Emerging Sensing Technologies Towards Smart Machine Tools

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NIST → Economic Growth

- NIST within U.S. Department of Commerce
- NIST promotes U.S. innovation by advancing measurement science, standards, and technology
- 6,500 Employees/Associates
- NIST partners with about 1,200 manufacturing specialists through manufacturing extensions
Manufacturing = Economic Growth

- Manufacturing = 12.5M U.S. jobs & about 60% exports
- 2.8% economic growth for U.S. machine tool orders

Modern Machine Shop, 2015 Capital Spending Survey & Forecast

U.S. Bureau of Labor Statistics

Oxford Economics
Machine Tools are Vital for Production

- 100s of machine tools used in plants to mill precision parts
- 3+ axis motion
Problem = Unplanned Downtime

- Faults/failures → 10s of $Billions per year (> new machines!)
- Machine tool degradation causes performance changes and unplanned downtime

Wear

Machinery Lubrication (2004), Wear in Rolling Element Bearings and Gears

Reliabilityweb.com (2018), Lubrication FMEA: The Big Picture
Why Not Measure Health?

- Major manufacturers say routine tracking of performance is **too expensive**.
- Accuracy a pro, but setup and operation time/cost a con.
  - Offline
  - Lack of periodic data
  - Expensive

Laser $\rightarrow$ 1-2 days

Cap probes $\rightarrow$ hours

Ballbar $\rightarrow$ 1 hour
GOAL: Smart Machine Tools

- **Industry challenge**: “Machine health in 5 min?”
- On-machine measurement science to diagnose performance and root-causes
  - Offline Online
  - Lack of periodic data Data-rich
  - Expensive Inexpensive

- Linear Axis Health Tracking
  [How?]

- Spindle Health Tracking
  [How?]

- Squareness Health Tracking
  [How?]
GOAL: Smart Machine Tools

- Make machine tools self-aware with diagnostics of performance & root causes
- Predict part errors based on health tracking & optimize asset management

Machine #1
- Axis 1
  - 15 µm range
  - Spalling detected
- Spindle
- Axis 2
  - 70 µrad range

Optimum Machine: #5

Hyundai Wia Plant
IMU for Linear Axis Monitoring

Data Fusion with Accelerometer (A) and Rate Gyroscope (RG) Data

Translational Motion

Angular Motion

**IMU Data Collection**

- Each run uses 3 different axis speeds
- IMU can live within machine tool for usage with no setup

Slow Speed (but sped up in video)
NIST Linear Axis Testbed

- Testbed to study IMU-based method & diagnostics / root-cause analysis
NIST Linear Axis Testbed

- Testbed to study IMU-based method & diagnostics / root-cause analysis
Root-Cause Analysis for Rail Wear

- Find root cause of changing error motions
- 4 possible physical causes: inner/outer raceway damage on Rail 1 or 2
- Root-cause analysis correctly identified spalling on inner raceway of Rail 1
IMU for Linear Axis Health Tracking

- Research Opportunities to use IMU for Comprehensive Root-Cause Analysis
GOAL: Smart Machine Tools

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Linear Axis Health Tracking
[How?] IMU

Spindle Health Tracking
[How?] TBD

Squareness Health Tracking
[How?] IMU
Lesson #1 – Smart & Metrological

• Traceable – Data is traceable to NIST
  • Sensors calibrated along “measurement chain” to NIST

• Dimensional – Results are physical quantities
  • Inspired by international machining standards
  • Tracking $\Delta$ error motion > 2 $\mu$m and > 6 $\mu$rad
  • Physical quantities can be measured

• Verify and validate – If possible!
  • Compare results to those from traceable independent reference
  • Even complicated diagnostics can be shown to be correct
Lesson #2 – Smart & Simple

• Simple analytics
  • Can be explained and standardized
  • More robust because tested more easily
  • Easier to implement for great adoption
  • Goal- or physics-based thresholds

• Simple user setup
  • Plug and play solutions
  • Vendor neutral for flexibility

ISO/TR 17243-1:2014

Spindle Metric

Operation Time

D C B A

1 2 3 4 5 6

ISO/TR 17243-1:2014
Lesson #3 – Future Directions

- Make **smart machine tools** with *online, data-rich, and inexpensive* diagnostics & prognostics of performance & root causes of faults/failures
- Predict part errors based on health tracking & optimize asset management
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