University of Huddersfield Repository

Chen, Xun

Fundamental Study of Corrective Abrasive Machining Technology

Original Citation


This version is available at http://eprints.hud.ac.uk/10621/

The University Repository is a digital collection of the research output of the University, available on Open Access. Copyright and Moral Rights for the items on this site are retained by the individual author and/or other copyright owners. Users may access full items free of charge; copies of full text items generally can be reproduced, displayed or performed and given to third parties in any format or medium for personal research or study, educational or not-for-profit purposes without prior permission or charge, provided:

- The authors, title and full bibliographic details is credited in any copy;
- A hyperlink and/or URL is included for the original metadata page; and
- The content is not changed in any way.

For more information, including our policy and submission procedure, please contact the Repository Team at: E.mailbox@hud.ac.uk.

http://eprints.hud.ac.uk/
Fundamental Study of Corrective Abrasive Machining Technology

Dr Xun Chen
Advanced Machining Technology Group
Centre for Precision Technologies
School of Computing and Engineering

CIRP UK Meeting 8th May 2009

Precision machining technology

*Unique pioneer challenge in developing next generation machining technology*

**Current Research Themes**

- Precision machining
  - Abrasive machining
  - Diamond turning
  - Finite element analysis and molecular dynamics
- Intelligent process monitoring and control
  - Contact detection using acoustic emission
  - Abrasive machining monitoring using AI techniques
- Knowledge support systems
  - Database / Knowledge warehouse
Basic principle of precision corrective machining

![Diagram of machining process]

Framework of a grinding process control

<table>
<thead>
<tr>
<th>Control methods</th>
<th>Three major measures of grinding qualities</th>
<th>Sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>• adaptive control, • constraint control.</td>
<td>• accuracy of size and form, • surface roughness, • surface integrity.</td>
<td>• Power and torque • Forces • Size gauging • Grinding force • Vibration monitoring • Temperature sensing • Eddy current sensing • Acoustic emission • Image sensing</td>
</tr>
</tbody>
</table>

Wheel preparation:
• Wheel type
• Dressing conditions
• Dressing depth
• Dressing load

Environmental factors:
• Machine
• Workpiece
• Coolant

Wheel conditioning:
• Wheel balance
• Wheel topography

Control parameters:
• Grinding conditions
• Grinding speed
•Workspeed
• Grade
• Coolant delivery
• Grinding cycle

Grinding process:
• Force
• Power
• Vibration
• Temperature
• Acoustic emission
• Material removal
• Displacement
• Wheel wear
• Grinding burn

Quality inspection:
• Surface roughness
• Surface wave
• Surface integrity
• Crack
• Hardness change
• Residual stress
• Phase changes
• Form error
• Size accuracy

Outputs

Monitoring & control; Surface integrity; Coolant delivery; Wheel dressing
From the macroworld to the nanoworld
(The Hitchhiker’s Guide to Nanotechnology, 2006)

Micro-machining is considered to cover the production of minute components and features from a wide range of materials, generally in the size range of 200 microns to a few nanometres and may also be known as micro DRILLING, micro cutting, micro milling, micro grinding and micro etching.

Challenge of nanometre scale machining

Sa < 1 nm
Form error < 0.1 μm

Aluminum (Al) Sa = 0.742 nm
- Spindle RPM: 2000
- Finish Feedrate: 7.5 mm/min
- Finish Depth of Cut: 2 μm
- Coolant: Odorless Mineral Spirits

Nickel (Ni) Sa = 0.924 nm
- Spindle RPM: 3000
- Finish Feedrate: 5 mm/min
- Finish Depth of Cut: 4 μm
- Coolant: Odorless Mineral Spirits

Grain boundary indicates the limitation of the conventional turning operation limitation. What can be done?

It was claimed that grinding has no minimum depth of cut.
Basic Relationships of a Grinding Process and Simulation

Inputs of grinding process:
- grinding wheel
- dressing tool
- dressing kinematics
- grinding wheel topography
- chip geometry
- single grain load

Grinding process:
- grinding forces
- grinding temperature
- grinding vibration
- wheel wear
- grinding deformation
- grinding power
- surface integrity
- surface roughness
- size error
- form error

Outputs of grinding process:
- grinding wheel topography
- chip geometry
- single grain load

Fundamental Mechanism of Grinding

Three stages of chip generation:
- chip formation
- ploughing
- sliding

AE signals would have certain features that present three stages of chip generation.
Rigs for single grit grinding tests

AE signals of single grit scratch
Single grit scratch test

Grinding mechanism classification using Neural Networks

Wheel rotational speed = 4000 rpm, Feedrate = 4 m/s.
Workpiece materials: CMSX4
Feature extraction of AE in grinding

Wheel rotational speed = 4000 rpm,
Feedrate = 4 m/s,
Workpiece materials: CMSX4.

<table>
<thead>
<tr>
<th></th>
<th>C%</th>
<th>P%</th>
<th>R%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 µm cut</td>
<td>45</td>
<td>29</td>
<td>26</td>
</tr>
<tr>
<td>1 µm cut</td>
<td>45</td>
<td>47</td>
<td>8</td>
</tr>
<tr>
<td>0.1 mm cut</td>
<td>57</td>
<td>40</td>
<td>3</td>
</tr>
</tbody>
</table>

Laser irradiation imitating grinding thermal behaviour

Laser machine: Lumonics JK704 Nd:YAG
Wave length: 1.06 µm
Pulse energy: 1.26J
Maximum peak power: 2.5kW
Laser irradiation time: 0.06 ms
Focal length: 120 mm
Light beam diameter: 12 mm
Off-focal length: 34~46 mm
Features of thermal stress induced AE signals

Comparison of AE signals generated by laser and grinding
Grinding thermal behaviour monitoring by using thermal AE signatures

The NN created using AE signatures from laser irradiation

Grinding burn identification using the NN from thermal AE signatures

Pattern recognition for grinding defects

Fuzzy recognition block diagram

Fuzzy recognition procedure

• Success rate 92.3%
Support vector machine classification

Ra measurements for each cut (3 Trials separated by lines)

SVM classification

Benefits of SVM:
- Small amount of training data required
- Small amount of classifying time
SVM Classification

Machine: Makino A55 CNC machine centre.
Workpiece: Inconel 718.
Wheel: VIPER wheel.
Depth of cut: 1 mm;
Grinding speed: 35 m/s;
Workspeed: 1000 mm/min.

Machine: Makino A55 CNC machine centre.
Workpiece: Inconel 718.
Wheel: VIPER wheel.
Depth of cut: 1 mm;
Grinding speed: 55 m/s;
Workspeed: 1000 mm/min.

Multi-classification of normal grinding, grinding chatter and burn using the GP

Distance

Distance

Distance

Distance

Distance

# Classification of grinding anomalies using genetic programming

<table>
<thead>
<tr>
<th>No.</th>
<th>GP fitness function</th>
<th>Data set</th>
<th>Function Nodes</th>
<th>Test Score</th>
<th>Accuracy %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>sum diff fitness</td>
<td>ICA Chatter and burn</td>
<td>+, -, /, *</td>
<td>32/40</td>
<td>80</td>
</tr>
<tr>
<td>2</td>
<td>sum diff fitness</td>
<td>*reduction: burn and no burn</td>
<td>+, -, /, *</td>
<td>36/40</td>
<td>90</td>
</tr>
<tr>
<td>3</td>
<td>sum diff fitness</td>
<td>*reduction: burn and no burn</td>
<td>=&lt;, =&gt;, if</td>
<td>36/40</td>
<td>90</td>
</tr>
<tr>
<td>4</td>
<td>sum diff fitness</td>
<td>*reduction: burn and chatter</td>
<td>+, -, /, *</td>
<td>36/40</td>
<td>90</td>
</tr>
<tr>
<td>5</td>
<td>sum diff fitness</td>
<td>*reduction: burn and chatter</td>
<td>=&lt;, =&gt;, if</td>
<td>38/40</td>
<td>95</td>
</tr>
<tr>
<td>6</td>
<td>classes overlap</td>
<td>ICA Burn and no burn</td>
<td>+, -, /, *</td>
<td>33/40</td>
<td>82.5</td>
</tr>
<tr>
<td>7</td>
<td>classes overlap</td>
<td>ICA chatter and no chatter</td>
<td>+, -, /, *</td>
<td>32/40</td>
<td>80</td>
</tr>
<tr>
<td>8</td>
<td>classes overlap</td>
<td>ICA chatter and no chatter</td>
<td>+, -, /, *</td>
<td>40/40</td>
<td>100</td>
</tr>
<tr>
<td>9</td>
<td>sum diff fitness</td>
<td>ICA chatter and no chatter</td>
<td>+, -, /, *</td>
<td>36/40</td>
<td>90</td>
</tr>
<tr>
<td>10</td>
<td>classes overlap</td>
<td>ICA Burn and no burn</td>
<td>+, -, /, *</td>
<td>40/40</td>
<td>100</td>
</tr>
<tr>
<td>11</td>
<td>classes overlap</td>
<td>*reduction: burn and no burn</td>
<td>+, -, /, *</td>
<td>40/40</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>classes overlap</td>
<td>*reduction: chatter &amp; no chatter</td>
<td>+, -, /, *</td>
<td>40/40</td>
<td>100</td>
</tr>
</tbody>
</table>

*reduction: is based on the statistical window n-dimensional reduction technique

---

# Micro and nano scale corrective abrasive machining

- **Process modelling**
  - Continuum
  - Finite Element
  - Atomistic
  - Molecular Dynamics

- **Two-body and three-body erosions**

- **Grinding**
- **Lapping**
- **Polishing**

- **Grolishing**

- **Models**
- **Suitable conditions**
- **Process monitoring**
- **On machine probing**
Grolishing Process Tools

Models of material removal

Preston material removal rate model
\[
\frac{dz}{dt} = C_p \rho V_r
\]

Archard material removal volume model
\[
V_W = K \frac{F_n S}{H}
\]

X. Wu, Y. Kita, K. Ikoku (2007)

Actual depth of cut (μm)

Polishing parameter Sp

X. Wu, Y. Kita, K. Ikoku (2007)
Grolishing material removal

Modelling of Zeeko grolishing tools
Simulation of Deformations and Stresses

Hertzian contact theory

Real result

Taguchi test results

<table>
<thead>
<tr>
<th>Representation</th>
<th>Control Factors</th>
<th>Levels</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>A</td>
<td>Head speed (rev/min)</td>
<td>1000</td>
<td>2000</td>
</tr>
<tr>
<td>B</td>
<td>Tool Angle (°)</td>
<td>0°</td>
<td>10°</td>
</tr>
<tr>
<td>C</td>
<td>Grit Size (µm)</td>
<td>7</td>
<td>25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Control Factors</th>
<th>Mean $S_a(av)$</th>
<th>S/N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A1, B1, C1</td>
<td>0.350</td>
<td>9.12</td>
</tr>
<tr>
<td>2</td>
<td>A1, B2, C2</td>
<td>0.470</td>
<td>6.45</td>
</tr>
<tr>
<td>3</td>
<td>A2, B1, C2</td>
<td>0.350</td>
<td>9.12</td>
</tr>
<tr>
<td>4</td>
<td>A2, B2, C1</td>
<td>0.221</td>
<td>13.12</td>
</tr>
</tbody>
</table>

The best result is A2, B2, C1
Further improvement could be achieved by using different pad.
Error compensation On-Machine Metrology enhanced

2D and 3D Metrology

Utilizing UltraComp's™ LVDT, 2D and 3D data files of the part profile can be gathered including the machine axes.

DIFFSYS® MC3 performs data import, graphically displays and auto-corrects the 3-dimensional part profiles from the LVDT measurement data to the desired part profile.

AE detection of contact

Before contact After contact
Manufacturing Knowledge Warehouse Development

Contents of communication in CoP:
- Questions and answers.
- Passing documents or web links.
- Calling for events or conferences.
- Sending news box.
- Others.

Framework of the warehouse:
- Date input module
- Database module
- Problem solving module
- Knowledge discovery module
- Knowledge warehouse
- Knowledge analysis module.

Opportunities of further development:
- Ultra precision corrective machining at nanometre scale (micro material removal).
- Intelligent machining monitoring and optimisation.
- Precision machining knowledge support system.

Thanks for listening