Control of the Grinding Process
Using In-Process Gage Feedback

PMRC Industrial Advisory Board Meeting
Georgia Institute of Technology
October 2000

David Longanbach
Overview

❖ Research Objective
❖ Need for Research
❖ Internal Grinding Model Development
❖ External Grinding Model Development
❖ Experimental Methodology
❖ Importance of Research
❖ Summary
Research Objective

❖ To regulate the part diameter size variation and cycle time of a high volume dedicated grinding machine process using a externally applied control strategy to adjust the feedrate of the machine.
Need for Research

- To realize the potential of gage systems resulting from advances in machine tool design and control
- To overcome limitations of traditional control strategies by using in-process diameter gage feedback
In-Process ID Gage Detail

- Two diamond-tipped tactile probes
- Provides direct measurement of diameter
- Feed perpendicular to measurement line

Typical Grind Cycle
- load part
- wheel in
- gage in
- grind
- retract spindle
- retract gage
- load part
- ...
Internal Grinding Schematic

Deflection \[ \Delta x = \left( v_f - v_w - v_s \right) \Delta t \]

- $D_w$: Work piece diameter
- $D_s$: Grinding wheel diameter
- $v_w$: Work piece diameter rate of change
- $v_s$: Work piece surface velocity
- $v_f$: Grinding wheel diameter rate of change
- $v_s$: Grinding wheel surface velocity
- $v_f$: Grinding wheel velocity
- $F_n$: Normal force
- $F_t$: Tangential force
- $W$: Grinding contact width (not shown)
Internal Grinding Dynamic Model

- Grinding system elements
  - System mass, $M$
  - System stiffness, $k$
  - Servo system input, $u$
  - Grinding process dynamics, $b$
  - Slide position, $z$
  - Grinding wheel position, $y$
  - System deflection, $(z - y)$

[Diagram of the grinding dynamic model with symbols and arrows indicating inputs ($u$), system mass ($M$), system stiffness ($k_s$), and outputs ($z$, $y$, $(z - y)$).]
In-Process OD Gage Detail

- Two diamond-tipped tactile probes
- Provides direct measurement of diameter
- Feed perpendicular to measurement line

Typical Grind Cycle

load part
wheel in
gage in
grind
retract spindle
retract gage
load part
...

End View

In-Process OD Gage

Upper Arm

Lower Arm

Measurement Line

Grinding Wheel

Feed
Deflection \[ \Delta x = (v_f - v_w - v_s) \Delta t \]

- \( D_w \): Work piece diameter
- \( D_s \): Grinding wheel diameter
- \( v_w \): Work piece diameter rate of change
- \( v_w \): Work piece surface velocity
- \( v_s \): Grinding wheel diameter rate of change
- \( v_s \): Grinding wheel surface velocity
- \( v_f \): Grinding wheel velocity
- \( F_n \): Normal force
- \( F_t \): Tangential force
- \( W \): Grinding contact width (not shown)
**External Grinding Dynamic Model**

- Grinding system elements
  - System mass, $M$
  - System stiffness, $k$
  - Servo system input, $u$
  - Grinding process dynamics, $b$
  - Slide position, $z$
  - Grinding wheel position, $y$
  - System deflection, $(z - y)$

![Diagram of grinding dynamic model]
Traditional Gage Sizing Setup

- Cycle time limitations using fixed set point control
- Relay and PLC delay increases part diameter variation
Experimental Setup

Control Strategy

A/D Conversion

Signal Conditioning

Electrical Cabinet

Feedrate Override

Servo Drives

Power Transducer

In-Process Gage

Spindle

Force Sensor

Gage Amplifier

Charge Amplifier

Top View
Importance of Research

❖ First use of continuous part diameter feedback to control the grinding process

❖ Will be a standard feature on all future dedicated high volume production grinding machines

❖ Will reduce costs and make high volume components less expensive to produce

❖ Will be able to control any machine with gage diameter feedback to reduce cycle time and part diameter size variation
Summary

❖ Part diameter information from an in-process gage as feedback to the control of a non-trivial machine tool process

❖ Internal and external grinding process dynamic model development

❖ Implementation and evaluation of control design on an external universal grinder at Georgia Tech