Understanding Process and Material Improvements through Ultrasonic Assisted Machining

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Overview

- At UIA 2010
- Drill Module
- Drilling Data
- Modeling Trust Force
- Future Developments
- Summary

At UIA 2010

What is Ultrasonic Machining?

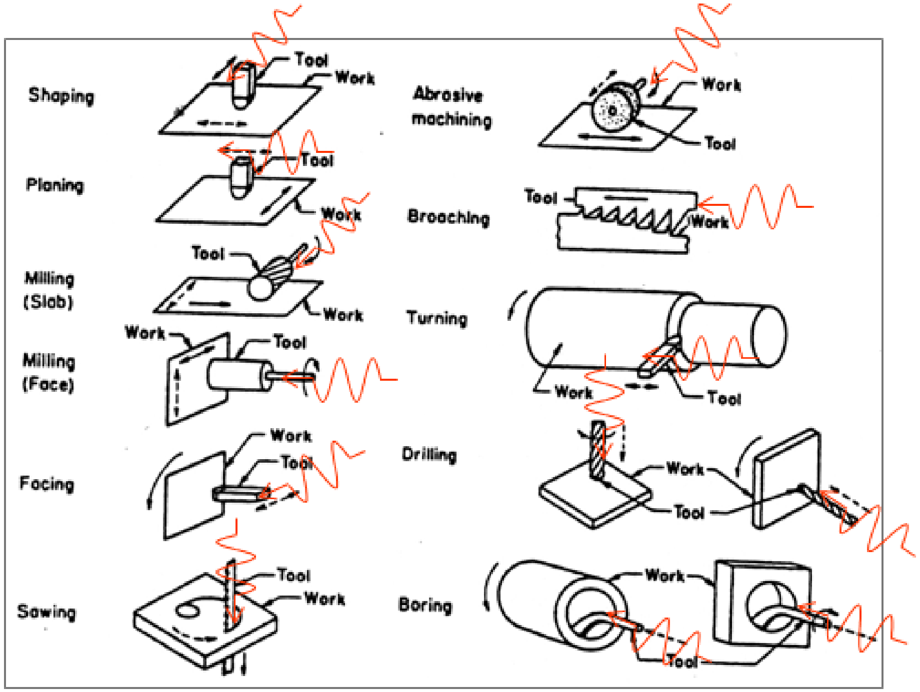
Ultrasonic Vibration

+

Conventional Machining
(Drilling, Reaming, Turning, Milling,..)

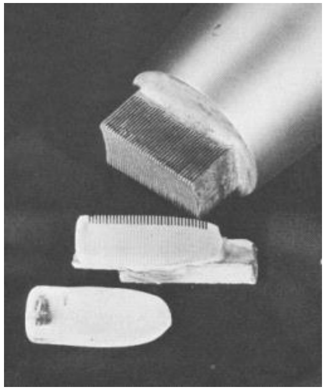
Improved Performance

- Higher productivity (faster feed)
- Better tool life
- Better surface finish
- Increased dimensional accuracy



Note: UM is not ……..

Ultrasonic-based Slurry Drilling Process



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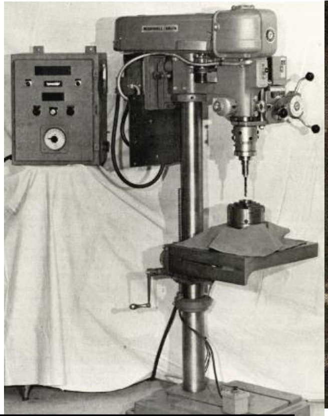
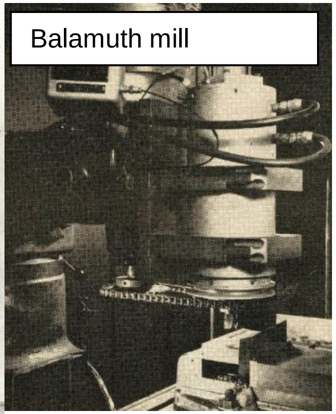
At UIA 2010

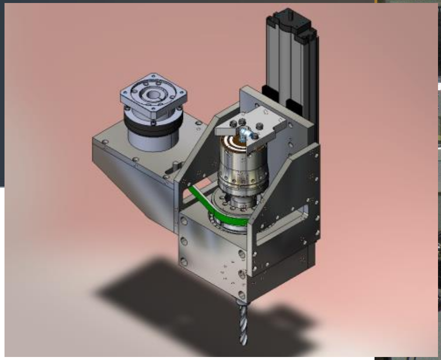


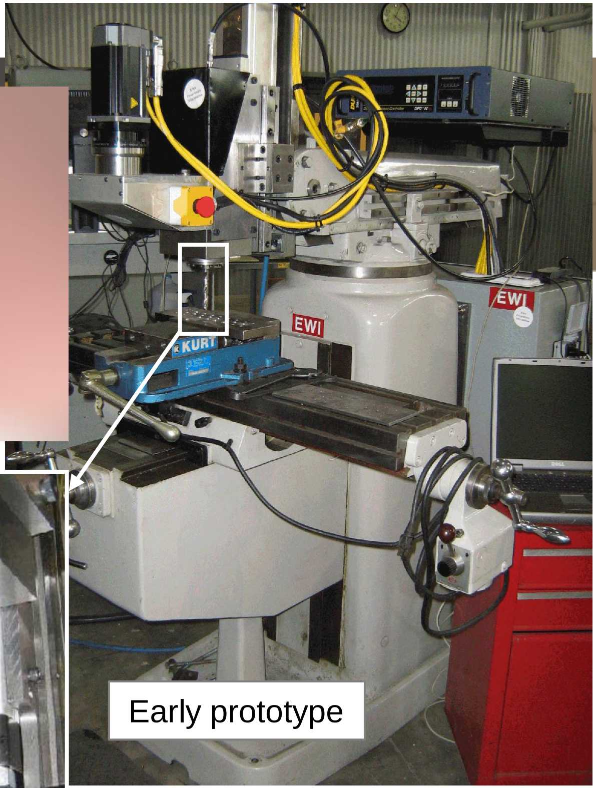
Sonobond Drilling



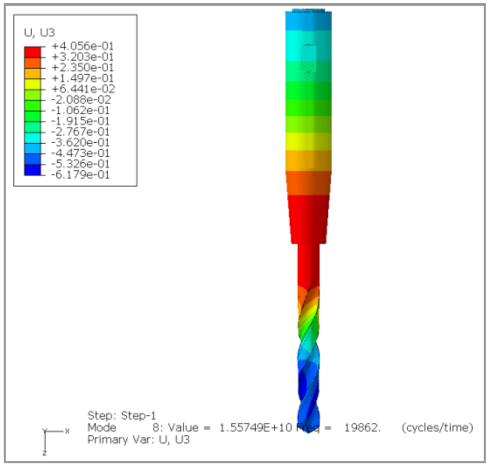
Balamuth mill

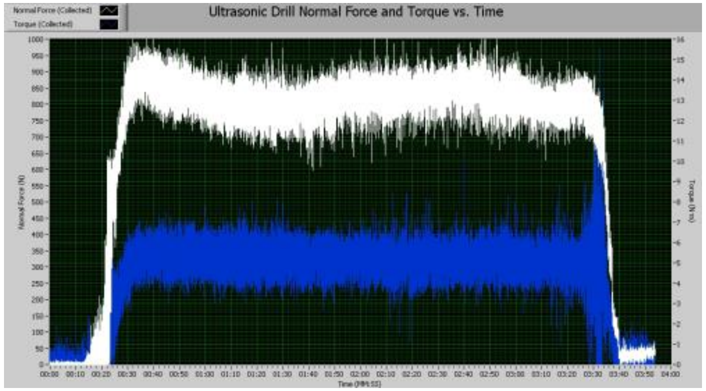
Previous work reviewed



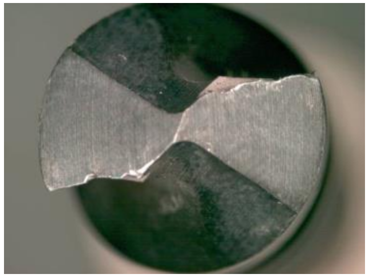


Early prototype





Titanium Trials with Ultrasonics



Tool wear studies

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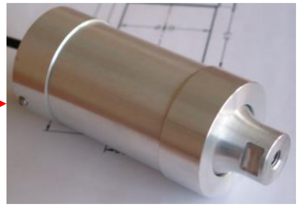
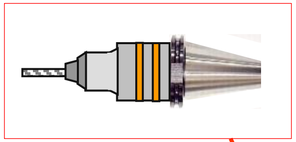
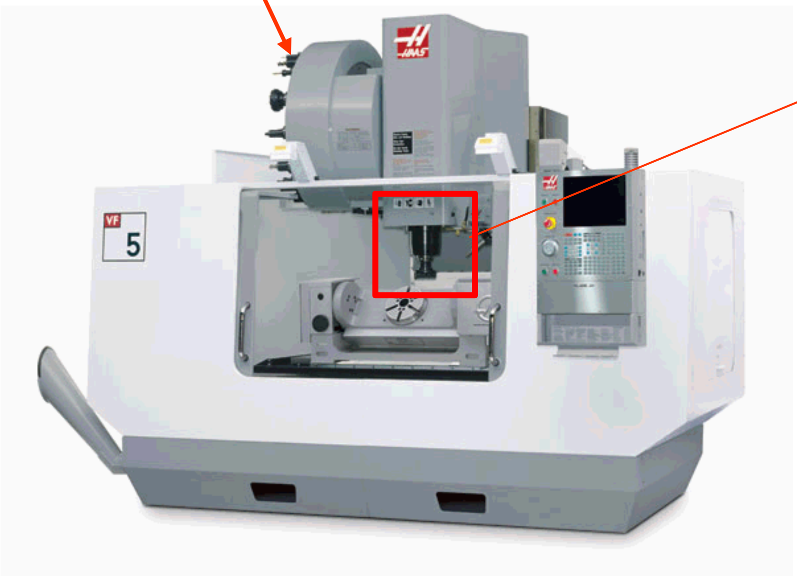
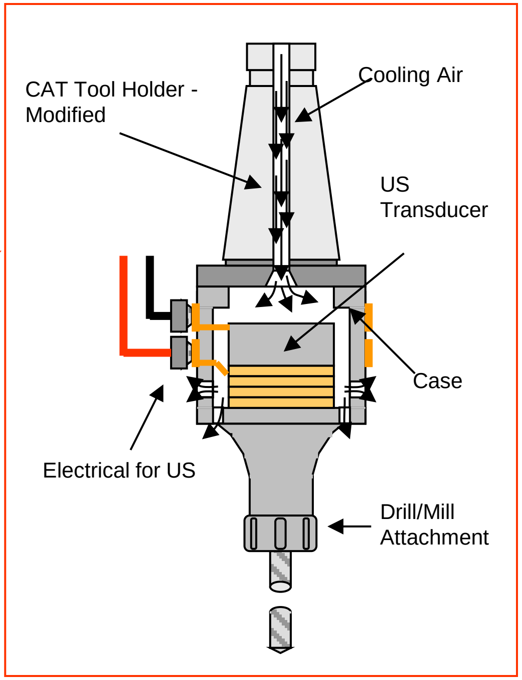
Vision for development ...

- Development of machining center compatible US tools* seen as critical to expanding US machining technology



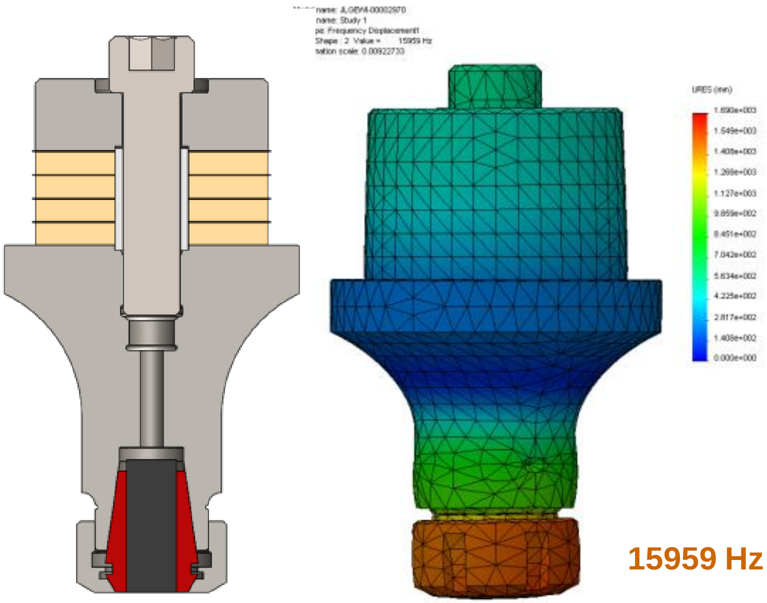




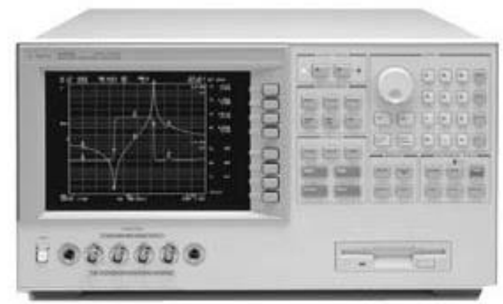


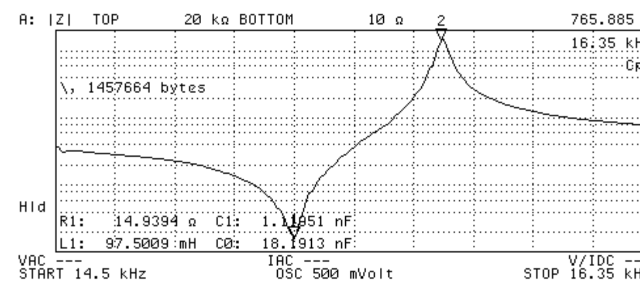
US Module Development

Compression Collet – FEA Results



15959 Hz





Marker	STIMULUS	VAL
0	16.35 kHz	765.885 Ω
1	15.239982 kHz	15.5876 Ω
2	15.693639 kHz	13.7122 kΩ

15,694 Hz

Note: Transducer/collet tuned low – brought to 20kHz with drill

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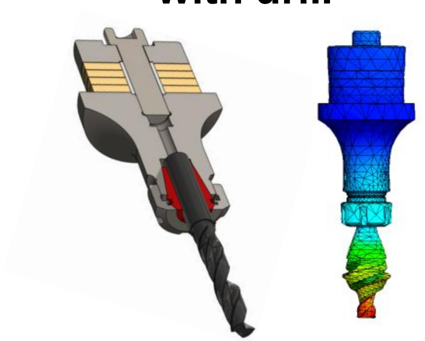
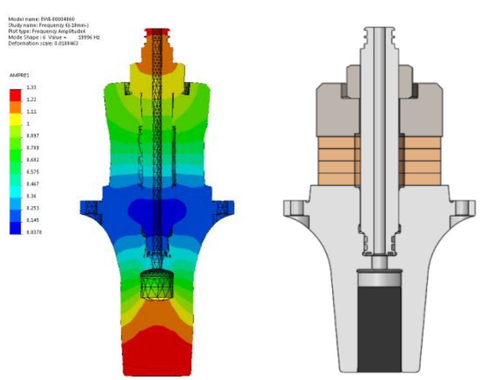
US Module Development

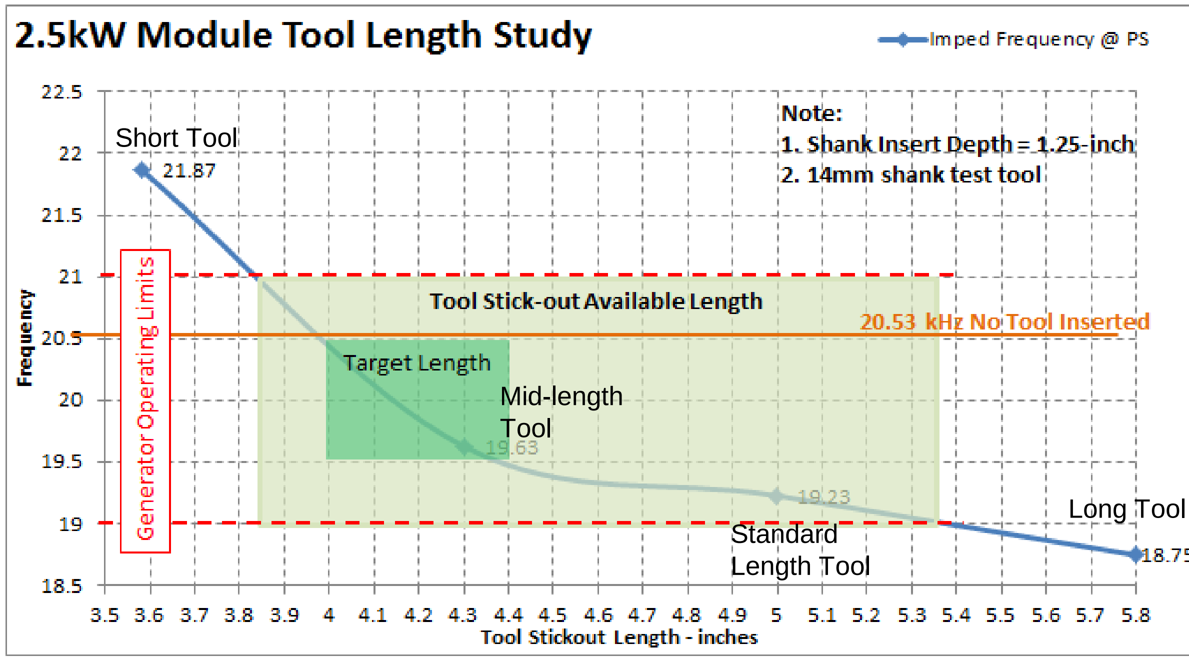
Compression Collet with drill



2nd Mode @ 20149 Hz
3.16” drill ‘stick-out’

Shrink fit collet with 18mm drill shank





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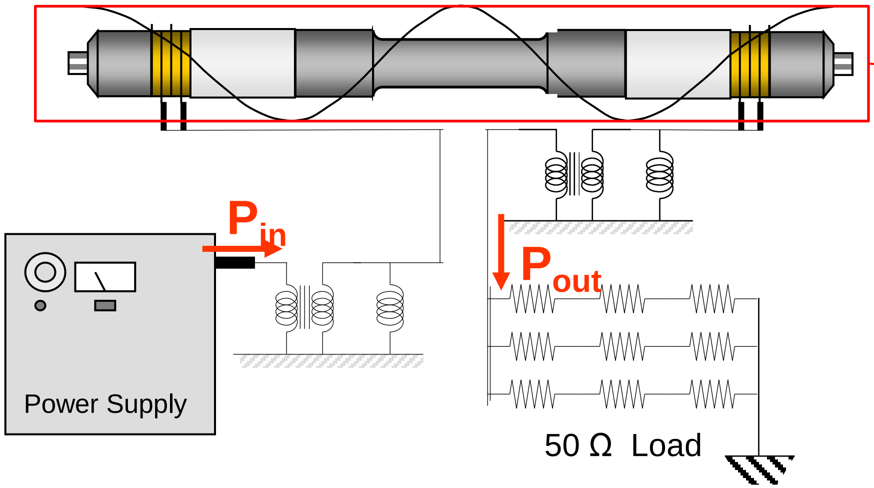
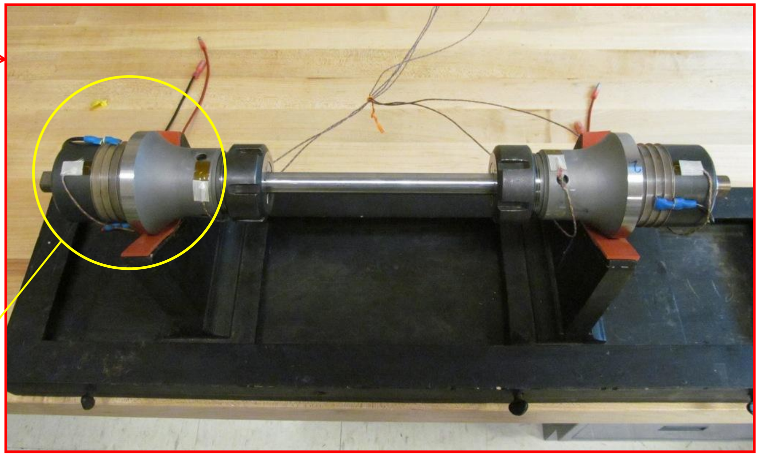
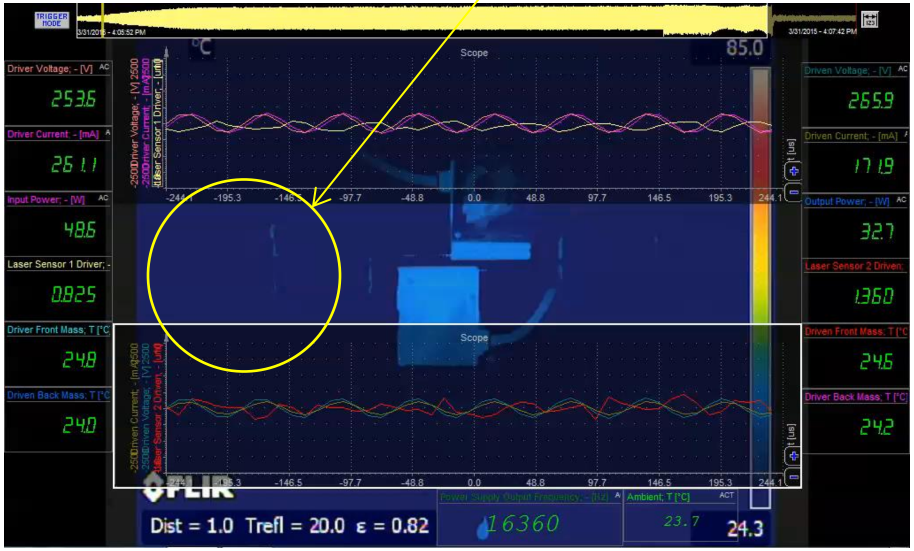
Transducer Power Testing







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Acoustech Modules

- **2.5kW and 5-kW Acoustech Modules**
  - 20-kHz, 2.5kW @ 35µm
  - 20-kHz, 4.5kW @ 28µm
  - 2.5kW @ 4lbs, 2.75”OD x 6” L
  - 4.5kW @ 7-lbs, 3.75” OD x 7” L
  - Both use CAT, HSK or BT tool holders.
  - Both can have Hydraulic, Compression or Shrink-fit collets ***and use conventional tools (drills, mill, taps, reamers)***

4.5kW module with shrink fit collet

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Second Generation US Module

- **Critical Requirements of Design**
  - Minimal addition to tool stick-out
  - Robustness for varying load conditions
  - Ease of installation
  - Through spindle coolant within transducer
  - Easily repaired
  - Maximum tool run-out of 0.0001-in
  - Leak proof
  - 20-kHz nominal frequency
- **Improvements**
  - IP-68 rated
  - Static resonance under 30-Watts
  - Run-out held to 0.00008-in
  - Under 3.5lbs

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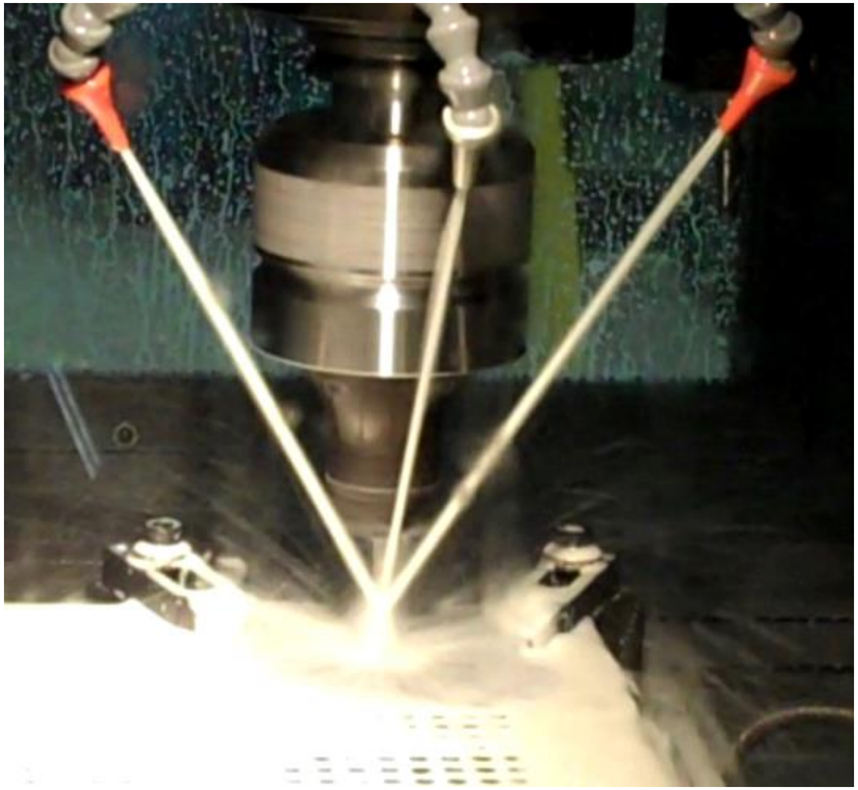
Acoustech Machining Module

- **System Demonstrations**



Drilling Data

Drilling tests on:

- Aluminum 6061→ Rep. of soft material
- Stainless Steel 316
- Alloy Steel 4340
- Titanium → Rep. of harder material

Results:

- Force
- Torque
- Tool life
- Surface roughness
- Dimensional error
- Microstructure of the hole

Three types of Collet:

Shrink Fit Module

Compression Collet Module

Hydraulic Module

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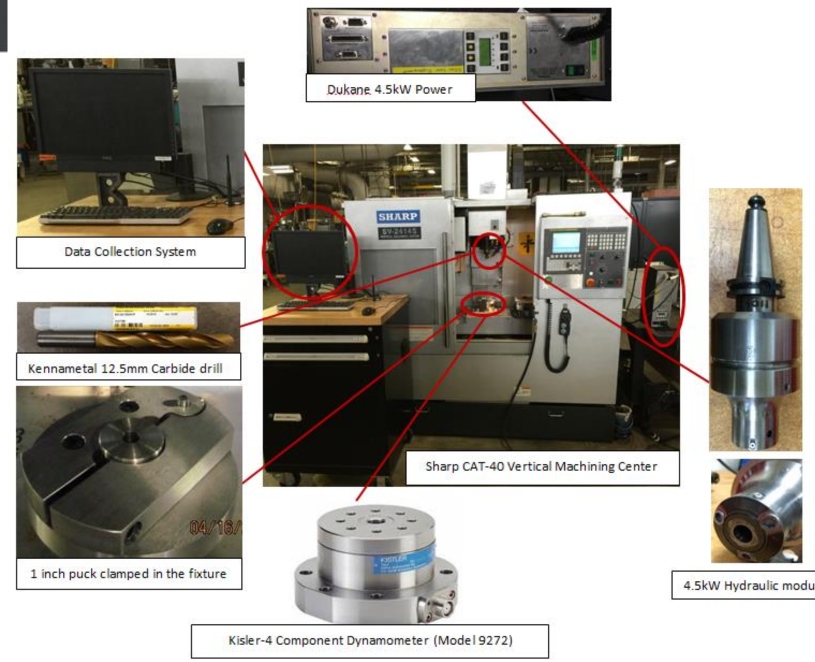
Aluminum Drilling

Drilling Data for Aluminum 6061

Trial	Amplitude	RPM	IPM	IPR	Force (N)	Torque (Nm)	Ra (µm)
1	0%	1392	29	0.0208	712.3	10.34	1.5007
2	100%	1392	29	0.0208	197.6	6.607	1.2701
3	100%	1392	69	0.0496	671.4	17.6	1.4088

100% Amplitude + Baseline test parameters → 72% Force Drop
100 % Amplitude + 3x Feed → Same force as baseline with US
The same or even better surface quality

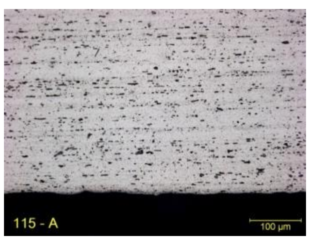


Measuring surface roughness

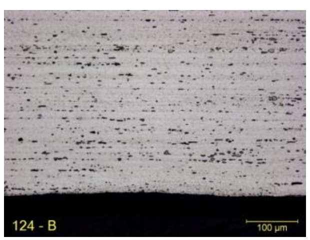

Measuring hole diameter

	Location 1		Location 2		
	x	Y	x	y	Total Average
Baseline	12.56284	12.56538	12.57808	12.55014	12.564
100% - 1392RPM 29 IPM	12.53998	12.60094	12.6111	12.55014	12.576
100% - 1392RPM 69 IPM	12.5857	12.5857	12.54252	12.6365	12.588

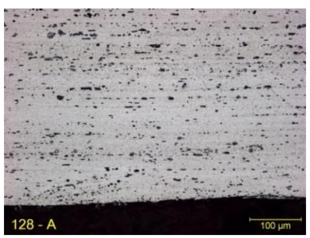
*All measurements shown in mm



Baseline testing
No U.S. - 1392RPM – 29IPM
712.3N , 10.34Nm , 1.5007Ra(µm)
200x Magnification



Baseline Parameters with U.S.
U.S. 100% - 1392RPM – 29IPM
197.6N , 6.607Nm , 1.2701Ra(µm)
200x Magnification



Advanced Parameters with U.S.
U.S. 100% - 1392RPM – 69IPM
671.4N , 17.6Nm , 1.4088Ra(µm)
200x Magnification

No Effect on dimensional accuracy

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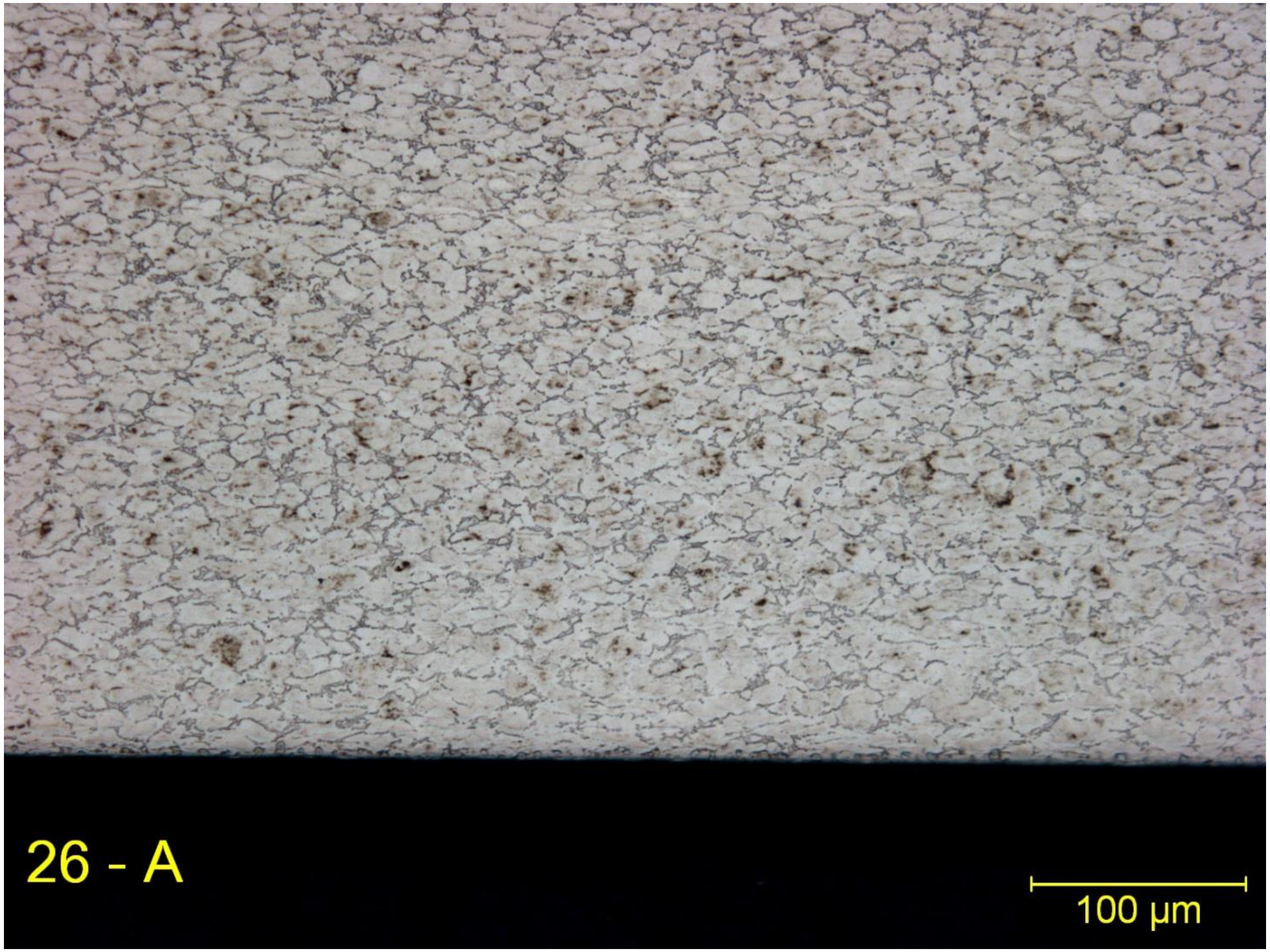
Summary of data

Summery of drilling data for Al 6061, Stainless steel, Alloy steel 4340 and Ti

Material	Trial	Amplitude	RPM	IPM	Force (N)	Torque (Nm)	Ra (µm)	Dia. Average (mm)	Note
Al 6061	1	0%	1392	29	712.3	10.34	1.5007	12.564	----
	2	100%	1392	29	197.6	6.607	1.2701	12.576	72% Force drop
	3	100%	1392	69	671.4	17.6	1.4088	12.588	3 x Baseline Feed
Stainless Steel	1	0%	910	7.28	1065	17.25	2.6488	16.059	----
	2	72%	910	7.28	708.9	17.04	2.4272	16.052	34% Force drop
	3	72%	910	14.56	934	25.85	2.3164	16.045	2 x Feed + 12% Force drop
Alloy steel 4340	1	0%	2161	15	848.9	9.708	0.44145	12.539	----
	2	100%	2161	15	417.8	7.165	0.16445	12.534	51% Force drop + 62% Ra improvement
	3	100%	2161	55	866.9	23.68	1.2897	12.534	3.7 x Baseline Feed
Titanium	1	0%	1500	10	803.2	13.15	1.0553	12.548	----
	2	70%	1500	10	482.5	13.68	2.0943	12.536	40% Force drop
	3	70%	1500	15	562.3	18.86	1.6676	12.539	1.5 x Feed + 30% Force drop

Material Improvements



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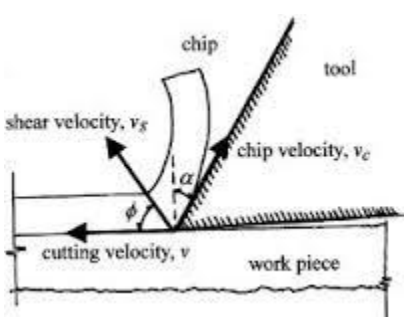
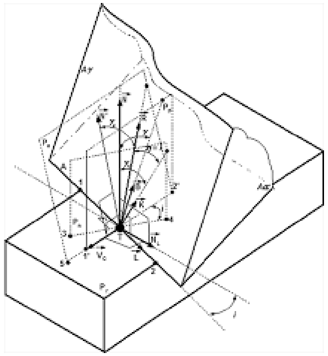
Mechanism of US Drilling

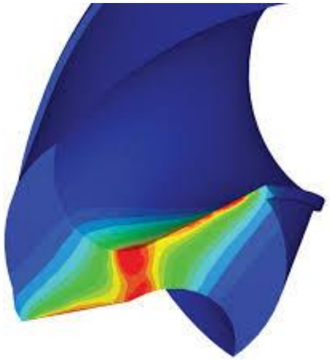
3 General Methods

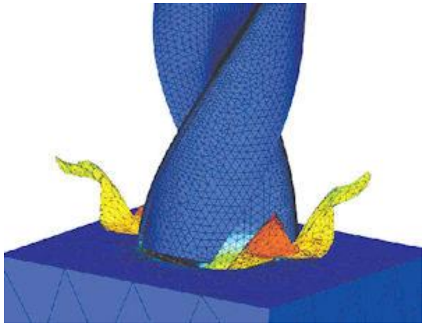
Thrust force and Torque in US Drilling

- **Empirical Models** — Time consuming and Expensive; Use Regression analysis to fit the equations
- **Mechanistic Models** — More precise model than the Empirical model; Require study of cutting process in depth
- **Finite Element Models** — Cheaper model and faster analysis; Use to optimize the drill bit geometry and cutting condition









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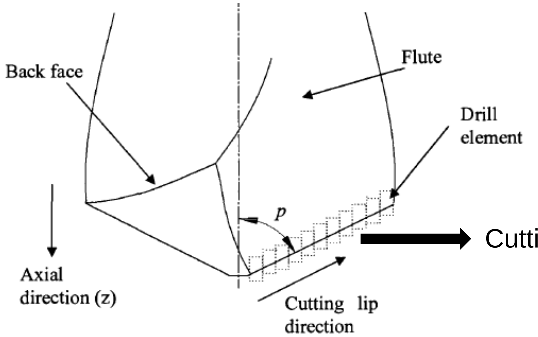
Mechanistic Models

Step 1: Evaluating the current mechanistic models

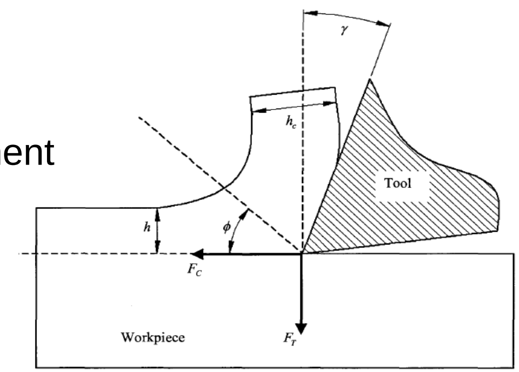
Geometry of the cutting edge

Total Force

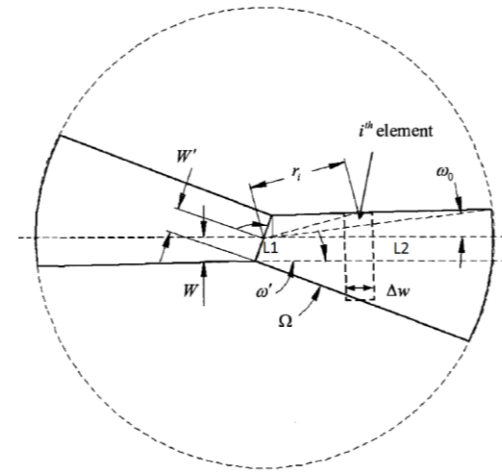
Summing the force components at each element



Cutting edge divided into a number of element



Chang Simon S. F., "*Thrust force model for vibration-assisted drilling of aluminum 6061-T6*" (2009) 1070–1076



$$F_c = F * \cos(\lambda - \gamma) = \frac{\tau_s * A_c * \cos(\lambda - \gamma)}{\sin\varphi \cos(\varphi + \lambda - \gamma)} = \frac{\tau_s * w * h * \cos(\lambda - \gamma)}{\sin\varphi \cos(\varphi + \lambda - \gamma)}$$

$$F_T = F * \sin(\lambda - \gamma) = \frac{\tau_s * A_c * \sin(\lambda - \gamma)}{\sin\varphi \cos(\varphi + \lambda - \gamma)} = \frac{\tau_s * w * h * \sin(\lambda - \gamma)}{\sin\varphi \cos(\varphi + \lambda - \gamma)}$$

$$\Delta P_l = F_{l,T} * \sin p * \cos\eta_d + F_{l,C} * \sin\eta_d + F_{pt}$$

$$\bar{F}_{Th} = \frac{1}{T}\int_0^T P_{Total}\,dt$$

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Next steps in modeling

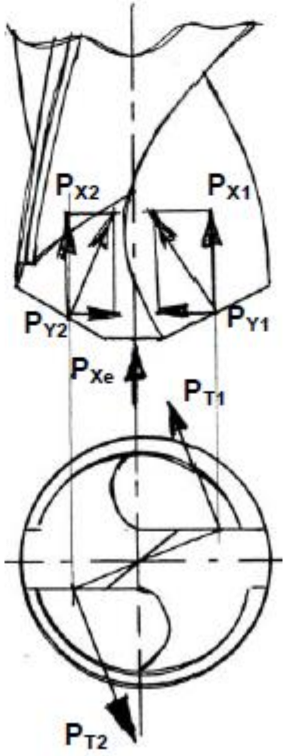
Step 2: Validating the current mechanistic model

1. Use math software (e.g. MATLAB) to calculate thrust force, drilling parameters for a specific material – Al

2. Conduct experiments to calibrate the model for above conditions

3. Use the calibrated model to predict thrust force for other cutting and US conditions

4. Conduct experiments to determine if predicted forces are accurate



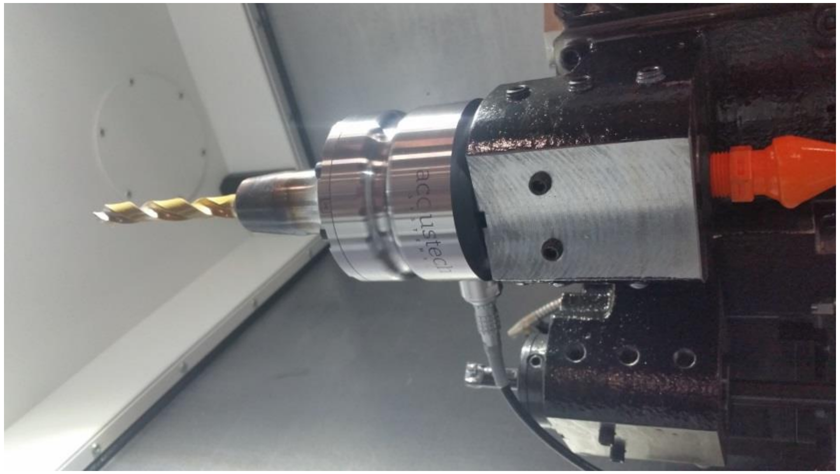
Step 3: Improving the mechanistic models

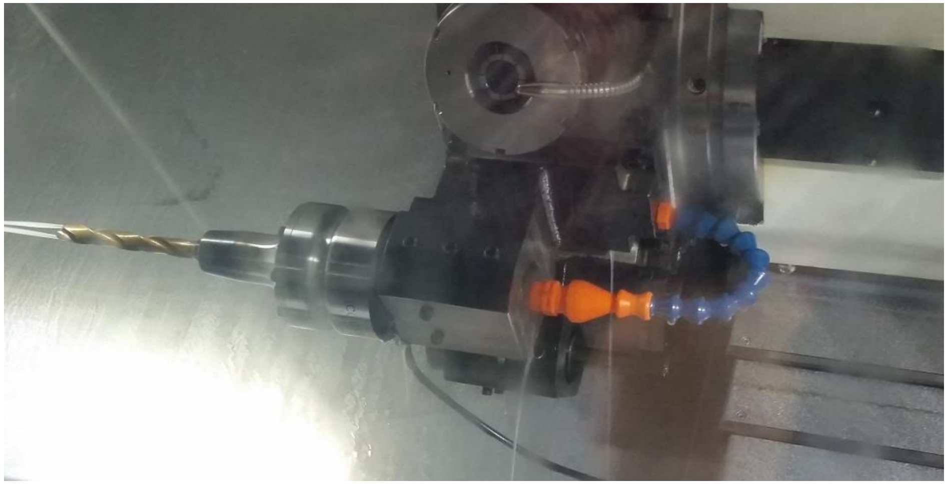
- If the model shows promise, work to increase accuracy

- If not, develop a new force model

Future Developments

Mazak CNC Turning Center

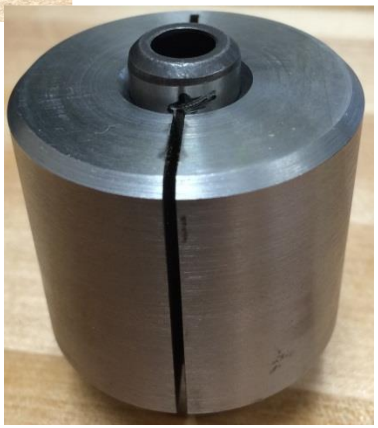




Ultrasonic Assisted Reaming

Application Details:

- 8-mm TSC Carbide Reamer
- Powder Metallurgy Valve Guide – HRc72
- Pressed to NNS – ream to size



Summary of Reaming Trials

Baseline Results	
Force (N)	169.0
Torque (Nm)	2.141
Surface Finish (Ra µm)	0.2648
Bore Size (mm)	8.014

At baseline settings provided by Federal Mogul (1406RPM – 22.5IPM), an axial feed force of 169N was achieved.

Ultrasonic Results	
Force (N)	108.0
Torque (Nm)	0.9525
Surface Finish (Ra µm)	0.6153
Bore Size (mm)	8.024

At the same baseline settings as above, this time adding ultrasonic energy, the feed force was dropped by **36%.**

Ultrasonics Applied at 150% of baseline feed rate	
Force (N)	123.9
Torque (Nm)	1.816
Surface Finish (Ra µm)	0.2839
Bore Size (mm)	8.031

Utilizing the benefits of the ultrasonic energy, the feed rate was increased by **150%,** from 22.5IPM to 34.5IPM, and the axial force was still **27%** less than the baseline force generated.

Ultrasonic Assisted Tapping

- **Application Details**
  - Applying ultrasonics to 4340-HRc48 hub
  - Extend tool life and increase quality of threads

Hub Design 2

ER-32 collet with Guhring solid carbide Tap.

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Tapping Trials Summary

- Objective is to reduce torque applied to tap generally causing breakage
- Difficult materials to tap (Stainless Steel, Inconel, Titanium, hardened alloys) rapidly wear cutting faces producing slop in thread clearance or undercut thread

Ultrasonic Amplitude	Power Supply	RPM	IPM	IPR	Axial Force (N)	Torque (Nm)
0%	L.D.	809	47.8119	0.059	172	6.234
20%	L.D.	809	47.8119	0.059	168	5.495
30%	L.D.	809	47.8119	0.059	162	5.975
			...			
100%	L.D.	809	47.8119	0.059	147	5.511
20%	Std.	809	47.8119	0.059	145	5.485
30%	Std.	809	47.8119	0.059	138	6.272
			...			
80%	Std.	809	47.8119	0.059	93	4.601
90%	Std.	809	47.8119	0.059	52	3.713
100%	Std.	809	47.8119	0.059	Overloaded	

Summary of Tapping Study performed on 4340 Alloy steel

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Summary

- **EWI has continued the development of UAD for new or existing machining centers**
- **Technology has advanced to a point where we can control heat**
- **Ultrasonic system successfully integrated with very stringent metalworking systems and practices**
- **Drilling mechanisms being studied**
  - Other processes to follow including turning operations

- **Acoustech Systems**
  - Spin-out company taking product to market
  - Provides sales, service, installation, training

acoustech™ SYSTEMS

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