HIROSHIMA-QUEBEC AEROSPACE BUSINESS DEVELOPMENT INITIATIVE:
AREAS OF R&TD COMMON INTEREST

Helmi Attia, Program Manager,
Aerospace Manufacturing Technology Centre (AMTC)
Institute for Aerospace Research (IAR),
National Research Council Canada (NRC)

AMTC, Montreal, Quebec, June 22, 2010
• NRC IAR-AMTC Profiles
• Areas of Common Interest in Machining:
  ▪ Modeling and simulation of the machining process.
  ▪ Process optimization based on selection of machining strategy.
  ▪ High performance superabrasive grinding technology,
  ▪ Laser assisted machining of difficult-to-cut materials,
  ▪ Sustainable Manufacturing; Near Dry Machining or Minimum Quantity Lubrication (MQL),
  ▪ Dynamics modeling for machining thin structures.
IAR PROFILE

- The main centre for aerospace research in Canada
  - 350 employees (100 guest workers)
  - $30-35M budget ($20M income)
  - 2 Ottawa sites, 1 Montreal site

- Five Laboratories
  - Aerodynamics (AL)
  - Structures & Materials Performance (SMPL)
  - Flight Research (FRL)
  - Gas Turbine (GTL)
  - Manufacturing (AMTC)
Four Technology Thrusts:

- Material removal technologies.
- Forming and joining of metallic products.
- Automation, robotics and IMS.
- Forming and joining of composite products.
1. Machining/Drilling of Composites and MMC
   1. Process Development and Optimization; VAM, orbital drilling (S/A tools), and MQL technologies.
   2. Defect characterization and effect of defects (testing/modeling of mechanical performance).

2. Grinding/Polishing Processes
   1. HP/Superabrasive Grinding; processes development for 5X grinding.
   2. Process modeling and simulation (virtual grinding).

3. Machinability Enhancement, Sustainable Manufacturing and Tool Life Management
   1. Machinability of aerospace materials.
   2. Laser assisted machining.
   3. Minimum Quantity Lubrication (MQL).
4. Physics-based Modeling / Simulation of the Machining System
   1. Identification of materials constitutive laws in machining; metals/ *composites*, MMC.
   2. Dynamics of Tool-WP-Fixture System.

5. Process Optimization and Control
   2. Process monitoring for Closed Machining System.
   3. Compensation of thermal errors in machine tools/ workpiece and CMM structures.
Develop a methodology for material characterization at high ($\tau, \varepsilon, \ddot{\varepsilon}, T$).

Laser preheated cutting tests

- Laser Head
- Cutting Tool
- Workpiece
- Slip Ring
- Dynamometer

3D stress-strain-temperature graph.
• Process simulation and optimization (residual stresses, distortion, burr formation, microstructure evolution, …).

<table>
<thead>
<tr>
<th>Model</th>
<th>$F_c$ (N/mm)</th>
<th>$t_c$ (mm)</th>
<th>$l_c$ (mm)</th>
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<tbody>
<tr>
<td>Proposed</td>
<td>10%</td>
<td>40%</td>
<td>20%</td>
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<tr>
<td>S-O-T-A</td>
<td>350%</td>
<td>200%</td>
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**Martensite**

**Martensite + Ferrite**

**Ferrite + Pearlite**
Machining Strategies

Evaluation of different strategies for pocket-milling of Beta-Titanium Ti-10V-2Fe-3Al. The assessment was made based on the following criteria:

- Cutting forces.
- Power consumption.
- Tool wear.
- Form accuracy.
- Dimensional accuracy.
- Surface finish.
- Machining Time.
Strategies and Cutting Conditions:
Three combinations of cutting operations including helical milling, drilling, plunging, slotting, end and side milling.

Cutting Tools:
Solid and indexable-insert endmills, drills, and plungers.
Tool diameters between 16 and 32 mm.

Cutting Speed:
Up to 120 m/min (394 sfm).

Feed/Tooth:
Up to 0.2 mm (0.008”)

Radial Immersion:
Up to 32 mm (11/4”)

Depth of Cut:
Up to 39.8 mm (1.567”)

### Machining Strategies: Summary

<table>
<thead>
<tr>
<th>Pocket</th>
<th>Cutting Time</th>
<th>Pocket Quality</th>
<th>Tool Wear</th>
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<tr>
<td></td>
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<td>Appearance</td>
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**Rating:**
- **Best:** Green
- **2nd Best:** Blue
- **Third:** Red
Objective:

- Modeling of high speed deep grinding of steels, nodular C.I. AND Ni-alloys
- Process optimization to achieve maximum material removal rates.

Challenges:

- Usage of high wheel speeds (up to 75,000 rpm).
- Perform OD grinding on machining centers with multiple functionality and control systems.
- Workpiece materials, e.g., superalloys, and nodular cast iron which is very sensitive to thermal damage and cracking.
Prediction of Grinding Force Distribution in the Contact Zone

- For process Optimization: Prediction of temperature distribution, thermal damage, surface finish, part dimension, wheel life, surface integrity, cycle times etc.
- Analytical solution.
- Experimental; a novel technique.
- 3D-Numerical solution; multi grain case with random grain height and spatial distributions.

![Graph showing force distribution over contact arc location](image)
Laser Assisted Machining of Inconel 718

SEM image of failed ceramic tool at 300 m/min and 0.4 mm/rev under (a) conventional, (b) LAM.

Experimental setup of Laser Assisted Machining
**Near Dry Machining (NDM) / Minimum Quantity Lubrication (MQL)**

**Motivation**
Substitution of dry and wet cutting due to its impact on the economy (cost reduction by 20-35%) [CIRP, EU FP-5 Program] and the environment (50% reduction of power consumption and 60% reduction in waste disposal volumes).

**Description**
Effect of MQL on machining performance in turning, drilling and milling of Al 6061, 300M high strength steel, and CFRP composites, compared to dry and wet cutting.
Minimum Quantity Lubrication (MQL): (4,000 rpm, 0.15 mm/tooth, 5 mm depth of cut, 9 ml/hr)

Aluminium adhering to the workpiece

Surface damage

MQL Milling Applications Al 6061

IR camera
MQL nozzle
Force Transducer
Cutter

NRC-AEROSPACE MANUFACTURING
Sustainable Manufacturing: Near Dry Machining/MQL

M300 Steel (400 m/min)

Roughness $R_a$, $\mu$m

0
0.4
0.8
1.2

Nose Radius Wear, $\mu$m

0
100
200
300

Dry
Flood
MQL

Dry
Flood
MQL

Minimum Quantity Lubrication (MQL): (4,000 rpm, 0.15 mm/tooth, 5 mm depth of cut, 9 ml/hr)
Development of model for the dynamics of thin-walled structures:

- The continuous change of thickness.
- Effect of the constraints imposed by the fixture.
- Prediction errors < 10%.
- Computationally efficiency: One order of magnitude improvement.
- Numerically and experimentally validation.
Development of model for the dynamics of thin-walled structures:

- The continuous change of thickness.
- Effect of the constraints imposed by the fixture.
- Prediction errors < 10%.
- Computationally efficiency: One order of magnitude improvement.
- Numerically and experimentally validation.
Machining Dynamics of Thin Structures

Development of a data-base for the stability lobes of tool/tool holder systems and application to the optimization of the milling process of complex parts.
Other Areas of Common Interest

- Robotized welding processes
- Processes development for injection molding that offer equivalent mechanical properties of compression molded plastic composites (IMI).
- Material development for injection molding reinforced by glass fibre (IMI).
- Precision machining of large complex and large components; jet engine components, fan frames, duct fan fronts, compressors frames, etc.
- BTA deep hole drilling/ Gundrilling.
- Precision sheet metal processing.
- In-situ repair of machine tools spindles (inner surface taper correction).
Other Areas of Common Interest

- Hydroforming.
- Remote laser welding systems.
- Friction stir welding.
- Robotized systems (HS vision platform).
- Hard coatings (CVD, PVD).
- Manufacturing sensors technology, for measurement and control purposes.
Thank you! Questions?

See also: NRCaerospace.com