Evolution of Titanium Machining Performance

- **Industrial Revolution**
- **1900**
- **1930**
- **1970**
- **1980**

- **T=400°F**
  - **Carbon Steel**

- **T=500°C**
  - **HSS**

- **T=800°C**
  - **Carbide**

- **T=<500°C**
  - **PCD**

- **Cryogenic Age**
  - **Tc=T-200°C**

- **Cryogenic LN2 Machining**

- **Carbide Grades, & Coatings**
What is 5ME® Cryogenic Machining?

- Cryogenic temperatures applied for sustainable and high performance machining resulting from shear heat dissipation and suppression of harmful thermal-chemical reactions for tool and work piece materials
- Application of LN2 at -321° F (-196° C or 77° K)
- Counteracts tool cutting edge heat produced in machining (shifts critical temp by -321° F)
- Super-cooled liquid is applied internally to the cutting edge of a tool
- LN2 is exposed to heat (inside the cutting edge) and is exhausted as safe, inert, breathable nitrogen gas

Most Sustainable Titanium cutting technology
Eliminates typical EH&S
Increase Performance of Titanium cutting
Significant Surface Integrity Improvement over conventional machining
5ME® Cryogenic Machining Technology & System Overview
5ME® Cryogenic Machine System
(Source, Feed, Sub-Cooler, Control, Lance, Tool)
5ME® Cryogenic Machine System
(View Side Machine)
Machine Tool Builders (MTB)  
Recent Aerospace Projects

- Okuma
  - MA-600HII – *Lockheed Martin Aeronautics*
  - MU-5000VL – *AeroEngine Tier 1 Supplier*
  - MU-8000V – *Aero Engine Process Development*
  - MU-8000VL – *IMTS 2016 (for sale)*
- MAZAK
  - VARIAXIS i-800T - *IMTS 2016 (for sale)*
- DMG MORI
  - NVX-5000 II – *Lockheed Martin Aeronautics Tier 1 Supplier*
  - DMU 105FD monoBLOCK – *AeroEngine OEM*
5ME® Cryogenic Cutting Tool Technology
BlueZone™
Prior nitrogen cooling applications were all external, like conventional coolants, aimed at the face of the insert and chip. 5ME plumbs liquid nitrogen through the insert to allow a heat-sink effect rather than chip zone cooling.
- Developed, tested, and proven Carbide grades and coatings that allow for optimal cutting performance when machining with Cryogenics

- **5ME® Cryogenic Cutting Tool Portfolio**
  - Indexable Face Milling
  - Indexable Hi-Feed Milling
  - Indexable Drilling
  - Indexable Boring
  - Solid Carbide Milling
  - Solid Carbide Drilling
  - Solid Carbide Thread Milling
  - Solid Carbide Reaming
  - CAT 40, CAT 50, CAT 60, HSK63A, HSK100A, HSK125A
5ME® Cryogenic Tooling  BlueZone™

- 5ME engineering designs all cryogenic cutting tool specifications
  - Internal plumbing and venting of liquid nitrogen
  - Cryogenic spindle interfaces
- Licensed cutting tool companies manufacture to 5ME tool specifications
  - Fifteen (15) Small to Medium Suppliers
  - Solid Carbide Cutting Tools
  - Indexable Cutting Tools & Inserts
  - Tool Holders
- In process of working with global tool companies to design, build and sell
  Cryogenic cutting tools under 5ME license
- Fullerton Tool Company & Star Cutter Company offer BlueZone™ Cryogenic
  Cutting Tool Technology licensed by 5ME®
5ME® Cryogenic Machining Benefits

- Environmental
- Surface Integrity
Benefits of 5ME® Cryogenic Machining

Environmental

- Environmentally-Friendly Green Manufacturing
  - Eliminate of Coolant oils, mist collection, filtration & disposal of coolant waste
  - Lower energy consumption without coolant fans and pumps
  - Chips and workpieces remain dry and uncontaminated for a safer work area and higher value recycling
  - There is no contamination of the work environment in the form of fumes and slippery surfaces
  - Nitrogen is an inert atmospheric gas which is 78% of the air we breath
  - Very easily safeguarded with an Oxygen sensor
  - Nitrogen is not a greenhouse gas
  - Eliminates management, infrastructure and additives associated with flood coolants (anti foam, bacteria control)
  - Eliminates cleaners needed to remove coolant residue from machine and parts
  - No stick factor with dry chips, possible reduction of part washers
  - R&M improvements from eliminating coolant infrastructure; washers, pumps, plumbing leaks, filtration and CNC coolant faults
  - Cost as low as $0.08/L
  - Sustainable Manufacturing
Non 5ME publish data:
- Reduction of White Layer / Alpha Layer
  - Hard turning of AISI 52100 steel using CBN dry and with Cryogen
  - 88% reduction in white layer

5ME Internal Tests:
- Reduction of White Layer / Alpha Layer
  - Drilling of 4340 steel at 40 HRC
  - Cryogenic drilling reduced white layer by 50%
  - Altered layer is 56% of wet
Benefits of 5ME® Cryogenic Machining

**Surface Integrity**

- **Reduction of Residual Stress**
  - Turning AISI 52100 using CBN dry and with Cryogen
  - More than 20% reduction in residual stress using Cryogenics

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![Graph showing the reduction of residual stress with cryogenic machining.](image_url)

*Reduction in residual stress with 5ME® Cryogenic Machining.*

*Source:* Umbrello et al., University of Kentucky and University of Calabria (Italy), 2012
Benefits of 5ME® Cryogenic Machining

Surface Integrity

- Reduction in Burr Formation
  - Significantly reduced burr formation for both Ti and Al alloys
  - b Titanium alloy, Ti-10V-2Fe-3Al

Institute of Machining Technology (ISF, Germany), 2010, 2011
Benefits of 5ME® Cryogenic Machining

Surface Integrity

- Reduction of Surface Distortion (Grain Boundary)
Aerospace Approvals of 5ME Cryogenic Technology

- Aero Structure and Aero Engine Manufacturing Approvals
  - Metallurgical Analysis (including White Layer)
  - Tensile Strength Analysis
  - Fatigue Analysis
  - Rough & Finish Machining

Lockheed Martin Aeronautics
Ti6Al4V B Annealed

Commercial Aircraft OEM
Cert. Not Required for Ti6Al4V

AeroEngine OEM
Ti6Al4V
(5) Additional Materials

Commercial Aircraft OEM
Ti6Al4V

AeroEngine Tier 1 Supplier
Ti6Al4V
5ME® Cryogenic Technology
Performance & Case Studies
Benefits of 5ME® Cryogenic Machining

Performance

- Increased Processing Speeds
  - Cut more parts in the same amount of time with the same machine, lowering the cost per piece
Aero Structure - Titanium 6Al4V
Applying Cryogenics results in the ability to machine at a 52% decrease in cut time with equal cutter consumption

- 21 Hours with Cryogenics vs 44 Hours with Coolant
- 5ME Solid Carbide Cryogenic End Mill
- Improved Surface Integrity and Part Quality
- Reduced White Layer
- Lower Energy Consumption
- Improved Worker Safety
- Eliminates Purchase, Disposal, Management, and Infrastructure Associated with Flood Coolants

Conventionally Cut
Aero Engine - Titanium 6Al4V
Applying 5ME Cryogenics results in the ability to machine at a 50% faster cut time in 6Al4V

5ME Solid Carbide Cryogenic End Mill
- 300 SFM Rough 2.5 hours life
- 360 SFM Finish 3+ hours life
- Improved Surface Integrity and Part Quality
- Reduced White Layer
- Lower Energy Consumption
- Improved Worker Safety
- Eliminates Purchase, Disposal, Management, and Infrastructure Associated with Flood Coolants
Aero Engine - Titanium 6Al4V
Applying Cryogenics with the 5ME® Aero grade insert results in the ability to machine at 200% increased cut speeds with minimal total wear observed after 60 min.

**2X Speed, >32X Tool life**

<table>
<thead>
<tr>
<th>Feed (IPR)</th>
<th>DOC (IN)</th>
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<tr>
<td>0.005</td>
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<tr>
<th>Wet GC1115</th>
<th>327 SFM, 889 ft, 2.7 min</th>
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<tbody>
<tr>
<td>5ME CARBIDE, CRYO</td>
<td>654 SFM, 1556 ft, 2.4 min</td>
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<tr>
<td>5ME AERO, CRYO (Ti 6Al4)</td>
<td>654 SFM, 39278 ft, 60 min</td>
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<tr>
<td>5ME AERO, CRYO (cust HT. 6AL4)</td>
<td>654 SFM, 28144 ft, 43 min</td>
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Benefits of 5ME® Cryogenic Machining

Summary:

- **Sustainability**
  - Carbon footprint reduction (less energy/part, less machines, no coolant motors, no fossil oils)
  - Eliminate environmental contamination

- **Performance**
  - Increased Metal Removal Rates (MRR) 30% to 500%+
  - Ti. Piece Part cost reduction (30%+) – up to $500M total savings projected on F-35 Program
  - Allows the efficient machining of emerging light weight materials, e.g. ceramic matrix composites
  - Technology enabler, e.g. development and application of non-traditional cutting tool materials

- **Part Quality**
  - White layer reduction up to 90%
  - Reduced grain boundary distortion, less surface damage, better finish, less burrs
  - Reduced force/heat stresses and part distortion
  - Product design implications with less material damage resulting in lighter, smaller components
Thank You
See us here at the conference
or visit us @
www.5ME.com