Engineered Defect SNL Targets

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Fusion In Magnetically-Driven Z Pinches Is Reduced By The Magneto-Rayleigh Taylor (MRT) Instability

Since the 1950s, much z-pinch research has been rooted in understanding and mitigating MHD instabilities.

Imploding Be liner on Z

R.D. McBride et al., PRL 109, 135004 (2012)
Simulations Of Imploding Liners Match Experiment Only When An Artificial Azimuthal Seed Perturbation Is Added

What seeds the unexpected large amplitude and azimuthally symmetric MRT?
A 2013 Z-Campaign Evaluated Turning vs. Axial Broaching To Determine Effect Of Initial Surface Texture

Modified Fabrication Process: Changing the orientation of the machining grooves from azimuthal (lathe) to axial (broaching) had little impact on MRT development. CONCLUSION: INITIAL OUTER SURFACE TEXTURE IS NOT THE MRT SEED

 Experimentally observed MRT development resembles lathe grooves, so machined texture was initially suspected as the seed.

Could The Electrothermal Instability (ETI) Provide The Seed For the MRT Instability?

ETI Theory:
1. Near inclusions, current is amplified, causing hot spots.
2. Conductivity decreases with increasing T, so a feedback loop results, causing runaway hot spots.
Experiments At U of Nevada, Reno Zebra Facility Support The Theory That Surface Defects Cause Hot Spots

Experiment: I~0.7 MA
Experiment: I~0.75 MA
Al 6061:
Diamond Turned & Electropolished

The number of emission (hot) spots is comparable to the number of surface inclusions.

Experiments At Zebra Also Agree with Computer Simulations Predicting Azimuthal Merging Of Hot Spots

A hotter strip is developing between the inclusions.

Simulation Graphics Coutesy of Edmund P. Yu
Sandia National Laboratories (2019)
Targets For SNL Mykonos Facility Will Have “Engineered Defects” In Various Patterns To Probe ETI Evolution

- Targets will use pits because they exhibit qualitatively similar behavior to inclusions and are easier to machine.
- Pit size doesn’t significantly affect physics, so they will be larger than common inclusions for ease of machining and diagnosis.
Target With Engineered Defects

- Diameter: 0.800mm
- Thickness: 0.027mm
- Radius: 0.017mm
- Length: 28.575mm
All Machining Is Completed In One Setup

ϕ¼” x 1-1/8”, 99.999% Pure Aluminum Rod Mounted In Collet In Precitech FF-700 Lathe (4/5-Axis)

#1 - Turn Profile In Lathe Mode

#2 - Cut Defects in C-Axis (STS) Mode
Defect Machining Strategy #1:
Tool Rotates Around Defect Center

1. Little Relief Required At Start of Cut
2. Constant 0 Degree Rake Throughout Cut
Defect Machining Strategy #2: No Tool Rotation

1. Impossible to make diamond with required relief for start of cut.

2. Drive Tool Left & Up.
   - Good Rake and Relief At Middle Of Cut

3. Drive Tool Right & Up
   - Too Much Negative Rake At End Of Cut
These Strategies Form Two Limiting Cases

How To Choose Optimum Rotation Offset?

Strategy 1:
Tool Rotates Around Defect Center
(i.e., “Rotation Offset” = 0)

Strategy 2:
No Tool Rotation
(i.e., “Rotation Offset” = ∞)

Relief: Bad
Rake: Good

Relief: Good
Rake: Good

Relief: Good
Rake: Good

Relief: Bad
Rake: Good

IFT/P2019-039
Plugging Governing Equations Into Excel Reveals Satisfactory Defect Geometry and Rotation Offset

1. Little Relief Required At Start of Cut

2. Rotate Tool CW & Drive Left
   - Good Rake And Relief At Middle of Cut

3. Rotate Tool CW & Drive Right
   - Good Rake And Relief At End of Cut

If:
- $D/h = 4$
- Rotation Offset = $r$

Then:
- Minimum Tool Relief = 26.6 Degrees Throughout Cut
Single Crystal Diamond Tool For Cutting Divots

- 30 degrees diamond relief is greater than minimum requirement of 26.6, resulting in 3.4 degrees clearance.
- 30 degree relief angle is near the limit of what is possible to produce on a single crystal diamond.
Machine Kinematics To Virtually Rotate Tool

Machine Cannot Rotate Tool So “Virtual Rotation” Is Performed Using Simultaneous Motion of X, Y, and C Axes.
Despite Unusual Motion, NC Program For Machining Defects Is Very Short

; this program machines a hemi-shaped divot
; z-origin is front face
; tool faces operator
; tool must be calibrated at tip
; lathe must be in c-axis mode (m27)

; pick up tool offsets

; cutting parameters
p1=.005; radial peck depth
p2=.05; angular increment (degrees alpha)
p3=.0244; tool rotation axis offset (p-L)
p4=.1; retract distance

; part parameters
p11=3.; rod radius (R)
p12=.0244; divot spherical radius (r)
p13=4; divot dia/depth (B)
p14=0; divot clocking location (degrees)
p15=-.5; divot axial location

; calculate divot start coordinates
p20=90.000001; starting (alpha) to not divide by zero in p27 calculation
p21=p20; set (alpha) to starting (alpha)
p22=atan(p12*sin(p20)/(p3+p12*cos(p20))); starting (theta)
p23=p12*sin(180-p20)/sin(p22); starting (d)
p24=sqrt(p11*p11-p12*sin(p20)*p12*sin(p20))+p12*cos(p20); starting (L)
p25=(p3+p24)*cos(p22)-p23; starting (x)
p26=(p3+p24)*sin(p22); starting (y)

; calculate stock removal and set cut counter
p31=p12/p1
p31=fix(p31)
p31=p31+1; set rough cut counter
p90=p31*p1; set stock level

; set (alpha) counter
p41=180/p2

; watch: p1=cut depth
; watch: p31=cuts to go
; watch: p90=stock level

---
g1; feed
g14; feed mode all axes
g71; metric
g40; cancel comp
g59; cancel offset
m7.1; tool 1 coolant on
m7.2; tool 2 coolant on
g90; absolute mode

x25y0z25f2000; safe start point
z(p15)
while(p31>0); while # cuts remaining > 0...
p31=p31-1; decrement cut counter
p90=p90-p1; decrement stock level
x(p25+p90)y(p26)c(p14+p22)
gosub 1000
x25
y(p26)c(p14+p22)
p21=p20; reset to starting (alpha)
p41=180/p2; reset (alpha) counter
endwhile
x25y0z25; safe point
g13; feed mode x-y-z only
exit; end of main pgm

n1000
while(p41>0); decrement (alpha) counter
p41=p41-1; next (alpha)
p21=p21-2; next (alpha)
p52=atan(p12*sin(p21)/(p3+p12*cos(p21))); next (theta)
p53=p12*sin(180-p21)/sin(p52); next (d)
p54=sqrt(p11*p11-p12*sin(p21)*p12*sin(p21))+p12*cos(p21); next (L)
p55=(p3+p54)*cos(p52)+p53; next (x)
p56=(p3+p54)*sin(p52); next (y)
x(p55+p90)y(p56)c(p14+p52); go to next point
endwhile
ret

IFT/P2019-039
Microscopic Images of Defect Pattern

IFT/P2019-039
1. Defect is ~28um dia. at surface and is ~7um deep which is about 4:1 as wanted.

2. Light is not received on divot sides due to angle too steep for objective NA.

3. Burr shown as semi-circles on left side of divots. Will be removed by subsequent turning operation in production run.
Confocal Scan of Defect
• Using Slow Tool Servo on a diamond lathe with X, Y, Z, and C Axis control, it is possible to create very precise arrays of tiny, semi-hemispherical pits.

• Machine motion and tool geometry are critical to the success of this approach and are interdependent.

• Depth of pits can only be controlled precisely if turning and pit machining are performed in the same setup.

• QUESTIONS???
Detail of Spherical Defects
Precitech Lathe Axis Layout
Derive Equation For \( h = f(B, r) \)

Define Basic Defect Parameters: \( B = \frac{D}{h}; \quad r = \text{Defect Radius} \)

\[
h = \frac{8r}{B^2 + 4}
\]
Derive Equation For Machine’s Rotation Axis

\[ C = f(\alpha) \]

NC algorithm will calculate machine X, Y, and C for fine increments of \( \alpha \).
All machine coordinates must be therefore be based on \( \alpha \).

\[ C = \arctan \frac{rsina}{P - L + rcosa} \]
Derive Equation For Machine Translation Axes

$X \& Y = f(C)$

$X = P\cos C - d; \quad Y = P\sin C; \quad d = r \frac{\sin \alpha}{\sin C}$
Derive Equation For Tool Relief Angle $= f(\alpha)$

$$t = \arcsin\left(\cos\left(\frac{A - \alpha}{2}\right)\right) - \alpha + \arctan\left(\frac{rsin\alpha}{P - L + rcos\alpha}\right); \quad \text{Relief} = 90 - t$$
Input Equations Into Excel To Allow Optimization Of Variables

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<th>divot radius (r)</th>
<th>divot dia/depth (D/h)</th>
<th>divot depth (h)</th>
<th>divot dia (D)</th>
<th>rod radius (R)</th>
<th>divot center (L)</th>
<th>tool rot axis offset (P-L)</th>
<th>tool rot angle (alpha)</th>
<th>C-axis angle (theta)</th>
<th>triangle leg (d)</th>
<th>x</th>
<th>y</th>
<th>divot half-angle (max alpha)</th>
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25x Interferometer Scan Showing Portion of Defect Pattern
Confocal Scan of Defect
Machining Time Per Target

1. Diamond turn (leaving areas next to defect area oversized): 2.75 hrs
2. Cut defect pattern (60 defects) using C-axis mode: 2.25 hrs

Total: 5 hrs each