Georgia Tech
Precision Machining Research Center (PMRC)

http://pmrc.marc.gatech.edu/

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PMRC Core Team

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Morris M. Bryan Jr. Professor of Mechanical Engineering
Director, PMRC

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Research Engineer, PMRC, MARC,
Managing Director, HPM-CRC
PMRC Mission and Objectives

Industry
- Product Manufacturers
- Machine Tool Builders
- Cutting Tool Manufacturers
- Part Suppliers

Critical Needs
- Throughput Maximization
- Cost Reduction
- Better Part Quality
- Innovative Products

GT PMRC

Key Outputs from Research
- Enabling technologies and new scientific knowledge in the precision machining field
- Graduate students with world-class training in the science and technology of precision machining

Georgia Tech Manufacturing Institute
# State of the Art in Precision Machining

## Current State of the Art

Machining processes designed, improved and “optimized” using:
- Operator experience
- Handbooks
- Trial and error approaches
- Limited scientific experimentation
- Limited predictive modeling

**Limitations:**
- Methods are time consuming, costly, may not lead to optimum processes, and make it difficult to make changes once processes are established

## Envisioned State of the Art

Utilize critical scientific knowledge, accurate predictive models, and real-time process monitoring and control to design, improve, and optimize machining processes:

**Benefits:**
- Efficiently optimize processes for maximum productivity, quality, repeatability, and flexibility
- Eliminate or greatly reduce costly trial and error and experimental approaches
- “Shift manufacturing to the left”

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[Image: Georgia Tech Manufacturing Institute logo]
## PMRC Technology Differentiator

### Faculty
Leading experts in the field of precision machining with a combined total of 300+ publications

### Facilities
Wide range of machining, process monitoring, metrology, and characterization equipment available in the Precision Machining Research Laboratory

### Students
Some of the brightest young minds in the world

### Broad Expertise
- Process Characterization & Modeling
- Model-based Process Optimization
- Fixturing
- Hybrid Machining Processes
- Machine Tool/Process Monitoring & Control
- Environmentally Conscious Machining
- Mechanics of Materials in Machining

### GT PMRC
“One stop shop” with a 15+ year long track record of success for performing world-class, high impact precision machining research

### Research Staff
Dedicated Research Engineer to aid with sponsored projects
PMRC Modes of Interaction

Direct-sponsored Research projects from individual companies or government agencies

Membership in the High Performance Machining Collaborative Research Center (HPM – CRC)

Teaming with industry and national labs for government contracts

Industry internships for undergraduate and graduate students

Short-term on-campus internships for industry engineers
Partnership – PMRC Past & Current Sponsors

- Caterpillar
- Timken
- GM
- Kennametal
- Pratt & Whitney
- Third Wave Systems
- Ford
- Delphi
- ALCOA
- L3 Communications
- Carpenter Specialty Alloys
- Harding Machine Tools
- NSF
- Monitech Systems, Inc.
- Boeing
- Spaceworks
- IMTEC
- Third Wave Systems
- KGK
- IR Torrington
- Rolls-Royce
- Los Alamos National Laboratory
- GE Power Systems
- Honeywell
- PMC
- NIST
- United States Department of Commerce
- National Institute of Standards and Technology
PMRC Equipment and Facilities

- Hardinge 2-axis Hard Turning Center
- Okuma Millac-44V Vertical Machining Center
- Moore No. 3, PMAC-based Diamond Turning Machine
- Harig 2-axis Surface Grinder
- Bridge-Romi, 2-axis Turning Center
- CMS 2-axis Gang Tool Lathe
- Brother 2-axis Wire EDM
- Microscale 3-axis VMC
- Toyoda 2-axis Cylindrical Grinder
- Brown and Sharpe CMM
- Buehler Economet 6 Sample Polisher
- Zygo Optical Interferometer
- Taylor Hobson Talyround
- Taylor Hobson Talyround
Impact of PMRC Research

World-Class Training of Graduate Students
- 50+ M.S. students and 30+ Ph.D. students trained to date
- Graduates hired by leading US companies, government labs and universities

New Scientific Knowledge
Over 300+ journal publications and many more refereed publications to date

Technology Innovation
Machining simulation models, mechanical micromachining, laser-assisted micromachining, wireless monitoring of machining forces, constitutive material models, etc.

Benefits to Sponsors
Direct impact on 15+ industrial sponsors by performing research that led to improvements in their machining processes
Georgia Tech High Performance Machining Collaborative Research Center (HPM-CRC)

http://pmrc.marc.gatech.edu/HPM-CRC/

part of the

Precision Machining Research Center (PMRC)

http://pmrc.marc.gatech.edu/

and the

Georgia Tech Manufacturing Institute

Georgia Institute of Technology

Atlanta, GA 30332-0560
HPM-CRC Mission

Provide a high value-to-cost leverage mechanism for machining technology end users, machine equipment providers, cutting tool suppliers, technology developers and the Georgia Tech Precision Machining Research Center to work together in addressing existing issues and new challenges in machining processes.
HPM-CRC Objectives

- Maximize machining performance with better processes, fixtures, machine tools, and cutting tools
- Develop predictive models and critical knowledge necessary for machining technology users to design, select, and optimize process conditions, machines, and tools
- Develop new and innovative machining processes to foster revolutionary process performance enhancements
## HPM-CRC Focus Areas & Expertise

<table>
<thead>
<tr>
<th>Industry Needs</th>
<th>GT Areas of Expertise</th>
<th>Specific Topics</th>
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</thead>
<tbody>
<tr>
<td>Process Improvement</td>
<td>Process Characterization &amp; Modeling</td>
<td>Predictive Modeling based on Physical, Mechanistic &amp; Finite Element Analysis</td>
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<tr>
<td>Process Optimization</td>
<td>Model-based Process Optimization</td>
<td>Tool Wear &amp; Tool Life, Surface Finish &amp; Part Dimensional Accuracy</td>
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<tr>
<td>New Process Development</td>
<td>Hybrid Processes, Machine Tool/Process Monitoring &amp; Control</td>
<td>Laser-assisted Processes, Micromachining, Machining Dynamics, Wireless Sensing</td>
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<tr>
<td>Sustainable Machining Processes</td>
<td>Environmentally Conscious Machining</td>
<td>Minimum Quantity Lubrication, Air Quality in Machining, Nanoparticle-based Solid Lubrication</td>
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<tr>
<td>Part Quality &amp; Performance Enhancement</td>
<td>Surface Integrity</td>
<td>Residual Stresses, White Layer Formation, Impact on Fatigue Life</td>
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HPM-CRC Operational Overview

• Annual membership dues according to chosen membership level
• Research projects performed at GT with all members having access to results
• Industrial Advisory Board (IAB)
  – Eligible members have one seat on IAB which meets bi-annually to review and vote on active and proposed projects
• Projects will typically be 2 years in duration with annual progress reviews to ensure steady support for graduate students
# HPM-CRC Membership Levels

<table>
<thead>
<tr>
<th>Membership Level</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membership Open To:</td>
<td>Any Company</td>
<td>Small Manufacturing Companies (less than 500 employees)</td>
<td>Tooling, Software, &amp; Equipment Suppliers</td>
</tr>
<tr>
<td>Membership Dues</td>
<td>$65,000</td>
<td>$25,000</td>
<td>$15,000</td>
</tr>
<tr>
<td>IAB Seat &amp; Voting Rights</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Invention License Eligibility</td>
<td>Eligible</td>
<td>Not Eligible</td>
<td>Not Eligible</td>
</tr>
</tbody>
</table>
2 Technology End Users, 3 Suppliers, 2 Projects

A. Project Cost Leveraging

Baseline Single Company Project Cost**  $88,988

** Scenario I. Utilize Results from Both Projects
End-User Cost Per Project Per Company $32,500
  % Reduction in Cost per Project: 63%
Supplier Cost per Project Per Company $7,500
  % Reduction in Cost per Project: 92%

** Scenario II. Utilize Results from Only 1 Project
End-User Cost Per Project Per Company $65,000
  % Reduction in Cost per Project: 27%
Supplier Cost per Project Per Company $15,000
  % Reduction in Cost per Project: 83%

** Note: Baseline Single Company Project Cost assumes:
- 1 student + tuition
- 0.75 mo. Research Eng
- 0.5 mo. Faculty
- Fringe Benefits
- $3K M&S
- $3K Travel
- Overhead
Example: Development of 2 Projects

- Project Idea 1
- Project Idea 2
- Project Idea 3

GT Team Develops 2 Proposals

IAB Reviews Proposals

IAB requests final revisions (if necessary) to best meet all members' needs

Project 1
Project 2

Project Ideas from Center Members

Development & Selection

Performance
Example HPM-CRC Collaborative Project

Methodology for Rapid Development of Flow Stress Models for Machining Process Modeling

Machining Process Modeling

Johnson-Cook Constitutive Material Model

\[ \sigma = \left( A + B \varepsilon_p^n \right) \left( 1 + C \ln \left( \frac{\dot{\varepsilon}_p}{\dot{\varepsilon}_0} \right) \right) \left( 1 - \left( \frac{T - T_0}{T_m - T_0} \right)^m \right) \]

HPM-CRC Solution: Replace expensive, time-intensive split - Hopkinson bar experiments with a methodology that utilizes experimental machining tests and analytical models to determine flow stress constants.

Benefits: Each member benefits through use of the developed methodology on its proprietary materials of interest.
Inventions:

- GTRC retains title to patents, software or any other product resulting from the research funded by Center Membership dues. This is a requirement for GTRC in retaining its non-profit status.

- Each eligible member that pays pro rata patent costs obtains a non-exclusive, royalty-free, non-transferable, non-commercial license to make, have made, and use in its own facilities any patented or patent pending inventions supported by dues-funded research projects.

- Eligible members may negotiate a royalty bearing and/or fee based license agreement with GTRC in consultation with the Center Director if the member has an interest in commercialization of patented or patent pending inventions that result from dues-funded research.

- GTRC owns the copyright to software developed by the Center. Eligible members will be entitled to a non-exclusive, royalty-free, end-user license for internal use only.
Research Results:

- Research reports, presentations, etc. will be distributed in confidence to Members through a password-protected website enabling members to use the results for internal benefit and competitive advantage. All information will remain in confidence for a maximum of two years from initial disclosure or until such information is submitted for publication in a scientific journal or until a patent application is filed.

Publication:

- Members will have the opportunity to review manuscripts prior to submission for publication in scientific journals, conference proceedings, etc., to identify potential patentable developments or any proprietary information owned by the Members. Members will have a specified time period (typically forty-five days) from receipt of the proposed publication to request a delay of publication for filing patent applications or removing any proprietary information.
Summary of HPM-CRC Benefits

• Significant reductions in research investment
• Technology deliverables from multiple research projects
• Utilize GT PMRC as a cost-effective machining R&D wing
• Develop hiring pool of bright Georgia Tech students trained in machining and manufacturing
• Team with end-users, suppliers, and technology developers in a non-competitive environment to achieve common goals
• Utilize relationships and ideas to team and jointly pursue government funding (NSF, DOD, etc.)