Geometry Estimation and Adaptive Actuation for Centering

Presentation to PMRC Industrial Advisory Board

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Project Motivation

- Many bearing manufacturing processes include a manual centering operation using a hammer
- Feedback loop is through the operator’s eyes on a digital readout
- Typical time to center a part within the 2.5 µm tolerance window is one minute
- Problem =
  - High cost (manual labor)
  - Low throughput
- Solution =
  - Real Time Automation
Centering

- Circular ring placed on rotating plate
- Measure ring using probe mounted to following slide
- Measure and model ring surface
- Push ring to center
- Tolerance = 2.5µm
Prototype Plant Design
Measurement and Actuation Design

- Slide Characteristics
  - Max $v = 150 \text{ mm/s}$
  - Max $a = 8000 \text{ mm/s}^2$
  - Max $F = 280 \text{ N (63 lb)}$

- Measurement Resolution
  - Slide = 0.02µm
  - Probe = 0.05µm
  - Spindle = 0.09° (4000 ct/rev)
Distributed Control Algorithm

- Data Collection Loop
  - Probe → Data Queue

- Modeling Loop
  - Data Queue → Model → Push Parameters

- Motion Control Loop
  - In Position → Follow Probe
  - to Push? → Push

- Communication Loop
  - Data Packaging

- Ethernet → PC

Following

Pushing
Non-time critical tasks

- Change system parameters
  - Monitor system performance
  - Reconfigurable in real time based on environment
  - Completely removable ("headless" operation)
Performance Results

Centering Time Part 1
Partial Revolution Modeling

\[ m = 0.77 \text{ kg} \]

Centering Time Part 2
Partial Revolution Modeling

\[ m = 0.88 \text{ kg} \]

Centering Time Part 3
Partial Revolution Modeling

\[ m = 1.20 \text{ kg} \]

Centering Time Part 4
Partial Revolution Modeling

\[ m = 18.9 \text{ kg} \]
Distance Model

- Assume 2nd order, velocity-based coefficients

\[ d - d_0 = A(\mu - \mu_0)^2 \]

\[ d_0 = C_1v^{k_1} \]

\[ A = C_2v^{k_2} \]

\[ \mu_s = 0.3415 - \sqrt{\frac{d - 0.00041v^{1.8997}}{0.07379v^{1.6428}}} \]
System Friction Identification 2

- Applicability to long-term system monitoring
- Good application for Kalman state estimation
  - Underlying function unknown and variable
  - Interest in current state estimate, not refining past data as with geometry estimation
Conclusions – Centering is Viable

- Automated centering is practically achieved from
  - Valid estimation of system dynamic performance
  - Optimal state estimation of geometry
  - Robustness to disturbance from control architecture

- Work provides a demonstration platform for these and other research concepts
Thank You