Nano-Positioning at ESRF
Actuators for continuous scans

Nano-Position Seminar - Prodrive

Thomas Dehaeze

OUTLINE

1/ Limitation of stepper motors for continuous scans

The “Fast Jack” Actuator example

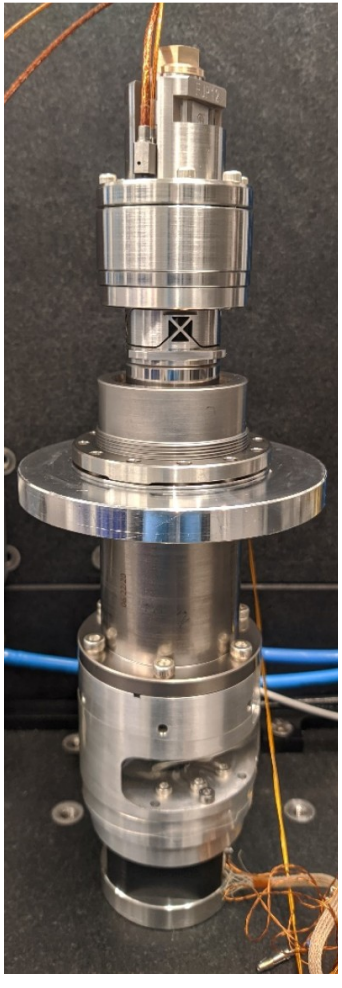
2/ Alternatives to Stepper Motors

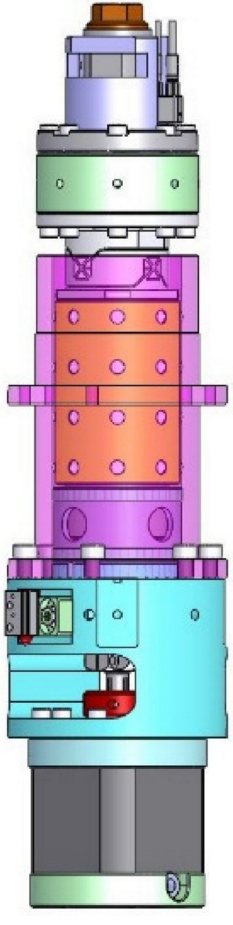
3-phase motors, 1-phase motors and associated electronics

3/ “Fast Jack” with 3-phase torque motor

Setup using the Prodrive controller and driver

THE FASTJACK HYBRID ACTUATOR





Piezoelectric Stack (15µm stroke)

Flexible Joint

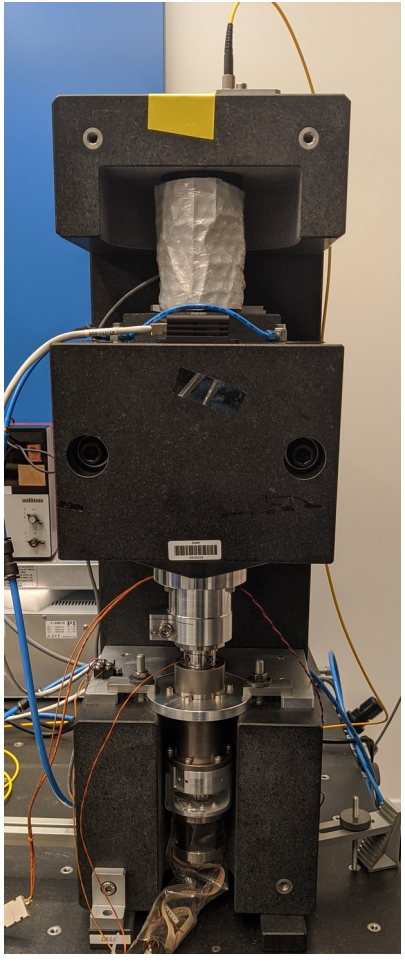
Satellite roller screw (1mm pitch)

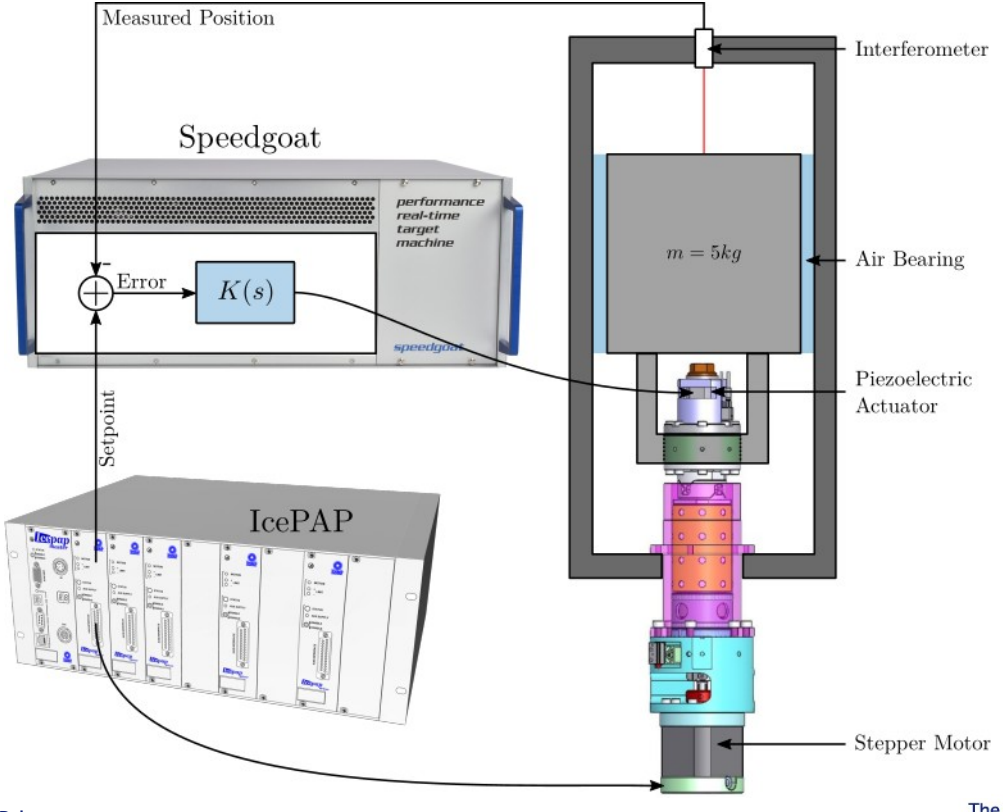
Ball bearing guide

Hybrid Stepper Motor (200 steps/turn)

Specifications	
Robustness: 10 million cycles without maintenance.	
Performance: 5nm RMS accuracy during scans	
UHV & radiation compatible	
Stroke	30 mm
Velocity	1 mm/s
Stiffness	> 10 N/µm
Payload	10 kg

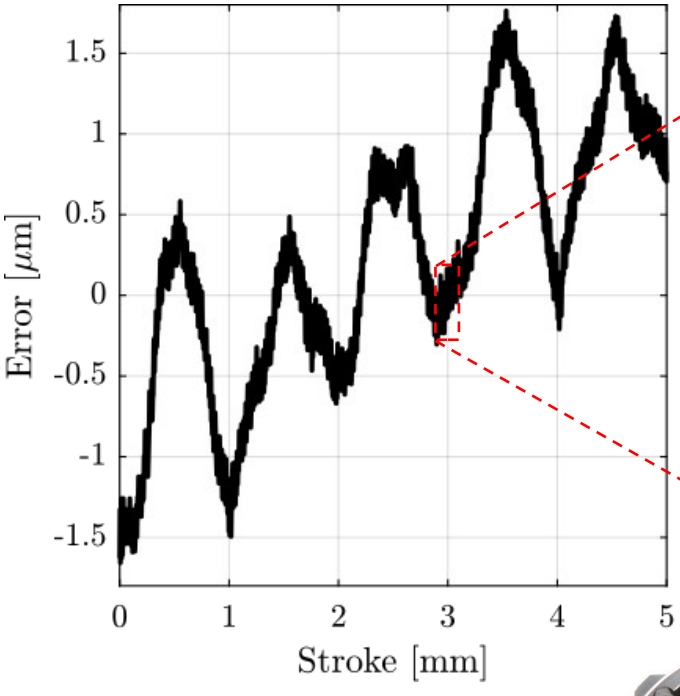
TEST BENCH



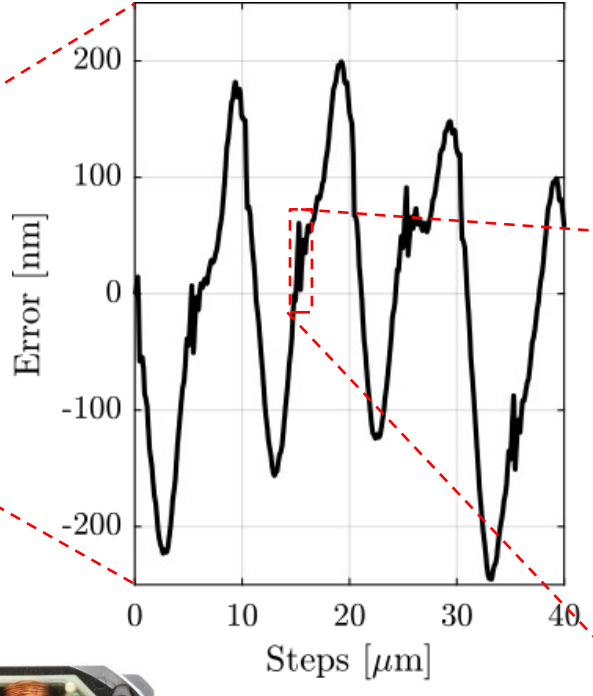

Measured Position
Interferometer
Speedgoat
performance
real-time
target
machine
Error
$K(s)$
$m = 5kg$
Air Bearing
Piezoelectric
Actuator
Setpoint
IcePAP
Stepper Motor

OPEN LOOP ERROR ANALYSIS

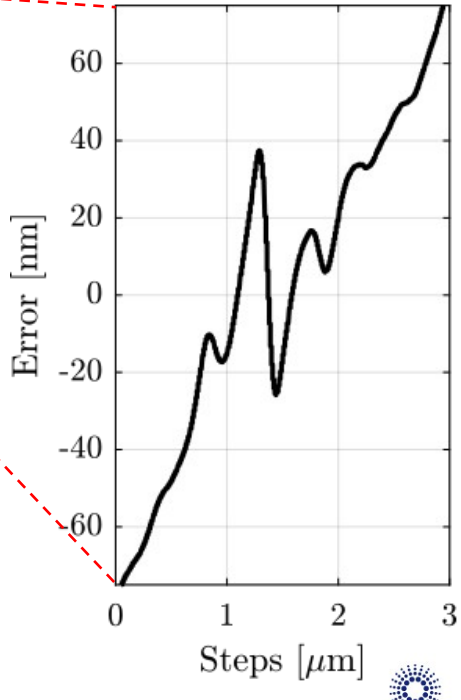
Lead Screw Errors

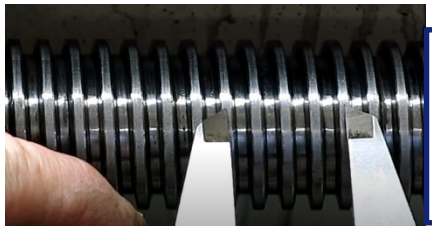


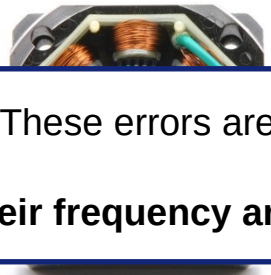
Microstepping Errors



Cogging



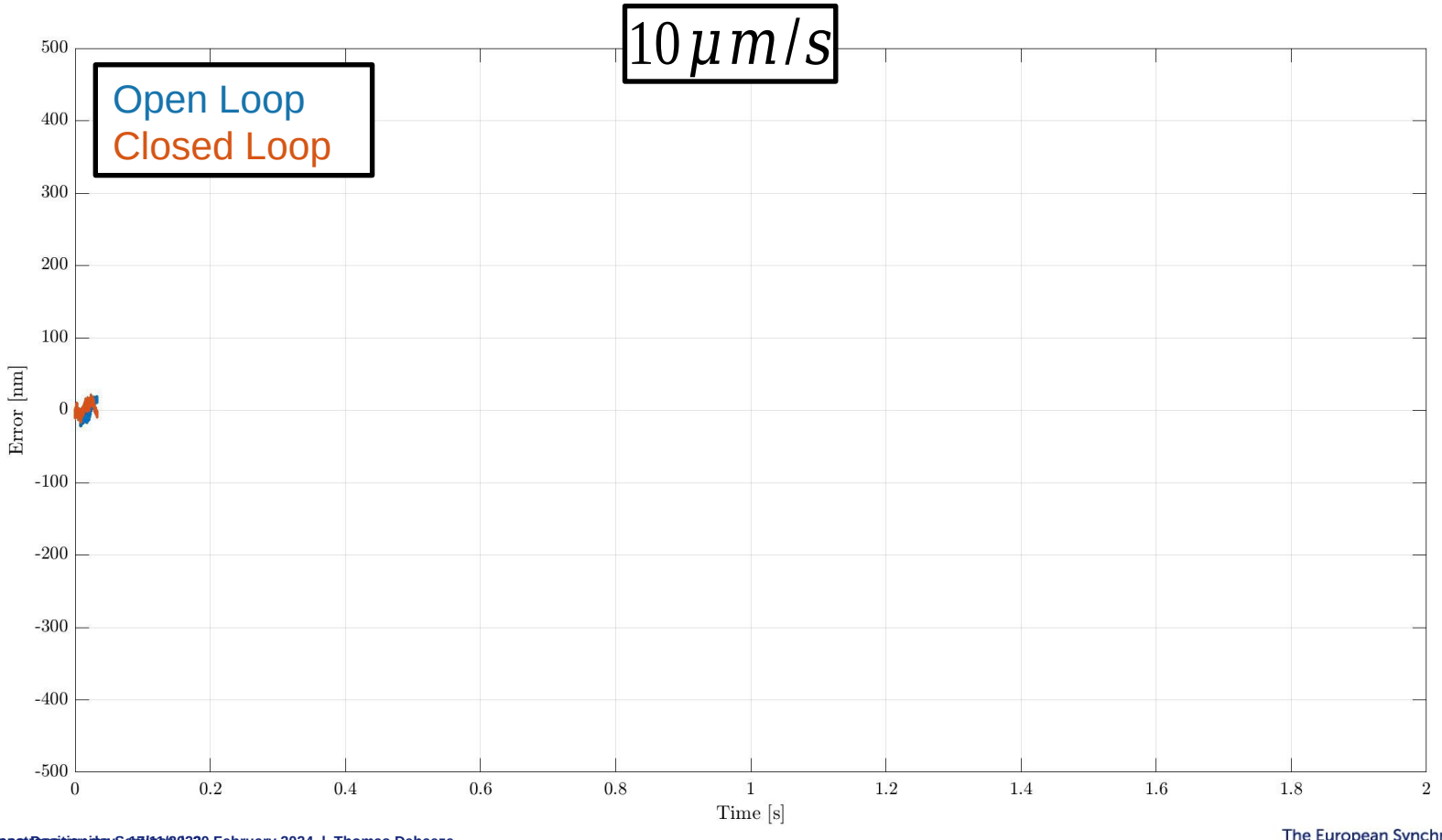




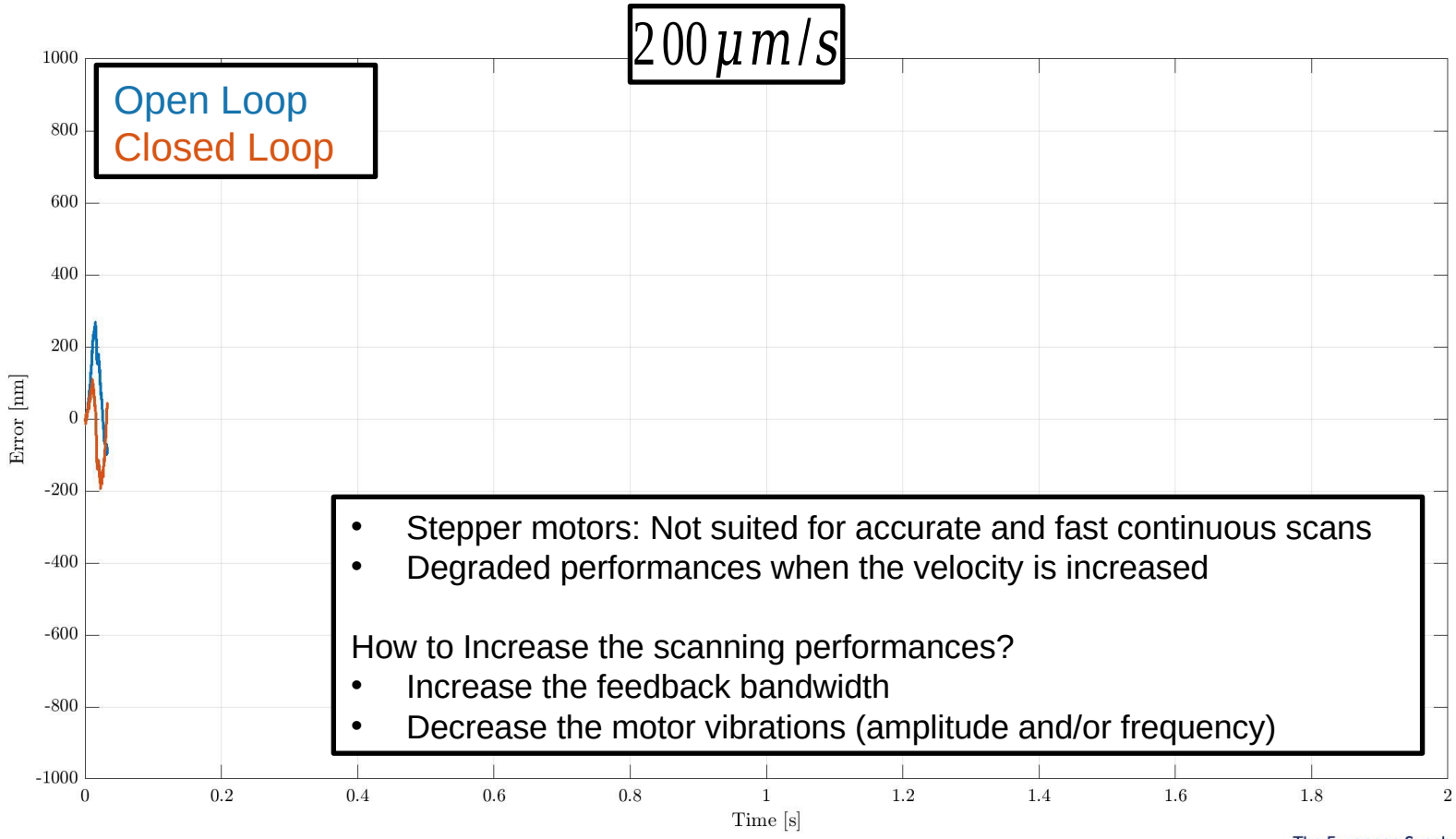
These errors are linked to spatial effects.

Their frequency are proportional to velocity

FAST JACK – SCANNING PERFORMANCES



FAST JACK – SCANNING PERFORMANCES



- Stepper motors: Not suited for accurate and fast continuous scans
- Degraded performances when the velocity is increased

How to Increase the scanning performances?

- Increase the feedback bandwidth
- Decrease the motor vibrations (amplitude and/or frequency)

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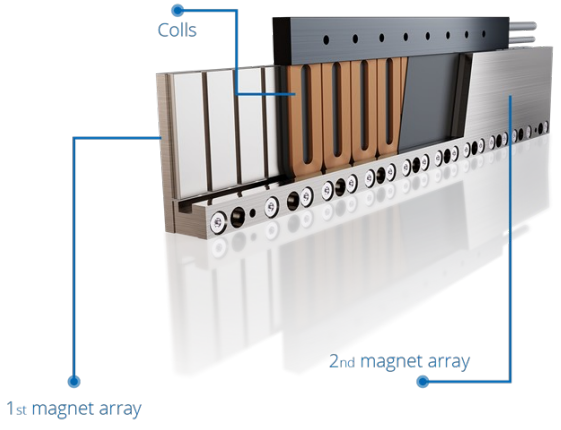
ALTERNATIVE TO STEPPER MOTORS?

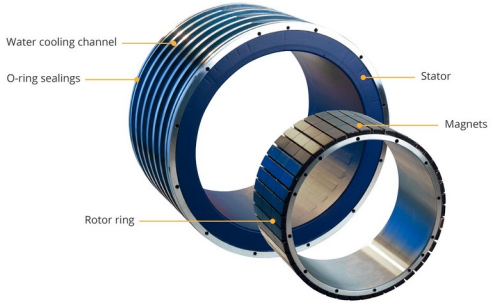
3-Phase Linear Motors

(Typ. linear air bearing stages)



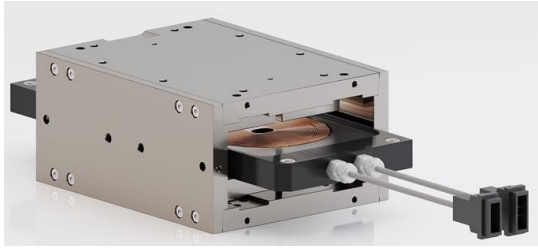
3-Phase Torque Motors

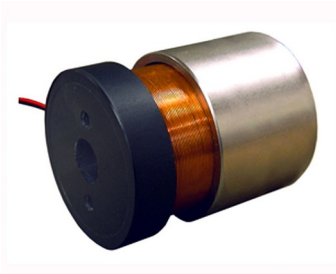
(Typ. air bearing Spindles)



Voice coil

(Not yet used at ESRF)





CONTROL OF 3-PHASE AND 1-PHASE MOTORS

Used 3-phase motor electronics at the ESRF

Would benefit by having one standard controller/driver for all 3-phase motor needs.

Requirements:

- Good input / outputs capabilities (encoders, triggering, …)
- Low Current Noise (rarely specified)
- High maximum current (>10A)
- Control architecture flexibility
- Easy interfacing with beamline control software

CHOSEN SOLUTION TO STUDY 3-PHASE MOTORS

Arcas Controller

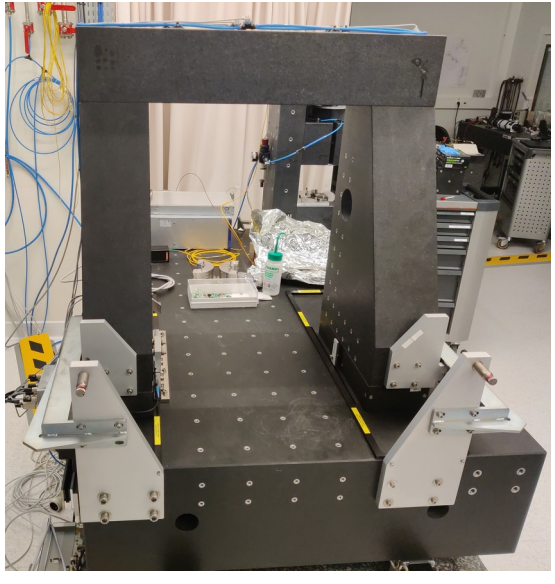
Apogee Driver

Some characteristics:

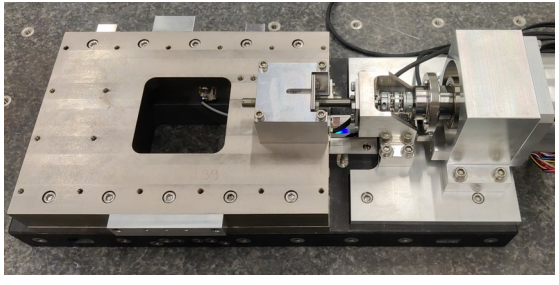
- Encoder inputs: Quadrature, Analog Sin/Cos, Endat, SSI, BissC
- Lots of digital / analog I/O
- Large current output: 6.5 Arms (16.5 peak)
- Easy programming with Simulink
- Lot's of flexibility on the configuration / control architecture
- High performance:
  - Low current noise:
  - High current bandwidth
  - 10kHz position control, 800kHz current control

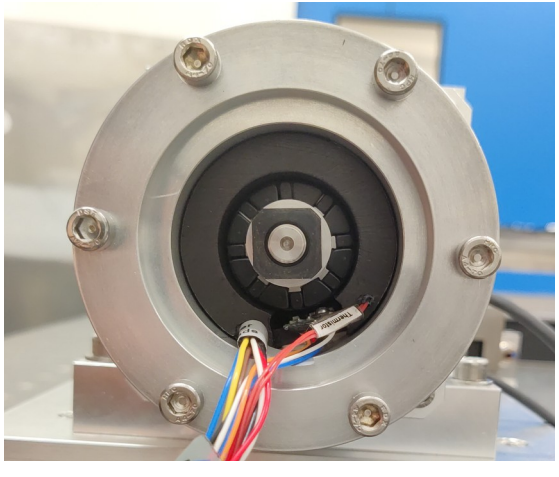
TEST BENCHES

Air Bearing Gantry
3-phase Linear Motor

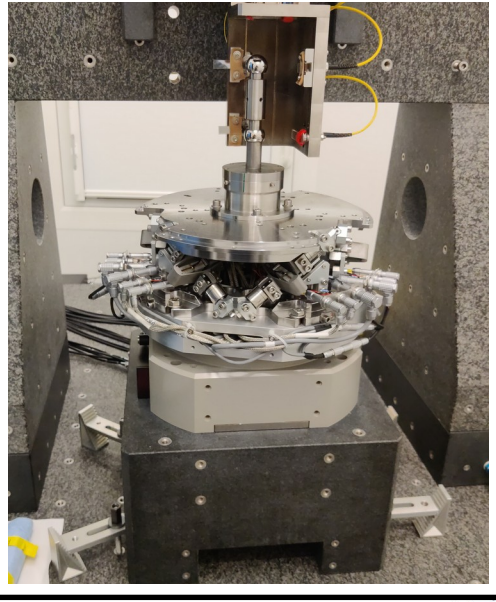


Linear stage, Leadscrew
3-phase Torque Motor





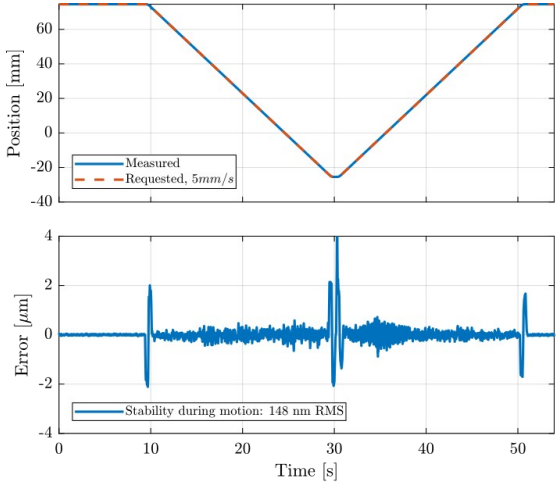
Air Bearing Spindle
3-phase Torque Motor



TEST BENCH: PRELIMINARY RESULTS

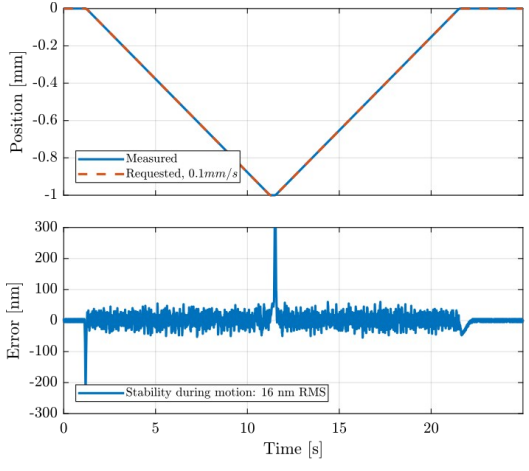
Air Bearing Gantry

3-phase Linear Motor
Incremental Linear Encoder



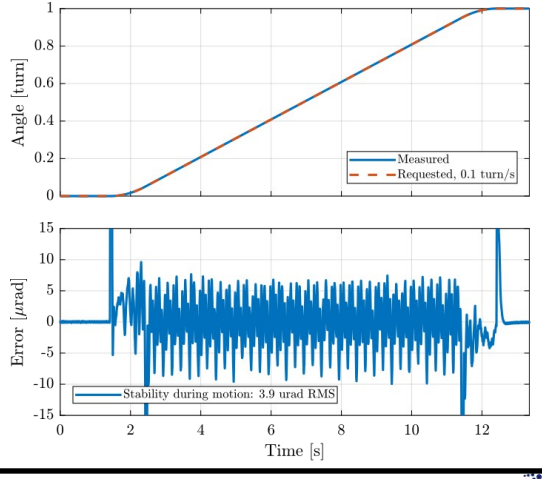
Linear stage

Leadscrew
3-phase Torque Motor
Incremental rotary encoder



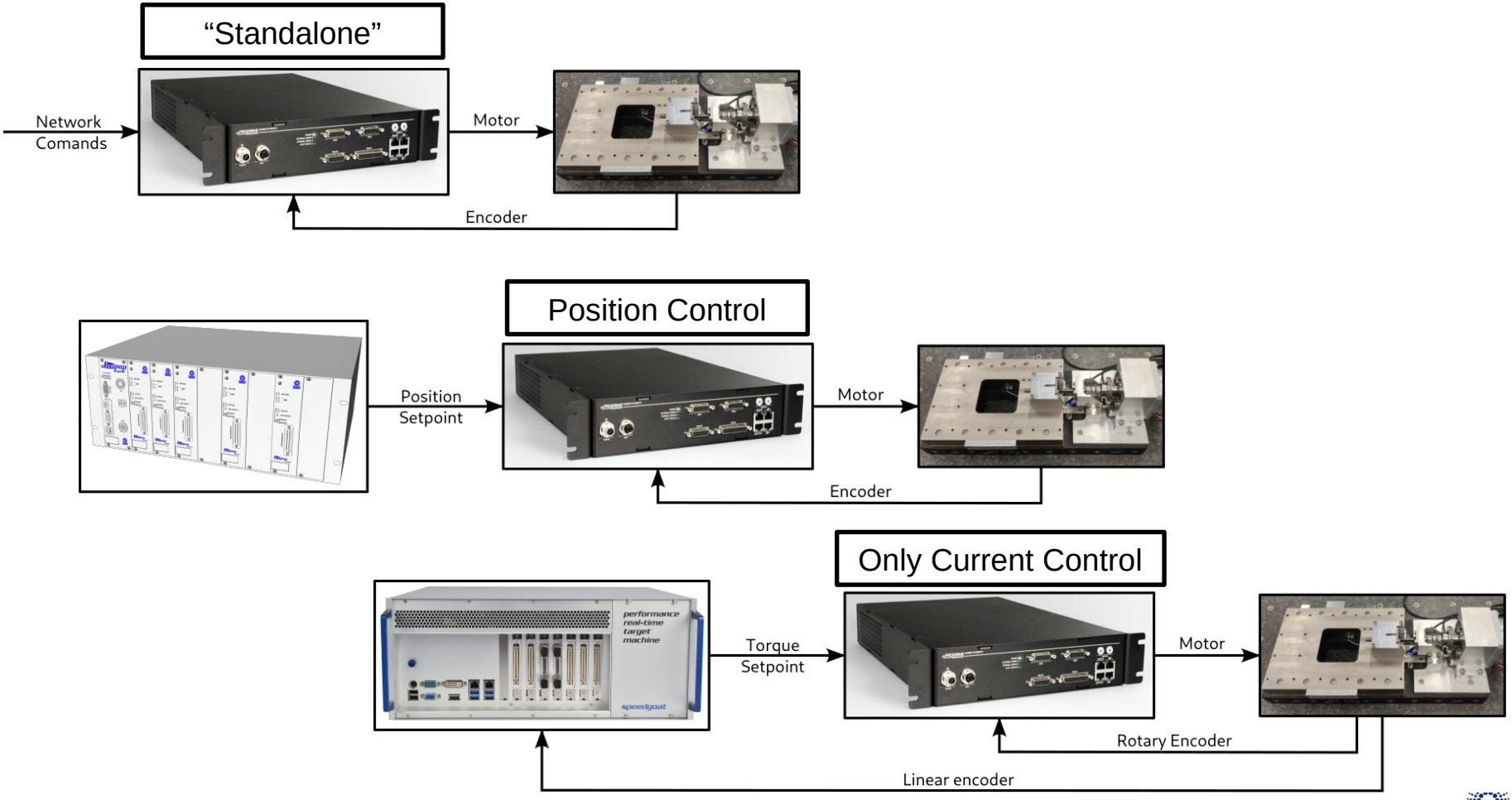
Air Bearing Spindle

3-phase torque motor
Absolute rotary encoder



Flexible and high performance system: allowed to control all the stages with similar/better performances than previous control architecture.

CONTROL ARCHITECTURE FLEXIBILITY



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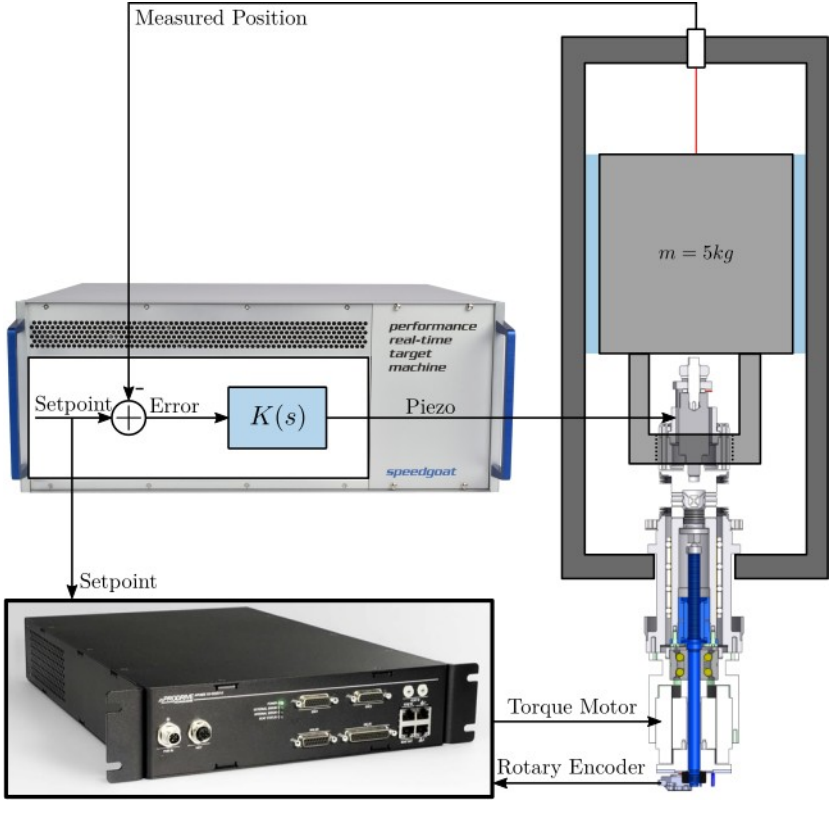
SETUP PROCEDURE

Setup one 3-phase motor (Fastjack example):

1. Choice of the control architecture
2. General motor and encoder configuration
3. Current Loop (Identification, Controller design)
4. Position Loop (Identification, …)
5. Validation of performances

CONTROL ARCHITECTURE / BASIC CONFIGURATION



Configuration using text (xml) files

Signal routing:

```
<Input Name="DemandPosition" Source="Apogee S3_120_07-0/Enc2Quadrature/Actual"/> <!-- Setpoint -->
<Input Name="PositionSensor" Source="Apogee S3_120_07-0/Enc1Quadrature/Actual"/> <!-- Feedback Sensor -->
```

Encoder / Motor configuration:

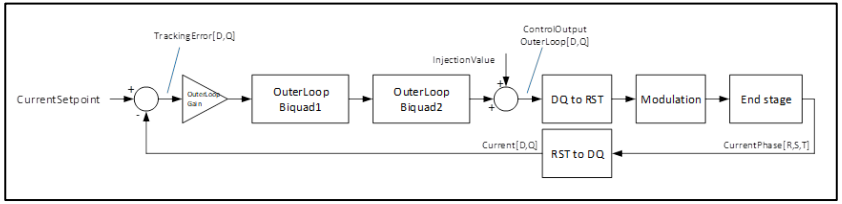
```
<Sensor Name="Enc1Quadrature">                      <!-- ENC1 quadrature encoder -->
¦   <Signal Name="ScaleFactor">0.0000012207</Signal> <!-- Encoder scaling 1 revolution [turn/count] -->
</Sensor>

<Sensor Name="Enc2Quadrature">                      <!-- ENC2 quadrature encoder -->
¦   <Signal Name="ScaleFactor">0.000001</Signal>     <!-- Encoder scaling 2 revolution [m/count] -->
</Sensor>

<Signal Name='EncoderCountsPerRevolution'>819200</Signal> <!-- Set encoder counts per mechanical revolution -->
<Signal Name="LoadInductance">0.17e-3</Signal>            <!-- Motor phase inductance [H] -->
<Signal Name="PolePairs">4</Signal>                       <!-- Number of pole pairs for the motor -->
```

Current protection:

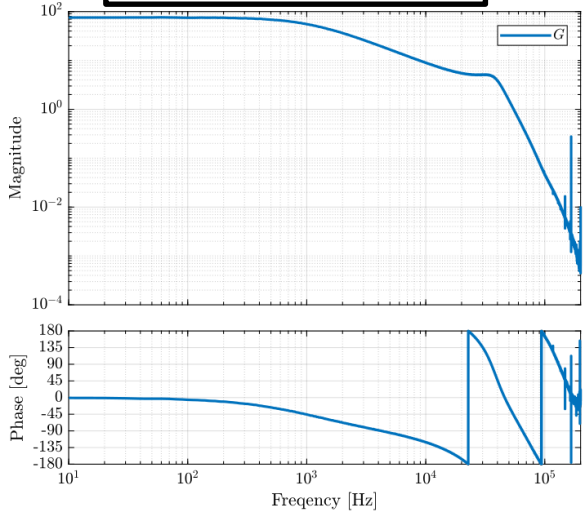
```
<Event Name="CfgRmsOcp">                    <!-- Output RMS current protection -->
¦   <Signal Name="TimeConstant">10</Signal> <!-- Motor/cable thermal time constant [s] -->
¦   <Signal Name="Limit">5.1</Signal>       <!-- Motor/cable RMS rating [Arms] -->
</Event>
```

CURRENT CONTROL

Current Control Architecture

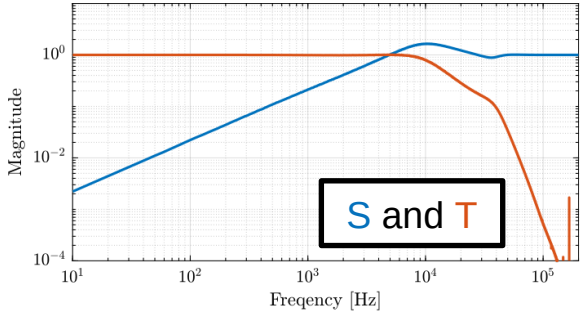


Identified Current Plant

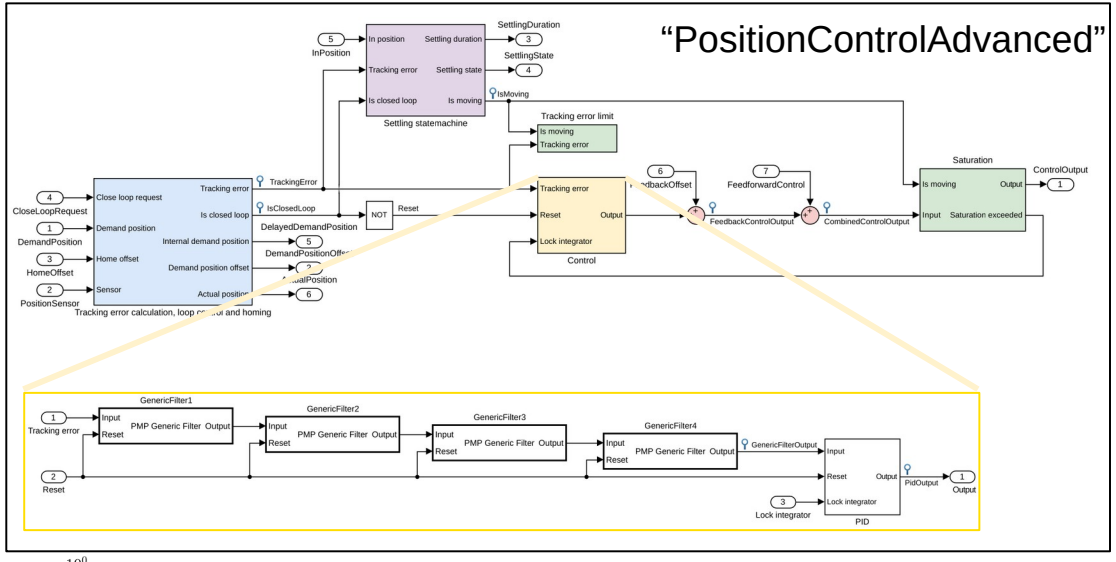


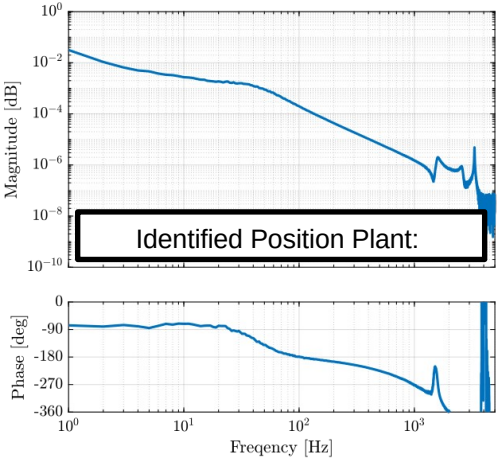
Current Control - Configuration

```
<!-- Current Controller Operating at 800kHz -->
<Signal Name='OuterLoopGain'>0.06</Signal>     <!-- Current control gain -->

<Filter Name="OuterLoopBiquad1">   <!-- Double lag/lead p=50Hz, z=500Hz -->
    <Signal Name="Type">7</Signal> <!-- Second order generic Z -->
    <Signal Name="Parameter0">0.5</Signal>
    <Signal Name="Parameter1">-0.996</Signal>
    <Signal Name="Parameter2">0.496</Signal>
    <Signal Name="Parameter3">-1.9992</Signal>
    <Signal Name="Parameter4">0.9992</Signal>
</Filter>

<Filter Name="OuterLoopBiquad2">
    <Signal Name="Type">2</Signal>           <!-- 2nd order LPF -->
    <Signal Name="Parameter0">1</Signal>     <!-- Gain -->
    <Signal Name="Parameter1">50e3</Signal>  <!-- Cut-off [Hz] -->
    <Signal Name="Parameter2">0.707</Signal> <!-- Damping -->
</Filter>
```

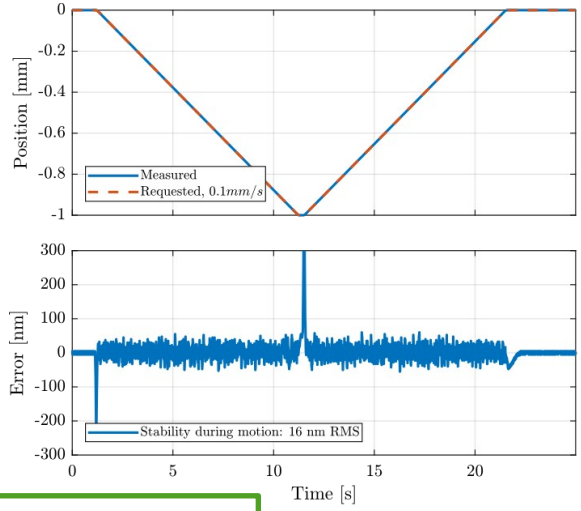


POSITION CONTROL





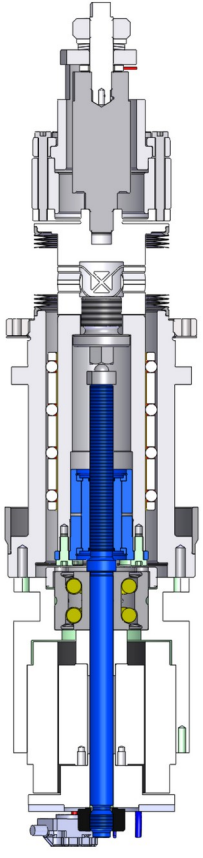
Identified Position Plant:



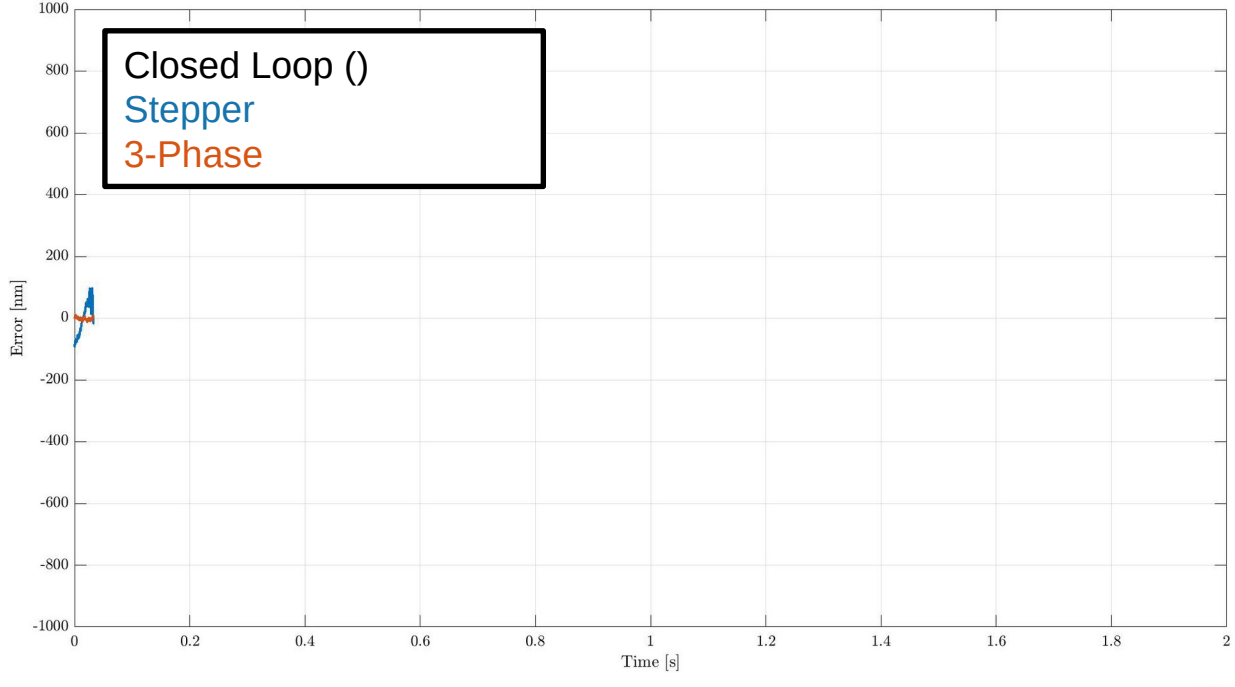
Position Control - Configuration

```
<!-- Position Controller -->
<Filter Name="Control_PID_LowPass">
  <Signal Name="ProportionalGain">0.25</Signal>          <!-- Controller gain [Arms/m] -->
  <Signal Name="DifferentiatorFrequency">3000</Signal>   <!-- [Hz] -->
  <Signal Name="IntegratorFrequency">100</Signal>        <!-- [Hz] -->
  <Signal Name="LowPassFrequency">1000</Signal>          <!-- Low pass filter Frequency [Hz] -->
  <Signal Name="LowPassDamping">0.707</Signal>           <!-- Low pass filter damping -->
</Filter>
```

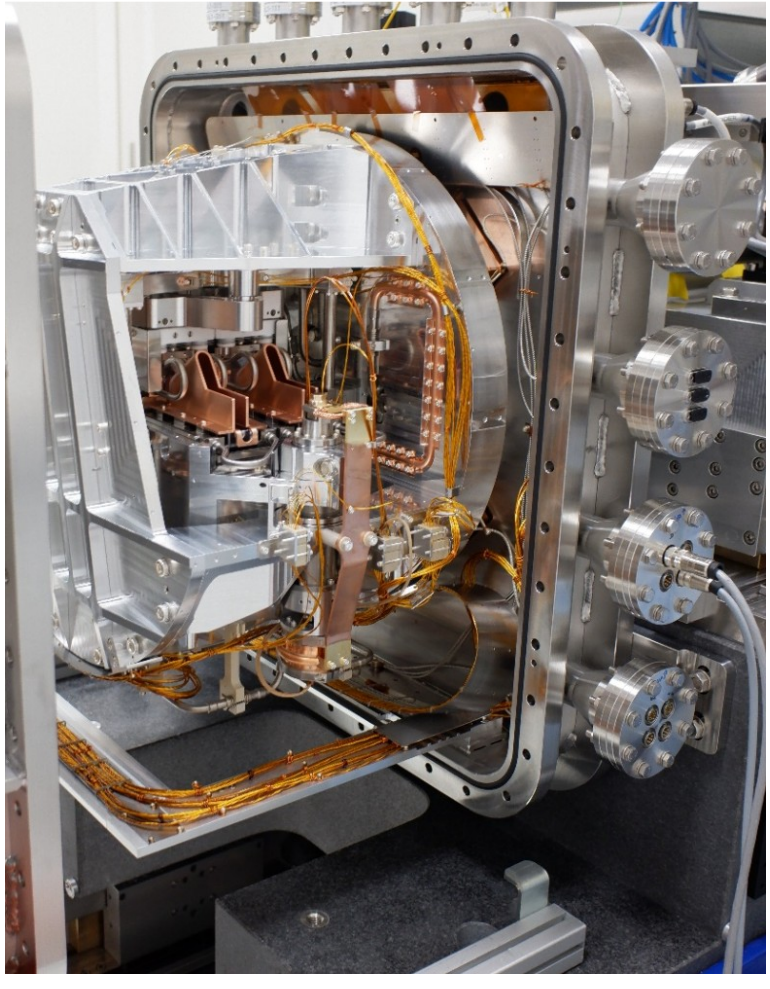
FASTJACK: TEST WITH 3-PHASE TORQUE MOTORS



Velocity	Stepper Motor	Torque Motor
	3nm RMS	3nm RMS
	5nm RMS	4nm RMS
	50nm RMS $\div 10$	6nm RMS
	670nm RMS $\div 15$	40nm RMS



CONCLUSION



Paper from MEDSI 2002:
“ At the start of the European Synchrotron, […] stepper motorizations were considered capable of satisfying all positioning requirements. ”

… this is no longer the case.
Stepper motors are well suited to static positioning but not for accurate and fast continuous scans.

“FastJack” example: Large performance increase by replacing stepper motor with 3-phase torque motor.

Arcas controller and Apogee driver are capable to satisfy all 3-phase control needs.