

# High-Capacity Mobile Robotic Drilling and Fastening System

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Electroimpact, Inc.

Special acknowledgement:  
The Boeing Company

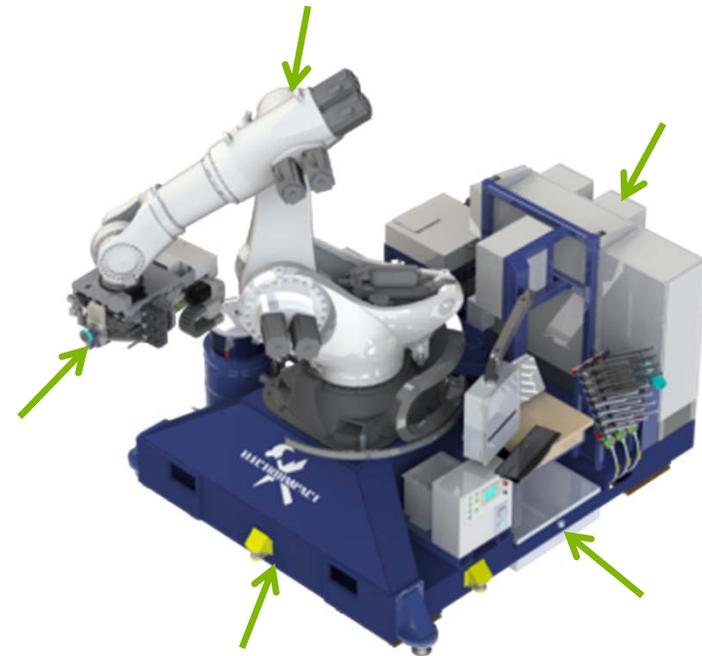
**SAE** *International*

# High-Capacity Mobile Robotic Drilling and Fastening System



# High-Capacity Mobile Robotic Drilling and Fastening System

- **What to expect in the next 25 minutes:**
  - **Application**
  - **Brief System Familiarization**
  - **Quick Comparison**
  - **System Design Requirements/Constraints**
  - **Interaction with Jigs**
  - **Automation System Basics**
    - **Mobile Platform**
    - **Robot**
    - **End Effector**
  - **Drilling Process**
    - **Skins**
    - **Fittings**
  - **Short Videos**
  - **Questions**



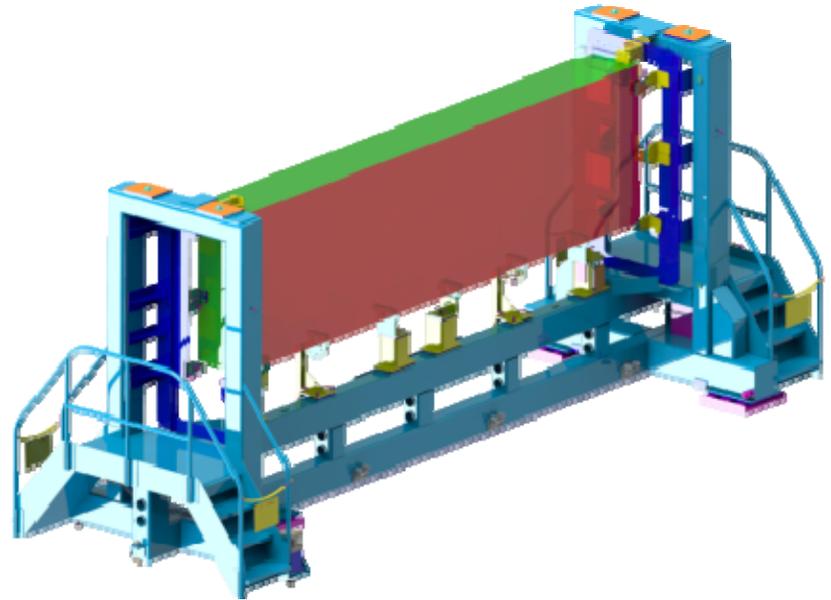
# Application: Aircraft Wing Section

- **Automation Goals**
  - Maximize quality
  - Reduce manual labor
    - Reduce dependence on drill plates
    - Reduce dependence on power feed drills



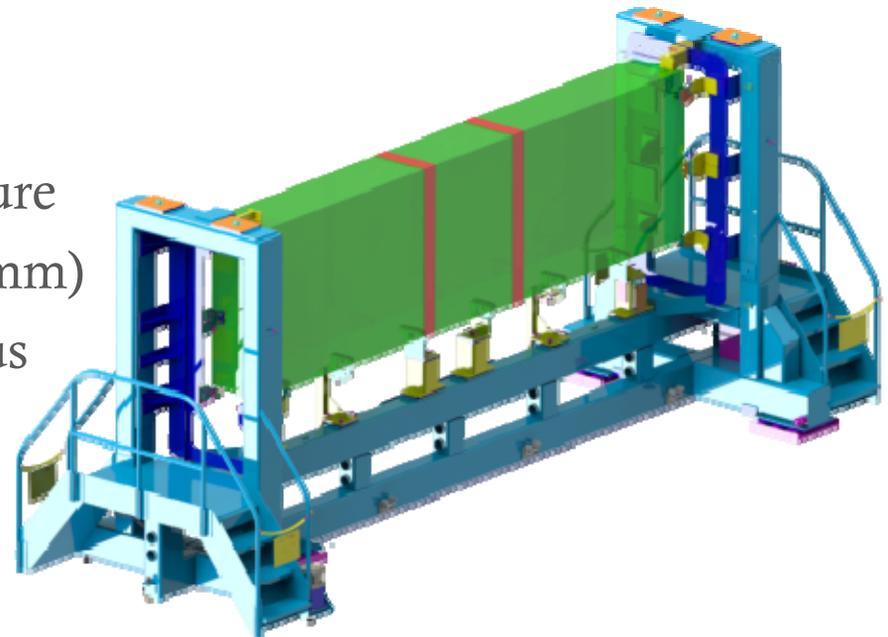
# Application: Aircraft Wing Section

- **Skins to Structure**
  - Drill, CSK, Measure, Temp Fasten
  - Drill sizes 3/16 - 3/8" (4.8 - 9.5mm)
  - Aluminum only
- **Fittings, Skins, Structure**
  - Spot/Endmill, Drill, Ream, Measure
  - Drill sizes 1/4 - 9/16" (6.4 – 14.3mm)
  - High-strength materials and various aluminum alloys

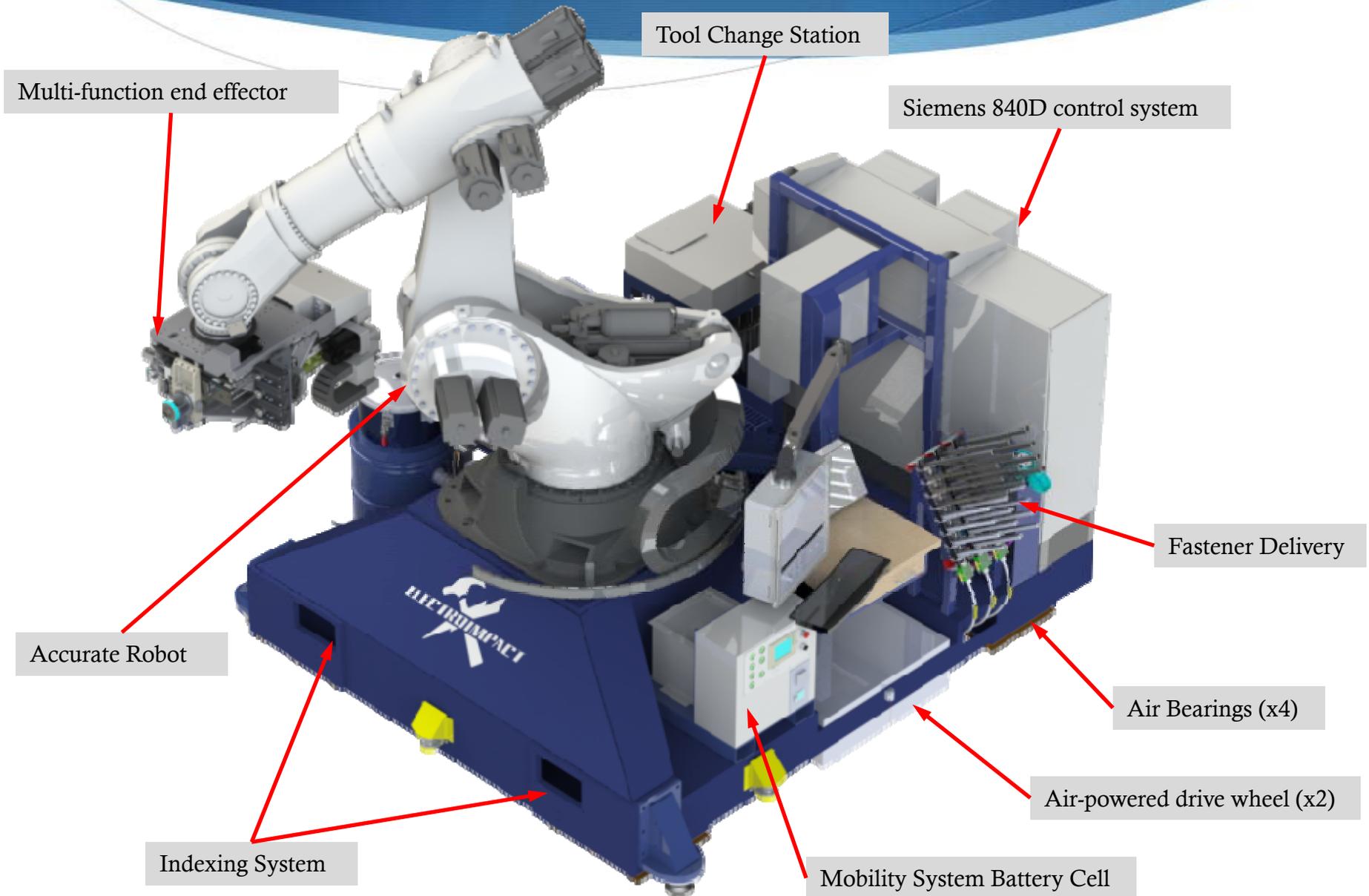


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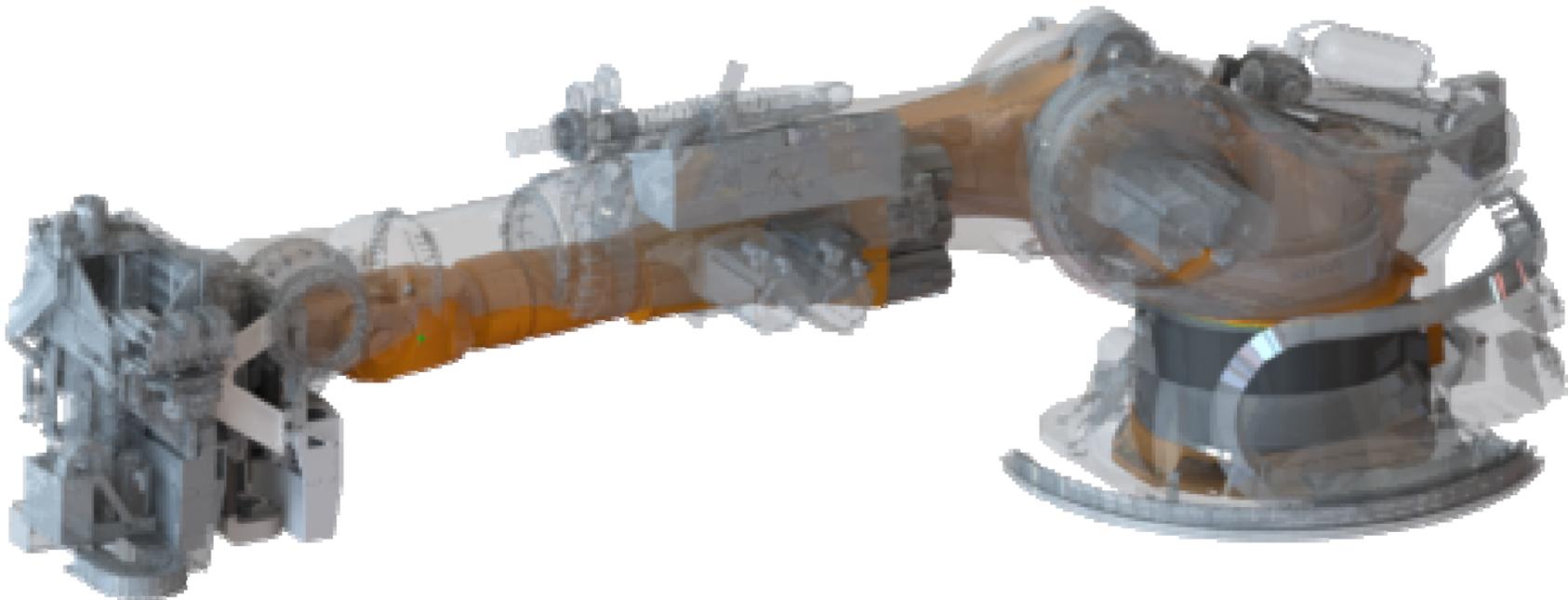
# System Familiarization



# Compare to Typical Robotic Drilling System

- **Robot**
  - Reach: 10% increase (4.3m vs. 3.9m)
  - Payload Capacity: 2.2x (750kg vs. 340kg)
  - Stiffness Increase: ~2.5x

\*\*Stiffness and stability – no bushing guiding drill\*\*



# Compare to Typical Robotic Drilling System

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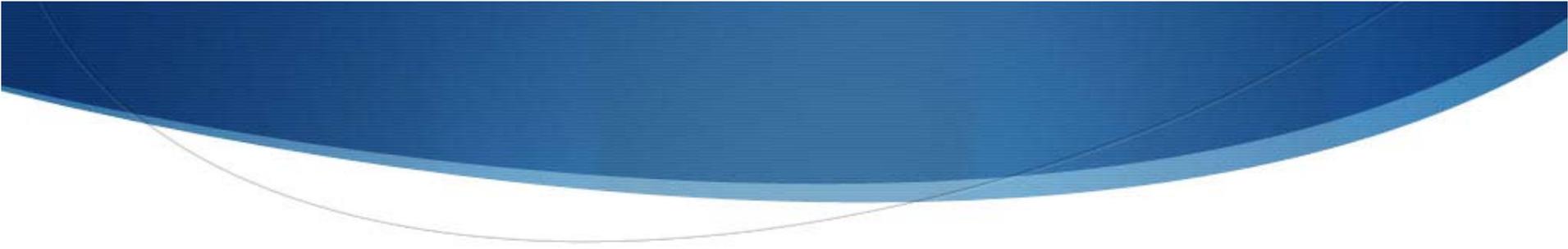


- **Process Head**

- Clamp load: 2.2x (1200 lbf vs. 550 lbf)
- Spindle: HSK63 vs. HSK40
  - Power Increase: 2.8x (25kW vs. 9kW)
  - Torque Increase: 2.7x (40Nm vs. 15Nm)
  - Hole size in Ti: 2x (~25mm vs. 13mm)

- **Extras**

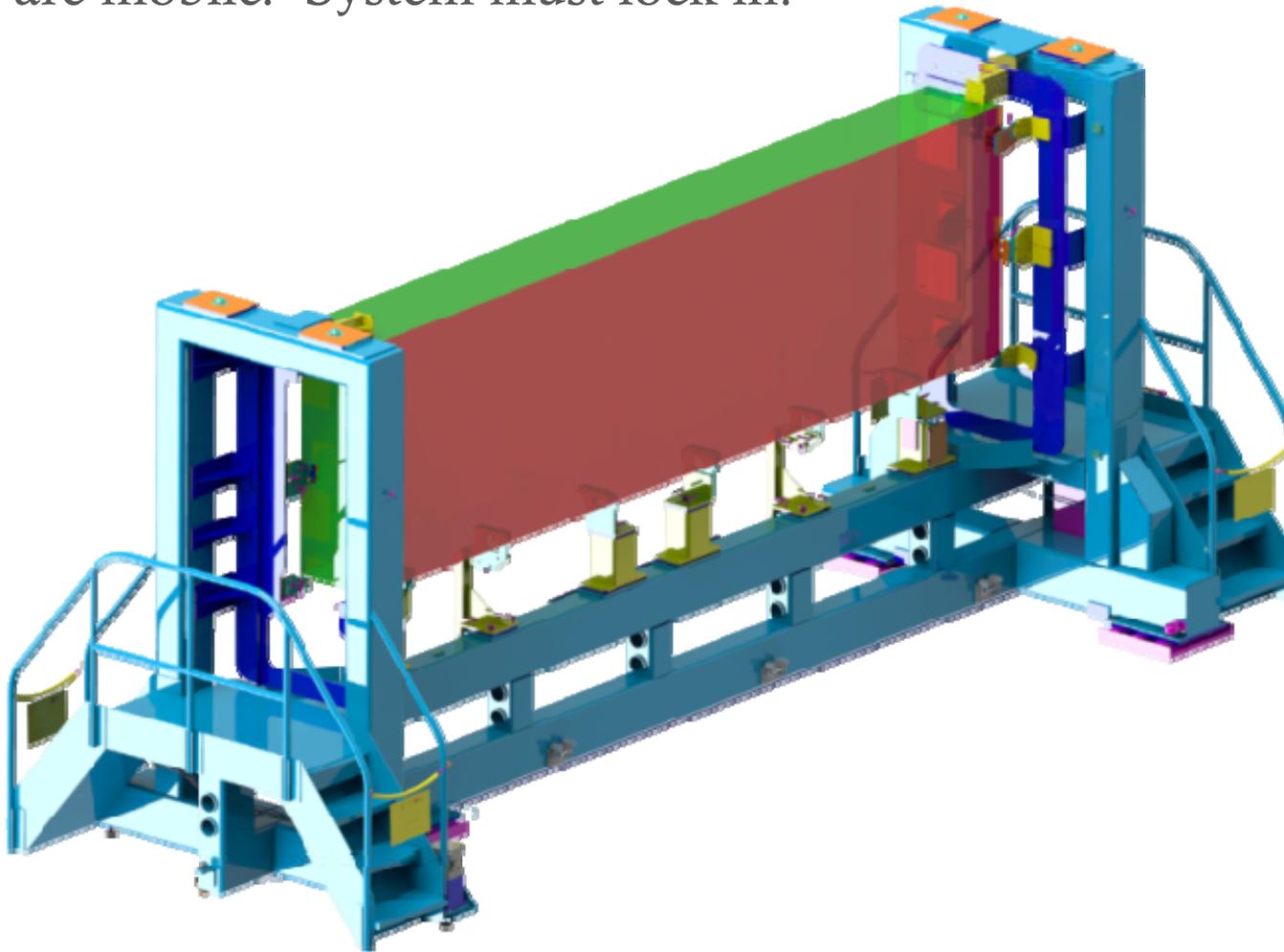
- On board tool swap
- Integral mobility system (pendent and/or camera controlled)



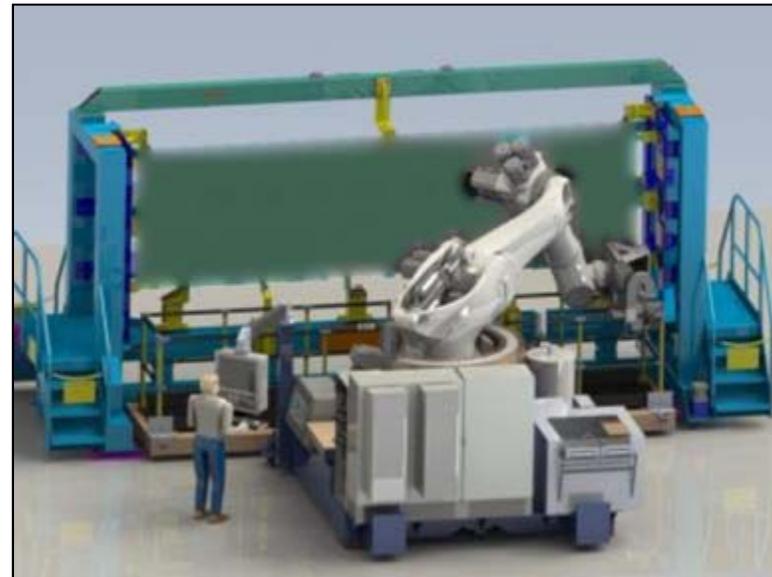
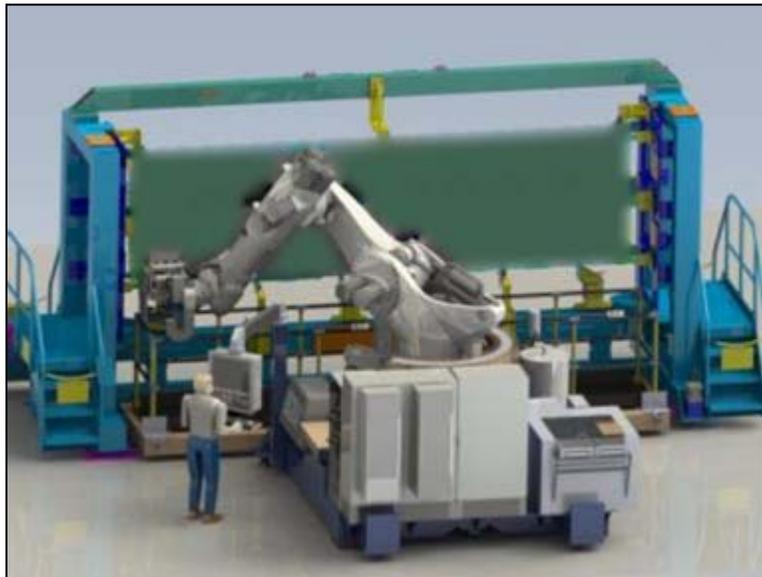
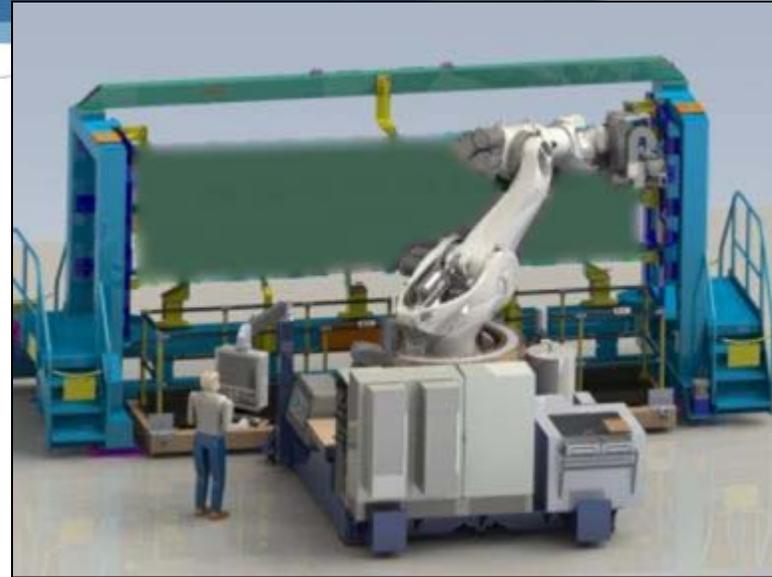
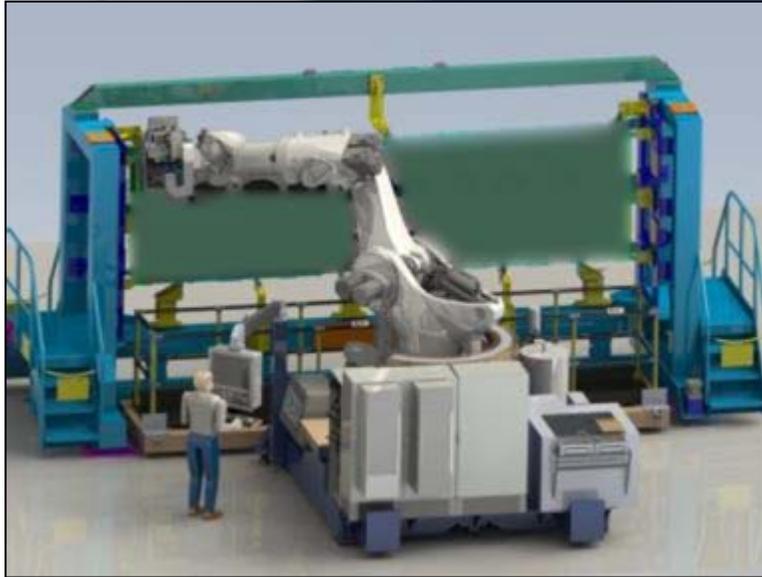
# Application-Specific Requirements/Constraints

# Requirements/Constraints: Existing Tools

- System must reach all areas of product without collision with tool
- Tools are mobile. System must lock in.



# Requirements/Constraints: Reach All Corners

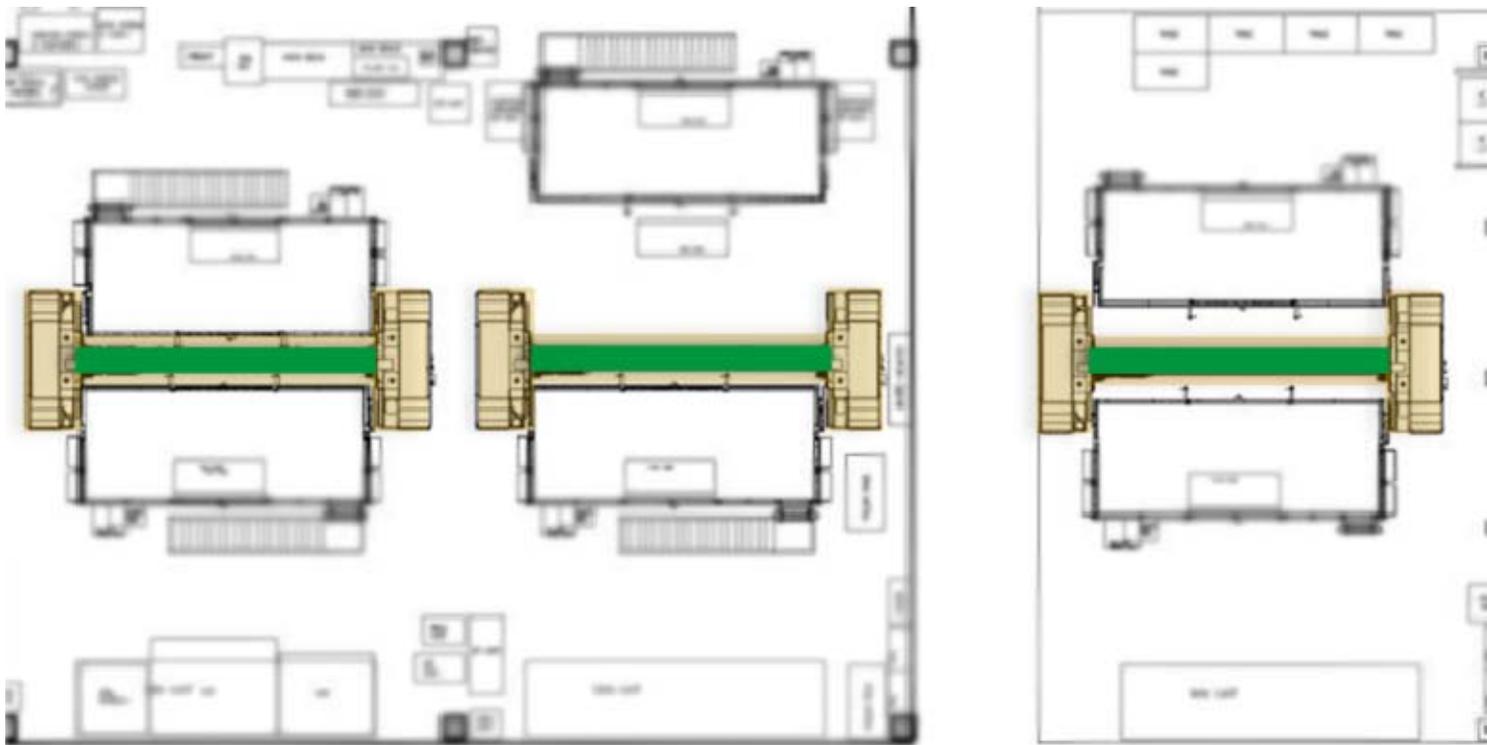


# Requirements/Constraints: Reach Top of Part

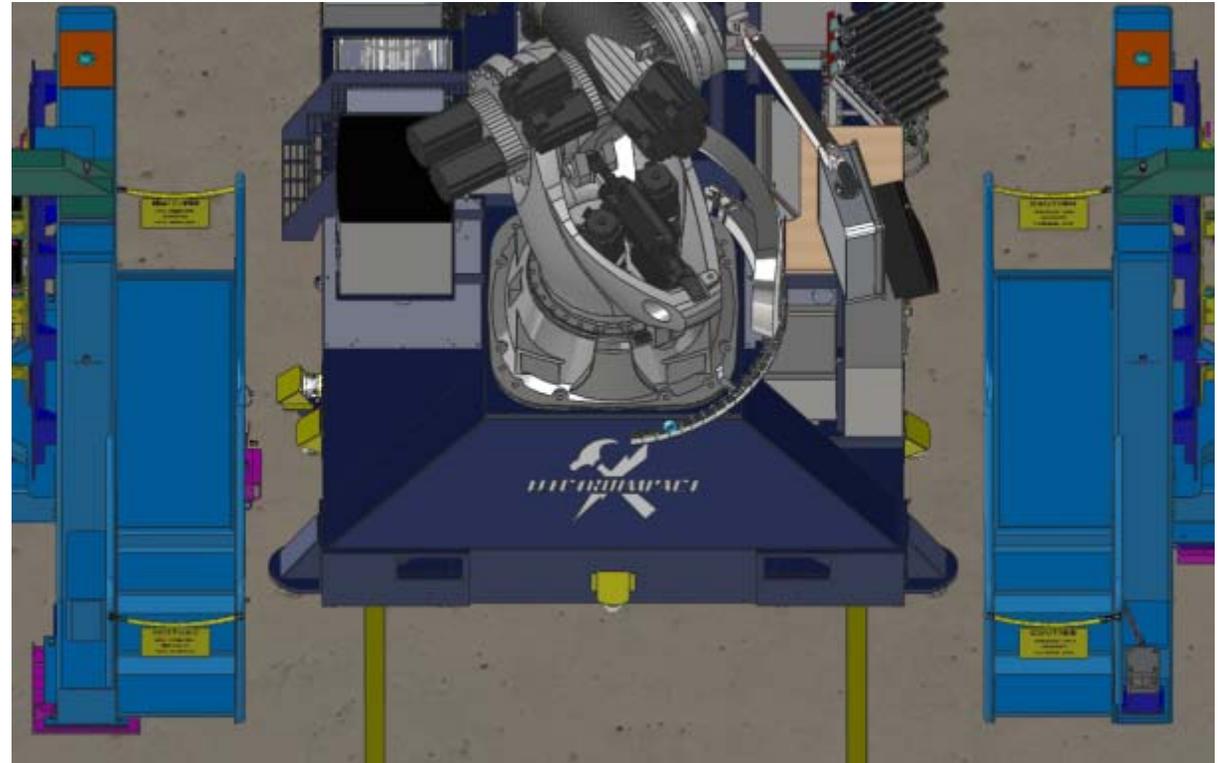
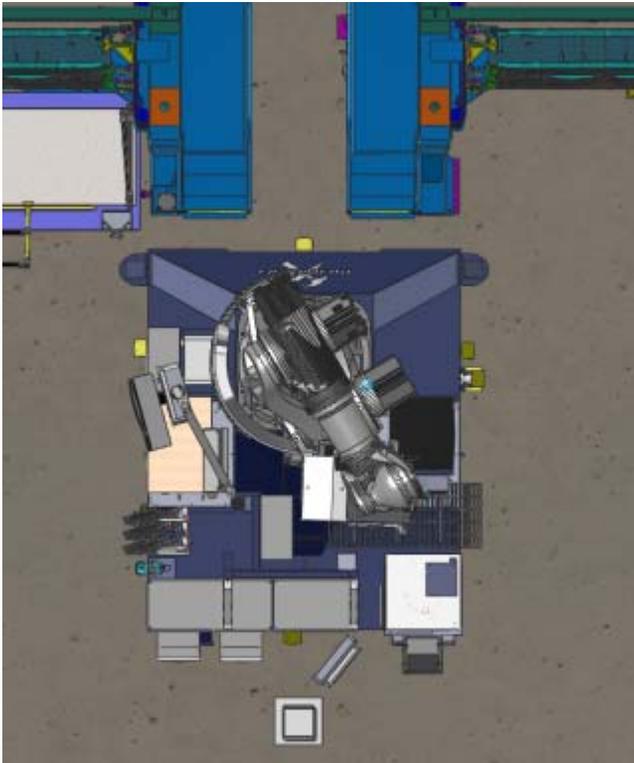


# Requirements/Constraints: Existing Factory

- Introducing automation to line already at full rate production
- System must fit within existing layout and navigate around

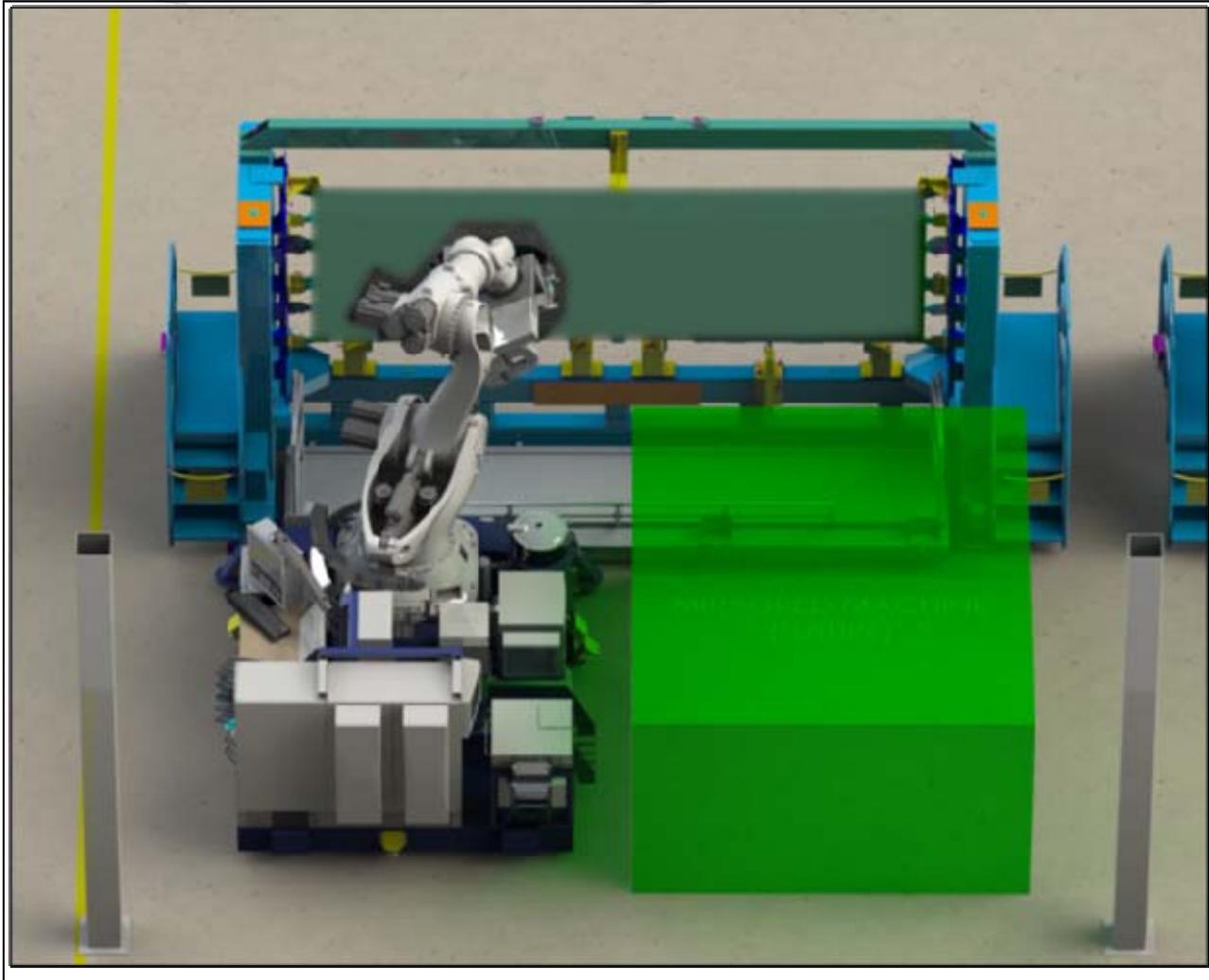


# Requirements/Constraints: Existing Factory

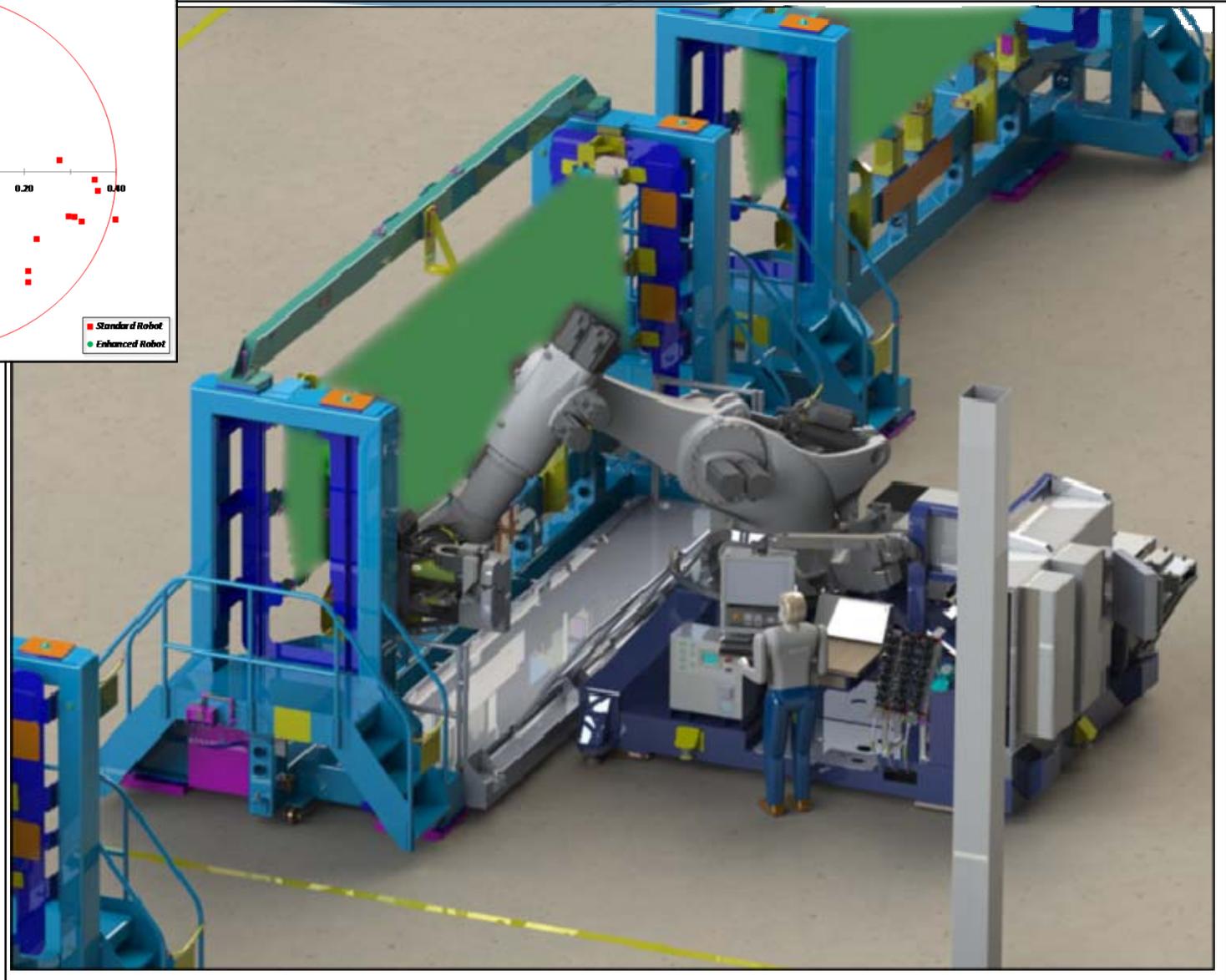
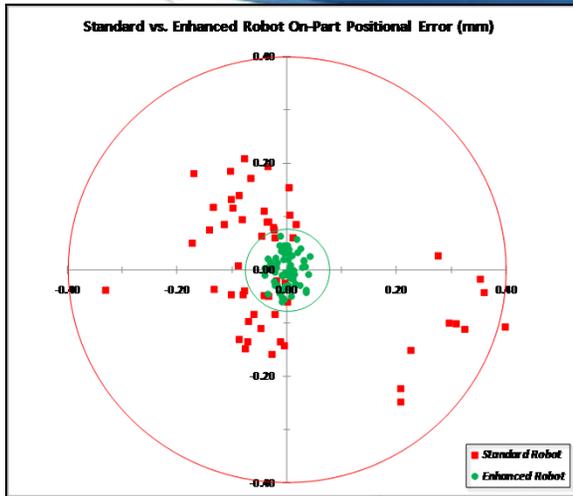


Close clearances dictate system packaging

# Requirements/Constraints: Potential Side-by-Side Operation



# Requirements/Constraints: +/-0.010" Positional Accuracy



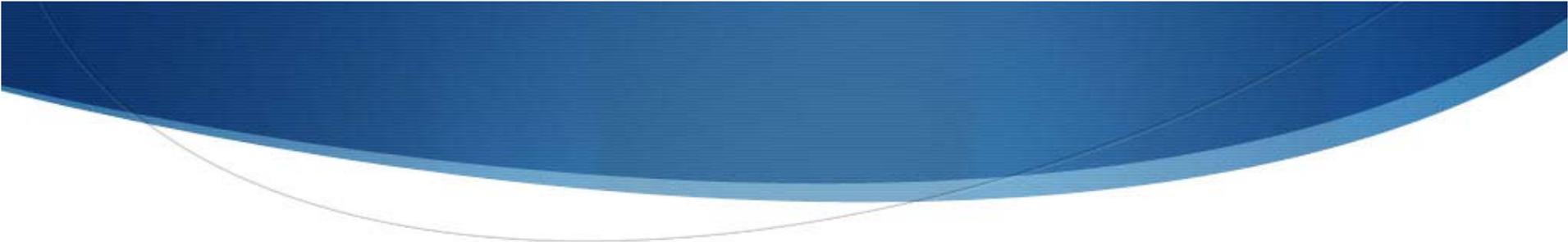
# Requirements/Constraints: Integral Lift



- Manually float in place

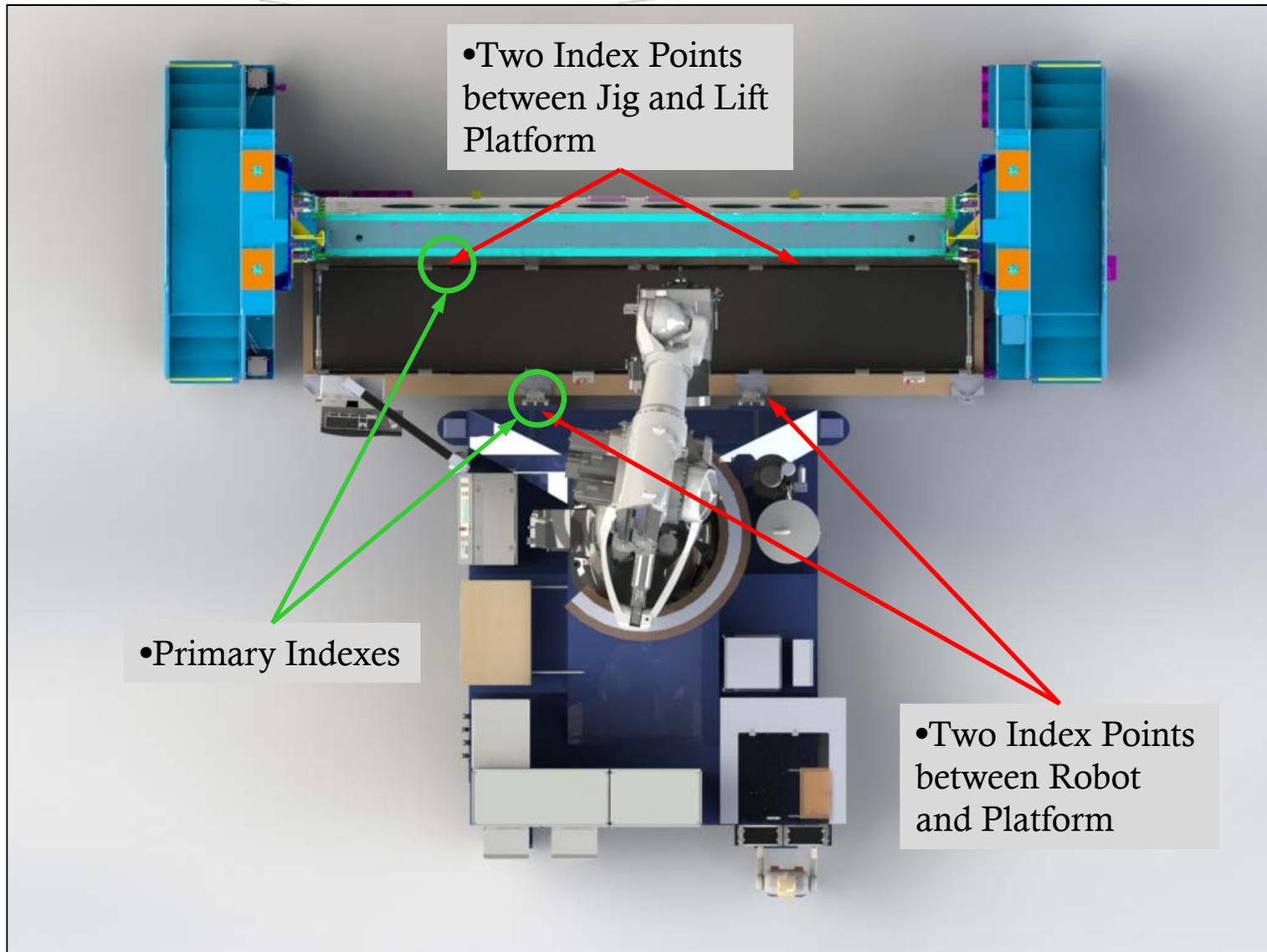


- Engage indexes on jig
- Robot mates with lift structure

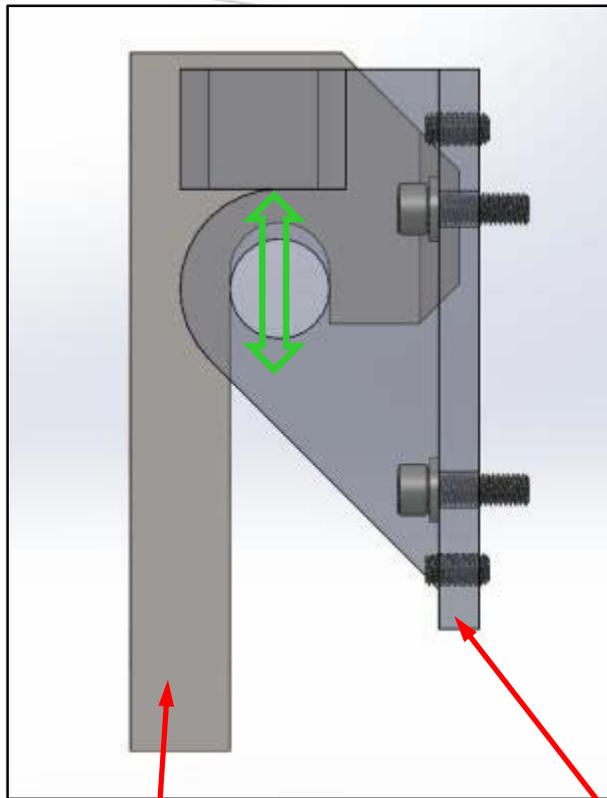


# Interaction Between Machine and Jig(s)

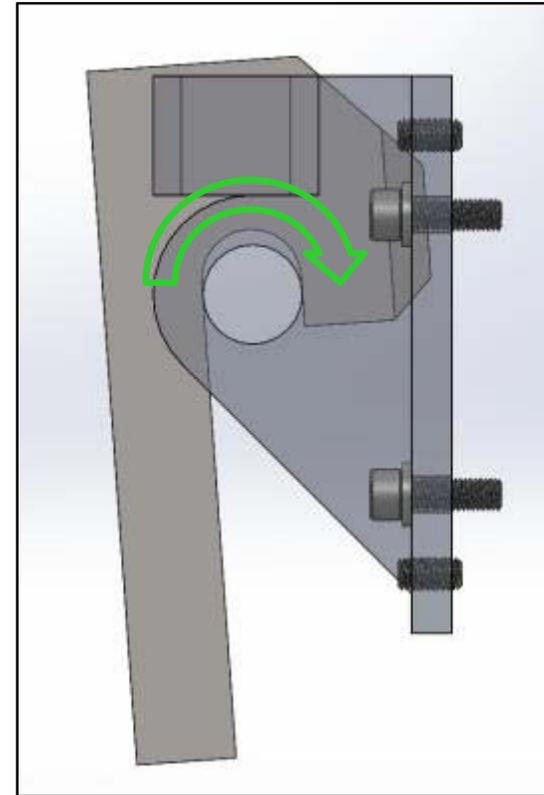
# Indexes



# Indexes

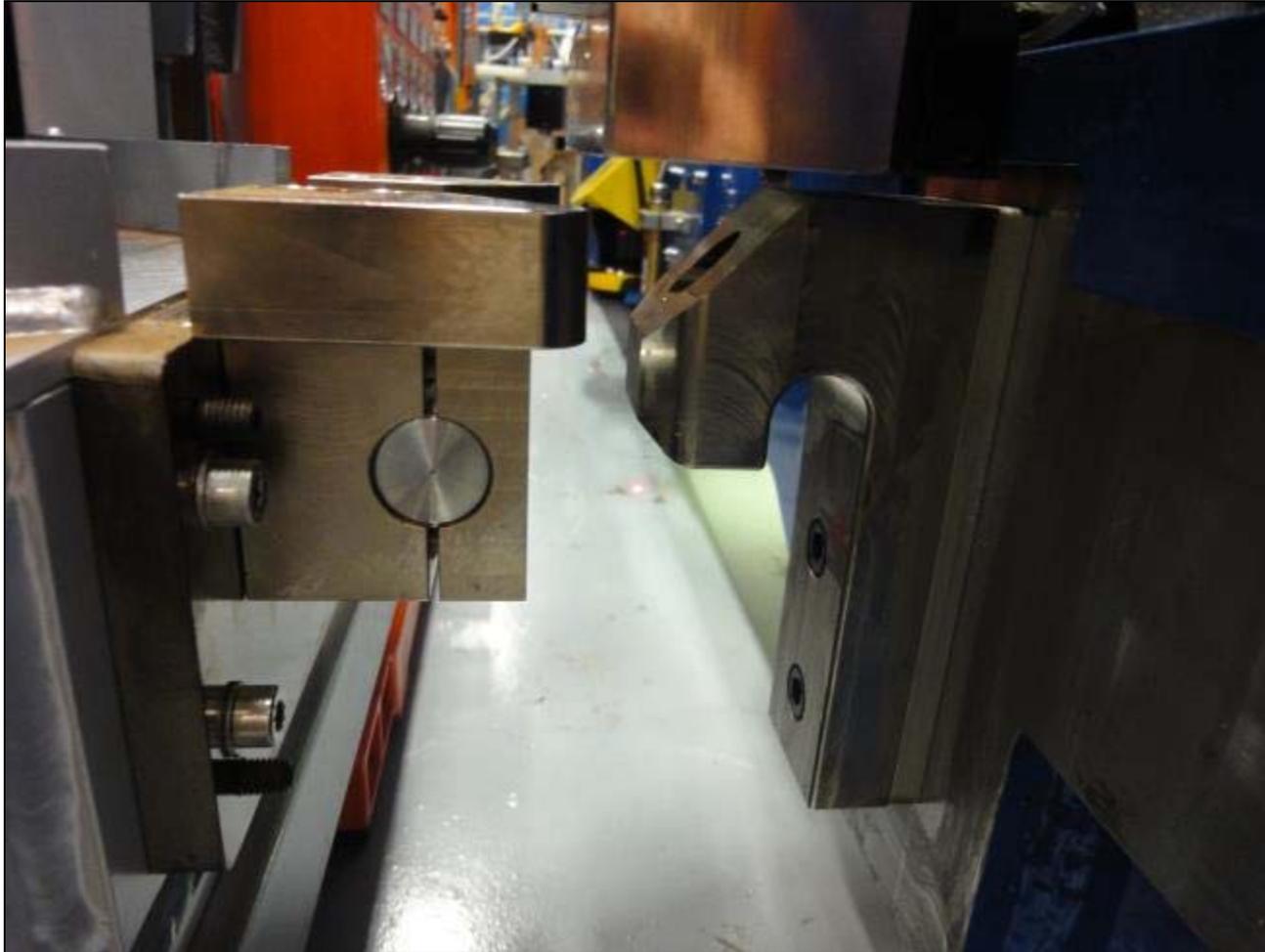


Hook Index  
(machine)



Guide and Index  
Receiver (lift)

# Indexes



- Automated indexes provide solid union between machine and jig

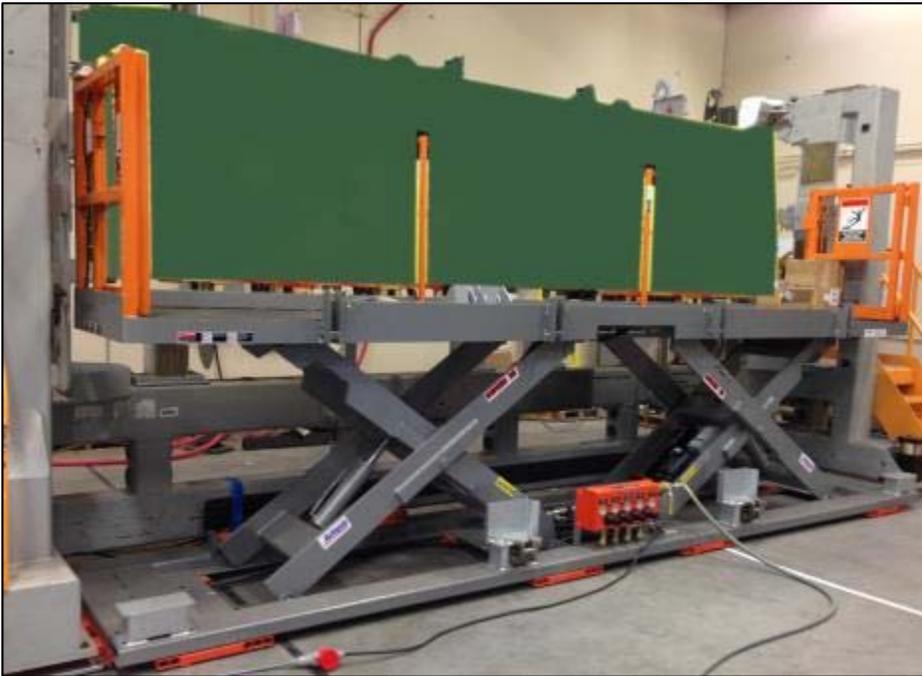
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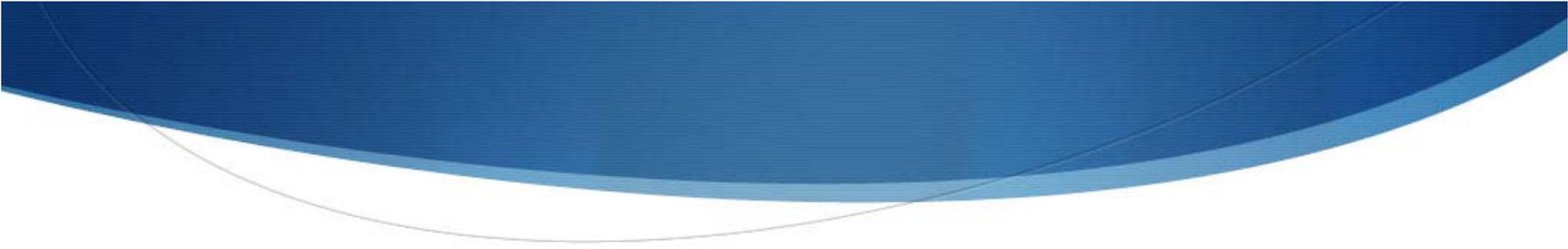


- Automated indexes provide solid union between machine and jig

# Integral Lift Platform

- 60 inches of lift with lowered height of 10.5 inches
- 2,000lbs lifting capacity.
- Reclinable handrail along one side of platform with swing gate on each end.





# Automation System Basics

# System Overview

KR1000L750 enhanced with EI  
*Accurate* robot technology

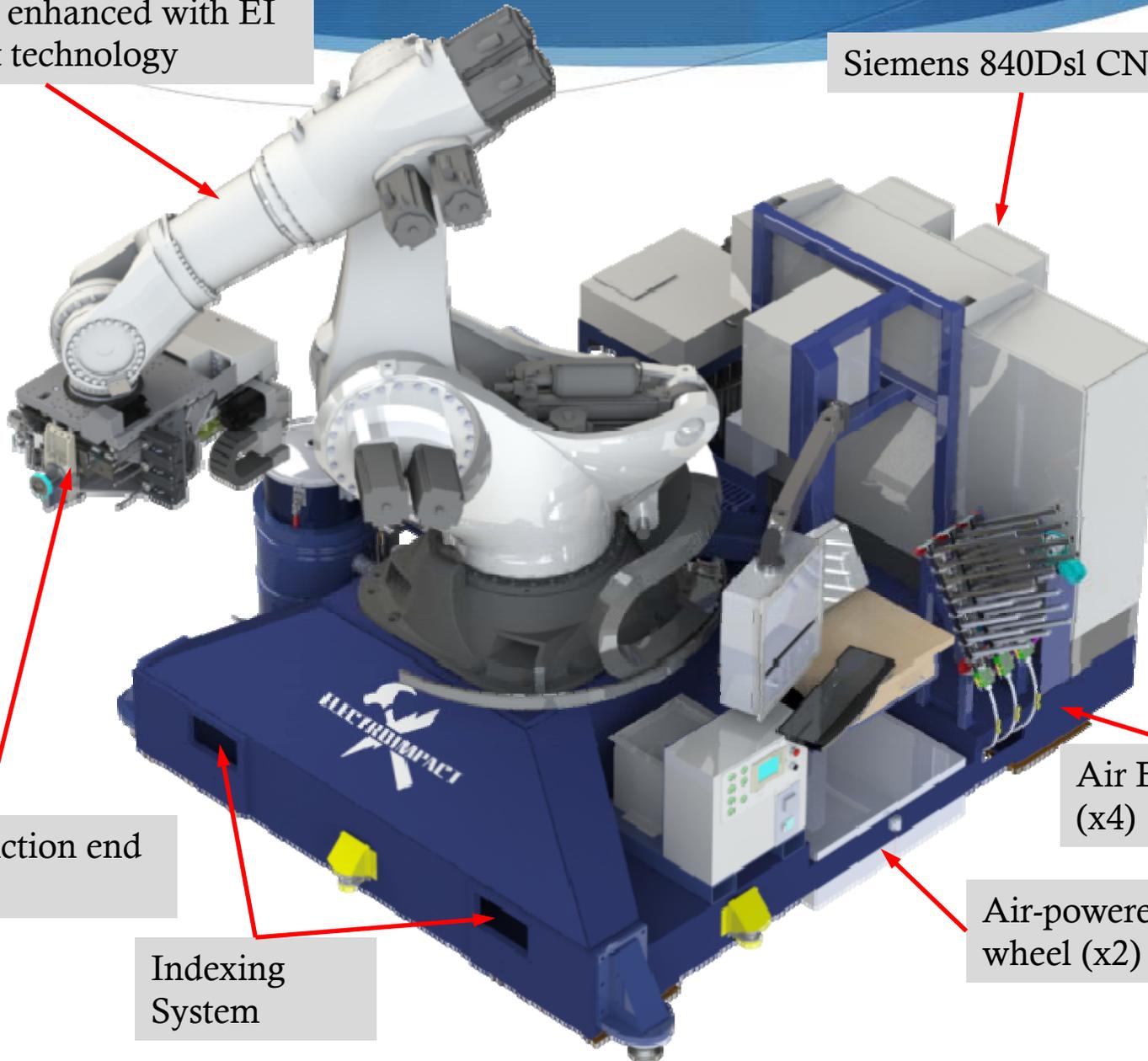
Siemens 840Dsl CNC

EI Multi-function end  
effector

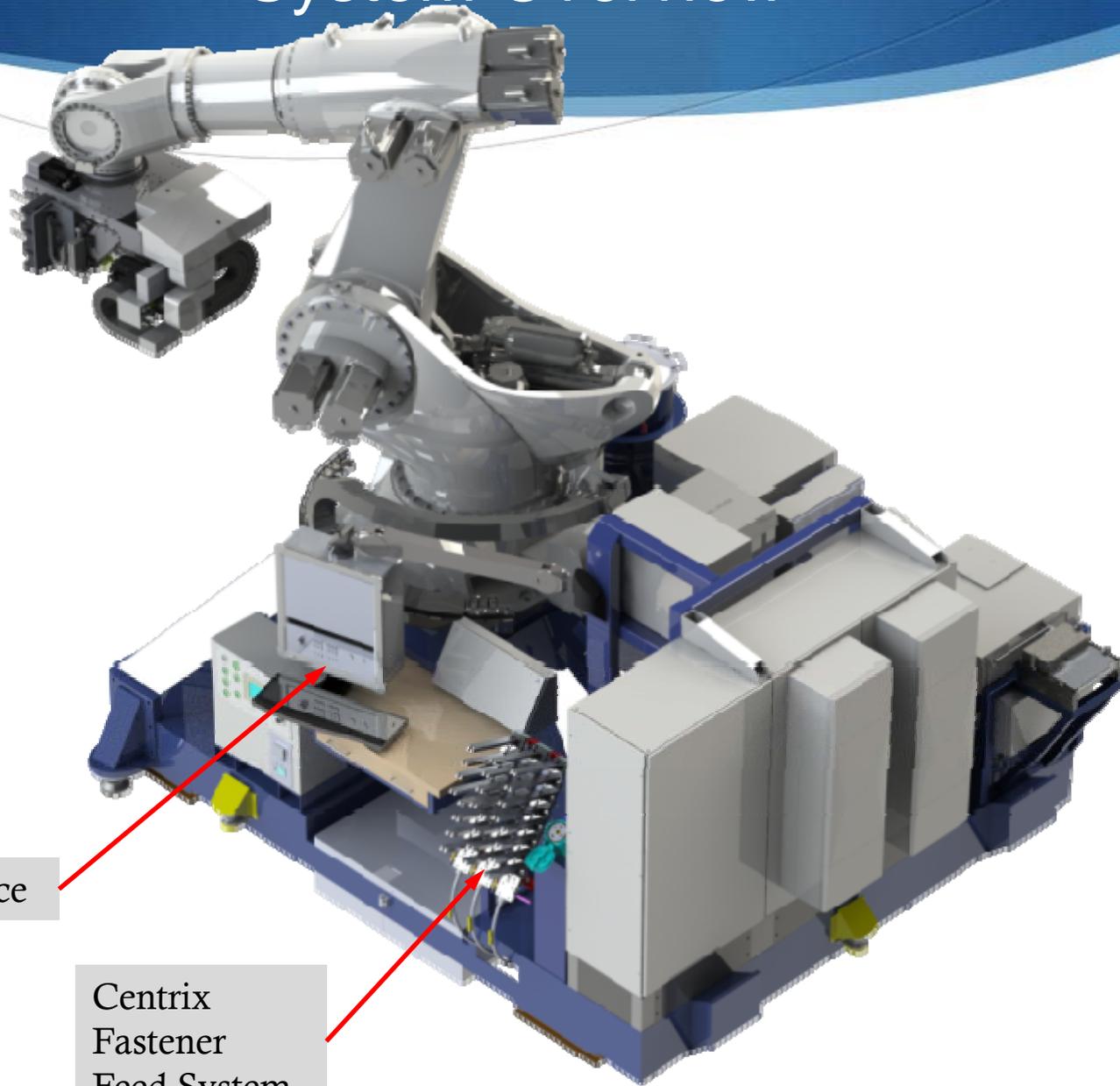
Indexing  
System

Air Bearings  
(x4)

Air-powered drive  
wheel (x2)



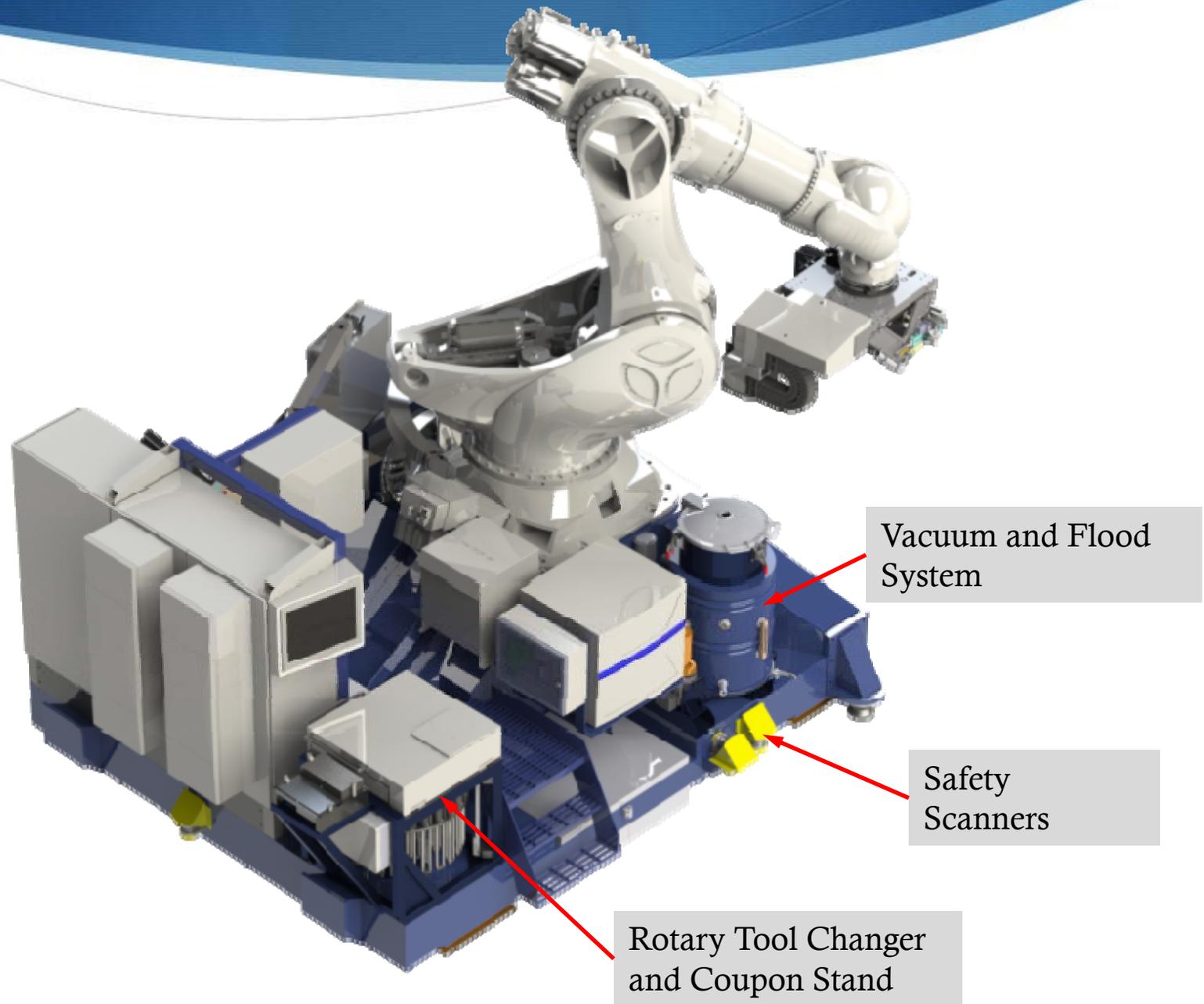
# System Overview



Operator Interface

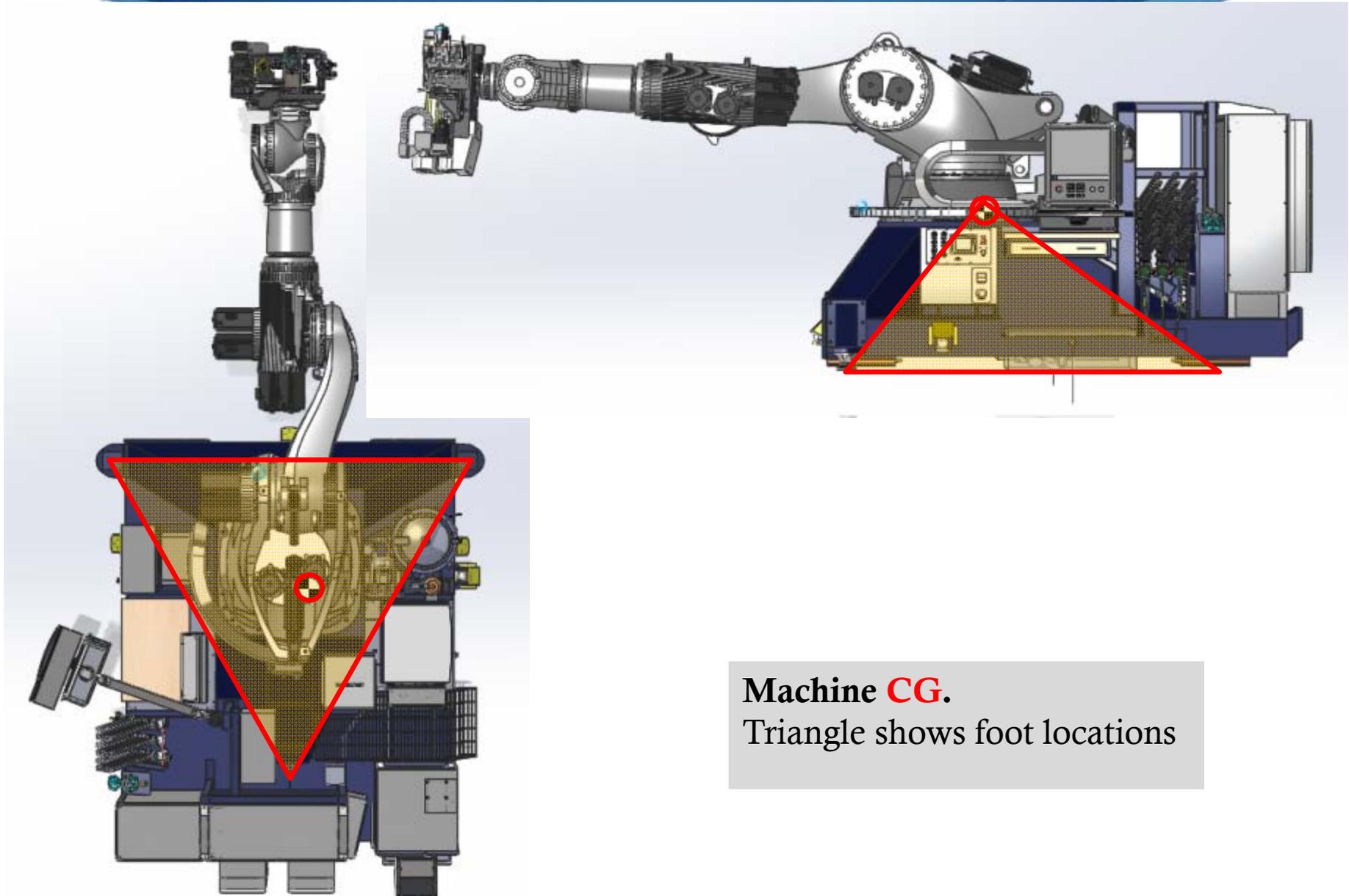
Centrix  
Fastener  
Feed System

# System Overview



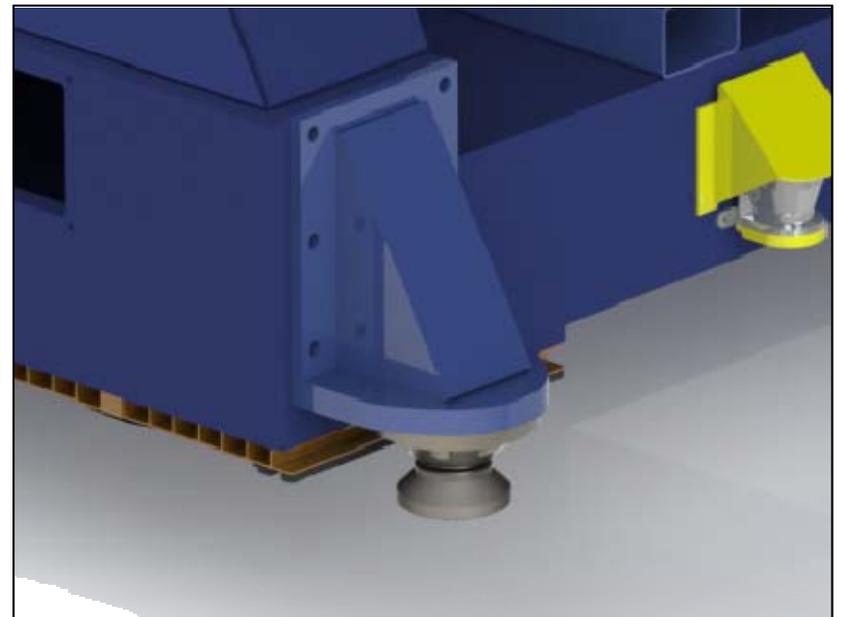
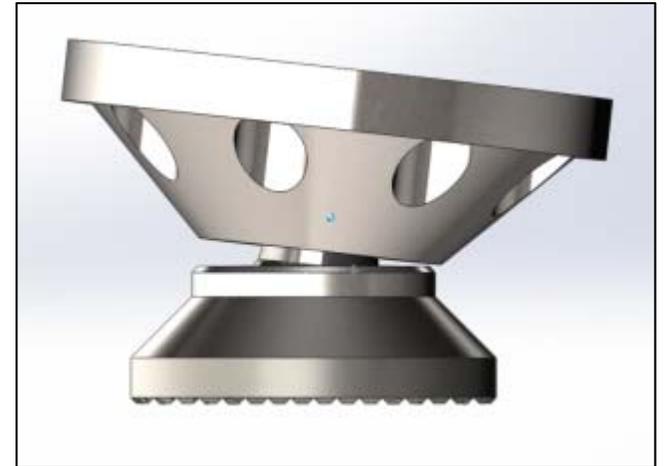


# Platform



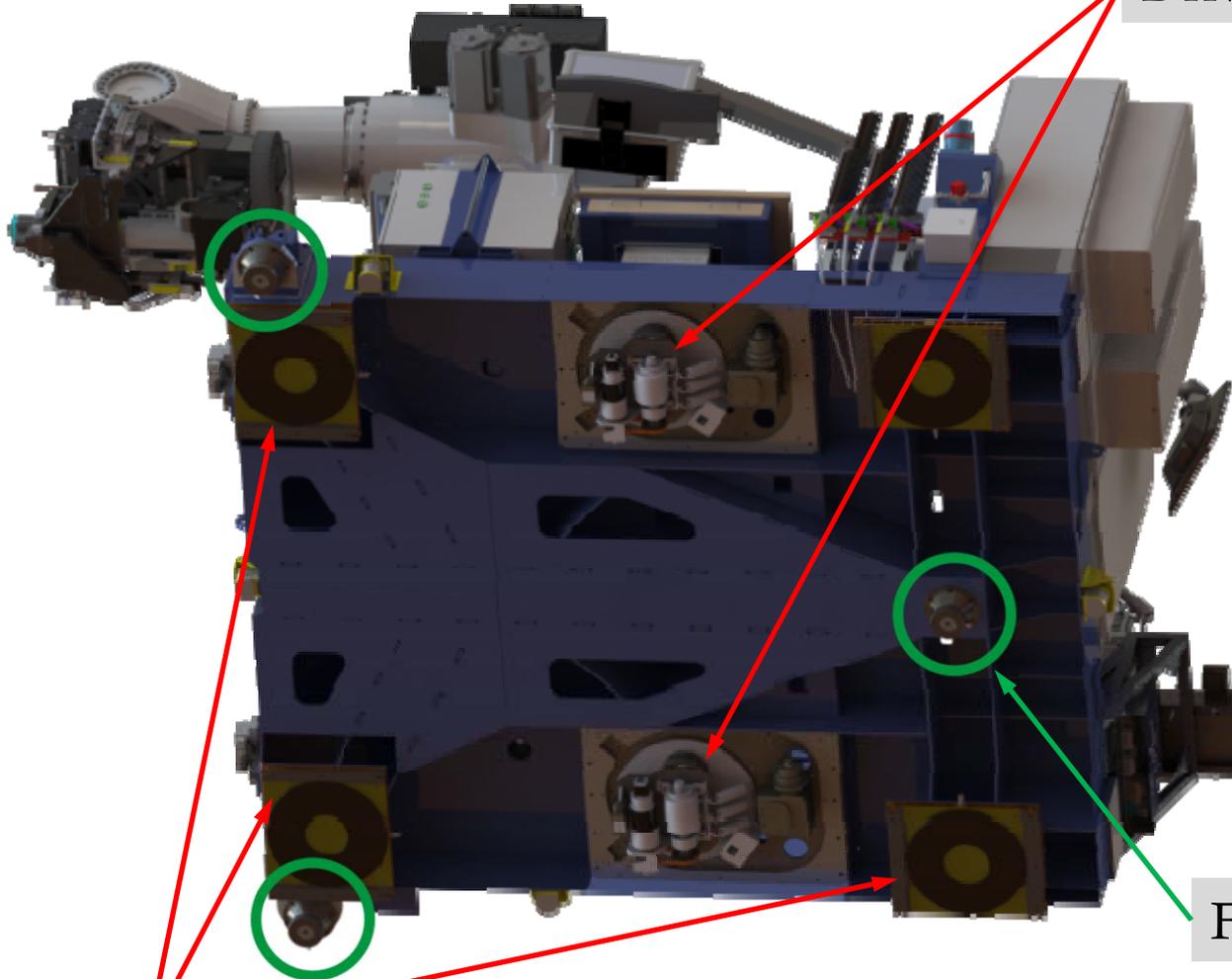
**Machine CG.**  
Triangle shows foot locations

# Platform



# Mobility Drive System

Drive and Steering

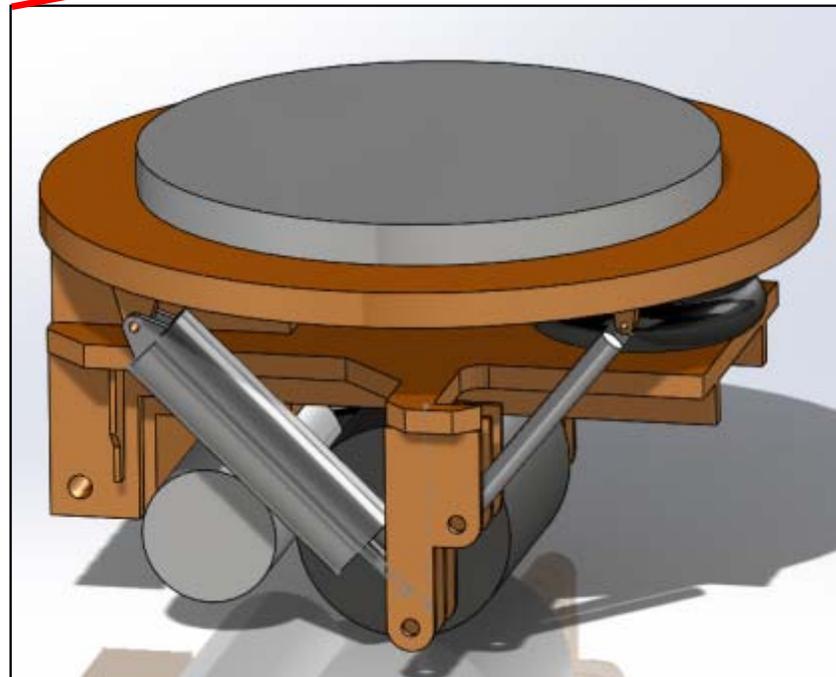
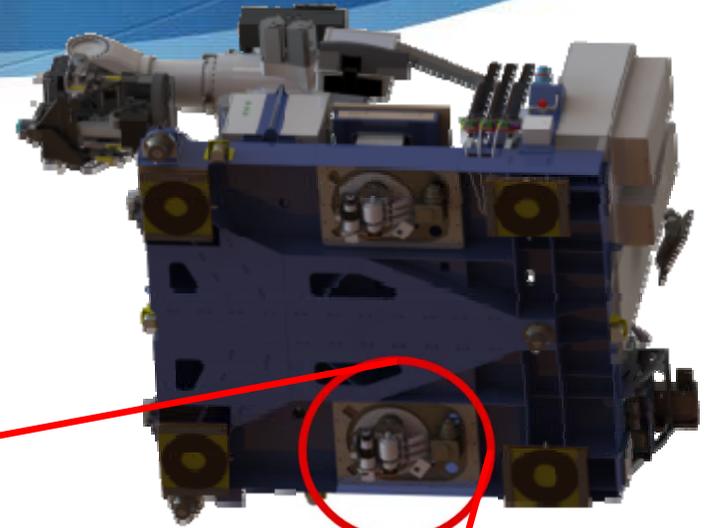


Feet

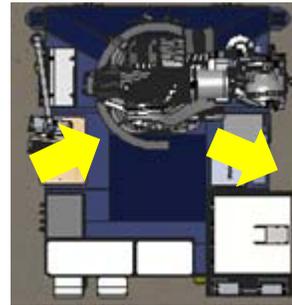
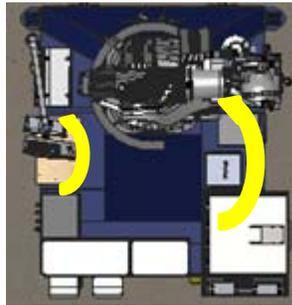
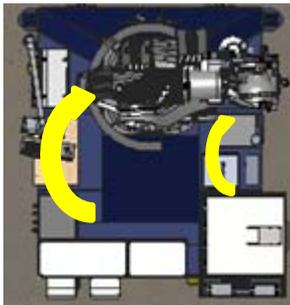
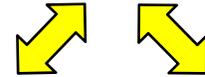
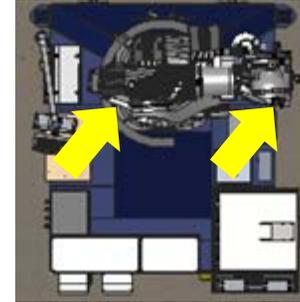
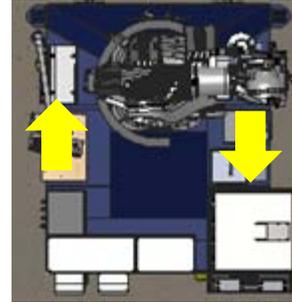
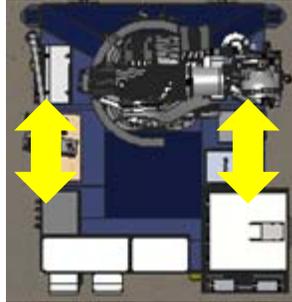
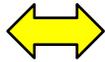
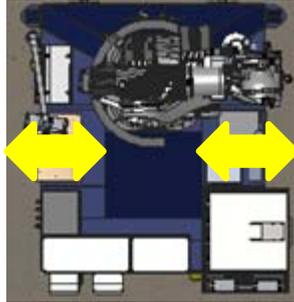
Air Bearings

# Mobility Drive System

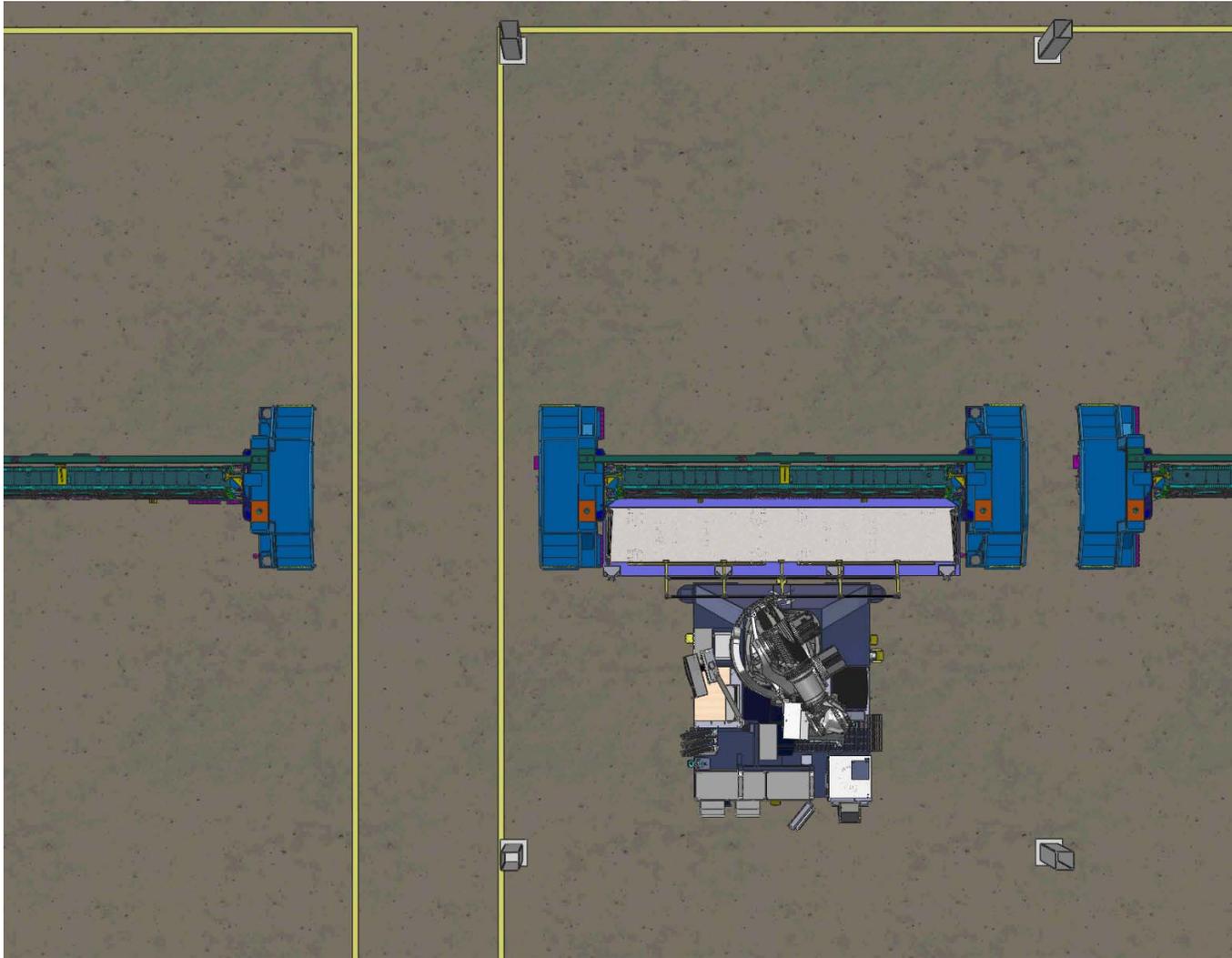
- Wireless Handheld Remote
- Integrated Battery/Charger for Controls
- Propulsion
  - Drive & Steering
  - Air Bearings (lift)



# Drive Modes



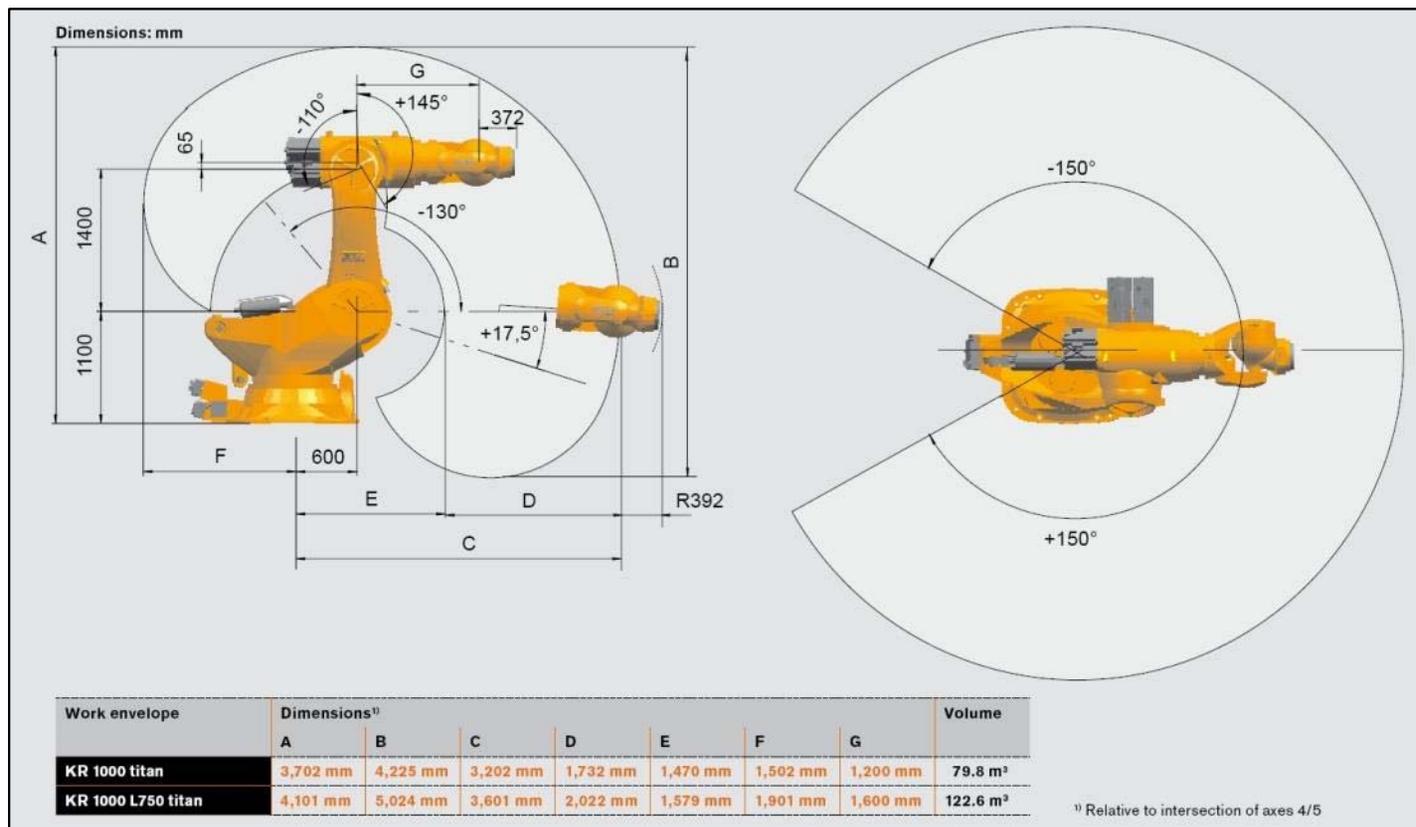
# Motion Simulation



# Accurate Robot



Enhanced KR1000L750



# Accurate Robot

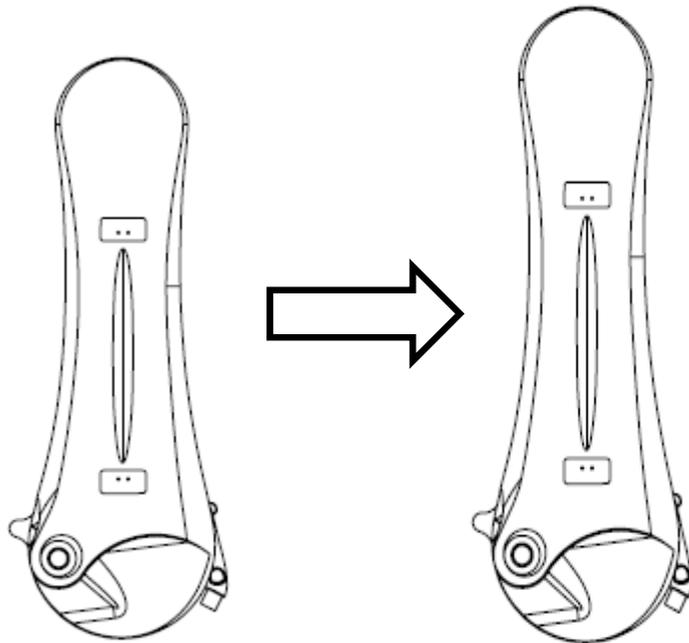
## Position Feedback on All Joints

- Standard industrial grade optical encoders
- Drive-Cliq compatible
- 50nm resolution ... Millions of counts per rev

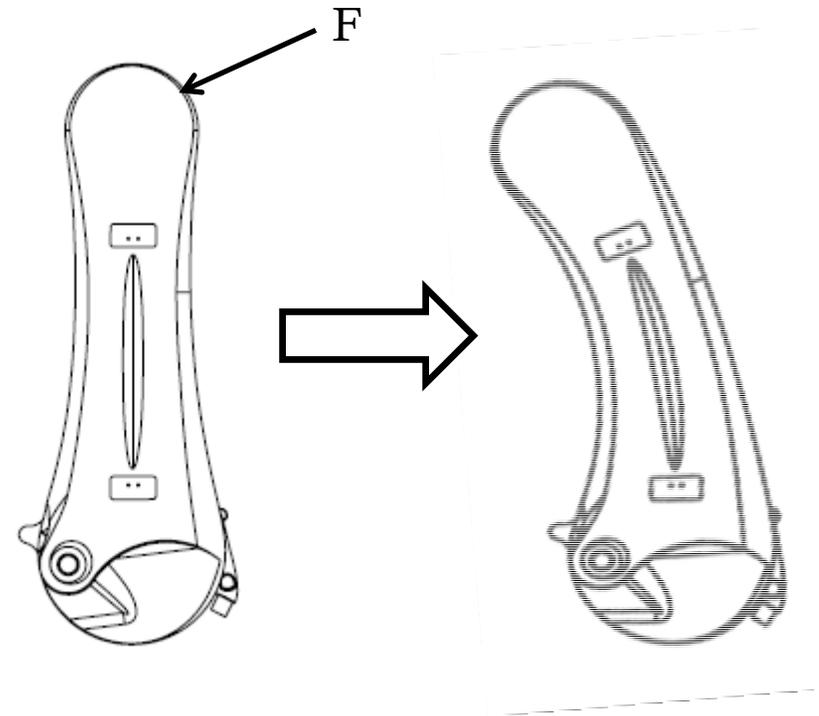


# Accurate Robot: Descriptive Kinematics

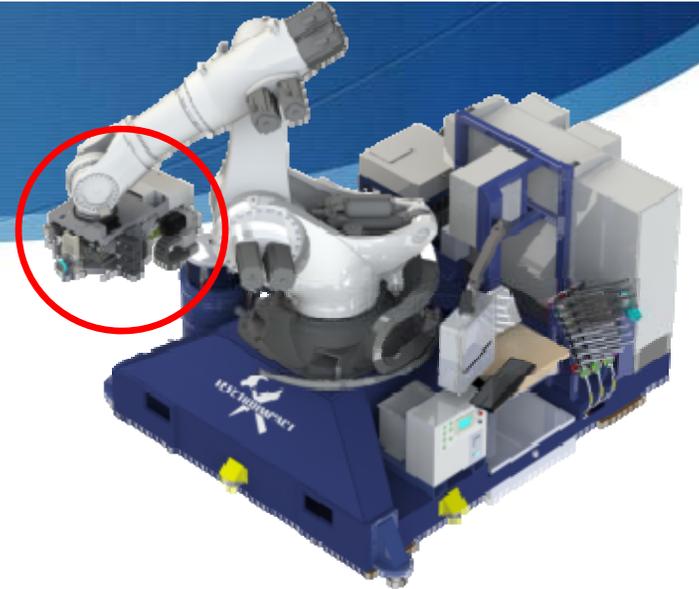
Offset from Nominal Measurements



How the Robot Deforms with Force  
(due to link and payload mass, as well as external)

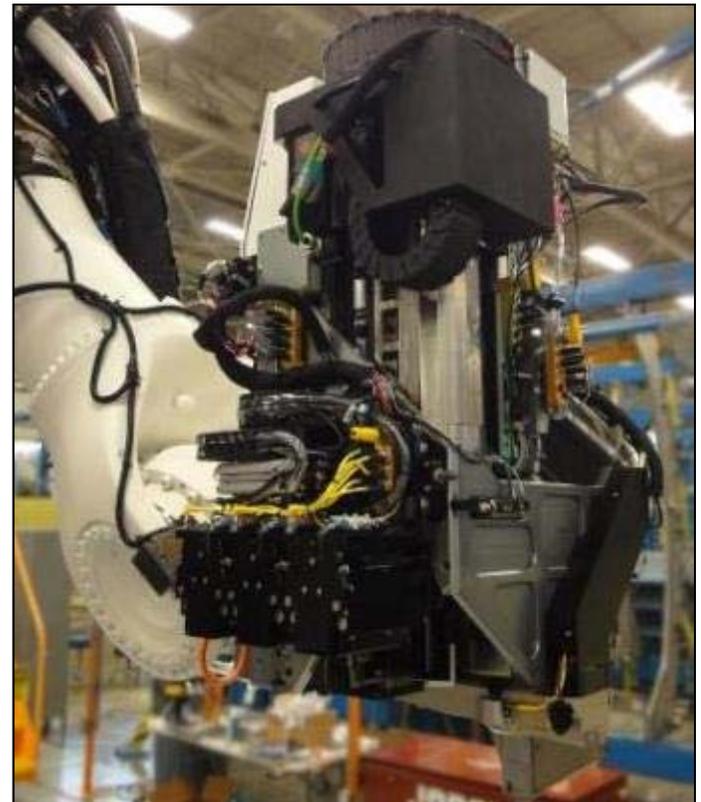


# End Effector

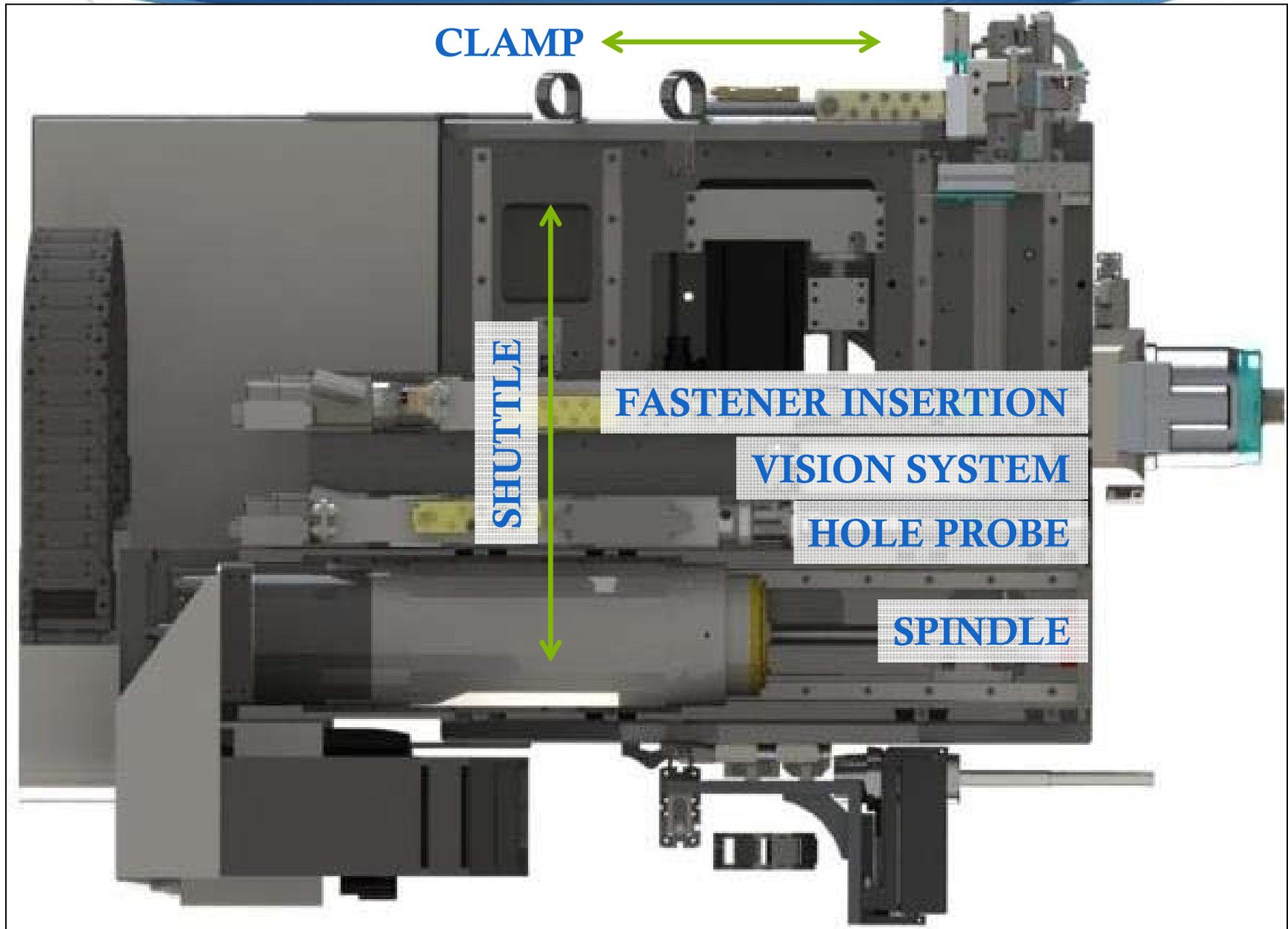


## Process Head:

- Servo clamp axis w/load cell feedback
- Servo tool shuttle axis w/encoder
- Servo spindle feed axis
- 12,000 rpm cartridge spindle
  - HSK63 ATC
  - High-torque
  - Thru-tool coolant
- Servo hole probe
  - In-process feedback of hole and countersink diameter
- Automated vision system
  - On-axis camera
- Servo Centrix fastener installation module
- 3-Position tool swapping system
- Balluff RFID for cutting tools



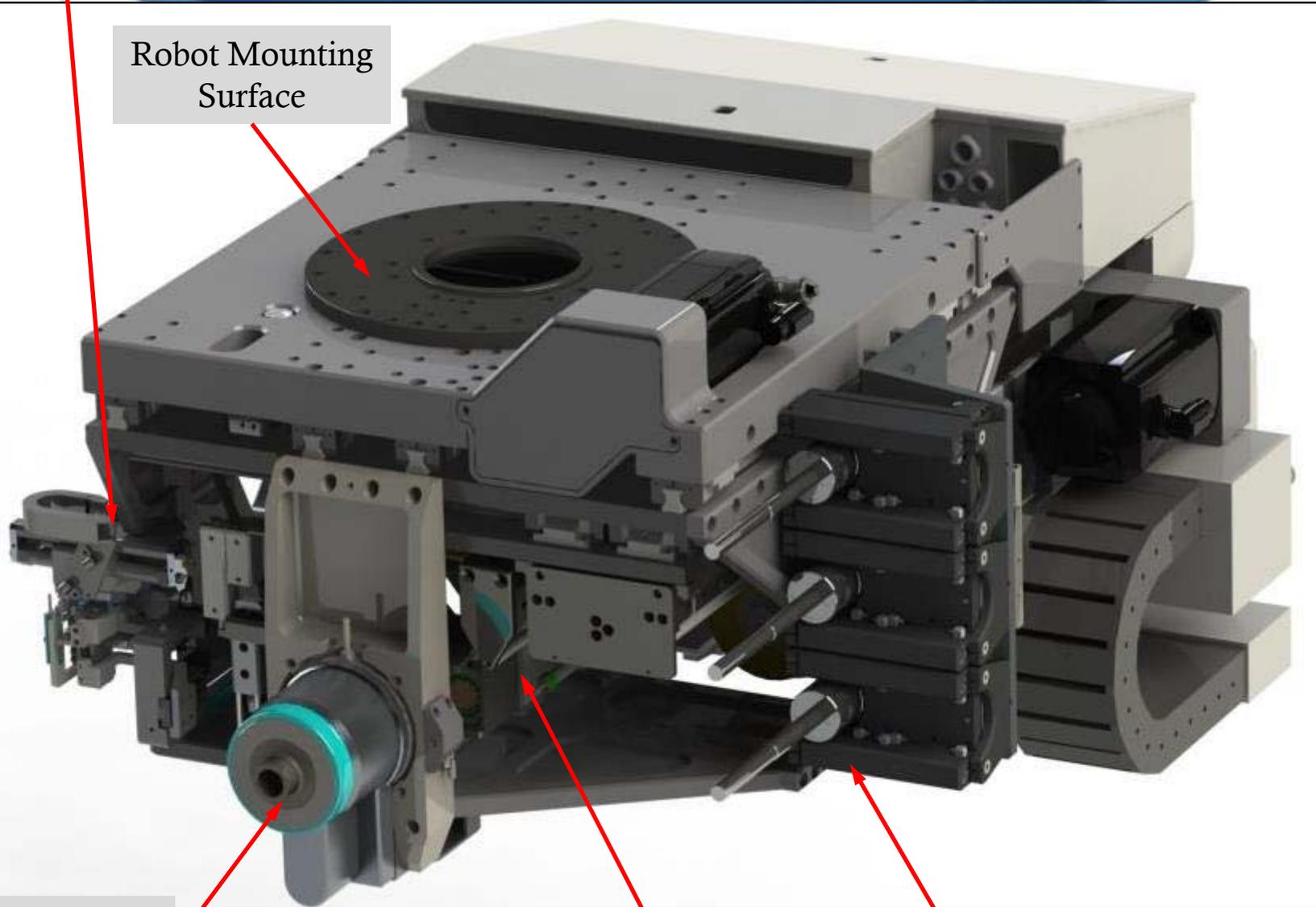
# End Effector



# End Effector

Fastener Injection

Robot Mounting Surface

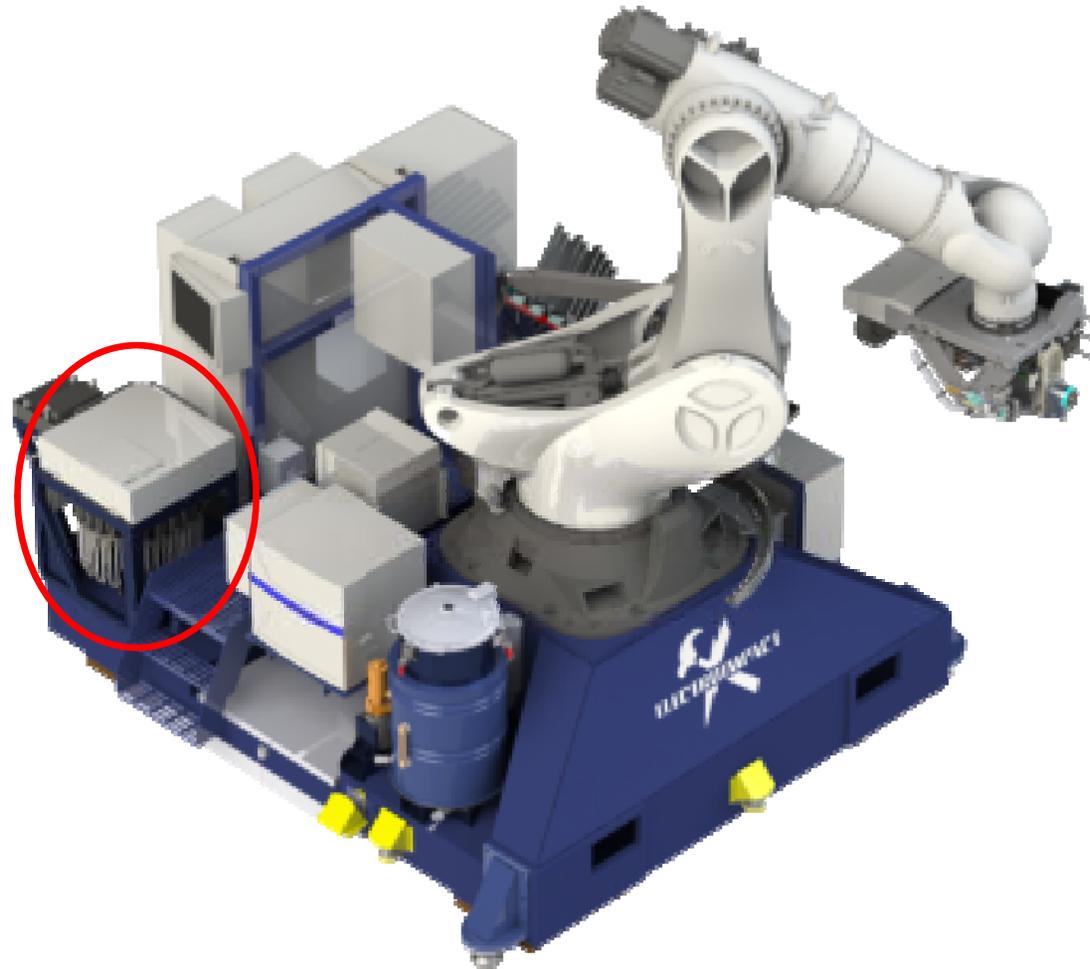


Interchangeable  
Nose Pieces

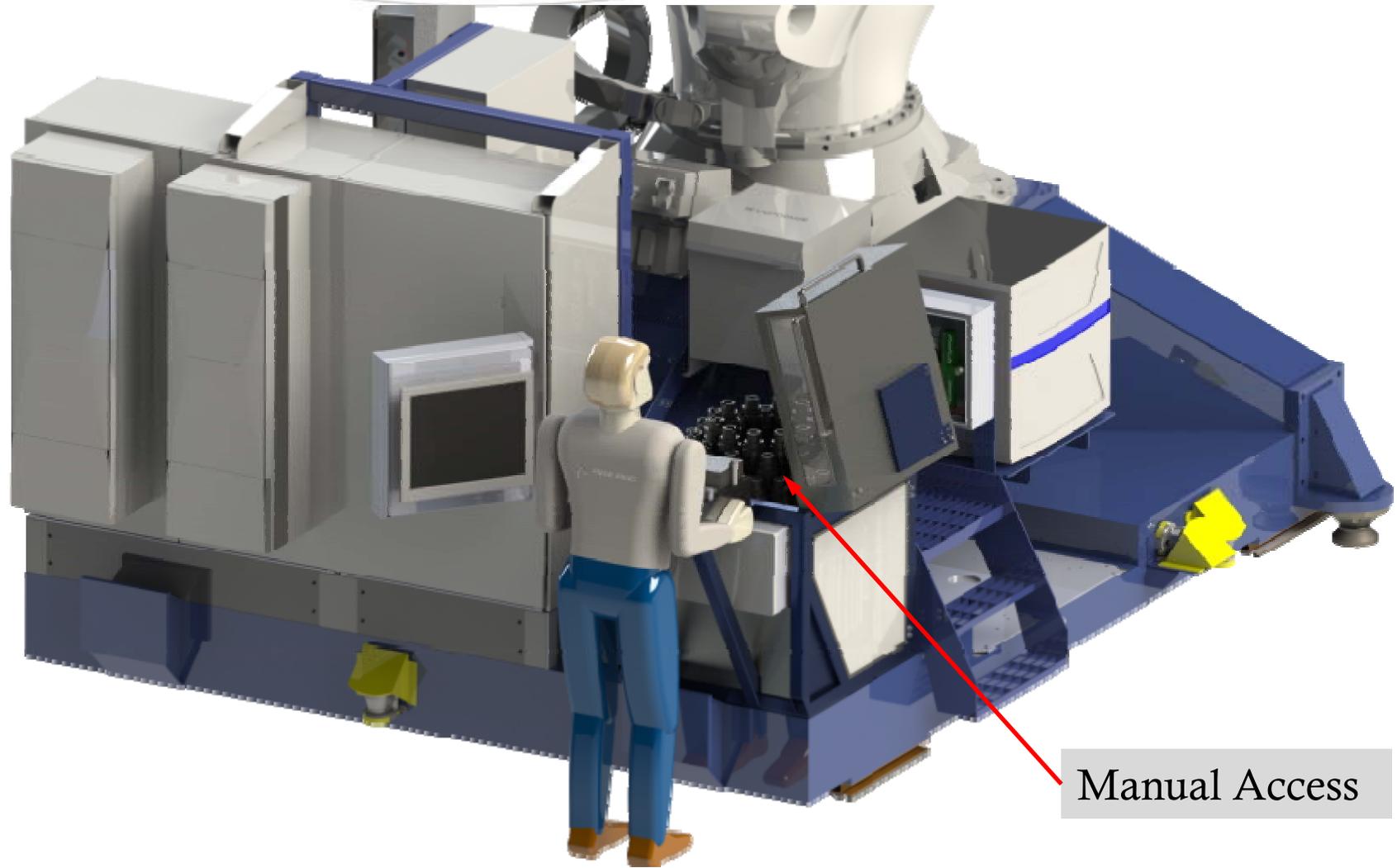
Process Tools

Tool Swapper

# Tool Changer

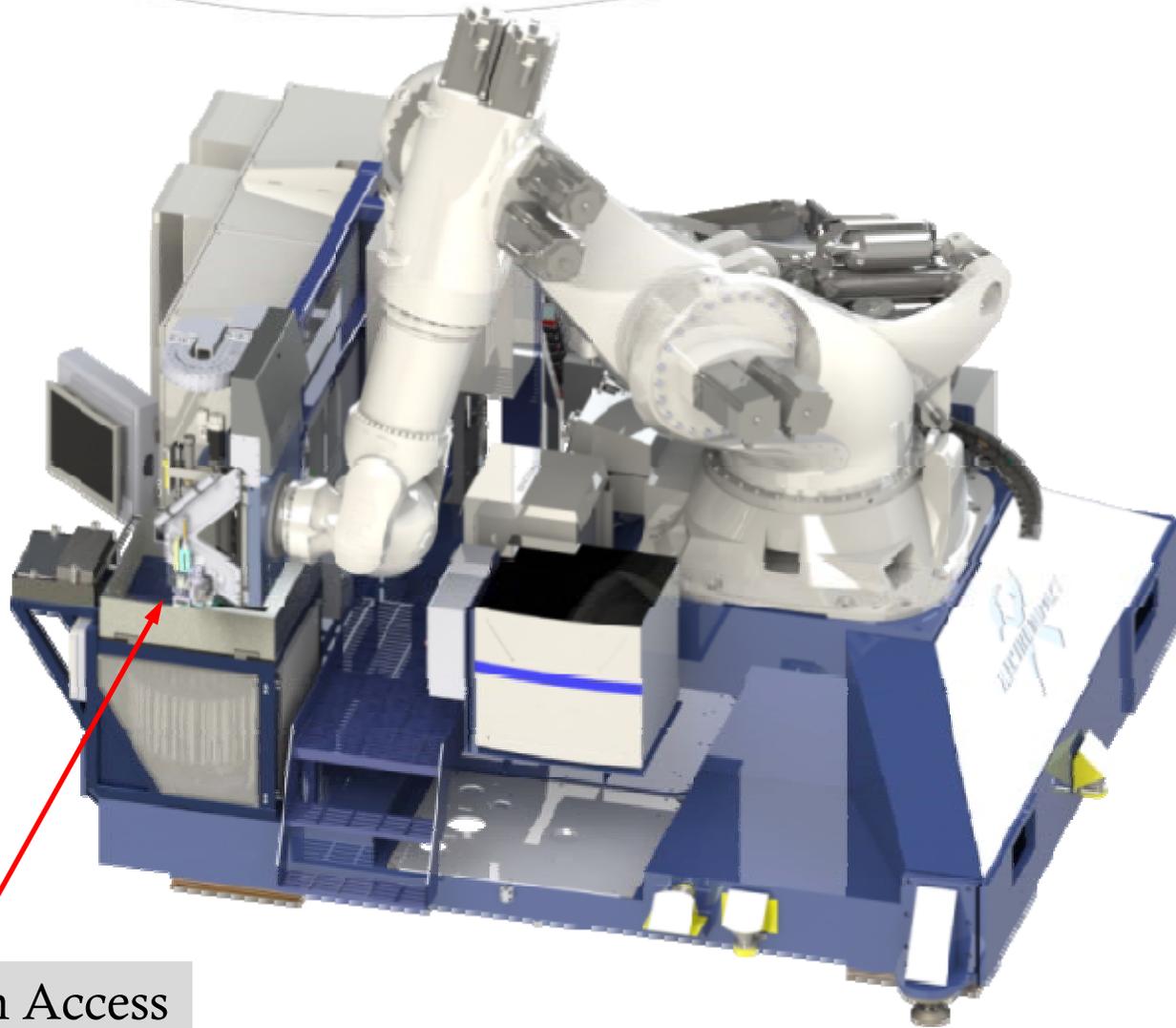


# Tool Changer



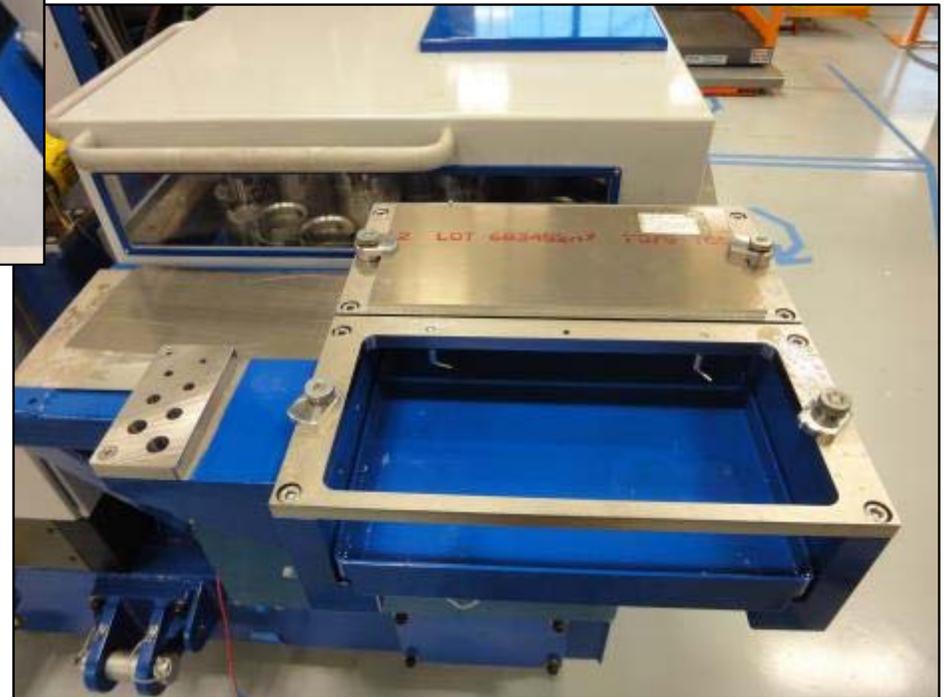
Manual Access

# Tool Changer



Automation Access

# Tool Changer



# Thru-bit Cutters

## Drills

- Holes direct coolant towards work piece.



## Reamers

- Coolant holes are located ahead of cutting edges
- Direct coolant back at cutting edges and is extracted by the vacuum through the hole



# Flood Pump and Vacuum

- Pump motor speed controlled with variable frequency drive
- Coolant flow rate is programmable



# Fastener Feed



# Fastener Feed



## Automated Centrix Installation

- -6, -8 Full Size
- Length and diameter inspection
- Precise control/feedback of angle/torque
- ~10% of locations receive fastener
- Provides support for high-speed drilling

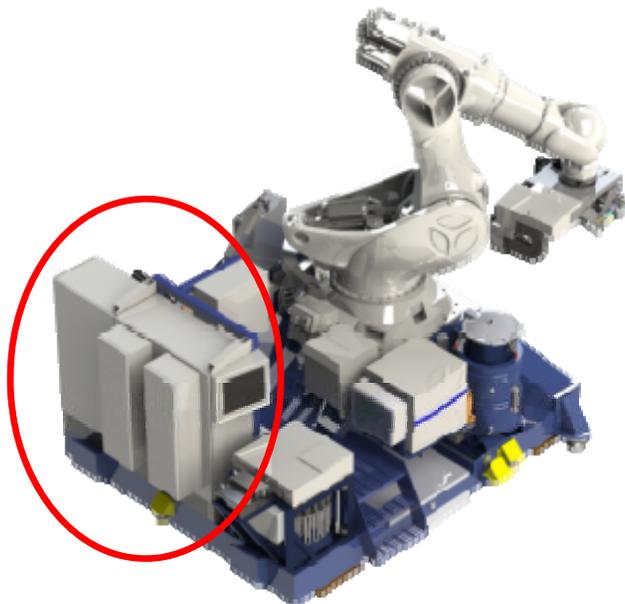


## Hanger Storage System

# Electrical and Controls

## Siemens CNC Controller

- 840Dsl
- Siemens servo and spindle drives
- Remote I/O via Profibus communication
- High speed I/O for load cell feedback, and hole diameter profiling
- Controls entire drilling system (robot, tool changer, and process head)



# Electrical and Controls

## **Operator Interface/Controls**

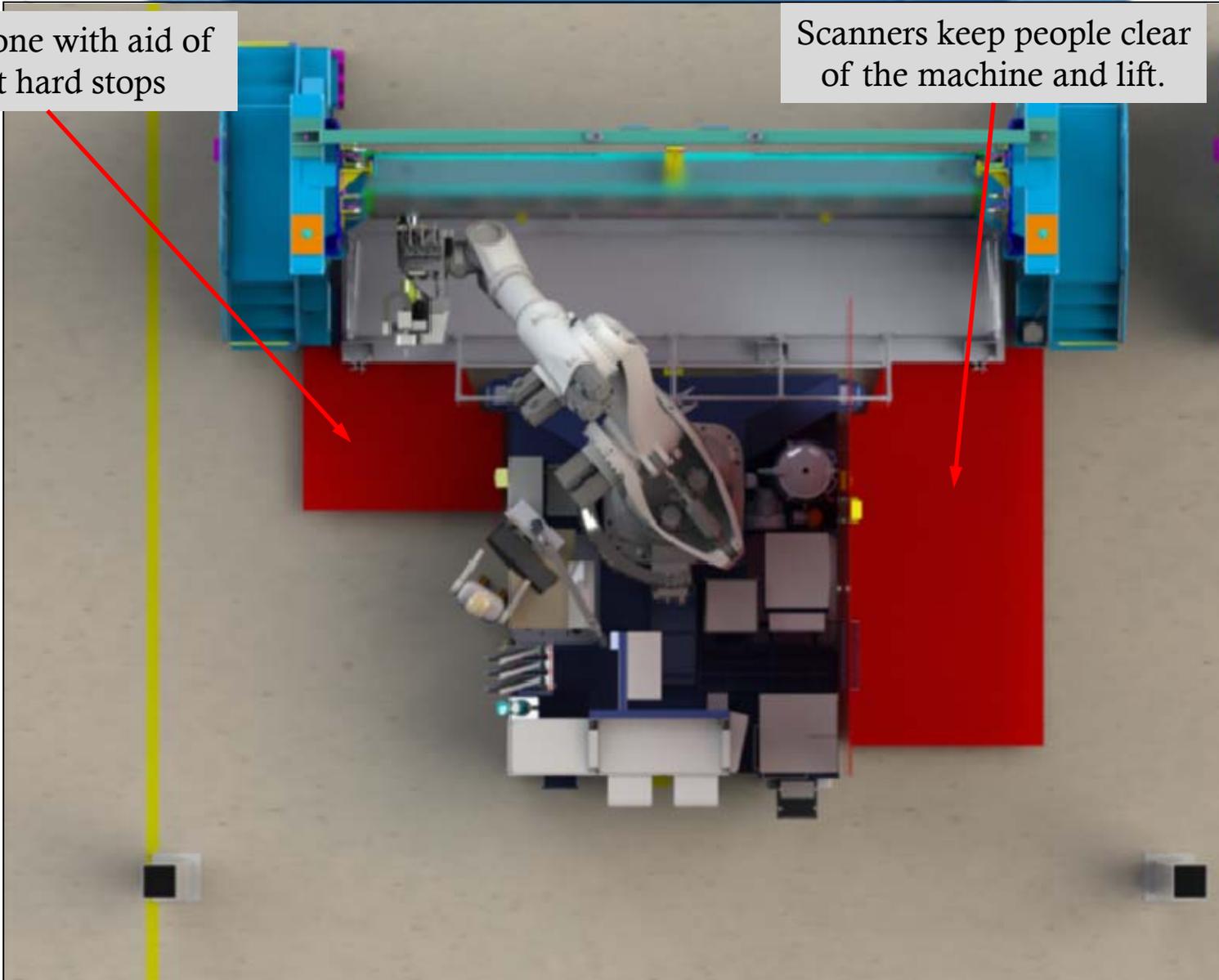
- Boom mounted HMI
- Pendant with live-man switch enables reduced feed rate remote control of jogging, setup, and tape tryout.



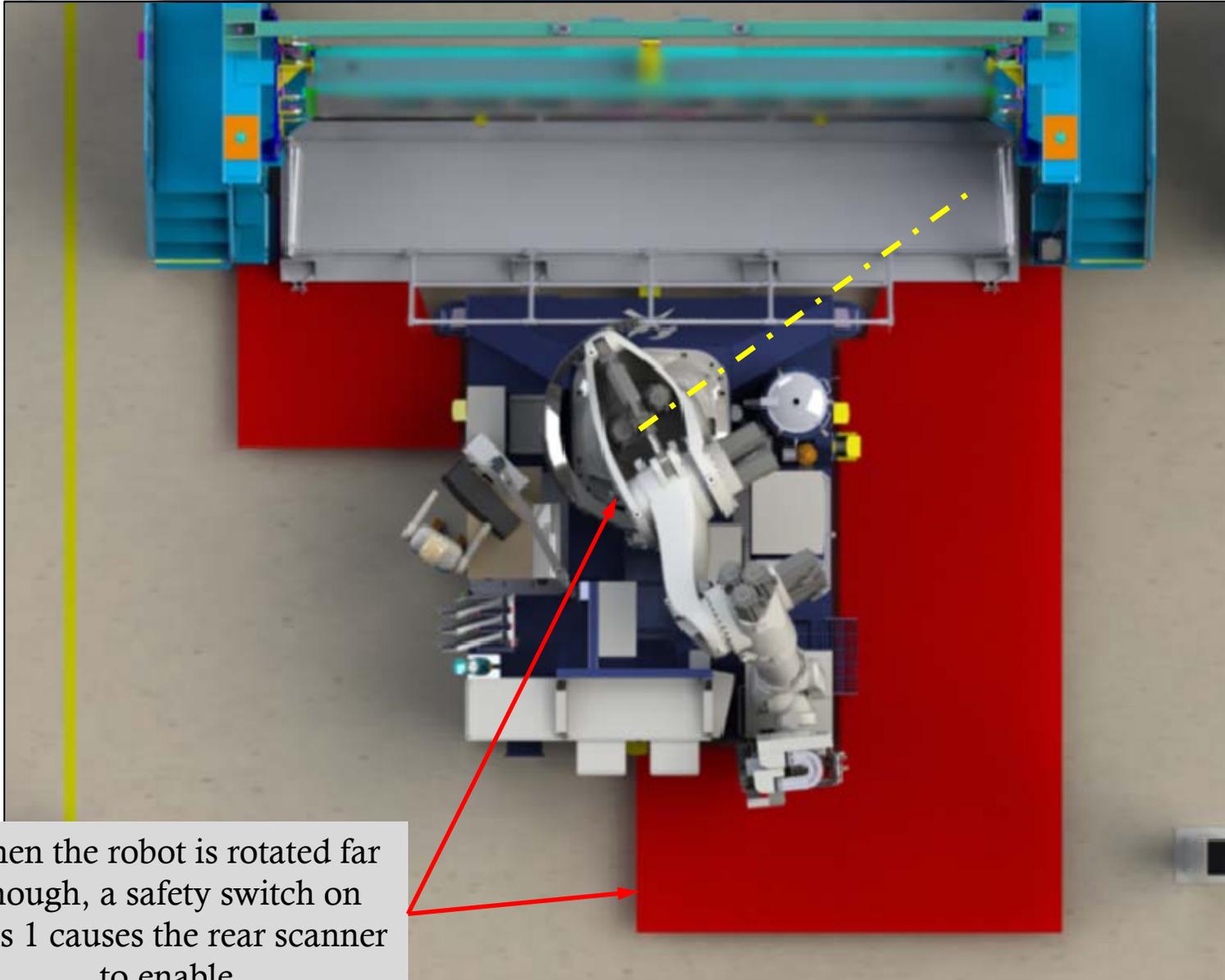
# Safety

Small zone with aid of robot hard stops

Scanners keep people clear of the machine and lift.

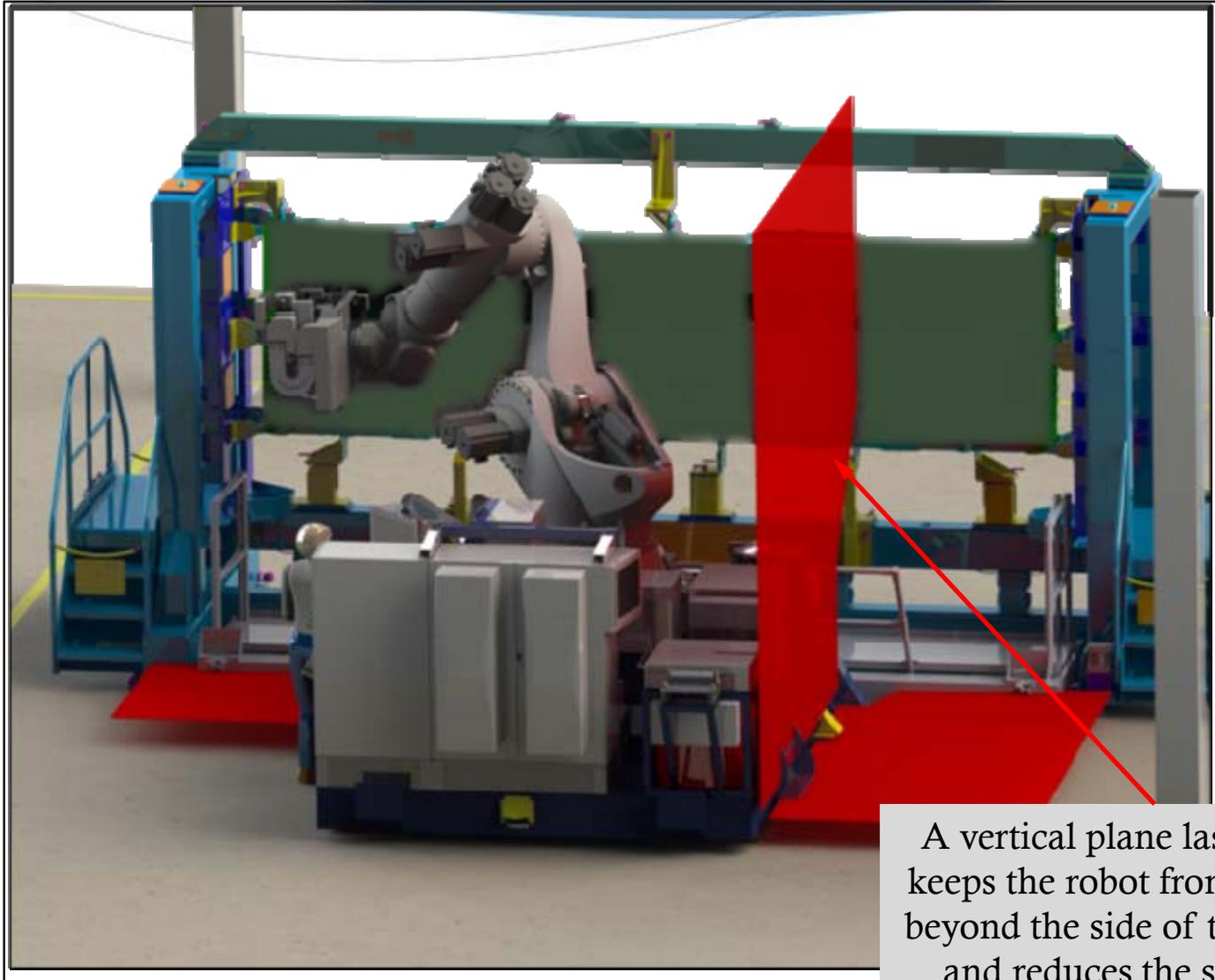


# Safety

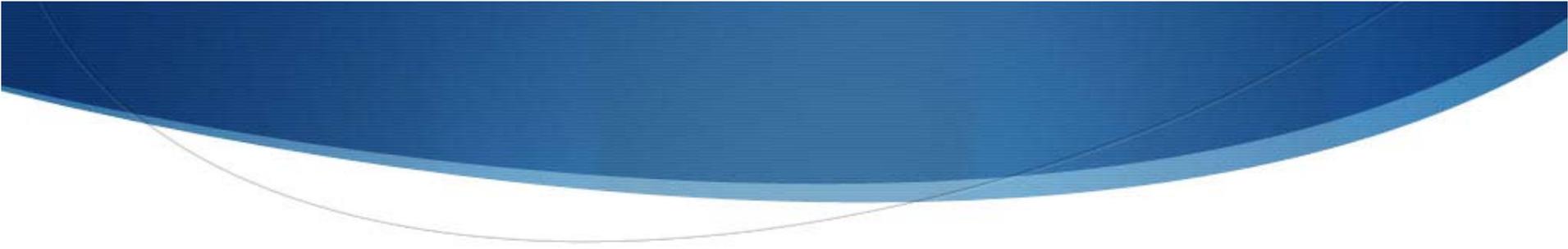


When the robot is rotated far enough, a safety switch on Axis 1 causes the rear scanner to enable

# Safety



A vertical plane laser scanner keeps the robot from extending beyond the side of the platform and reduces the size of the restricted space



# Production Process: Skin to Substructure

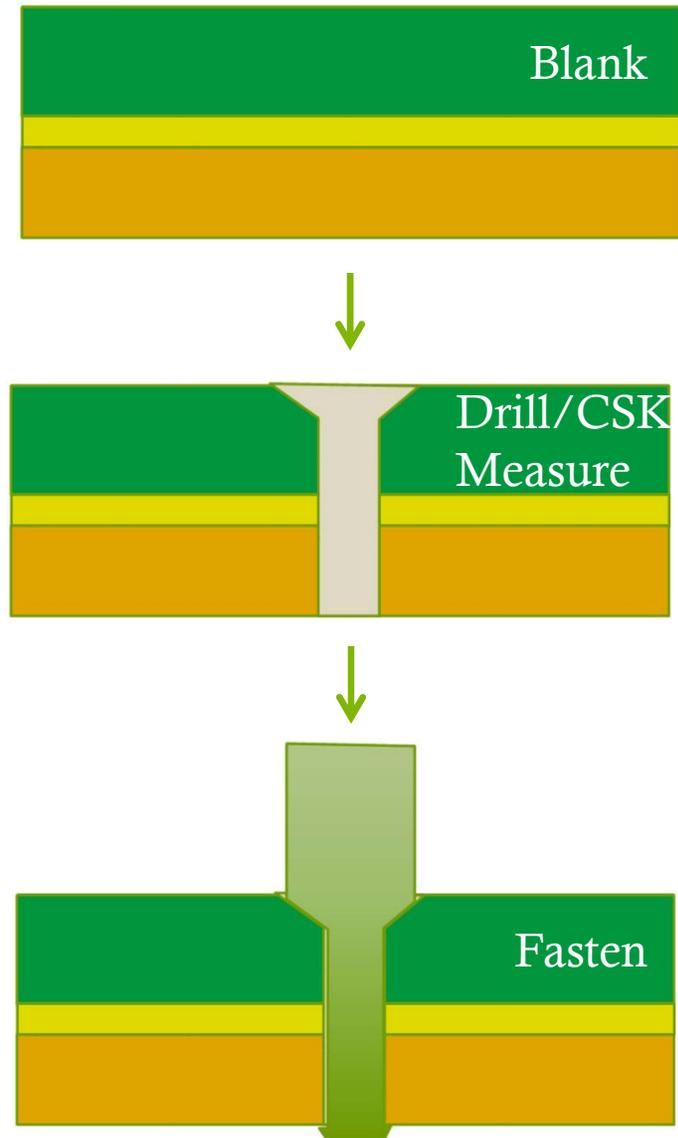
# Process: Skin Drilling

- **Skins to Structure**

- Drill, CSK, Measure, Temp Fasten
- Drill sizes 3/16 - 3/8" (4.8 - 9.5mm)
- Aluminum only

**Steps:**

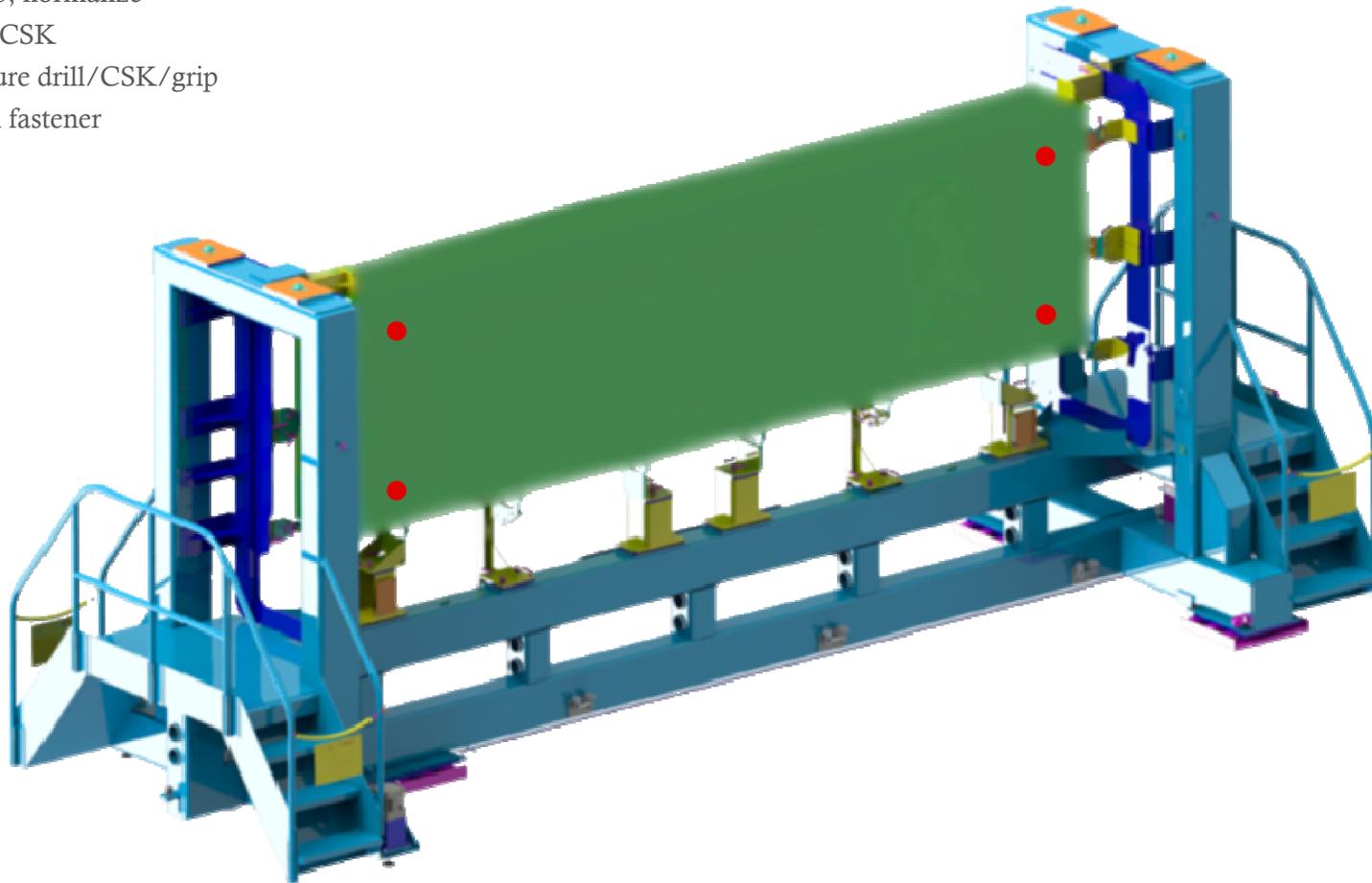
- "Scan" part using vision system
- Clamp, normalize
- Drill, CSK
- Measure drill/CSK/grip
- Install fastener



# Process: Skin Drilling – Scan Part

## Steps

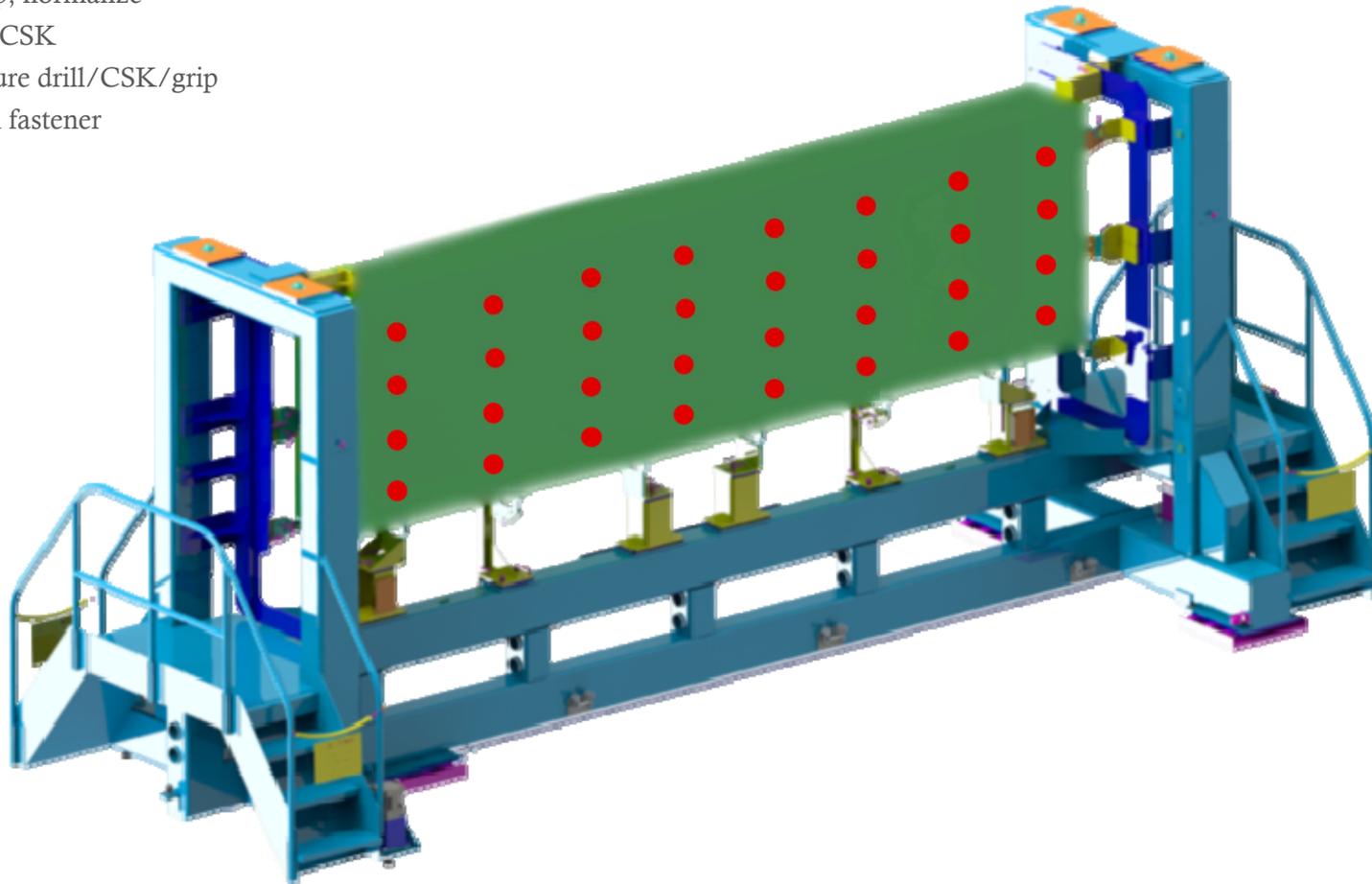
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# Process: Skin Drilling – Scan Part

## Steps

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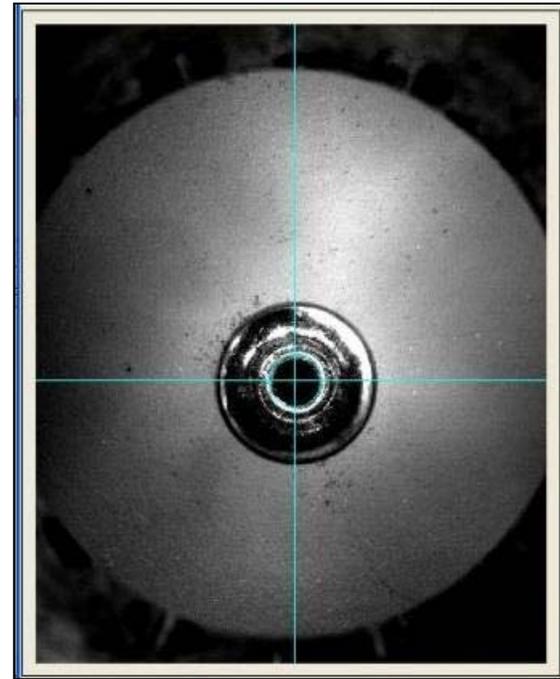
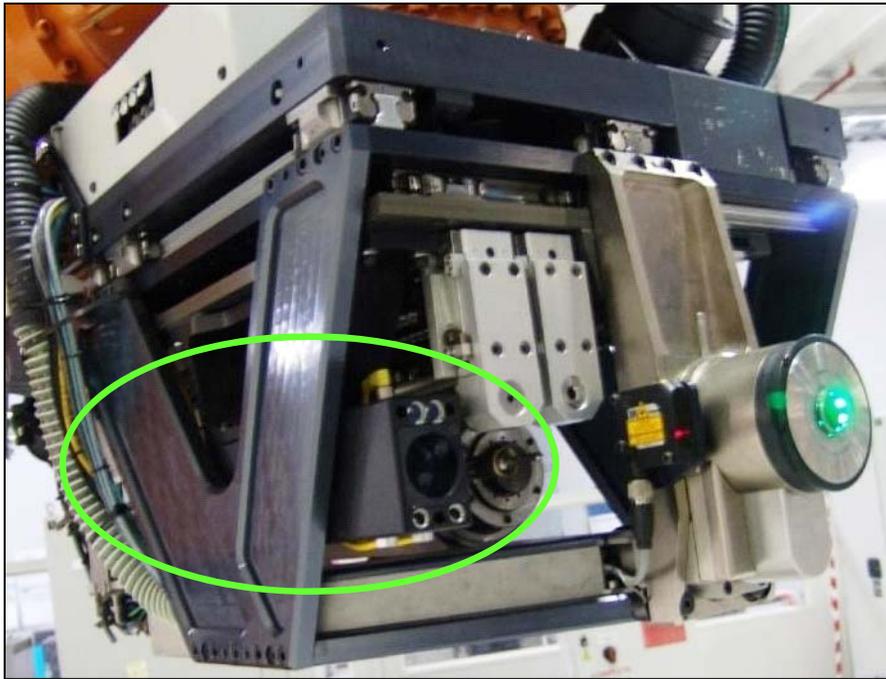
# Process: Skin Drilling – Scan Part

## Steps

- **“Scan” part using vision system**
- Clamp, normalize
- Drill, CSK
- Measure drill/CSK/grip
- Install fastener

## Automated Vision System

- Integrated on-axis lighting
- Mounted to shuttle table to enable alignment with TCP (camera view is thru spindle axis)

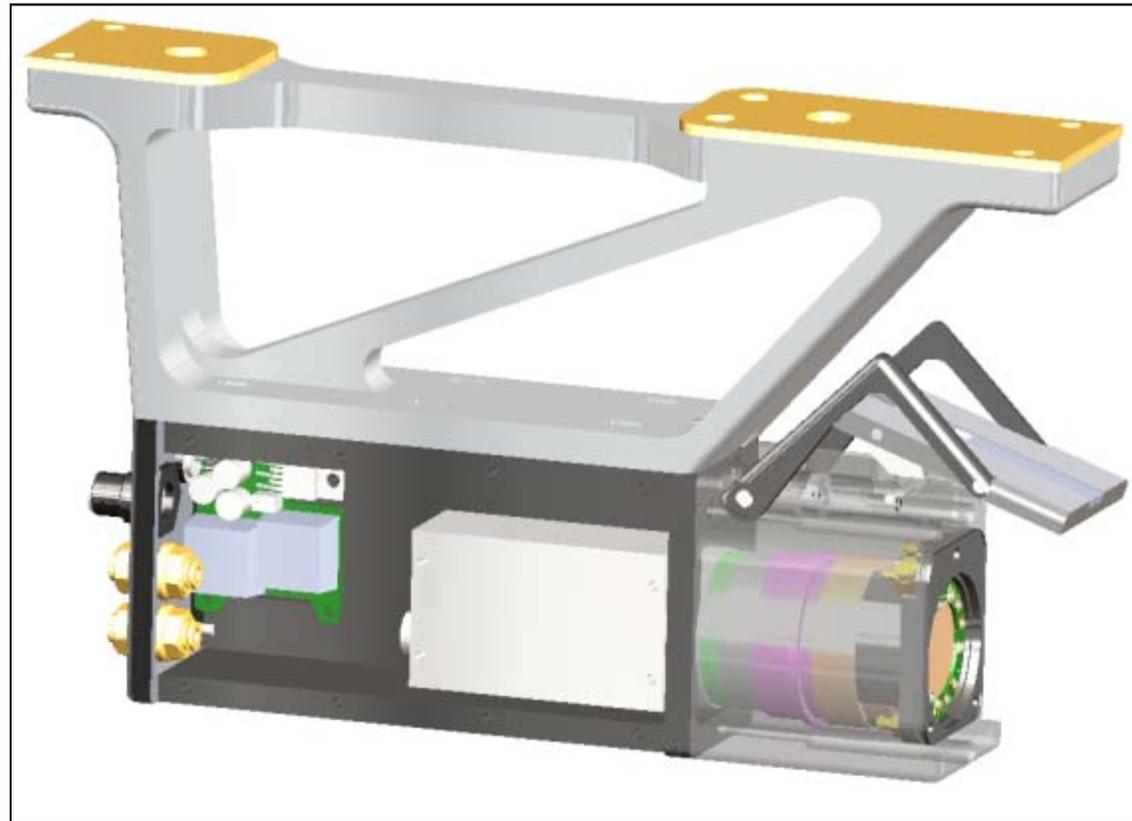


Similar production end effector shown

# Process: Skin Drilling – Scan Part

## Steps

- **“Scan” part using vision system**
- Clamp, normalize
- Drill, CSK
- Measure drill/CSK/grip
- Install fastener



# Process: Skin Drilling – Clamp/Normalize

## Steps

- “Scan” part using vision system
- **Clamp, normalize**
- Drill, CSK
- Measure drill/CSK/grip
- Install fastener

## Nose Piece

- Quick-connect w/damage-preventing breakaway feature
- Integrated Boelube delivery
- Angle feedback for auto-normalization
- Chip blast and vacuum extraction



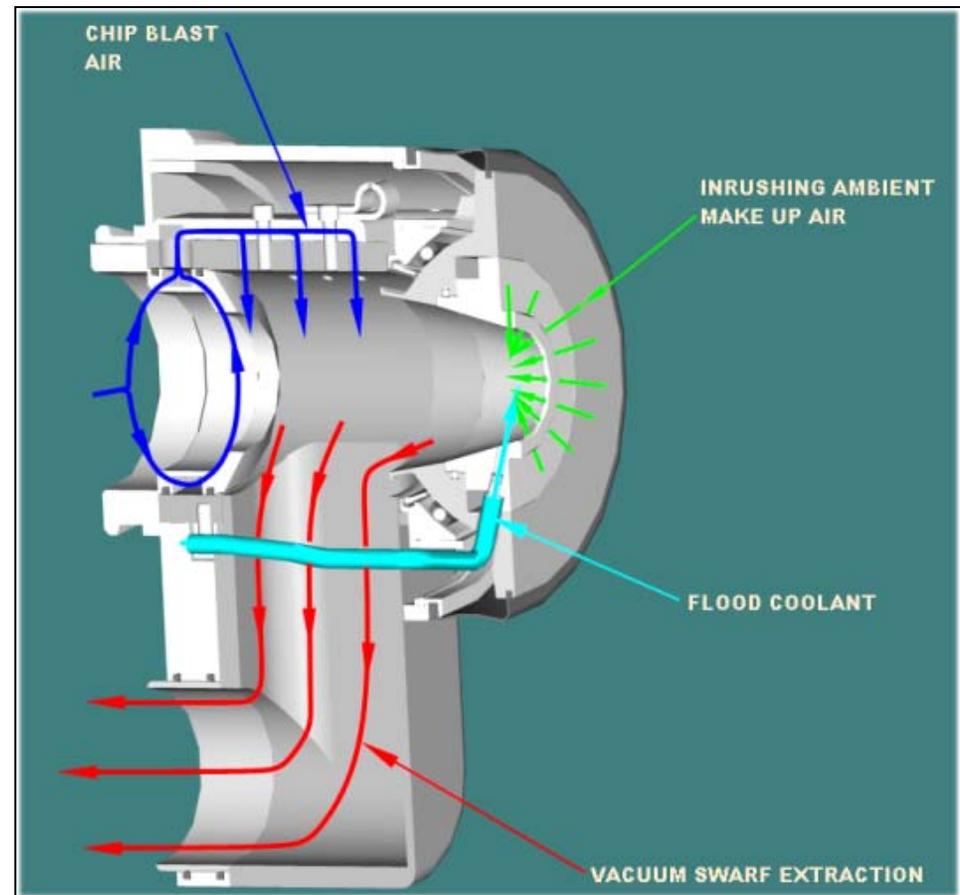
# Process: Skin Drilling – Clamp/Normalize

## Steps

- “Scan” part using vision system
- **Clamp, normalize**
- Drill, CSK
- Measure drill/CSK/grip
- Install fastener

## Nose Piece Features:

- Angle-sensing swivel tip
- Chip blast, Boelube delivery, vacuum



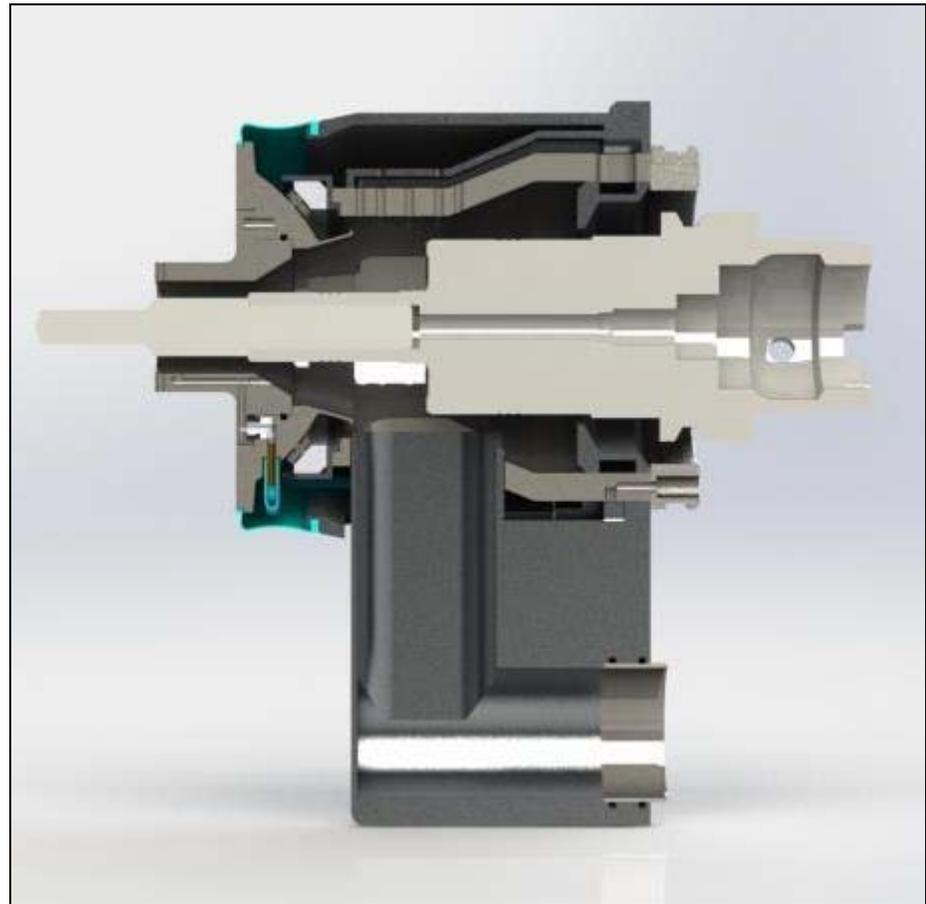
# Process: Skin Drilling – Clamp/Normalize

## Steps

- “Scan” part using vision system
- **Clamp, normalize**
- Drill, CSK
- Measure drill/CSK/grip
- Install fastener

## Skin Cell Nose Piece Features:

- Large inner diameter to accommodate Tribos ‘R’ tool holders as well as Centrix inserter nose



# Process: Skin Drilling – Clamp/Normalize

## Steps

- “Scan” part using vision system
- **Clamp, normalize**
- Drill, CSK
- Measure drill/CSK/grip
- Install fastener

## Skin Cell Nose Piece Features:

- $\pm 4^\circ$  Spherical Compliance with angle feedback



# Process: Skin Drilling – Clamp/Normalize

## Steps

- “Scan” part using vision system
- **Clamp, normalize**
- Drill, CSK
- Measure drill/CSK/grip
- Install fastener

## Quick change contact tips:

- 3 contact tips for use in skin cell
- Boelube delivery on all contact tips



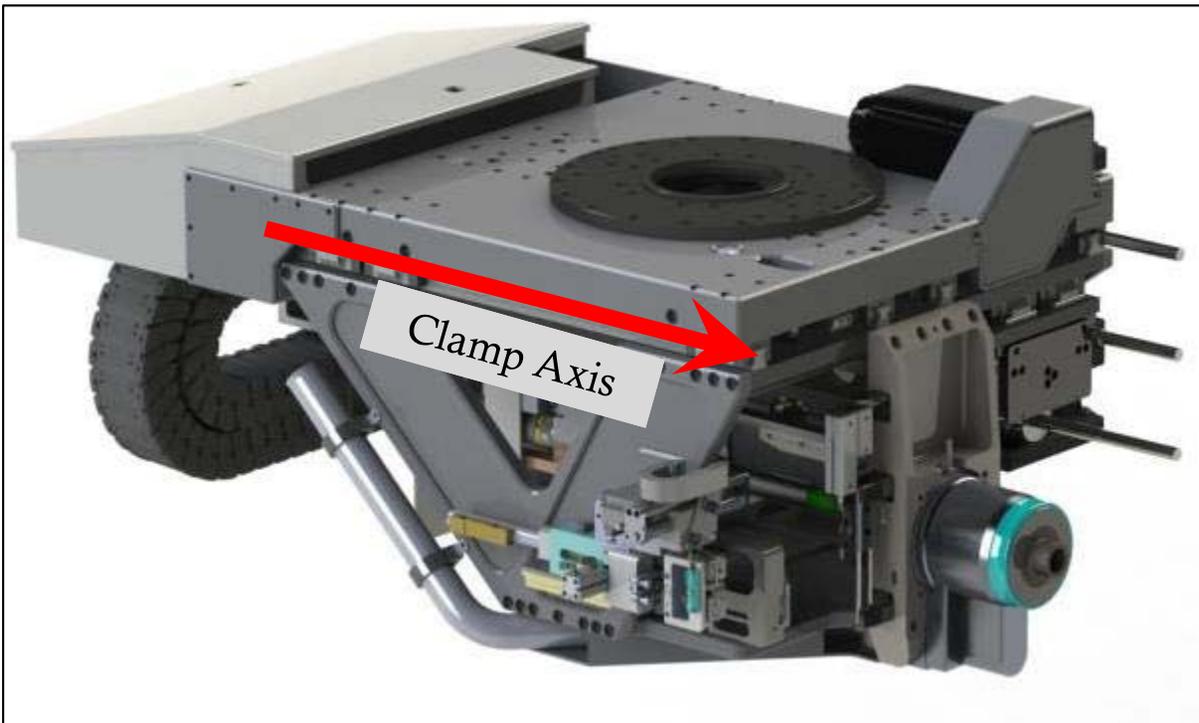
# Process: Skin Drilling – Clamp/Normalize

## Steps

- “Scan” part using vision system
- **Clamp, normalize**
- Drill, CSK
- Measure drill/CSK/grip
- Install fastener



Clamp Drive



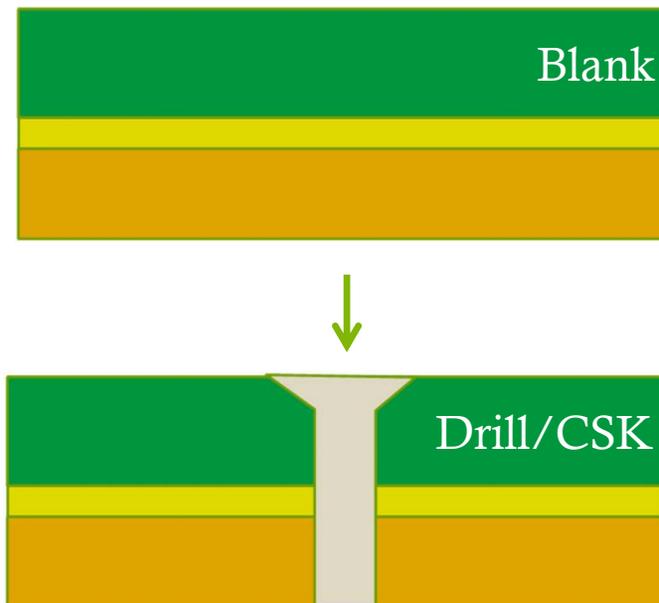
## *Clamp Axis*

- Servo-controlled with load cell feedback
- All process tools mount to clamp axis

# Process: Skin Drilling – Drill/CSK

## Steps

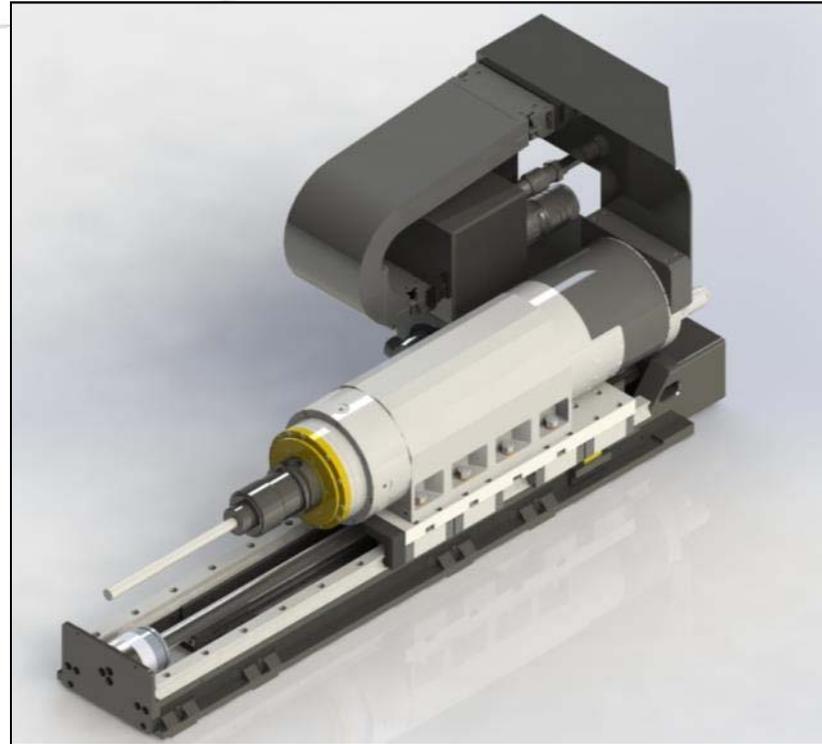
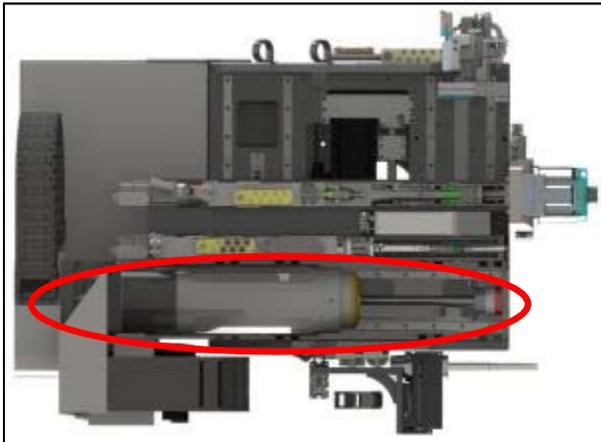
- “Scan” part using vision system
- Clamp, normalize
- **Drill, CSK**
- Measure drill/CSK/grip
- Install fastener



# Process: Skin Drilling – Drill/CSK

## Steps

- “Scan” part using vision system
- Clamp, normalize
- **Drill, CSK**
- Measure drill/CSK/grip
- Install fastener



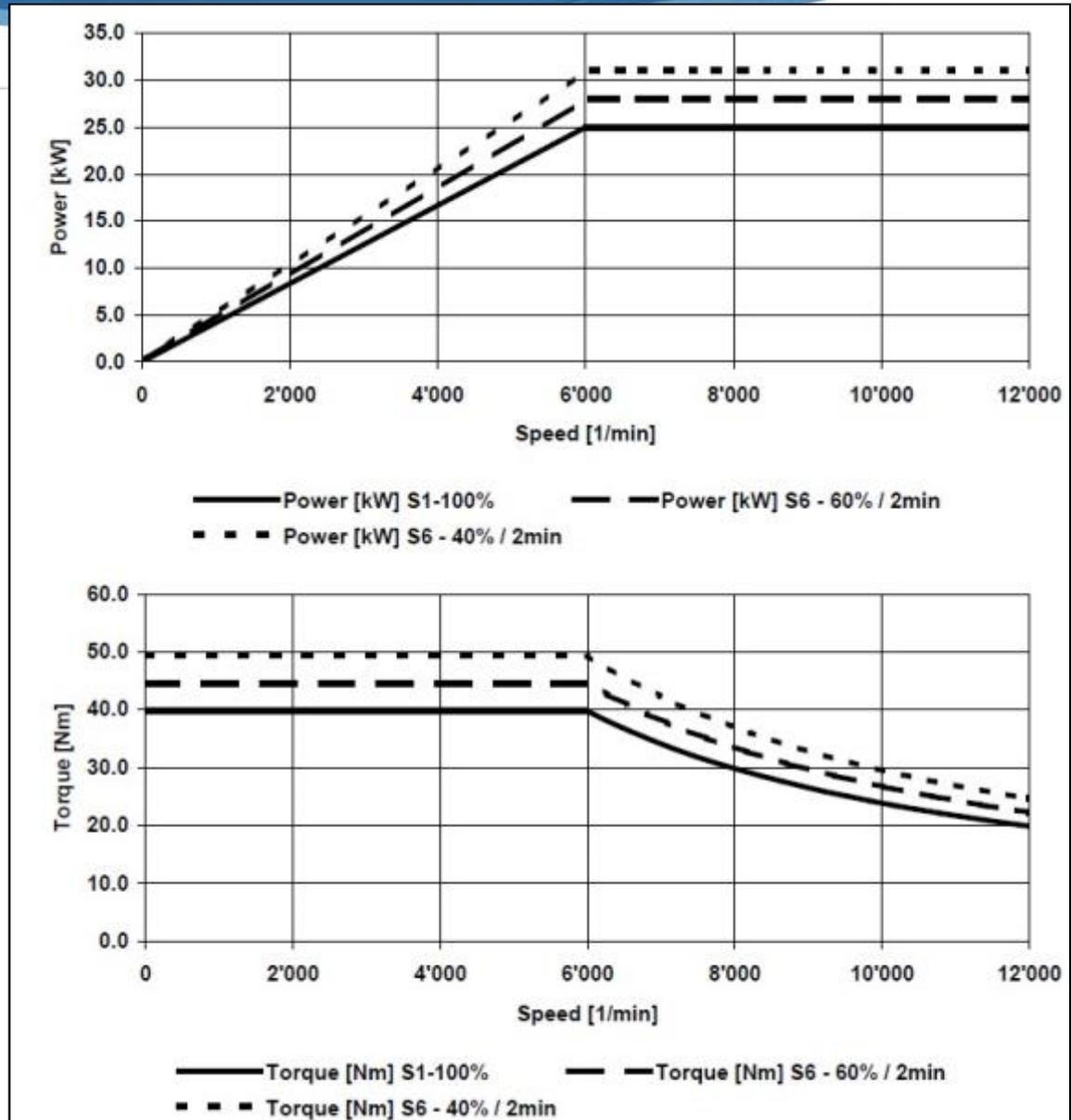
## Spindle

- Fischer 12,000 rpm, 40Nm (350 in-lbs.) continuous torque
- Hydraulic-release drawbar, HSK63A taper
- Liquid-cooled
- Servo/ball screw feed with linear encoder secondary feedback

# Process: Skin Drilling – Drill/CSK

## Steps

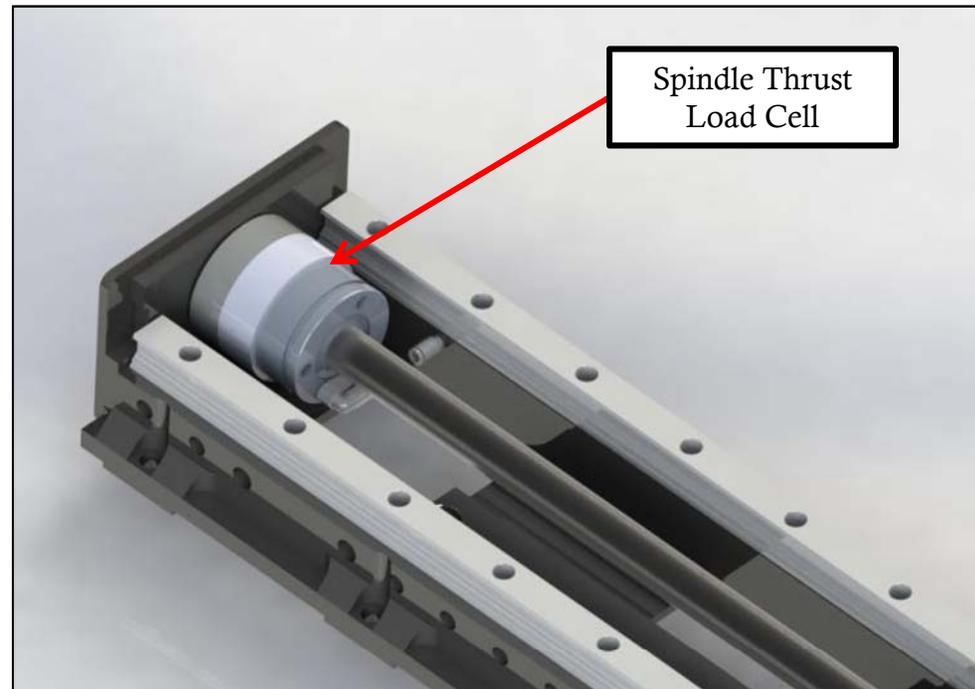
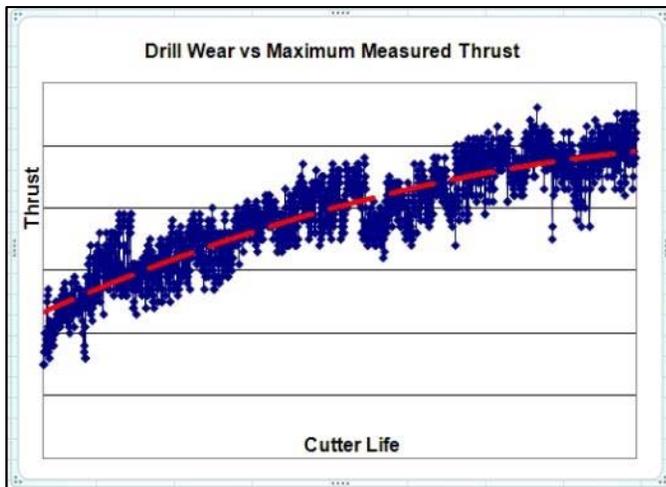
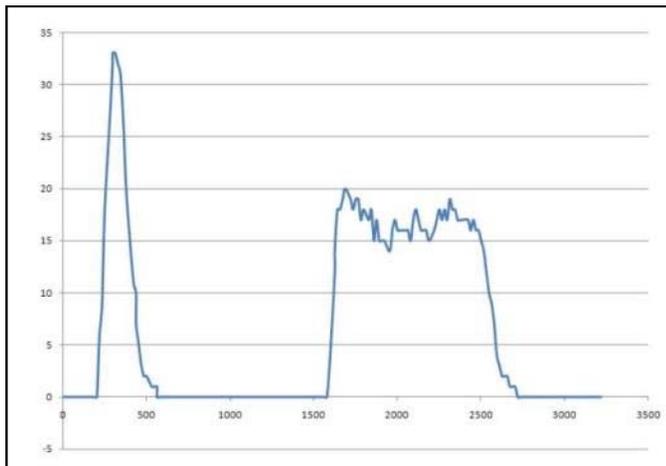
- “Scan” part using vision system
- Clamp, normalize
- **Drill, CSK**
- Measure drill/CSK/grip
- Install fastener



# Process: Skin Drilling – Drill/CSK

## Steps

- “Scan” part using vision system
- Clamp, normalize
- **Drill, CSK**
- Measure drill/CSK/grip
- Install fastener



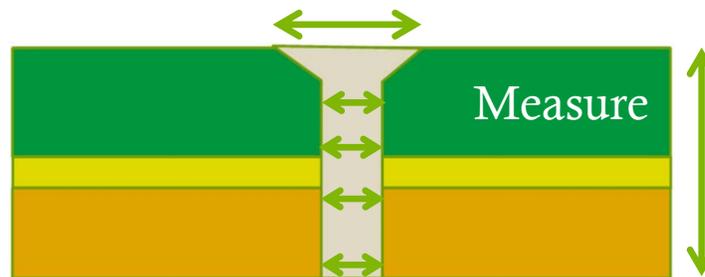
## Drill Thrust Feedback

- Process debug
- Cutter life tracking
- Broken bit detection

# Process: Skin Drilling – Measure

## Steps

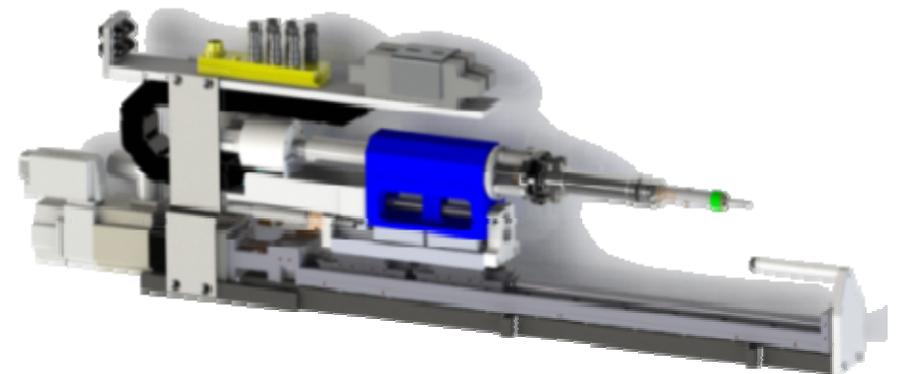
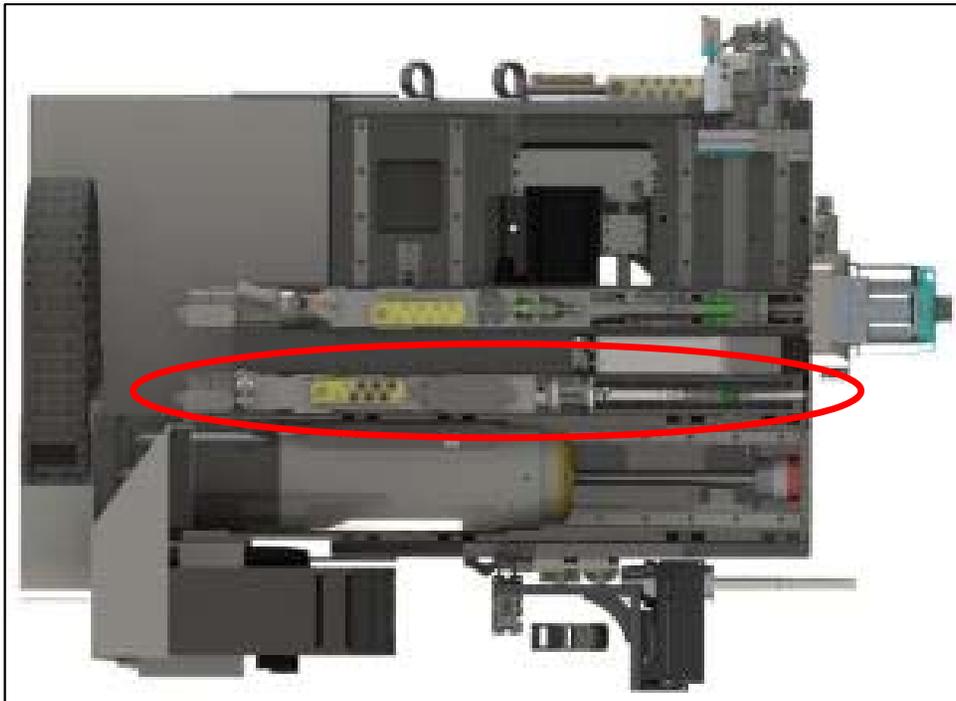
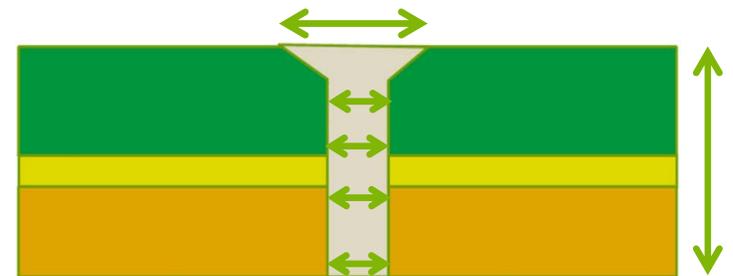
- “Scan” part using vision system
- Clamp, normalize
- Drill, CSK
- **Measure drill/CSK/grip**
- Install fastener



# Process: Skin Drilling – Measure

## Steps

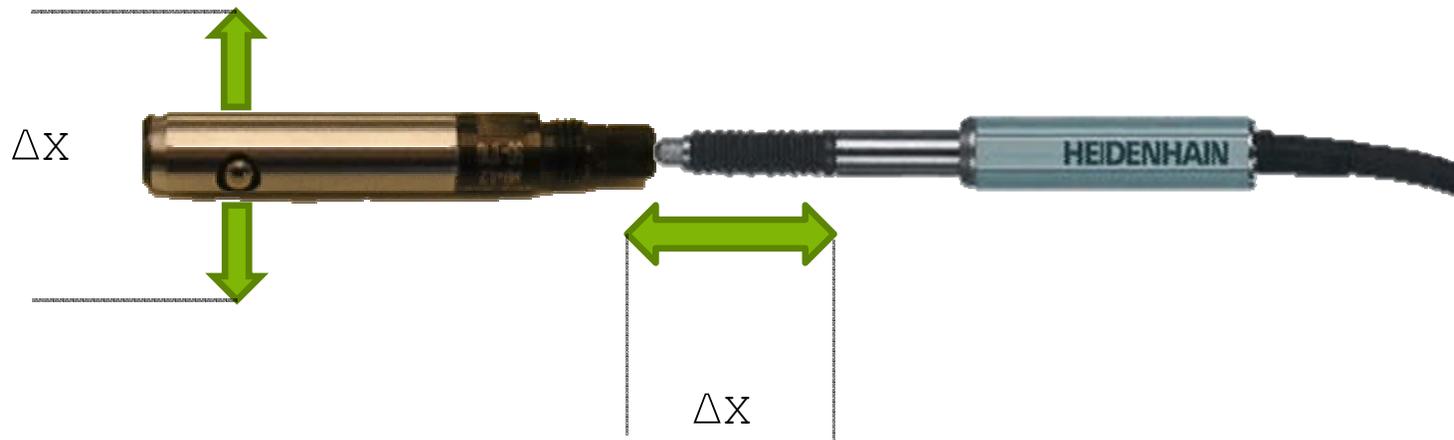
- “Scan” part using vision system
- Clamp, normalize
- Drill, CSK
- **Measure drill/CSK/grip**
- Install fastener



# Process: Skin Drilling – Measure

## Steps

- “Scan” part using vision system
- Clamp, normalize
- Drill, CSK
- **Measure drill/CSK/grip**
- Install fastener

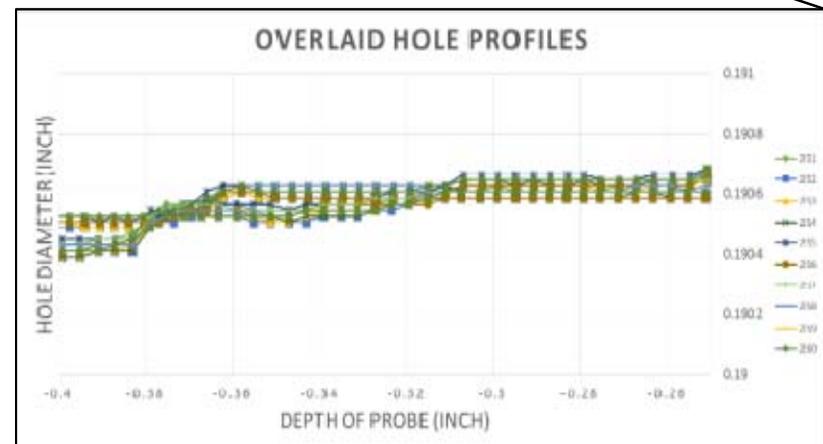
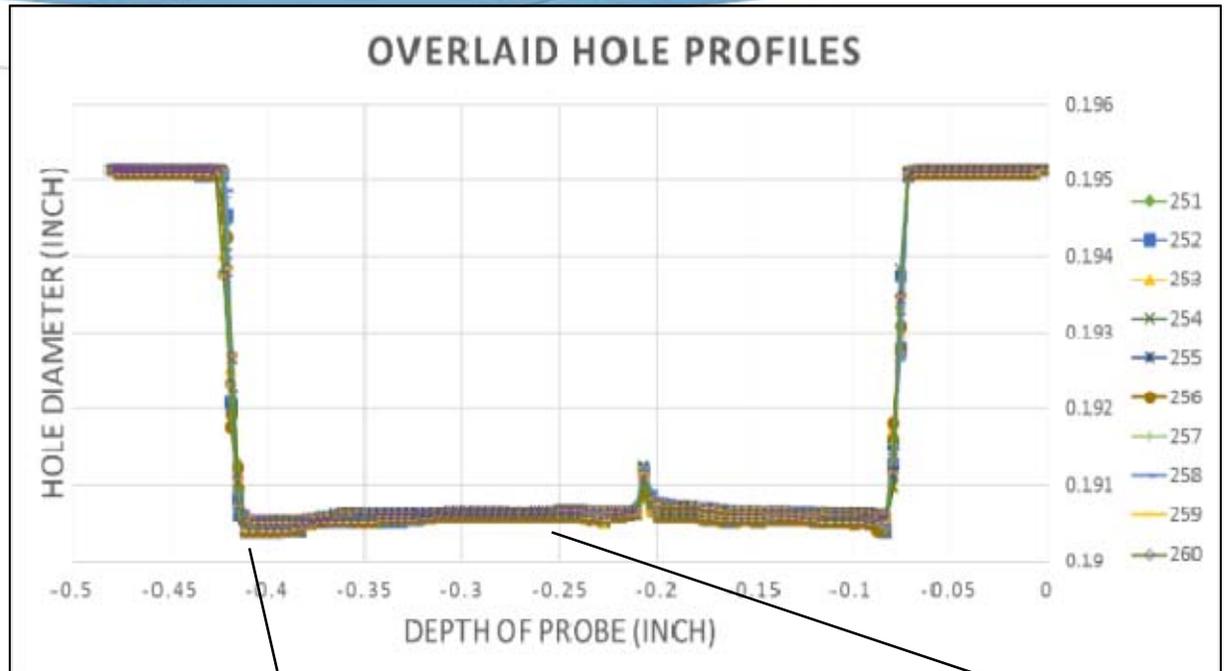


- 1/1 ratio of encoder movement to bore gage diameter change

# Process: Skin Drilling – Measure

## Steps

- “Scan” part using vision system
- Clamp, normalize
- Drill, CSK
- **Measure drill/CSK/grip**
- Install fastener



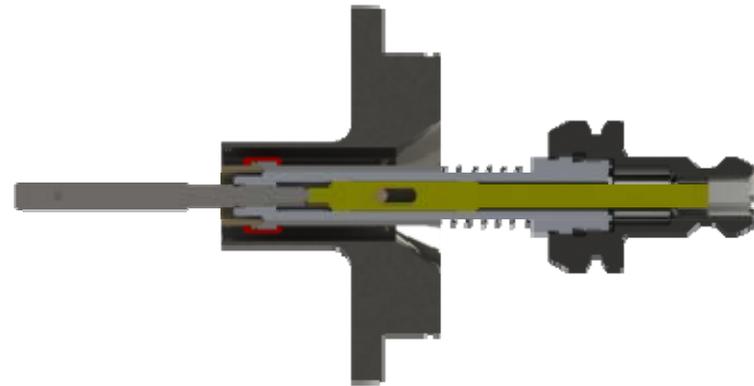
# Process: Skin Drilling – Measure

## Steps

- “Scan” part using vision system
- Clamp, normalize
- Drill, CSK
- **Measure drill/CSK/grip**
- Install fastener



Regular



Small Diameter

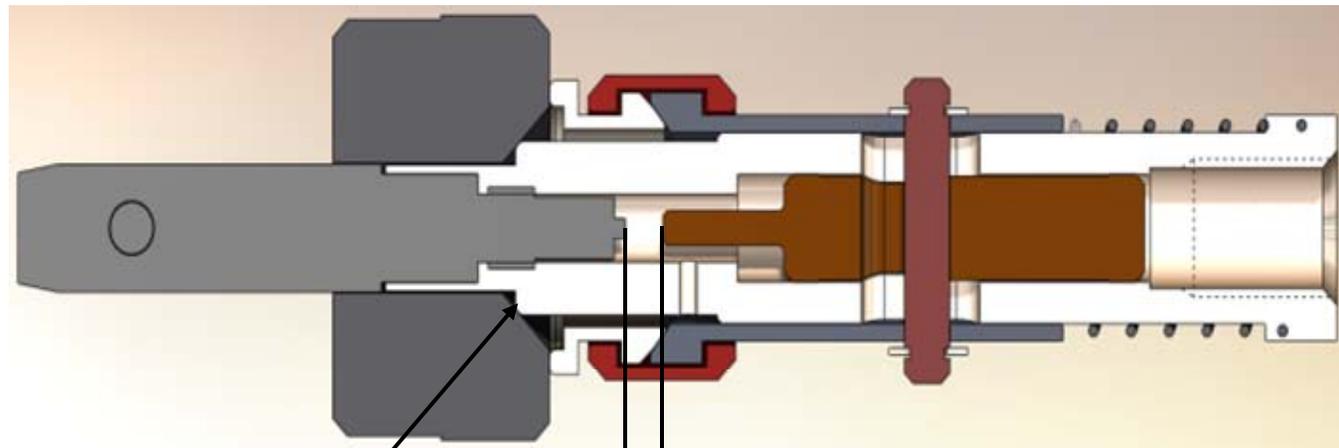


Extended

# Process: Skin Drilling – Measure

## Steps

- “Scan” part using vision system
- Clamp, normalize
- Drill, CSK
- **Measure drill/CSK/grip**
- Install fastener



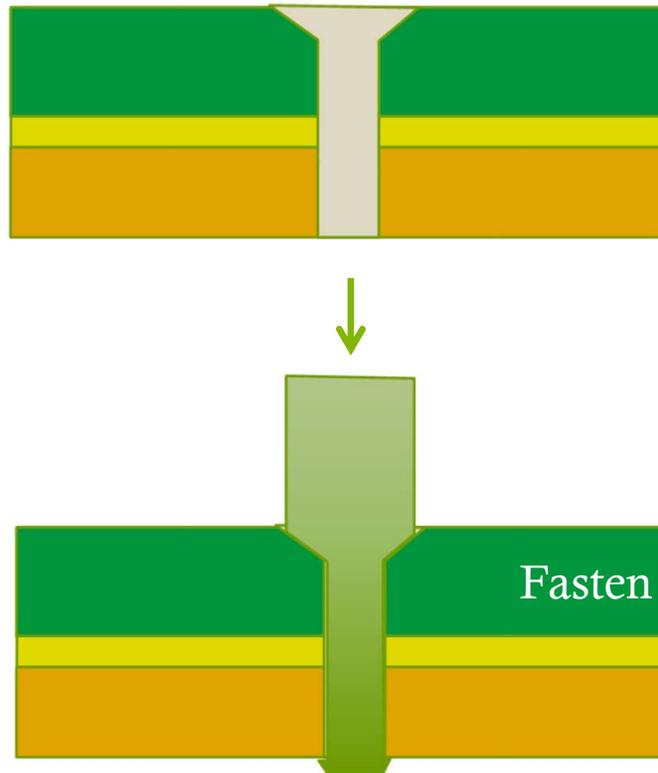
Reference CSK surface

Reference panel

# Process: Skin Drilling – Install Fastener

## Steps

- “Scan” part using vision system
- Clamp, normalize
- Drill, CSK
- Measure drill/CSK/grip
- **Install fastener**



# Process: Skin Drilling – Install Fastener

## Steps

- “Scan” part using vision system
- Clamp, normalize
- Drill, CSK
- Measure drill/CSK/grip
- **Install fastener**



Centrix, LLC

# Process: Skin Drilling – Install Fastener

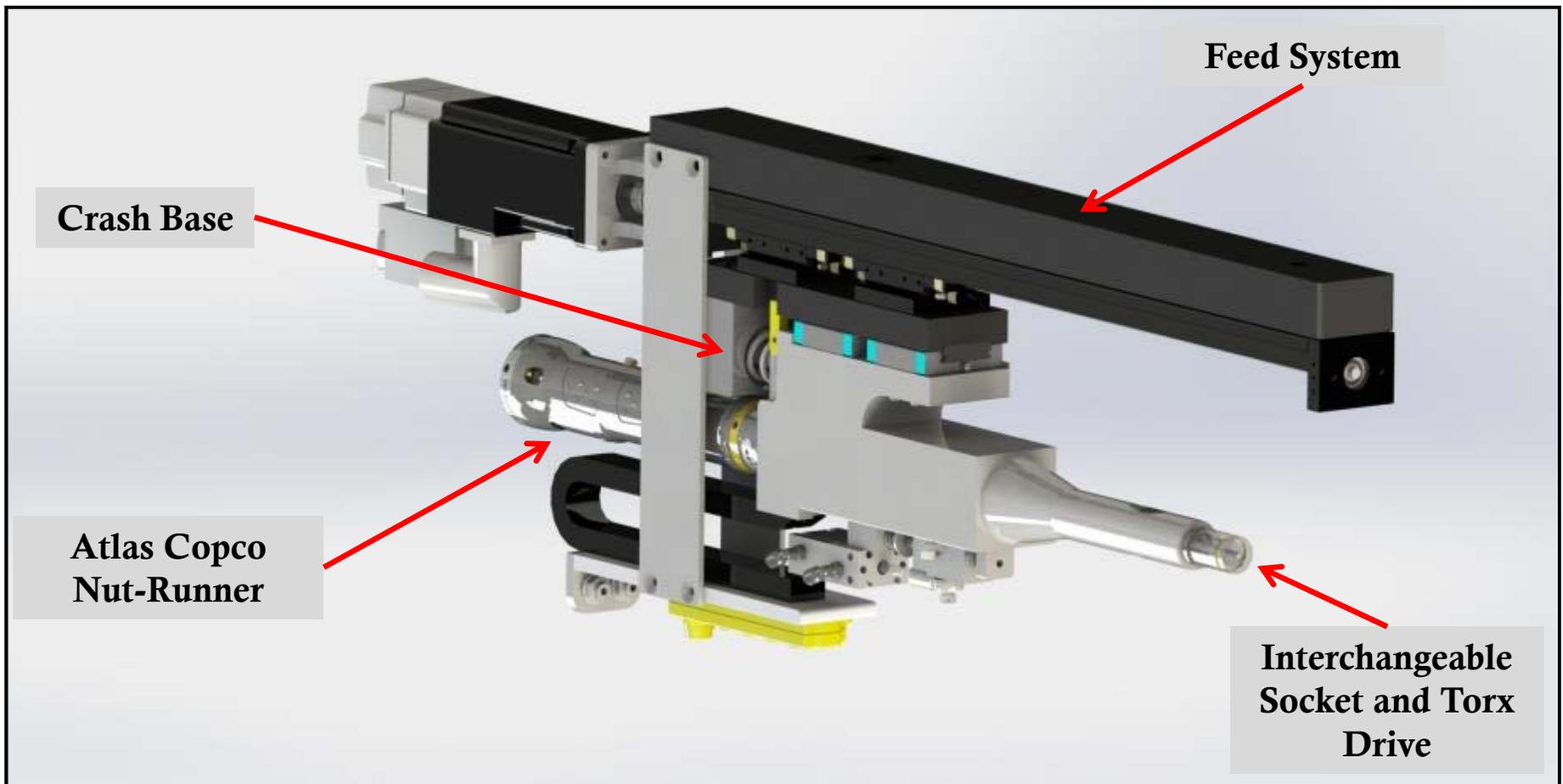
## Steps

- “Scan” part using vision system
- Clamp, normalize
- Drill, CSK
- Measure drill/CSK/grip
- **Install fastener**



Fastener is drawn in and clamped by rotating inner drive to programmed torque

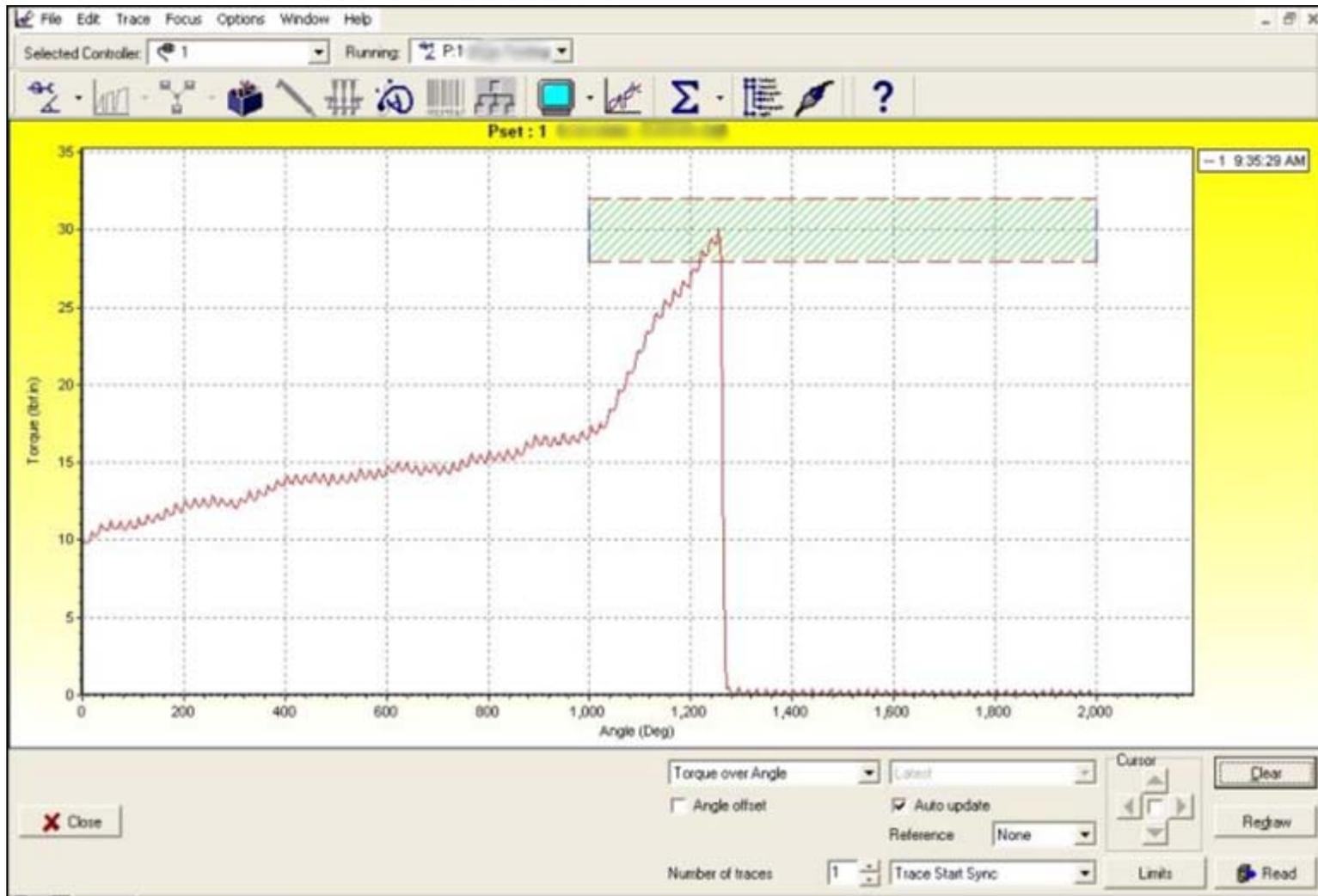
# Process: Skin Drilling – Install Fastener

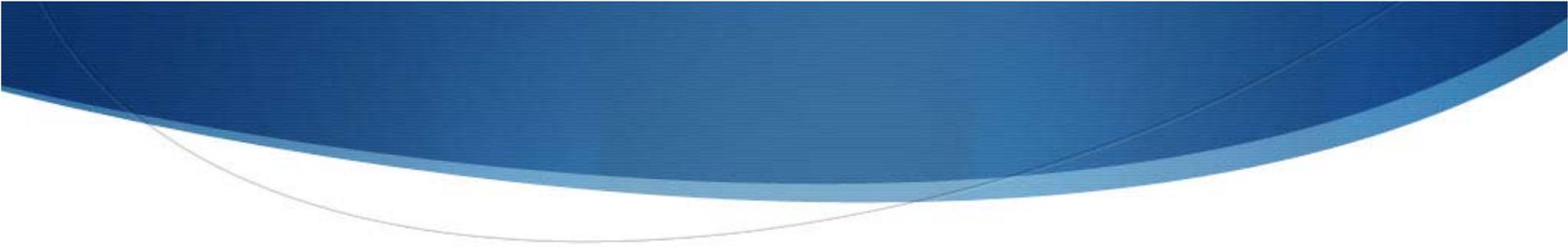


# Process: Skin Drilling – Install Fastener



# Process: Skin Drilling – Install Fastener

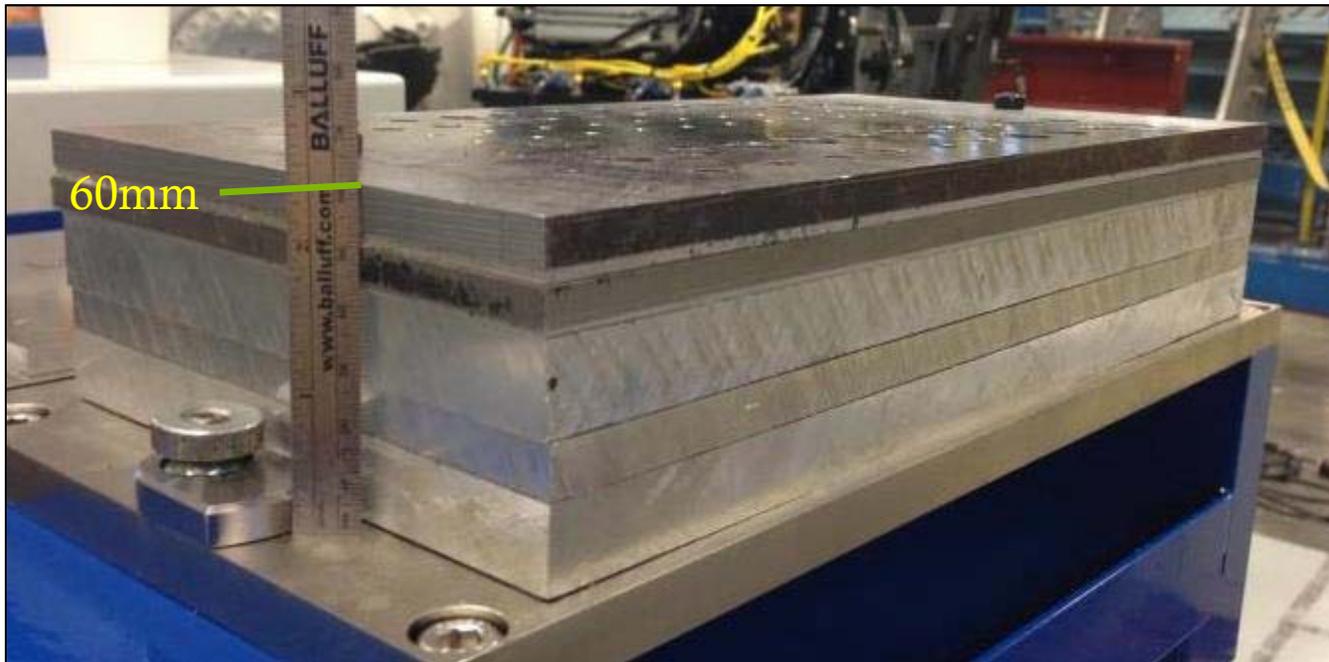




# Production Process: Fittings to Substructure

# Process: Drilling/Reaming Fittings

- **Fittings, Skins, Structure**
  - Spot/Endmill, Drill, Ream, Measure
  - Drill sizes 1/4 - 9/16" (6.4 – 14.3mm)
  - High-strength materials and various aluminum alloys



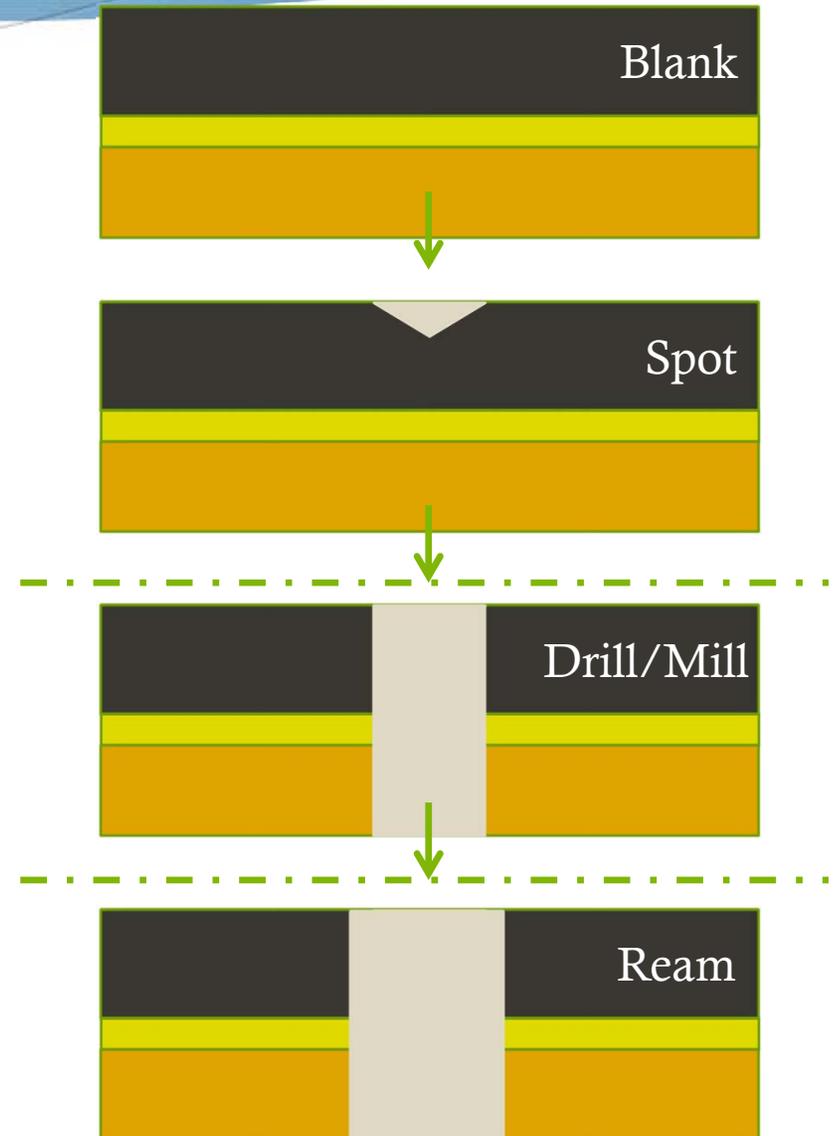
# Process: Drilling/Reaming Fittings

- **Fittings, Skins, Structure**

- Spot/Endmill, Drill, Ream, Measure
- Drill sizes -8 to -18
- High-strength materials and aluminum

## Steps

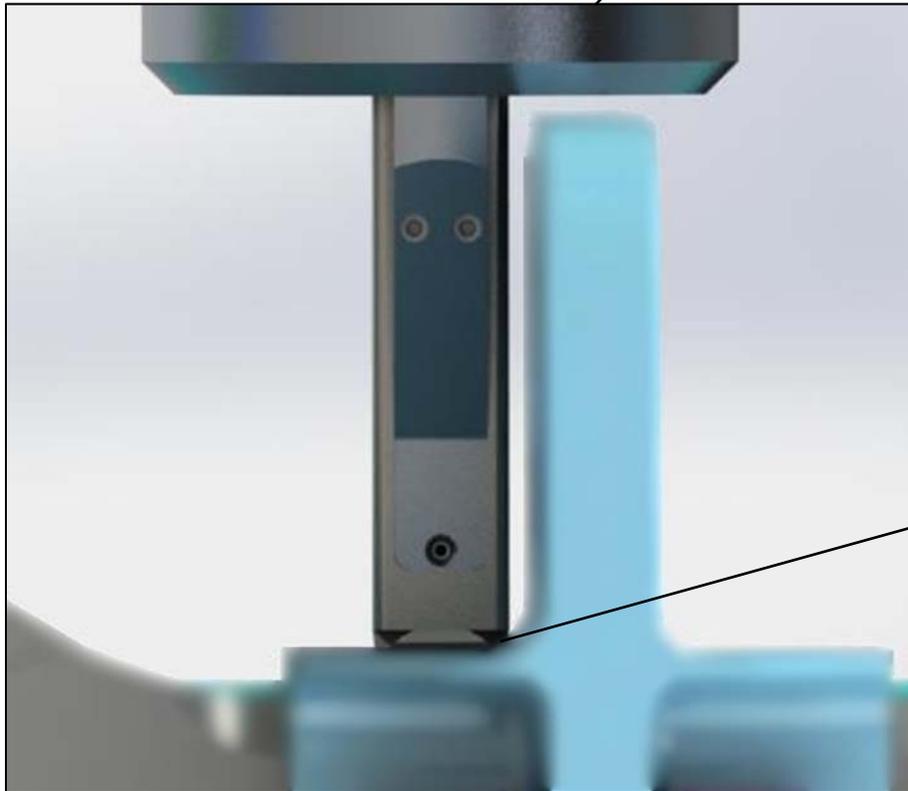
- “Scan” (if needed) using vision system
- Clamp
- Spot/EM, Drill, Ream
- Measure



# Process: Drilling/Reaming Fittings - Clamp

## Steps

- “Scan” part using vision system
- **Clamp**
- Spot/EM, Drill, Ream
- Measure



## **Narrow Nosepiece**

- Retains functionality of standard nosepiece less auto-normality
- Narrow profile give clearance for drilling next to fitting geometry

# Process: Drilling/Reaming Fittings - Clamp

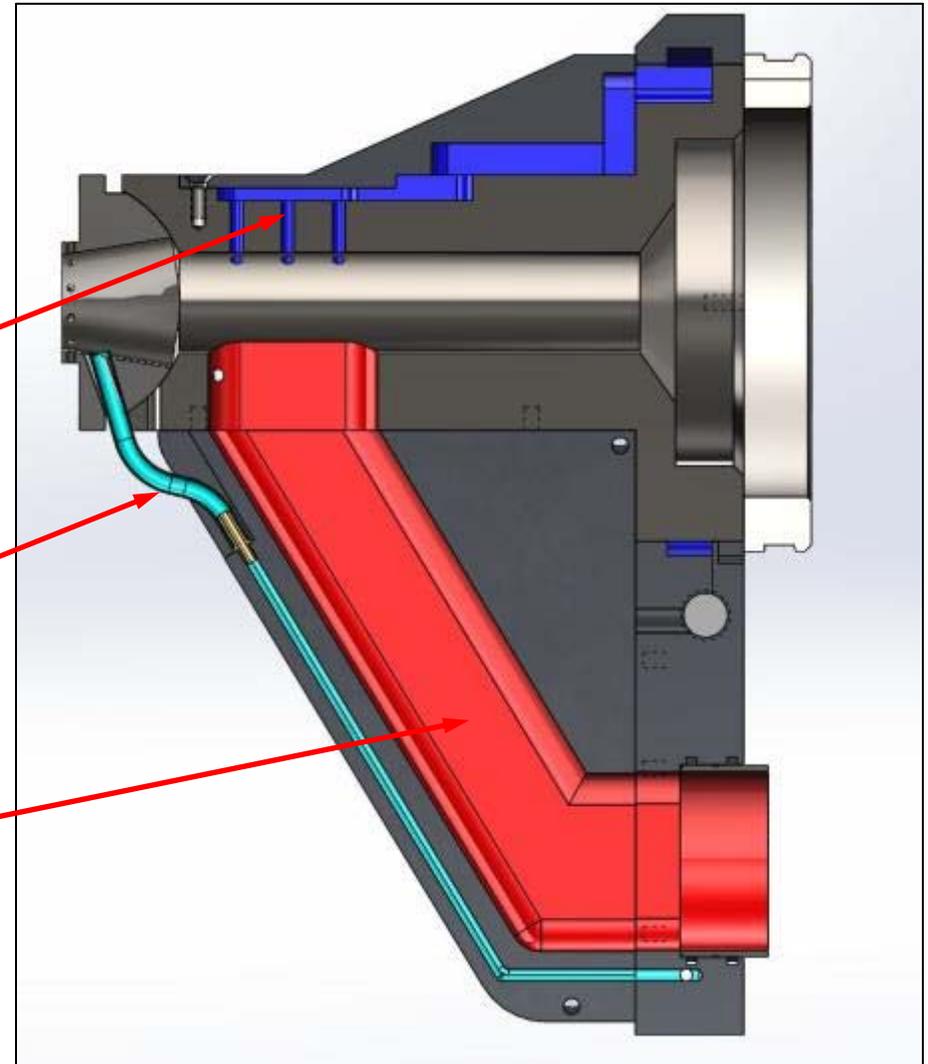
## Steps

- “Scan” part using vision system
- **Clamp**
- Spot/EM, Drill, Ream
- Measure

Chip Blast Air

External lubricant

Vacuum



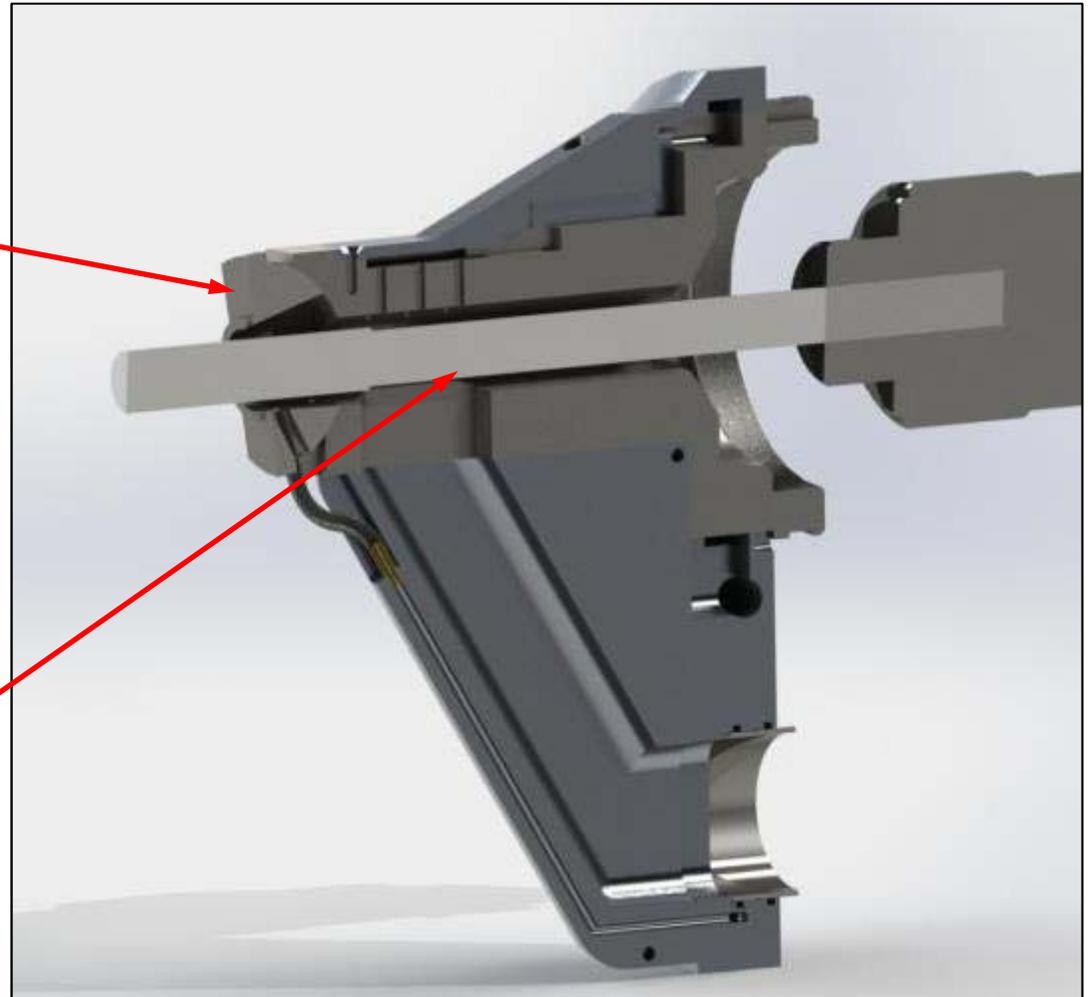
# Process: Drilling/Reaming Fittings - Clamp

## Steps

- “Scan” part using vision system
- **Clamp**
- Spot/EM, Drill, Ream
- Measure

Spherically compliant tip allows for up to 8° off-normal drilling

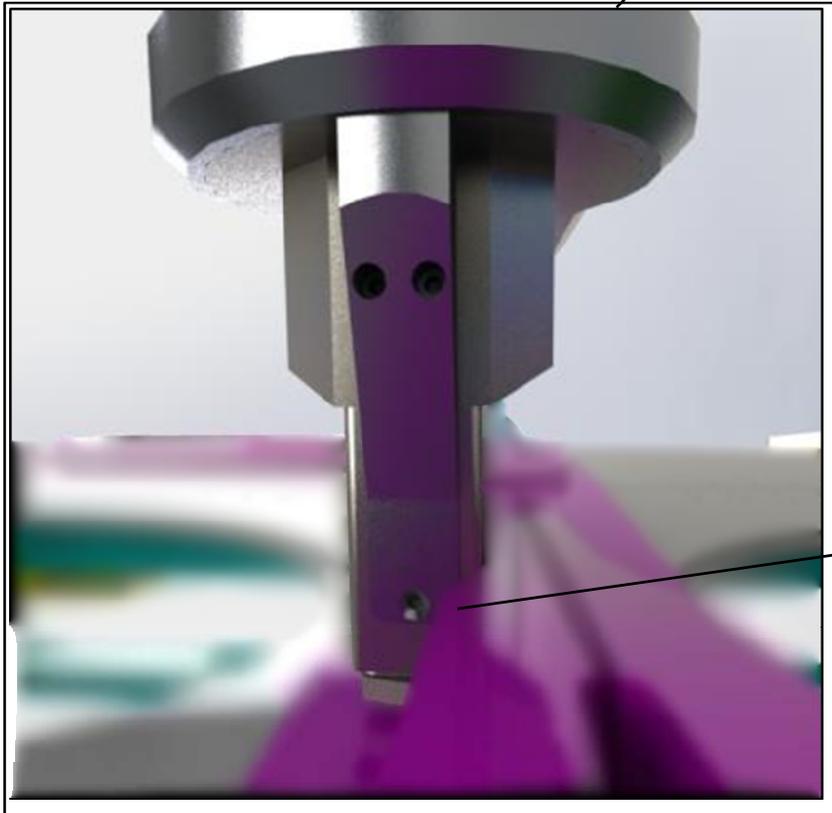
Clearance for largest reamers/drills



# Process: Drilling/Reaming Fittings - Clamp

## Steps

- “Scan” part using vision system
- **Clamp**
- Spot/EM, Drill, Ream
- Measure



## Intermediate Narrow Nosepiece

- Retains functionality of standard nosepiece less auto-normality
- Allows tool holder to extend further into nosepiece than with narrow nosepiece

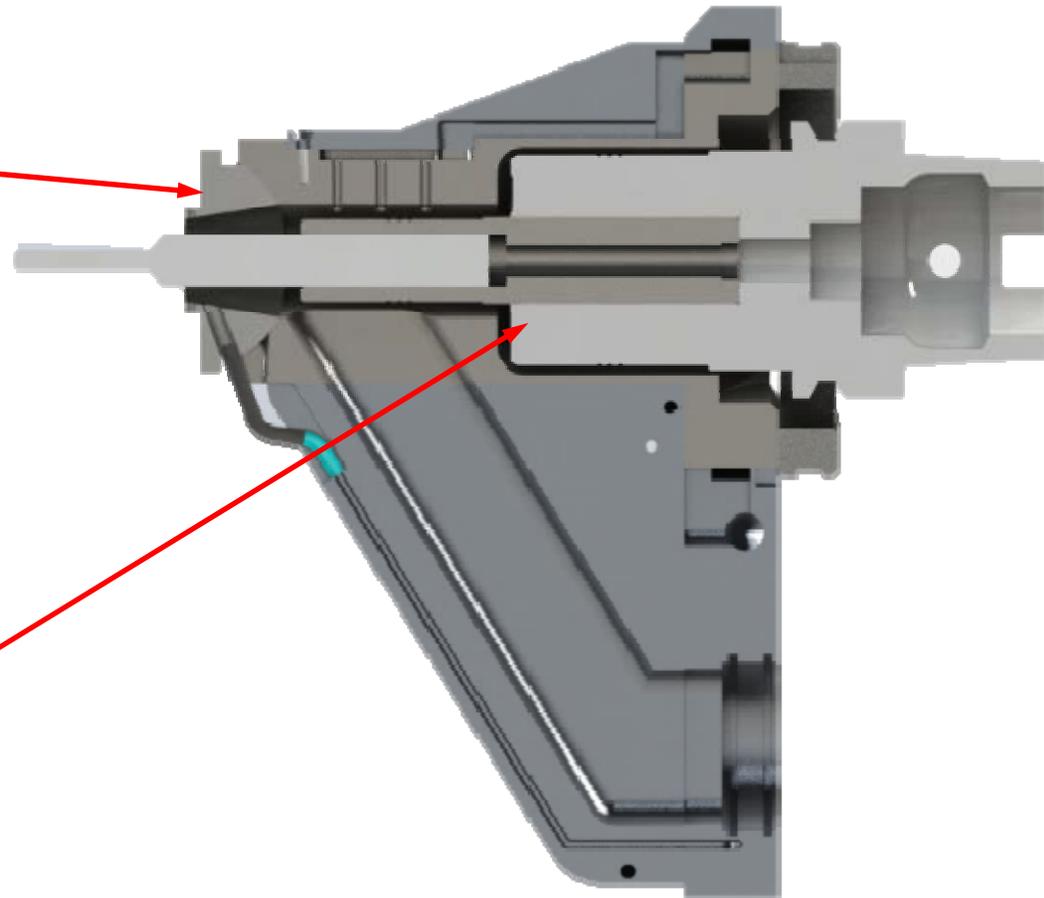
# Process: Drilling/Reaming Fittings - Clamp

## Steps

- “Scan” part using vision system
- **Clamp**
- Spot/EM, Drill, Ream
- Measure

Spherically compliant tip allows for up to 8° off-normal drilling

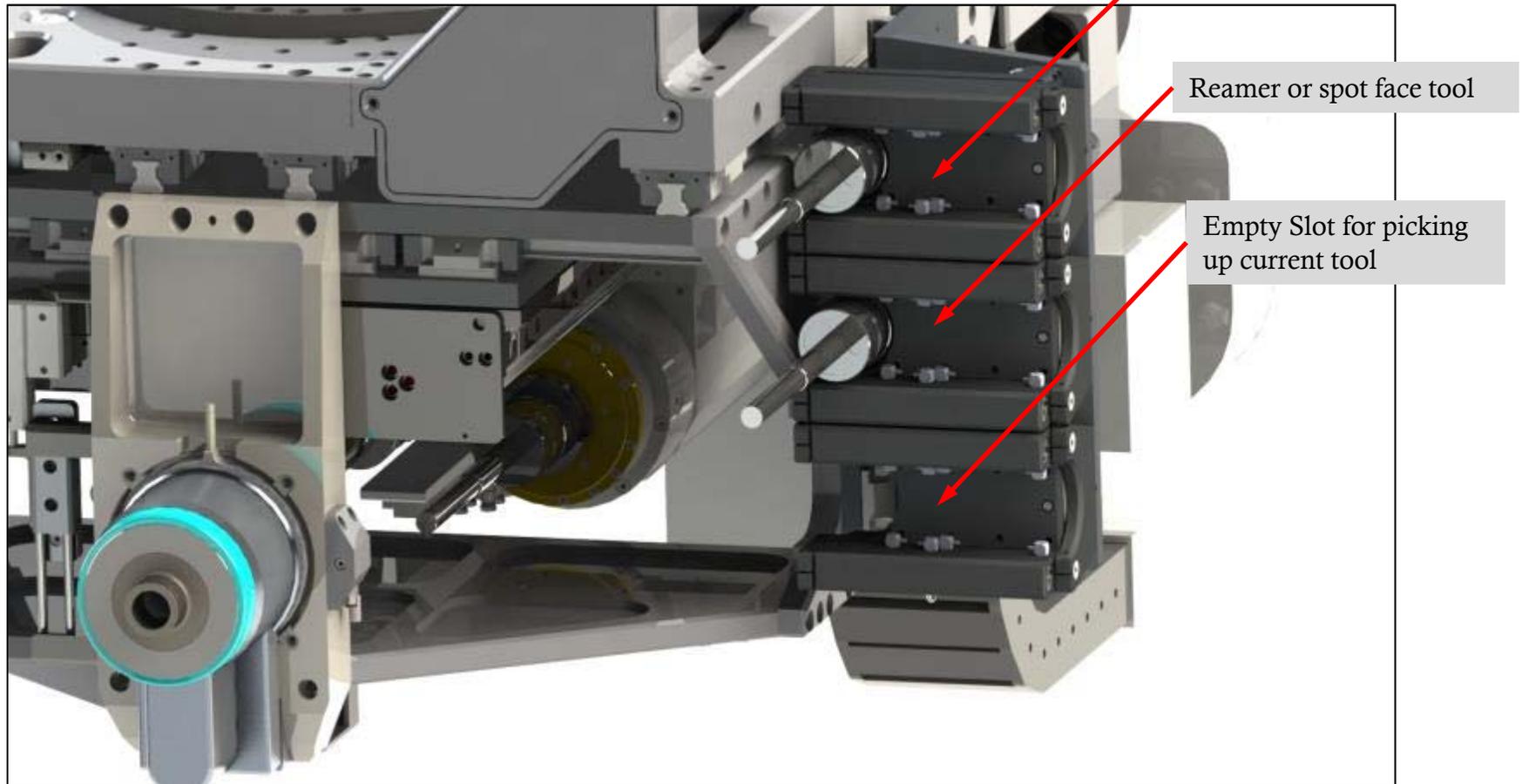
Clearance for tool holder and extension



# Process: Drilling/Reaming Fittings – Tool Swap

## Steps

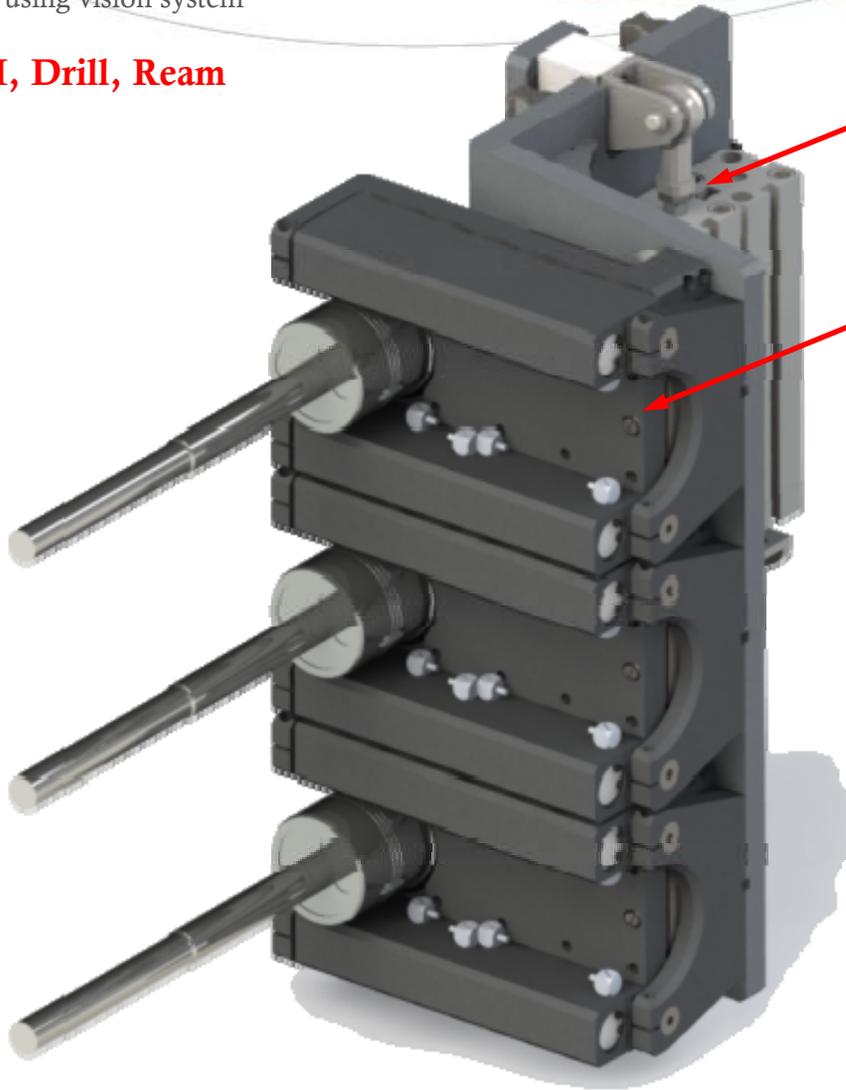
- “Scan” part using vision system
- Clamp
- **Spot/EM, Drill, Ream**
- Measure



# Process: Drilling/Reaming Fittings – Tool Swap

## Steps

- “Scan” part using vision system
- Clamp
- **Spot/EM, Drill, Ream**
- Measure

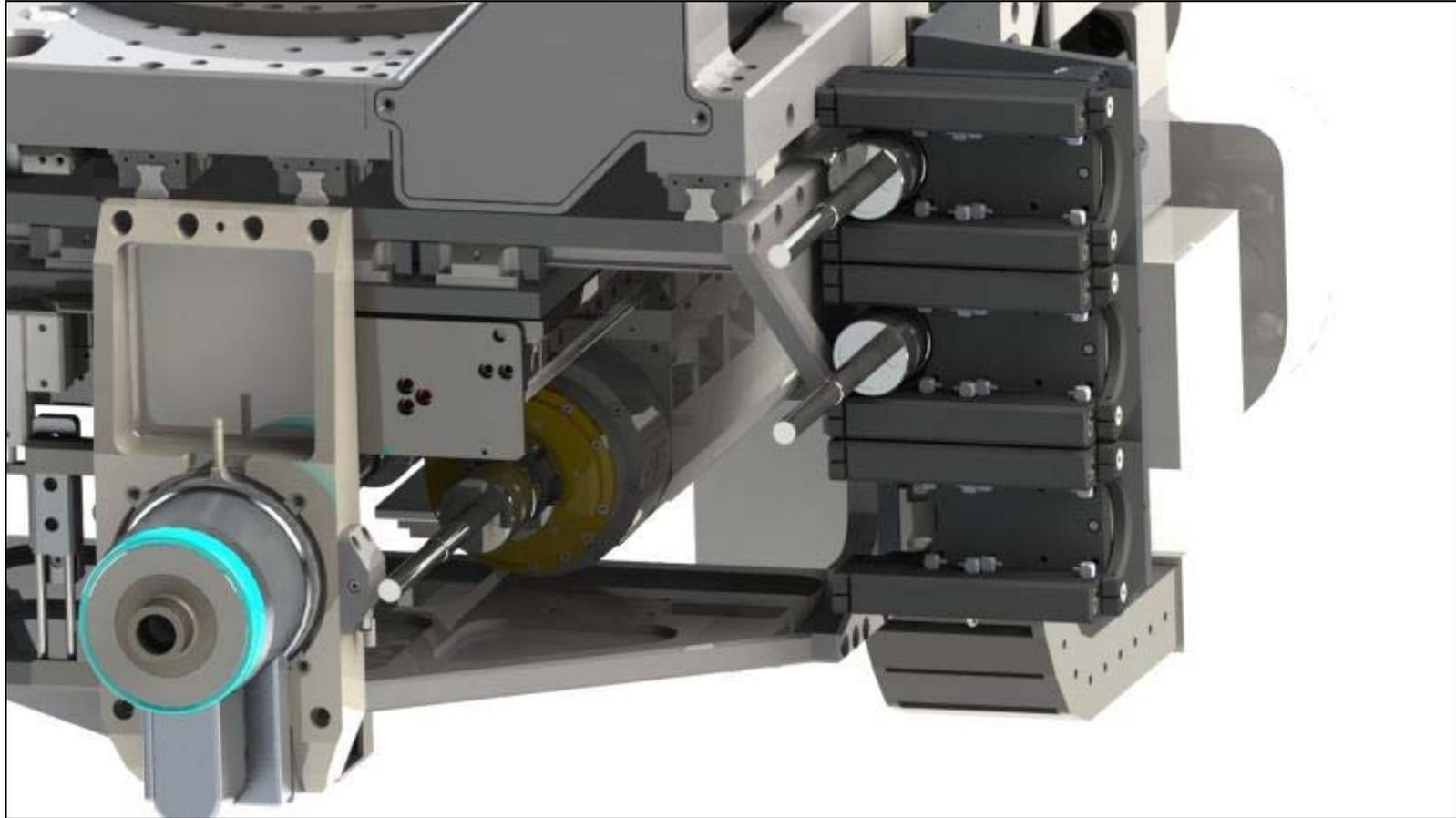


Tool Selection:  
3-position cylinder

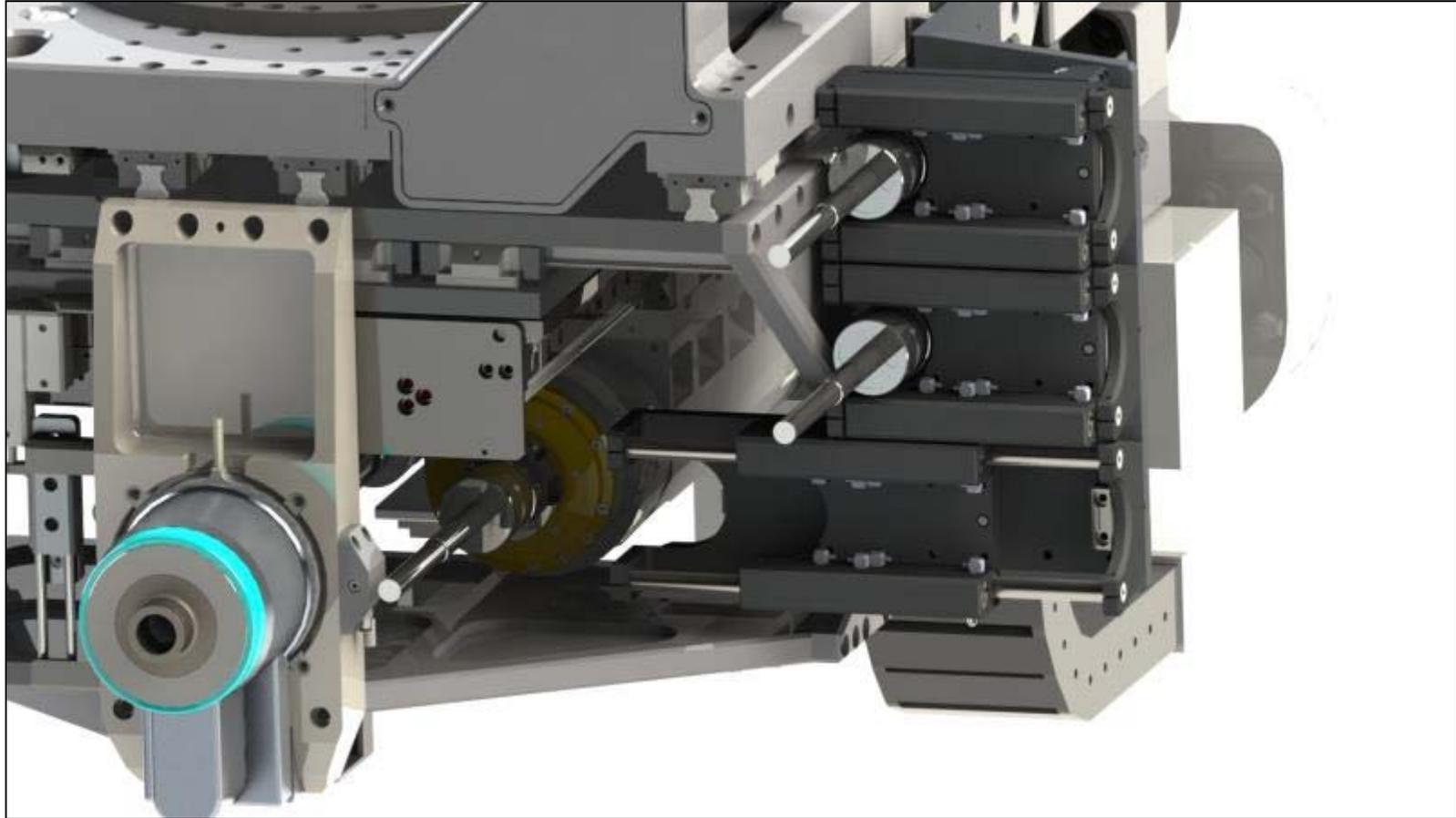
Gripper actuator  
(3x)

- Can hold any HSK63A tool
- All pneumatic
- Minimized overall width (7")

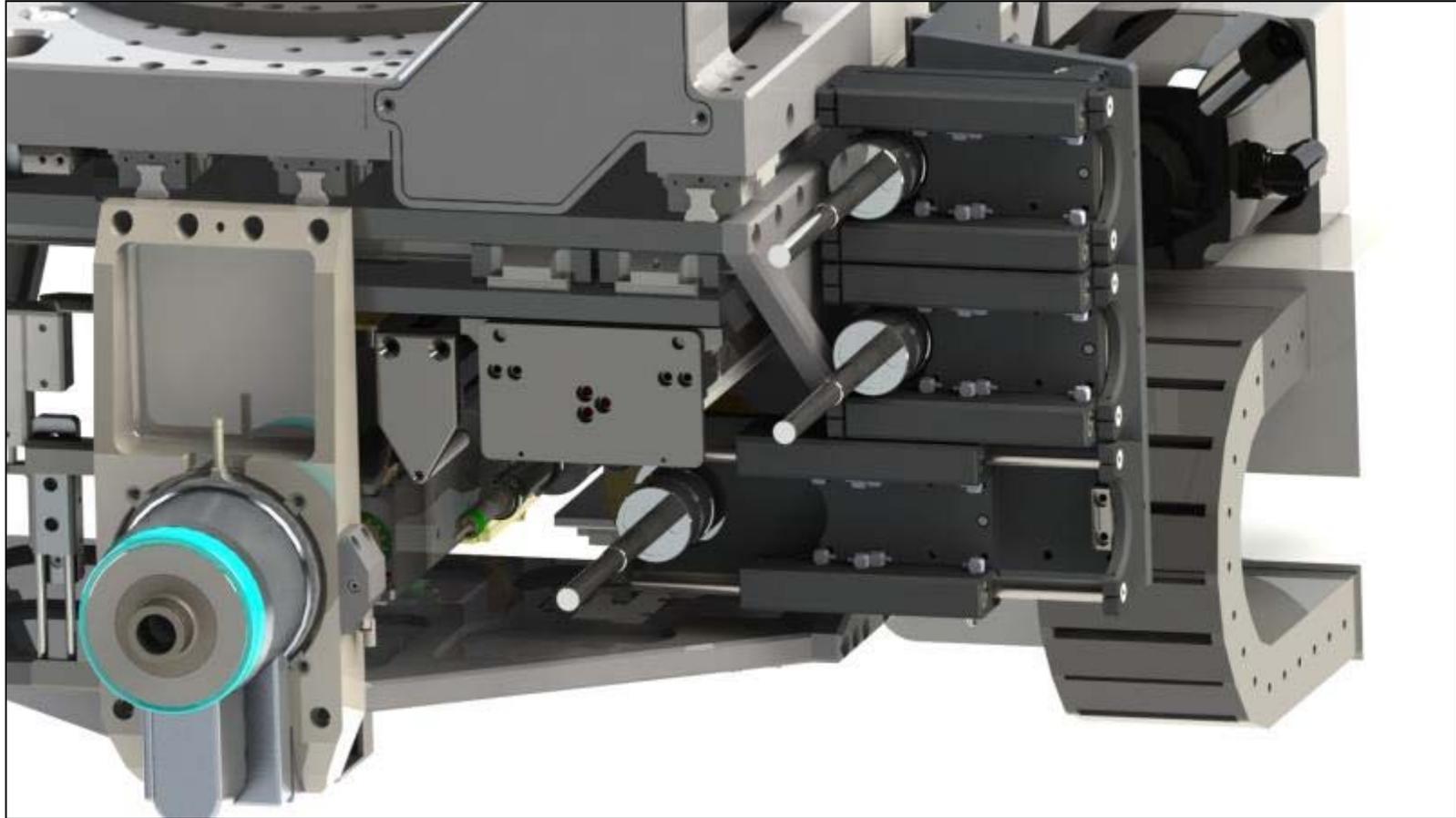
# Process: Drilling/Reaming Fittings – Tool Swap



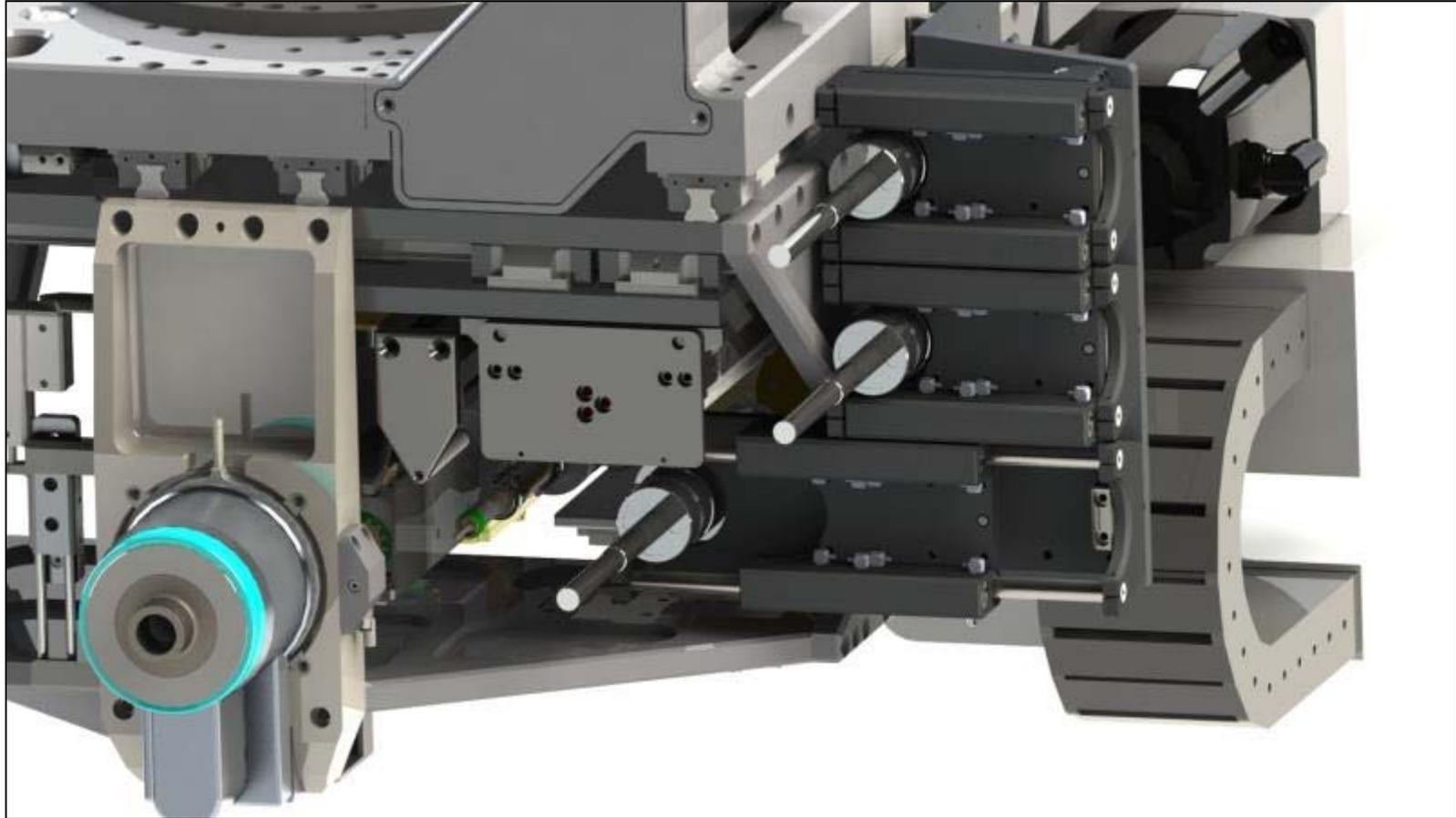
# Process: Drilling/Reaming Fittings – Tool Swap



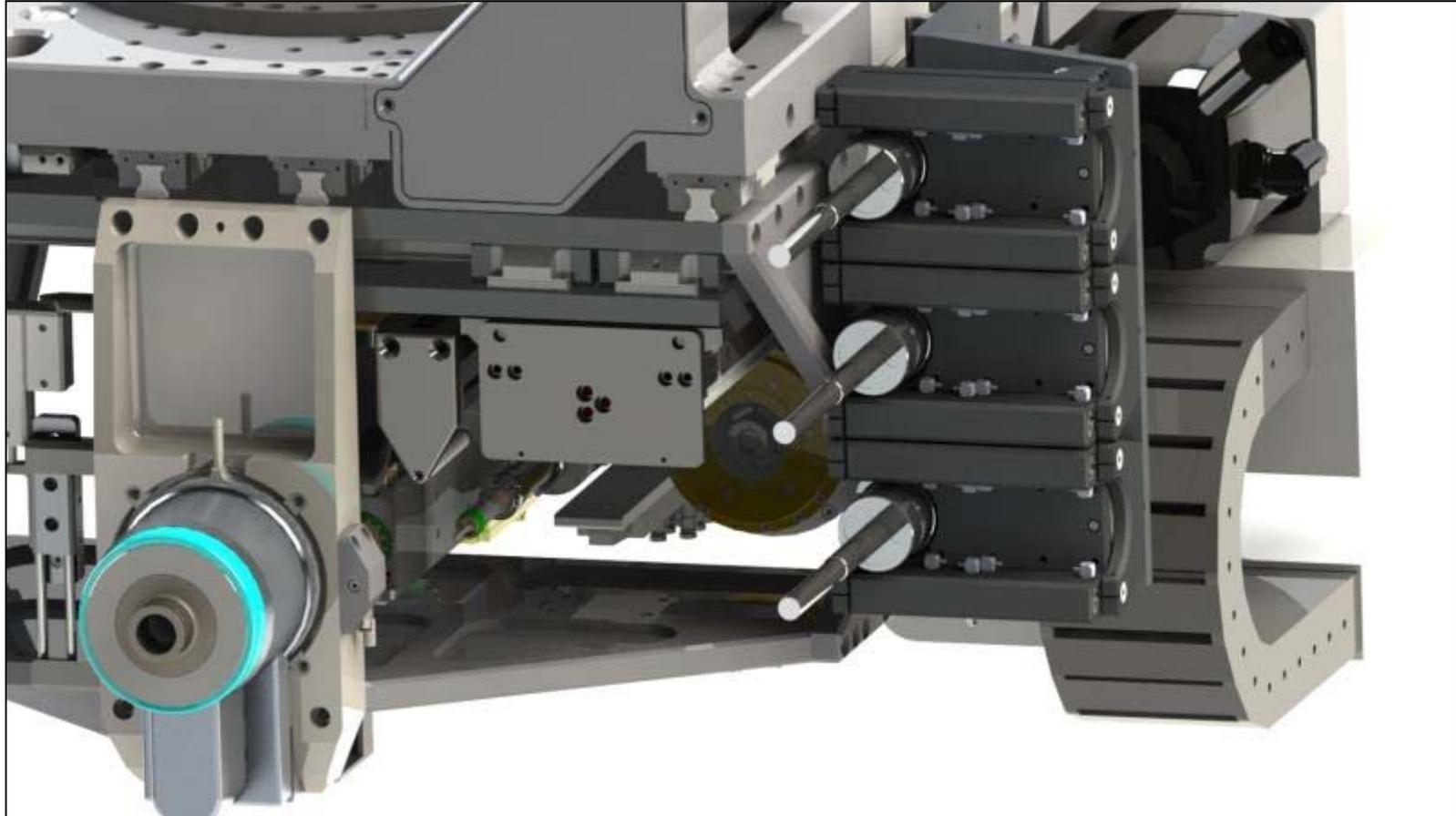
# Process: Drilling/Reaming Fittings – Tool Swap



# Process: Drilling/Reaming Fittings – Tool Swap



# Process: Drilling/Reaming Fittings – Tool Swap



# Process: Drilling/Reaming Fittings – Tool Swap



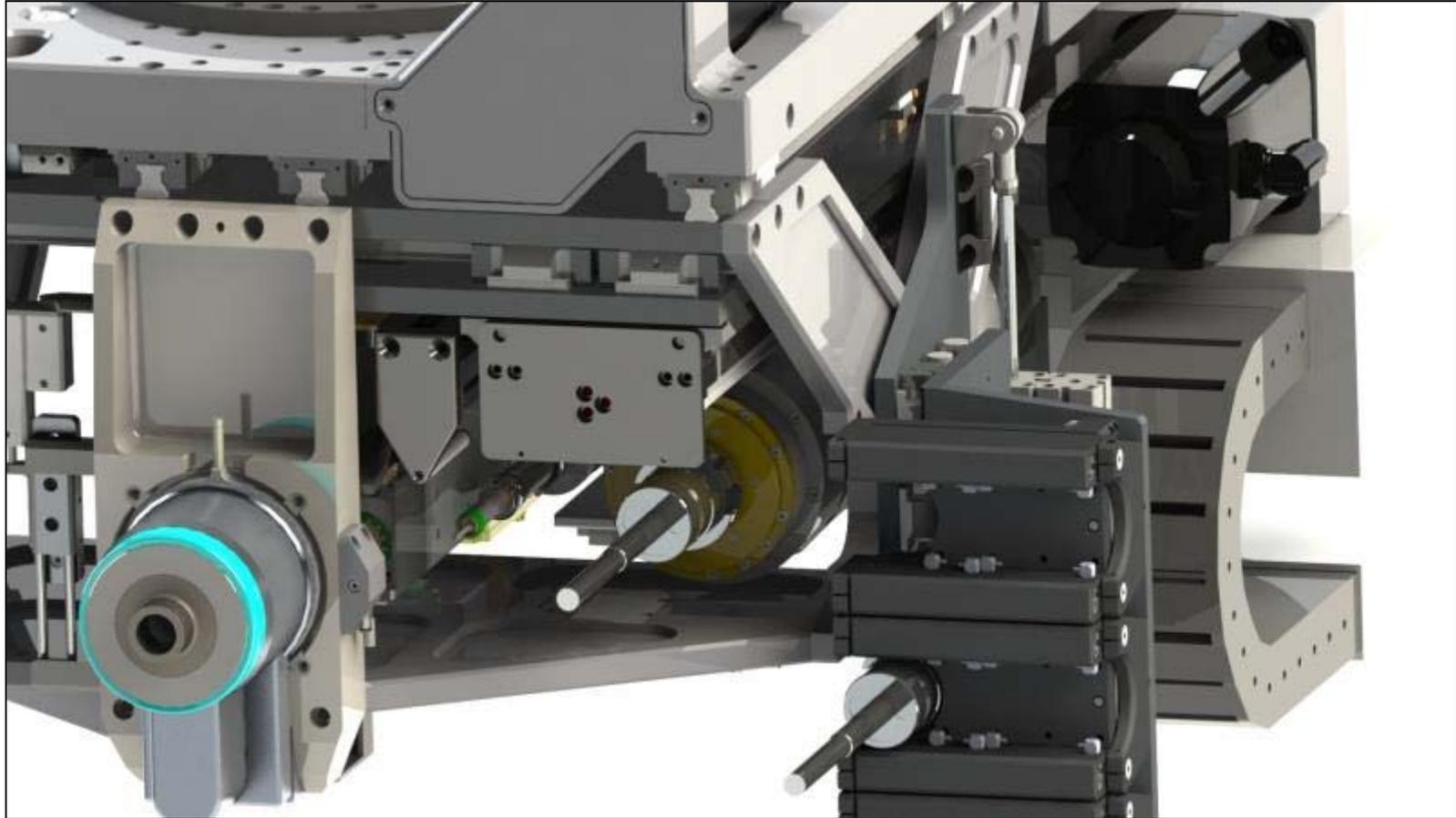
# Process: Drilling/Reaming Fittings – Tool Swap



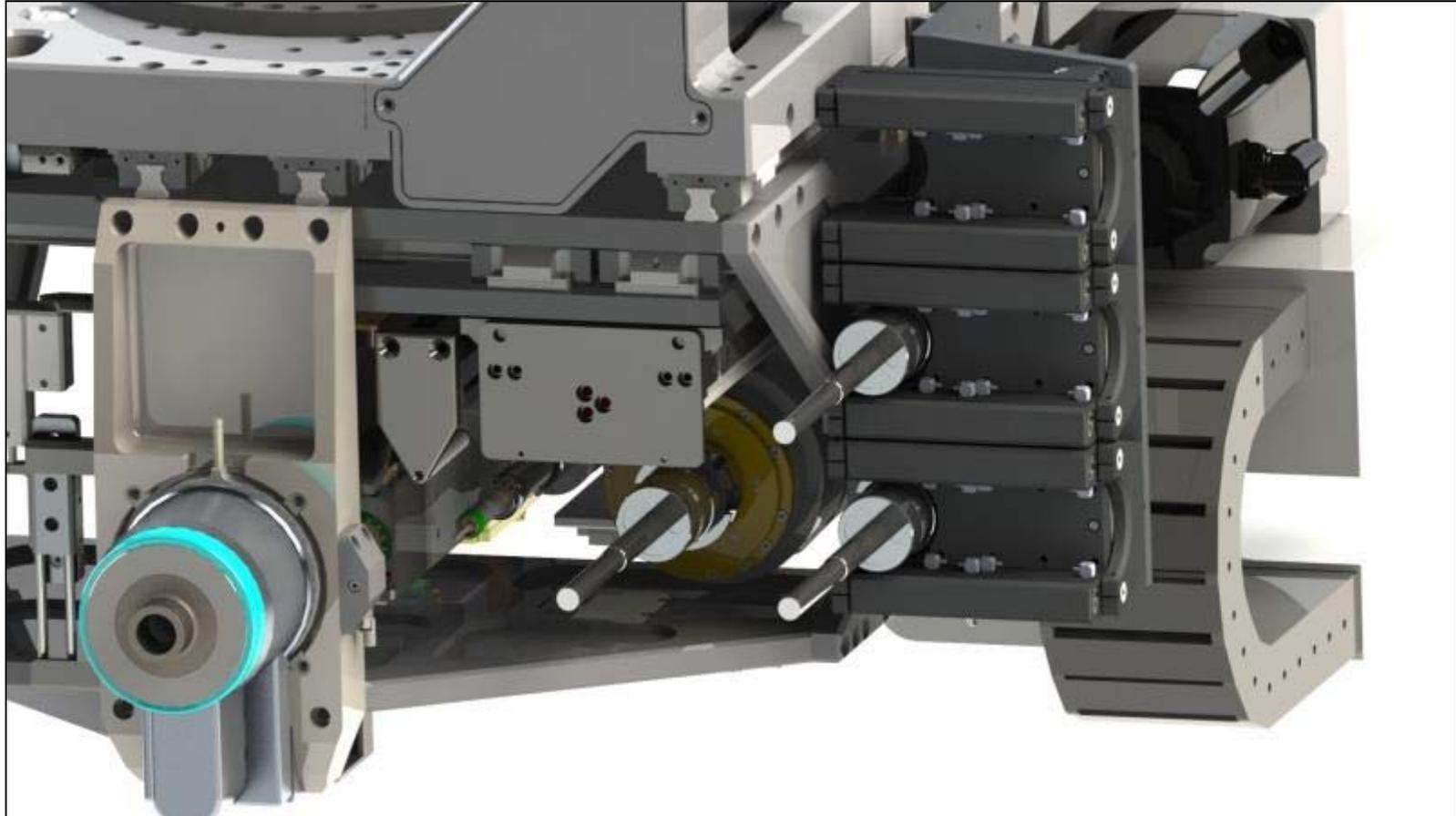
# Process: Drilling/Reaming Fittings – Tool Swap



# Process: Drilling/Reaming Fittings – Tool Swap



# Process: Drilling/Reaming Fittings – Tool Swap



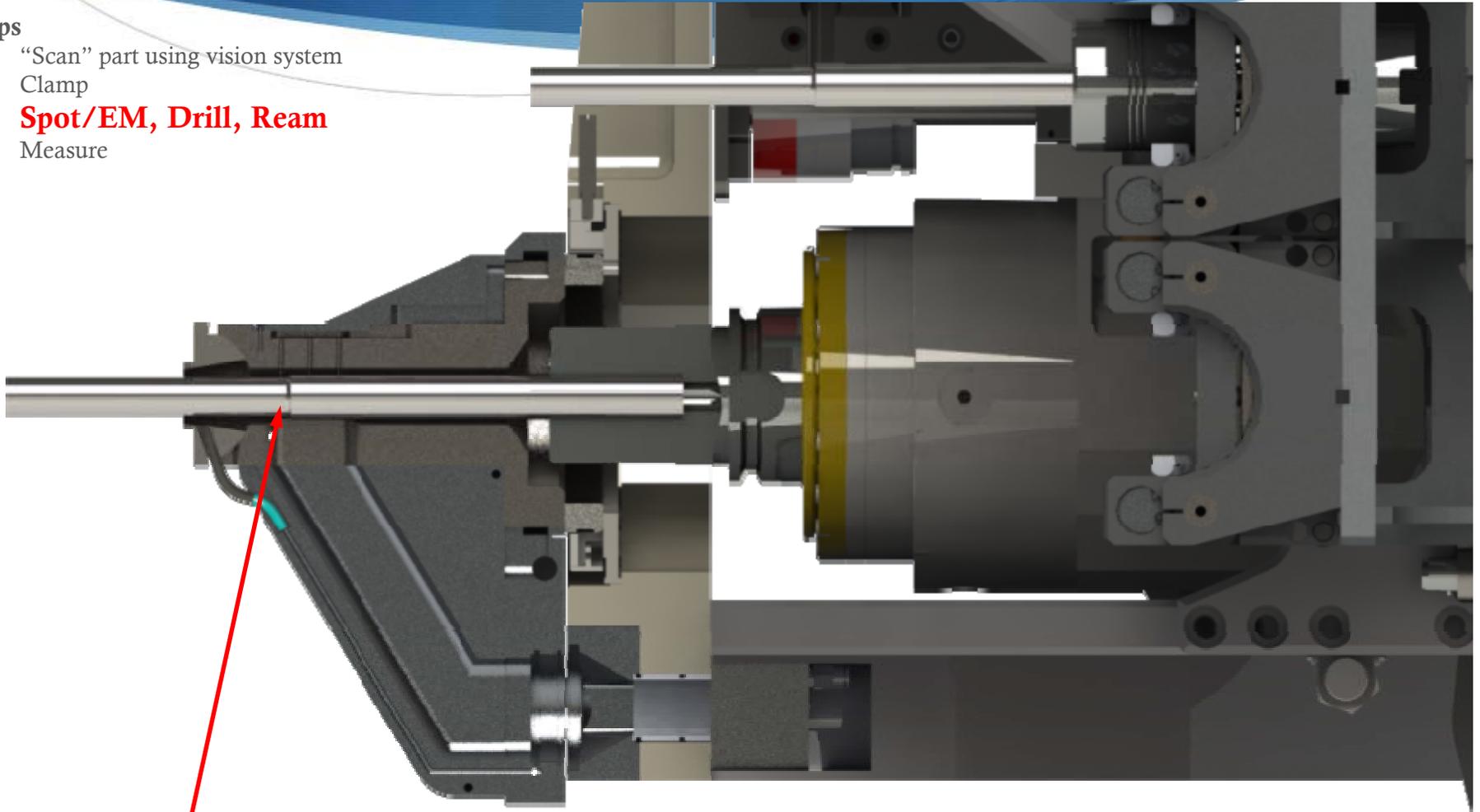
# Process: Drilling/Reaming Fittings – Tool Swap



# Process: Drilling/Reaming Fittings – Cutters

## Steps

- “Scan” part using vision system
- Clamp
- **Spot/EM, Drill, Ream**
- Measure

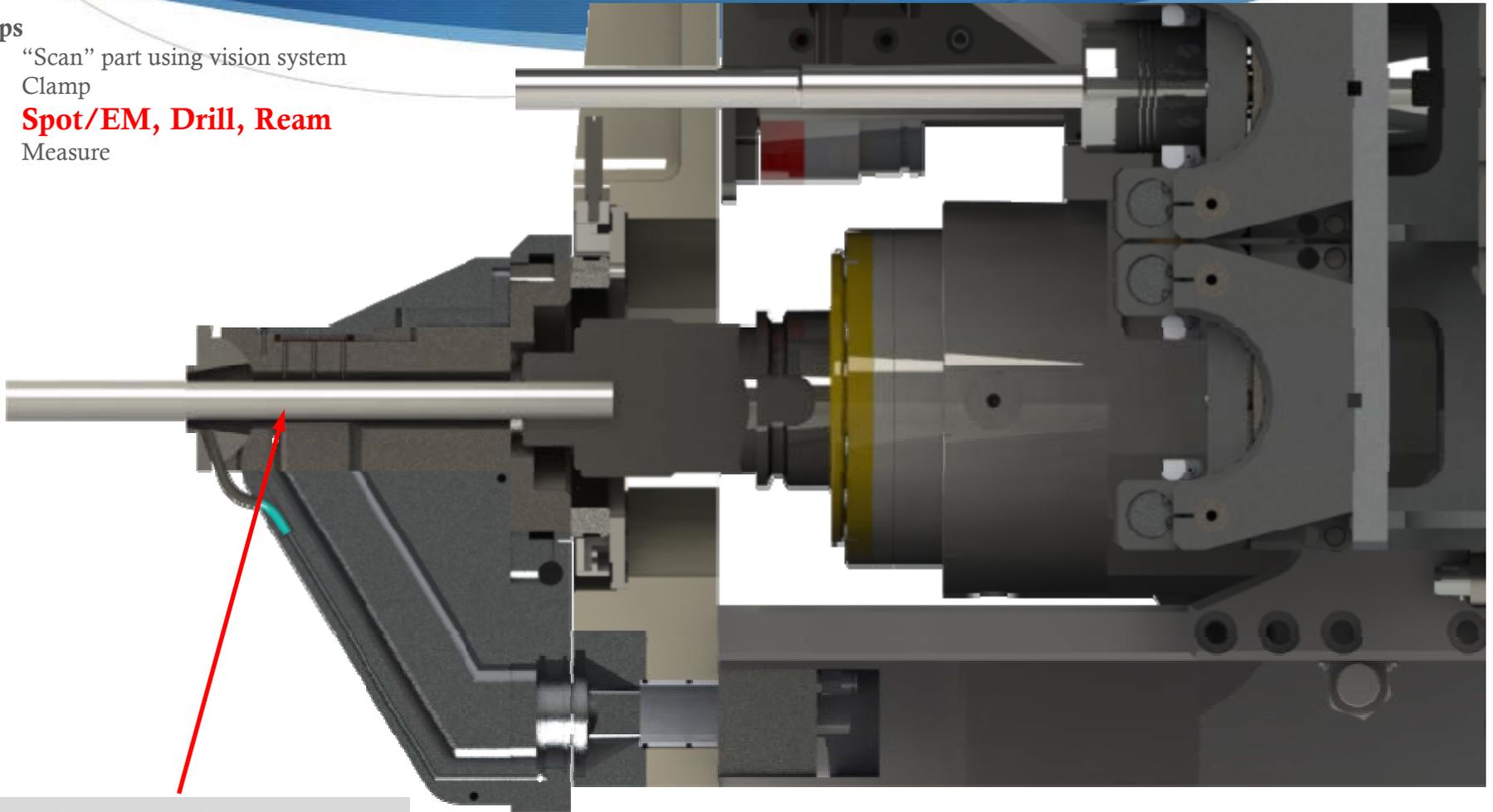


Drill/Ream thru narrow nose  
(2.5" plunge shown)

# Process: Drilling/Reaming Fittings – Cutters

## Steps

- “Scan” part using vision system
- Clamp
- **Spot/EM, Drill, Ream**
- Measure



Drill/Ream thru narrow nose with floating reamer

# Process: Drilling/Reaming Fittings – Cutters

