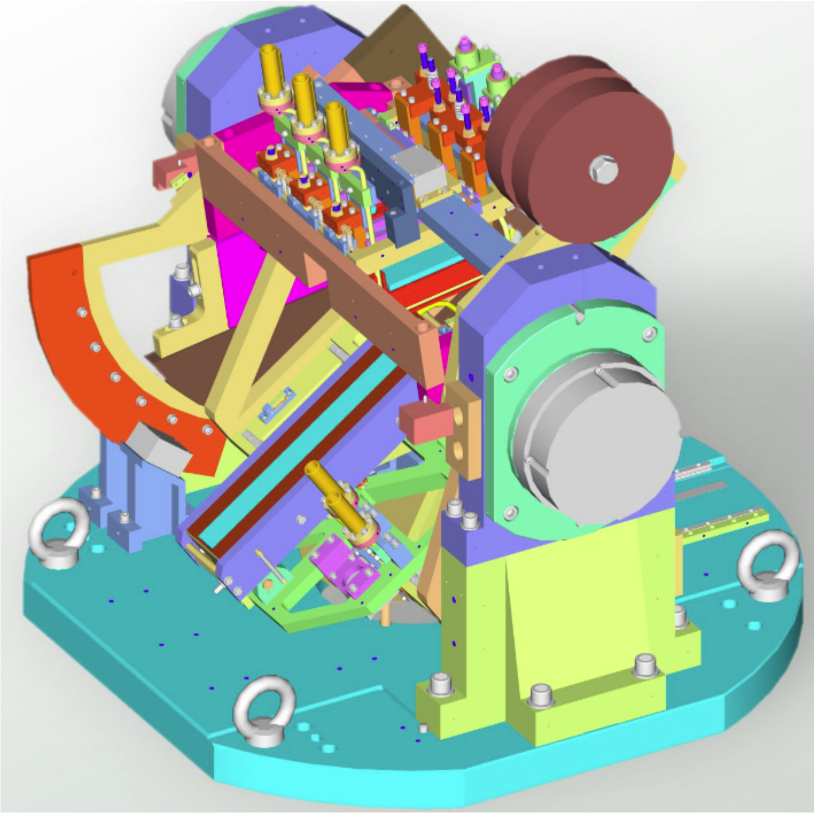
Advanced Monochromator Control

Outline

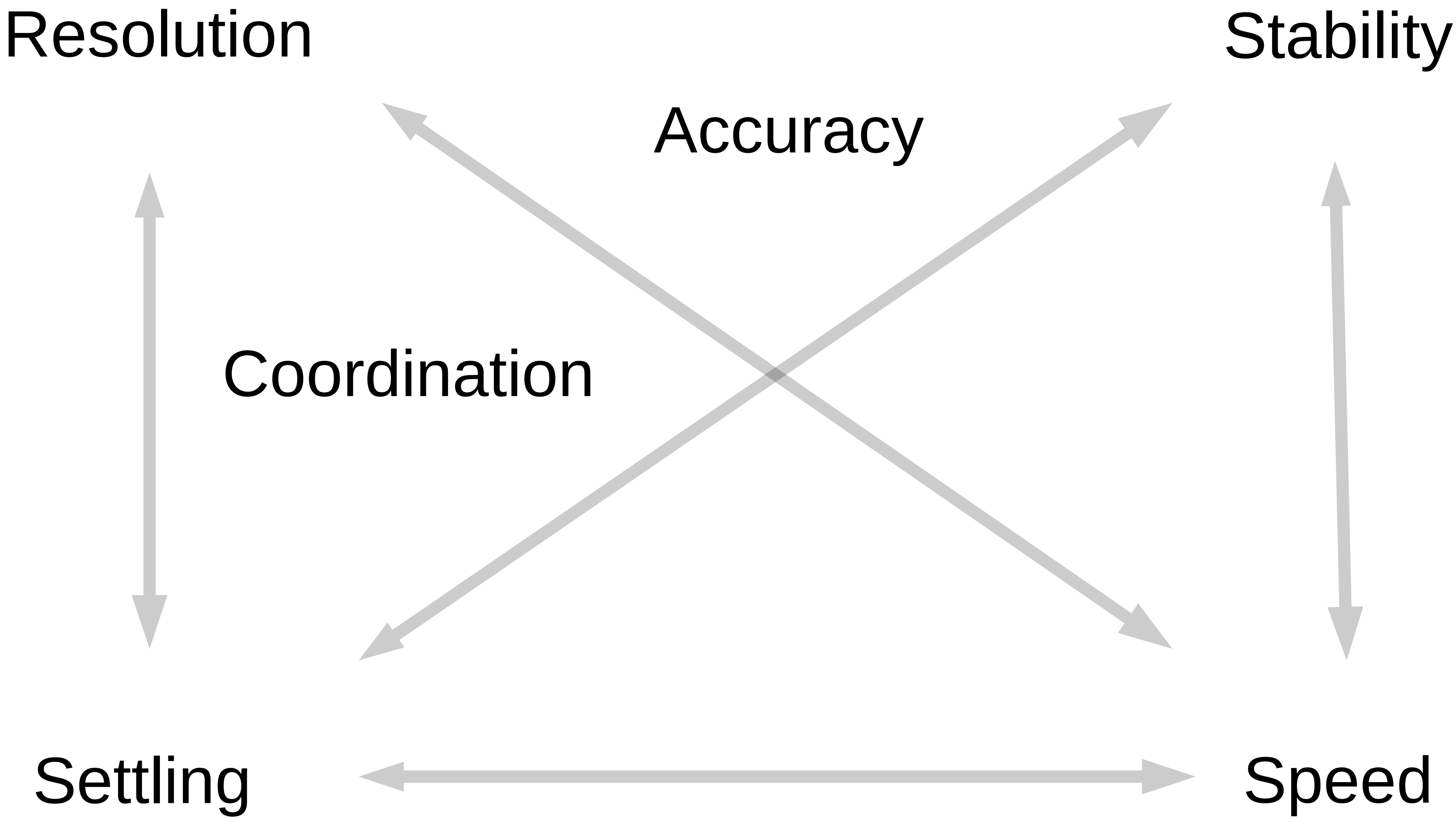
- Challenges
- Solutions
  - Hardware
    - Position Feedback
    - Motor Types
    - Interfaces
  - Software
    - Dynamic Parameter Scheduling & Dual PID
    - Kinematics & Continuous Scanning

Goals

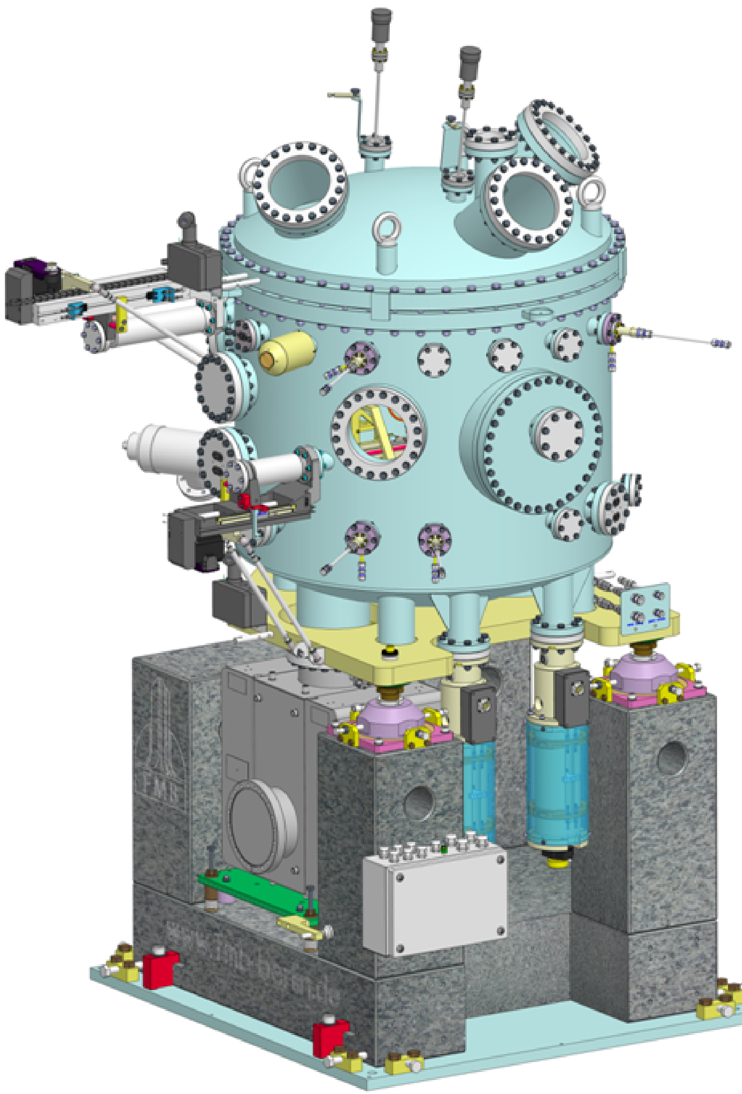
- High Resolution
- High Accuracy
- High Speed
- High Stability
- Short Settling Time
- Close Coordination

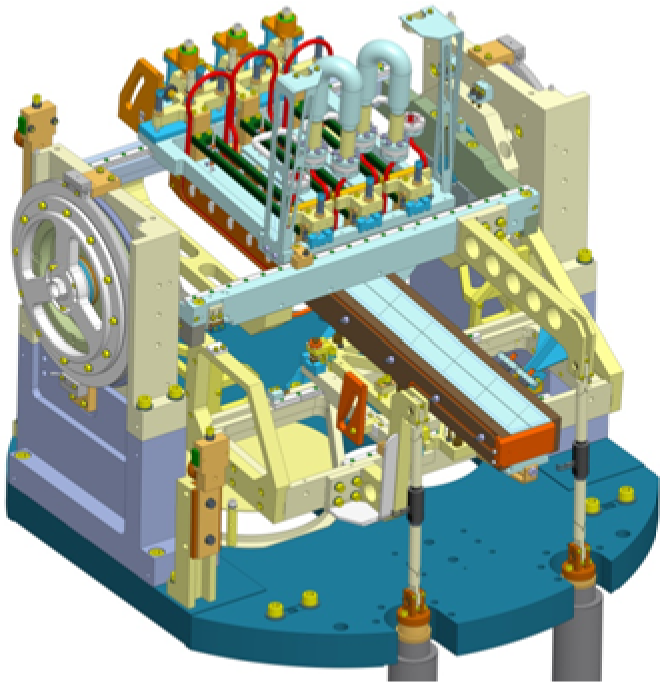


Goal Conflicts



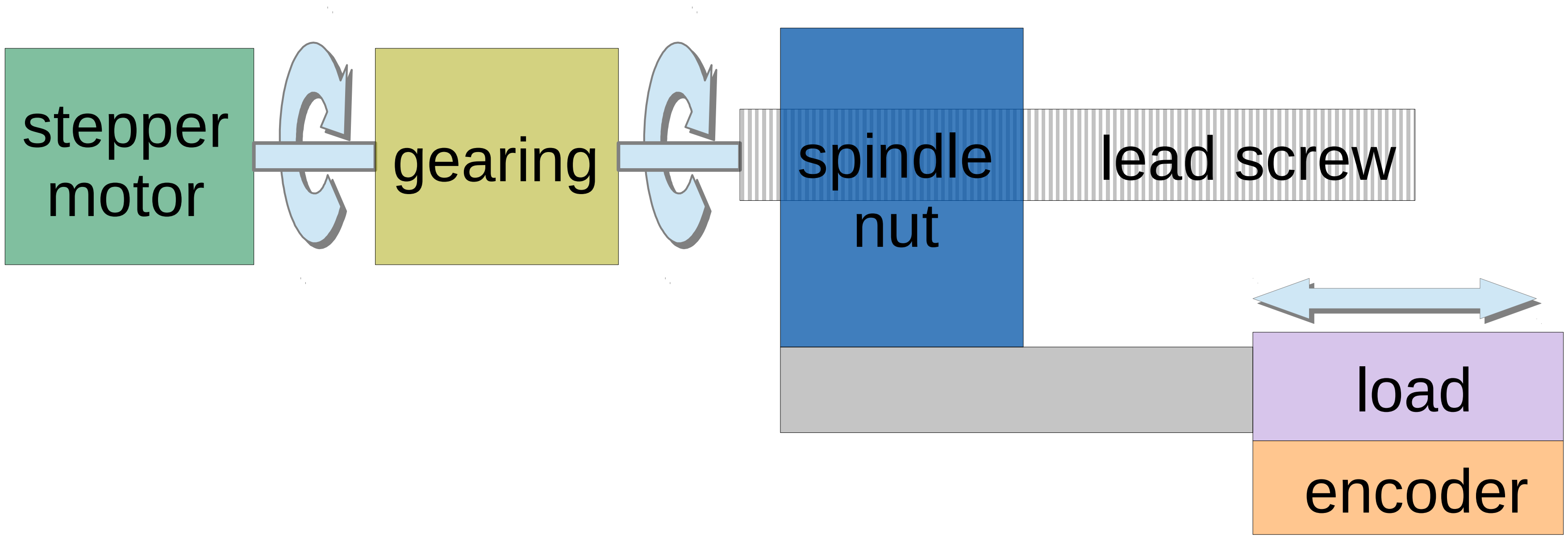
Monochromator





Conventional Design

Typical high precision drive

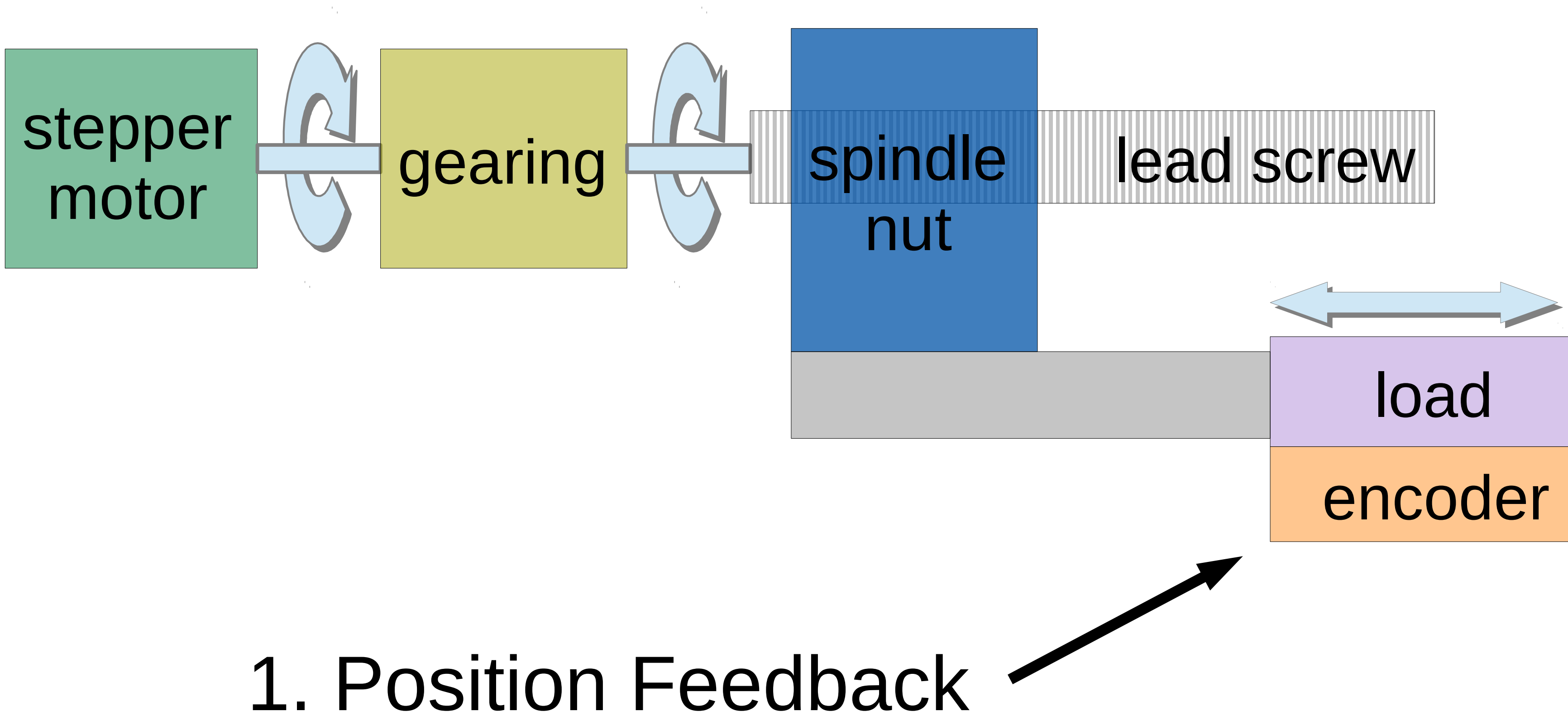


Alternative designs

- direct drive
- piezo based actuator

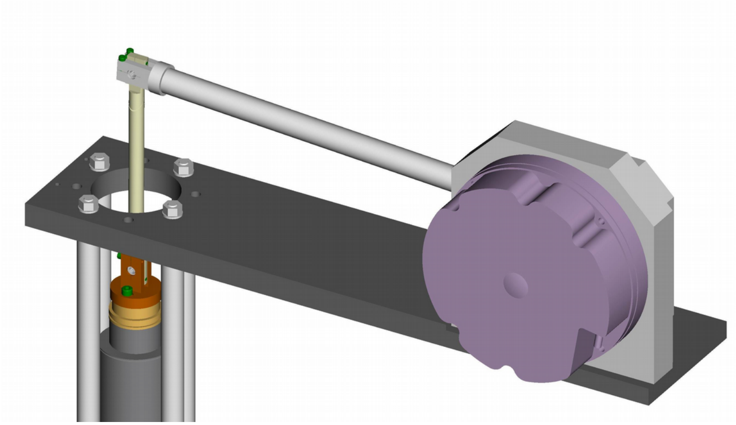
Conventional Design

Typical high precision drive



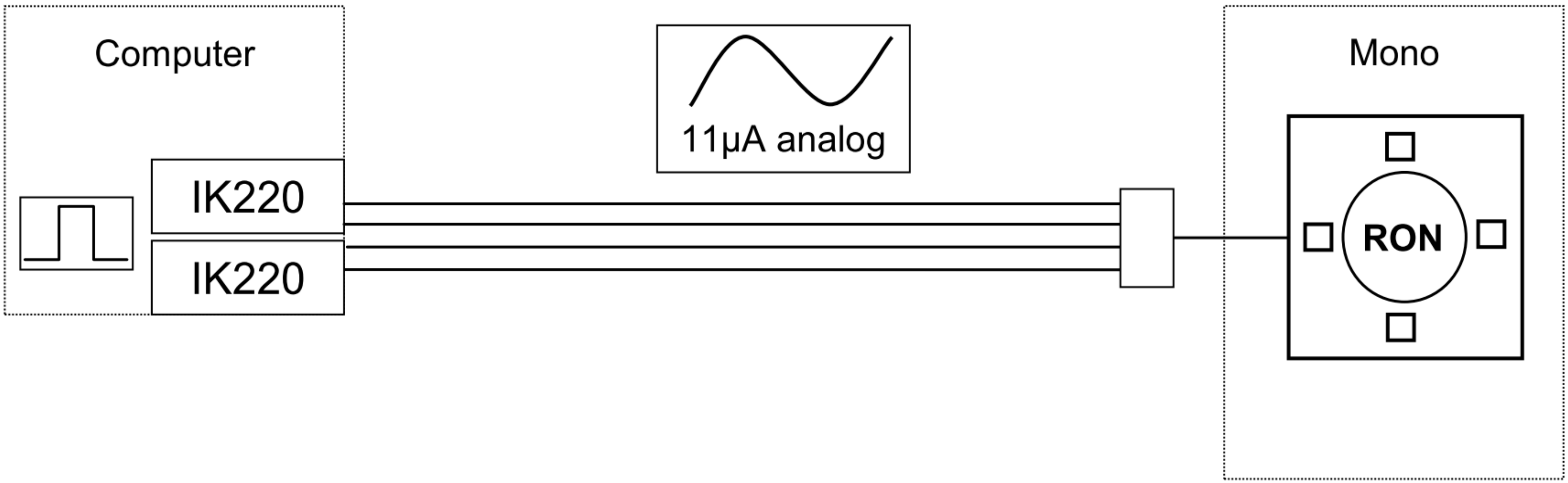
Position Feedback

Heidenhain RON905UHV rotary encoder



- four readheads
- internal bearing
- 36000 lines per revolution
- accuracy: +/- 0.2 arcsec
- analog 11µA signal output

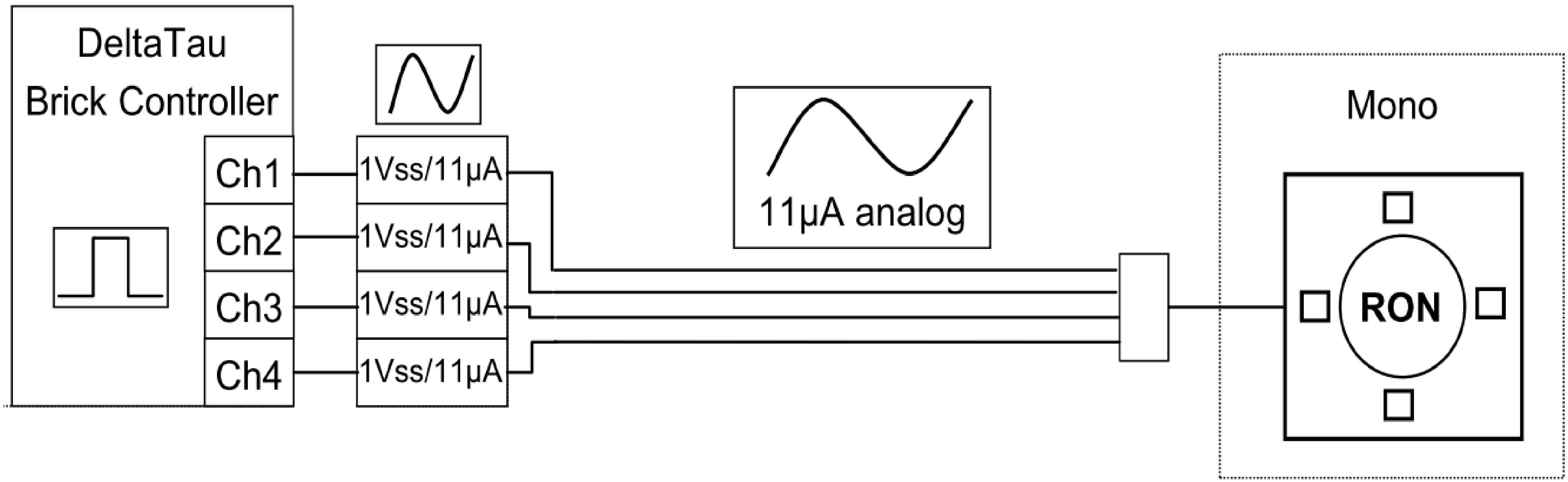
Original motion controller integration



- 4096-fold interpolation = 0.0081” resolution
- error compensation
- long transmission of analog signals
- slow read in through PC software
- fast closed loop control not possible

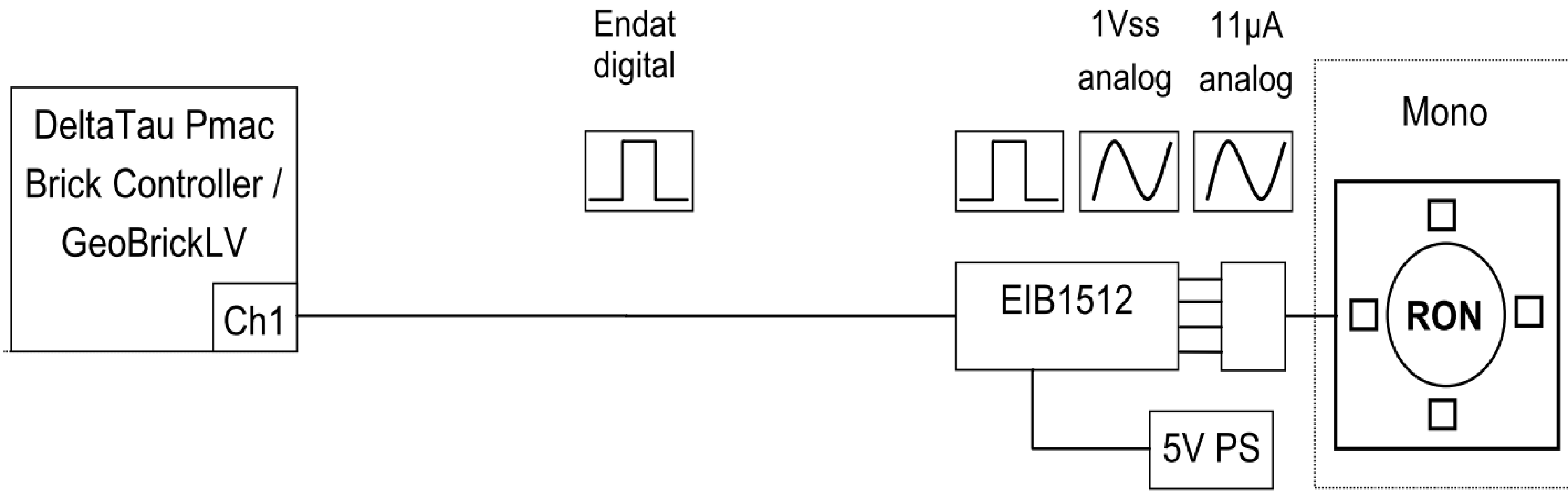
Position Feedback

Direct motion controller integration



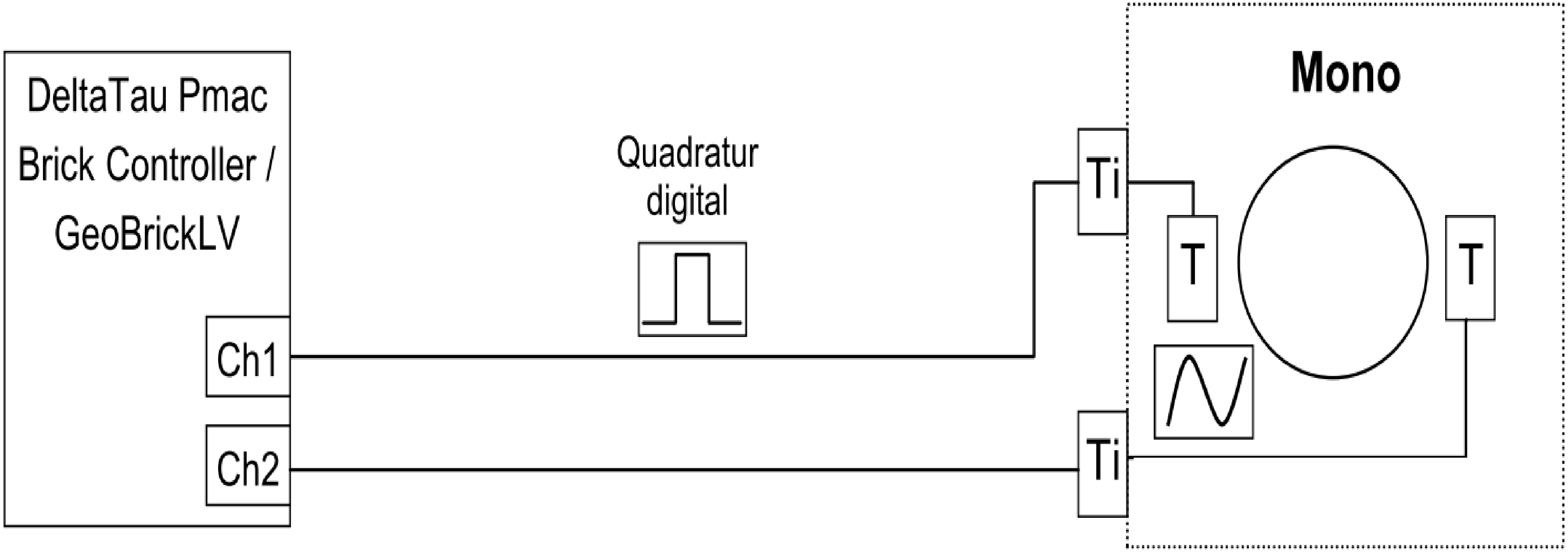
- 4096-fold interpolation = 0.0081” resolution
- less advanced error compensation
- long transmission of analog signals
- additional conversion error due to I/U conversion
- realtime read in and closed loop possible

Direct and digital motion controller integration



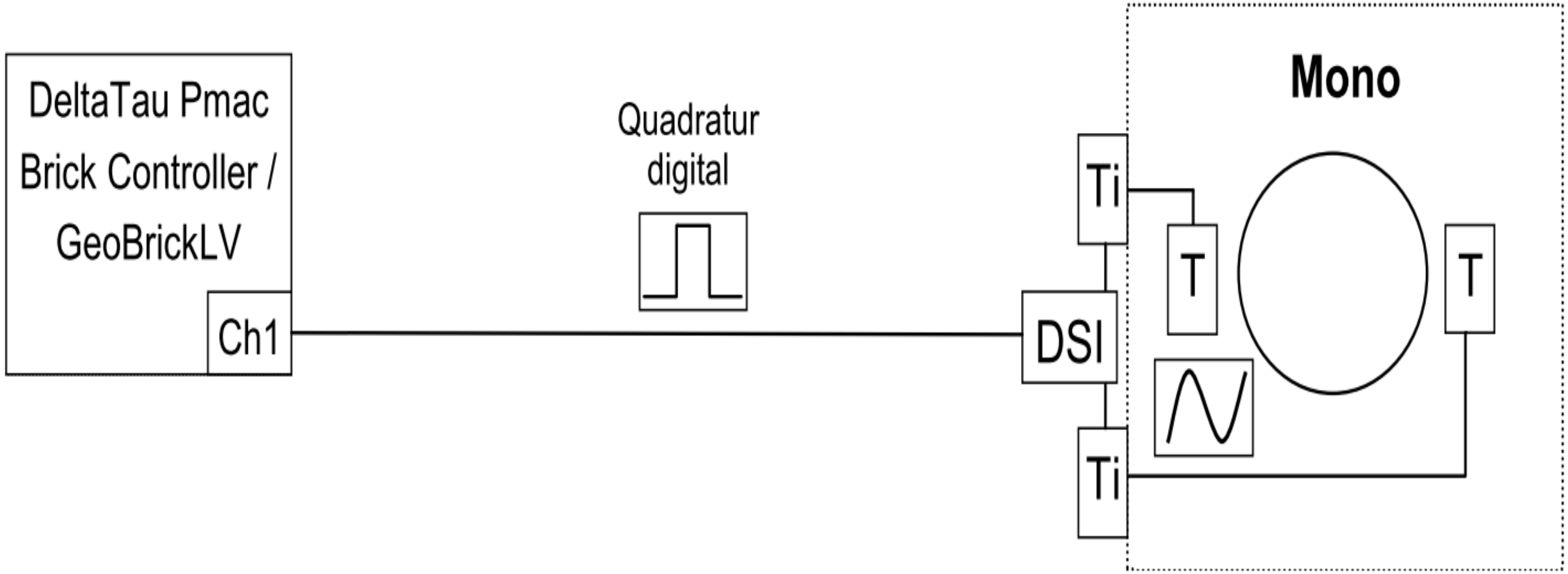
- 16384-fold interpolation = 0.002” resolution
- advanced error compensation
- short transmission of analog signals
- single channel input due to onboard handling of the four heads
- realtime read in and closed loop possible

Introduction of dual head systems



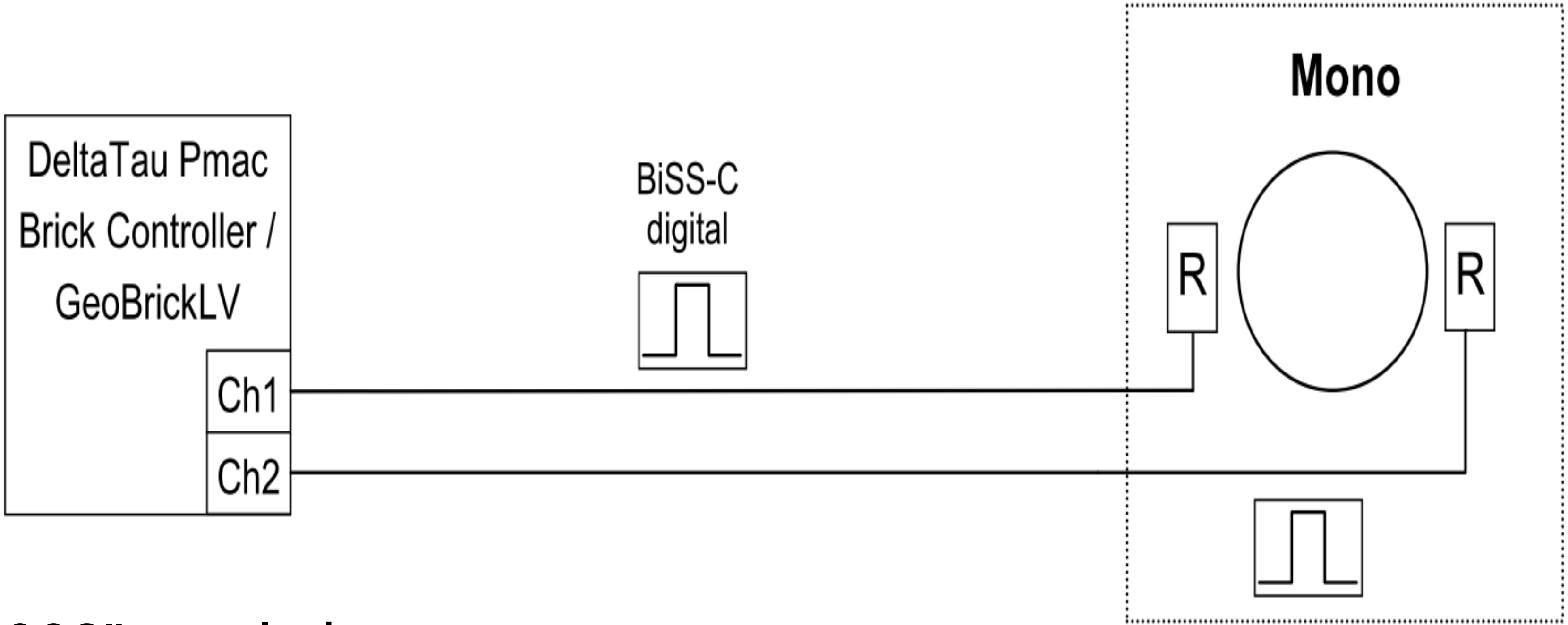
- 20000-fold interpolation = 0.0016” resolution
- advanced error compensation
- short transmission of analog signals
- two channel input
- realtime read in and closed loop possible

Dual head systems with Dual Signum Interface



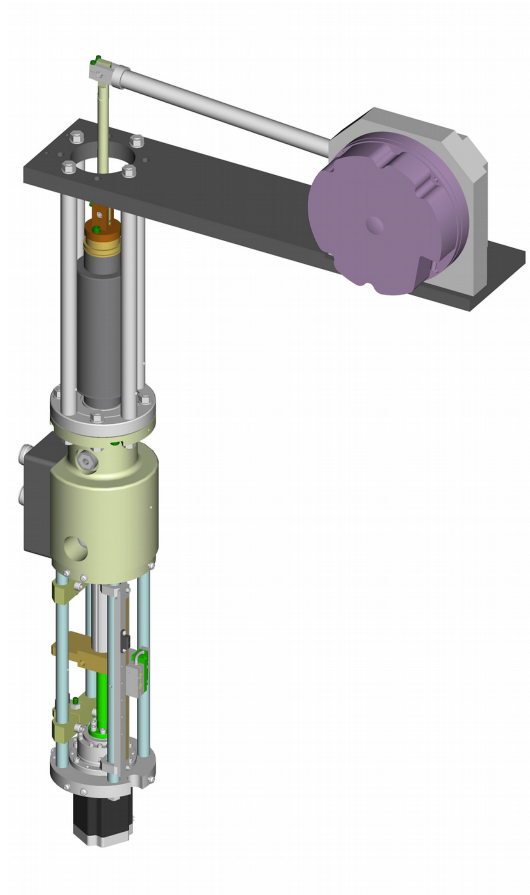
- 20000-fold interpolation = 0.0016” resolution
- advanced error compensation
- short transmission of analog signals
- one channel input
- realtime read in and closed loop possible

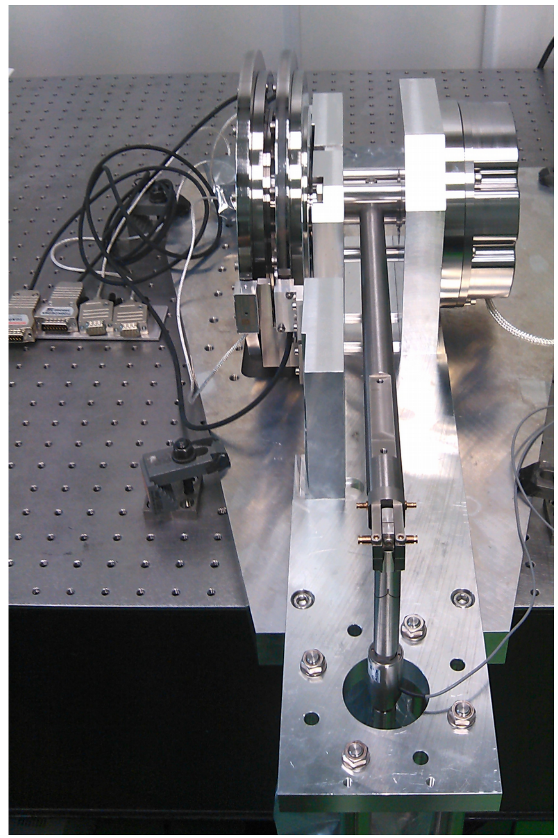
Introduction of absolute encoders

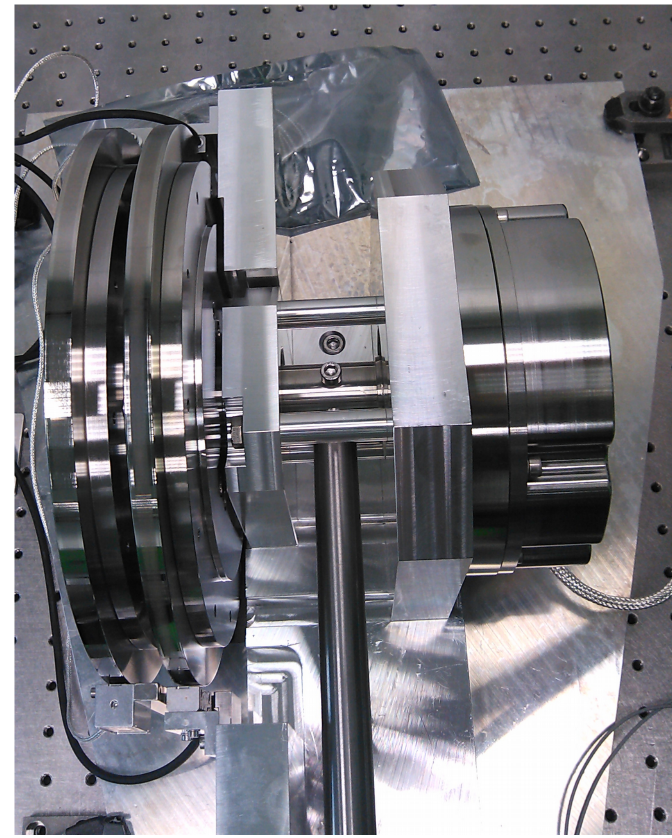


- 0.0003” resolution
- advanced error compensation
- no transmission of analog signals
- two channel input
- slower realtime read in and closed loop possible
- synchronisation more difficult compare to incremental encoders

Performance assessment of feedback systems





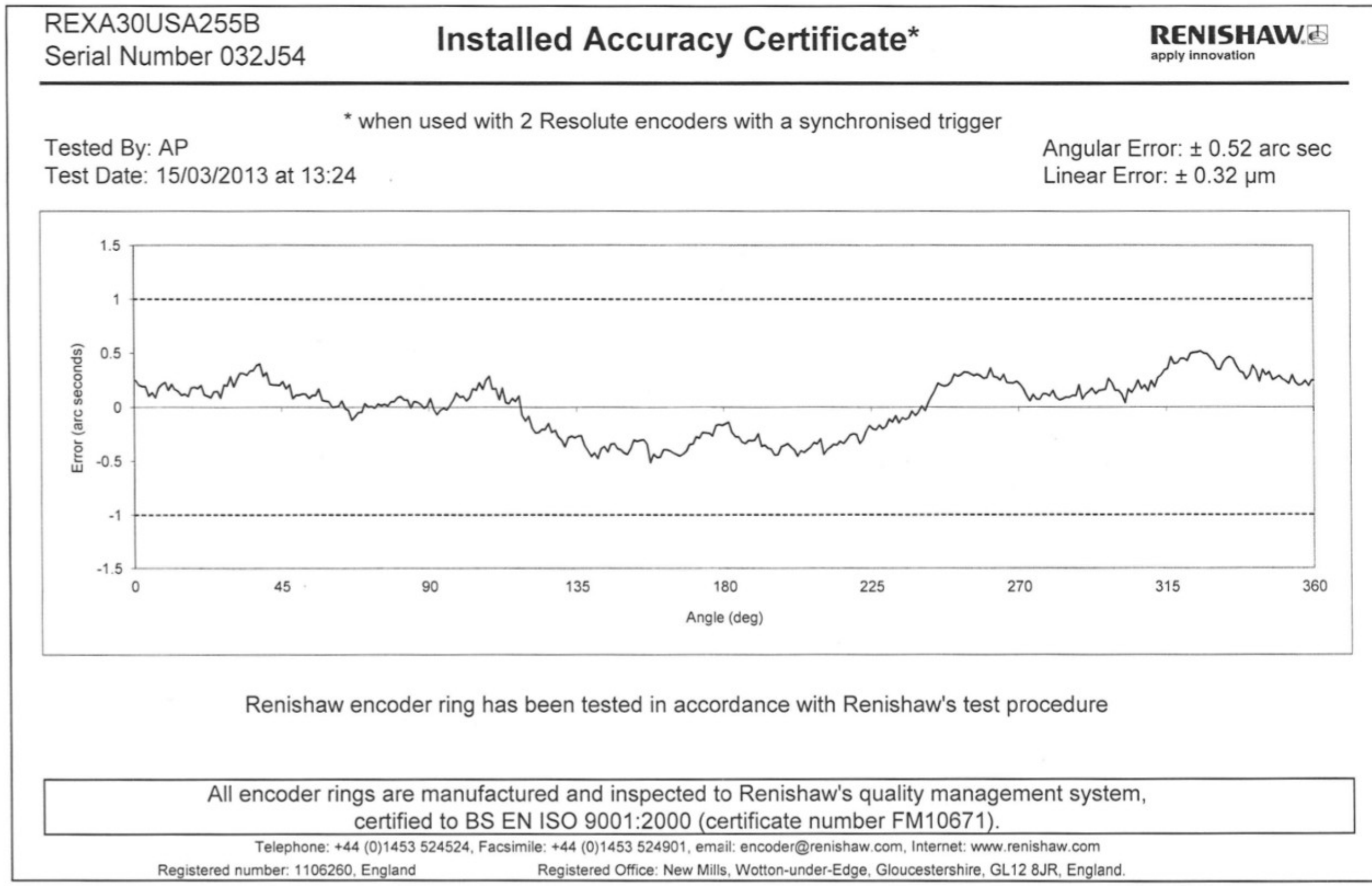


Side by side comparism:
Heidenhain RON versus incremental absolute Renishaw systems

Position Feedback

Error composition:

- graduation error
- installation error
- sub divisional error
- jitter



REXA30USA255B
Serial Number 032J54

Installed Accuracy Certificate*

RENISHAW
apply innovation

* when used with 2 Resolute encoders with a synchronised trigger

Tested By: AP
Test Date: 15/03/2013 at 13:24

Angular Error: ± 0.52 arc sec
Linear Error: ± 0.32 µm

Renishaw encoder ring has been tested in accordance with Renishaw's test procedure

All encoder rings are manufactured and inspected to Renishaw's quality management system, certified to BS EN ISO 9001:2000 (certificate number FM10671).

Telephone: +44 (0)1453 524524, Facsimile: +44 (0)1453 524901, email: encoder@renishaw.com, Internet: www.renishaw.com

Registered number: 1106260, England Registered Office: New Mills, Wotton-under-Edge, Gloucestershire, GL12 8JR, England.

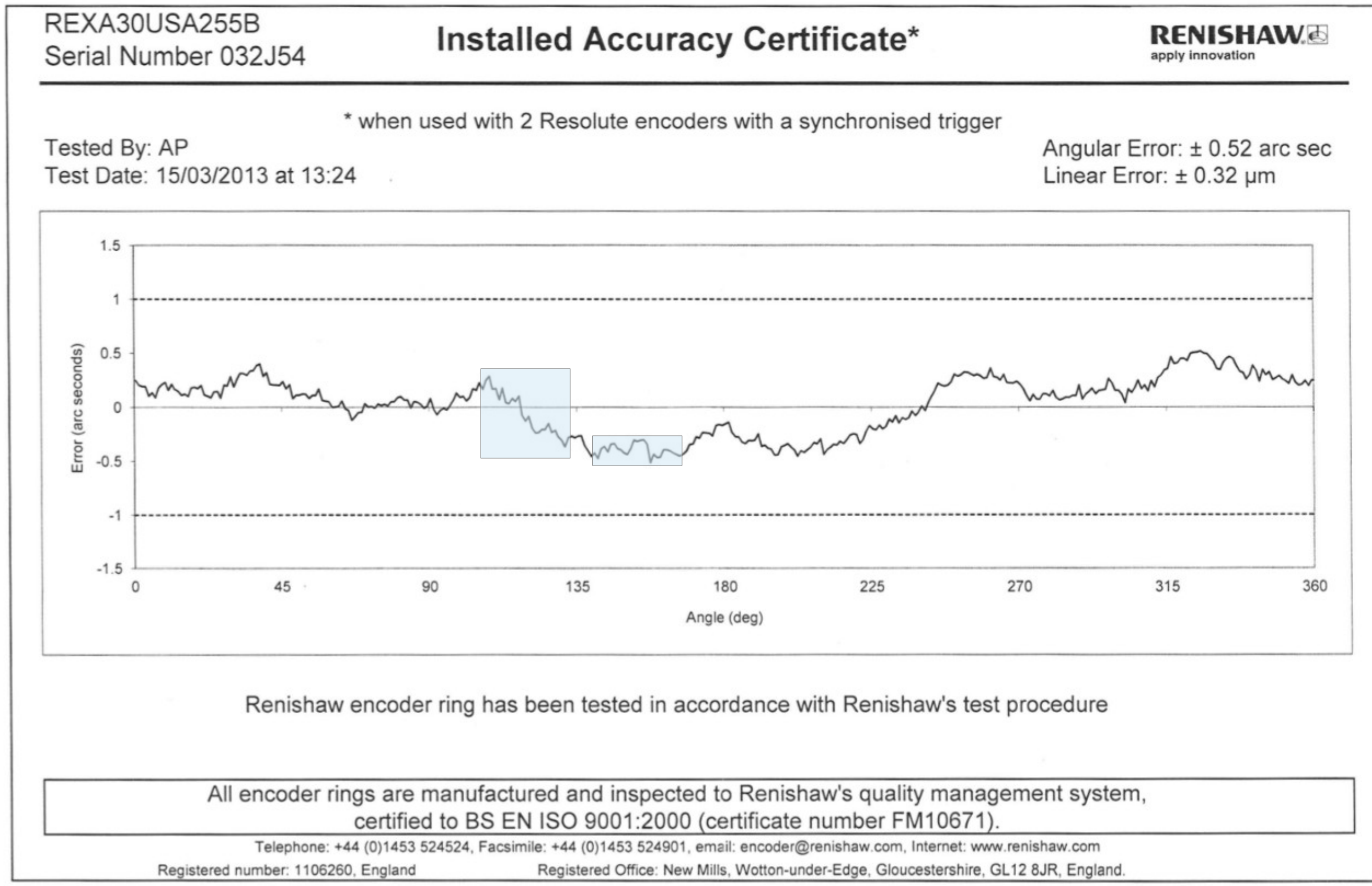
Position Feedback

Error composition:

- graduation error
- installation error
- sub divisional error
- jitter

Countermeasures:

- picking an ideal working region
- compensation tables


REXA30USA255B
Serial Number 032J54

Installed Accuracy Certificate*

RENISHAW
apply innovation

* when used with 2 Resolute encoders with a synchronised trigger

Tested By: AP
Test Date: 15/03/2013 at 13:24

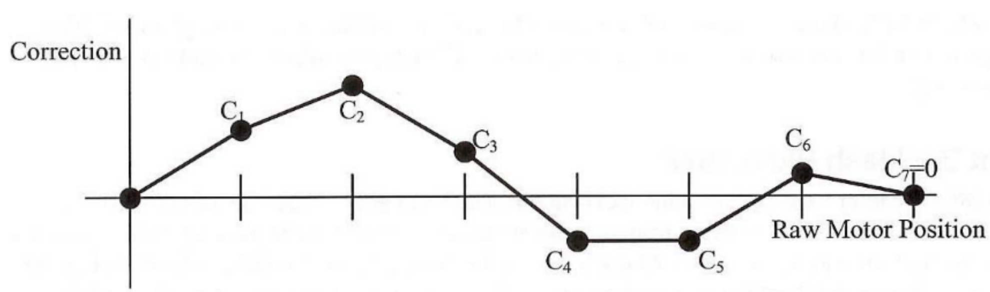
Angular Error: ± 0.52 arc sec
Linear Error: ± 0.32 µm

Renishaw encoder ring has been tested in accordance with Renishaw's test procedure

All encoder rings are manufactured and inspected to Renishaw's quality management system, certified to BS EN ISO 9001:2000 (certificate number FM10671).

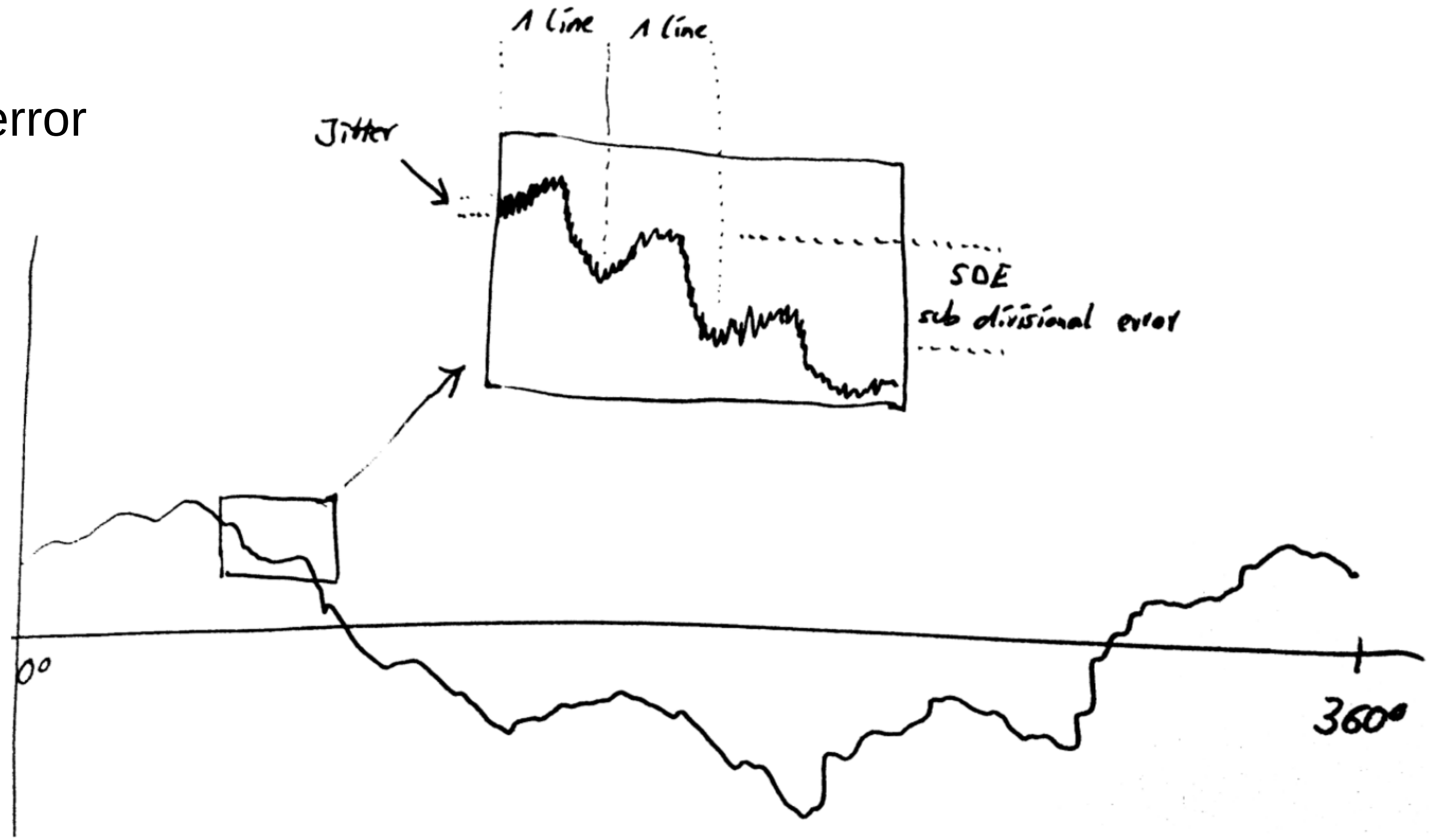
Telephone: +44 (0)1453 524524, Facsimile: +44 (0)1453 524901, email: encoder@renishaw.com, Internet: www.renishaw.com

Registered number: 1106260, England   Registered Office: New Mills, Wotton-under-Edge, Gloucestershire, GL12 8JR, England.



Error composition:

- sub divisional error
- jitter



Position Feedback

Results
Heidenhain RON905UHV with Heidenhain EIB1512, incremental
Renishaw TONiC, incremental
Renishaw Resolute, absolute

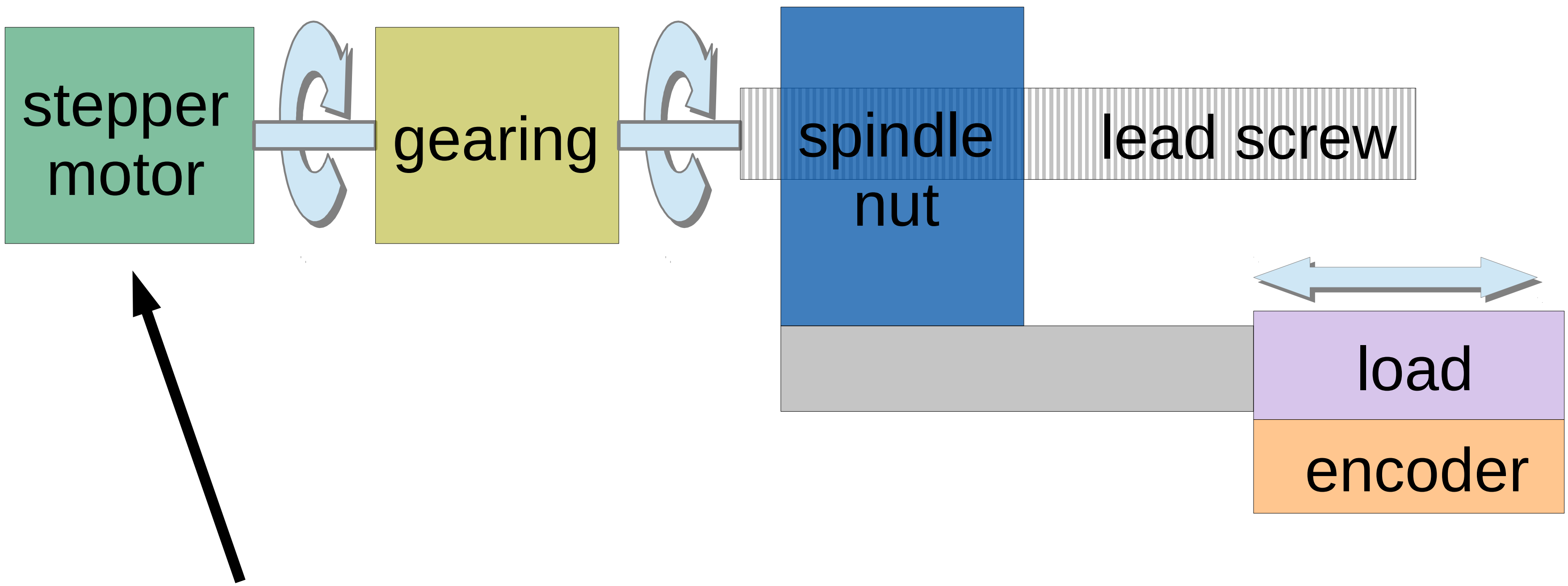
Sub divisional error
- RON905UHV < 0.12”
- TONiC/Resolute < 0.02”

Jitter
- RON905UHV < 0.011”
- TONiC < 0.005” (255mm) / < 0.003” (417mm)
- Resolute < 0.01” (255mm) / < 0.005” (417mm)

Accuracy (360° / 20° partial arc)
- RON905UHV < 0.24” / < 0.17”
- TONiC 255mm < 1.30” / < 0.7”
- TONiC 417mm < 0.86” / < 0.5”
- Resolute 255mm < 1.28” / < 0.76”
- Resolute 417mm < 0.94” / < 0.5”

Classic Design

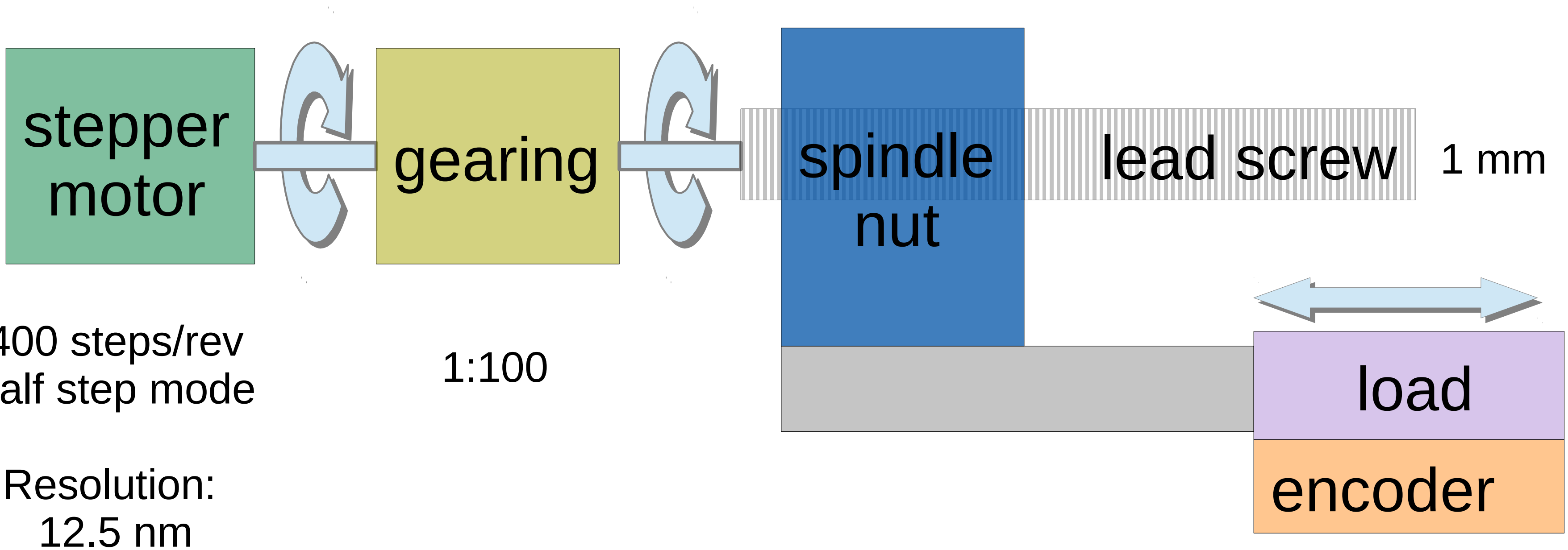
Typical high precision drive



2. Motor control improvements

Motor Control

Improvements driving stepper motors



400 steps/rev
half step mode

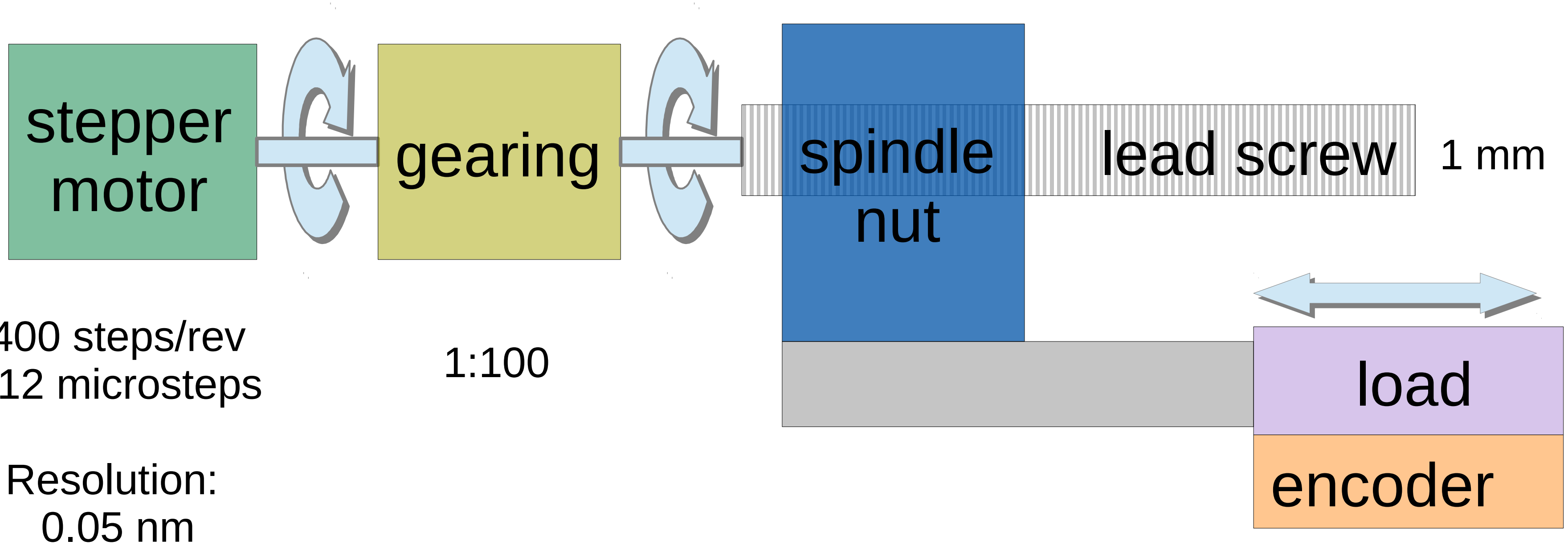
1:100

Resolution:
12.5 nm
0.008”

Speed:
1500 rpm (3000rpm)
0.05°/sec (0.1°/sec)

Motor Control

Improvements driving stepper motors



400 steps/rev
512 microsteps

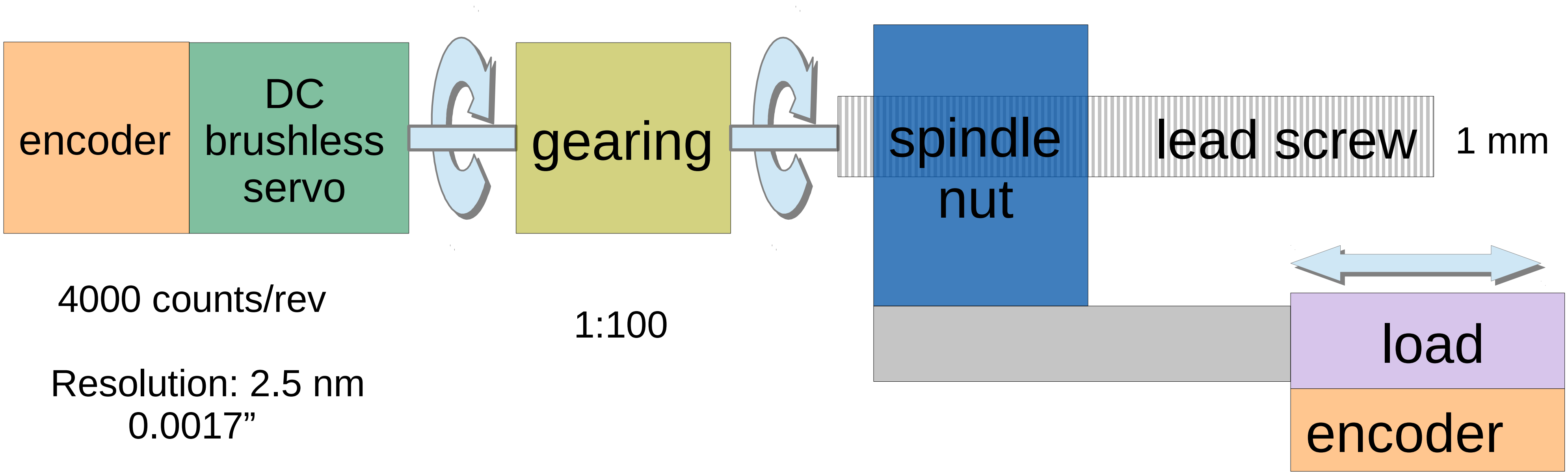
1:100

Resolution:
0.05 nm
0.000035”

Speed:
1500 rpm (3000rpm)
0.05°/sec (0.1°/sec)

Motor Control

Servomotor



4000 counts/rev

1:100

Resolution: 2.5 nm
0.0017”

Speed:
4000 rpm
0.12°/sec

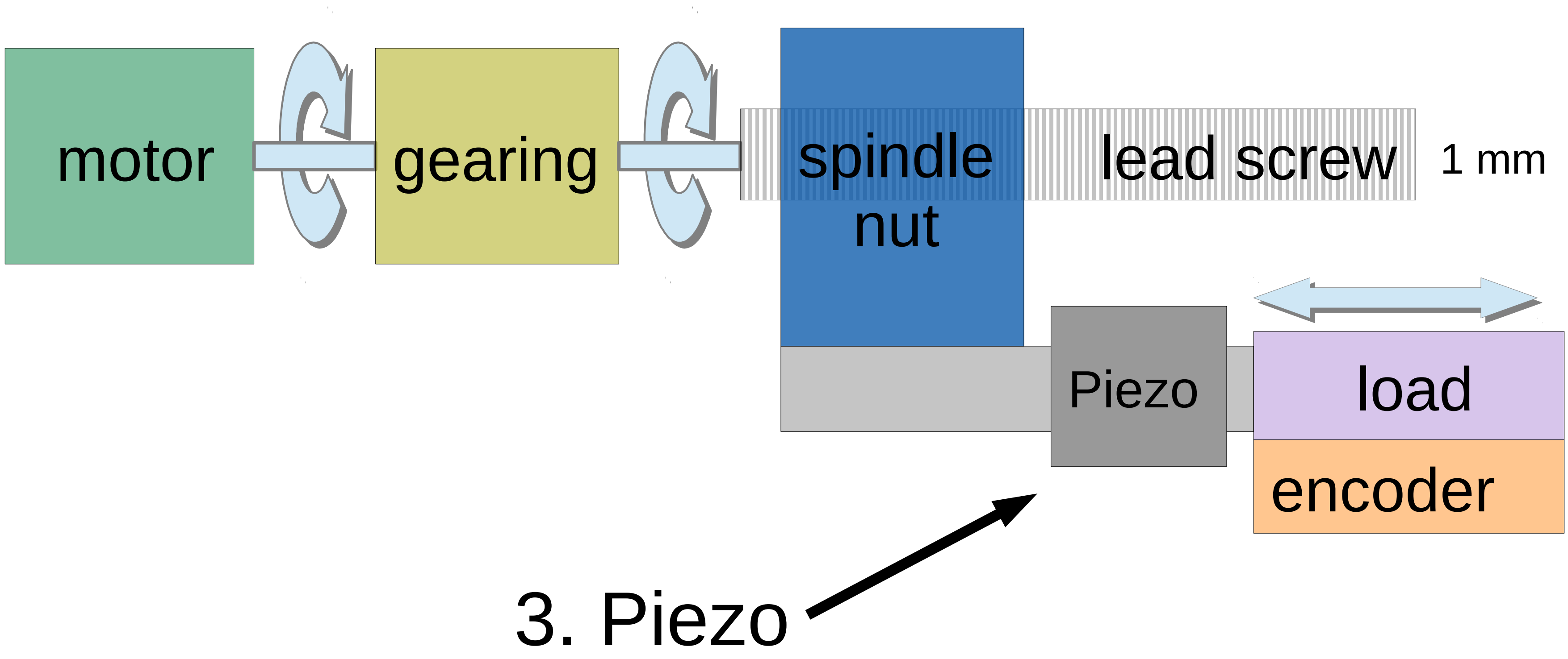
Servomotor

Smaller but sufficient resolution

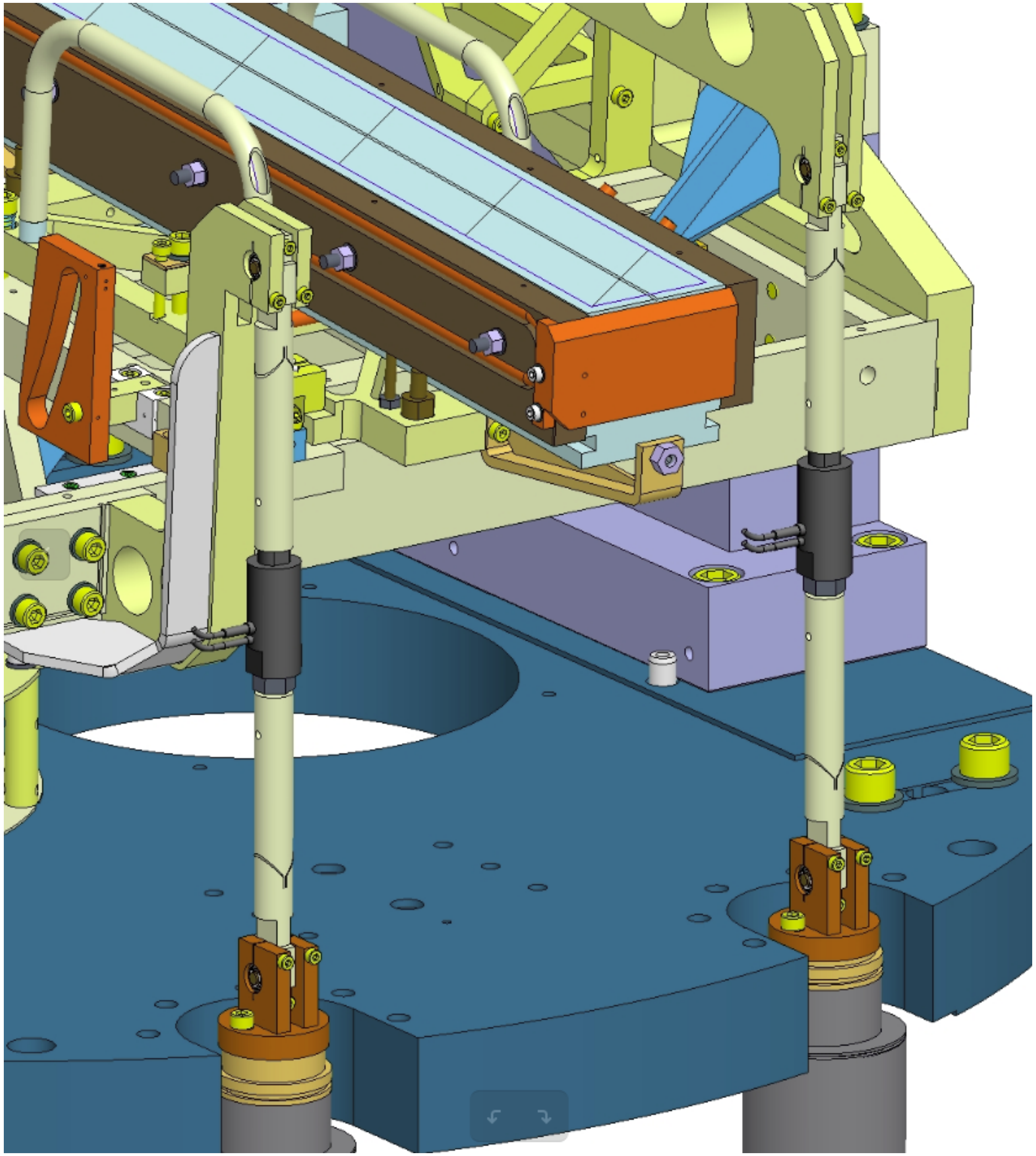
- Higher speed
- More dynamic command
- Smooth driving throughout wide range of speeds
- More energy efficiency, reduced thermal effects
- Standstill jitter seems to be no issue

Piezo

Fine adjustment based on piezo stack



Piezo



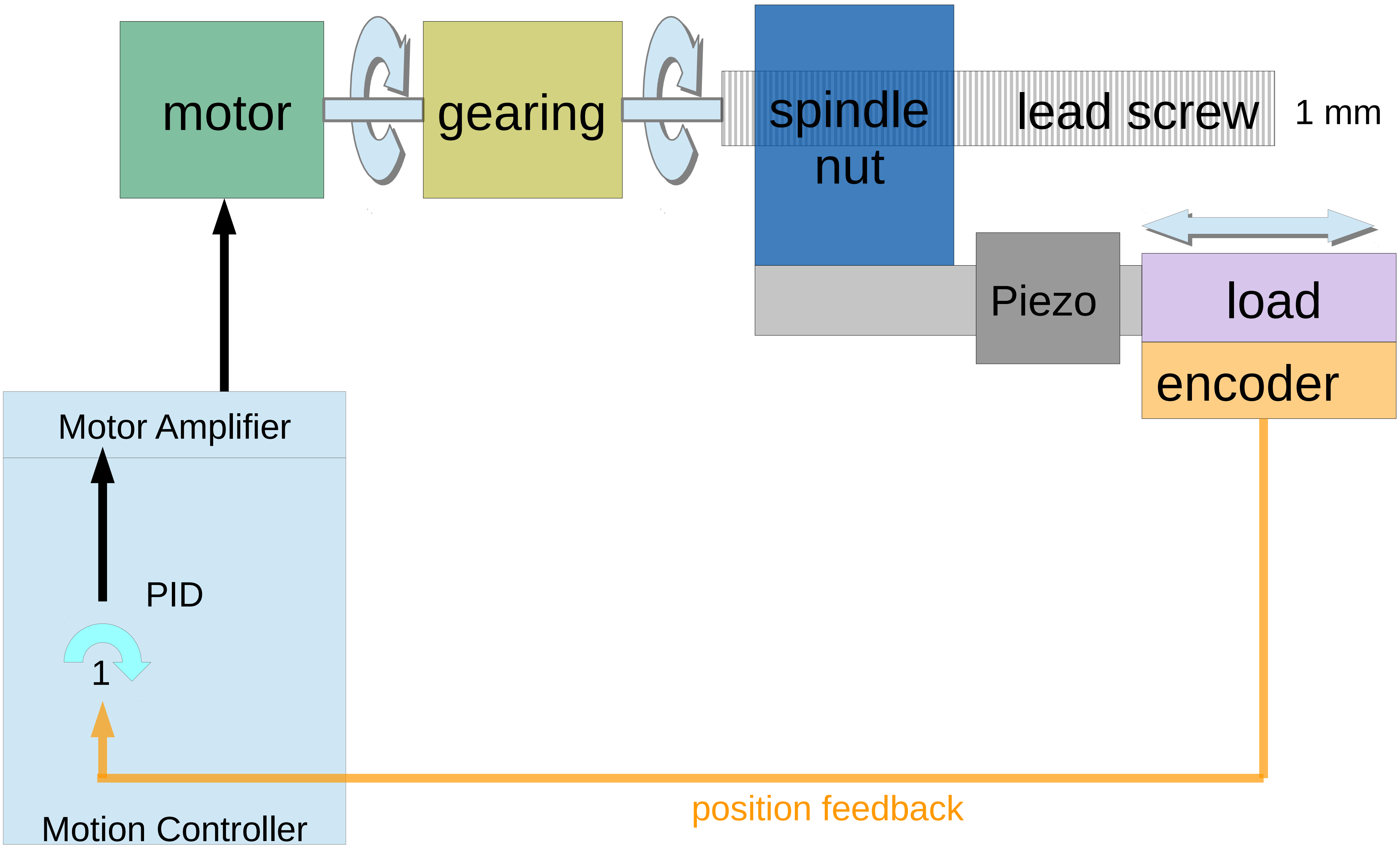
Targets

Very fast small steps
Decreased settling time
Vibration damping

Implementation

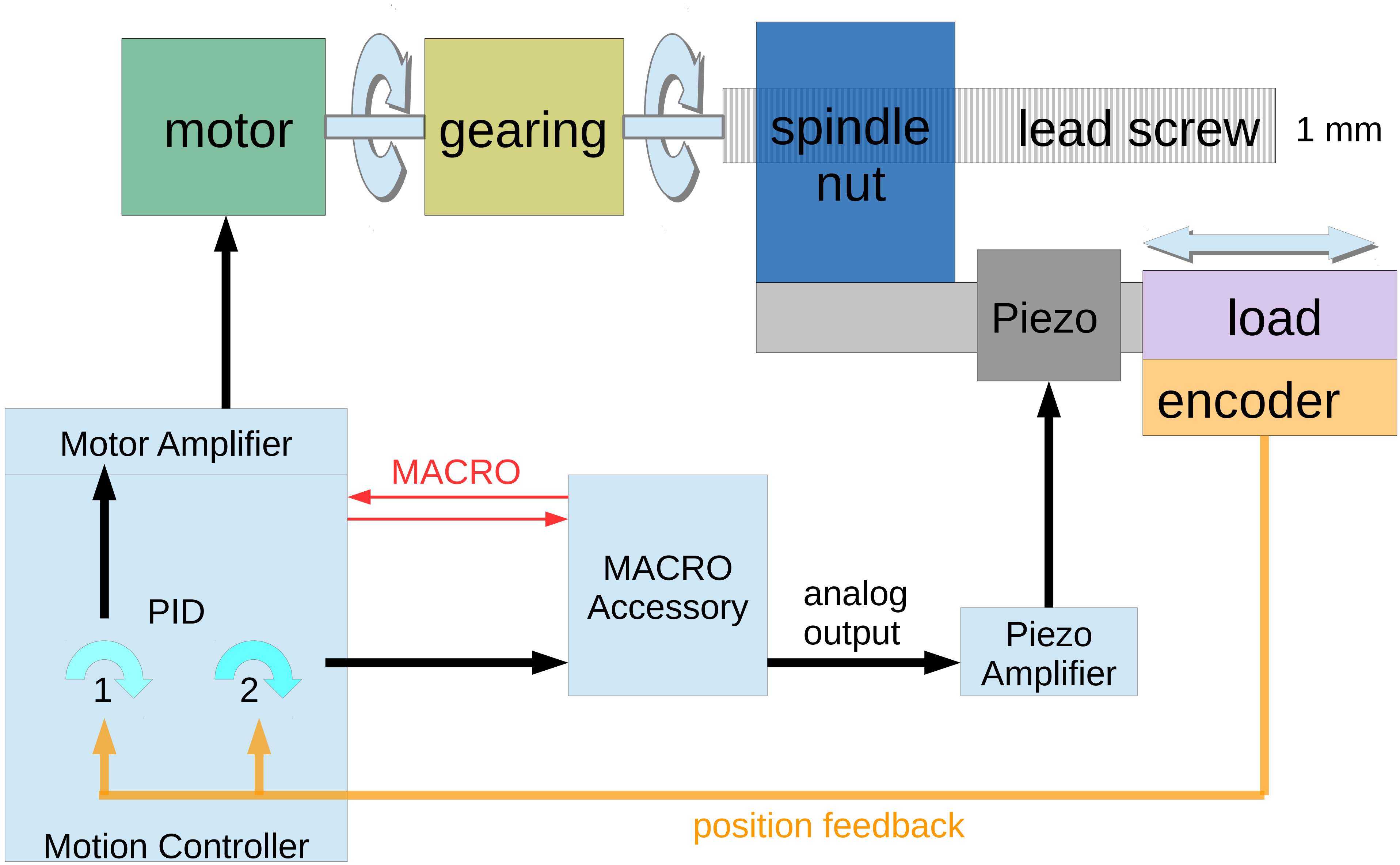
MACRO interface
Dual control loop
Open servo algorithm

Piezo



motor
gearing
spindle nut
lead screw
1 mm
Piezo
load
encoder
Motor Amplifier
PID
1
Motion Controller
position feedback

Piezo


motor
gearing
spindle nut
lead screw
1 mm
Piezo
load
encoder
Motor Amplifier
MACRO
MACRO Accessory
analog output
Piezo Amplifier
PID
1
2
Motion Controller
position feedback

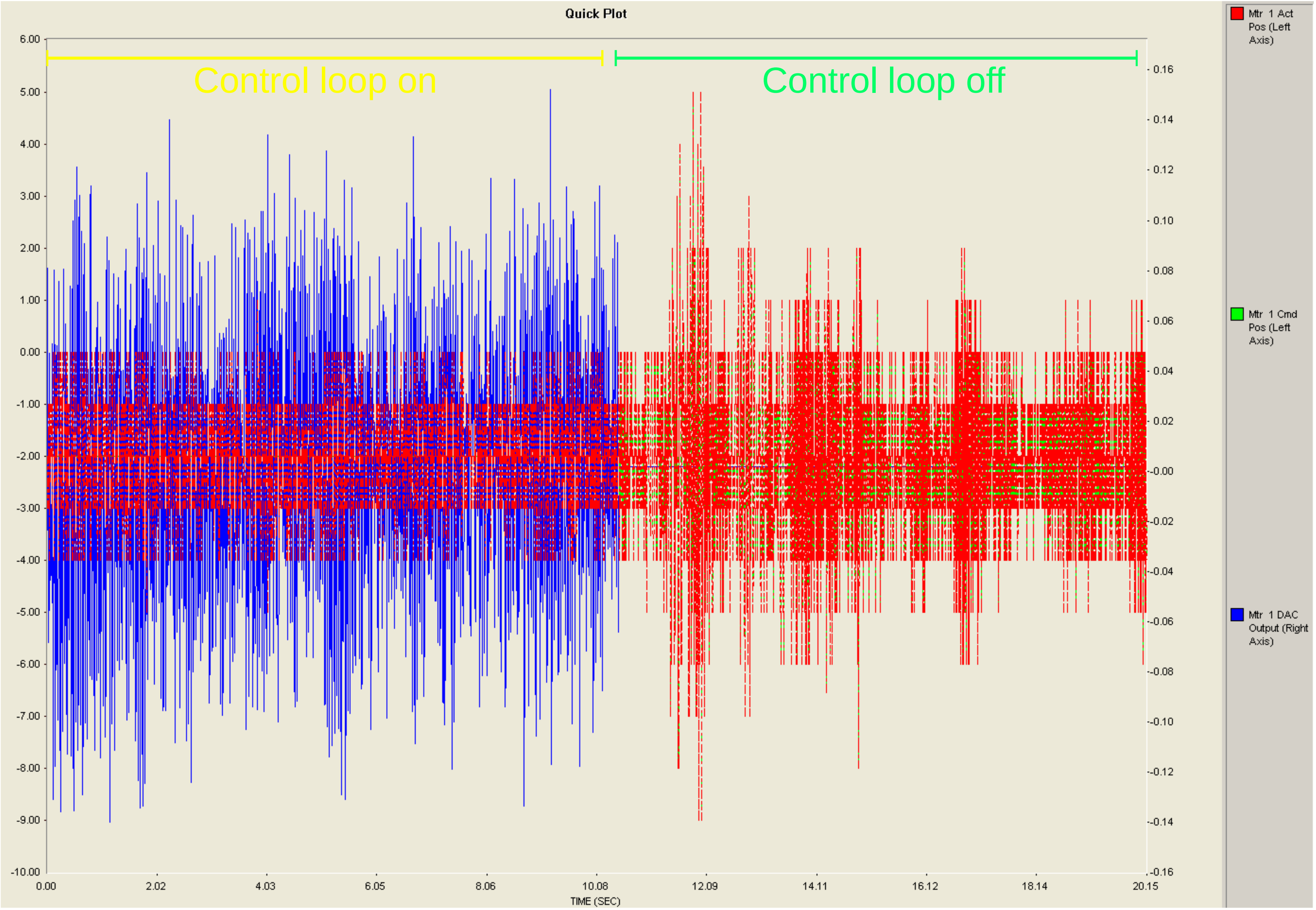
Piezo

Dual PID loop running on the same position feedback

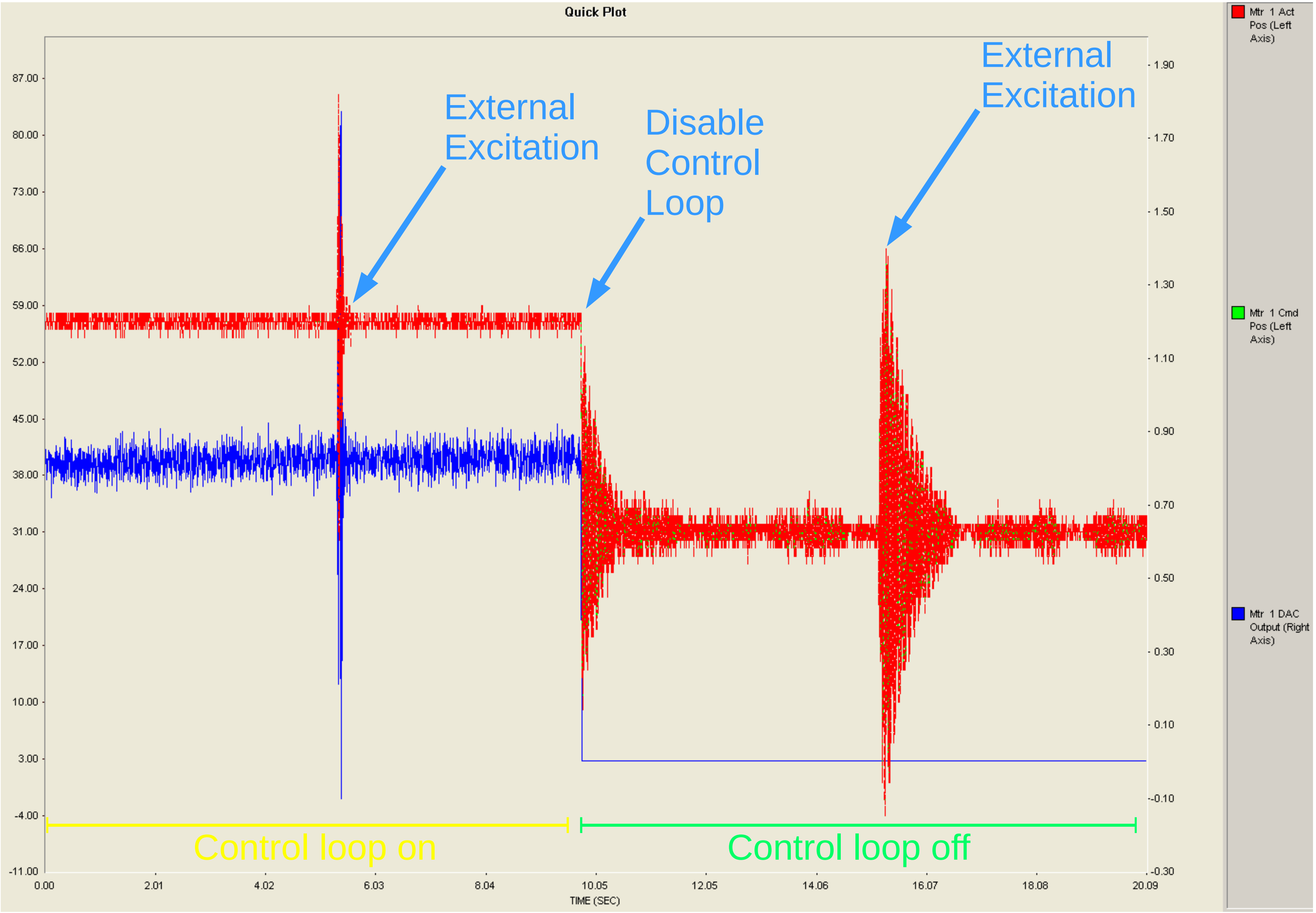
- PID set #1 for conventional motor
  - Parameter set for comparable slow reaction

- PID set #2 for piezo fine pitch
  - Parameter set for fast reaction
  - Input based on following error of PID #1
  - Notch filter to reduce oscillation
  - Use position bias on #1 to retain center position of #2

Piezo


Quick Plot
Control loop on
Control loop off
TIME (SEC)
Mtr 1 Act Pos (Left Axis)
Mtr 1 Cmd Pos (Left Axis)
Mtr 1 DAC Output (Right Axis)

Piezo


Quick Plot
87.00
80.00
73.00
66.00
59.00
52.00
45.00
38.00
31.00
24.00
17.00
10.00
3.00
-4.00
-11.00
1.90
1.70
1.50
1.30
1.10
0.90
0.70
0.50
0.30
0.10
-0.10
-0.30
0.00
2.01
4.02
6.03
8.04
10.05
12.05
14.06
16.07
18.08
20.09
TIME (SEC)
Mtr 1 Act Pos (Left Axis)
Mtr 1 Cmd Pos (Left Axis)
Mtr 1 DAC Output (Right Axis)
External Excitation
Disable Control Loop
External Excitation
Control loop on
Control loop off

Parameter Scheduling

Dynamic modification of control parameters

Using motion controller software PLC programs

Dynamic position loop parameter scheduling for

- Dealing with parasitic movements (sine bar)
- Handling different operation modes

Dynamic current loop settings

- Adapt magnetization current to movement mode
- Implement specific mechanical or thermal needs

Continuous Scan

Energy move -

Photon energy move through coordinate system

- Scan speed in eV per second
- Implementation of forward & inverse kinematics
- Motion program to perform scan
- Actual energy reporting

Conclusions

- Position feedback
  - Fast, digital, higher repeatability (not accuracy)
- Servomotor option
  - Fast, dynamic, flexible
- Stacked Piezo Actuator
  - Dual control loop
  - Seamless integration (MACRO interface)
- Dynamic scheduling of PID parameters
- More powerful continuous scanning