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Fiber Tooling:
Mid Spatial Frequency Error Reduction, Polishing MRR's and Finish

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Patent No.: US 10,562,146 entitled "FIBER BASED FINISHING TOOLS"

Freeforms – why so important?

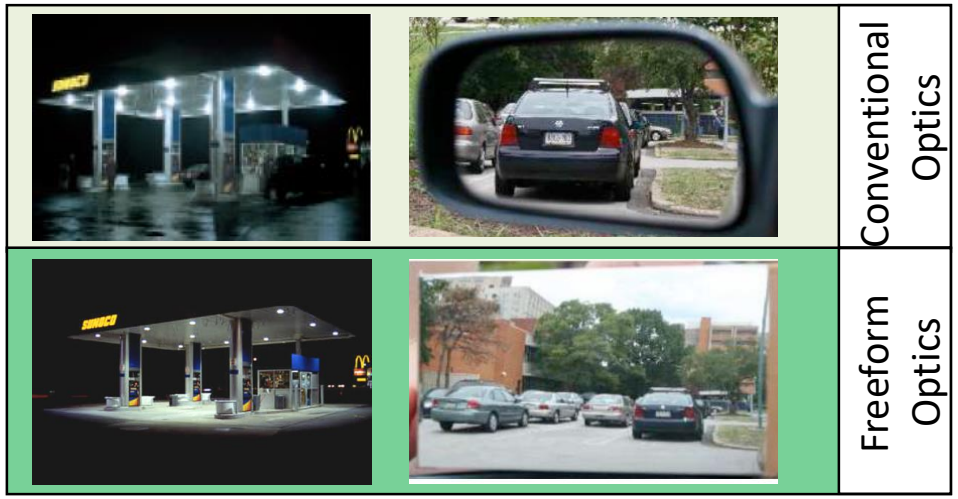
Freeform – radius of curvature varies over the workpiece surface

Sources: all images from Rösler.us

http://www.apple.com/iphone-6s/technology/

Freeforms enable:

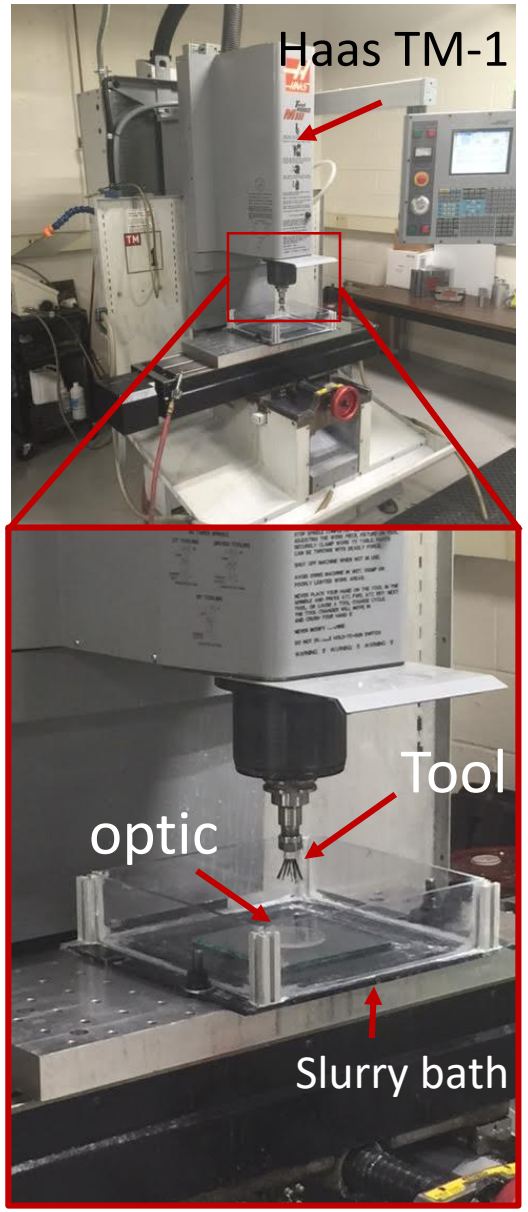
- Compact design
- Greater design space

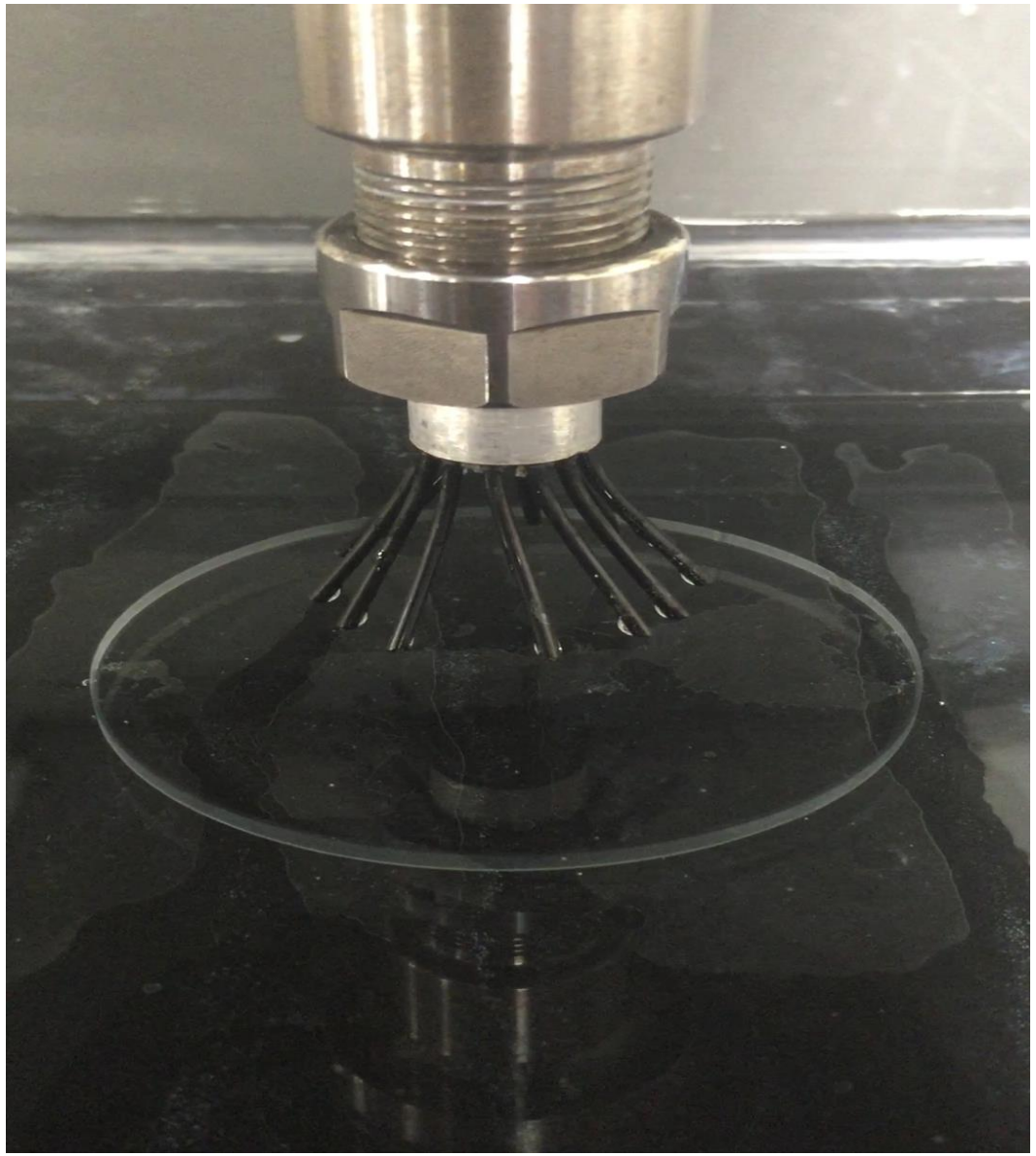


Boyce, Delta Snapshots, 2002

Hicks, Optics Letters, 2008

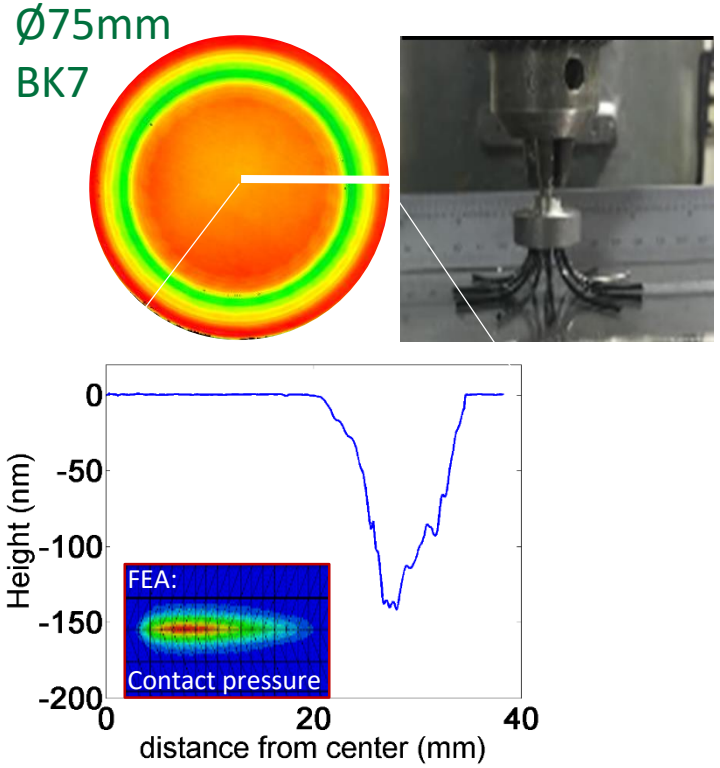
Fiberbased tooling – Material removal?





New process:

- Can you remove material?
- How does it remove material?
- Is the MR consistent?
- Can it get rid of MSF?



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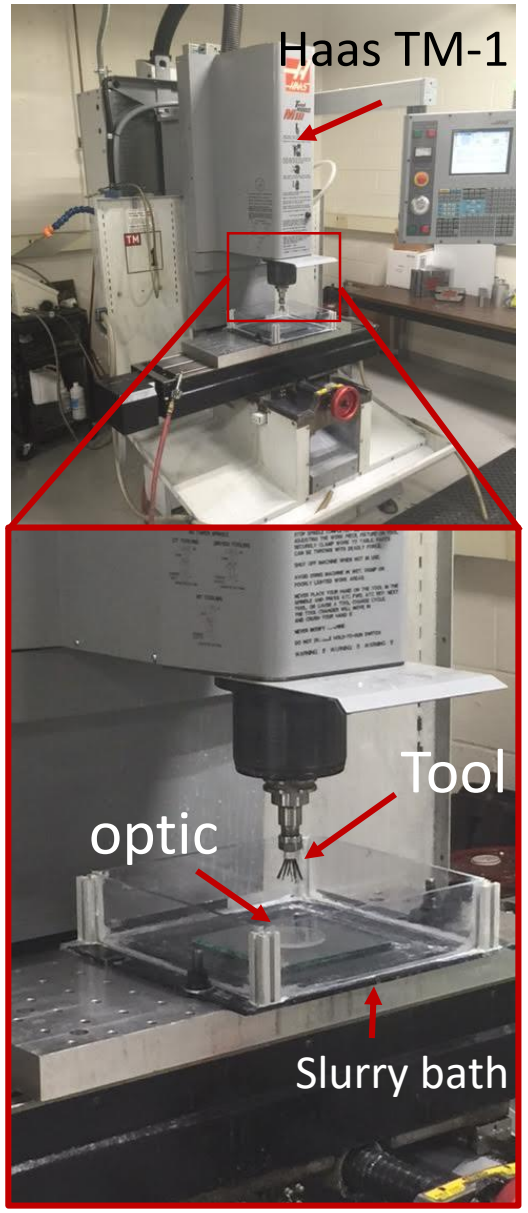
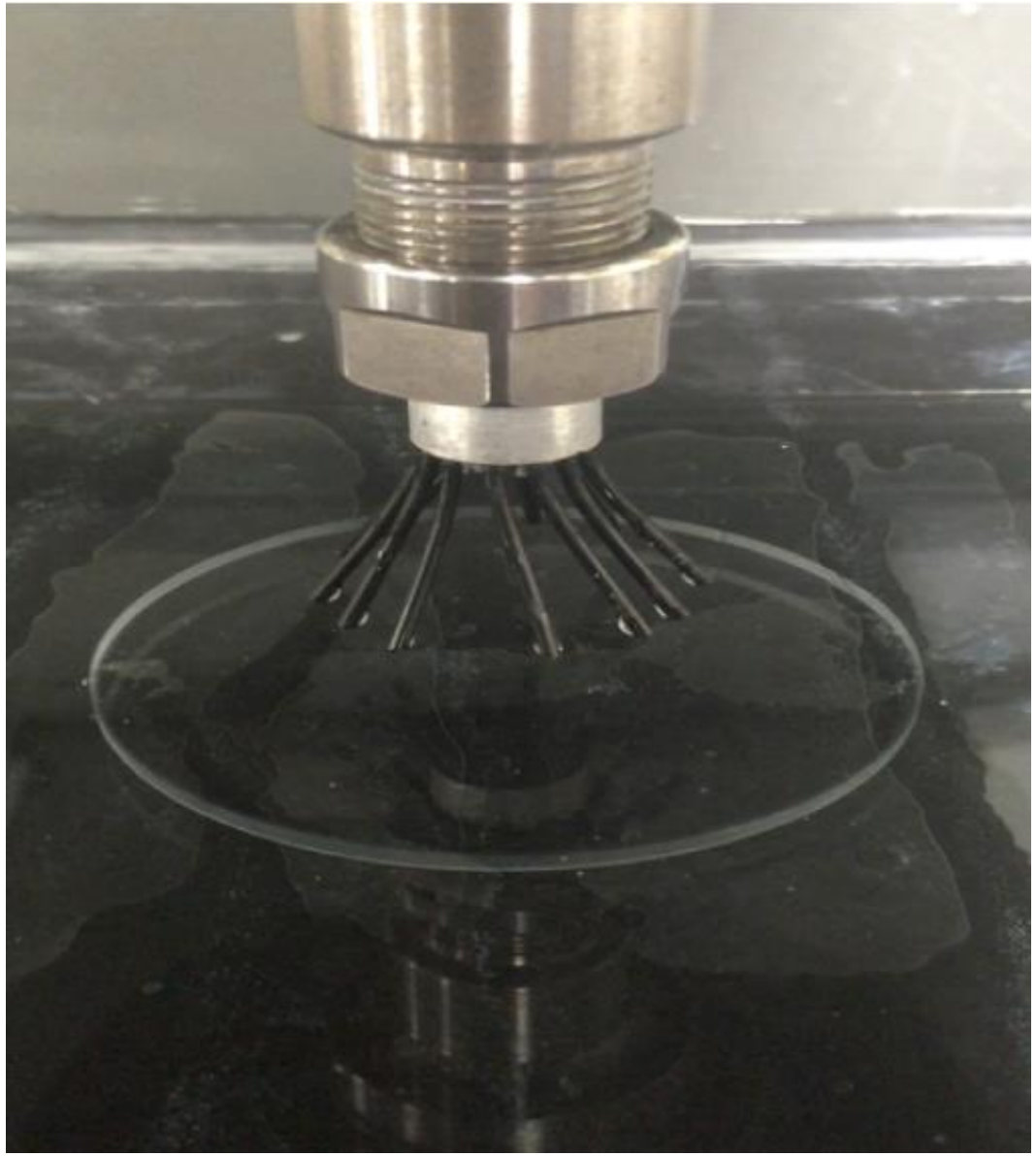
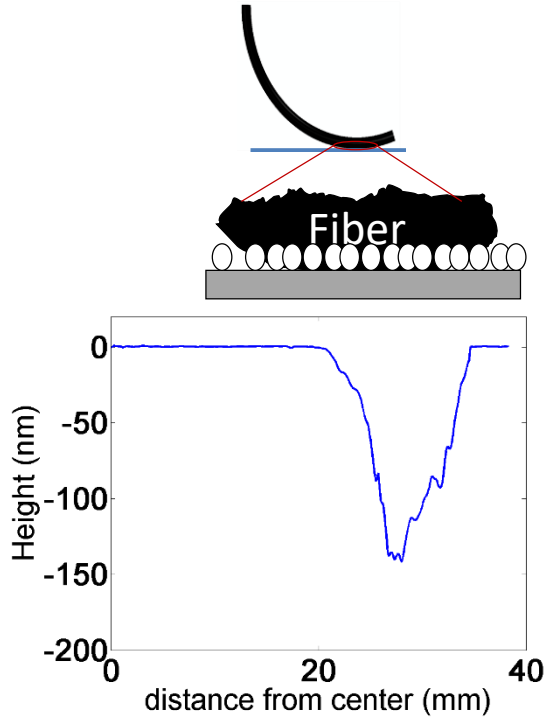




New process:

- Can you remove material?
- How does it remove material?
- Is the MR consistent?
- Does it damage the surface?
- Can it get rid of MSFs?



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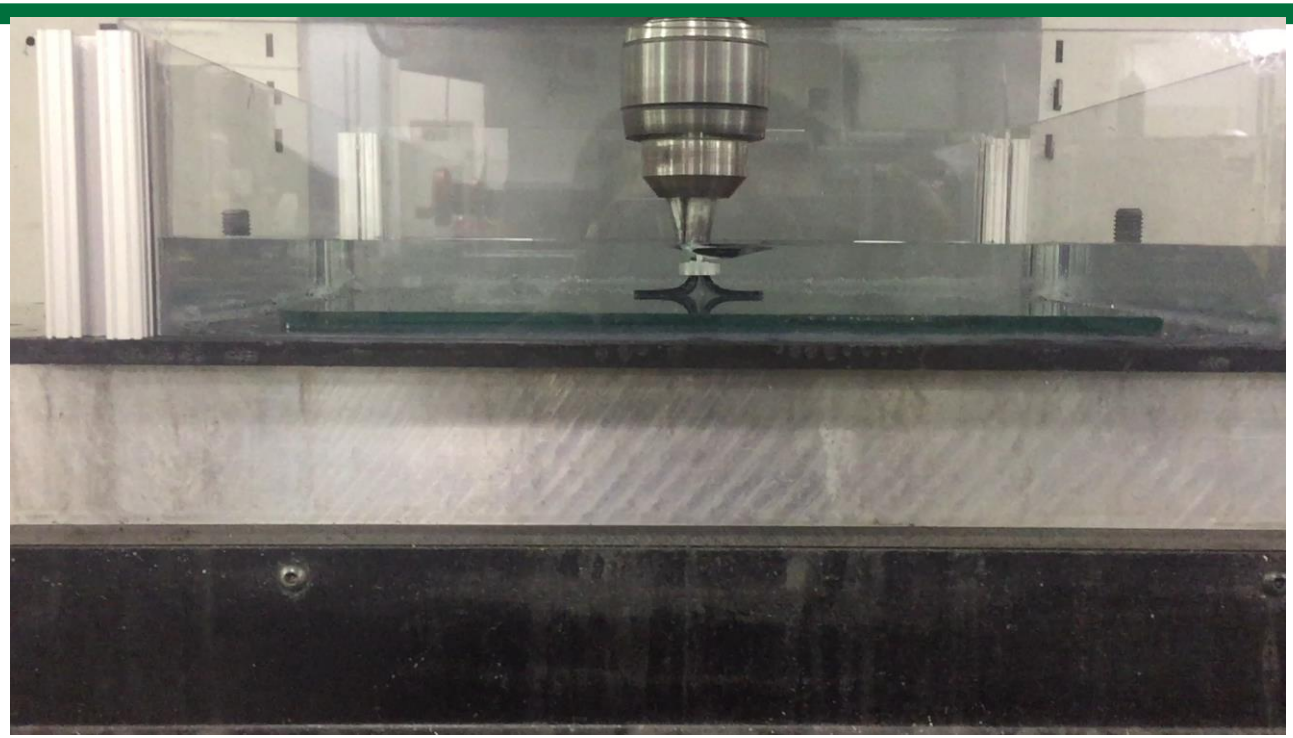
Fiberbased tooling – Stable processing?



Fibers tested:

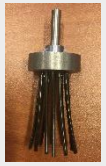
- **Materials:**
  polymer, carbon fiber
- **Cross section:**
  circular, triangular, rectangular
- **Critical Dimensions:**
  0.22 mm → 1.6 mm

Processing conditions:

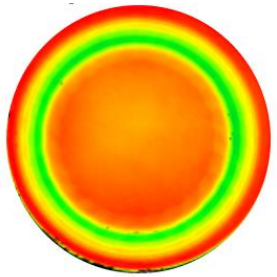
- **Spindle speeds:**
  100 rpm → 1000 rpm
- **Feed rates:**
  1 mm/s → 30 mm/s
- **Time:**
  up to 11 hours

Fiberbased tooling – Stable processing?

Test conditions



Tool: Nylon 66 (1.6mm)
Time: 30 min
Spindle Speed: 100rpm
Tool Feed-rate: 3 mm/s
Number of pass: 15
Slurry: Hastilite PO
Workpiece: Planar BK7



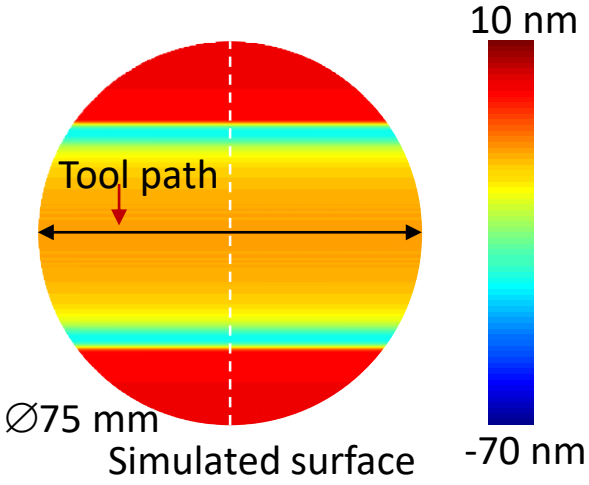
Tool TIF

+

$$\begin{bmatrix} 0 & 0 & \dots & 0 \\ T & T & \dots & T \\ 0 & 0 & \dots & 0 \end{bmatrix}$$

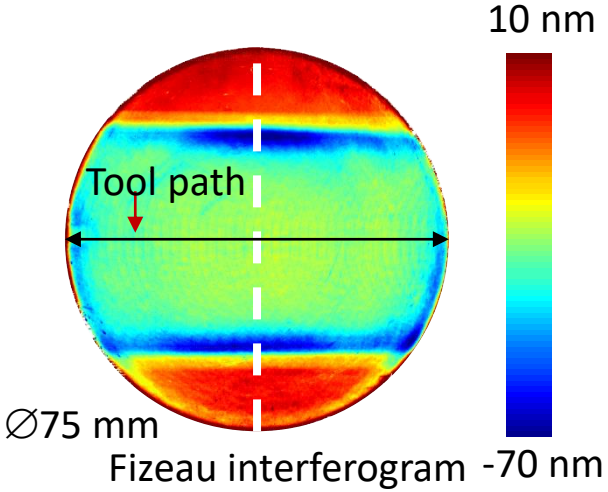
Dwell-time

Prediction by convolution



Profile across dashed line

Polishing outcome

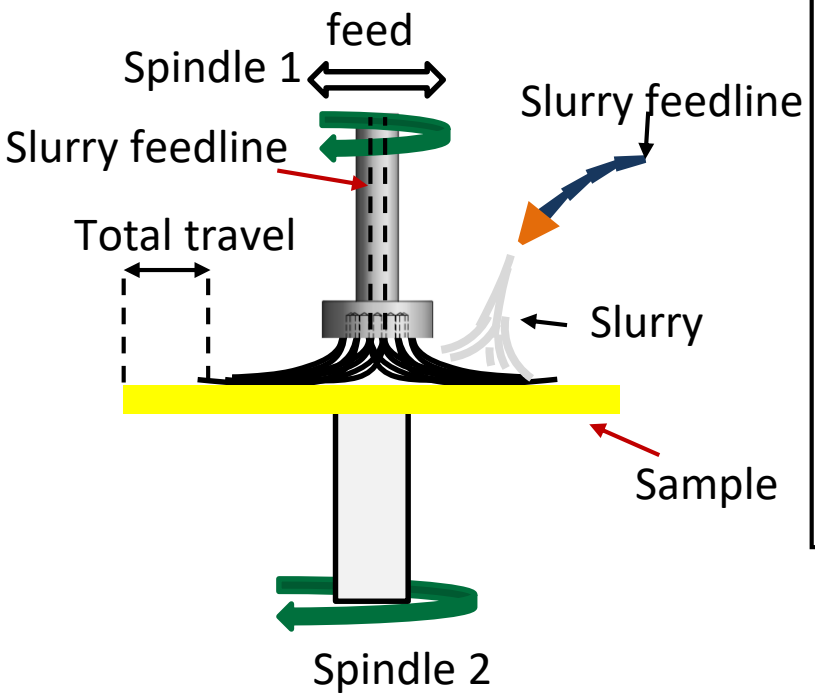


Profile across dashed line

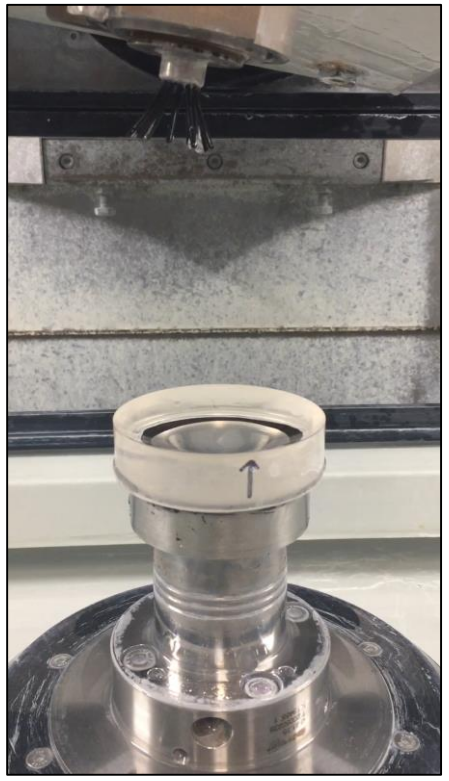
Fiberbased tooling – Stable processing?

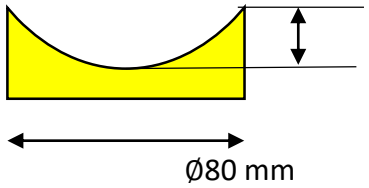
Commercial System

- OptiPro Triumph 5-axis machine
- Two spindles:
- Inline slurry feed

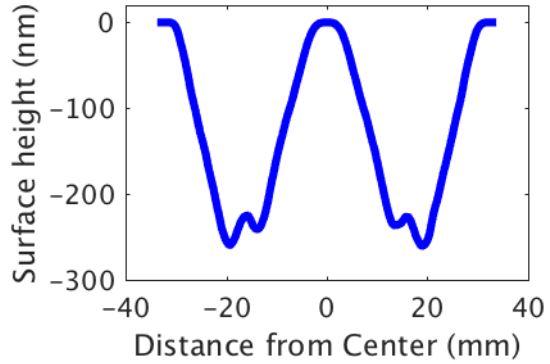


Concave Surface

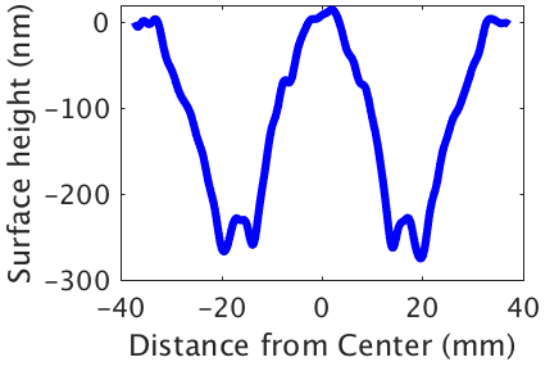




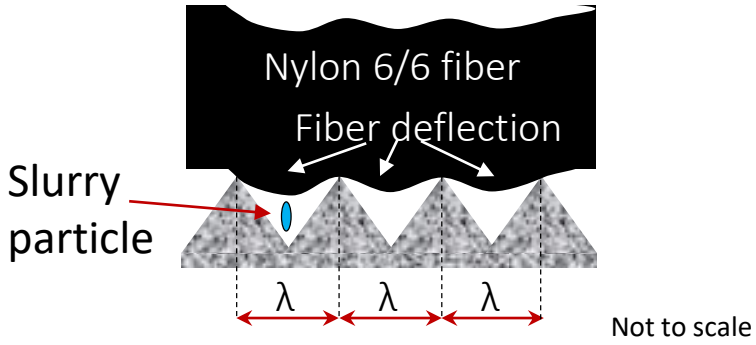
Predicted post polish form



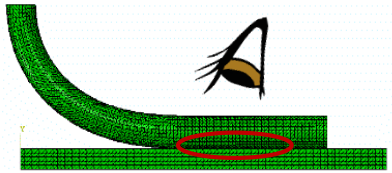
Measured post polish form



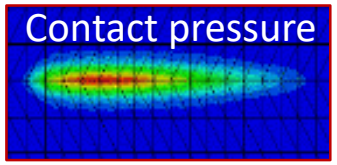
Fiberbased tooling – MSF reduction?



Step 1: Obtain fiber contact pressure distribution



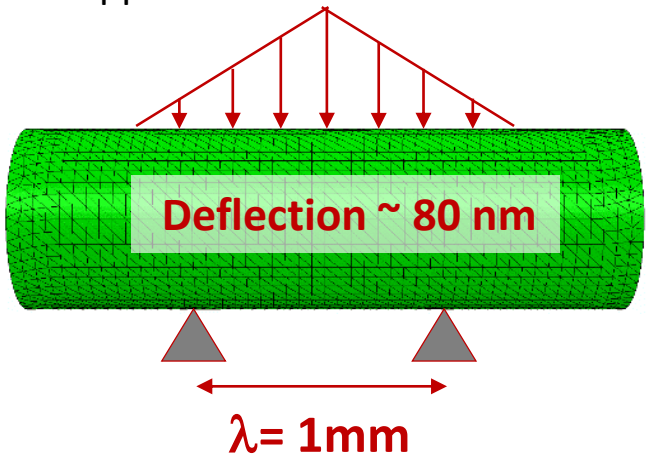
Model physical interaction



Obtain Pressure (CPRESS)

Step 2: Simulate fiber-MSF interaction

Approximated CPRESS



- Model MSF with a given wavelength, λ
- Apply the obtained pressure
- Note the maximum fiber deflection

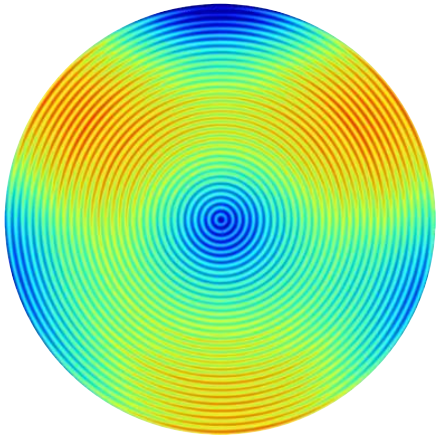
Factors influencing the extent fiber deflection:

- Cross sectional geometry

MSF reduction – Experimental results

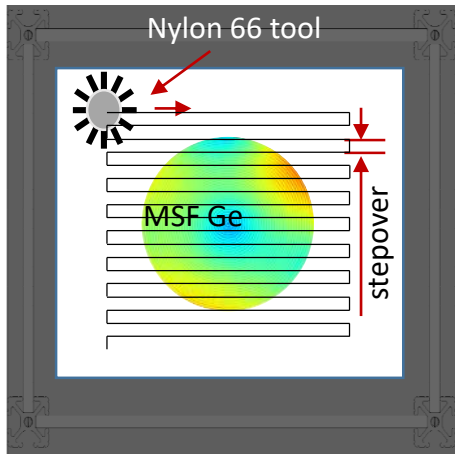
Workpiece

- **Material:** Germanium
- **Dimension:** Ø65 mm
- **Pre-made MSF features**
  - Wavelength (λ) ≈ 1 mm
  - PV ≈ 200 nm



Testing Conditions
Tool: Nylon 66 (1.6mm) **Stepover:** 0.5 mm **Slurry:** UltraSol 556 +H_2O_2 **Feeds and speeds** **Test 1 and Test 2** ○ 178 mm / min ○ 100 rpm **Test 3** ○ 89 mm/min ○ 340 rpm

MSF reduction – Experimental results



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