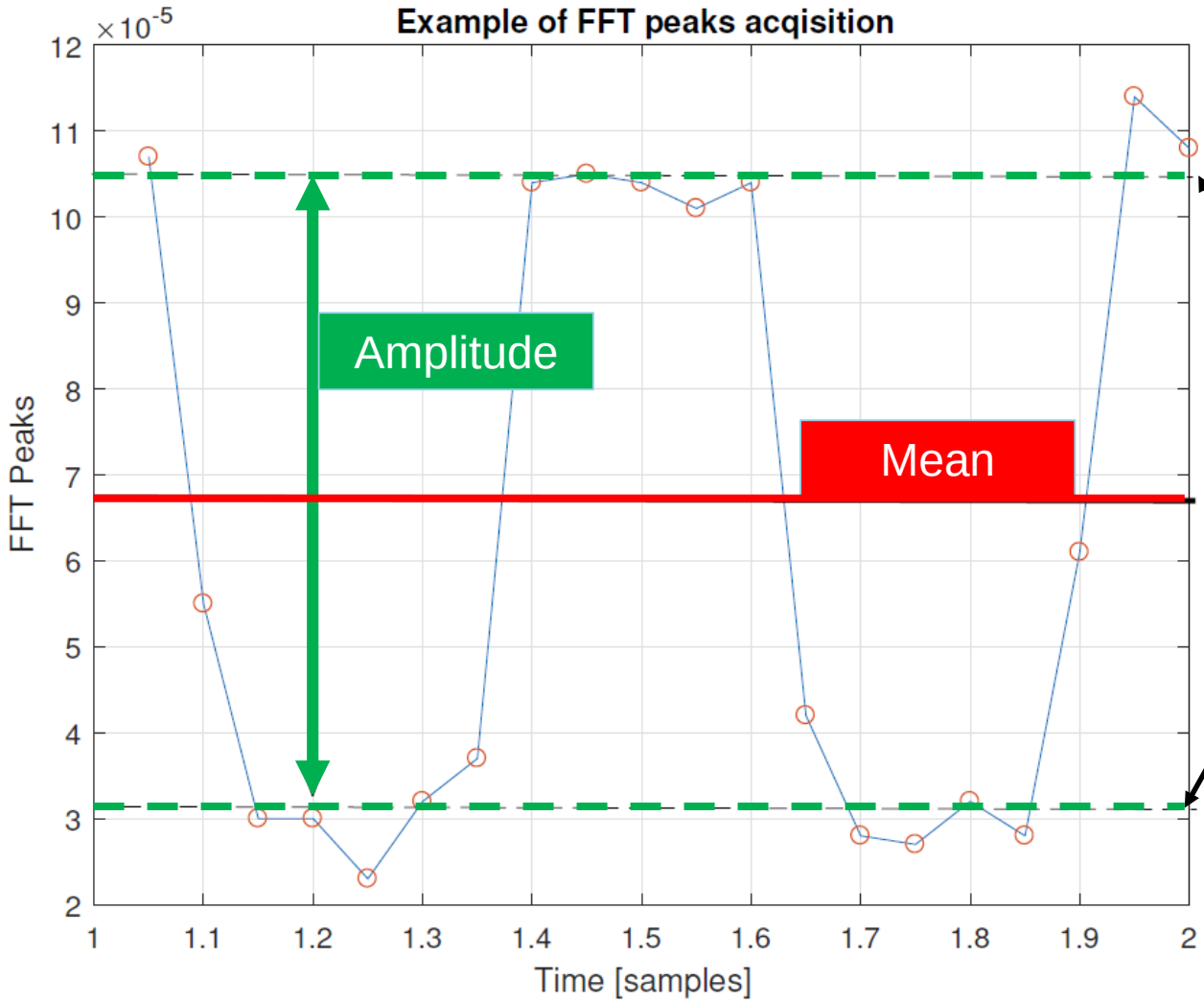
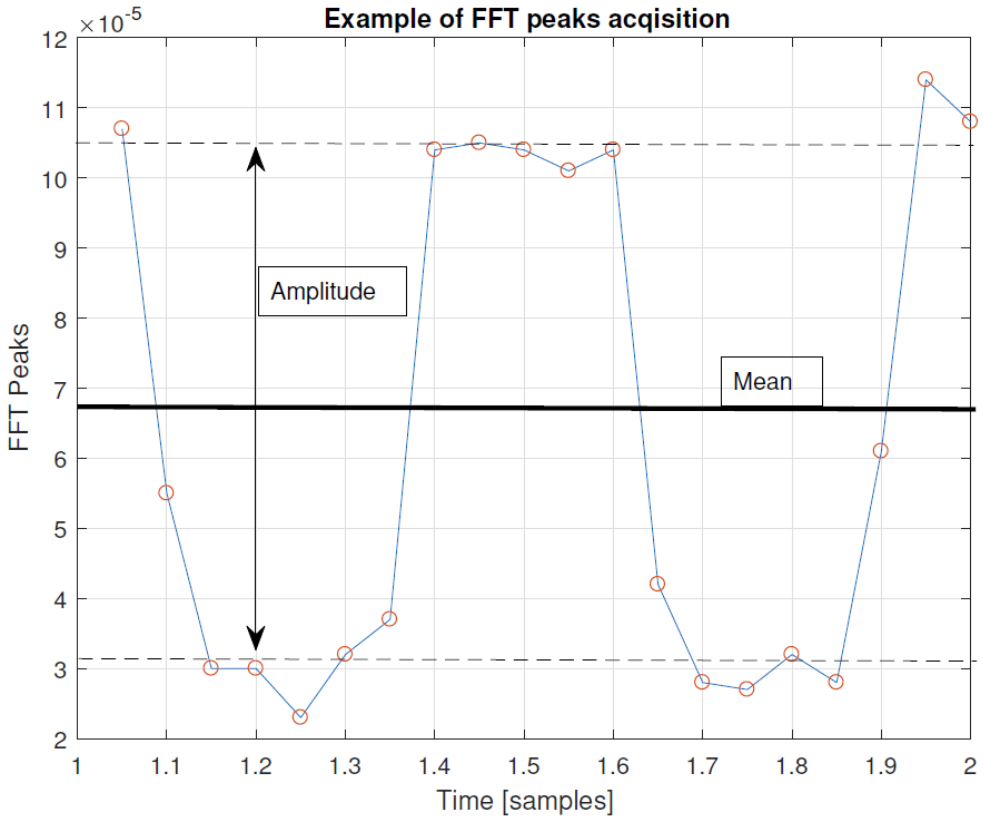
Understanding the Problem
Minimum Oscillation Search



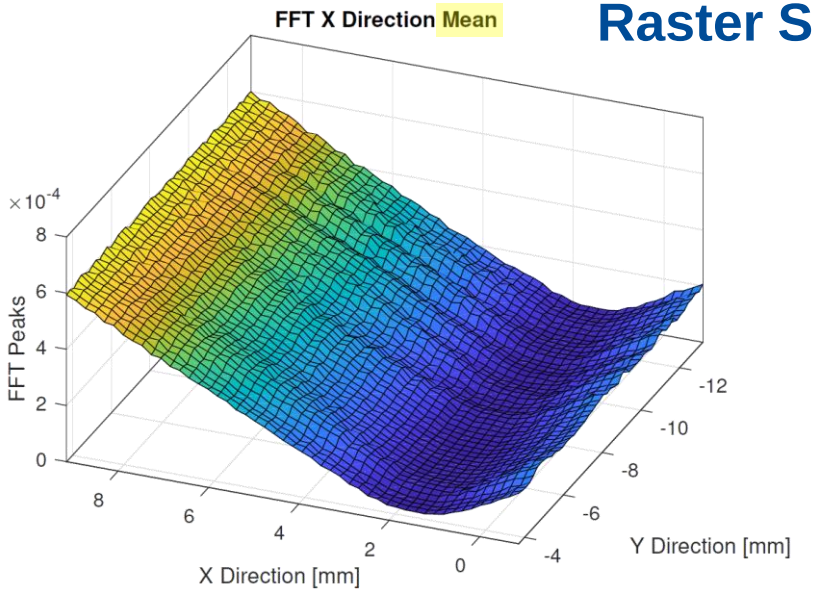
Understanding the Problem
Minimum Oscillation Search

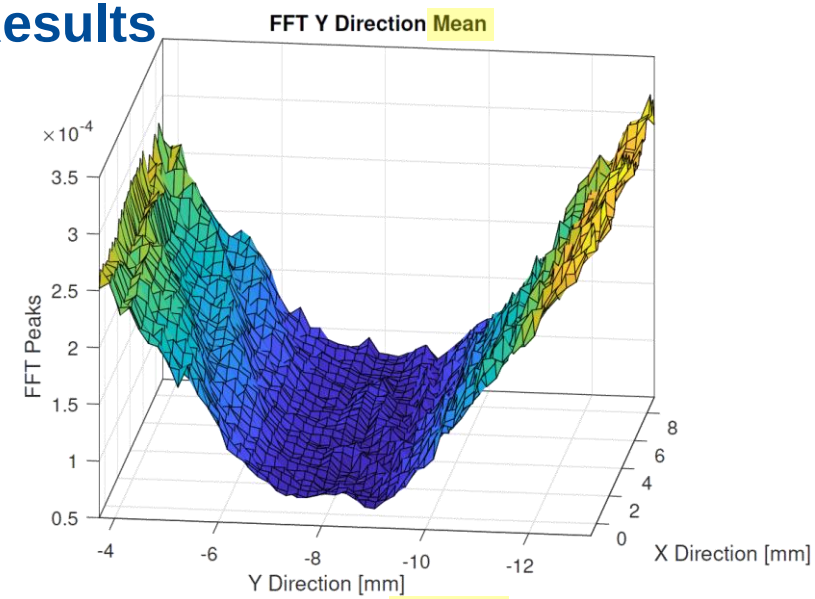


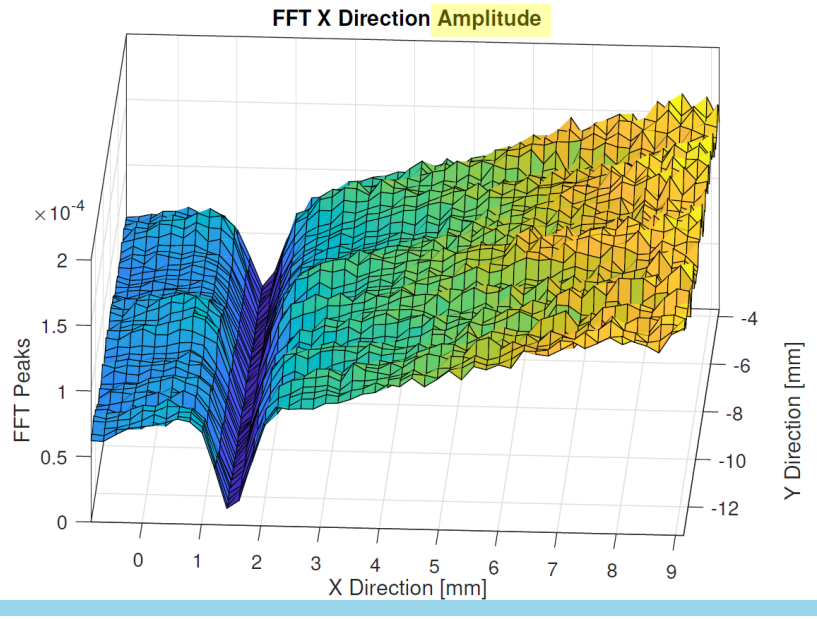
- **First Step**
  - Minimize **Mean**
- **Second Step**
  - Minimize **Amplitude** at **Resonance Frequency**
  - Minimize **Amplitude** at **2x Resonance Frequency**

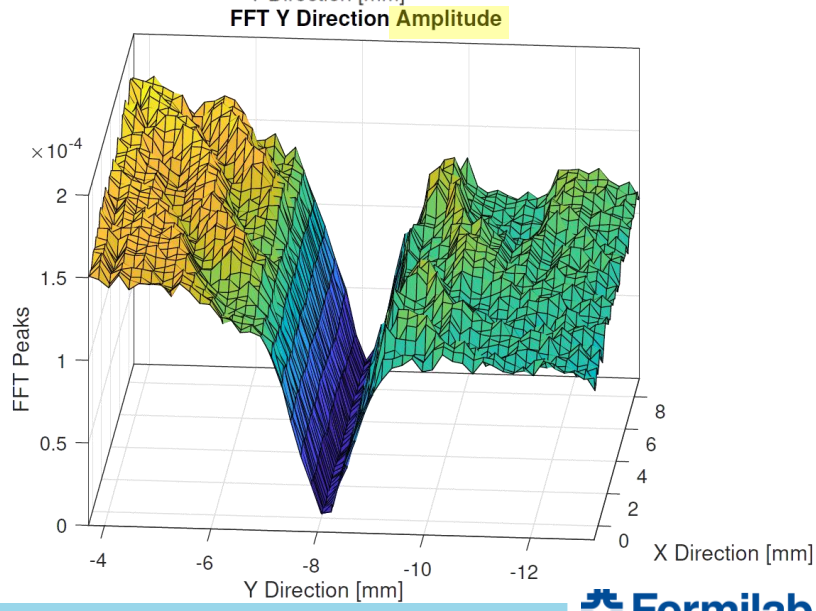
Understanding the Problem

Raster Scan Results









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Overview

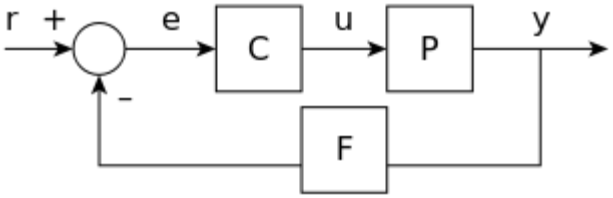
Understanding The Problem

Control Design and Results

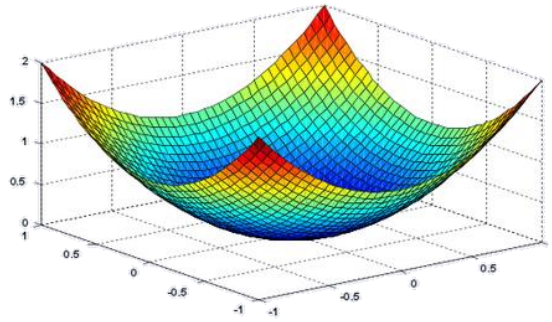
Control Design

- Two possible strategies

Control Theory



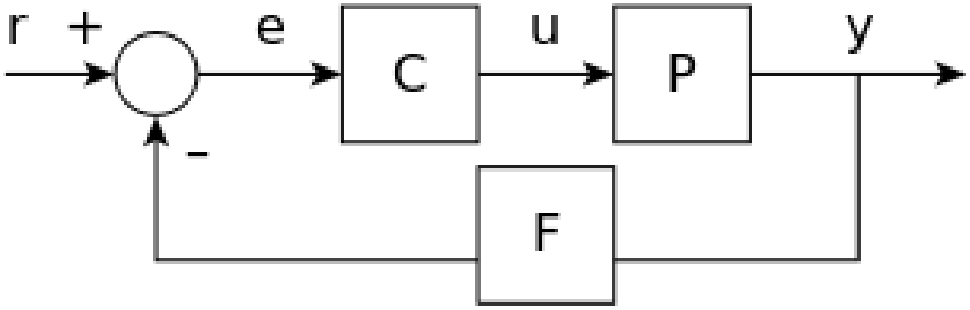
Convex Optimization



Control Design

- Two possible strategies

Control Theory



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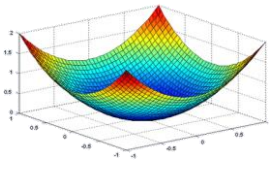


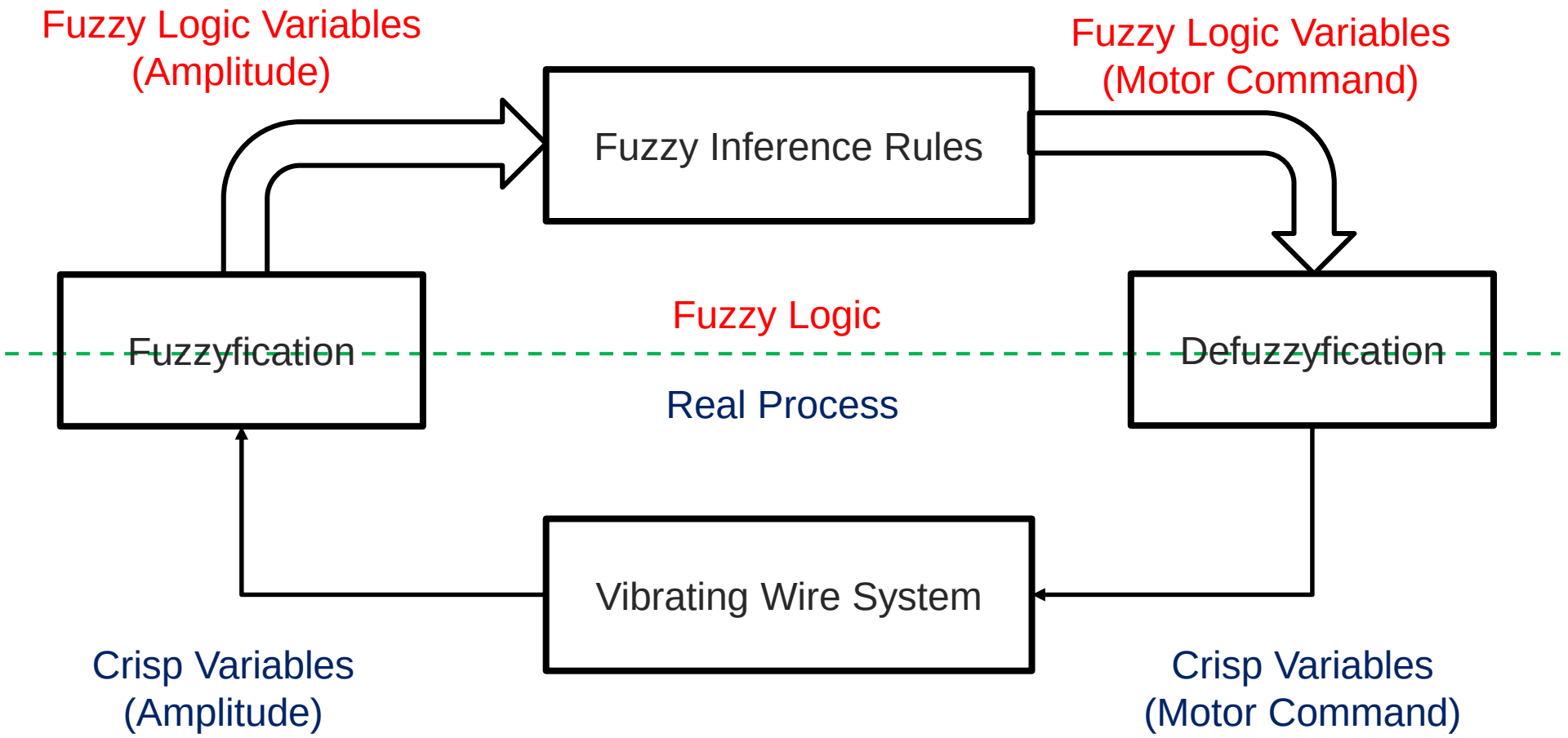
Control Design
Fuzzy Controller

Process is **NON LINEAR, not known, difficult to Identify**

A Standard Linear/Non Linear Controller **is not sufficient**

Fuzzy Controller

Control Design
Fuzzy Controller

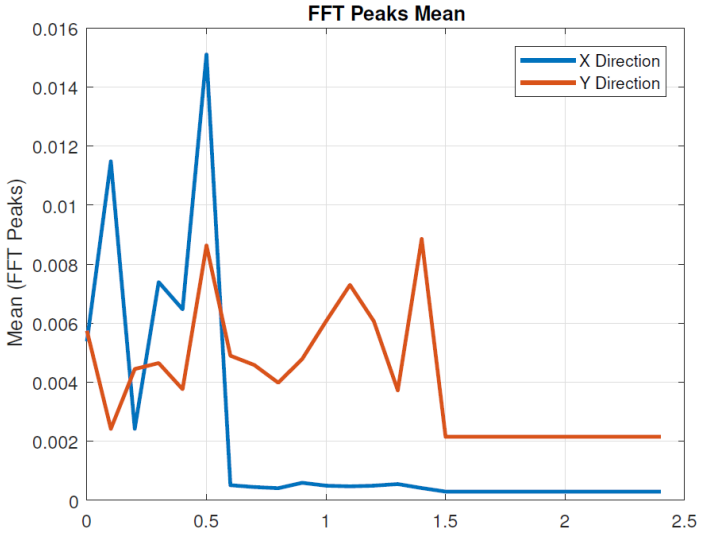


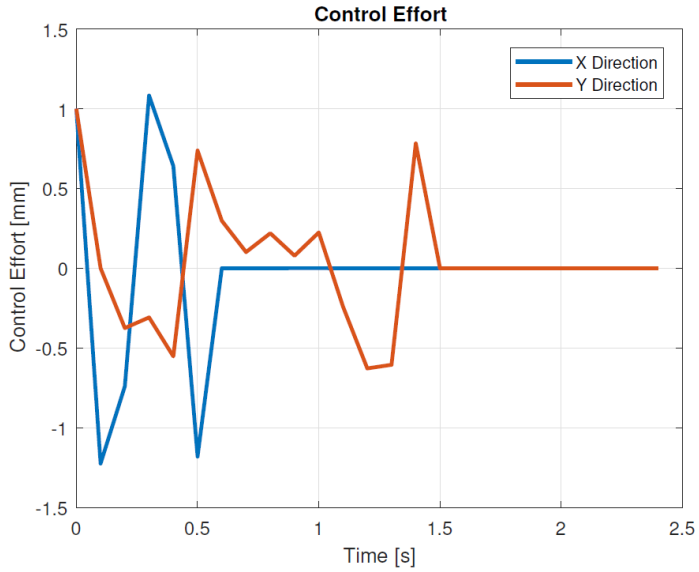
Control Design
Fuzzy Controller

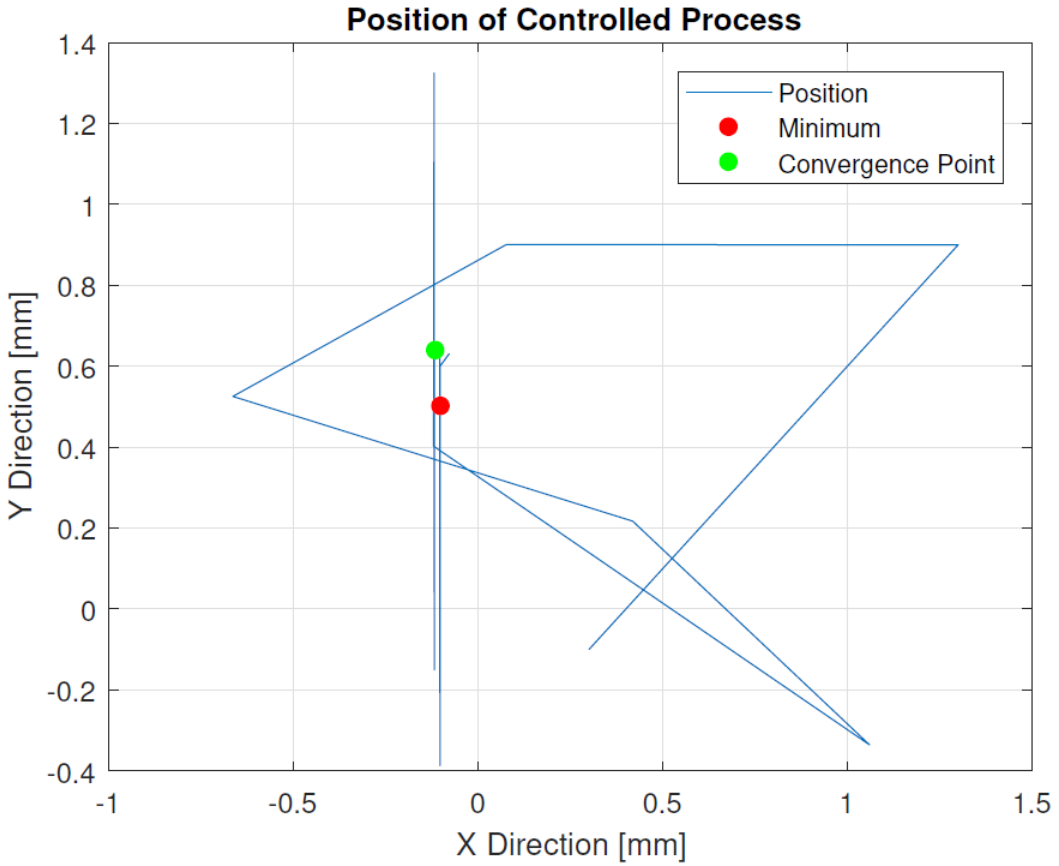
Strategy: step in one direction, see if Amplitude grows, decide if it was the right choice and correct

Control Design

Fuzzy Controller On Measured Data







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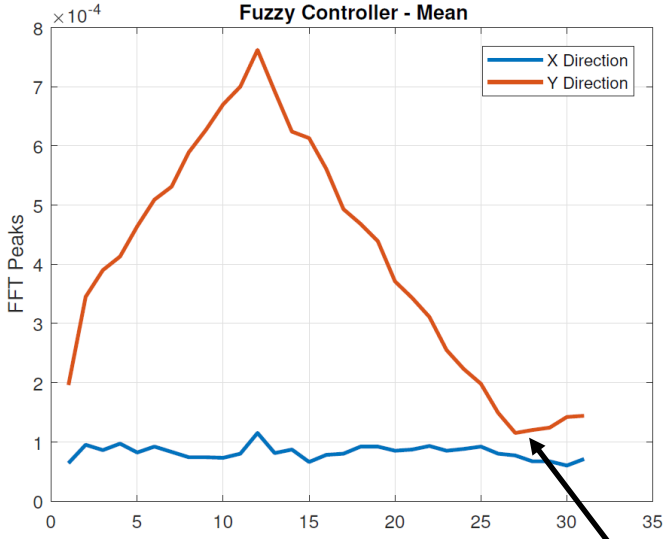
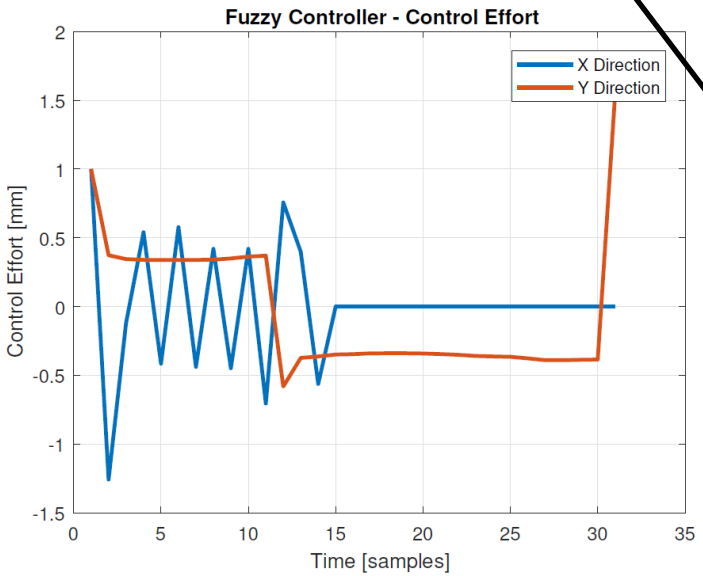
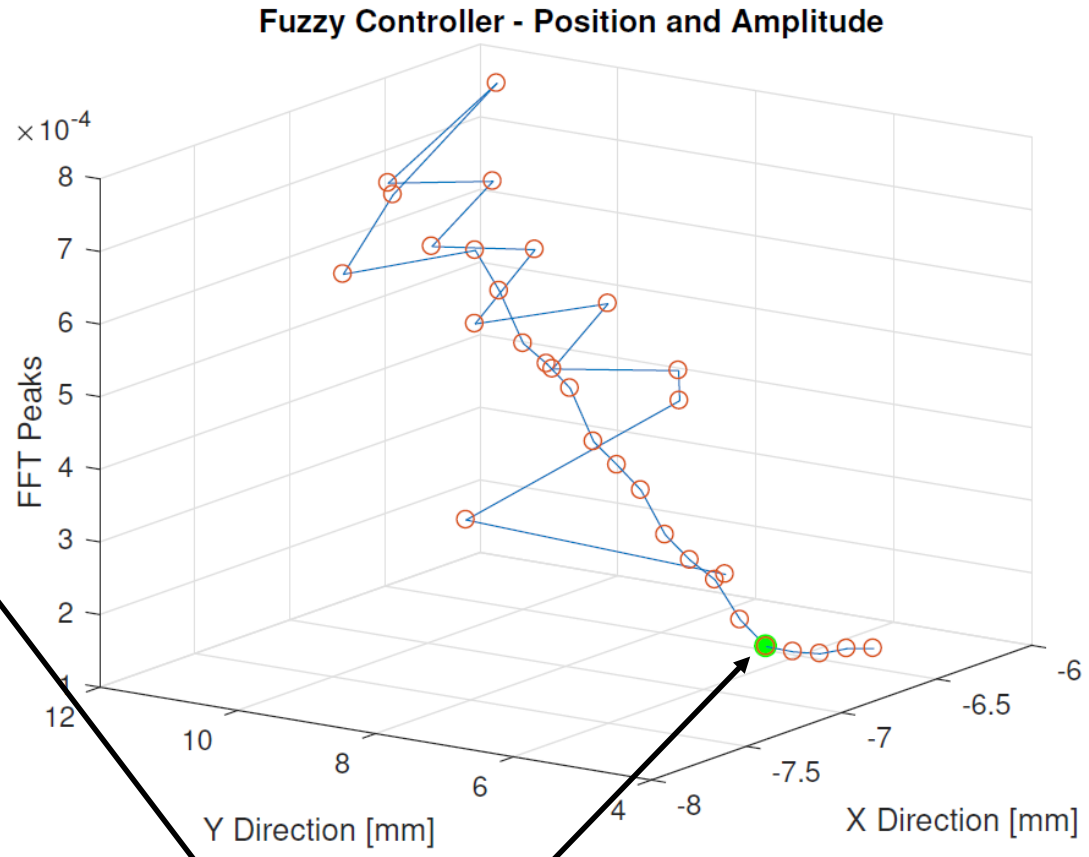
Control Design

Fuzzy Controller On Real Magnet







Not Converging!

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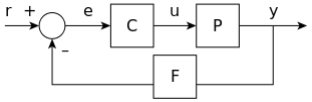
Control Design
Limits of Fuzzy Controller

- **Convergence** is **not proved**
- **Convergence** may be very **slow**
- Presence of **chattering** on the limits between the Membership Functions
- **Not robust to noise** (Air Conditioning flowing or people stepping close to the system) or different magnets
- **Not robust** to change in **current flowing** in the Quadrupole: Membership Functions must be defined each time in order to have convergence
- The **Accuracy** of the result is not in the specified range

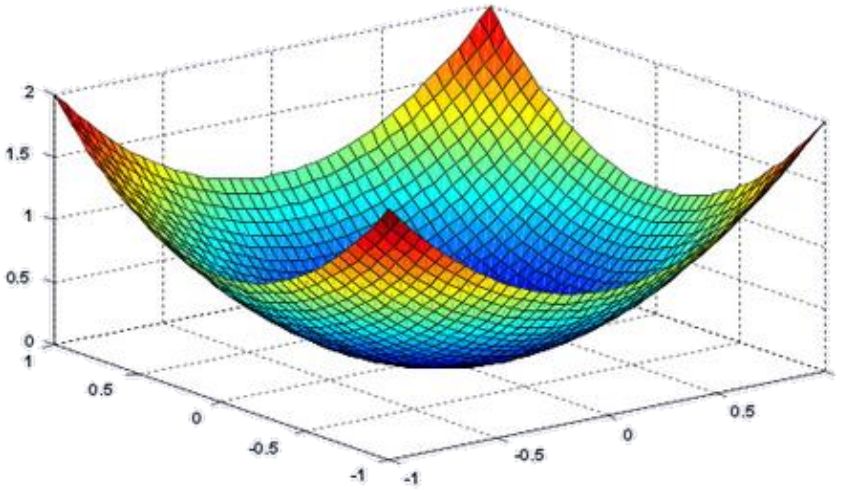
Control Design

- Two possible strategies

Control Theory



Convex Optimization



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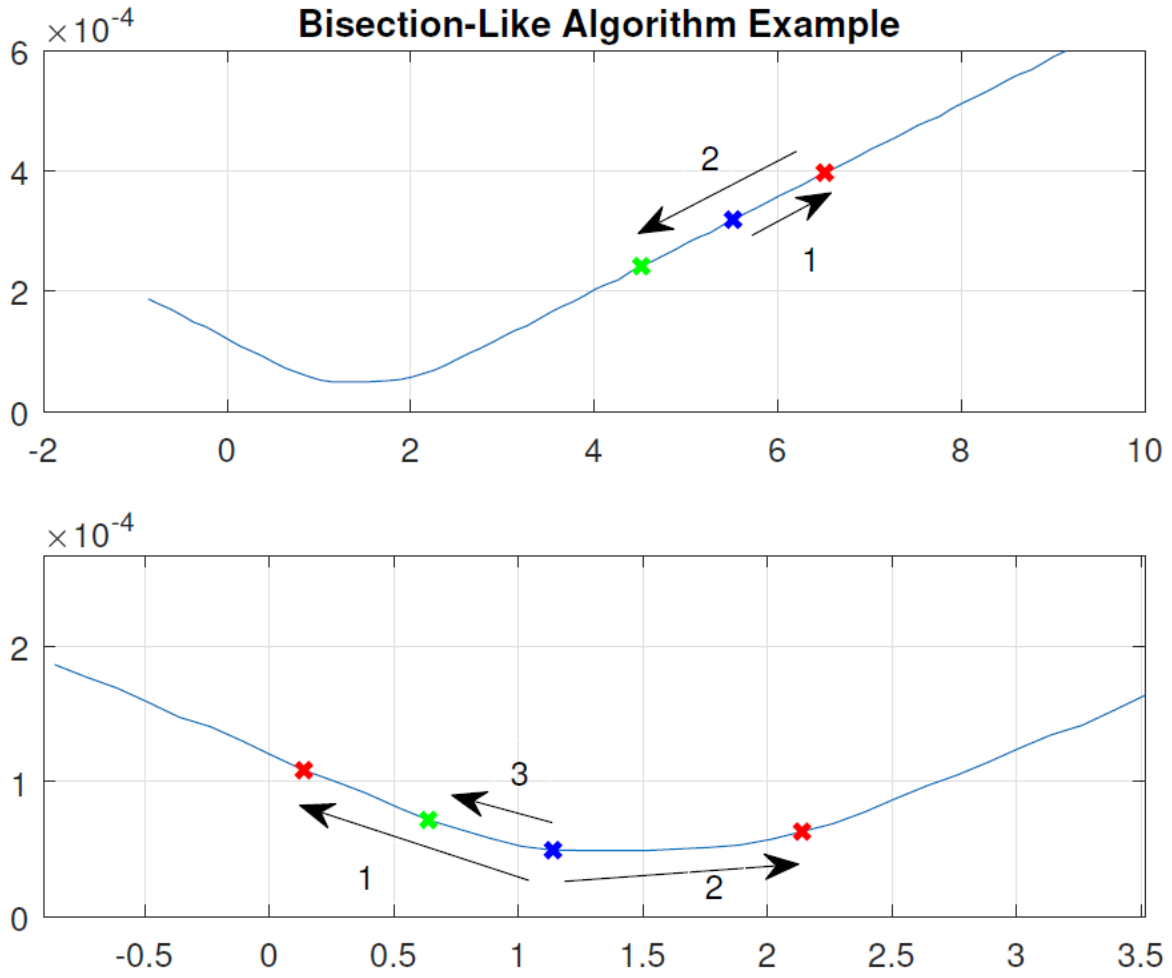
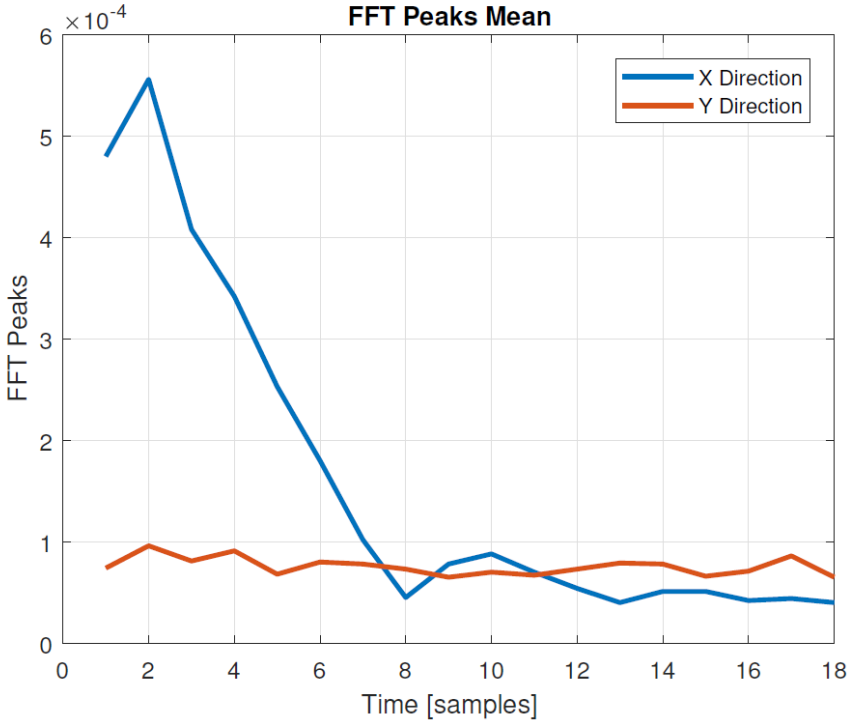
Control Design
Bisection – Like Algorithm

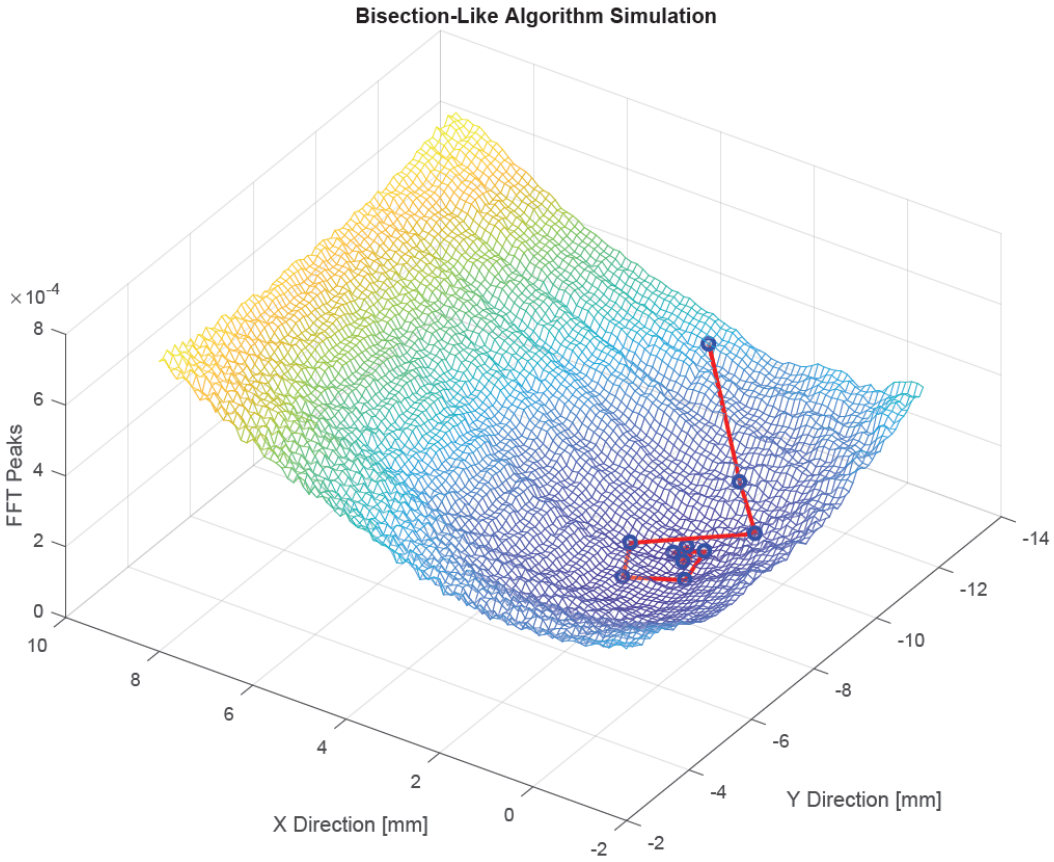


1. Initialization: Start from a random point, step in one direction
2. Iteration:
   a. If signal decreases, step in the same direction
   b. If signal increases, step in the other direction
   c. If signal increases in both directions, half the step resolution
3. Termination: When step resolution is under a certain threshold

Control Design

Bisection – Like Algorithm on Measured Data





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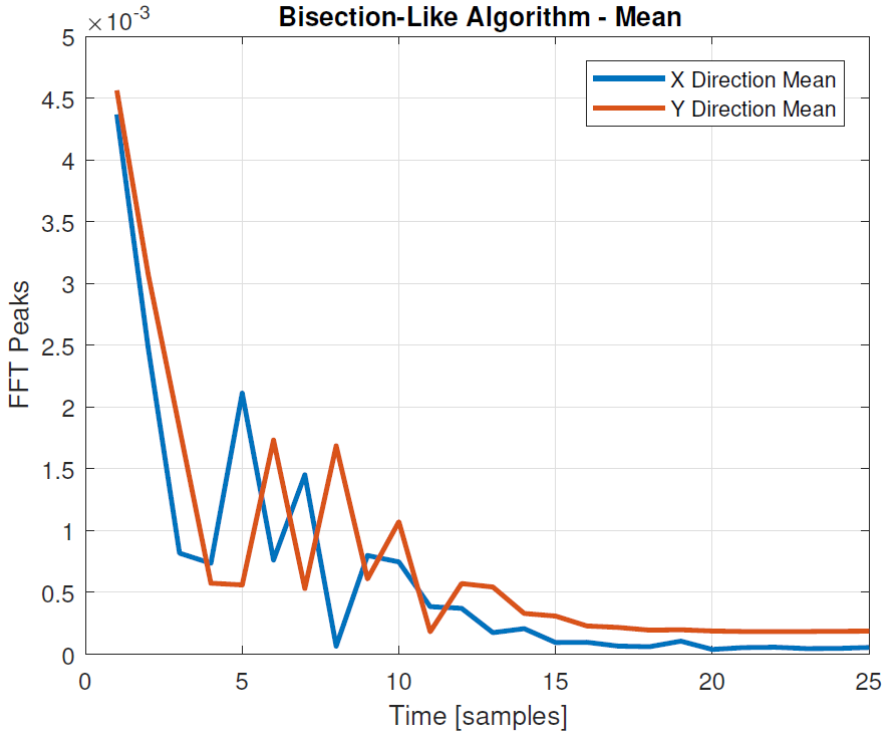
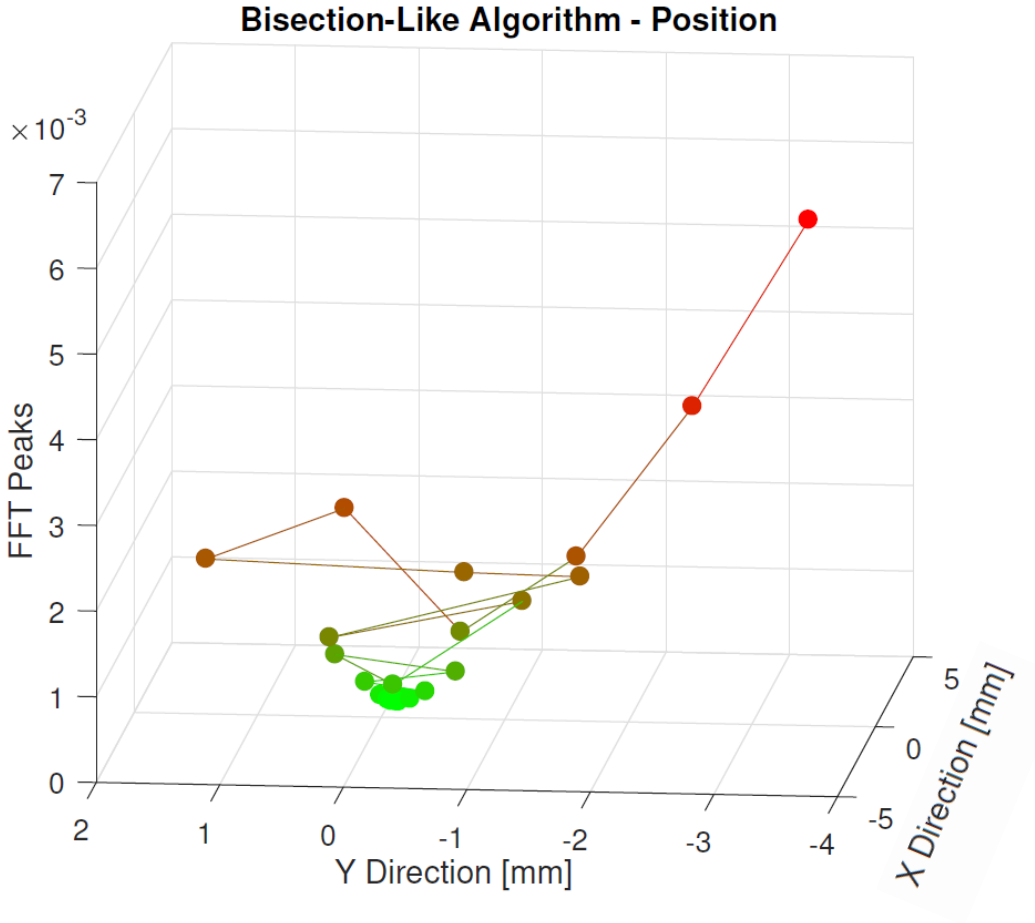
Control Design

Bisection – Like Algorithm on Real Magnet





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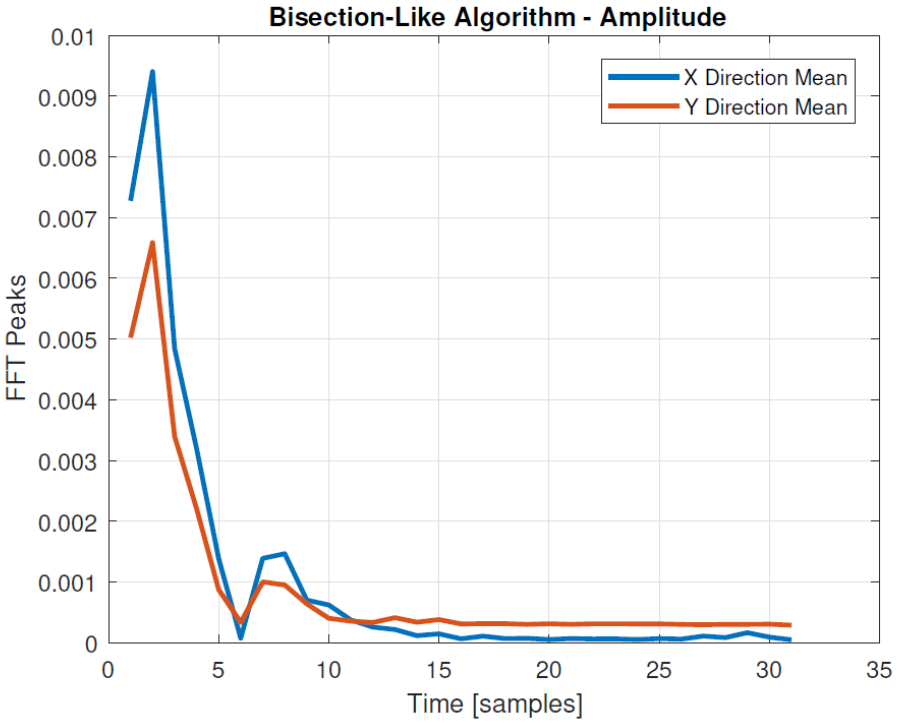
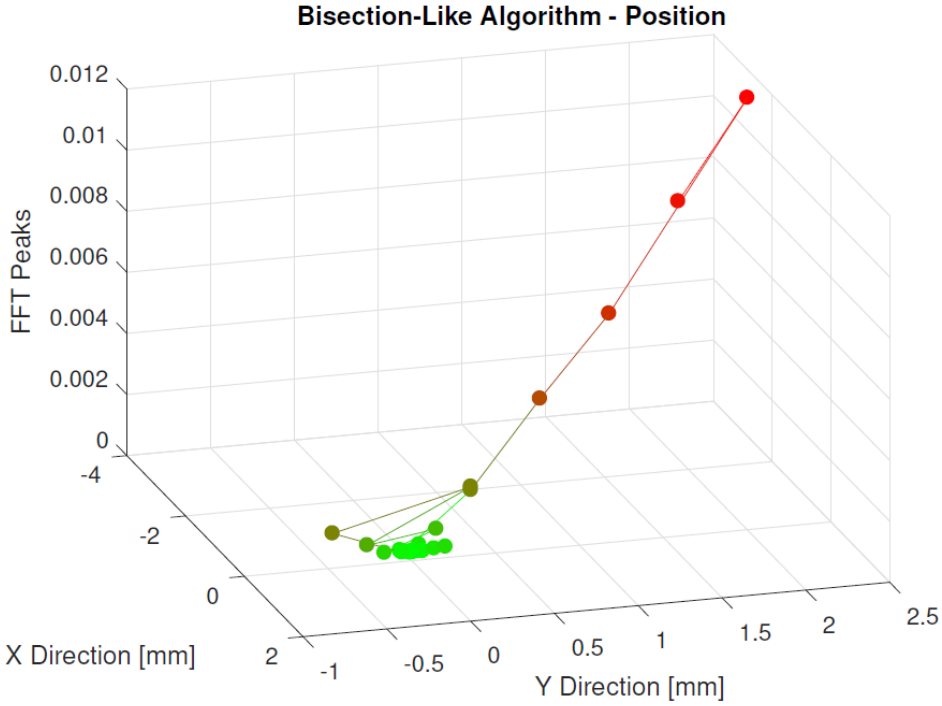
Control Design

Bisection – Like Algorithm on Real Magnet





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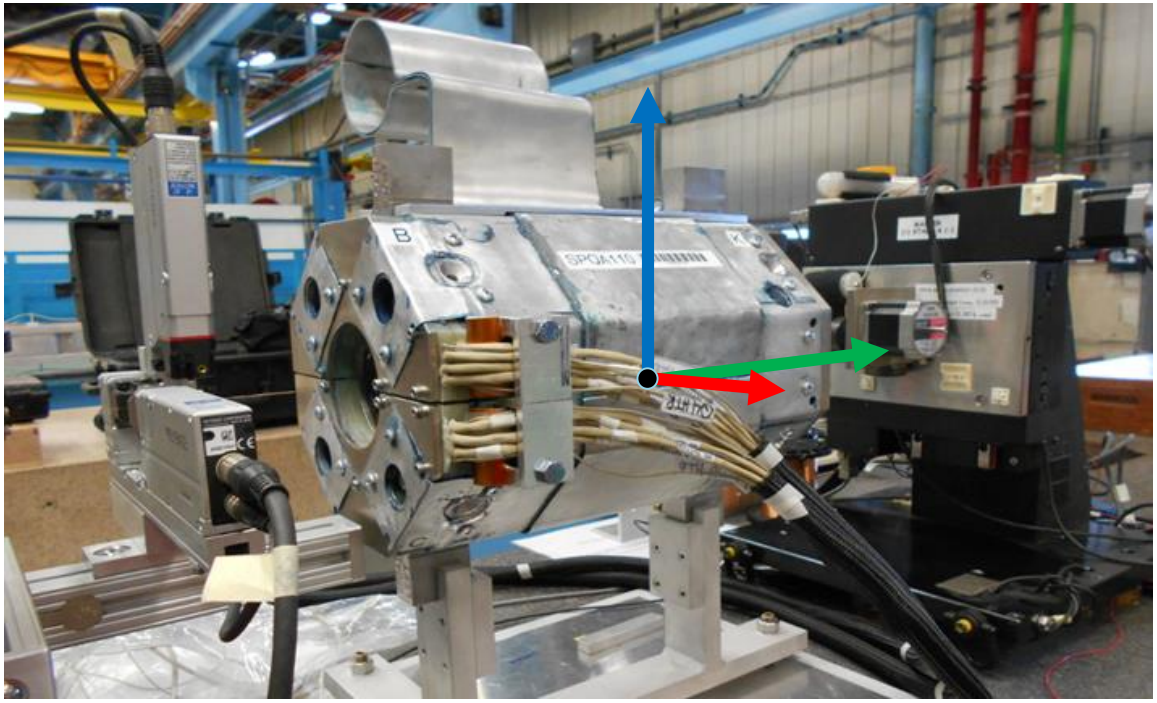
Results

Center Error from Survey



	Error [μm]
X Axis	127
Y Axis	0
Z Axis	68.6
Total Error	**144.34**

Below 250 microns limit

Conclusions

After testing on many Magnets:

- **Fuzzy has many problems:**
  - Convergence not proven
  - Slow Convergence
  - Not robust to parameter changes or Magnet change
  - Complex Controller
  - Low Accuracy

- **Bisection-Like Algorithm is fast, reliable, simple**