# Improving the Performance of Your 5-Axis Milling Machine

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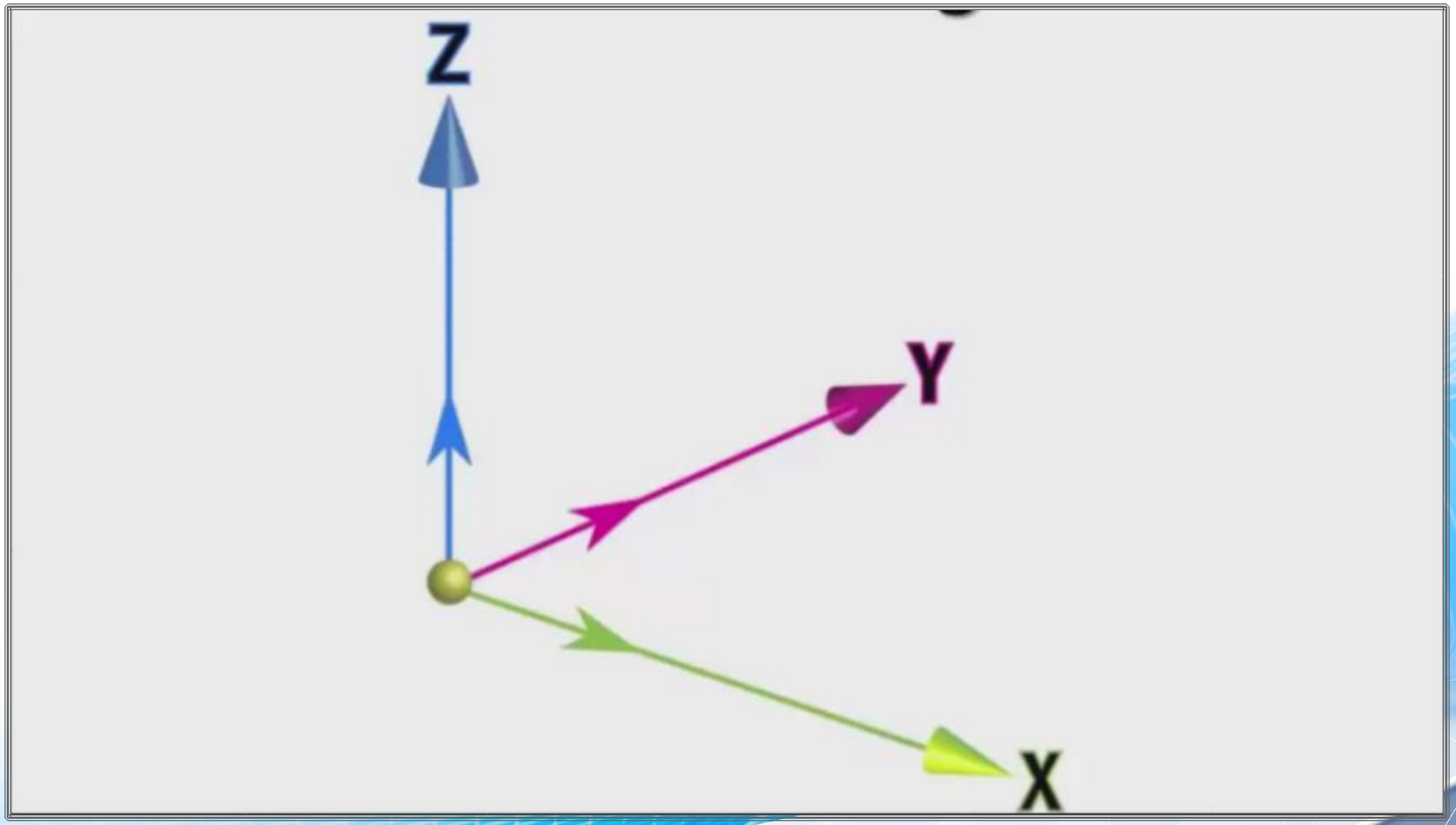
AUTODESK. UNIVERSITY

# 5 Axis Machining: Why?

- Fewer setups
- Shorter, more rigid tools
- Reduced cycle time

# “5 Axis” What does that mean?



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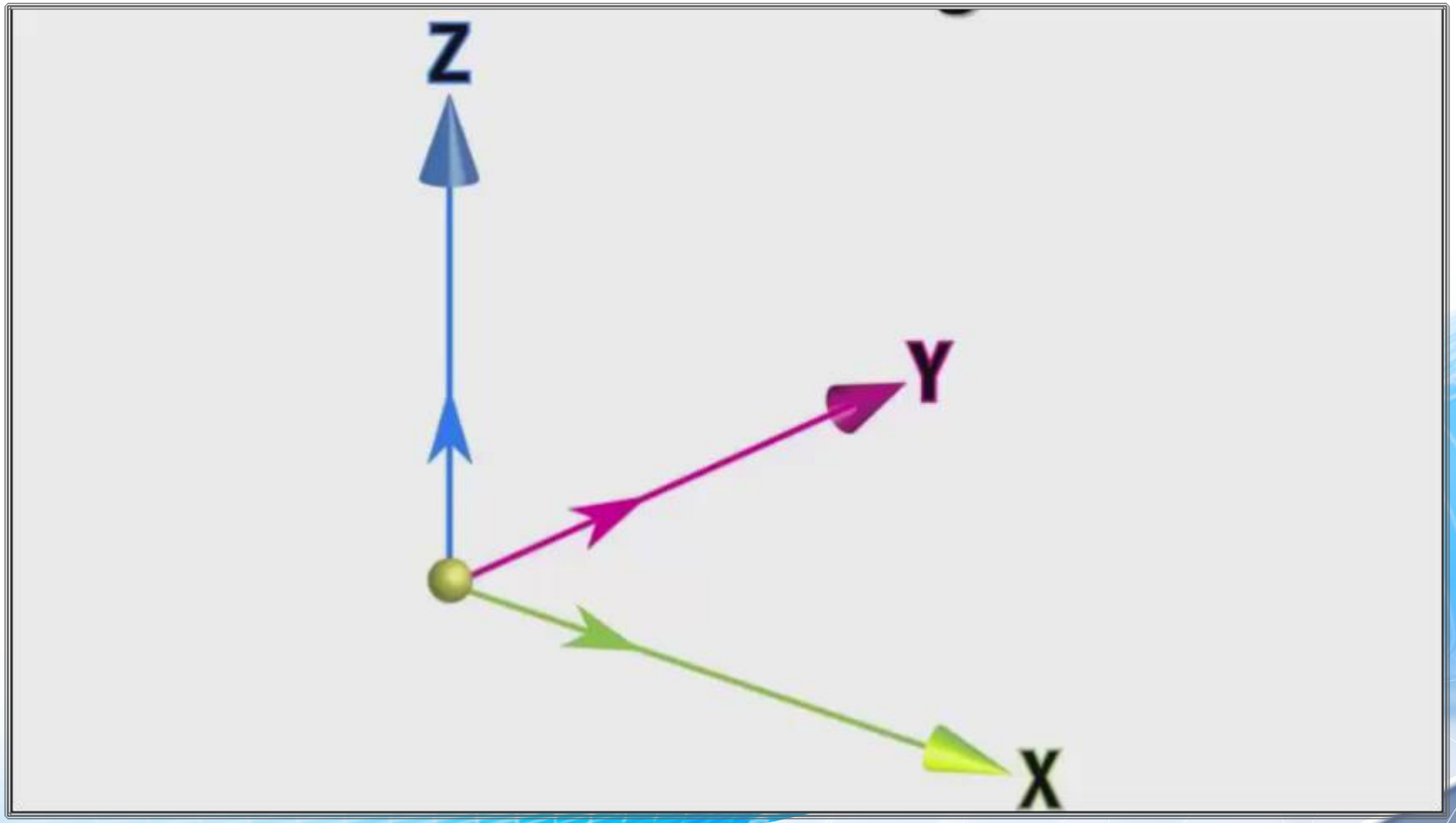

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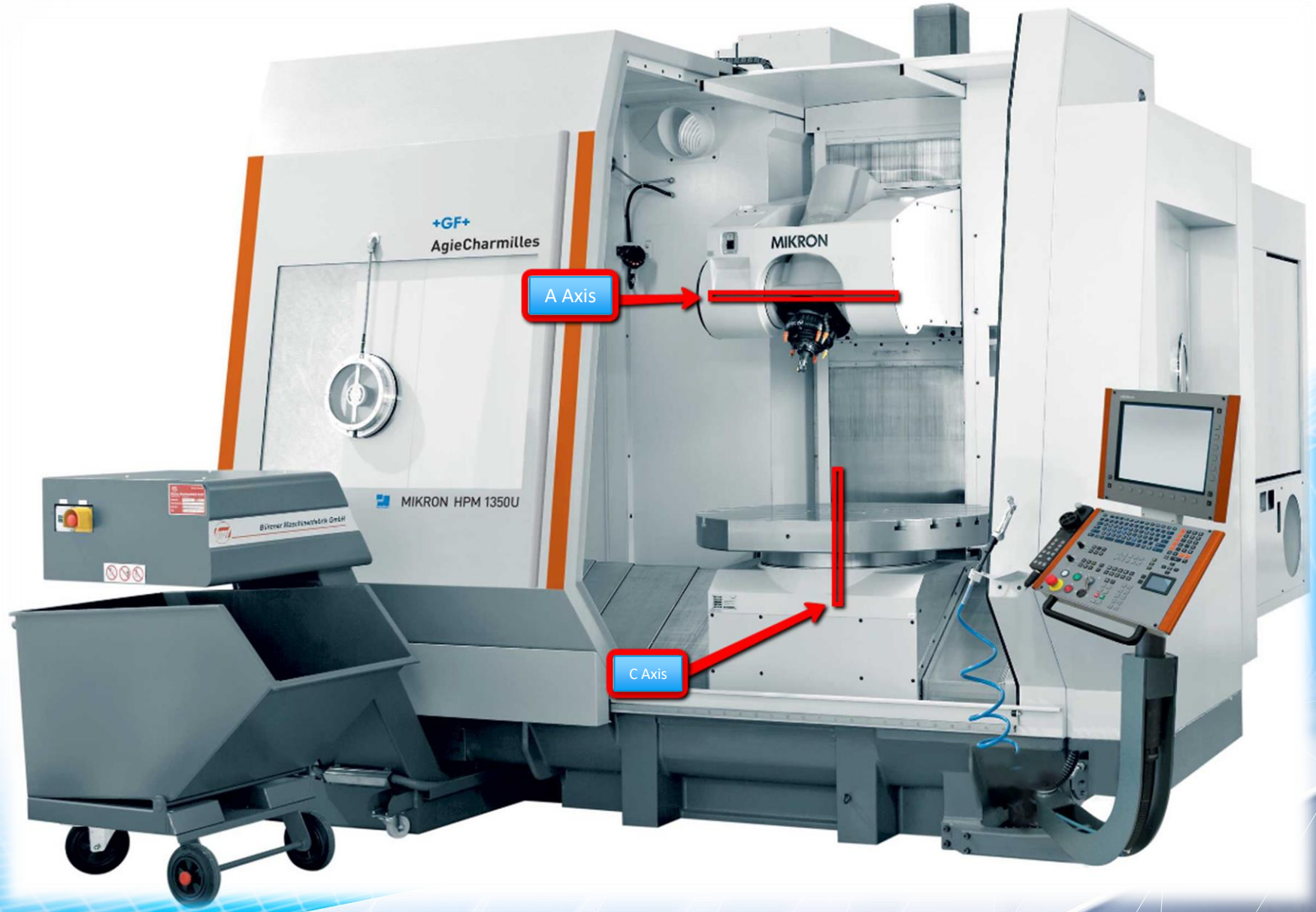

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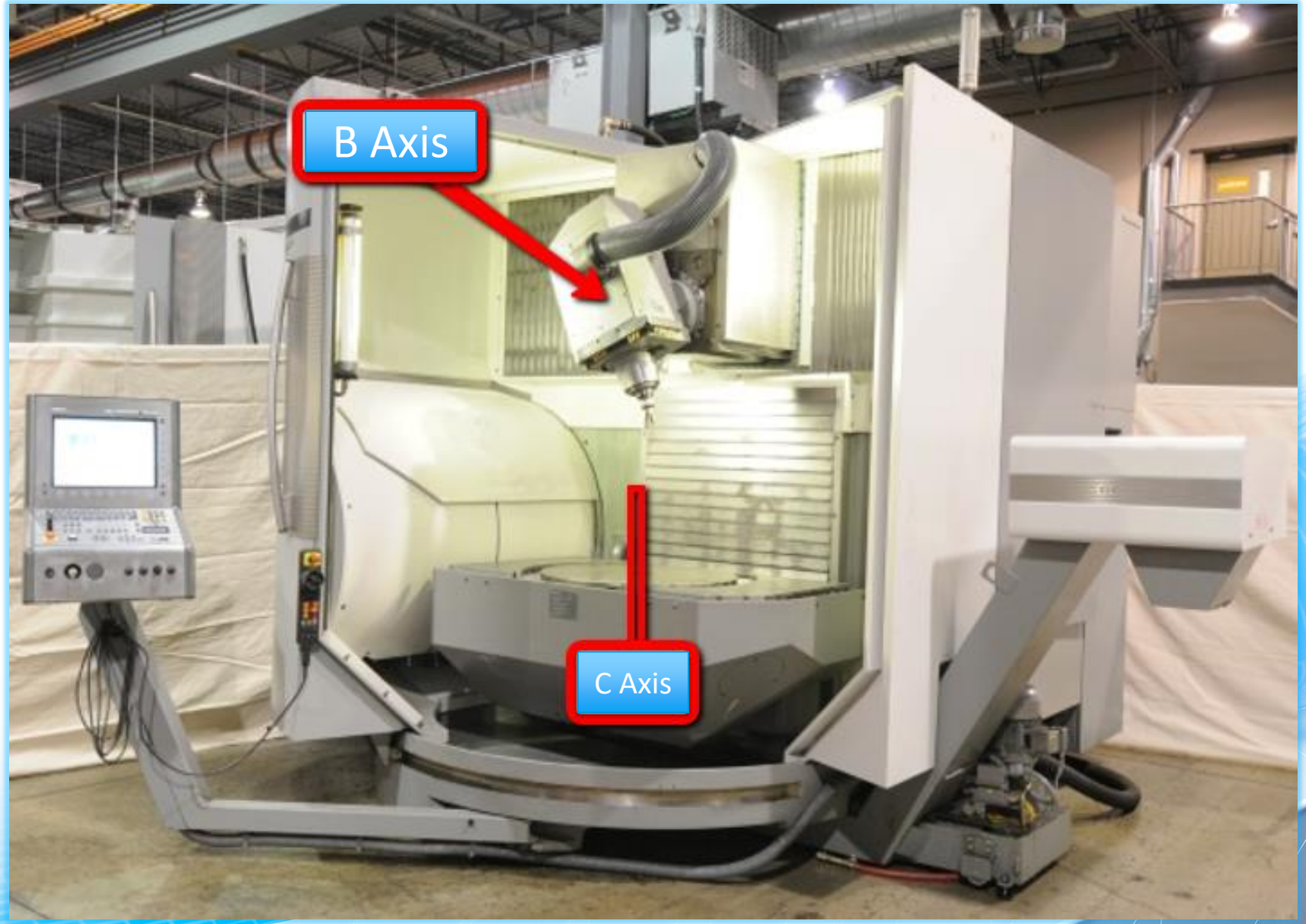

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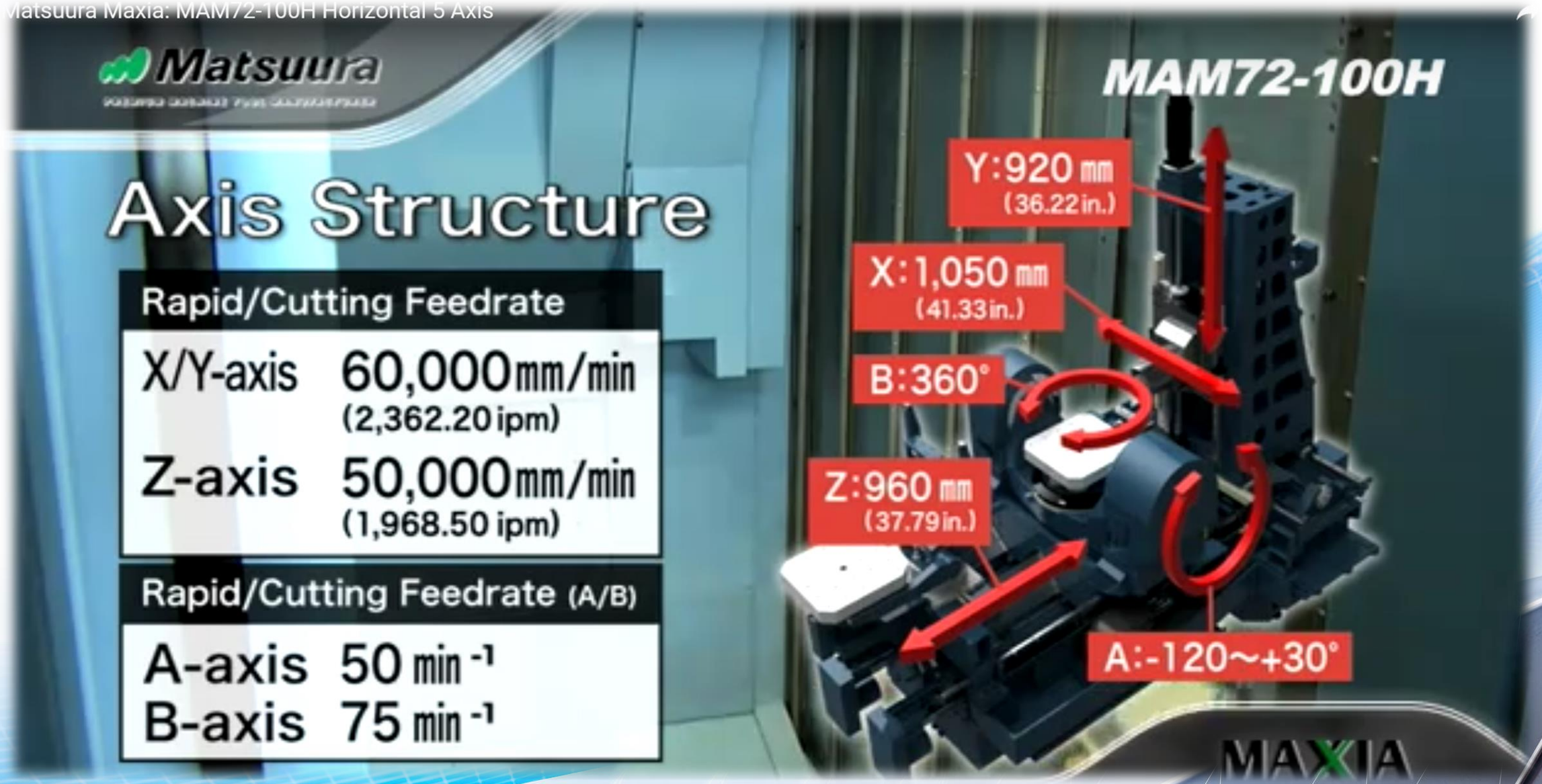
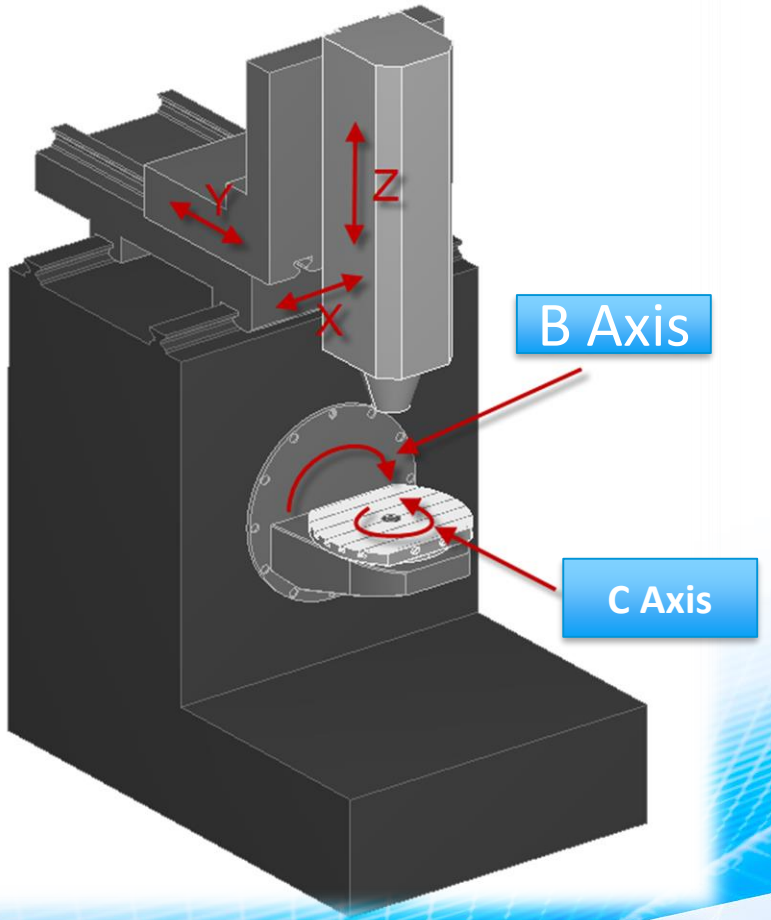
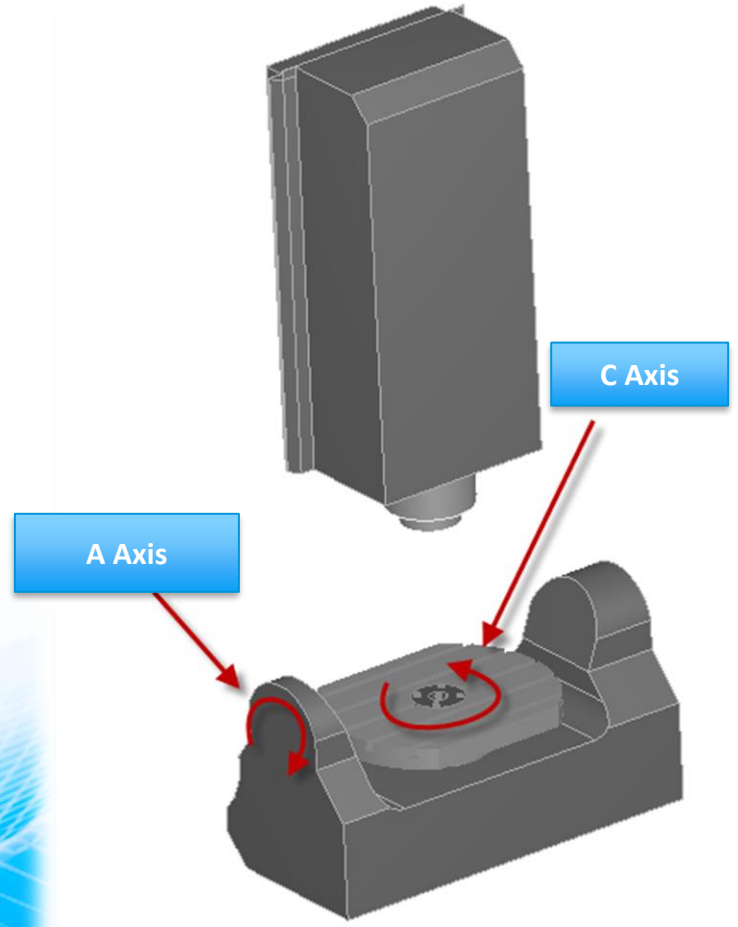


# Types of 5 axis Machine

- **Table/Table**

- Good for undercuts
  - Typically tilt >= 110 degrees
- Large working volume
  - Full XYZ range of travel
- A good choice for heavy metal removal
  - Geared or Belt driven spindle has greater torque at low RPM's
  - Stationary head is more rigid

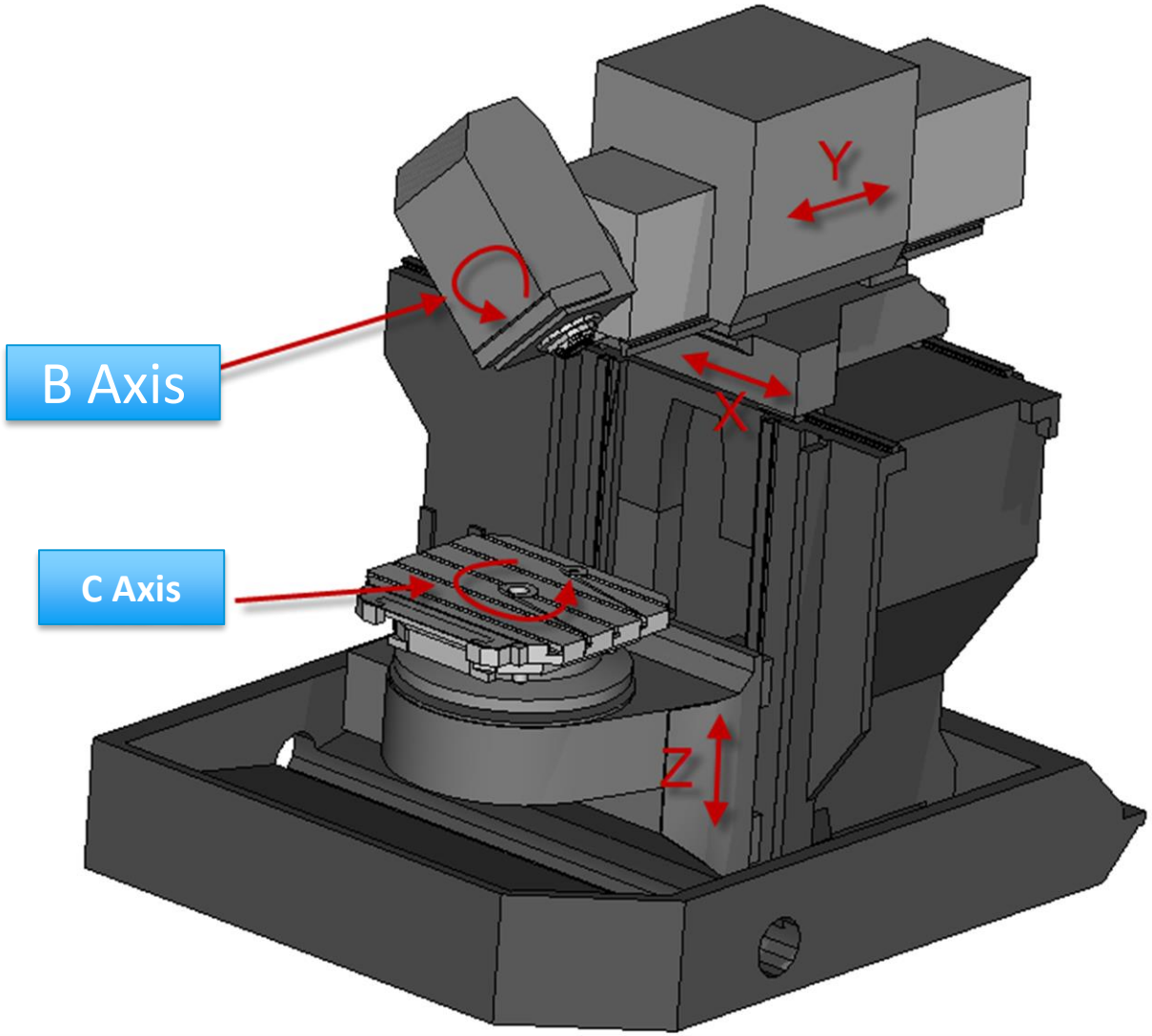


# Types of 5 axis Machine

- **Head/Table**

- Good for heavy parts
  - The table doesn't tilt so the weight is transferred directly down through the base of the machine
- Larger parts
  - Not limited by the trunnion upstands found on many table/table machines
- Fixtures/Tombstone
  - Ideal for cutting all faces of a tombstone fixture
- Chip control
  - This machine can be used as a horizontal mill for better chip evacuation

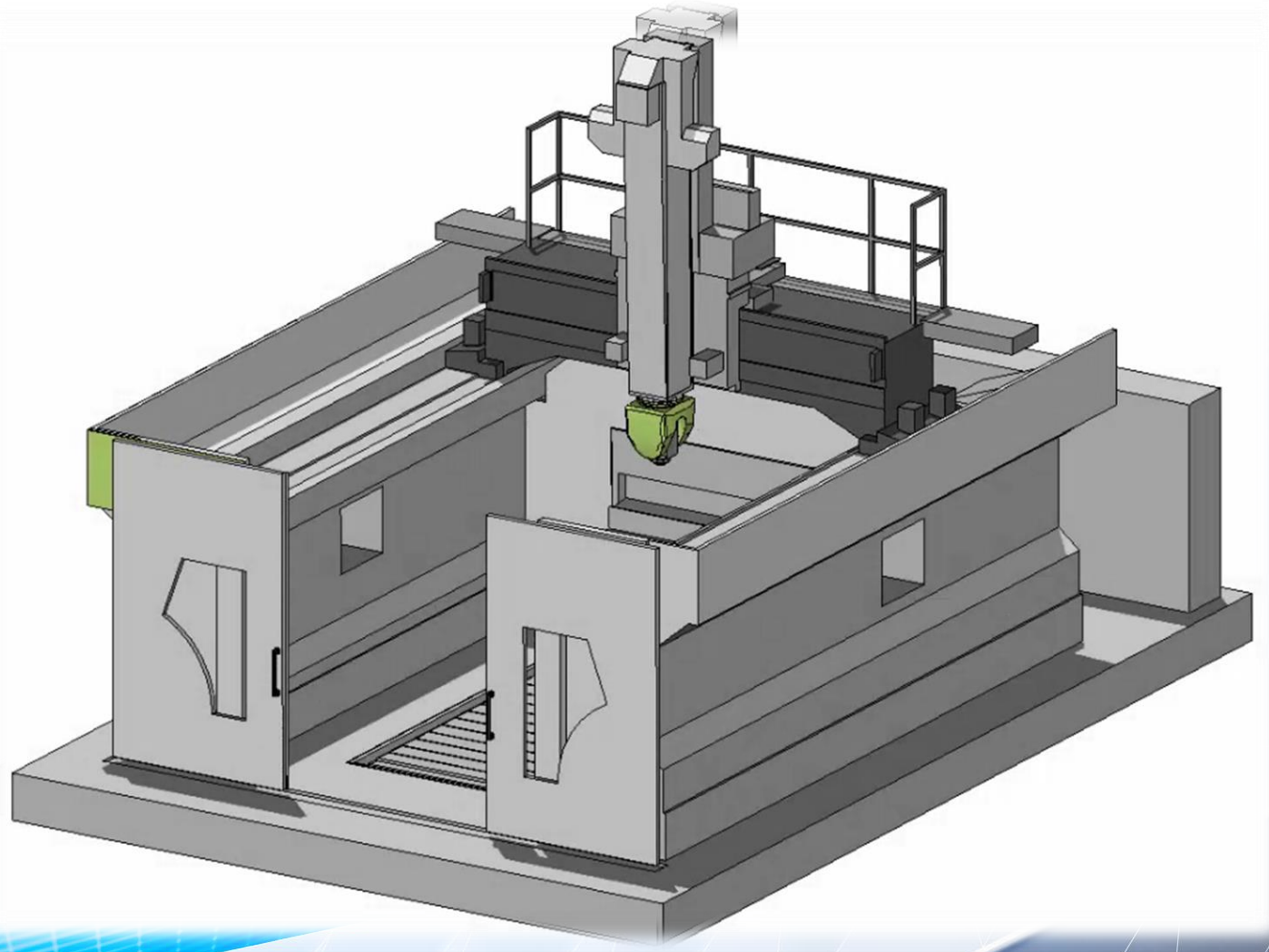


# Types of 5 axis Machine

- **Head/Head**

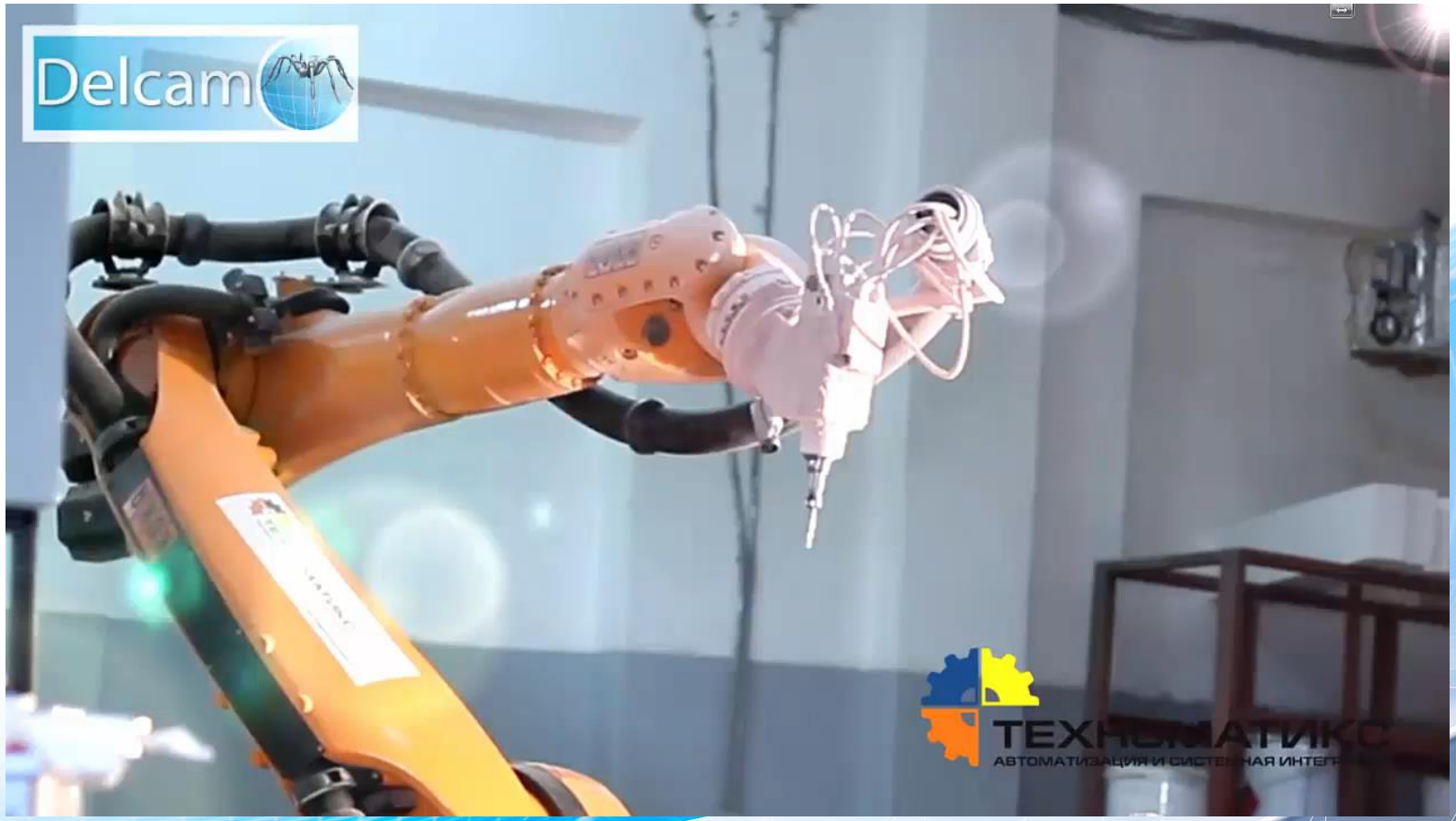
- Good for large and heavy parts

- Less good at heavy metal cutting
  - All toolaxis motion is on the head
  - Large Z axis travel also reduces rigidity
- Typically has a limited C axis range making it ‘challenging’ for simultaneous 5 axis milling



# Robots: 6 to 18 axis

- **Robots**
- Great for cutting large (Soft material) parts
- More complex to program without dedicated robotic controls
  - 6 or more degrees of freedom
  - Simultaneous rotary motion even for simple 2D facing operations
  - Need to avoid singularities
  - May need to control which of the 8 possible solutions to use



# Challenges

D = 0° E = +45°

D = 180° E = -45°

Configuration 1

Configuration 2

Configuration 3

Configuration 4

Configuration 5

Configuration 6

Configuration 7

Configuration 8

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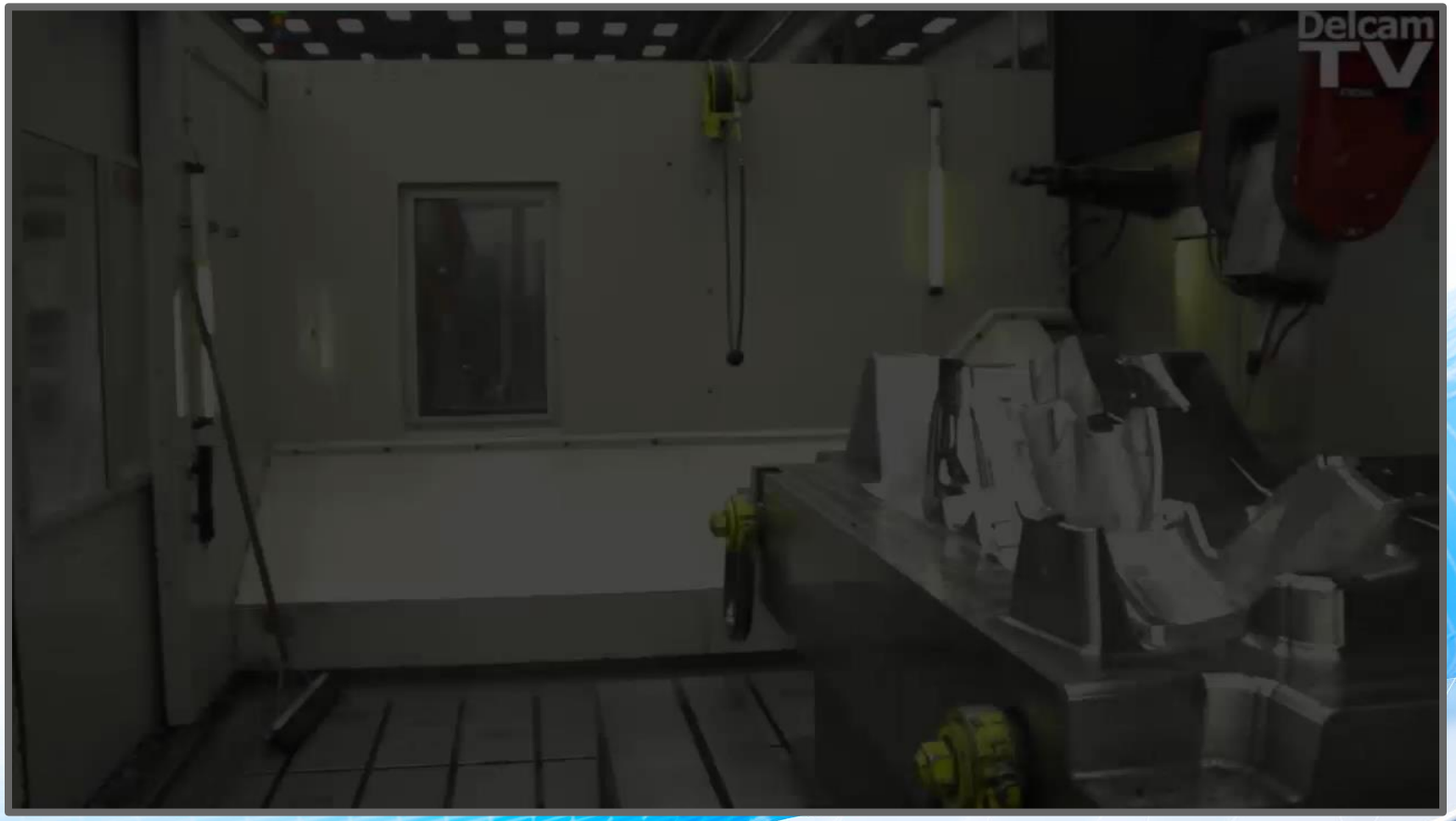
# So, is 5 axis machining for me?

# Common beliefs…

- Aerospace

# Common beliefs…

- Injection Molds



# Common beliefs…

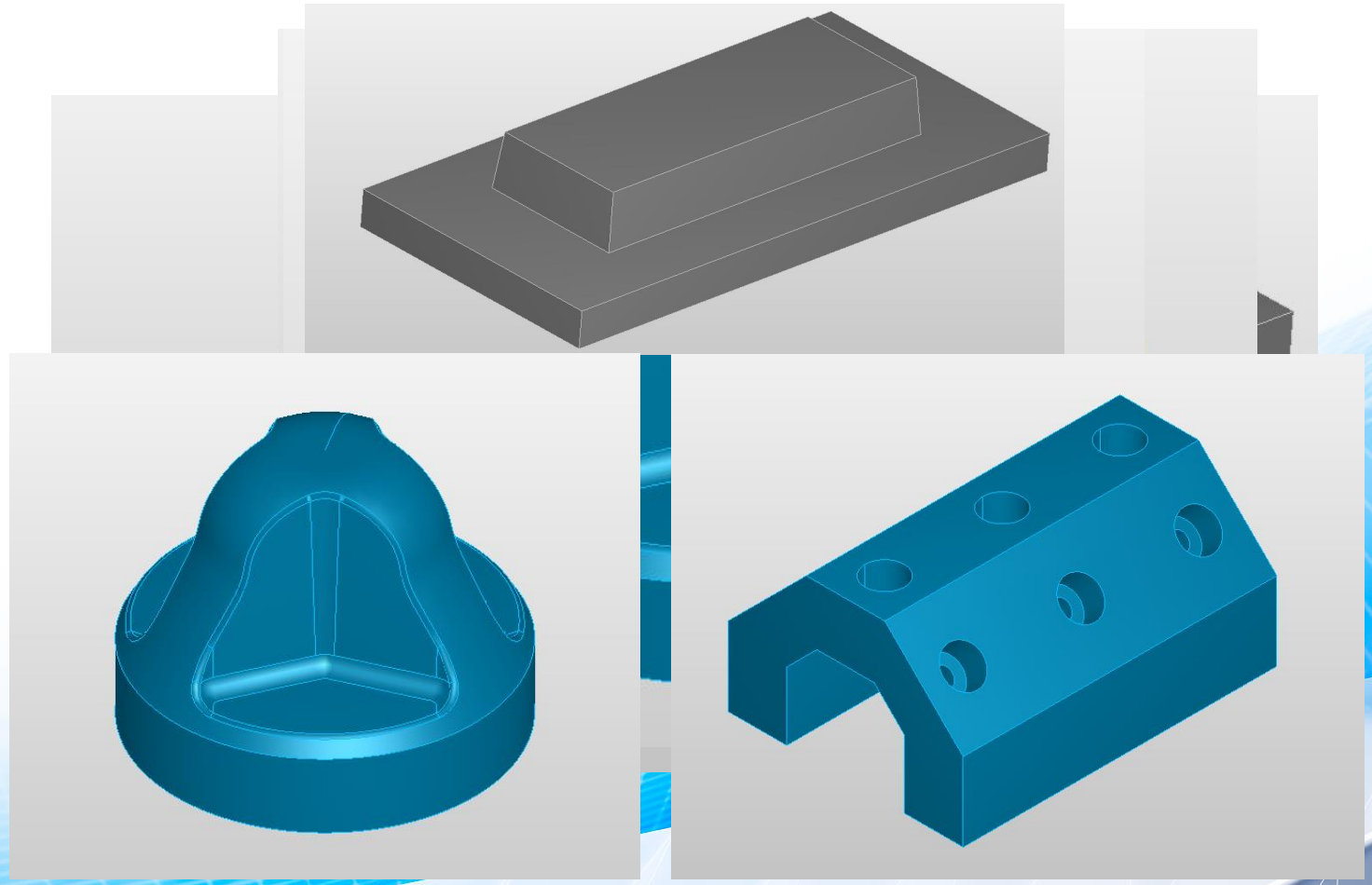
- Military and Defense

# Common beliefs…

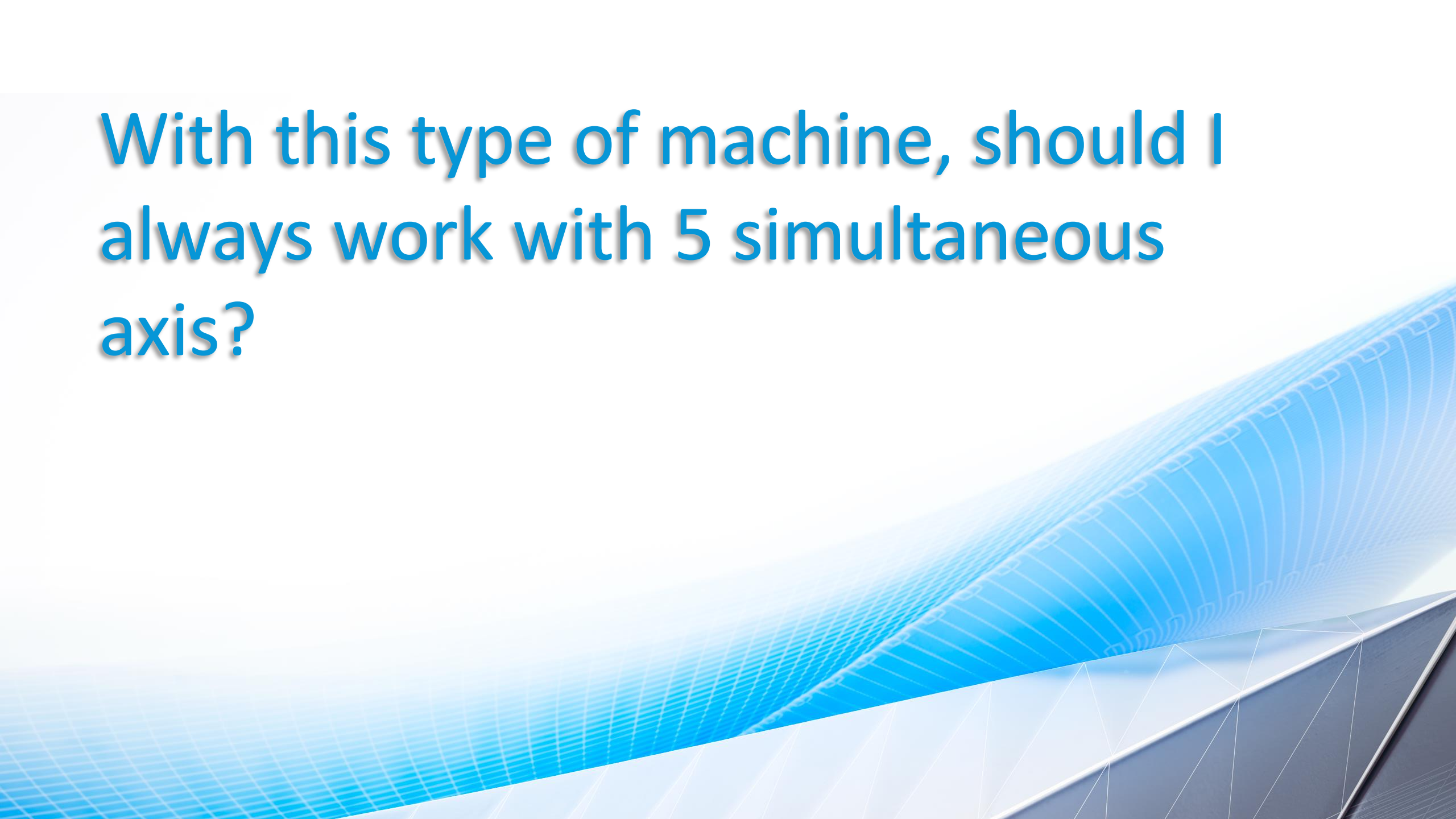
- Think again!

# Common beliefs…

- 5 axis machining is also for everyday simple parts.



# With this type of machine, should I always work with 5 simultaneous axis?

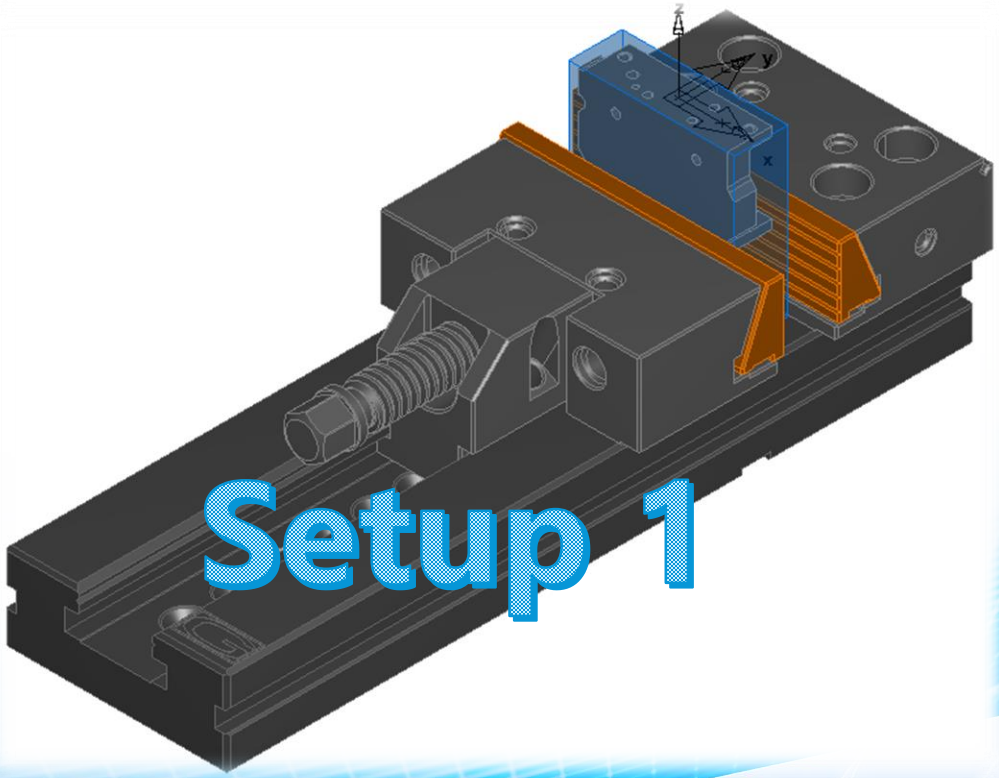


# Probably not!

- 5-axis machines are mostly used for 3 and 3+2 axis machining
  - Simple to program
  - Predictable motion
  - Predictable surface finish
- 3+2 axis machining is often faster than simultaneous machining
  - No large rotary moves over short distances
    - A machine can only go as fast as the slowest axis
- Some “5-axis” machines do not support simultaneous machining or have limited C axis range

# 3+2 axis Vs 3 axis

- 3+2 axis machining can reduce the number of Setups required for part manufacture




# 3+2 axis Vs 3 axis

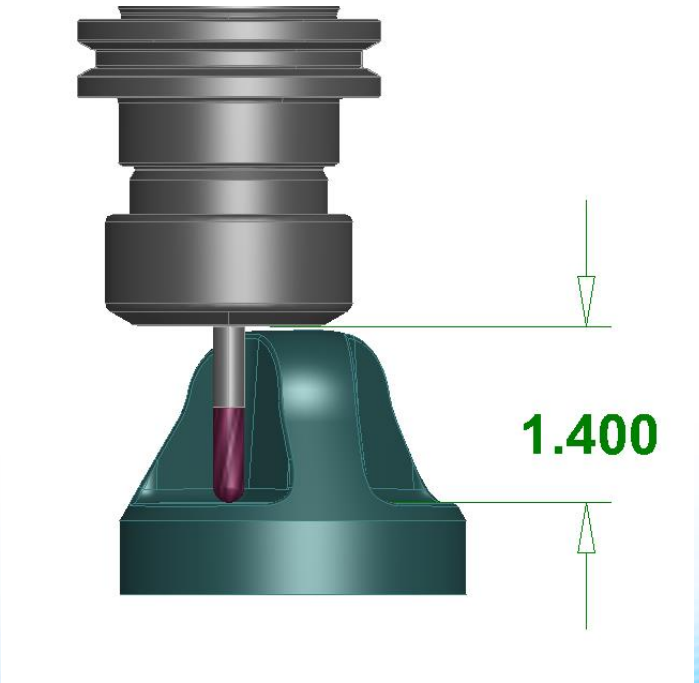
- Increase the precision of machining by reducing the number of setups

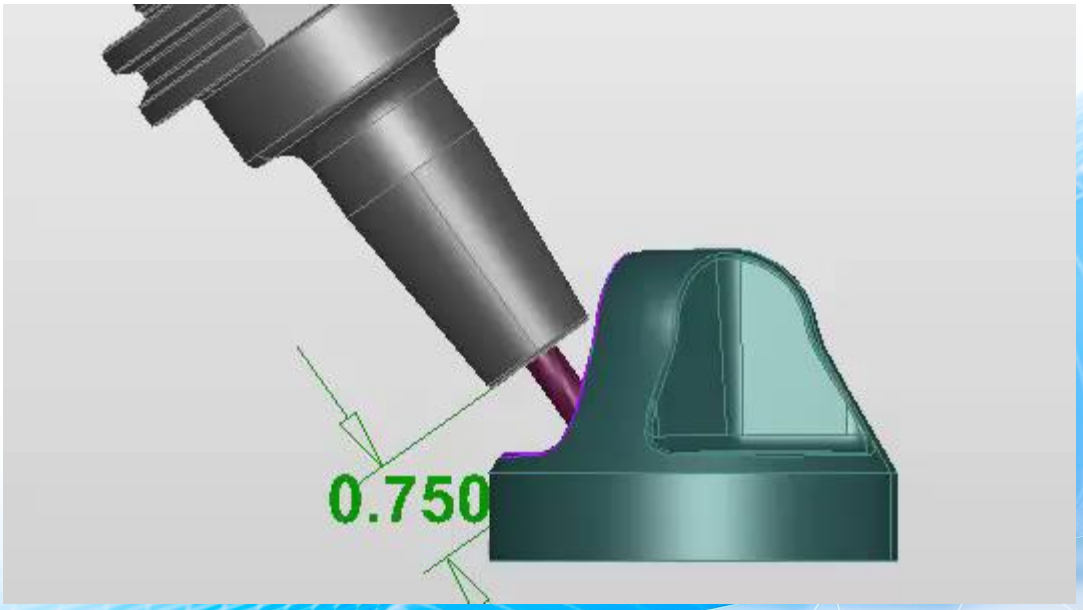
# 3+2 axis Vs 3 axis

- Minimize tool changes

# 3+2 axis Vs 3 axis

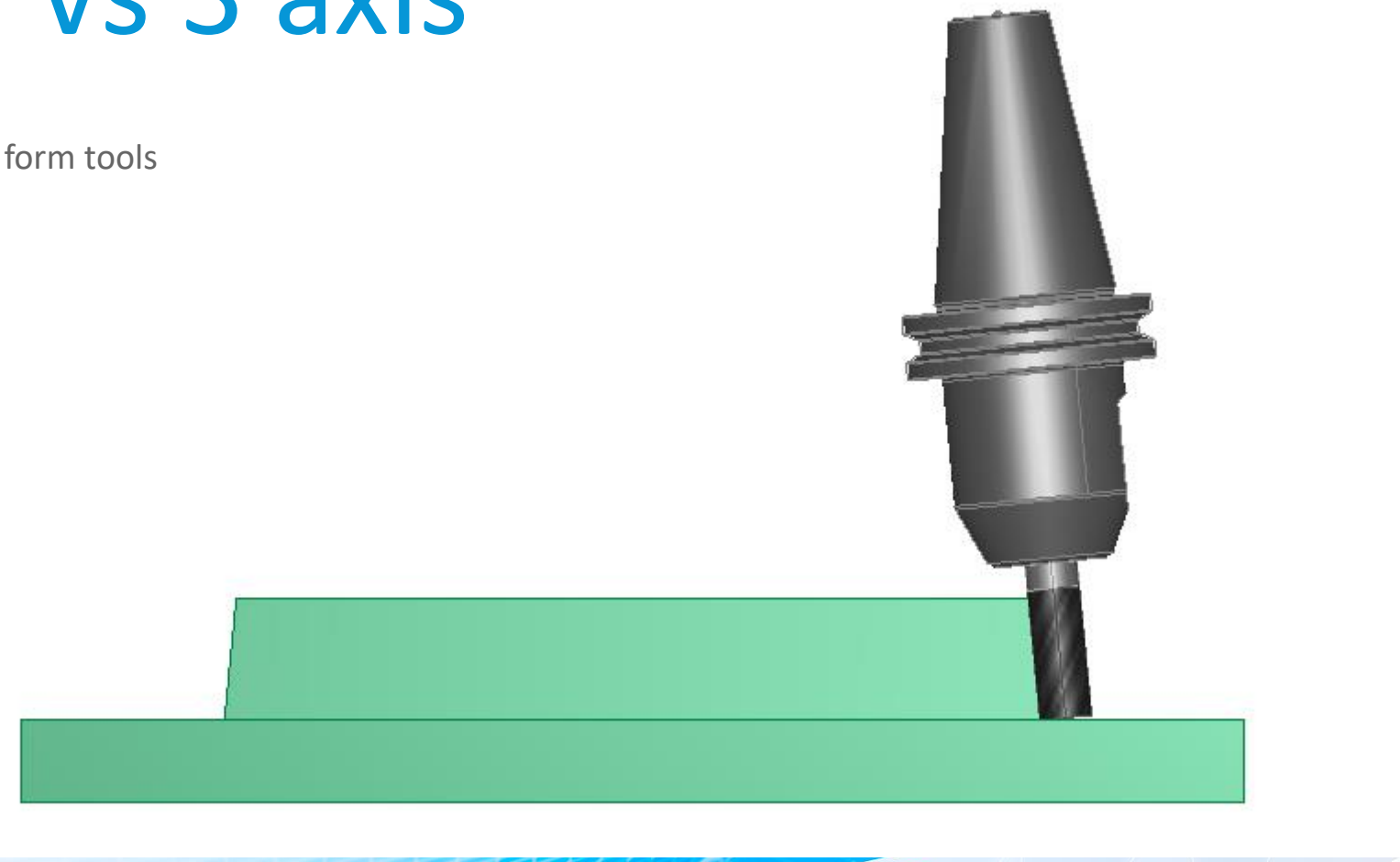
- Use of shorter tools



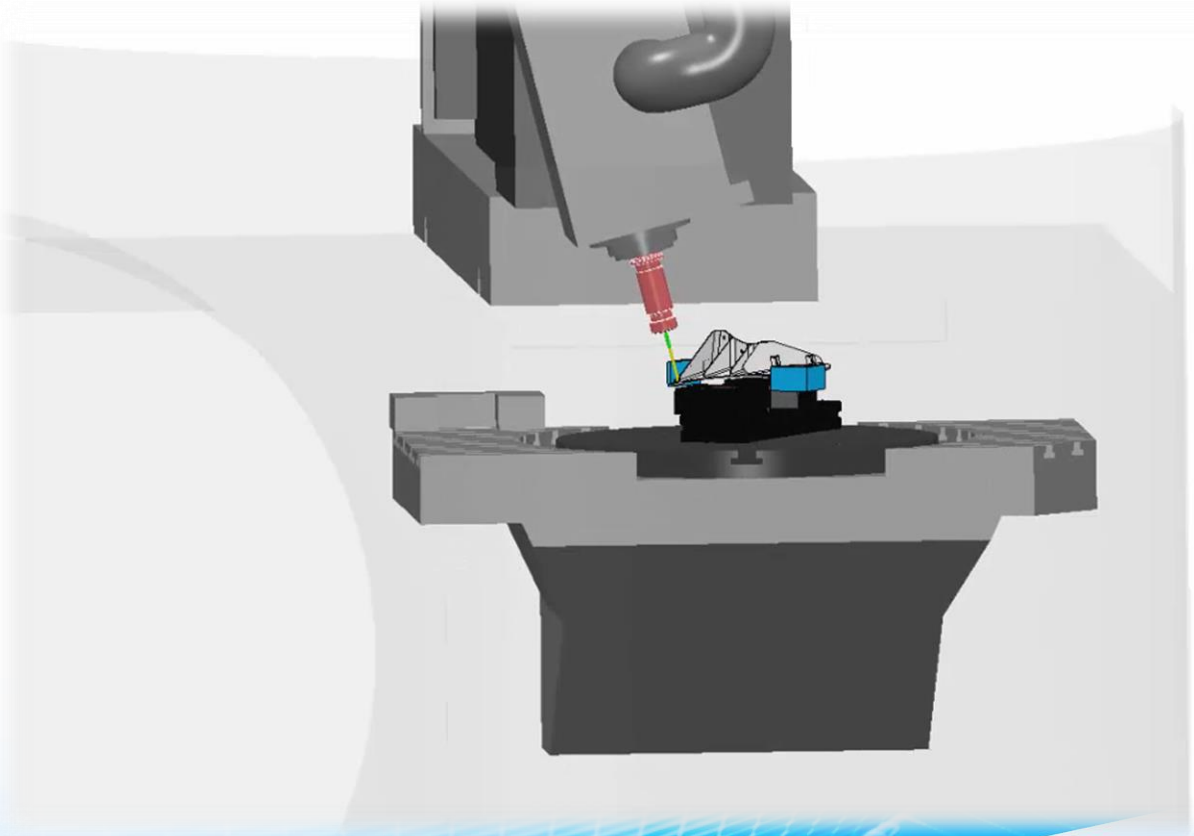



# 3+2 axis Vs 3 axis

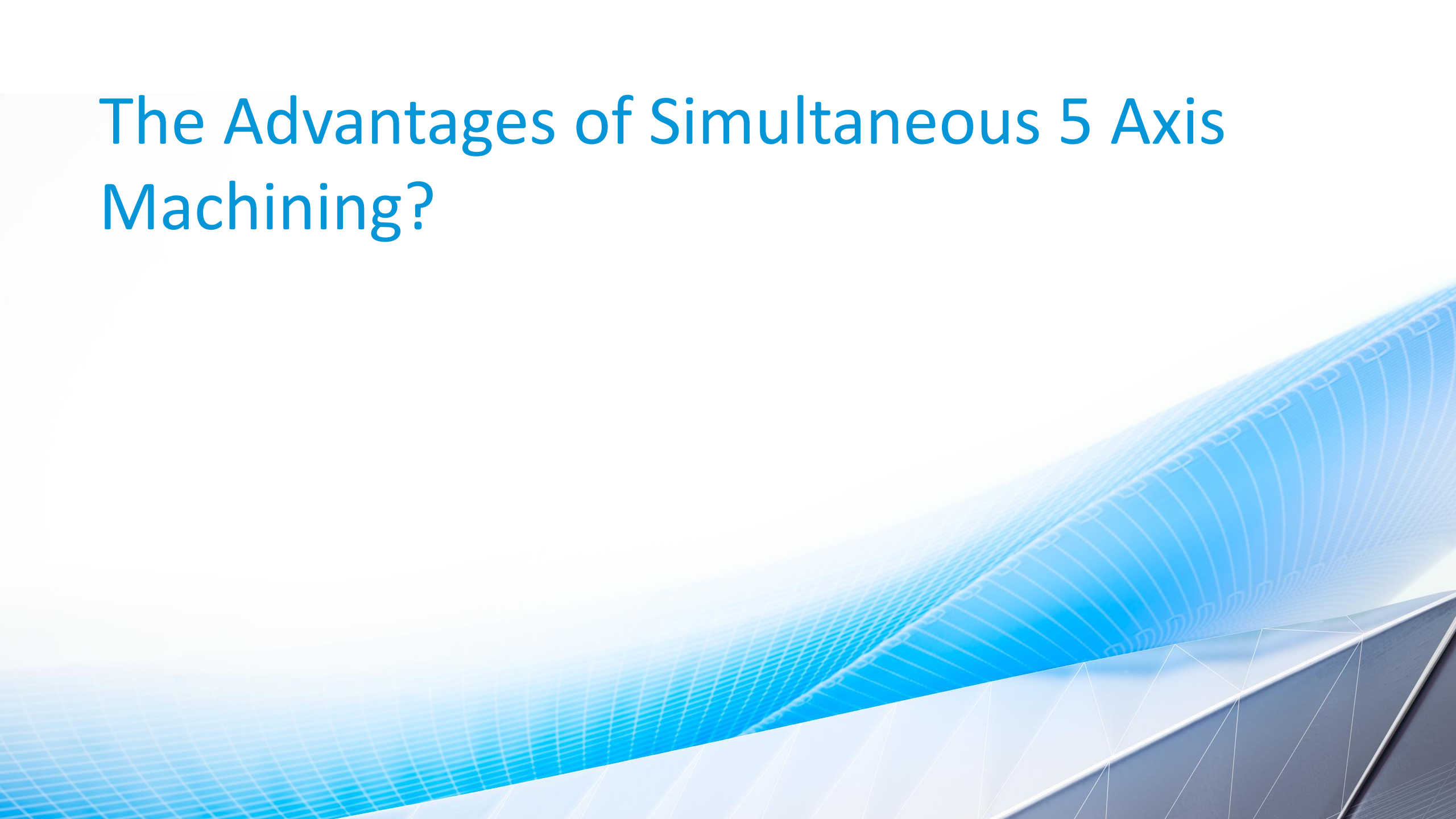
- Avoid the purchase of form tools



# 3+2 axis Machining



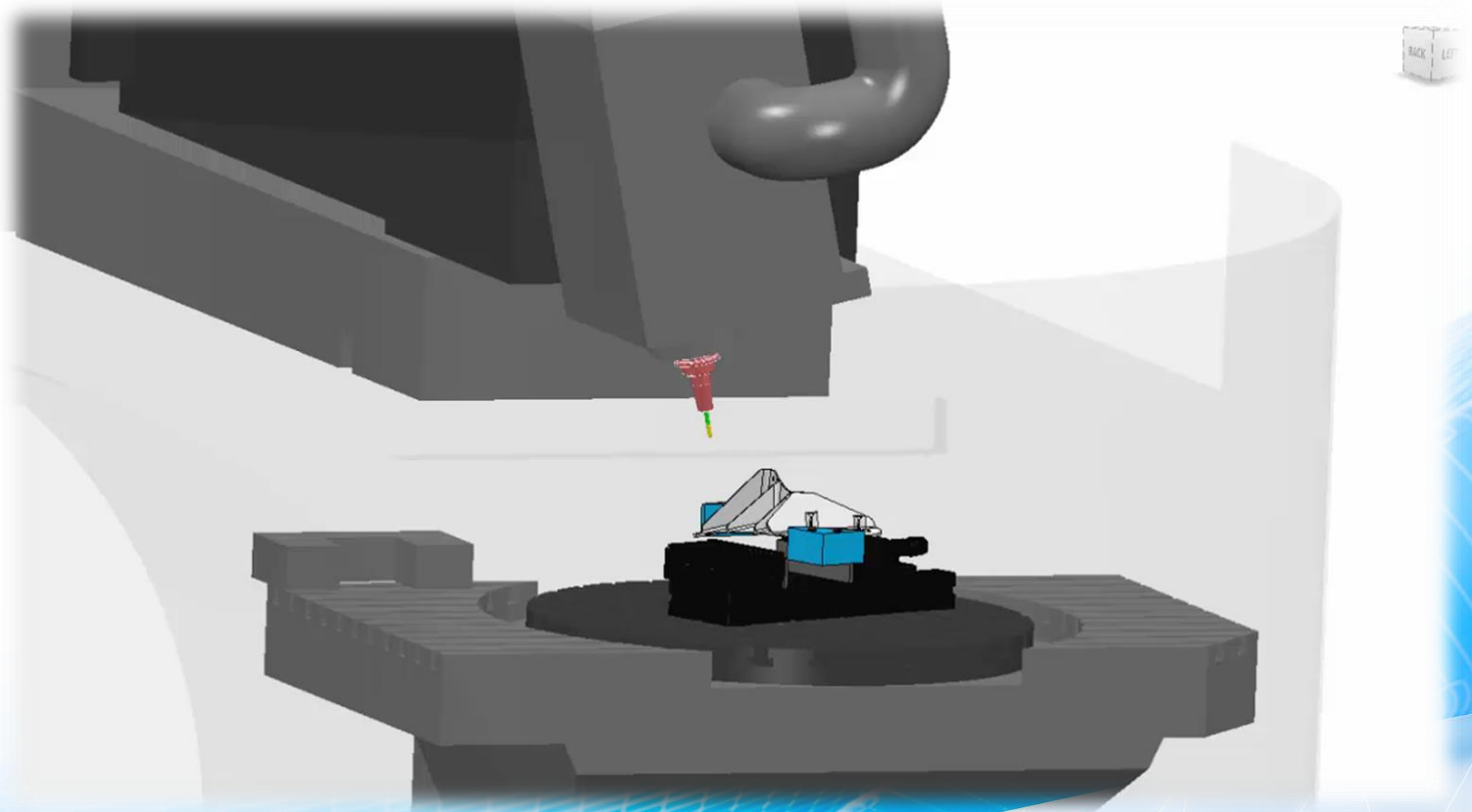
# The Advantages of Simultaneous 5 Axis Machining?



# A quick explanation of simultaneous 5 axis

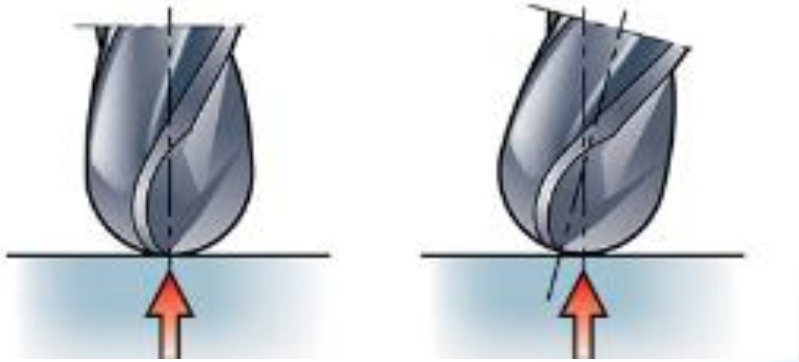
- Up to 5 Simultaneous axes:
  - Rotations can be applied throughout the machining
  - The lines of machining code will contain the axes of rotation in addition to the linear axes
  - More advanced programming
  - More complex machine tool motion

# Simultaneous 5 axis



# Simultaneous 5 axis Vs 3+2 axis

- Check the contact point on the tool



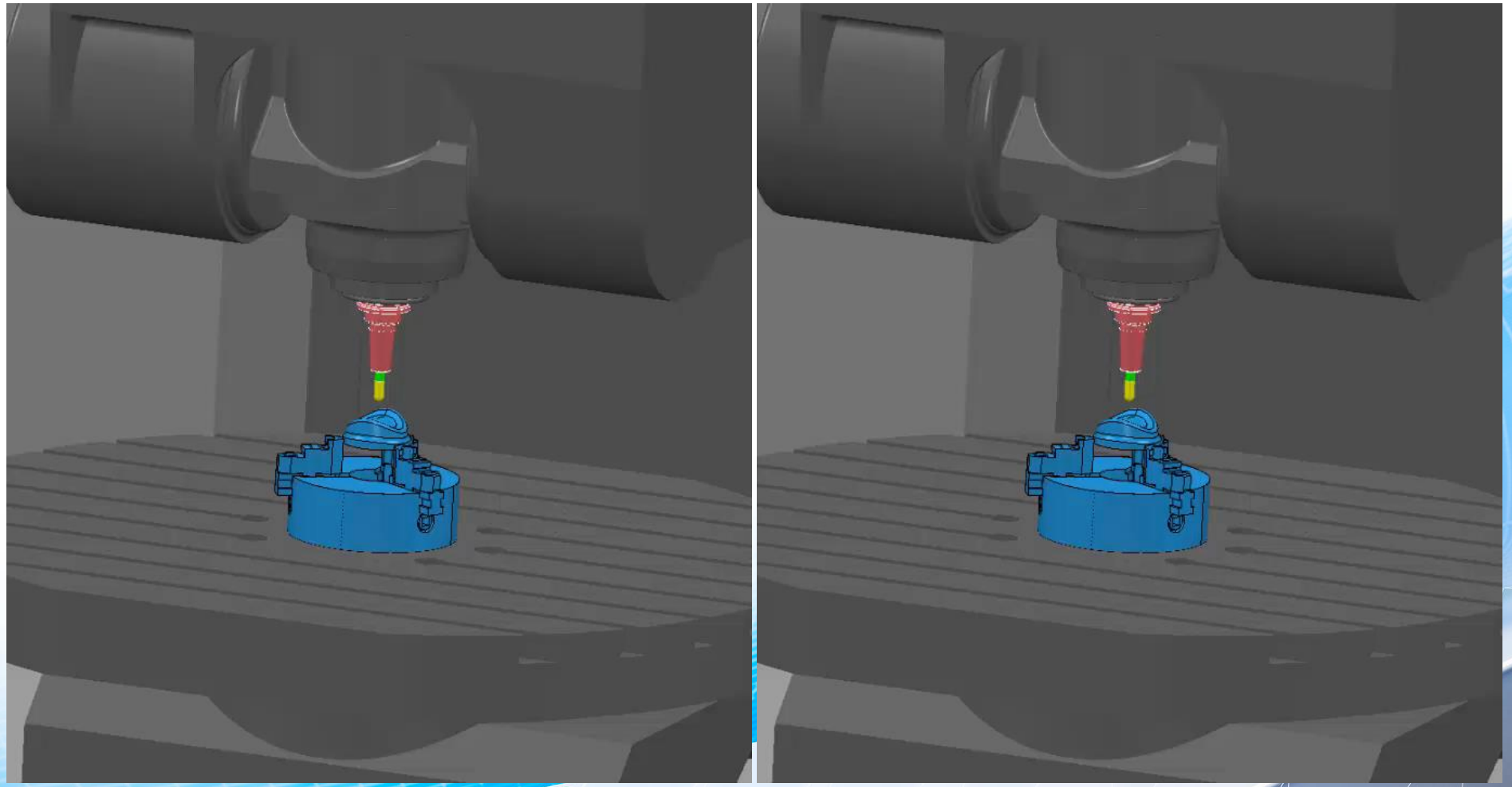
# Simultaneous 5 axis Vs 3+2 axis

- Check the contact point on the tool

| Operation | Non-tilted cutter | Tilted cutter (10°) |
|---|---|---|
| • **Semi-finishing $a_p$ – 2 mm**<br>The speed can be further increased by approx. 75% due to the shallow cut and short engagement time:<br>**$v_c$ – 300 m/min**<br>Feed per tooth, $f_z$, is the same for both the non-tilted and the tilted cutter, but the effective No of edges, $z_c$, differs near the centre as described on the previous page. | $D_c$ = 10 mm<br>$D_{cap}$ = 8 mm<br>$v_c$ = 300 m/min<br>$n$ = 11 940 rpm<br>$h_{ex}$ = 0.08 mm<br>$f_z$ = 0.12 mm/tooth<br>$z_c$ = 2<br>$f_n$ = 0.24 mm/r<br>$v_f$ = 2 860 mm/min | $D_c$ = 10 mm<br>$D_{cap}$ = 8.9 mm<br>$v_c$ = 300 m/min<br>$n$ = 10 700 rpm<br>$h_{ex}$ = 0.08 mm<br>$f_z$ = 0.12 mm/tooth<br>$z_c$ = 4<br>$f_n$ = 0.48 mm/r<br>$v_f$ = 5 100 mm/min |
| • **Super-finishing $a_e$ – 0.1 mm**<br>The cutting speed can be increased by the factor 3-5 due to the extremely short contact time:<br>**$v_c$ – 5 x 170 – 850 m/min**<br>***Note:*** In super-finishing a two teeth cutter $z_n$ = 2, should be used to minimize the run-out.<br>With this extremely small $a_p$, the $f_z$ will be limited by the surface finish demands. Therefore, $h_{ex}$ must be disregarded. A good rule of thumb in super-finishing is to use approx. the same $f_z$ as the $a_e$.<br>**$f_z$ – 0.12 mm/r** | A non-tilted cutter is not recommended for super- finishing | $D_c$ = 10 mm<br>$D_{cap}$ = 4.4 mm<br>$v_c$ = 850 m/min<br>$n$ = 61 100 rpm<br>$h_{ex}$ = 0.02 mm<br>$f_z$ = 0.12 mm/tooth<br>$z_c$ = 2<br>$f_n$ = 0.24 mm/r<br>$v_f$ = 14 600 mm/min |

# Simultaneous 5 axis Vs 3+2 axis

- Check the contact point on the tool



# Simultaneous 5 axis Vs 3+2 axis

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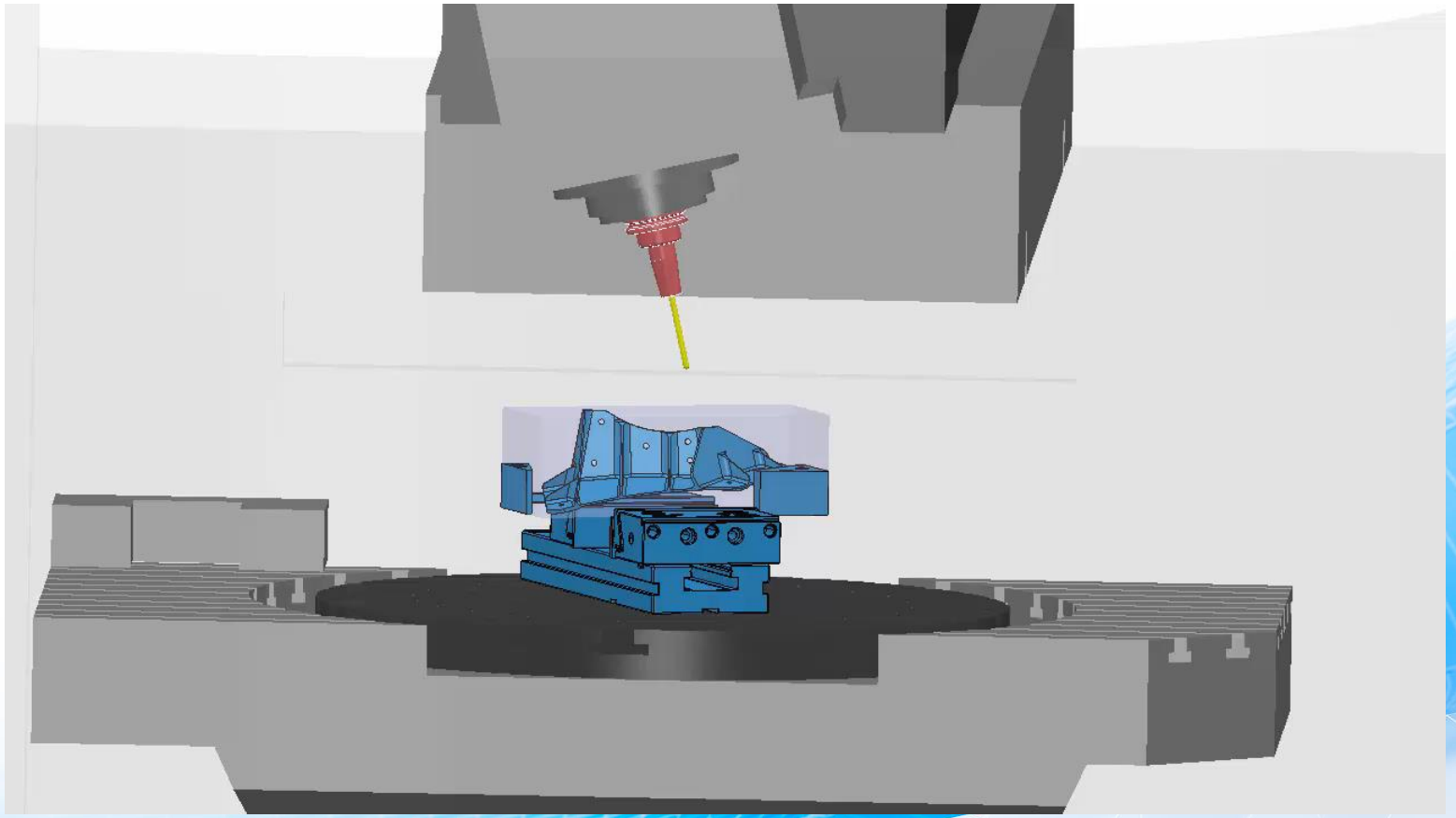
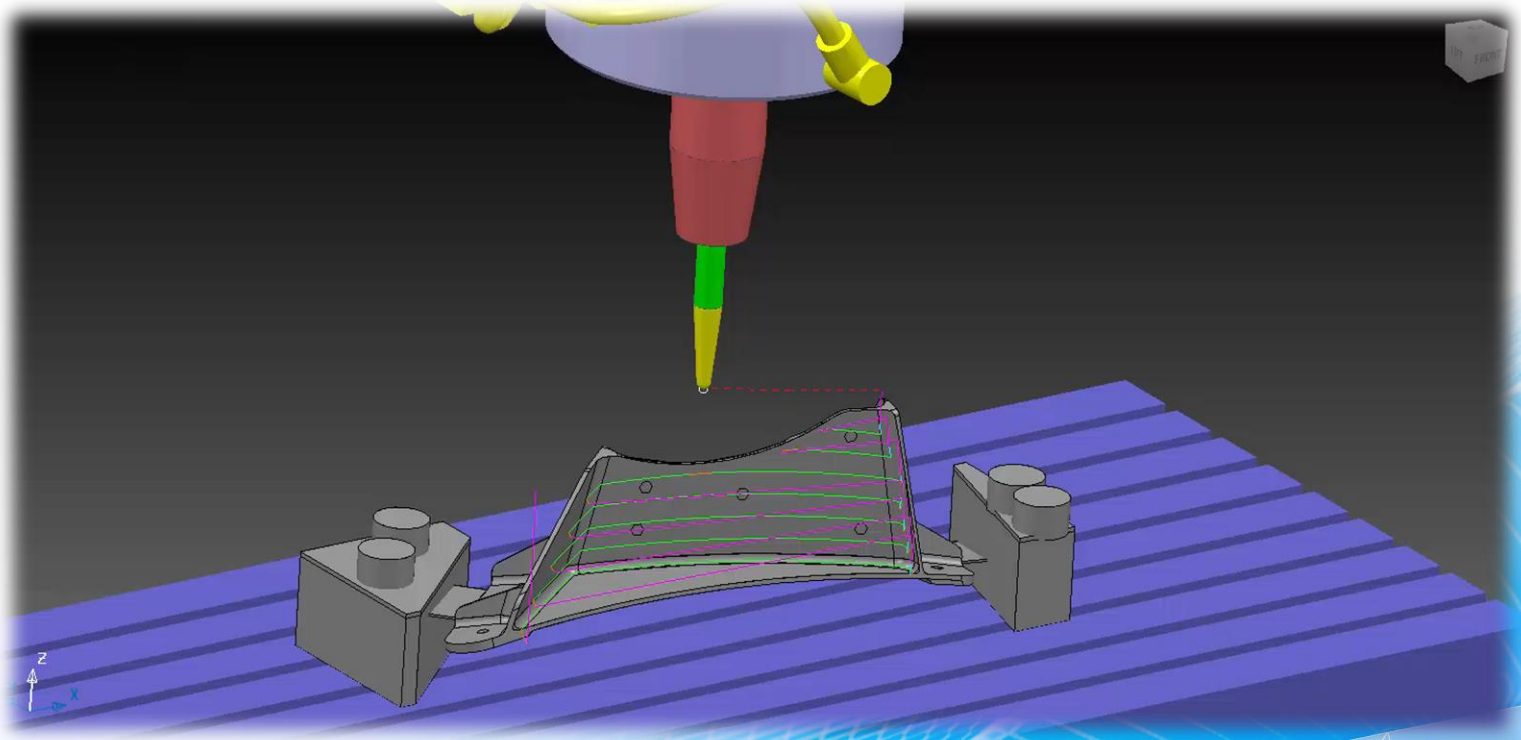


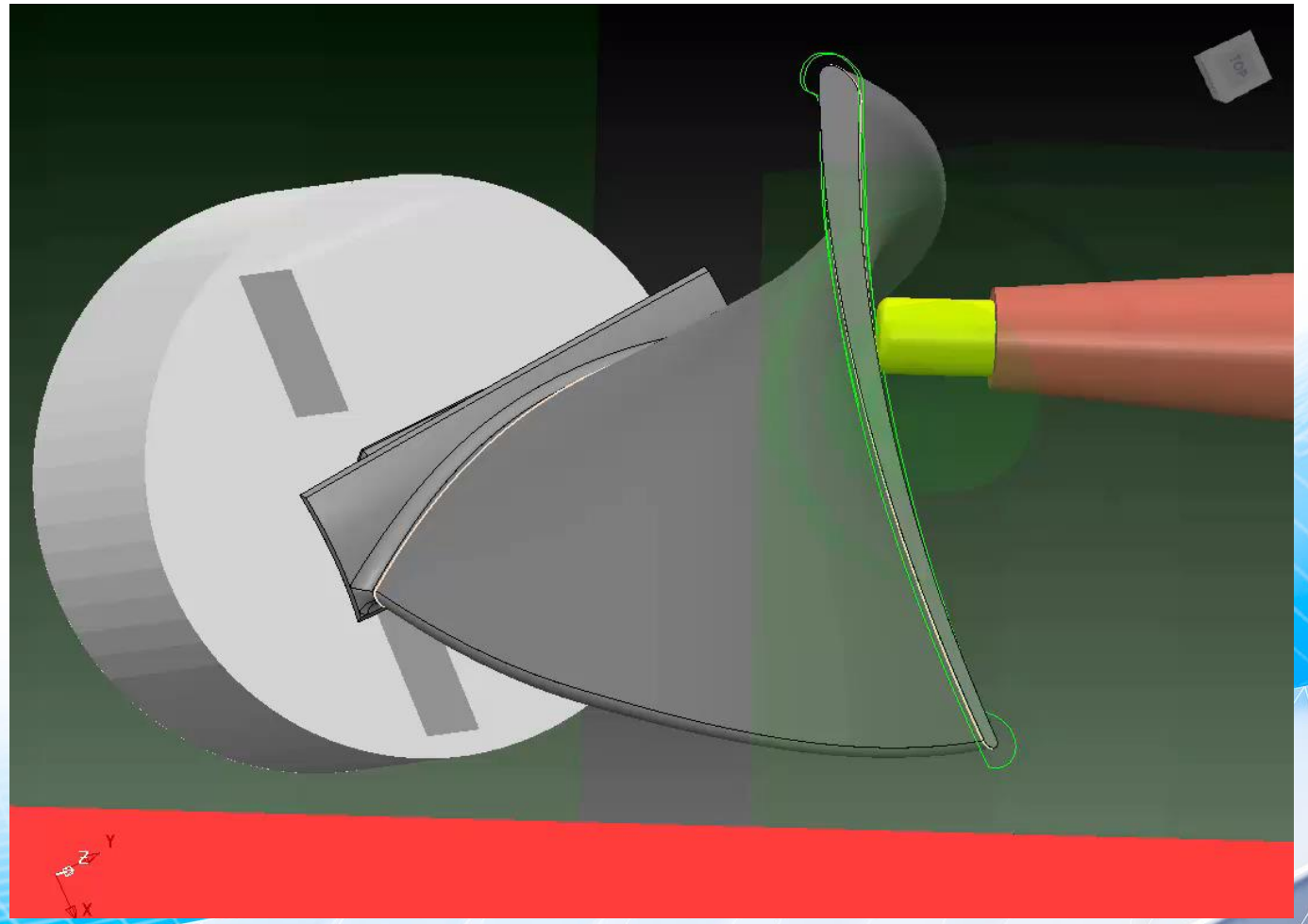
# Simultaneous 5 axis Vs 3+2 axis

- Check the contact point on the tool
- This tapered tool enables the lower fillet to be machined whilst increasing the rigidity of the tool



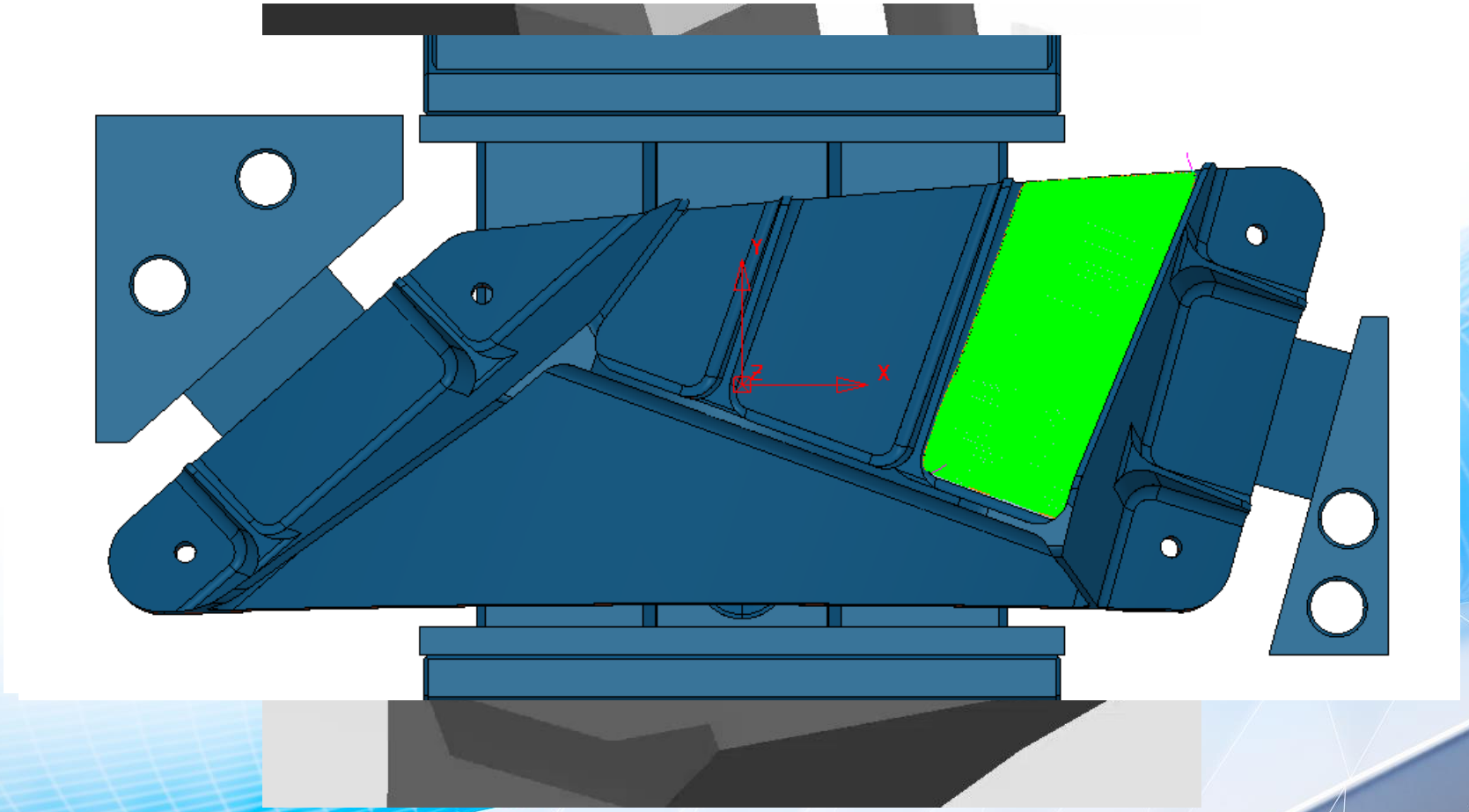
# Simultaneous 5 axis Vs 3+2 axis

- Check the contact point on the tool
- This tip radiused, flat bottomed tool machines very efficiently when maintaining a controlled lead angle



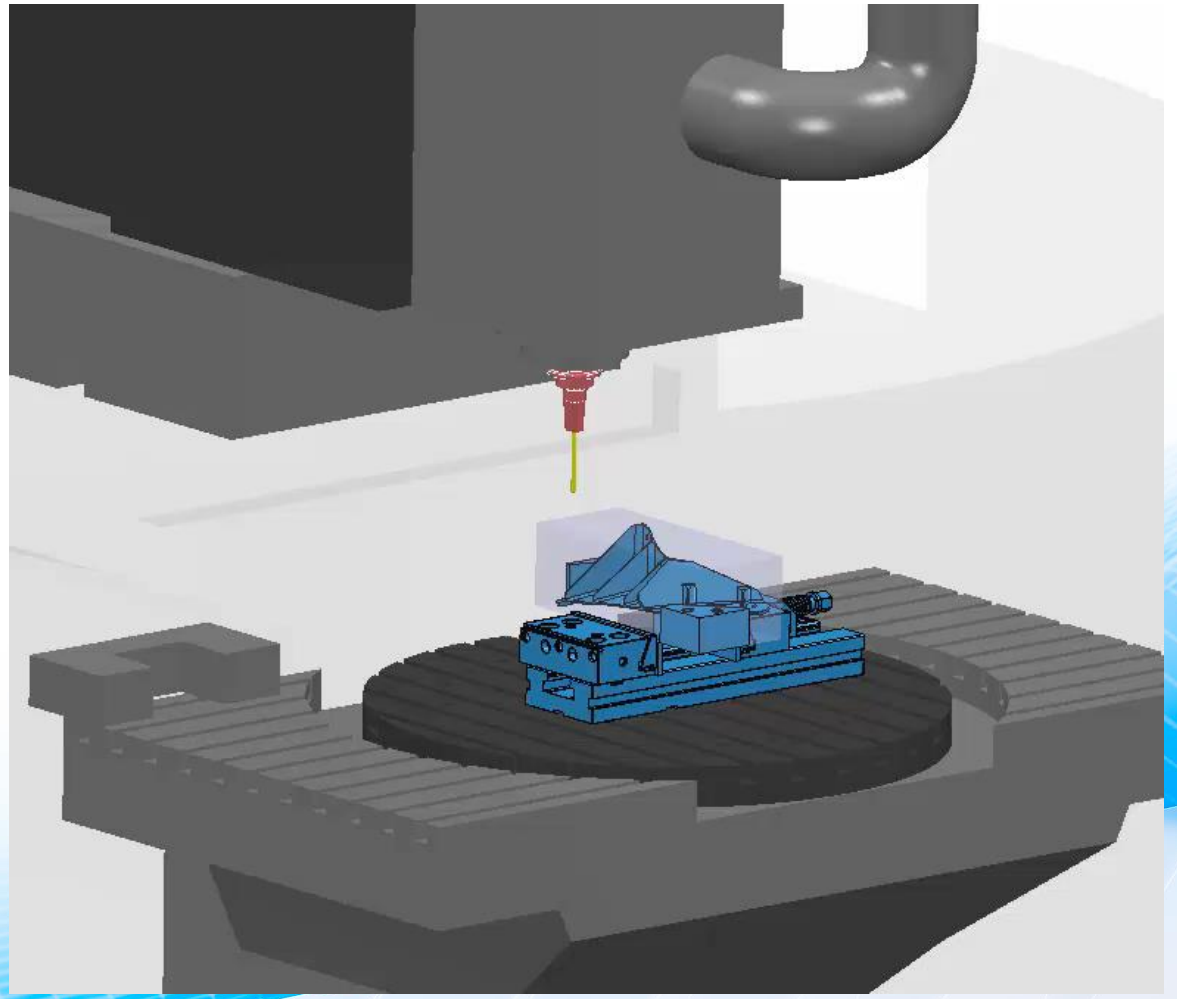
# Simultaneous 5 axis Vs 3+2 axis

- Machine regions that are difficult to access. For example, undercuts.



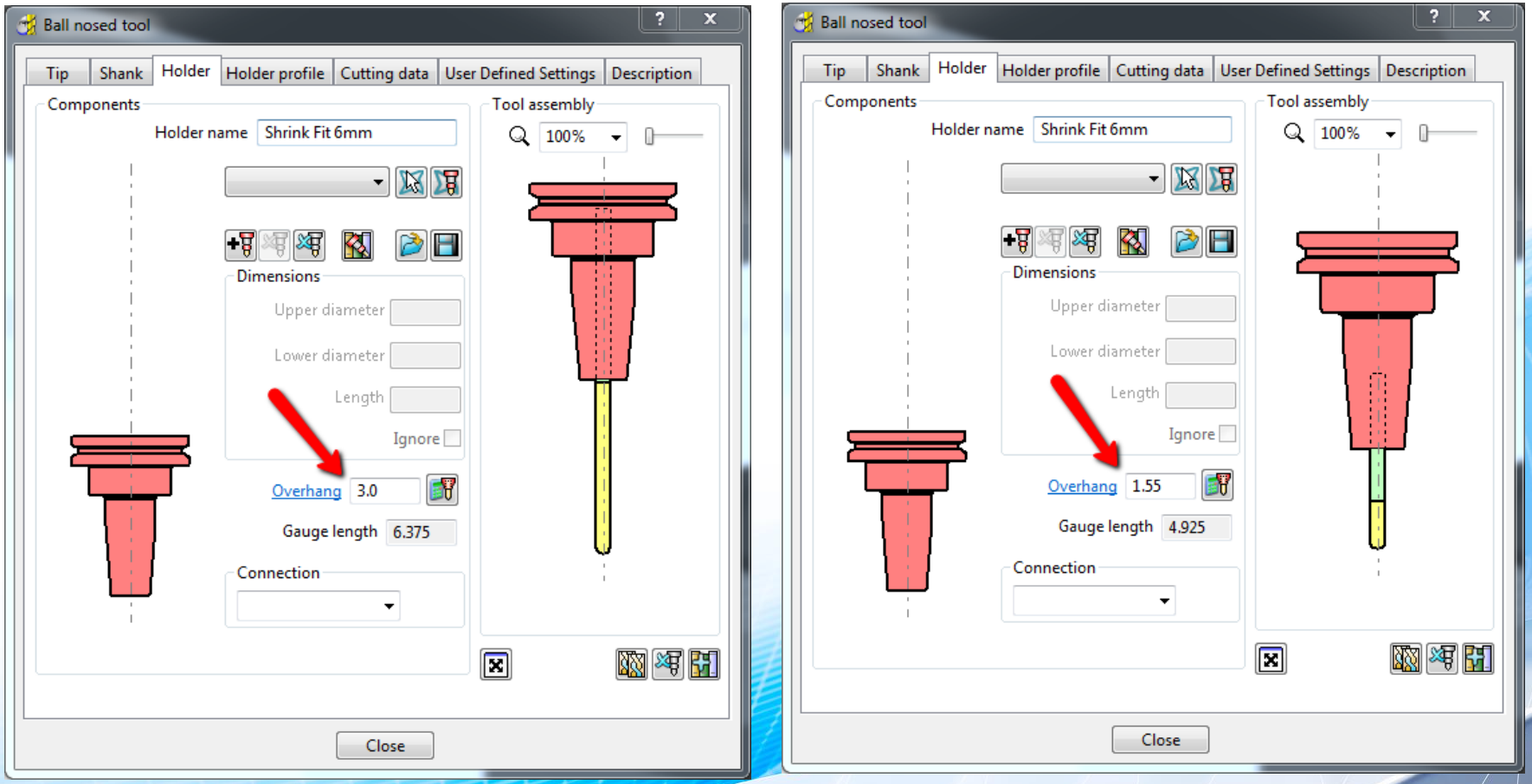
# Simultaneous 5 axis Vs 3+2 axis

- Reduced stickout length

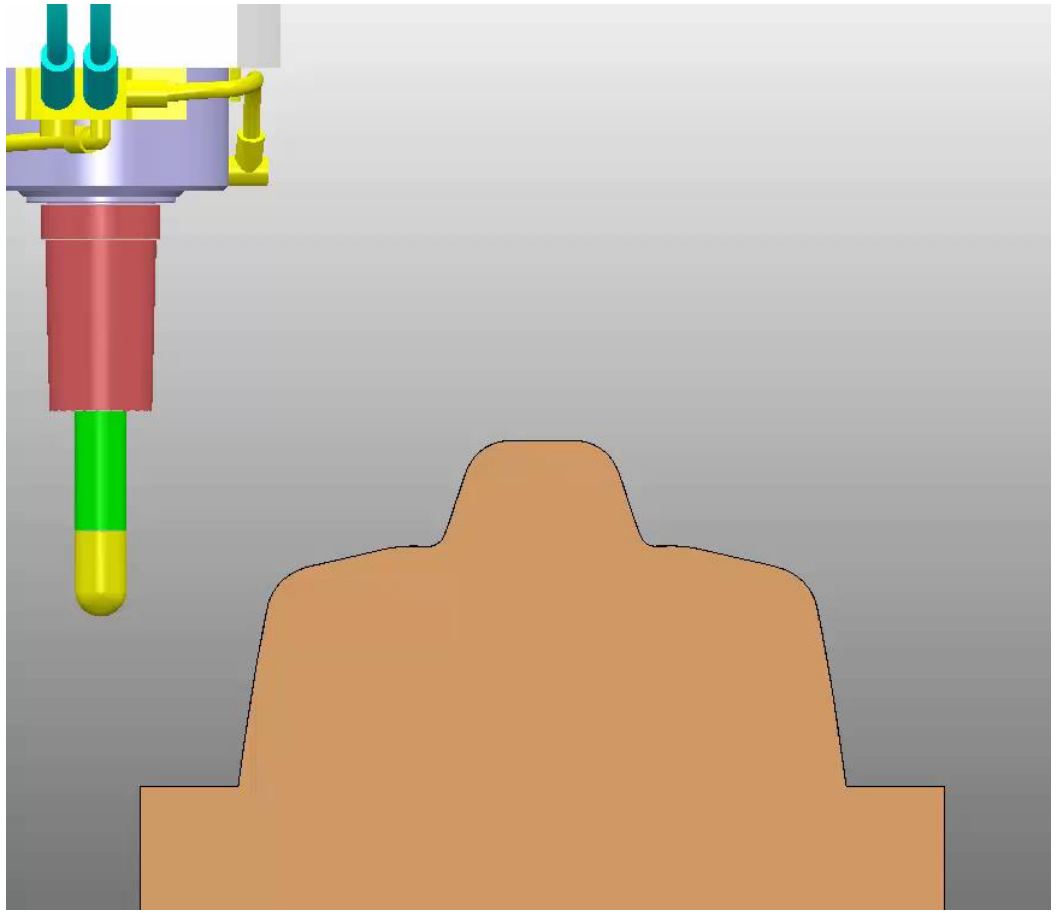


# Simultaneous 5 axis Vs 3+2 axis

- Reduced tool stickout



# Problems Caused by Excessive Stickout?



3 Axis Machining

- Greater tool deflection?
  - Poor tolerances
  - Increased probability of chatter
    - Poor surface finish
    - Reduced tool life

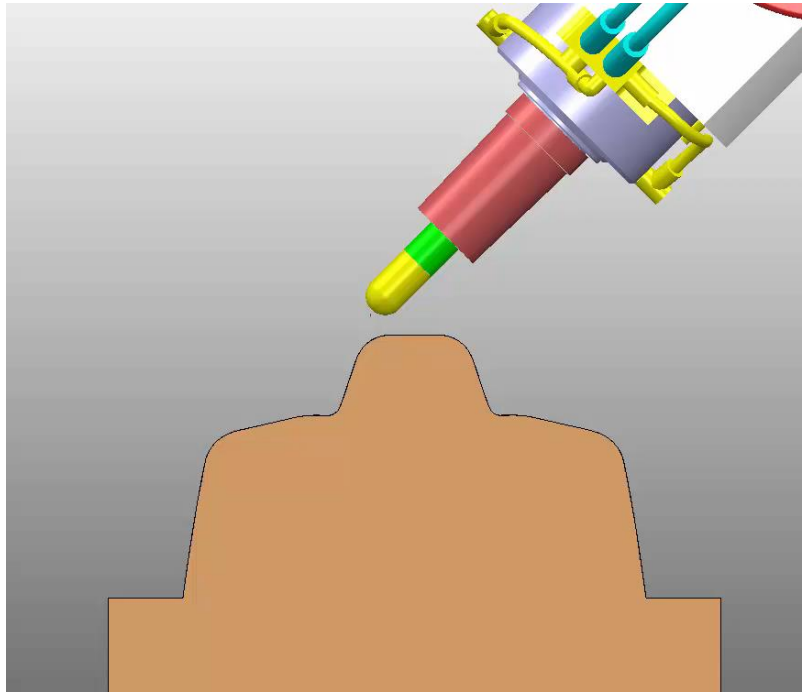
CNCCOOKBOOK.COM

Rigidity increases as the 3rd power of stickout.

Reducing stickout from 1.25″ to 0.75″ buys us 4.63x more rigidity…

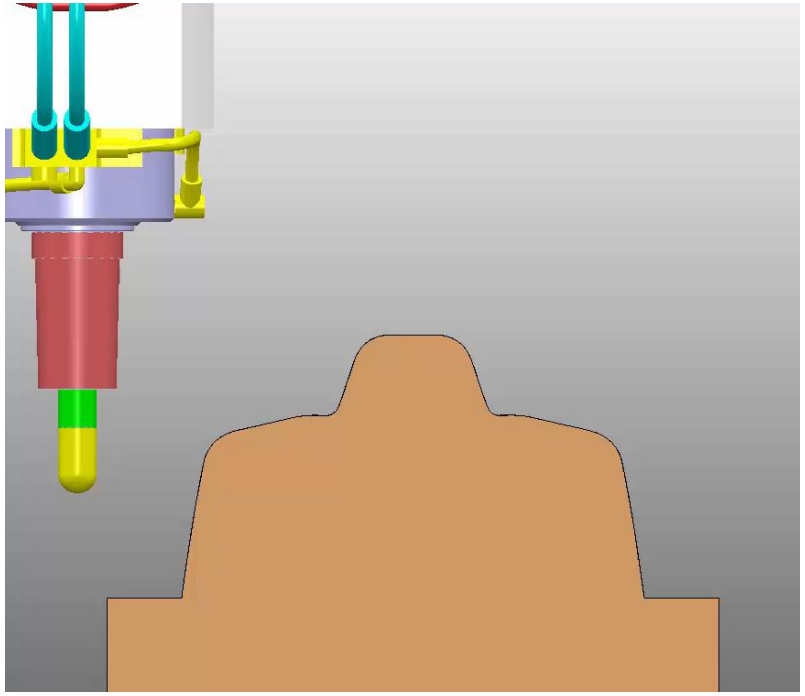
https://www.cnccookbook.com/afraid-tool-deflection/

# 3 Different ways to use your 5 axis machine tool



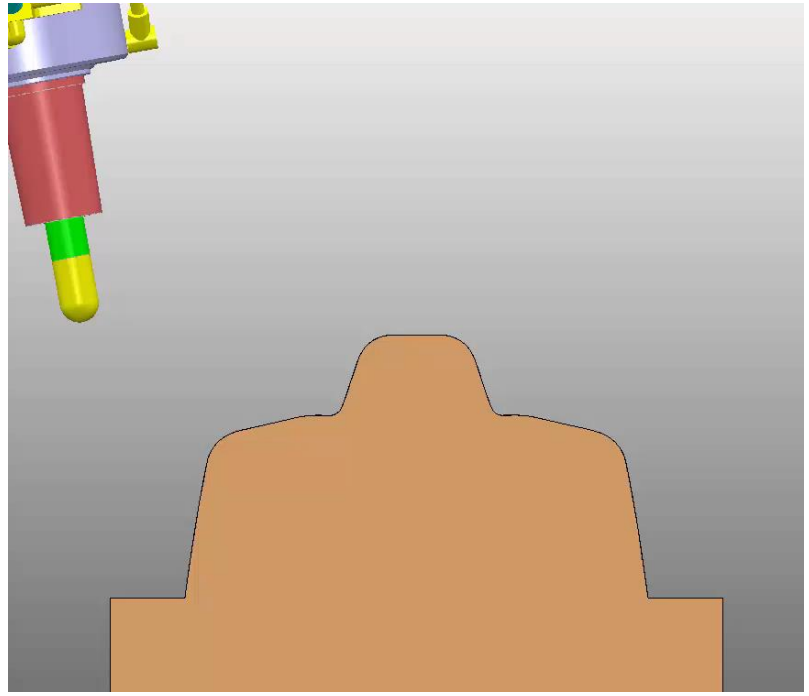
3+2 axis Machining

- Cutting has no  simultaneous rotary axis cutting motion. Predictable results
- Increased programming time on complex, feature rich parts
- More manual polishing to blend between individual toolpaths



4 Axis Machining
(Locking one rotary axis)

- Locking the C axis can improve the surface finish as there are no axis reversals or rapid C axis  accelerations
- Not suitable for more complex, feature rich geometry

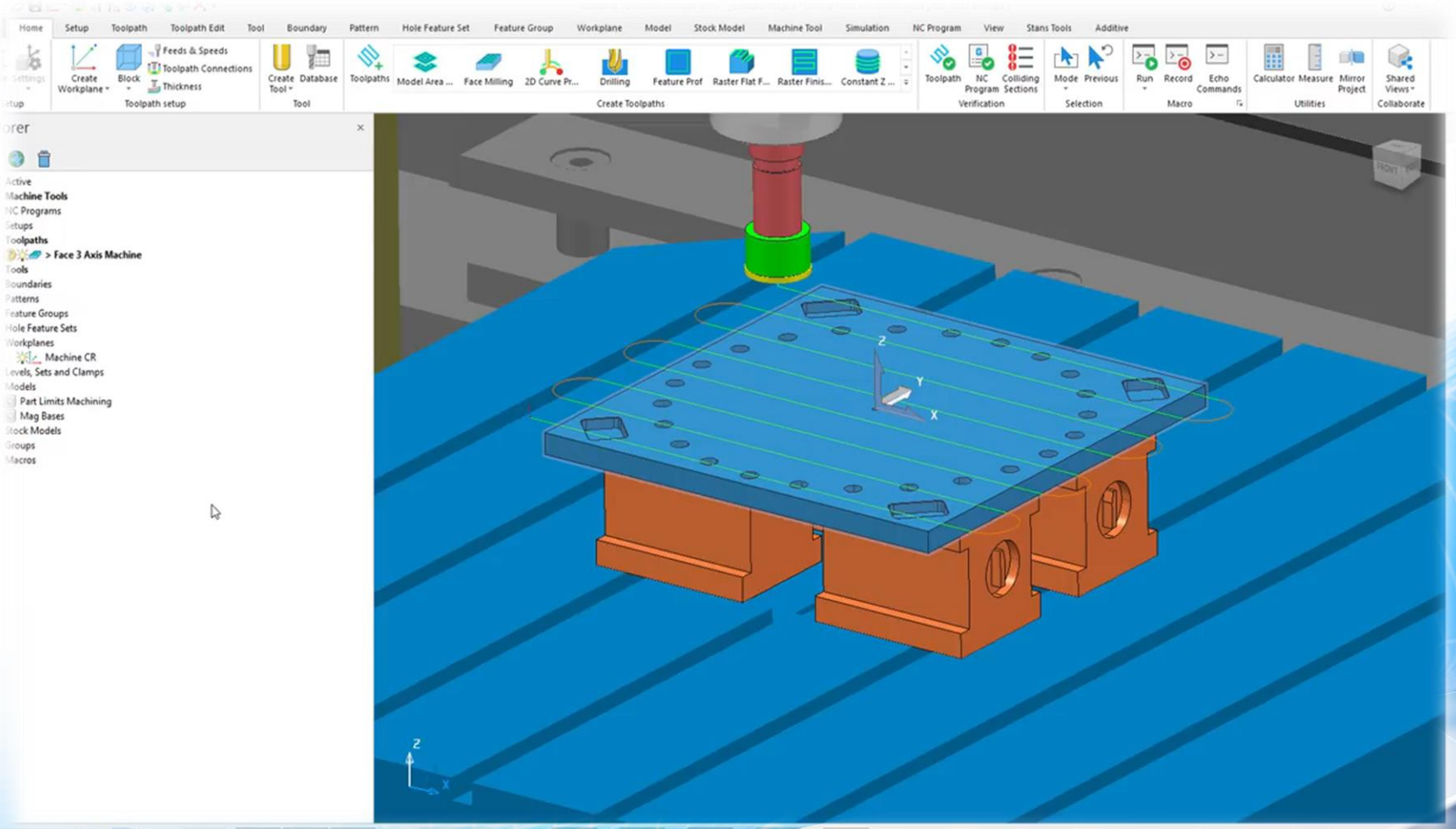


5 Axis Machining

- A single toolpath can cut the whole part. No ‘patchwork’ required
- Shortest possible tool stickout
- 2 simultaneous rotary axis can degrade the surface finish during sudden axis reversals or changes in acceleration

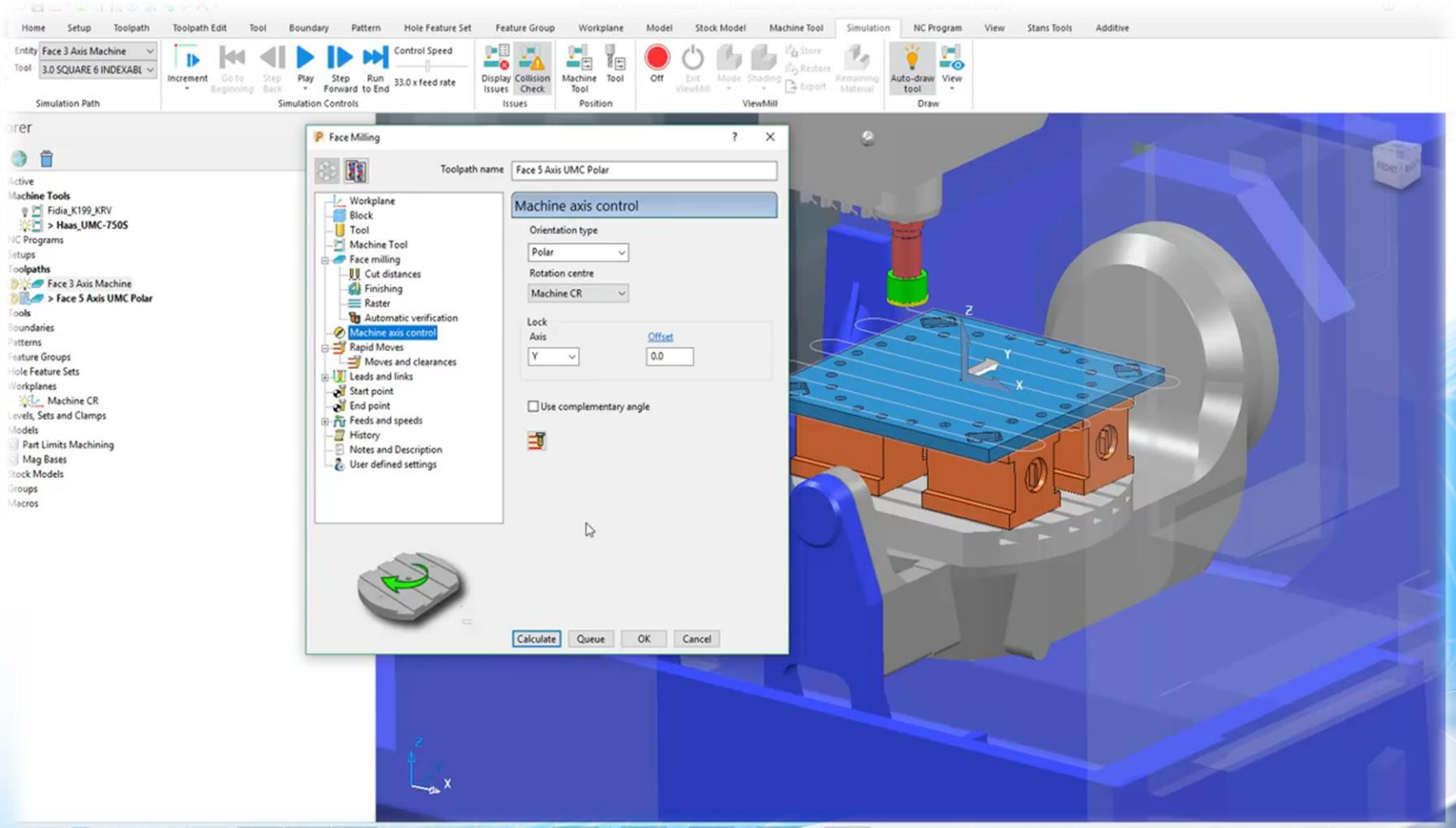
# Common 5 axis problems

- Problem? Toolpath exceeds the Y axis range



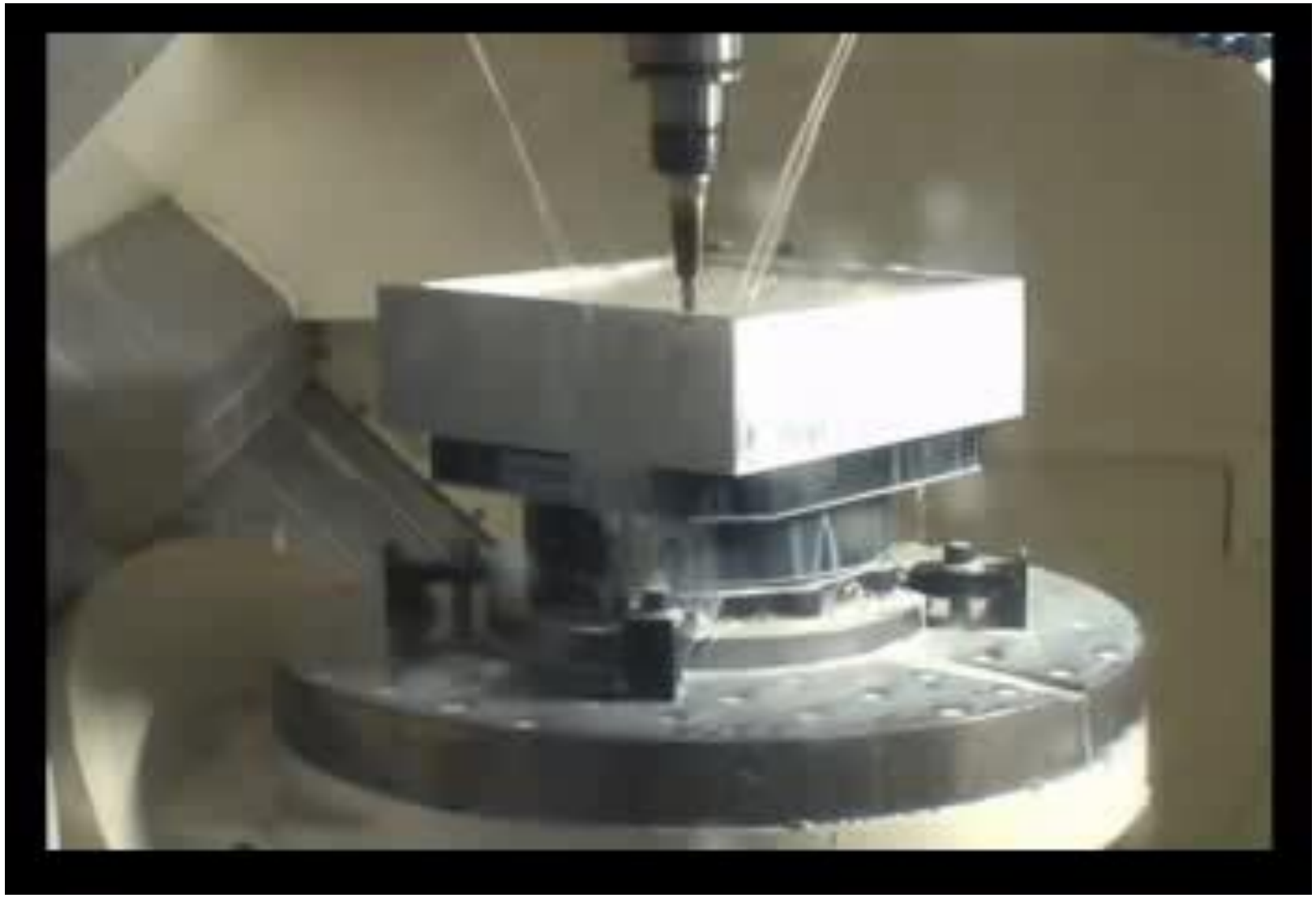
# Common 5 axis problems

- Solution? Fix the Y axis and replace it with the C axis (Polar Milling)



# Common 5 axis problems

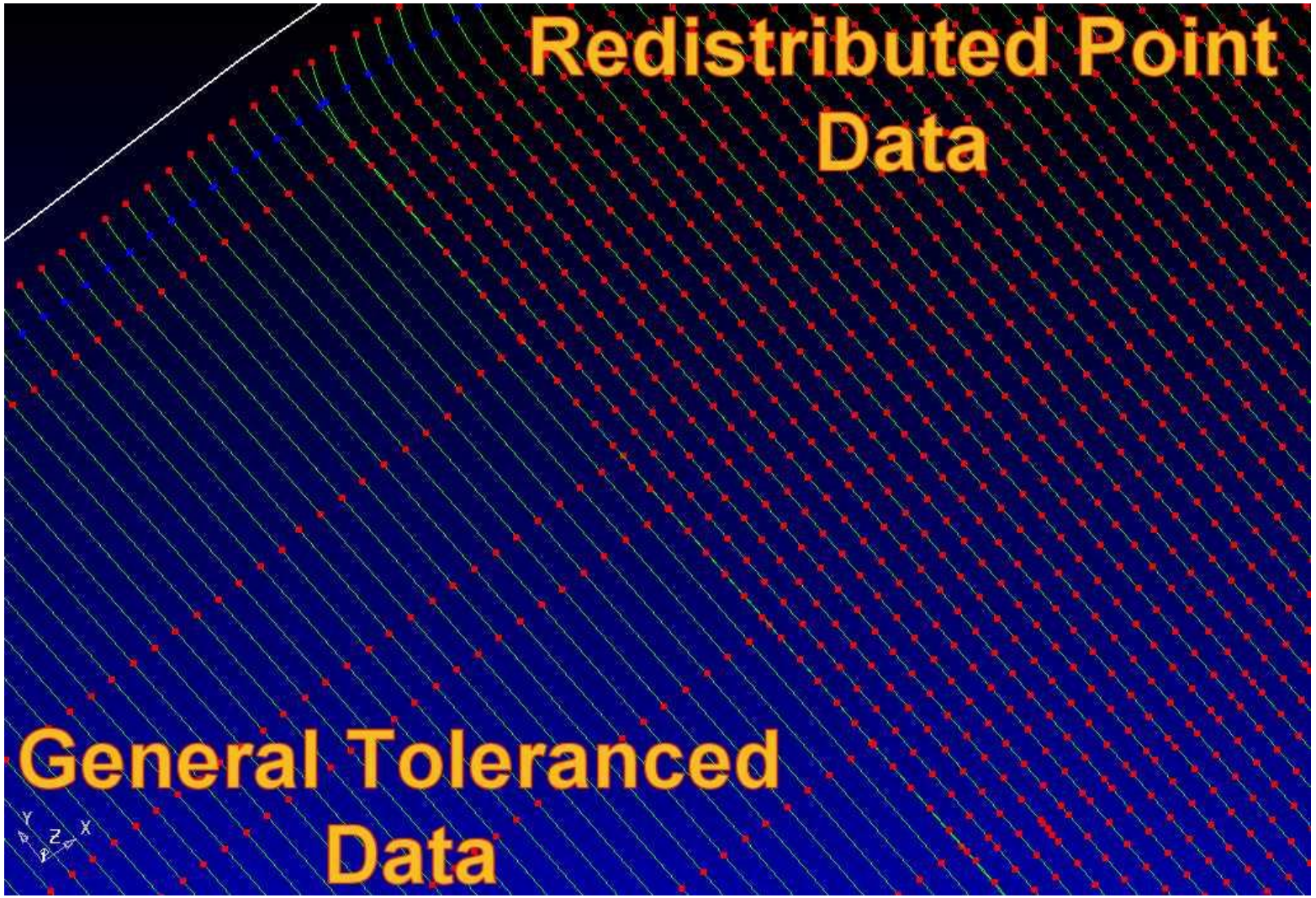
- Problem? Jerky Tool Motion



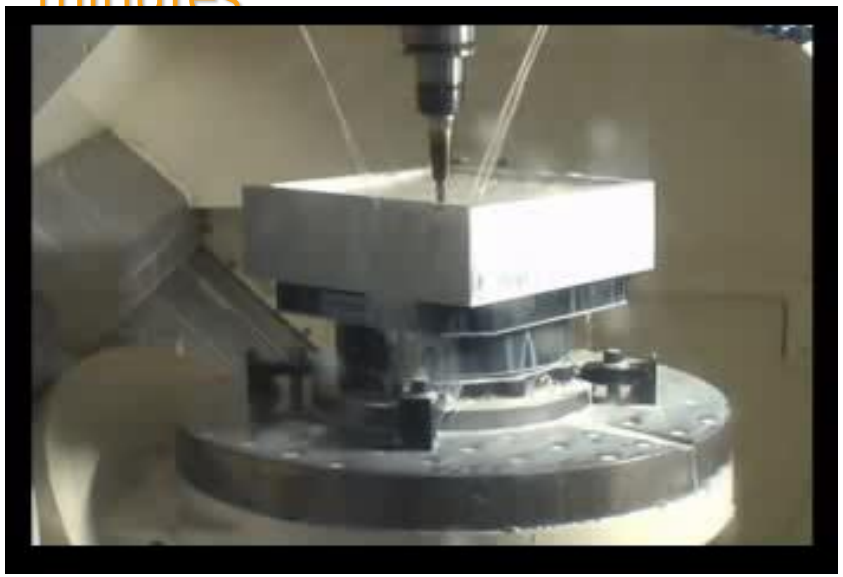
HuronKX8-Five
Siemens 840D
Feedrate:
7500mm/min

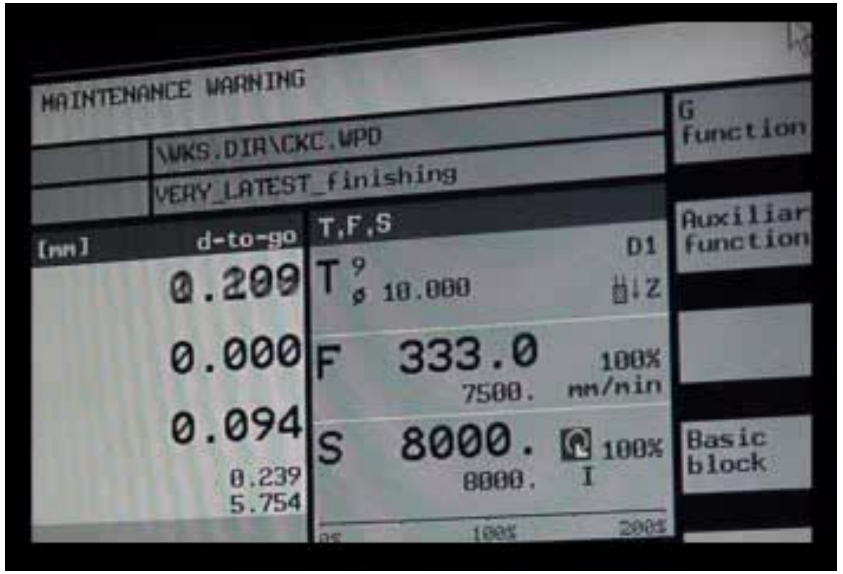
# Common 5 axis problems

- Common Solution? Evenly space the points on the toolpath. This enables the CNC control to process the toolpath faster and more smoothly

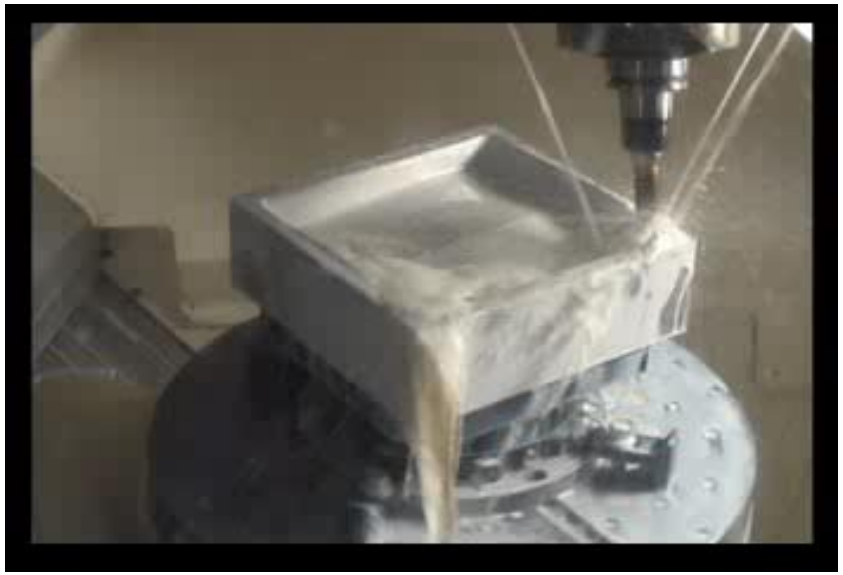


Standard Tolerance @Feedrate 7500 mm/min + CYCLE832. Machining time: 82 minutes





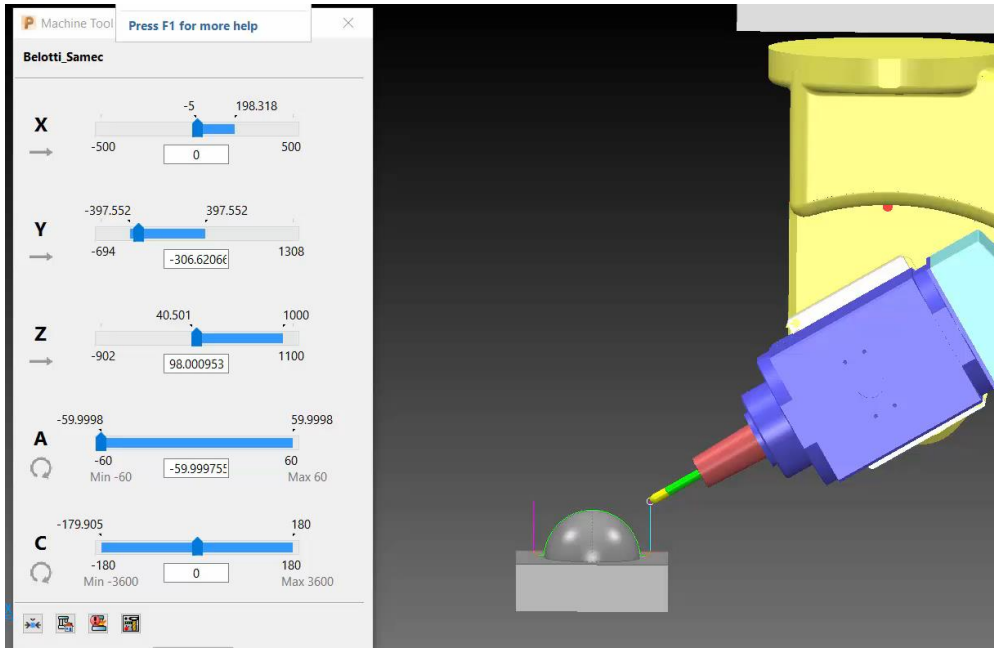

Redistributed Points @Feedrate 7500 mm/min + CYCLE832. Machining time: 50 minutes

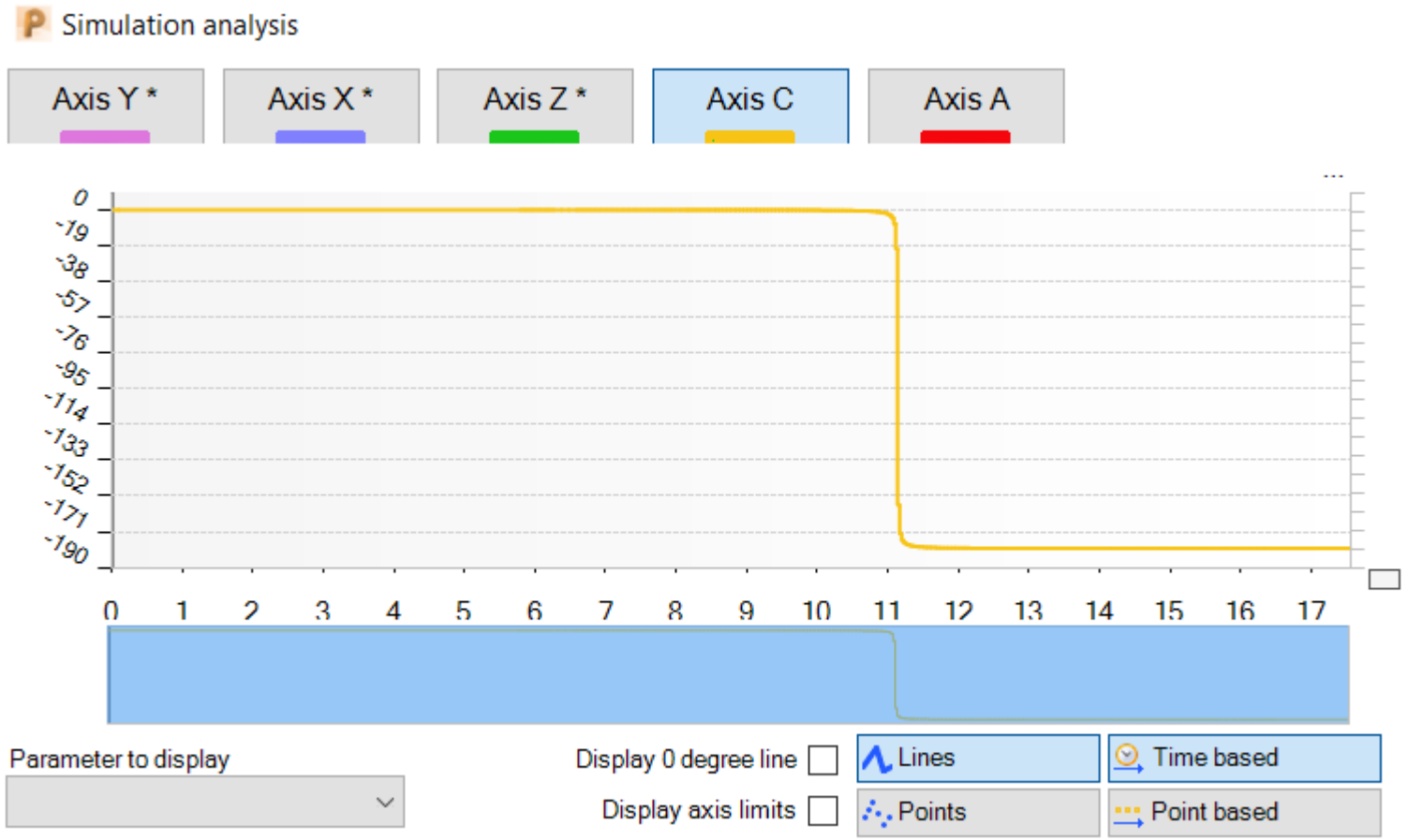


**39% cycle time saved by utilizing evenly spaced point distribution**

# Common 5 axis problems

- Problem: Rapid rotary axis acceleration. Typically occurs when the tool axis is close, but not through the machines singularity (The machines singularity commonly = the Z axis)



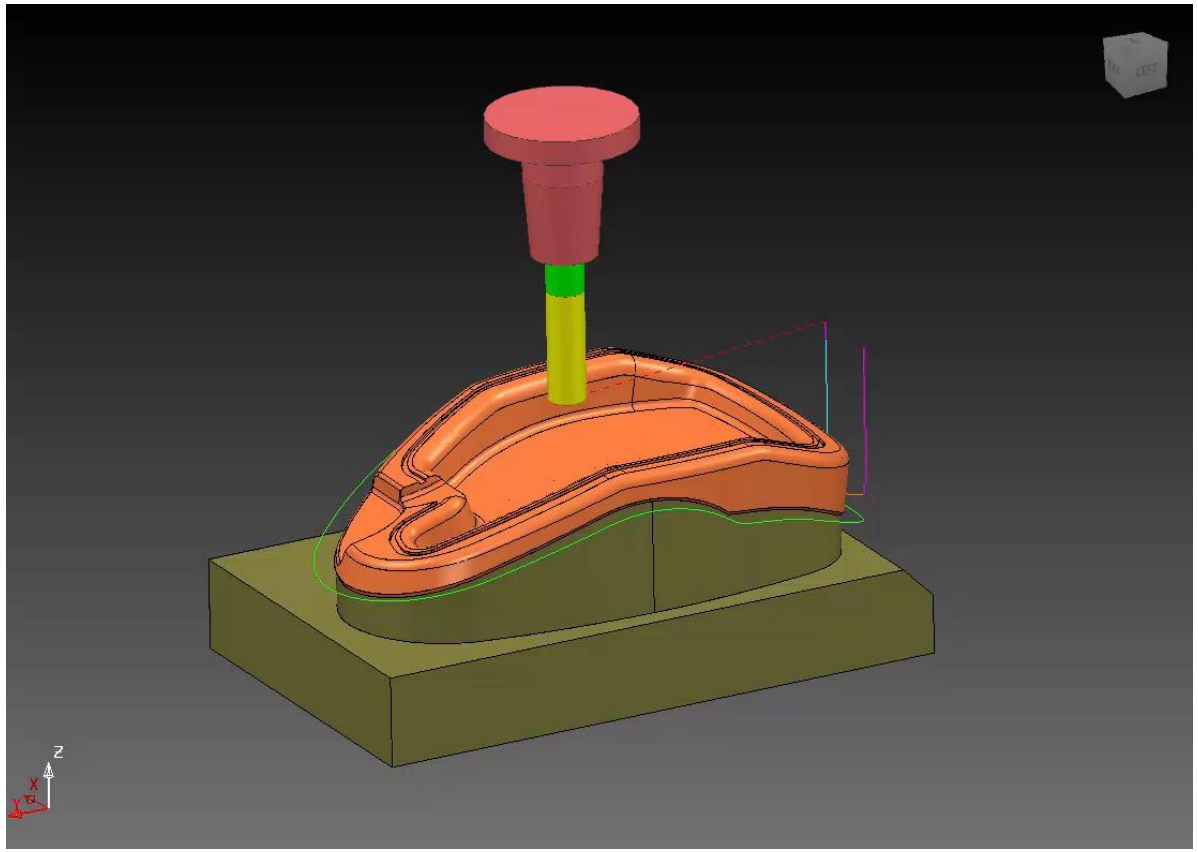




Tool axis pointing towards spherical center, passing directly over the center point at X0

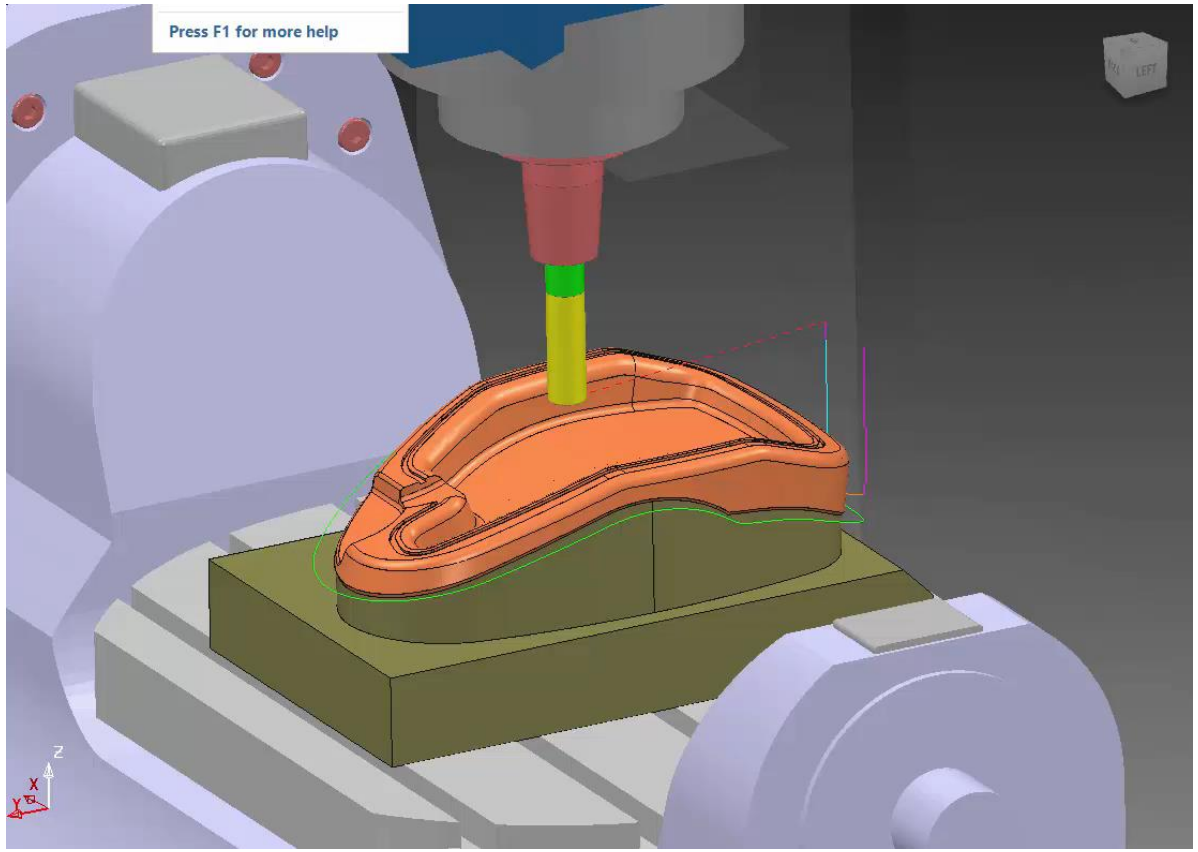
Tool axis pointing towards spherical center, offset in X by 0.01mm

# Common 5 axis problems

- Problem: Rapid rotary axis acceleration. Typically occurs when the tool axis is close to the machines singularity
  (The machines singularity commonly = the Z axis)



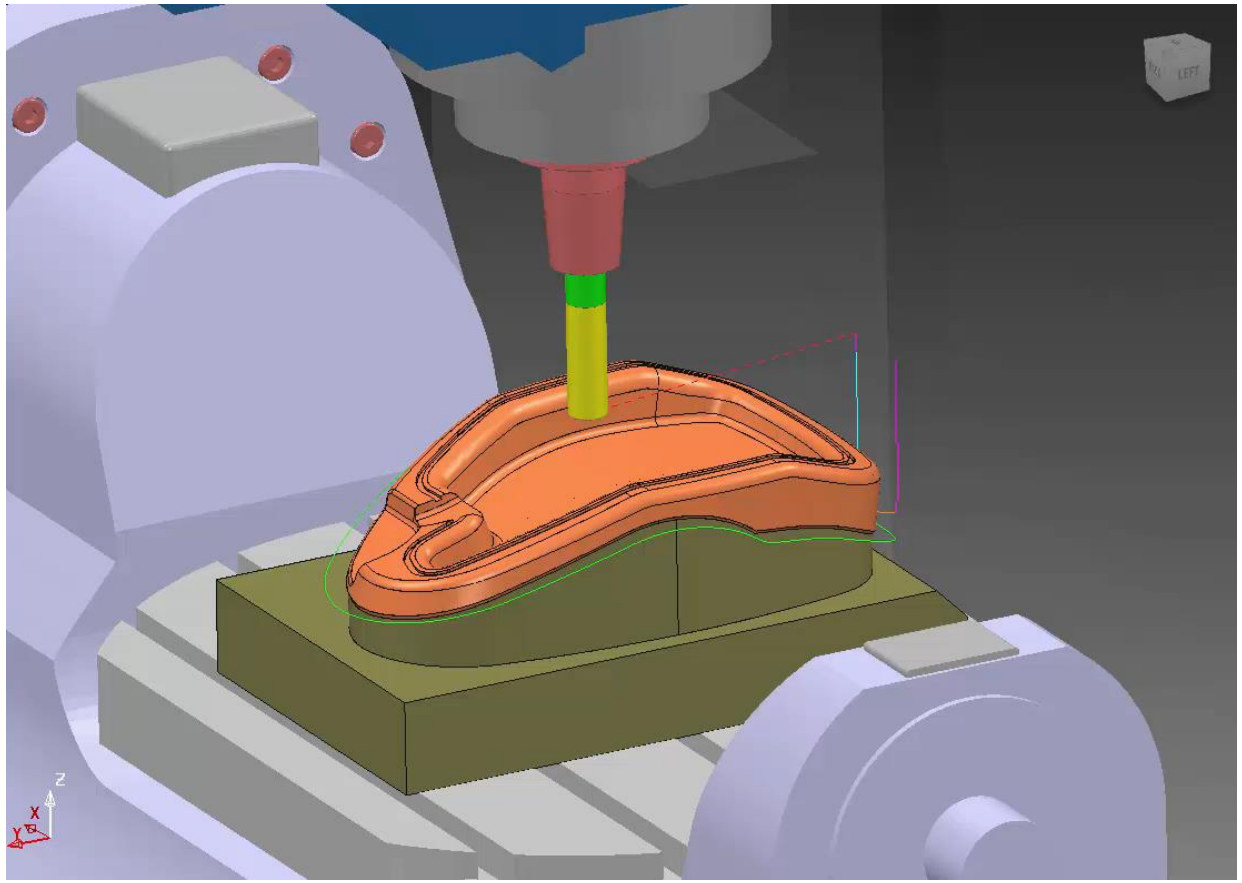
Is the machine motion smooth?



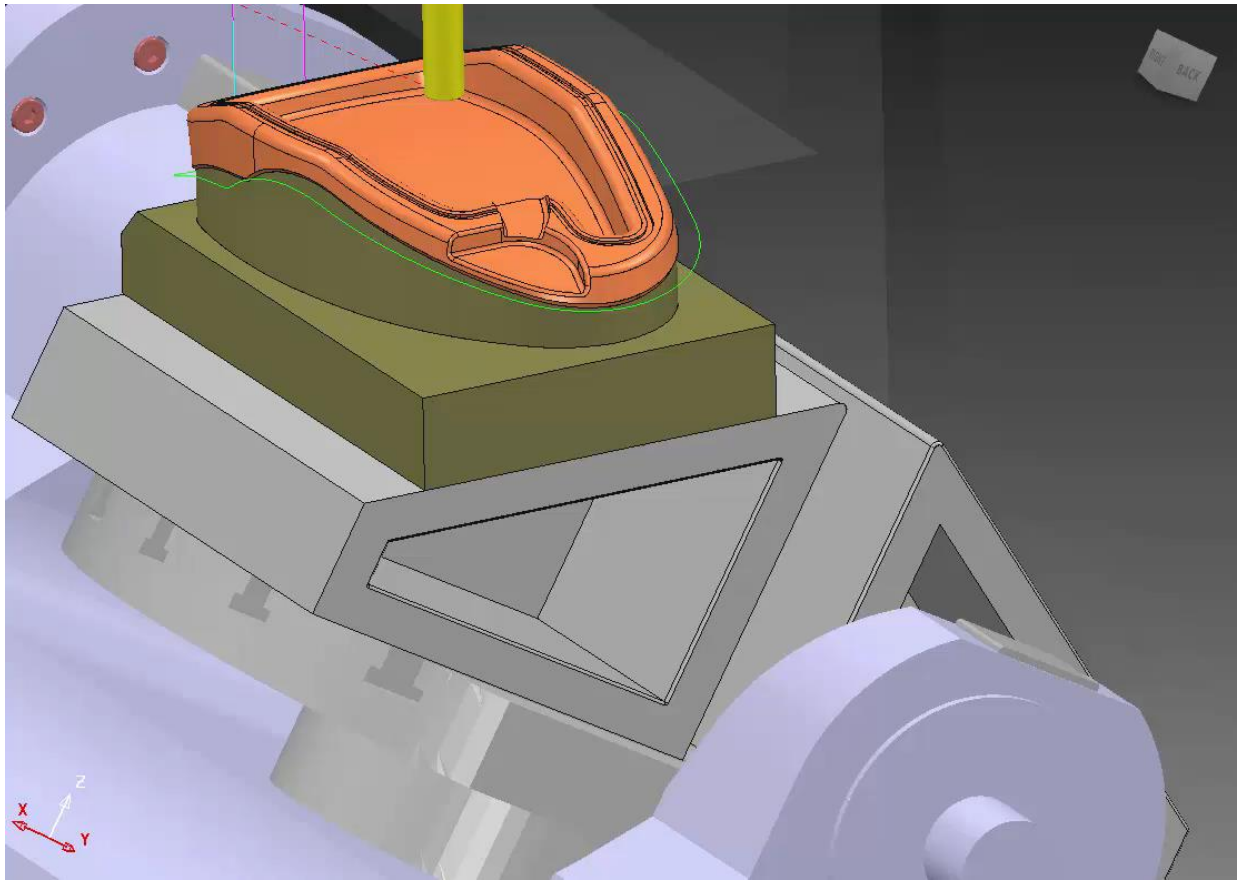

No! There are 2 rapid C axis accelerations.

# Common 5 axis problems

- Solution 1: Move the tool axis away from the singularity by mounting the part on an angled fixture



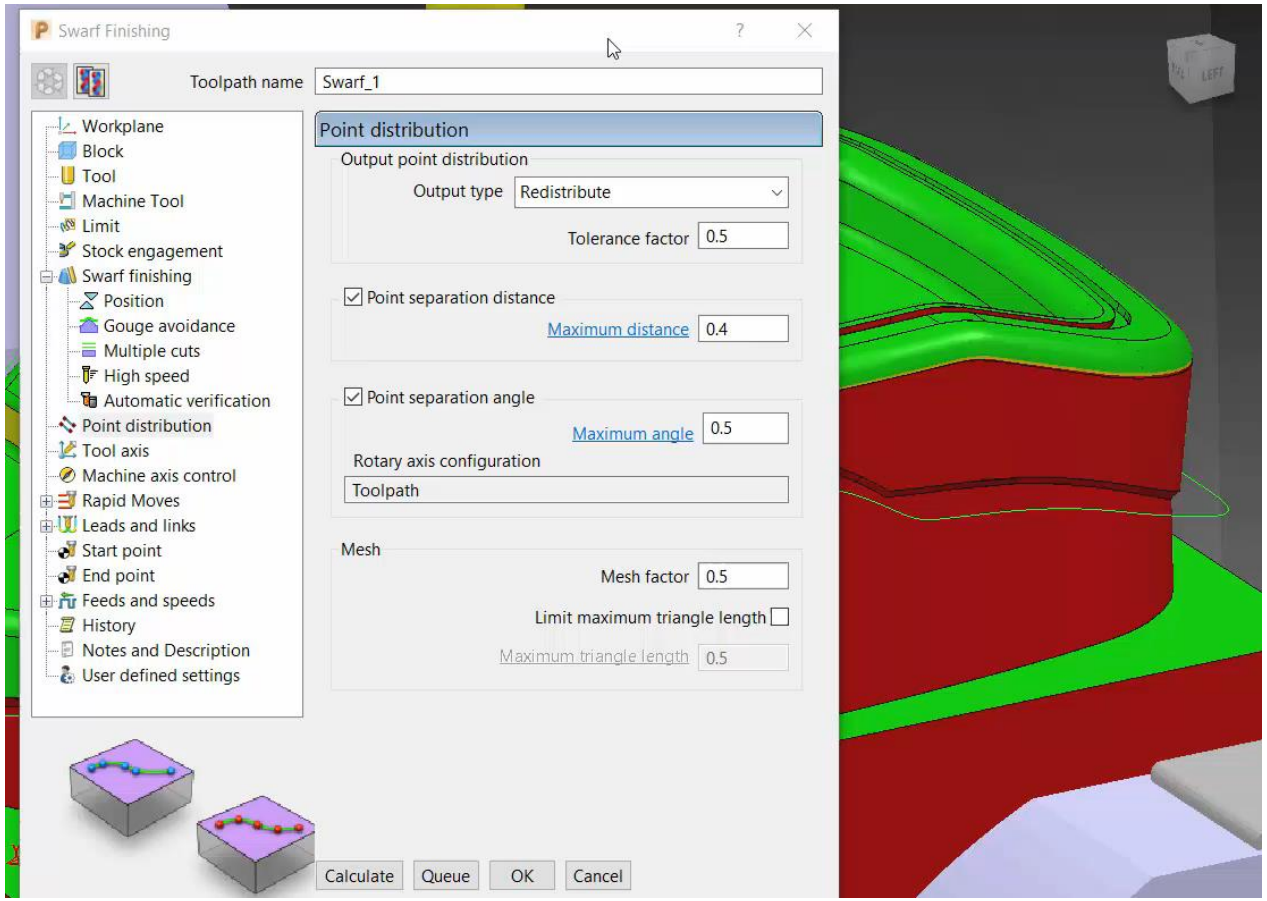
The problem: Large C axis move.
This is caused by the toolaxis moving from a +ve to a –ve draft angle, close to the singularity



The same toolpath on the same machine tool now runs smoothly. The fixture has moved the tool axis away from the singularity (Z Axis).

# Common 5 axis problems

- Solution 2: Add more points in the region where excessive rotary action occurs

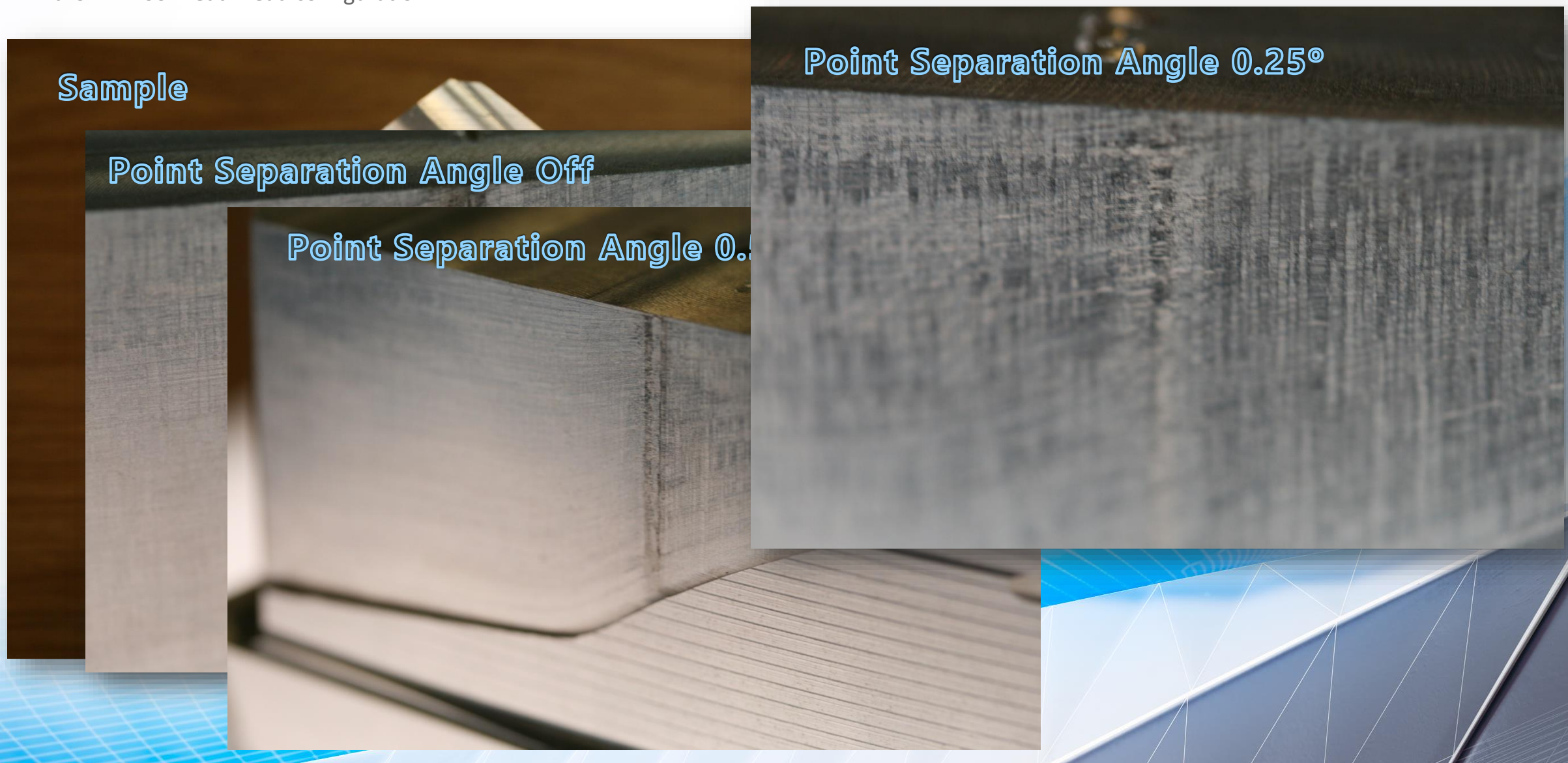



We can reduce the impact of the problem by adding additional points into the toolpath when simultaneous 5 axis machining close to the machine tools singularity.

This solution is not as effective as fixturing the part away from the singularity, but it is an easier and cheaper method of reducing the negative effects of this problem.

# Results

- Huron KX200  Head-Head configuration



# Questions?

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Make anything™

- RTCP
- An option not to be neglected

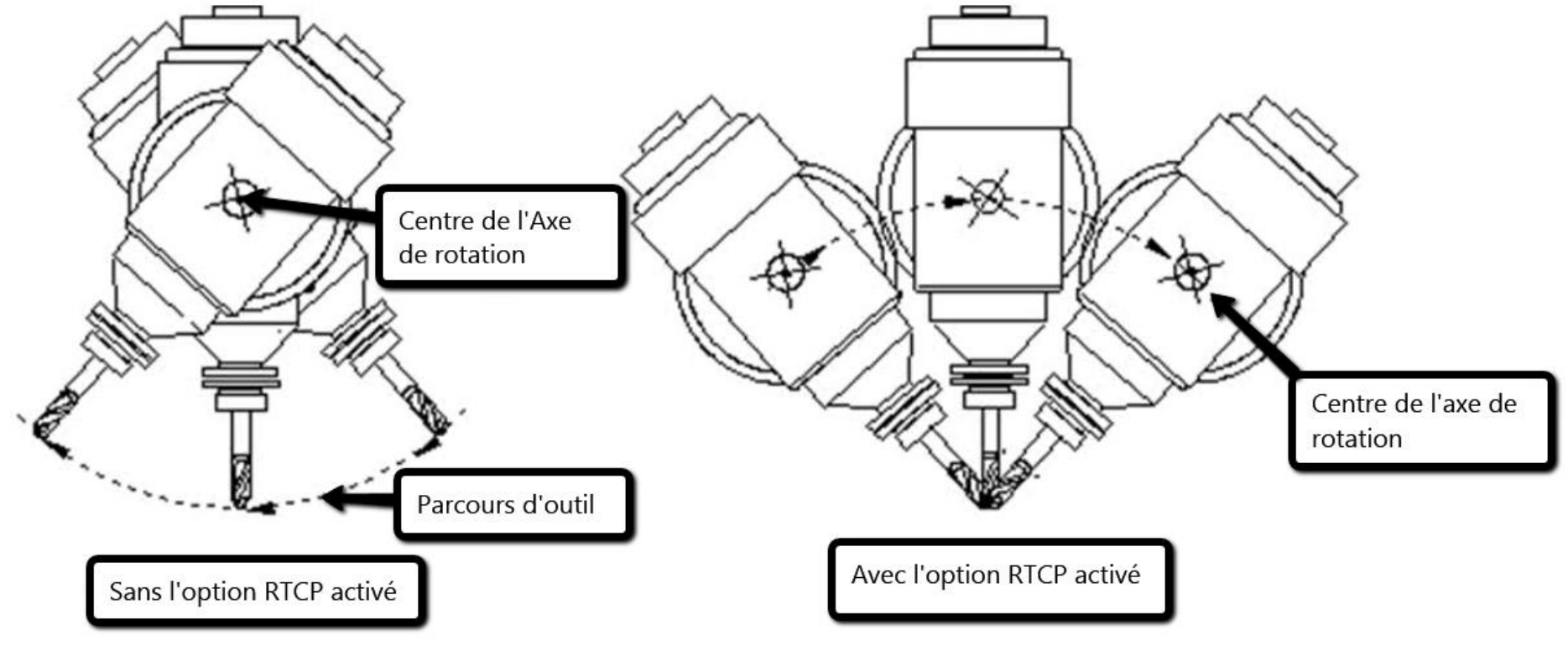
## RTCP (Rotation Tool Center Point)

- It is the sum of the distance of the pivot and the total length of the tool
- Generally referred to as G 43.1, G 43.4, G 43.5, G143, TRAORI or M128
- Usually disabled by the G49 code, TRAFOOF or M129
- Keeps movement fluid

- RTCP

- An option not to be neglected
-

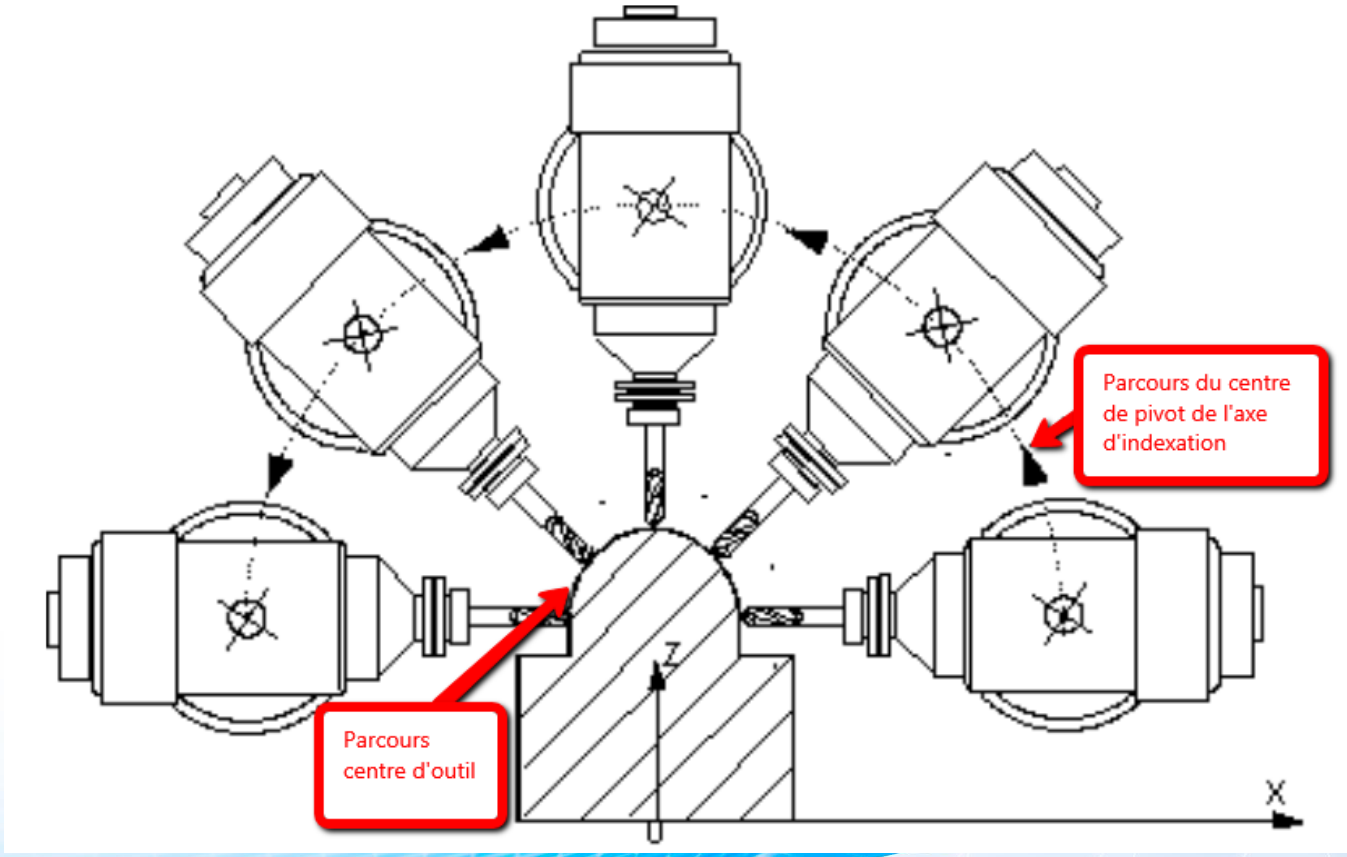
## RTCP (Rotation Tool Center Point)



- RTCP

- An option not to be neglected
-

## RTCP (Rotation Tool Center Point)



- RTCP

- Use Inverse Time feed
  - We will not be able to use feedrate in inch/min or mm/min
  - Calculate the time needed for each of the axes to get to the end of this movement
  - States that all axis will arrive at the end of this movement at the same time
  - Need to have a feed for each line.
- Manually calculate the RTCP of the machine
- We will have to enter the pivot distances in the programming software to get precise code.
- The pivot distances will have to be calculated very precisely.
- The location of the part on the machine must be known prior to post-processing

- Allows you to keep all the features as in 3 axes
- Easy to enable/disable
- Allows a single zero
- Location of the part not important