CIRP UK Meeting 8th May 2009

# Fundamental Study of Corrective Abrasive Machining Technology

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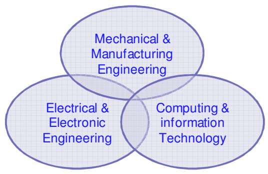
Centre for Precision Technologies
School of Computing and Engineering


# 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

Educating tomorrow's professionals

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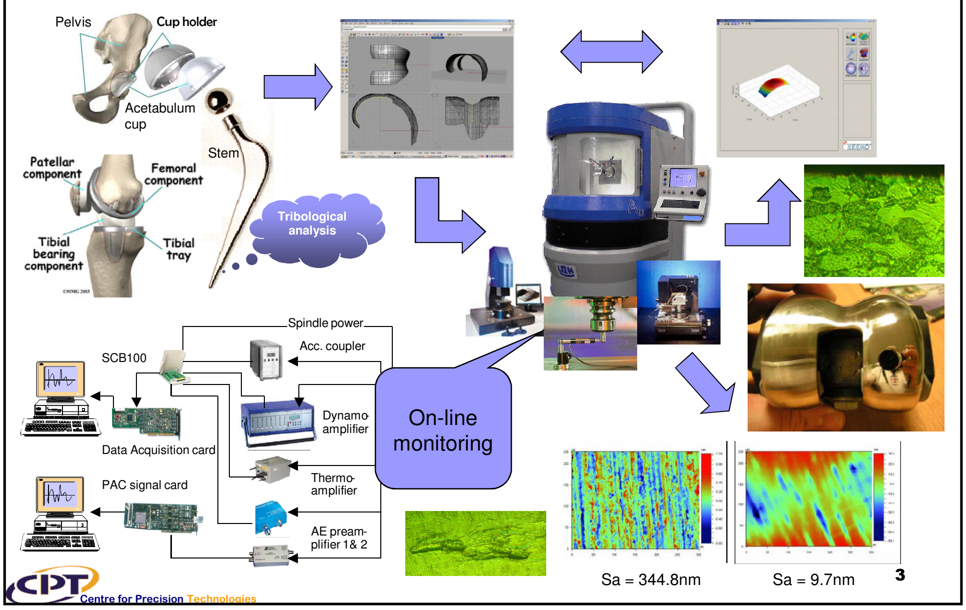
# Basic principle of precision corrective machining

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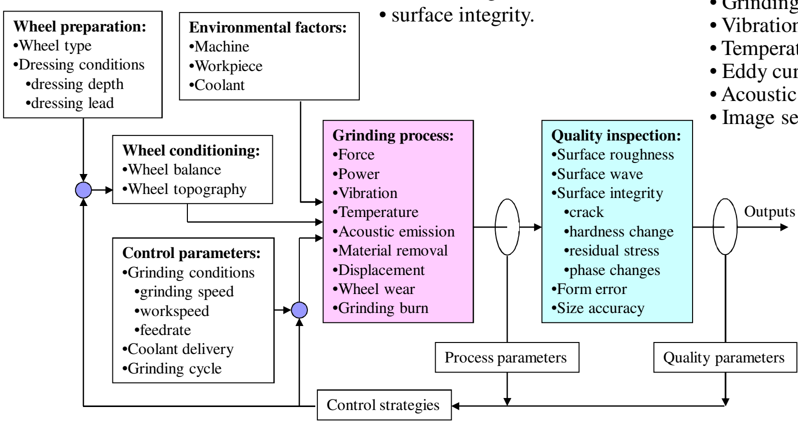
3

# Framework of a grinding process control

**Control methods**
- adaptive control,
- constraint control.

**Three major measures of grinding qualities**
- accuracy of size and form,
- surface roughness,
- surface integrity.

**Sensors:**
- Power and torque
- Forces
- Size gauging
- Grinding force
- Vibration monitoring
- Temperature sensing
- Eddy current sensing
- Acoustic emission
- Image sensing




Monitoring & control; Surface integrity; Coolant delivery; Wheel dressing

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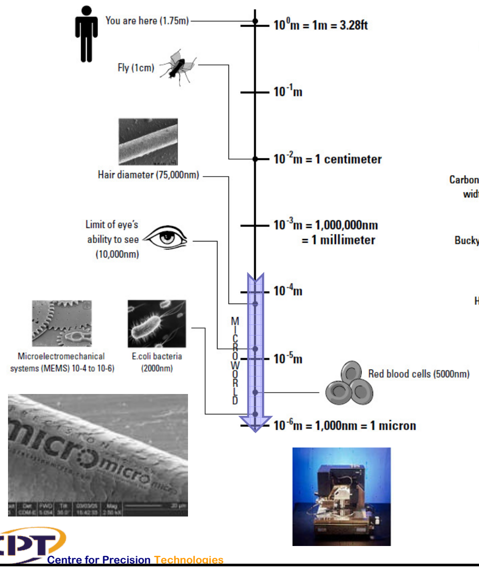
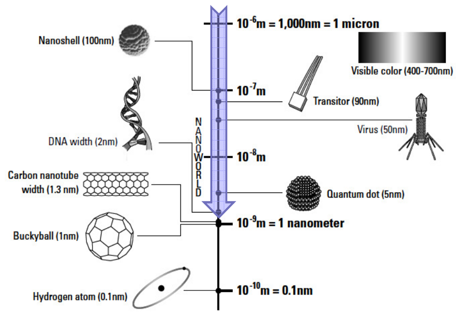
4

# 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.

5

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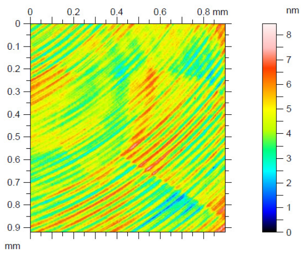
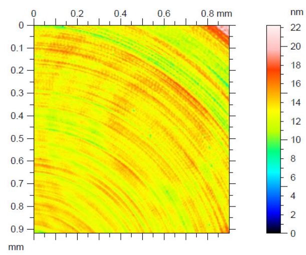
# Challenge of nanometre scale machining

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.**

6

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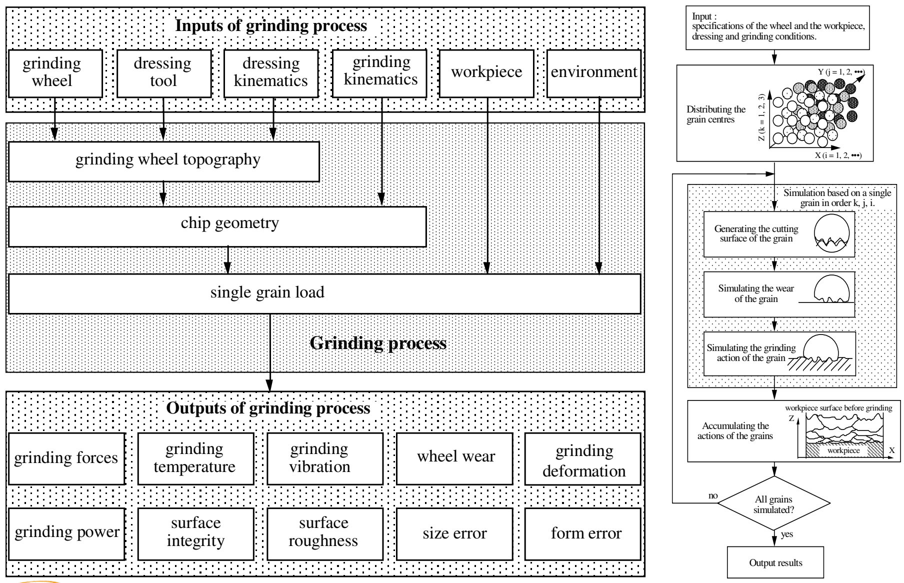
## Basic Relationships of a Grinding Process and Simulation



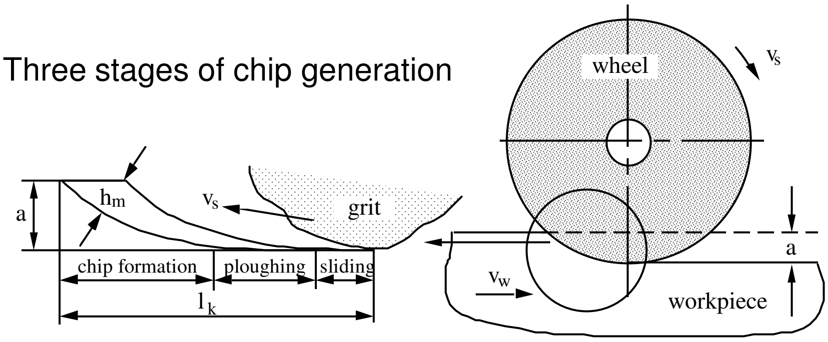






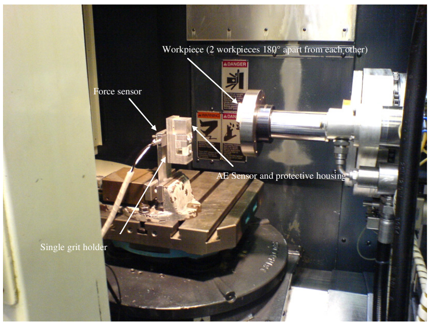

# Fundamental Mechanism of Grinding

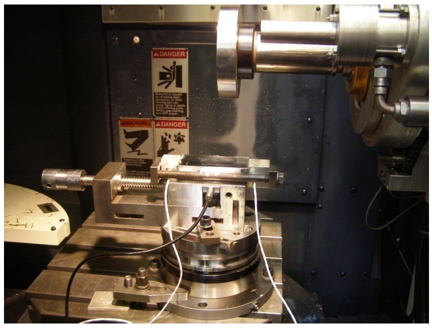
Three stages of chip generation

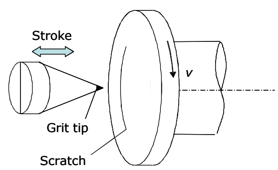


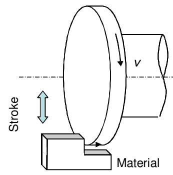

AE signals would have certain features that present three stages of chip generation.

# Rigs for single grit grinding tests



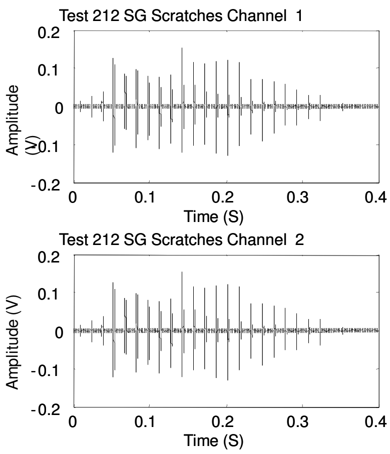


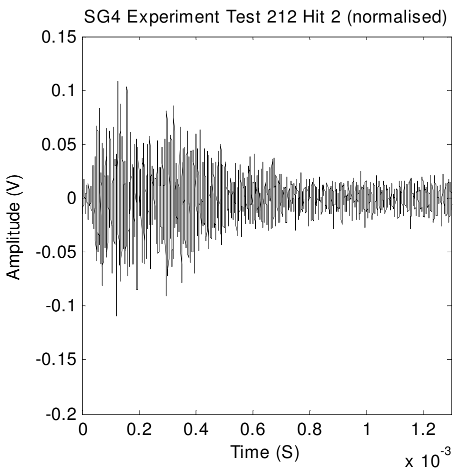








# AE signals of single grit scratch



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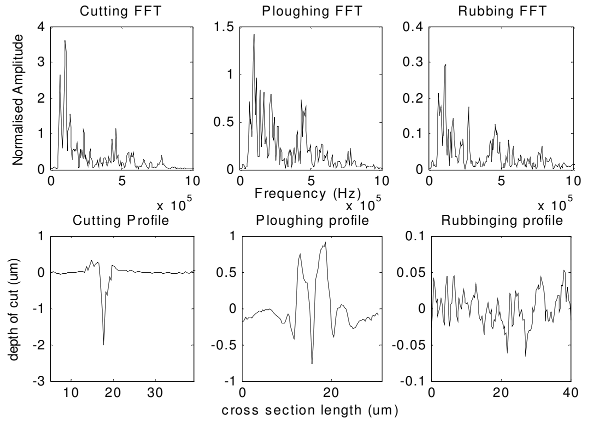
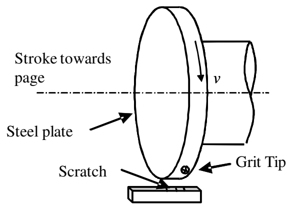
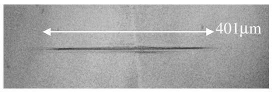
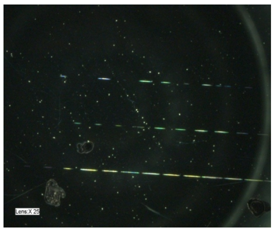
# Single grit scratch test



11

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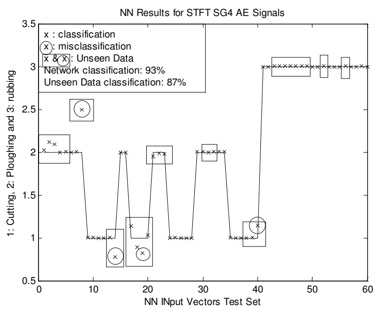
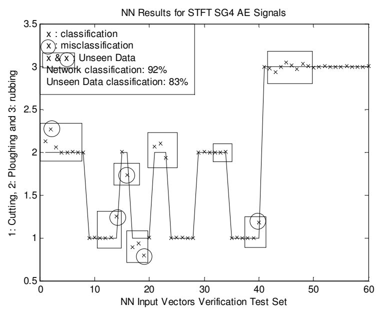
# Grinding mechanism classification using Neural Networks




Wheel rotational speed = 4000 rpm, Feedrate = 4 m/s.

Workpiece materials: CMSX4

12

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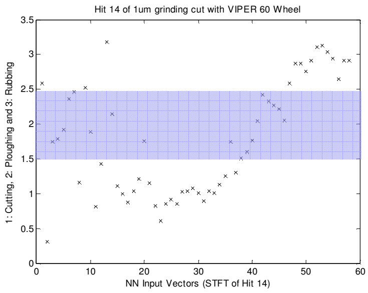
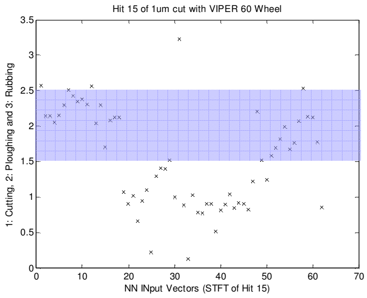
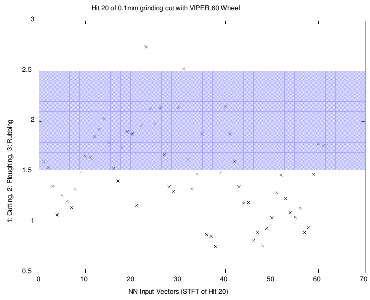
# Feature extraction of AE in grinding

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

| | C% | P% | R% |
|---|---|---|---|
| 1 µm cut | 45 | 29 | 26 |
| 1 µm cut | 45 | 47 | 8 |
| 0.1 mm cut | 57 | 40 | 3 |

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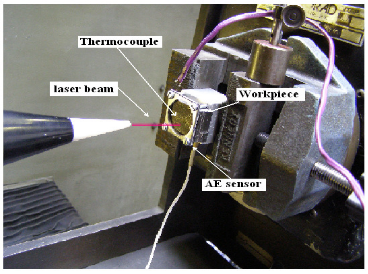
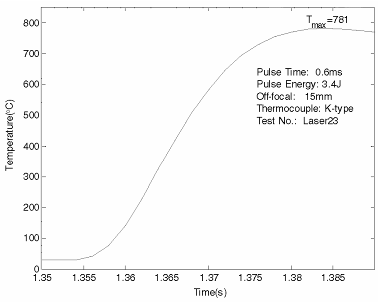
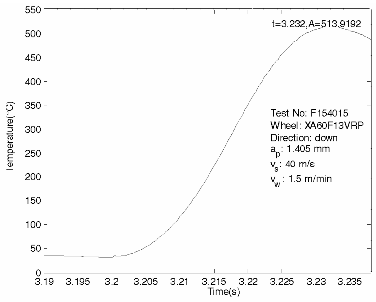
# Laser irradiation imitating grinding thermal behaviour

| | |
|---|---|
| Laser machine | Lumonics:JK704 Nd:YAG |
| *Wave length* | *1.06 ηm* |
| *Pulse energy* | *1.36J* |
| *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 |




(a)




(b)

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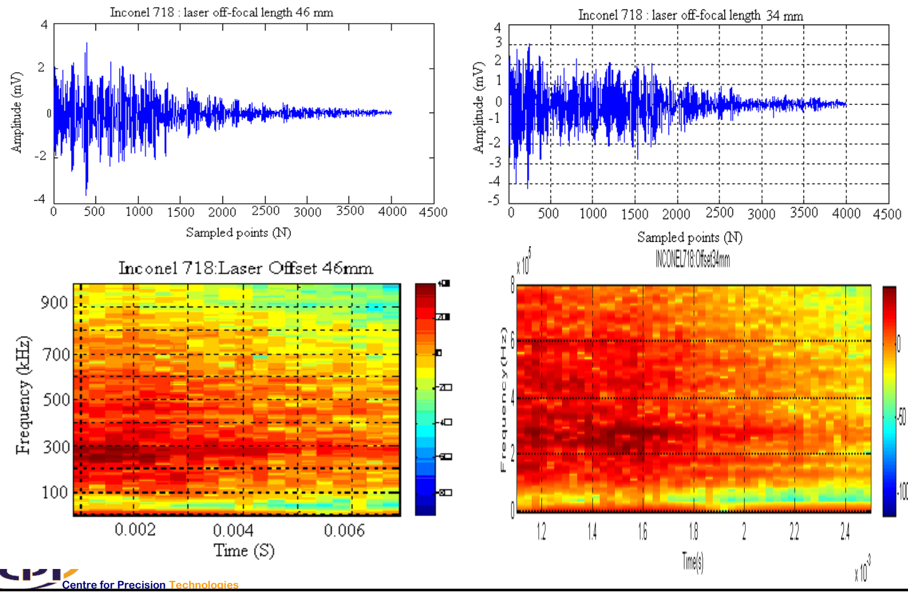
# Features of thermal stress induced AE signals

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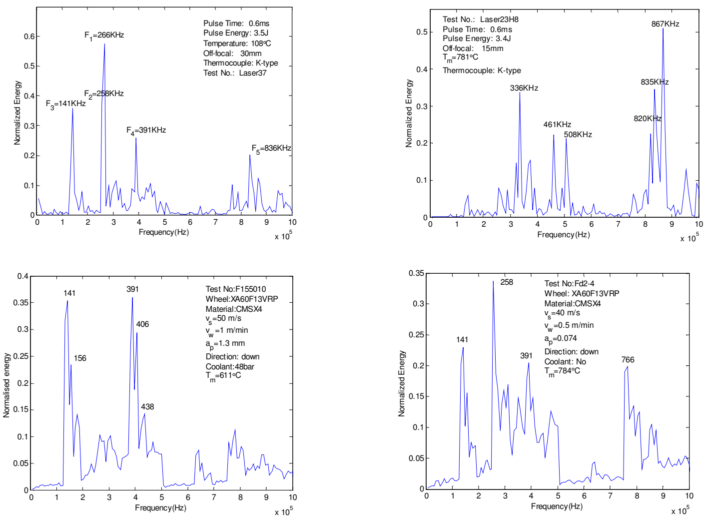
# Comparison of AE signals generated by laser and grinding

Laser

Grinding




Low temperature

High temperature

16

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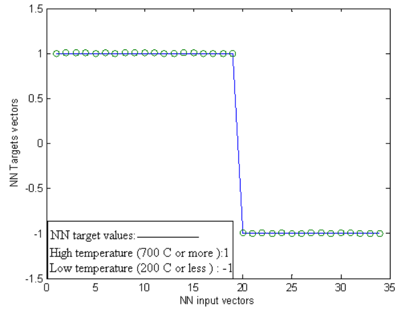
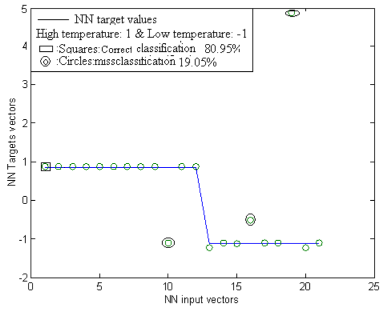
# Grinding thermal behaviour monitoring by using thermal AE signatures




The NN created using AE signatures from laser irradiation




Grinding burn identification using the NN from thermal AE signatures

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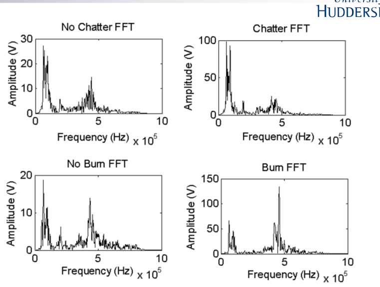
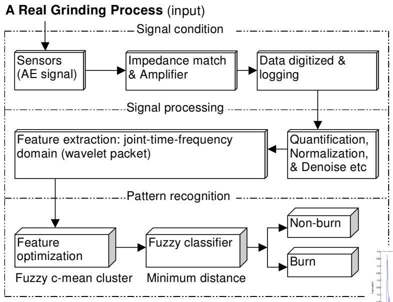
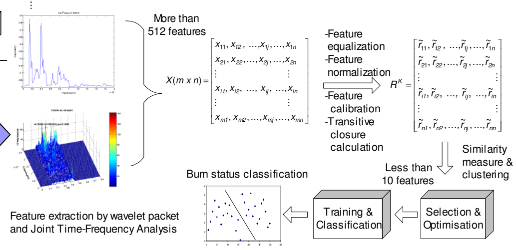
# Pattern recognition for grinding defects




Fuzzy recognition block diagraph

Fuzzy recognition procedure




- Success rate 92.3%

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18

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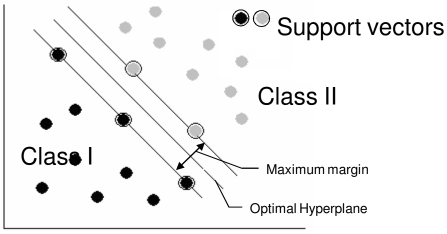
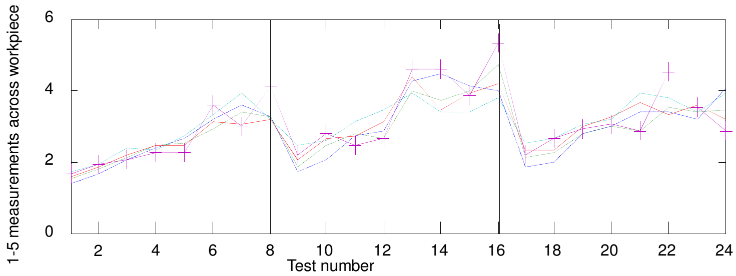
# Support vector machine classification




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

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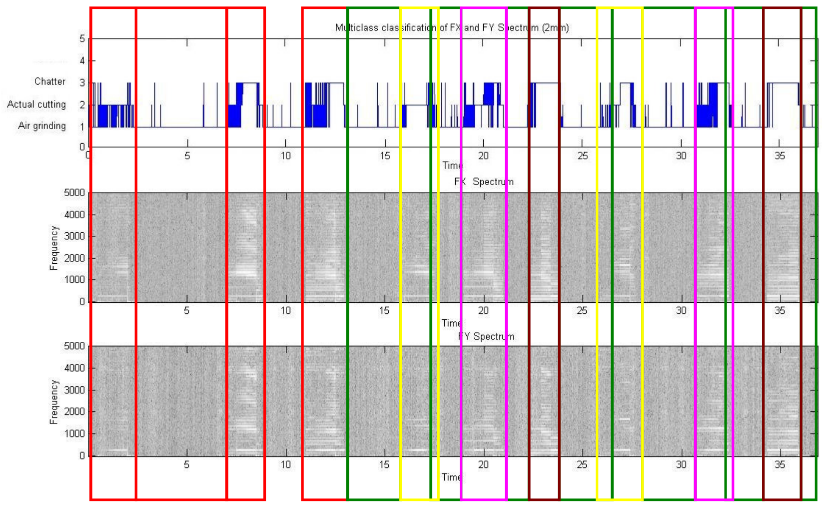
# SVM classification




**Benefits of SVM:** ❑Small amount of training data required
❑Small amount of classifying time

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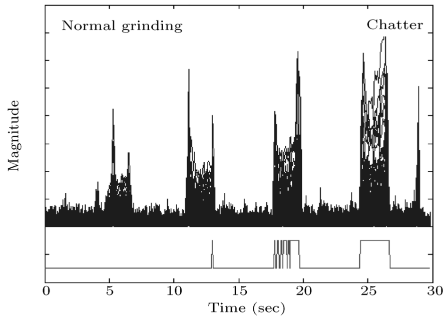
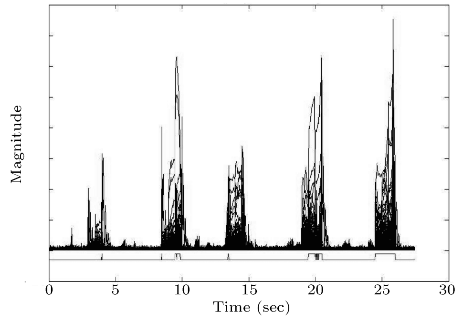
# SVM Classification




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.

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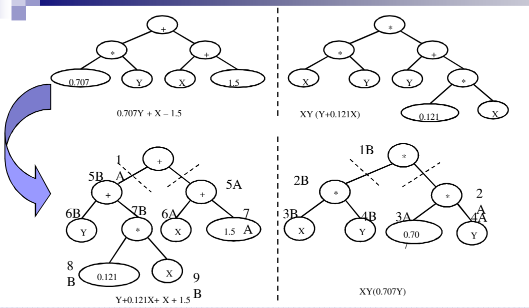
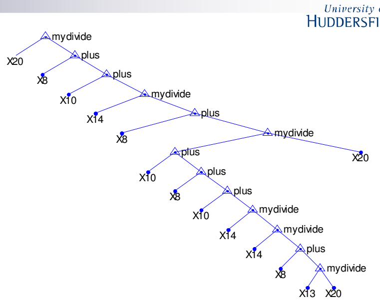
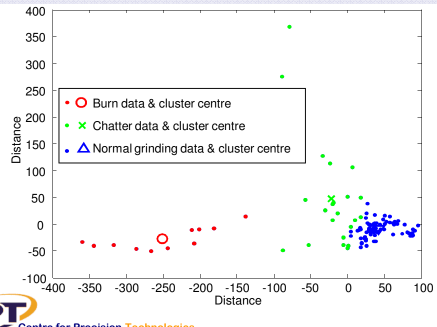
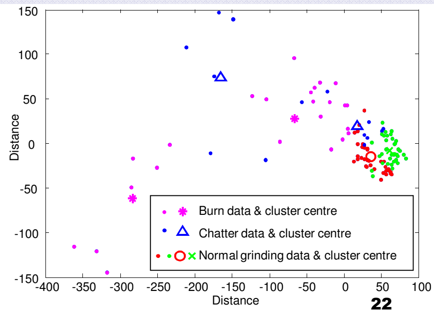



**Multi-classification of normal grinding, grinding chatter and burn using the GP**

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## Classification of grinding anomalies using genetic programming

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

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



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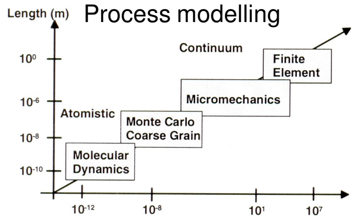
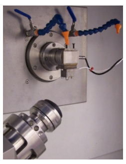
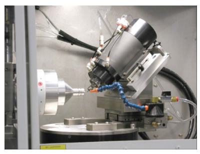
## Micro and nano scale corrective abrasive machining

Process modelling



Two-body and three-body errosions



Grinding Lapping Polishing


Models Suitable conditions Process monitoring On machine probing

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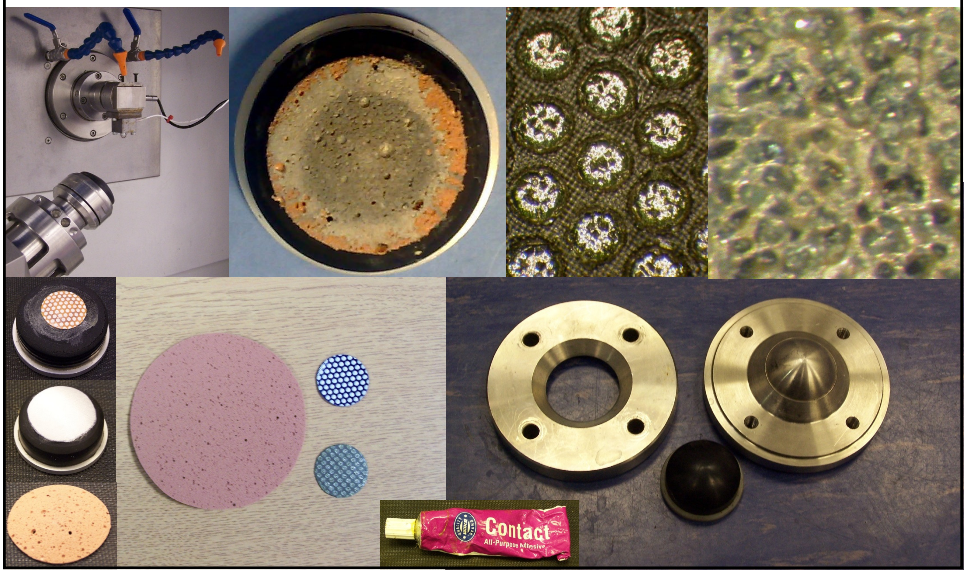
# Grolishing Process Tools

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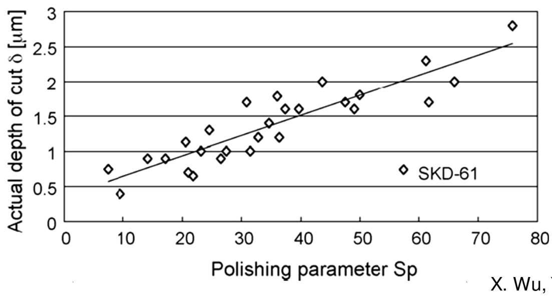
# Models of material removal

Preston material removal rate model $$\frac{dz}{dt} = C_p p v_r$$

Archard material removal volume model $$V_w = K \frac{F_n s}{H}$$




$$S_p = \frac{(V+f)p}{f H_v}$$

X. Wu, Y. Kita, K. Ikoku (2007) 26

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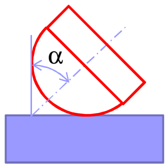
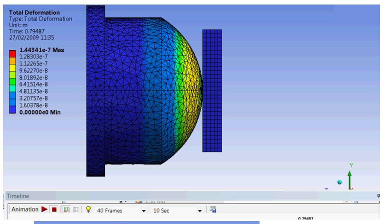
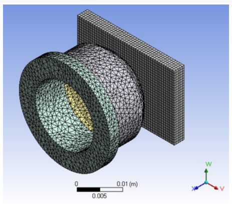
# Grolishing material removal

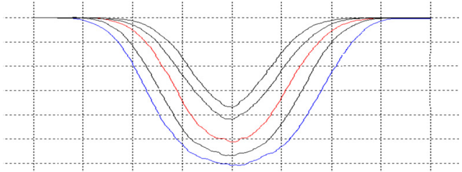



Modelling of Zeeko *g*rolishing tools
Simulation of Deformations and Stresses

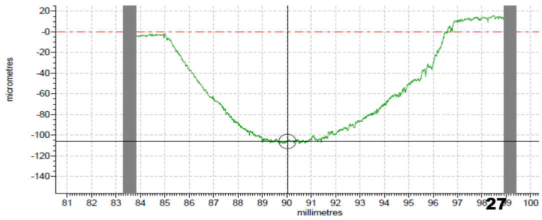




Hertzian contact theory



Real result

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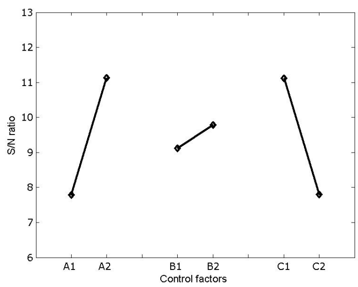
# Taguchi test results

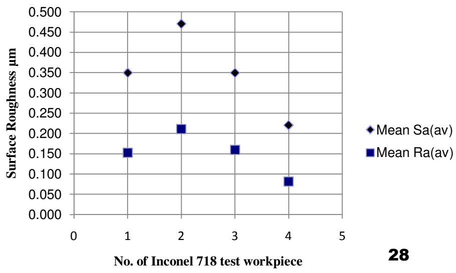
| Representation | Control Factors | Levels 1 | Levels 2 |
|---|---|---|---|
| A | Head speed (rev/min) | 1000 | 2000 |
| B | Tool Angle (°) | 0° | 10° |
| C | Grit Size (µm) | 7 | 25 |

| Test No. | Control Factors A | B | C | Mean $S_{a(av)}$ | S/N ratio |
|---|---|---|---|---|---|
| 1 | A1 | B1 | C1 | 0.350 | 9.12 |
| 2 | A1 | B2 | C2 | 0.470 | 6.45 |
| 3 | A2 | B1 | C2 | 0.350 | 9.12 |
| 4 | A2 | B2 | C1 | 0.221 | 13.12 |




The best result is A2, B2, C1

Further improvement could be achieved by using different pad.

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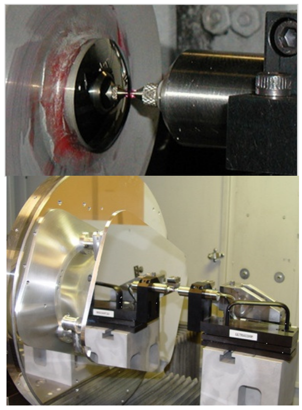
# Error compensation On-Machine Metrology enhanced

## 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.



- Machine part with DIFFSYS® **3D** X,Y,Z program → Gather data from **X,Y,Z** by point-to-point analysis or by scanning
- → Output data file to 3rd party software → Quality inspection
- → Output data file to DIFFSYS® → Auto-correct to desired tool path → Re-machine **3D** part to desired profile

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29

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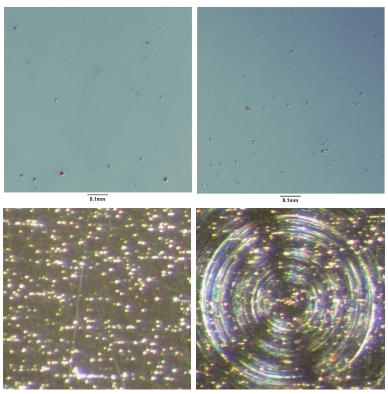
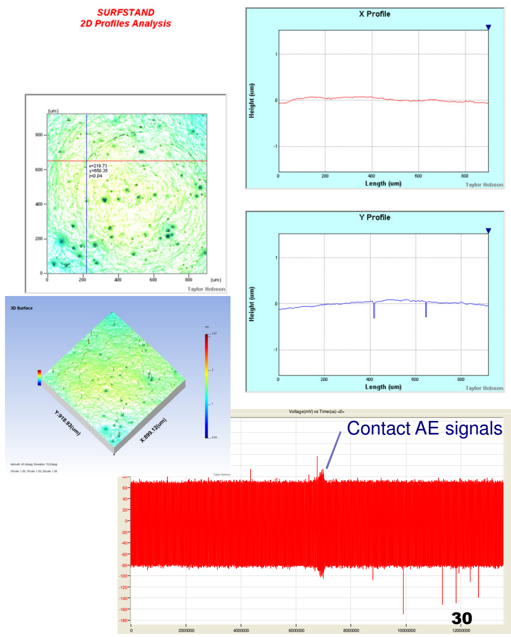
# AE detection of contact

Before contact After contact



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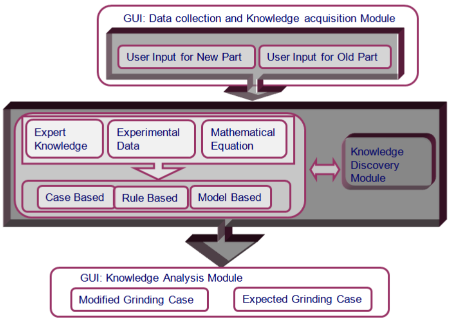
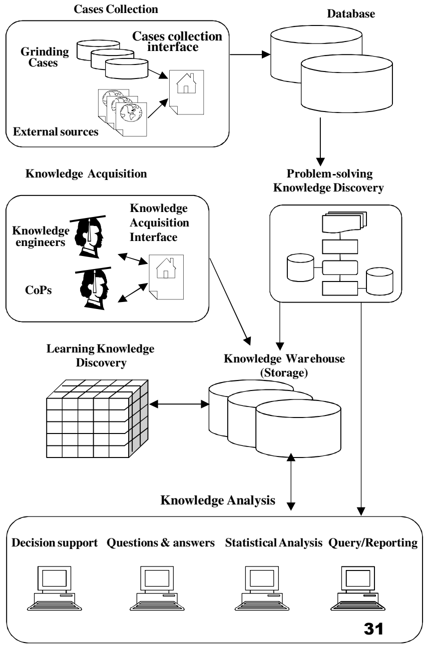
# Manufacturing Knowledge Warehouse Development

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

Framework of the warehouse
- date Input module
- database module
- problem solving module
- knowledge discovery module
- knowledge warehouse
- knowledge analysis module.

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# 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**

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