Robotic machining with embedded feedback

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Presented by Patrick Keogh

Professor of Machine Systems

Department of Mechanical Engineering

University of Bath

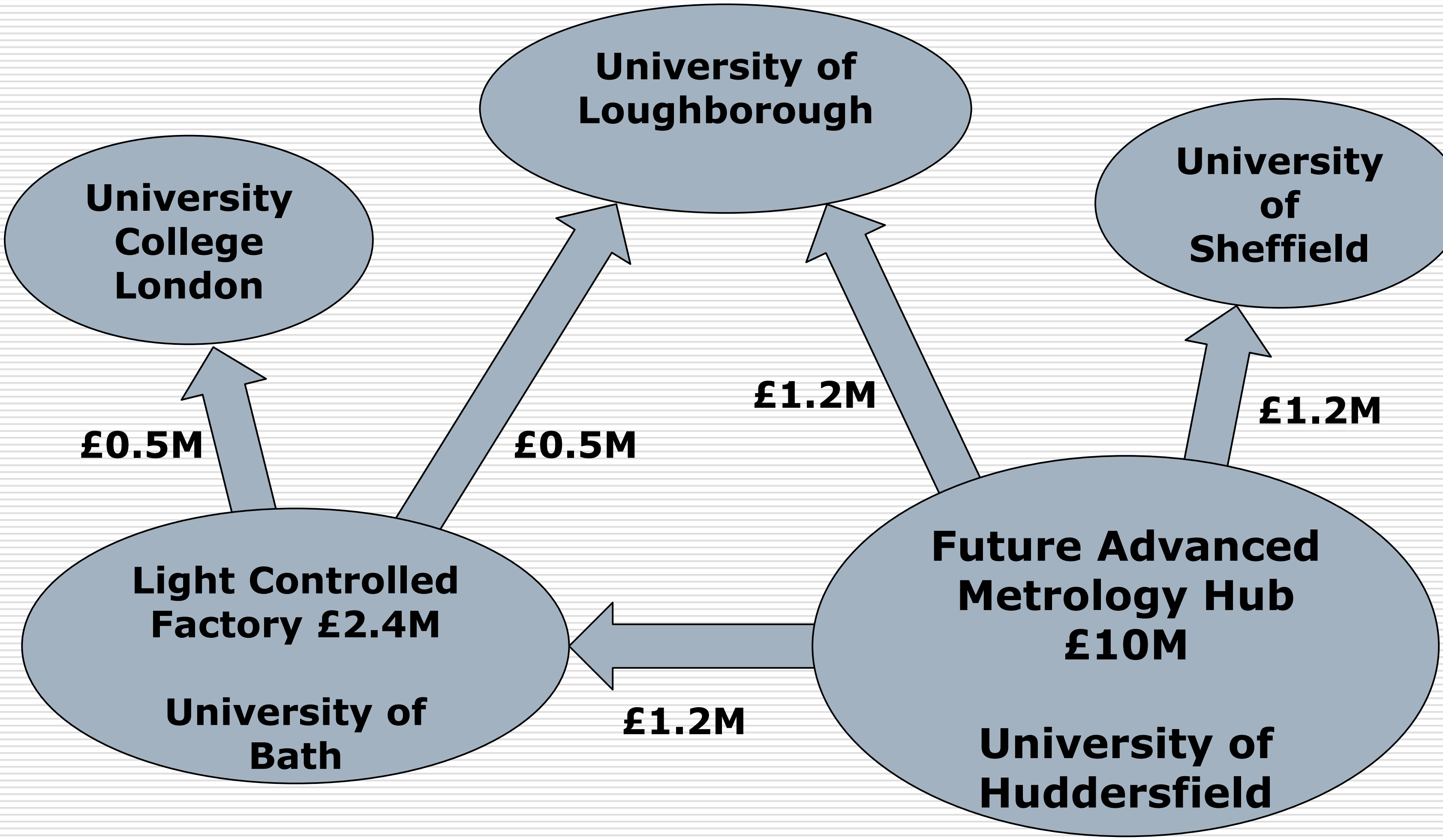
Bath BA2 7AY

UK

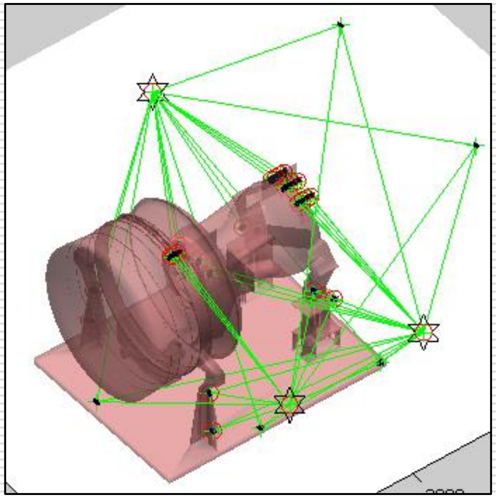
Presentation Overview

- Research undertaken in the EPSRC Light Controlled Factory (LCF) and Future Advanced Metrology Hub projects
- Robotic machining with embedded feedback
- Achievements and future challenges

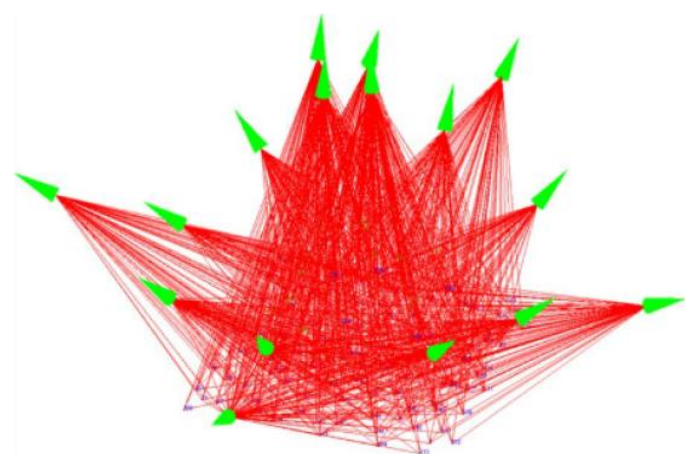
LCF/Hub Metrology Academic Links



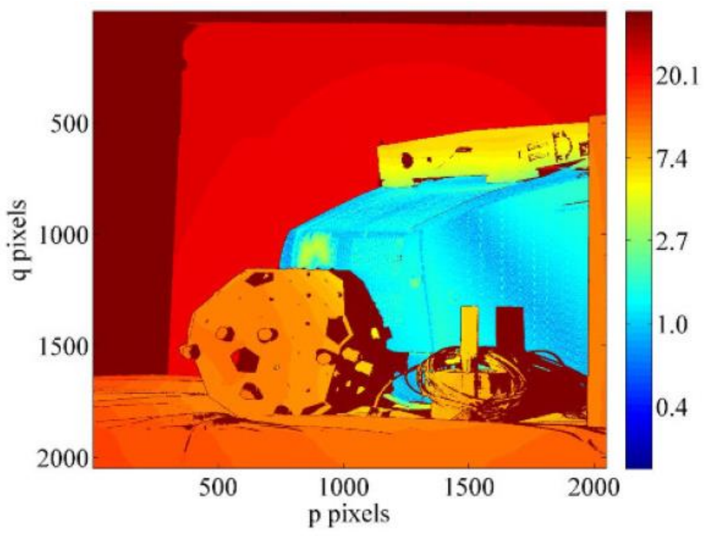
Metrology Options for Robotic Machining – considered for the LCF



Laser tracker network - Bath

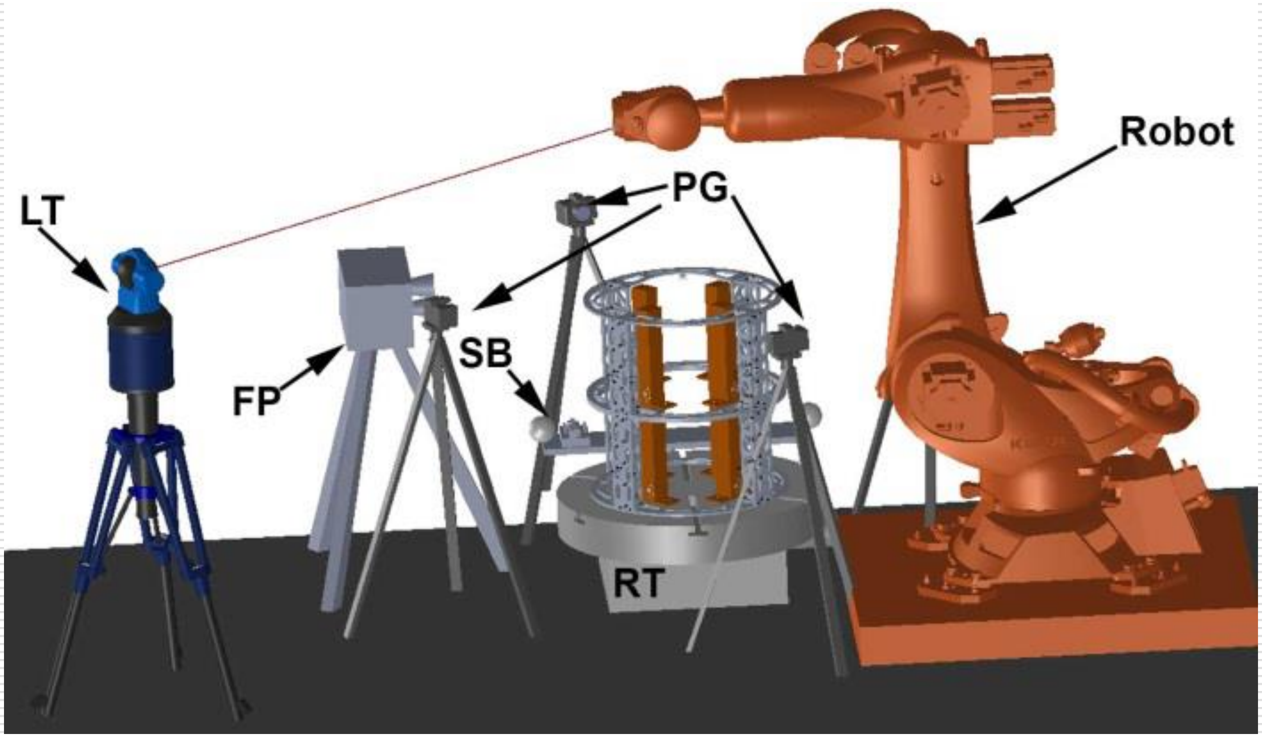


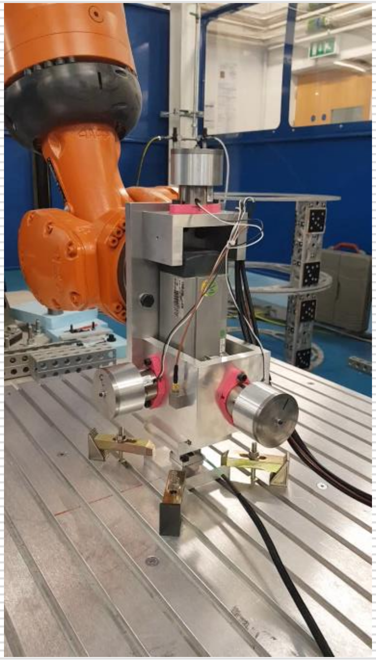
Photogrammetric network
- UCL
- Professor Stuart Robson



Fringe projection for object recognition
- Loughborough
- Professor Jonathan Huntley

LCF Demonstrator with System Integration for Robotic Machining

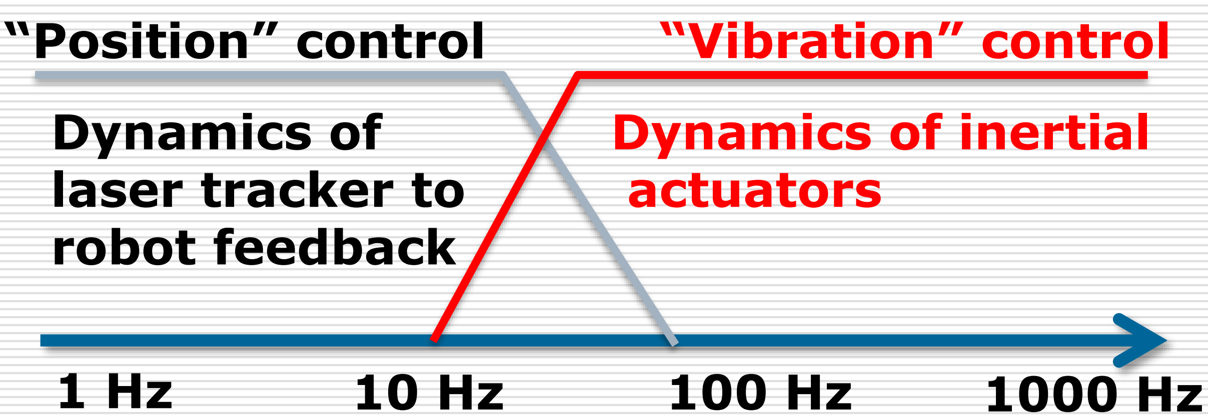




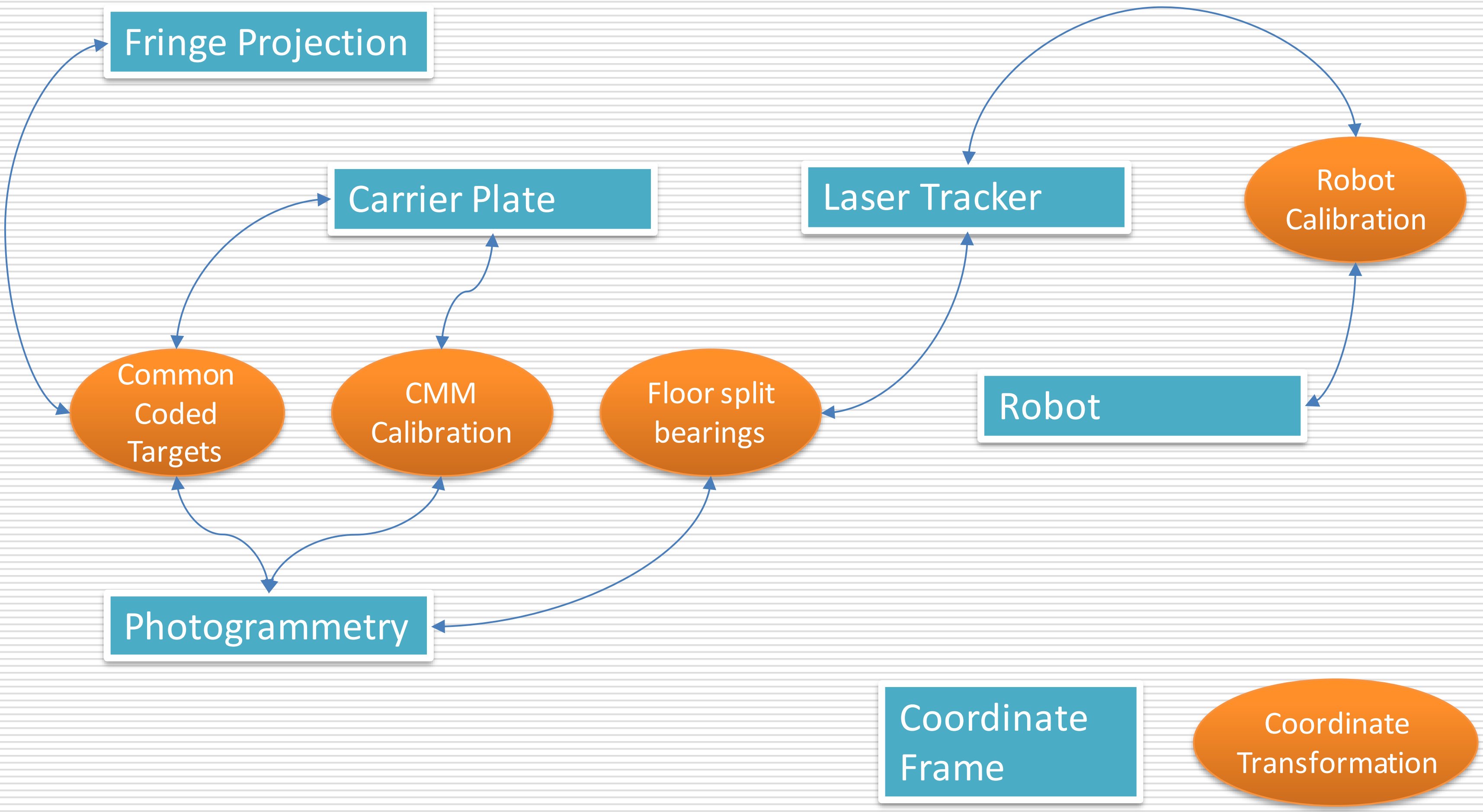
+ Active control of robotic machining

Robotic Machining Challenges

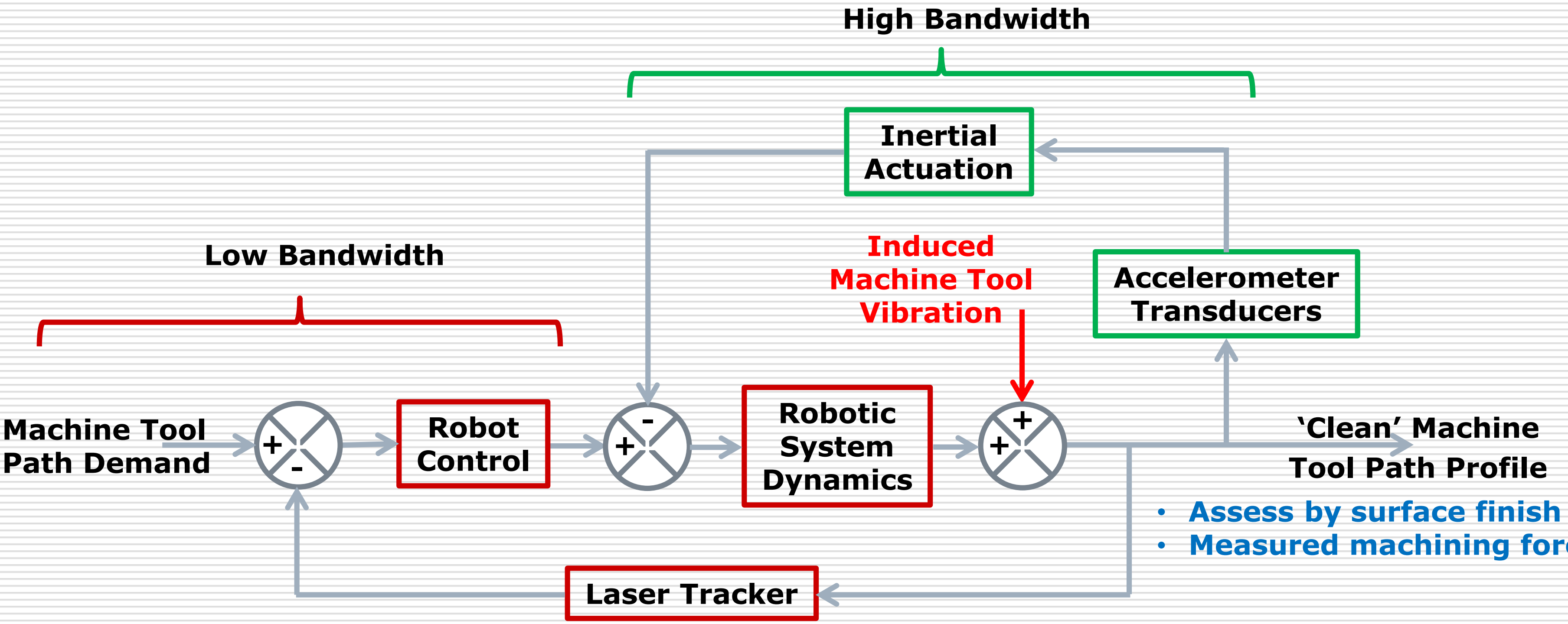
- Machining with industrial robots:
  - Flexible operation - Low cost – Large working volume – Small installation footprint
- However, under internal control only, robots have:
  - Poor absolute machining accuracy (up to ± 1 mm)
  - Relatively low stiffness
  - Low and high frequency regions for machining control
  - Low bandwidth
  - Joint backlash and other tribological uncertainties
  - Vibration modes that depend on pose



LCF Demonstrator with System Integration for Robotic Machining



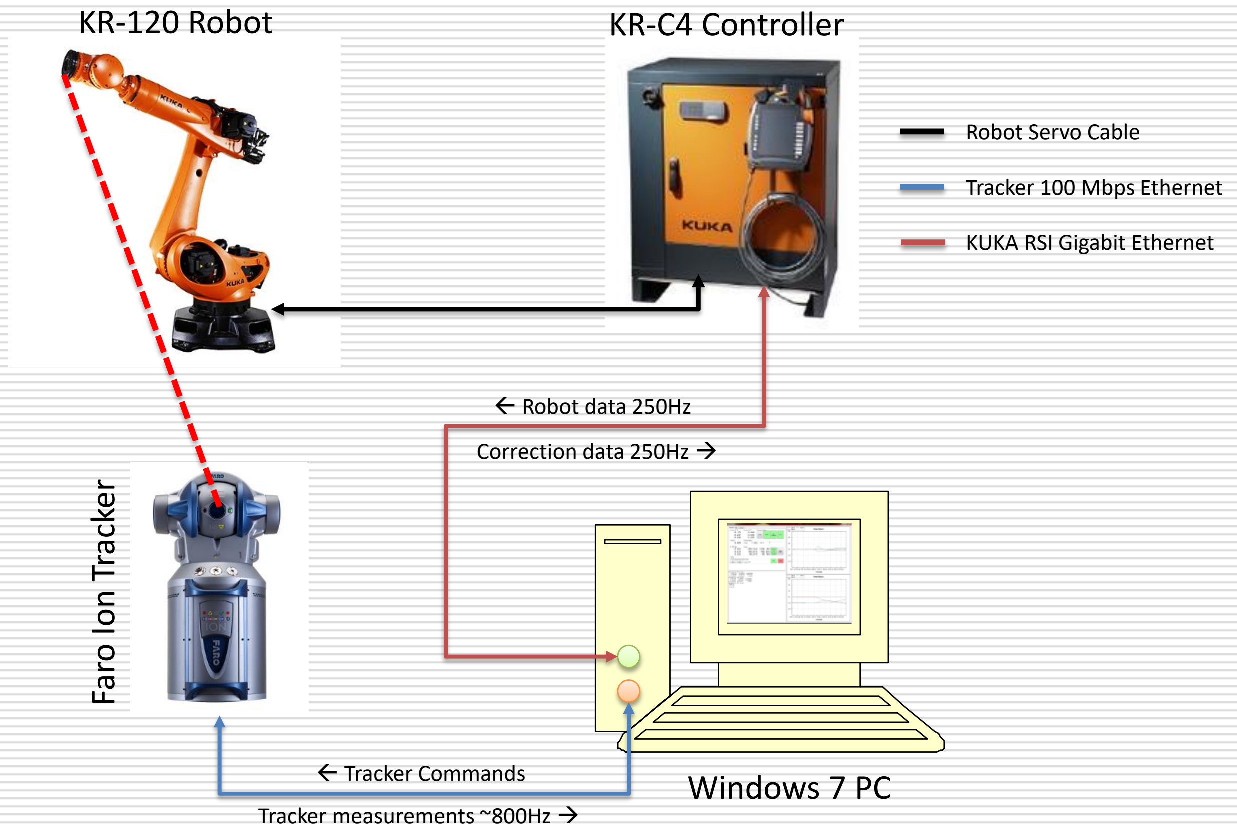
Real-time Multi-scale Control



- Assess by surface finish
- Measured machining forces

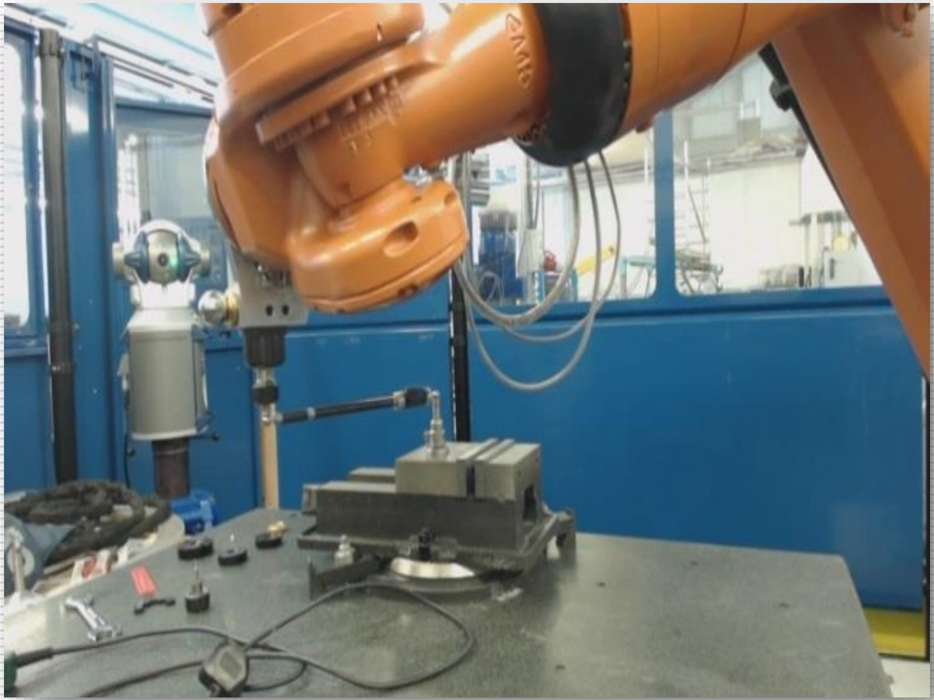
- Fringe projection and photogrammetry used to determine the accurate machine tool path demand to match up with a scanned artefact

Real-time Laser Tracker Position Compensation



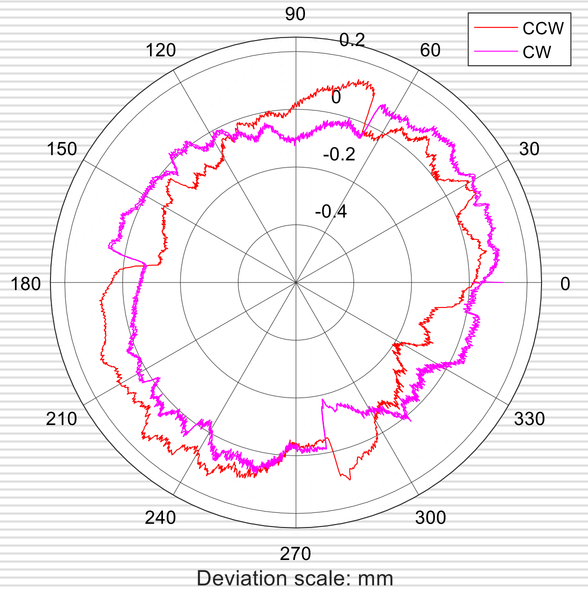
- Direct measurement of end effector position with laser tracker
- 250 Hz sampling control loop (for low bandwidth control)
- Custom real-time control software

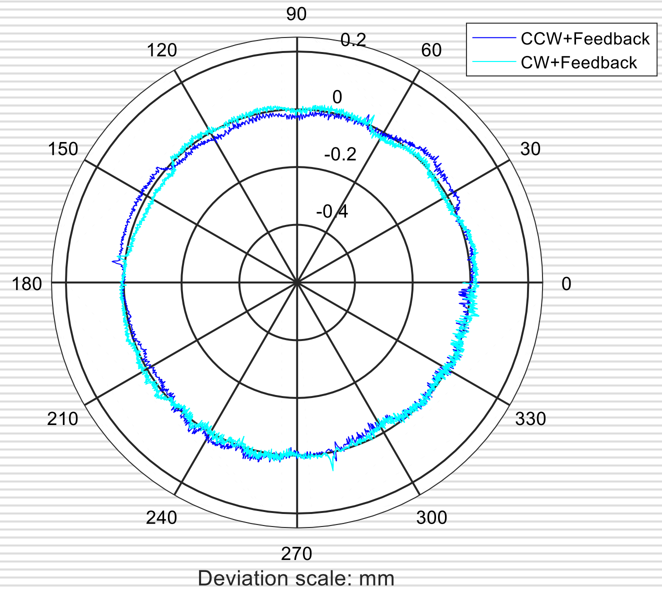
Renishaw Ballbar Tests



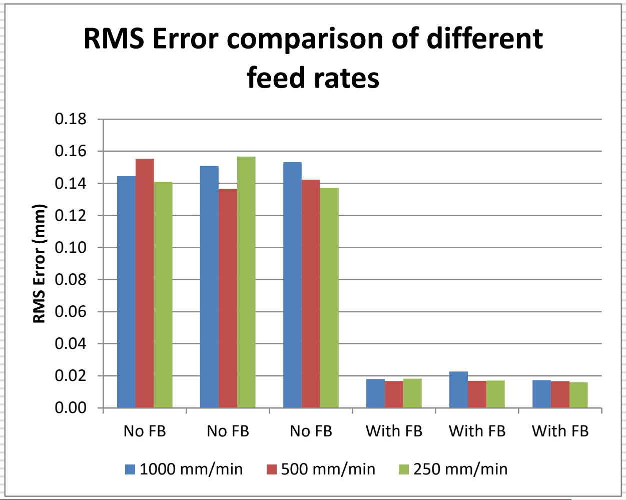
- Ballbar linear uncertainty of 0.7 µm ± 0.3%
- 1 DOF dynamic measurements
- Independent confirmation of performance
- Tests at 300, 600 mm radii, different ‘feed’ rates
- Joint reversal

Ballbar Test Results

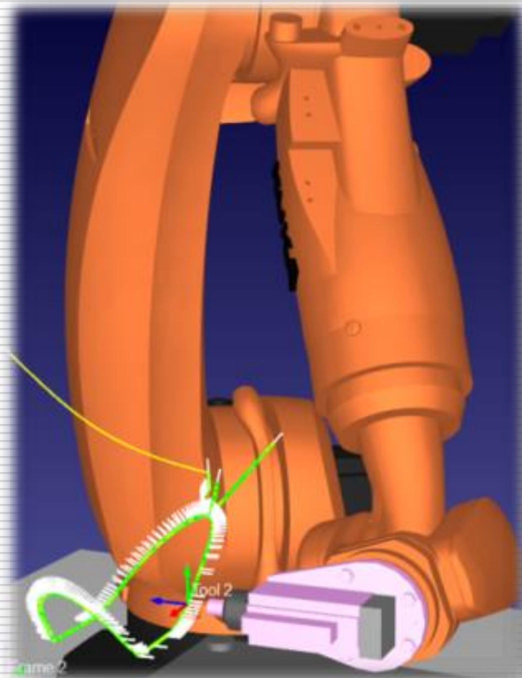




- With laser tracker control:
  - Reduction of RMS error from 74 µm to 16 µm
  - Small effect of feed rate



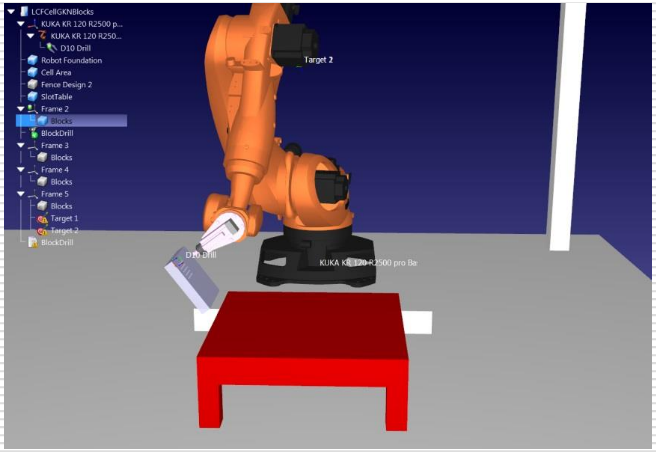
Industrial Case Study 1 – Profile Machining



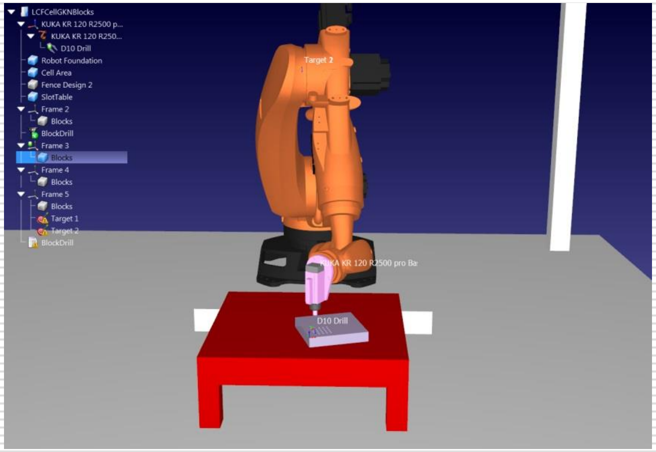

- Industrial project assessing robotic machining with real-time laser tracker feedback
- 10 components machined
  - 5 without feedback
  - 5 with feedback
- Profile errors greatly reduced with feedback

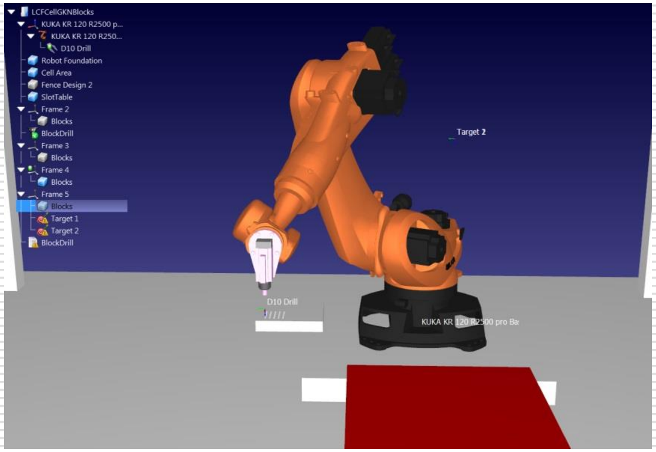
Industrial Case Study 2 - Block Drilling Trials

Position 1

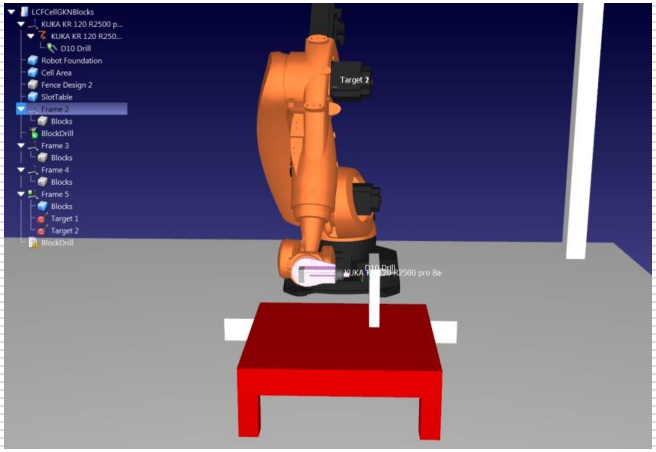


Position 2



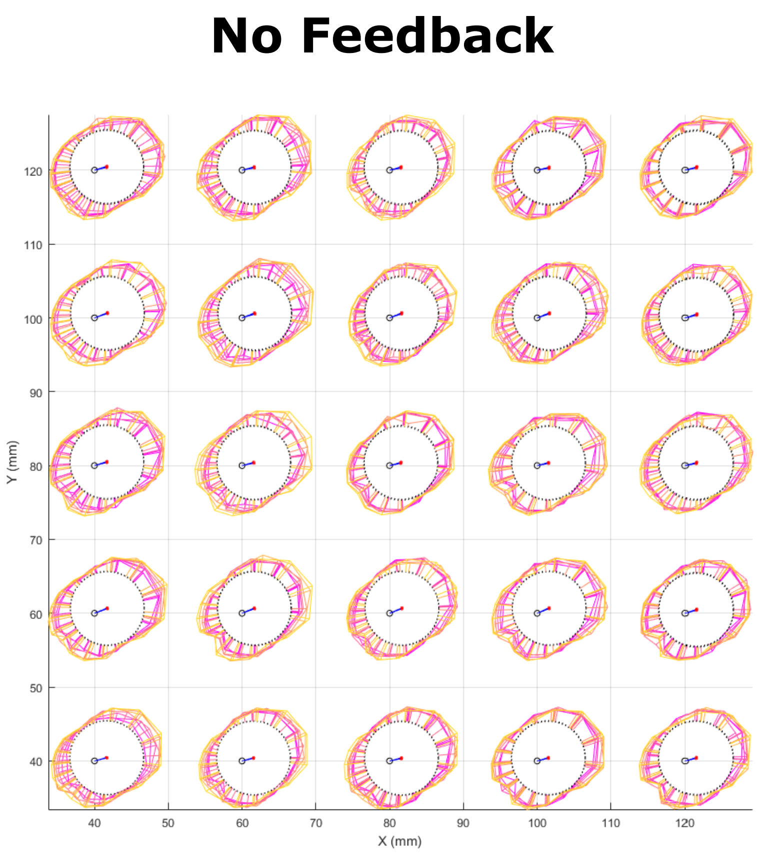


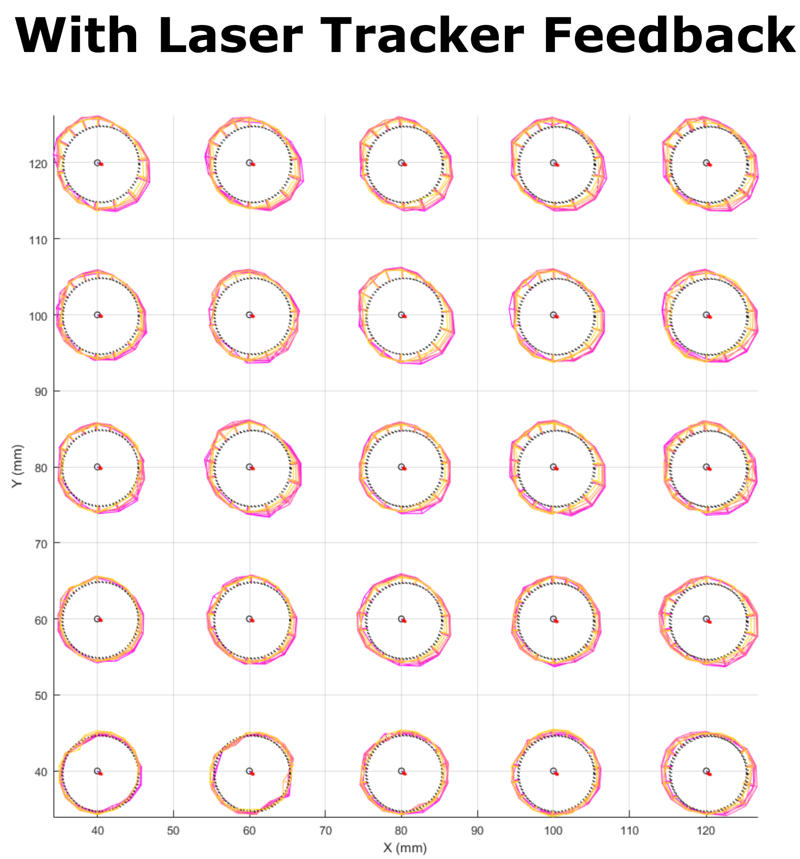
Position 3



Position 4

CMM Hole Probing - Exaggerated Hole Position (2x) and Radial Error (20x)



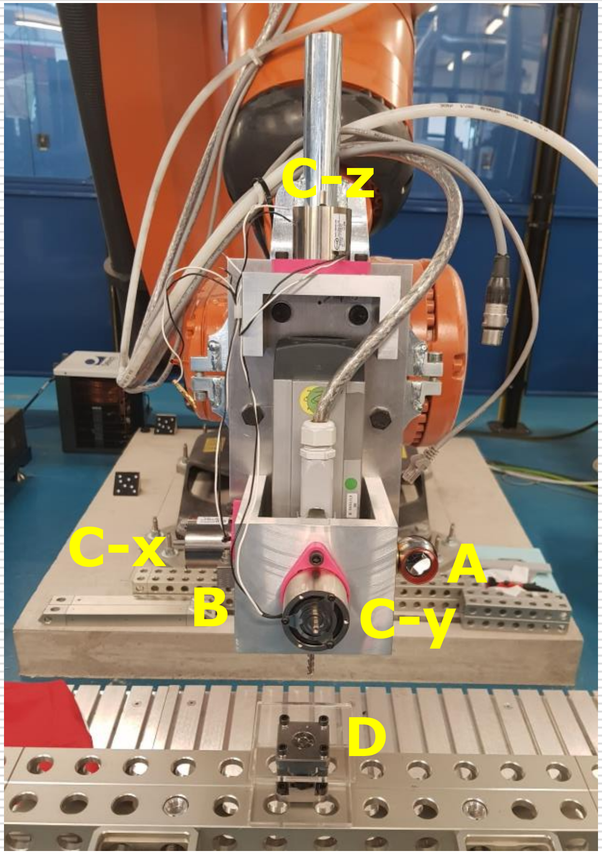


- + more consistent absolute hole position

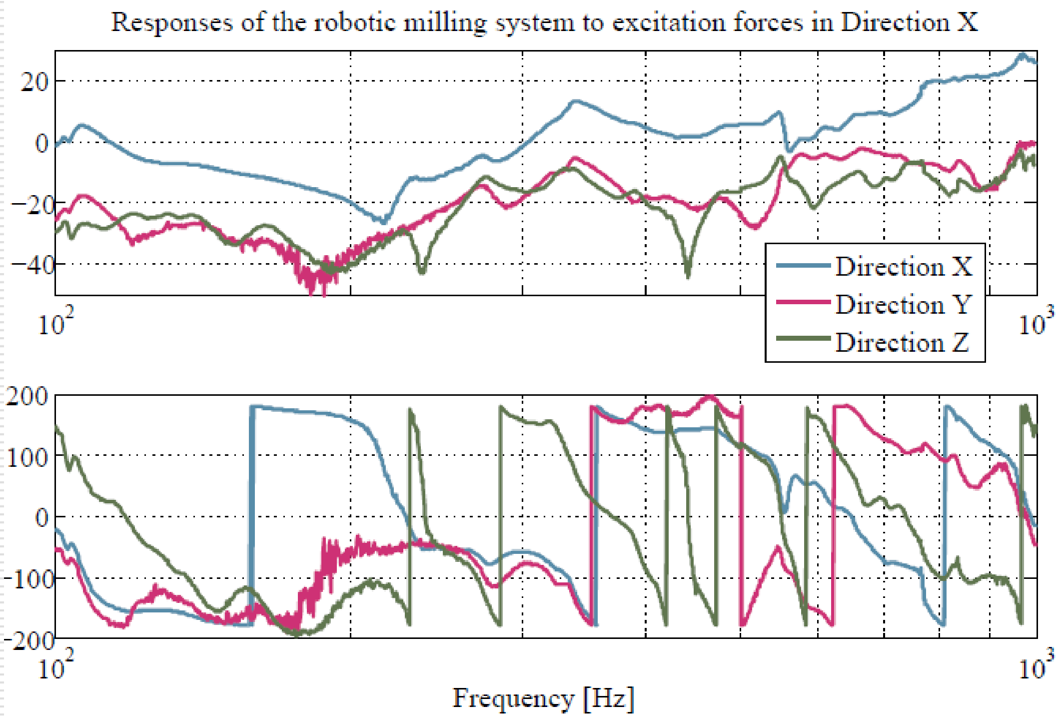
Vibration Control of Robotic Machining

- Robots are complex dynamic systems
  - Nonlinear parameters e.g. backlash
  - Vibration modes depend on pose
- Excitation frequency and magnitude vary dramatically
  - Spindle speed
  - Cutting depth
  - Material
- Active control is required
- Ongoing as part of the Advanced Metrology Hub

Vibration Control of Robotic Machining



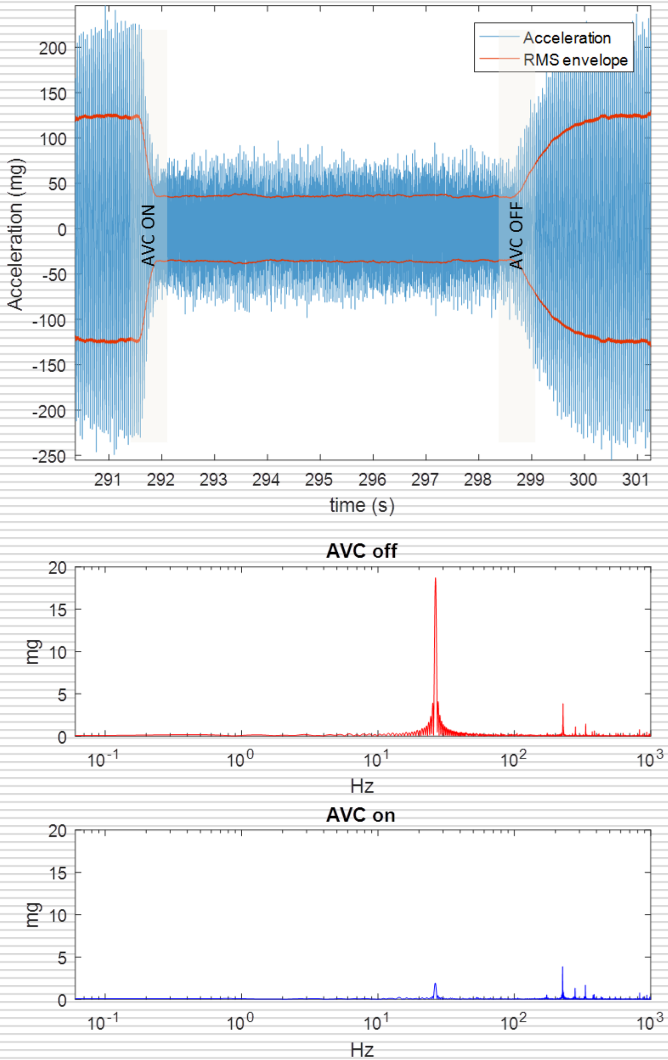
Frequency response identification



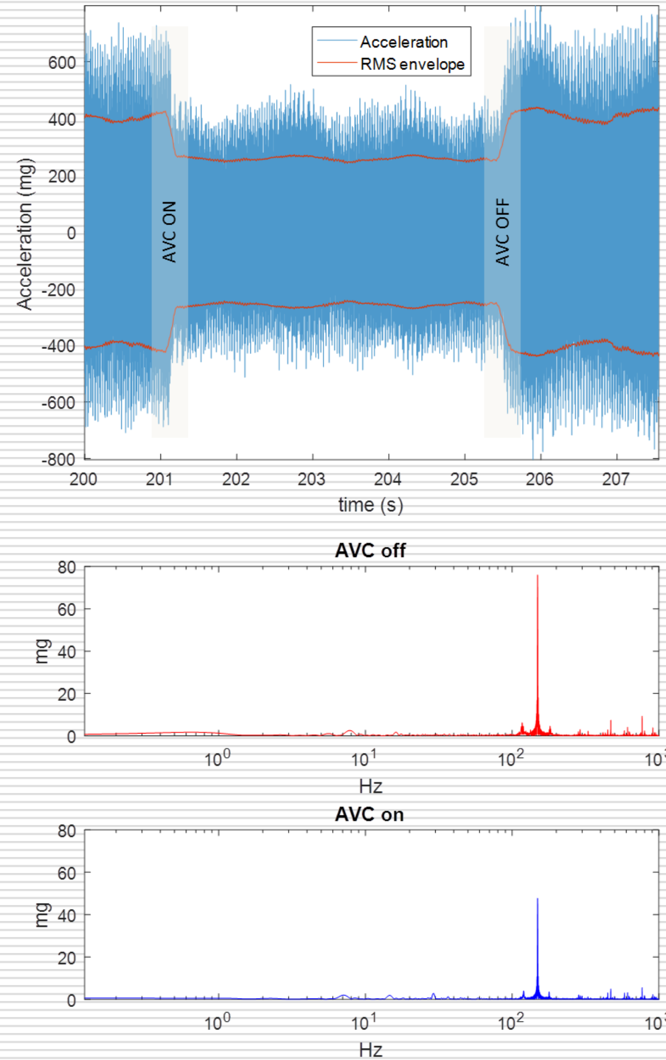
- Laser tracking for machine tool path control (A)
- 3 DoF *xyz* accelerometer measurement of dynamic spindle vibration (B)
- 3 inertial xyz actuators (C) to control machining forces up to 200 N
- Load cell to measure dynamic machining forces (D)

AVC Eccentric Mass Results

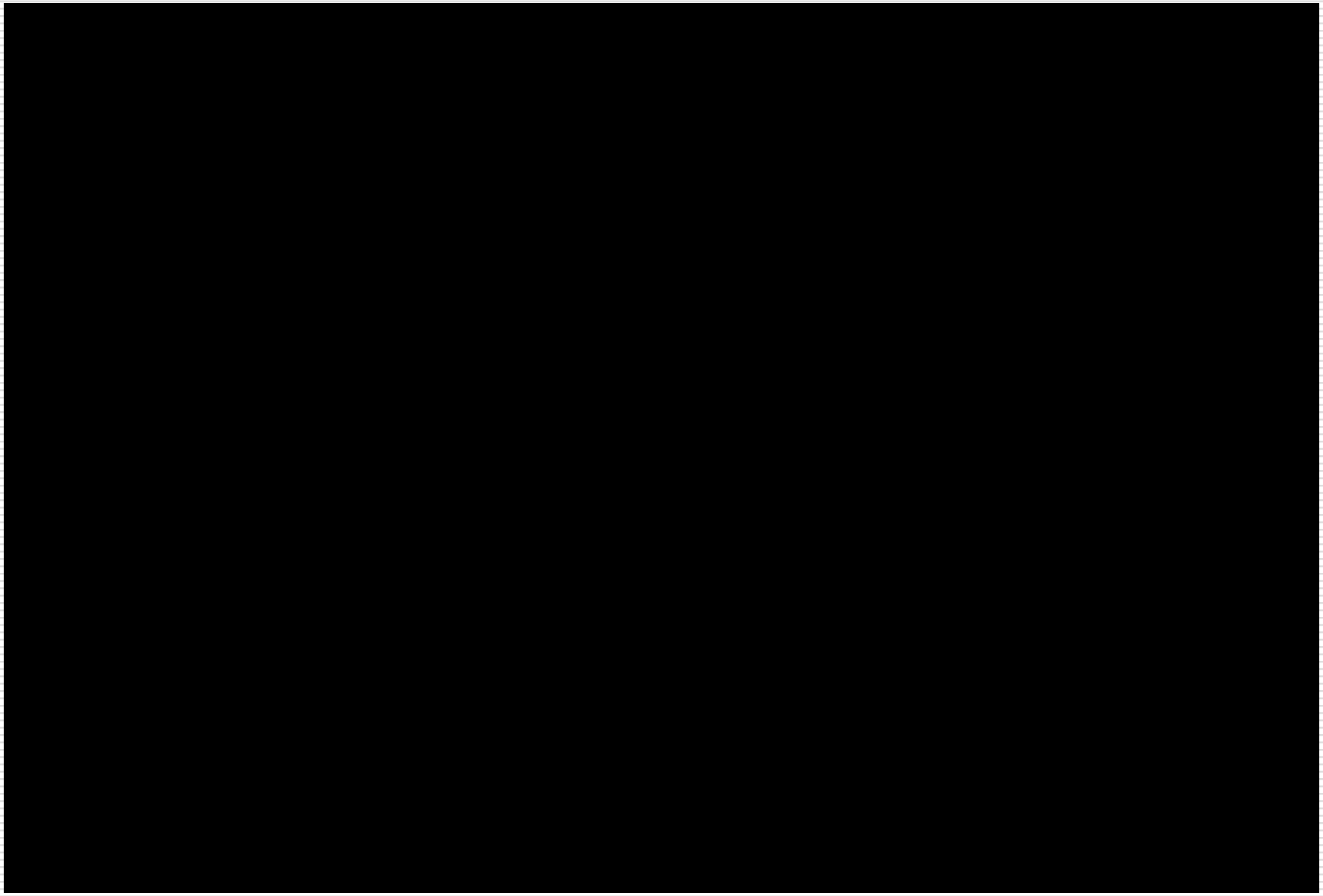
1580 RPM
26.4Hz Resonance



9000 RPM
149Hz Resonance



LCF Demonstrator – without vibration control



Conclusions ➡ Future Challenges

- Integration and metrology systems with robotic machining demonstrated ➡ Automation of processes to follow-on. Thermal variations require compensation for large volumes
- Revolute joint tribological influences are controllable to some extent though not exactly ➡ Nonlinear modelling uncertainty, variability. Flexure joints may have potential to eliminate these
- High frequency vibration control of machining is achievable with additional actuation, e.g. inertial ➡ Precision control depends on robot pose, hence challenges for the complete robot operating volume