A systematic approach to process planning (PRODEQ)

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Acknowledgement for important contributions by:

Martin Boremyr (Ariadne Engineering AB) and Mikael Hedlind (Sandvik Coromant)

Process design driven part quality

Today’s speakers

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PRODEQ – WHAT and WHY

Aim of PRODEQ is to:

- Strengthen process planning methods and tools in Swedish industry.
- Promote cross-industrial cooperation between Swedish automotive and aerospace industry.
- Strengthen collaboration between industry, institute and university.

PRODEQ – WHAT and WHY

Objectives with PRODEQ is to:

- Improve strategies for part and process measurement and control
  - Reduced variation
  - Improved ability to manufacture parts with future tighter tolerances
- Improve standardisation and dissemination of common work methods
  - Established best practice for process design
  - Eliminate duplication of method development work
- Shorten product introductions
  - Method and tools for a better first definition of production requirements
  - Improved manufacturability by early involvement of manufacturing aspects in product design
- Improve quality control
  - Ability to relate production and process requirements to product and process functions
  - Finer and continuous control of part quality
- Optimize use of production resources
  - Knowing where to measure less and where to measure more
  - Complementary process evaluation in addition to capability indexes as acceptance criteria’s

Project structure

WP4: Project result dissemination

WP2: Quality engineering method development

WP3: Model based process design

WP1: Project management

We will present

A systematic process planning approach

Mohammad Haddad Zade

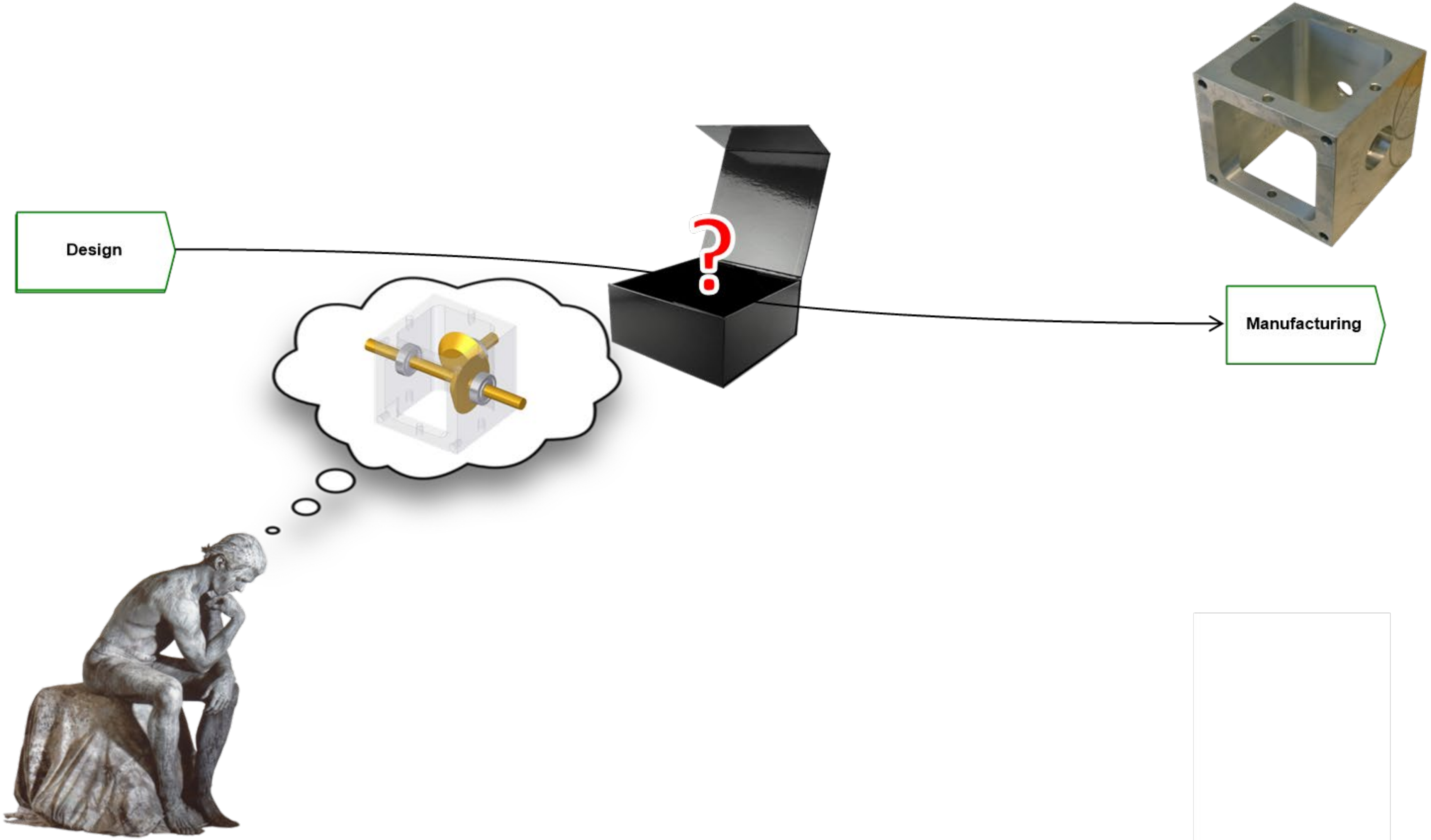
Scania

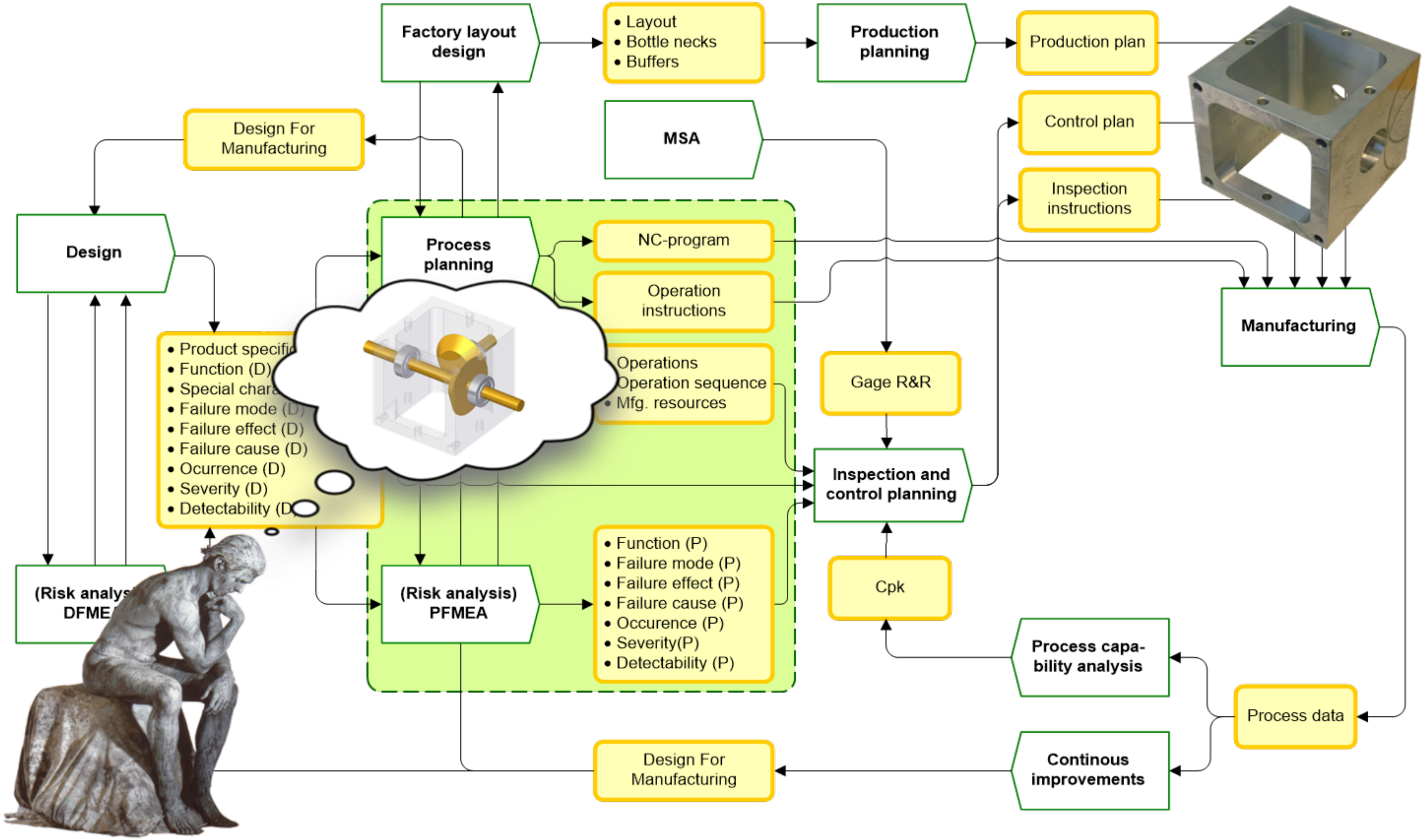
Model-based Tolerance Chain Analysis

Miroslaw Chamera

Ariadne Engineering

Process Planning - A link between…

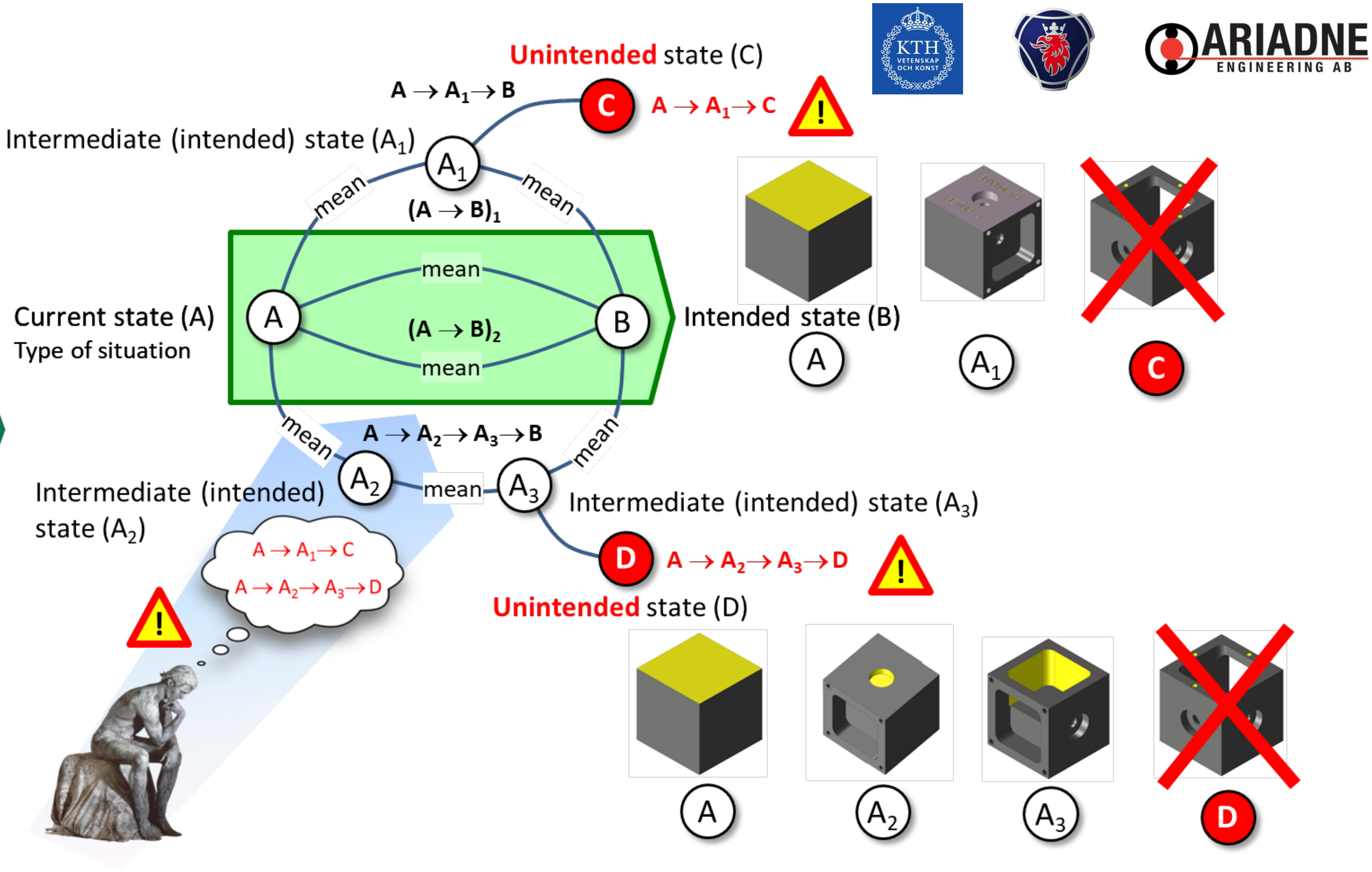


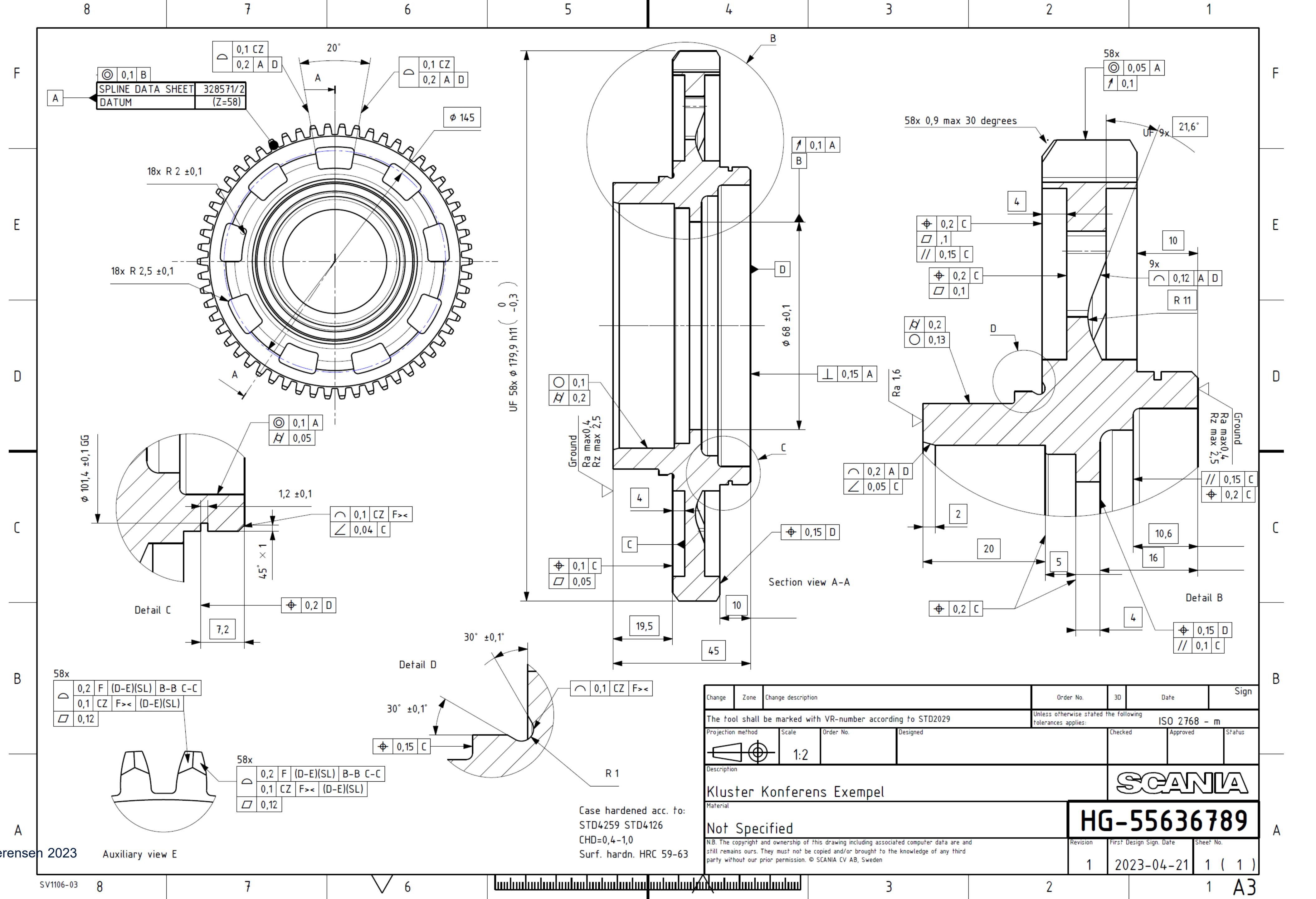


Factory layout design
• Layout
• Bottle necks
• Buffers
Production planning
Production plan
Control plan
Inspection instructions
Design For Manufacturing
MSA
Design
Process planning
NC-program
Operation instructions
• Product specific
• Function (D)
• Special chara
• Failure mode (D)
• Failure effect (D)
• Failure cause (D)
• Ocurrence (D)
• Severity (D)
• Detectability (D
Operations
Operation sequence
• Mfg. resources
Gage R&R
Manufacturing
Inspection and control planning
(Risk analys
DFME
(Risk analysis)
PFMEA
• Function (P)
• Failure mode (P)
• Failure effect (P)
• Failure cause (P)
• Occurence (P)
• Severity(P)
• Detectability (P)
Cpk
Process capa-bility analysis
Process data
Design For Manufacturing
Continous improvements

Important concepts

- ❑ unintended ⚠
- ❑ side-effects





SPLINE DATA SHEET 328571/2
DATUM (Z=58)
18x R 2 ±0,1
18x R 2,5 ±0,1
UF 58x ϕ 179,9 h11
ϕ 68 ±0,1
ϕ 101,4 ±0,1 GG
Ground Ra max0,4 Rz max 2,5
58x 0,9 max 30 degrees
Detail C
Detail D
Detail B
Section view A-A
Auxiliary view E
Case hardened acc. to:
STD4259 STD4126
CHD=0,4-1,0
Surf. hardn. HRC 59-63
The tool shall be marked with VR-number according to STD2029
Unless otherwise stated the following tolerances applies:
ISO 2768 - m
Scale 1:2
Description
Kluster Konferens Exempel
Material
Not Specified
HG-55636789
N.B. The copyright and ownership of this drawing including associated computer data are and still remains ours. They must not be copied and/or brought to the knowledge of any third party without our prior permission. © SCANIA CV AB, Sweden
Revision 1
First Design Sign. Date 2023-04-21
Sheet No. 1 (1)
A3
SV1106-03

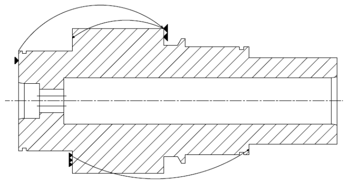
Find the most critical feature

Tight tolerance/ surface requirement

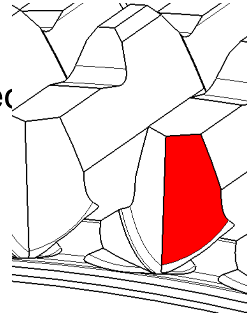
⏥	0,008
○	0,006

Is produced in several operations

Different references in each operation



Complex geo

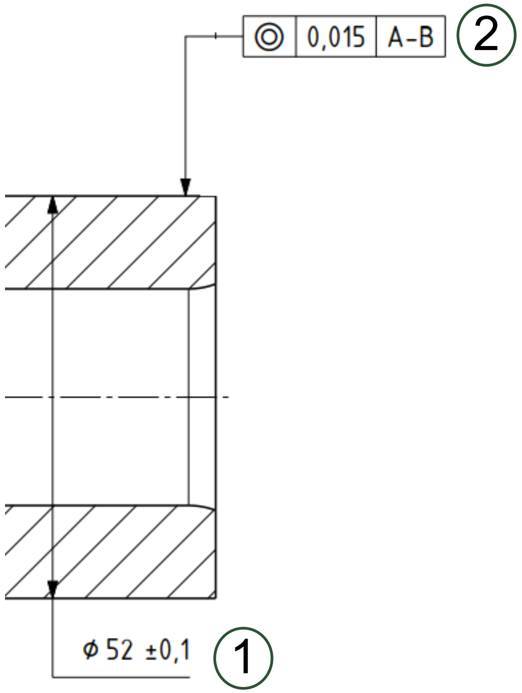


Is produced using different tools

Affected by heat treatment

What is a feature in PRODEQ?

- A feature is a set of surfaces which are used to define a requirement on a part.



At this example, the requirement 1 is just the cylindrical surface (single feature) while the requirement 2, the cylindrical surface, reference A and B make the feature (related feature)

Find the most critical feature

$$C_I = K_a \times K_b \times K_c \times K_d \times K_e \times K_f \times \prod_{i=1}^{n} K_{g_i} \times K_h$$

C_I: Critical index

K_a: Tolerance size / surface roughness

K_b: Type of tolerance

K_c: Feature size

K_d: Feature type

Affected by design

K_e: Production complexity

K_f: Heat treatment effect

$K_{g\,i}$: Machine performance of the i^{th} process

K_h: Tool effect

Affected by process planning

K_a: Tolerance range/ surface roughness

Tolerance range

Tolerance range	**K_a**
>0,5	
Over 0,1 Up to 0,5	
Over 0,05 Up to 0,1	
Over 0,01 Up to 0,05	
0,01 ≥	

Smaller values

Bigger values

Tighter tolerances lead to:

- Increased setup and inspection time
- Higher tooling and equipment costs
- More often inspections
- Greater complexity of machining operations
- Difficulty in maintaining tolerances over time

K_b: Type of tolerance

Dimensional tolerances

Type	K_b
Linear	1
Angle	2

Parameters that affect geometrical tolerances order:

- The material being machined
- Feature orientation
- Part geometry

Geometrical tolerances

Type	K_b
Straightness	
Flatness	
Circularity	
Cylindricity	
Line profile	
Surface profile	
Parallelism	
Perpendicularity	
Angularity	
Position	
Concentricity	
Symmetry	
Circular run-out	
Total run-out	

K_c: Feature size

Feature size	K_c
≤0,2	
Over 0,2 Up to 0,5	
Over 0,5 Up to 1	
Over 1 Up to 10	
Over 10 Up to 50	
Over 50 Up to 200	
Over 200 Up to 500	
>500	

Challenges for Small Features:

- Require high-precision machining tools and techniques.
- Tool wear and breakage can be a significant issue.
- Chip evacuation can be challenging.
- Measurement can be difficult to conduct.

Challenges for Large Features:

- Require larger and more powerful machining equipment.
- Material removal rates can be slower.
- Heat generation can affect accuracy and quality.

K_d: Feature type (Geometric complexity)

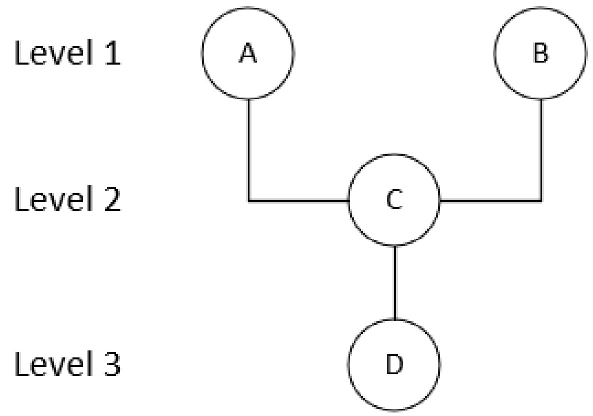
Shape	K_d
Flat	
Cylinder	
Cone	
Thin wall	
3D geometry (e.g. pointing)	

Challenges with more complex features:

- Increased machining time
- Tool access and clearance
- Machining accuracy
- Measurement accuracy
- Measurement repeatability

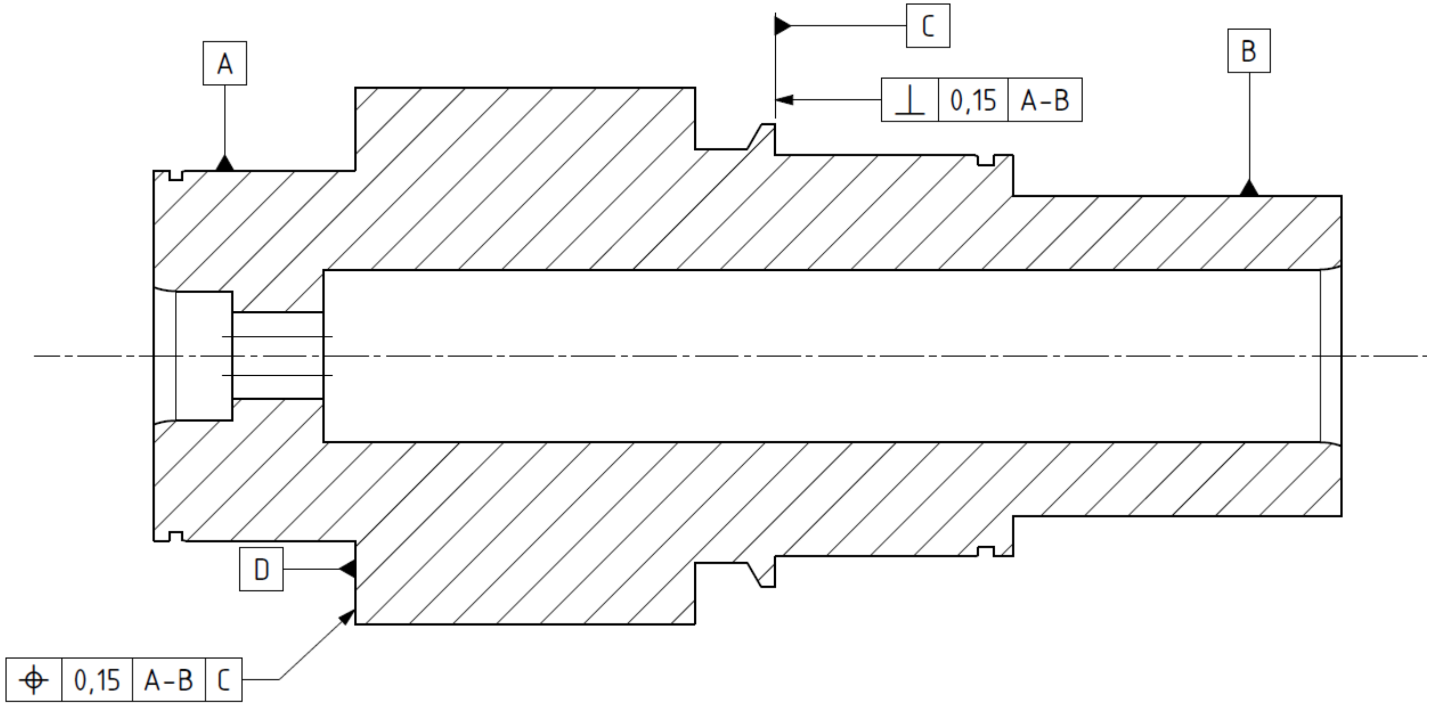
Note: The shape of a feature is related to the surface that has the requirement on it, rather than to any references or datums.

Reference dependency graph



Create a graph that shows the dependencies between datums (references).

Note: several datums may be located at the same level if they are independent.



Production complexity

		Production complexity	
		setup complexity	Reference level
The same setup and the same tool			
The same setup but different tools			
The same operation and different setups	One surface is used as a locating/probing surface		
	Completely independent surfaces		
Two different operations	Using the same locating surface		
	Using different surfaces		

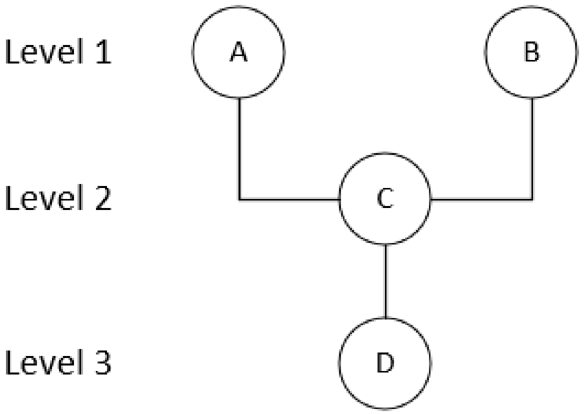
Note: As we go lower in the reference dependency graph, we should increase the production complexity value.

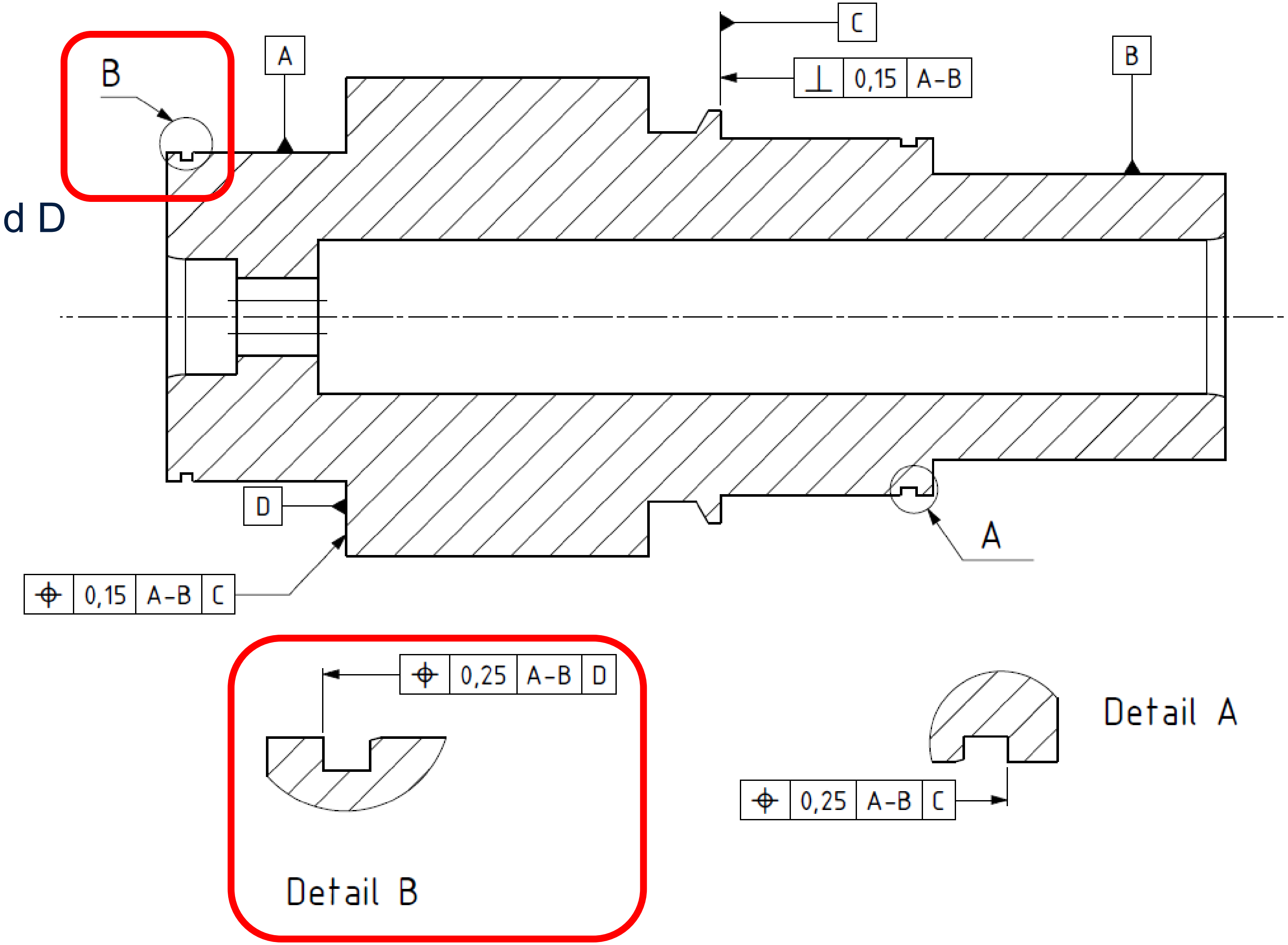
Example

Problem description:

Two grooves are related to datum C and D with the same position tolerance.

Reference dependency graph for this part looks like this:





K_f: Heat treatment effect

Affected by heat treatment	K_f
No	1
Yes	2

*A feature is considered not to be affected by heat treatment if there is no heat treatment on the surfaces of the feature/references or if all surfaces of the feature/references will be machined after the heat treatment.

Example

The machining step for this part is:

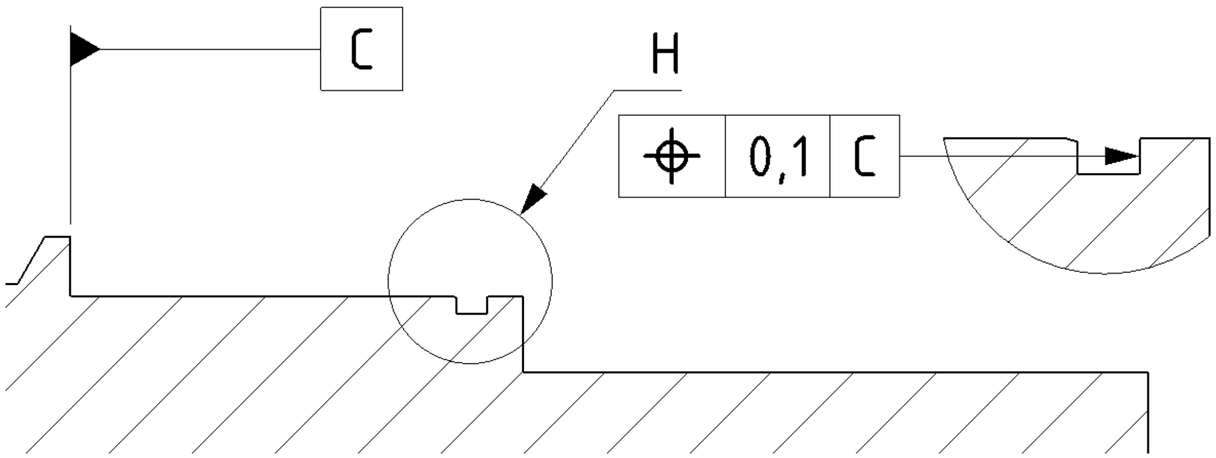
1- Soft turning of the datum C and the groove

2- Heat treatment

3- Hard turning of the datum C

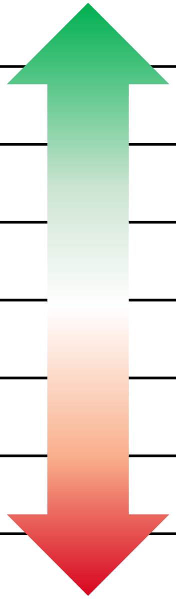
This feature consists of datum C and the groove.

$$K_e = 2$$



K_g: Machine performance

Process	K_g
Honing	
Grinding	
Broaching	
Turning/Milling	
Drilling / boring	
Hobbing	
Skiving	
Gear shaping	



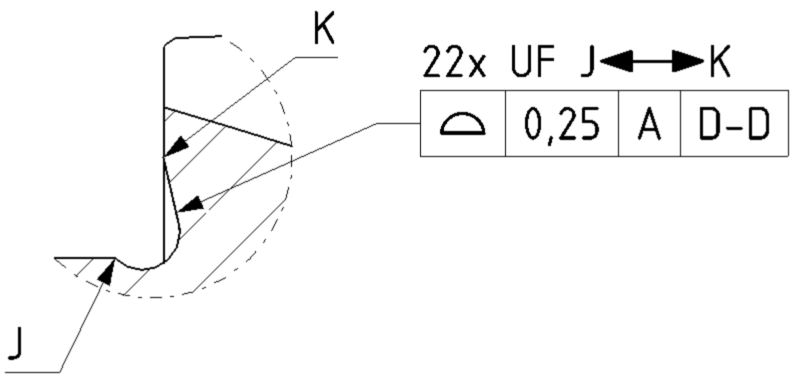
- Accuracy
- Surface finish
- Dimensional stability
- Production speed

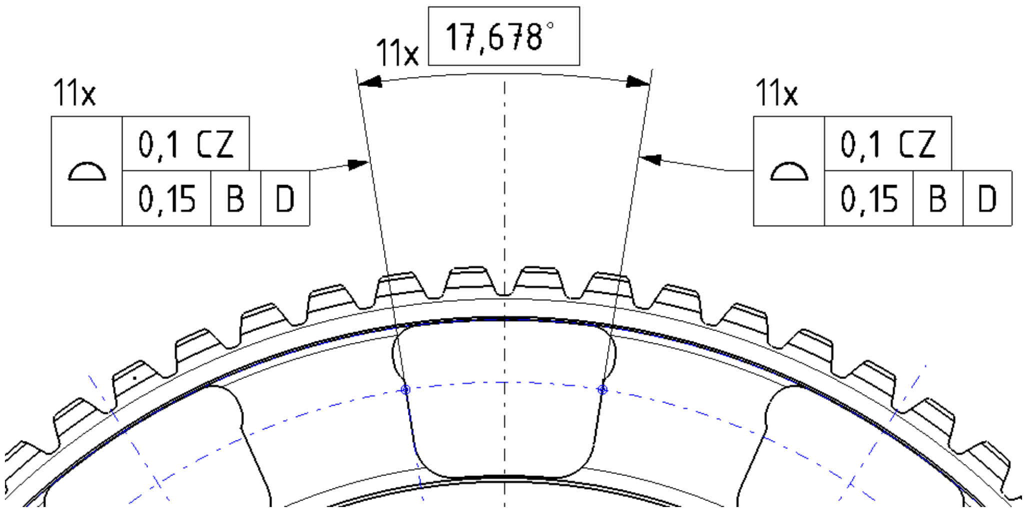
K_h: Tool effect

The number of tools which are used in one operation to produce the feature

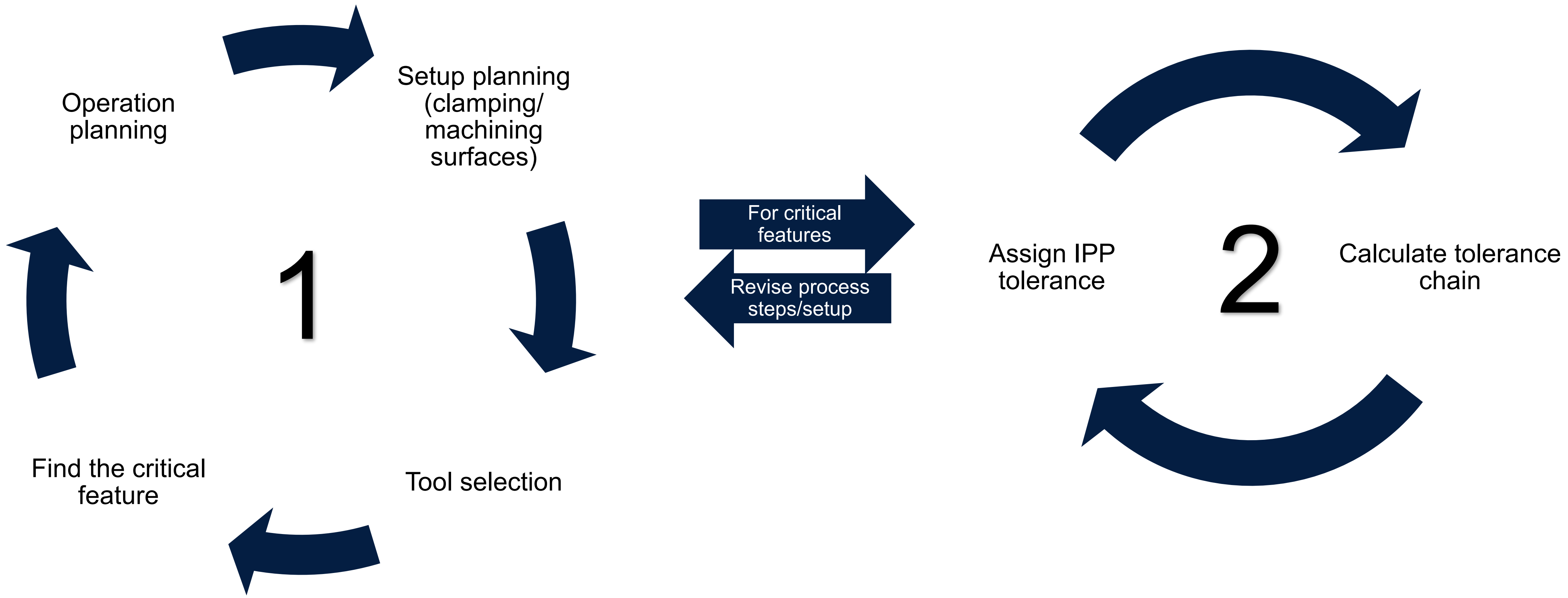
Number of tool	K_h
1	
2	
≥3	

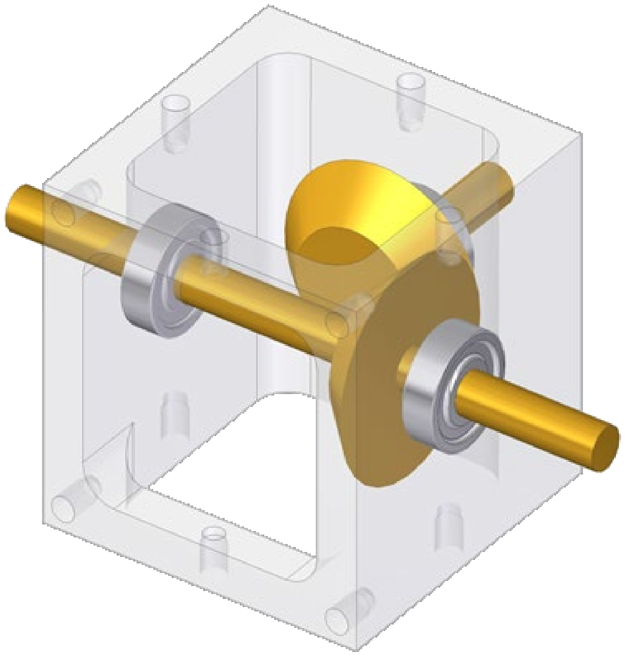
- roughing
- finishing
- profiling





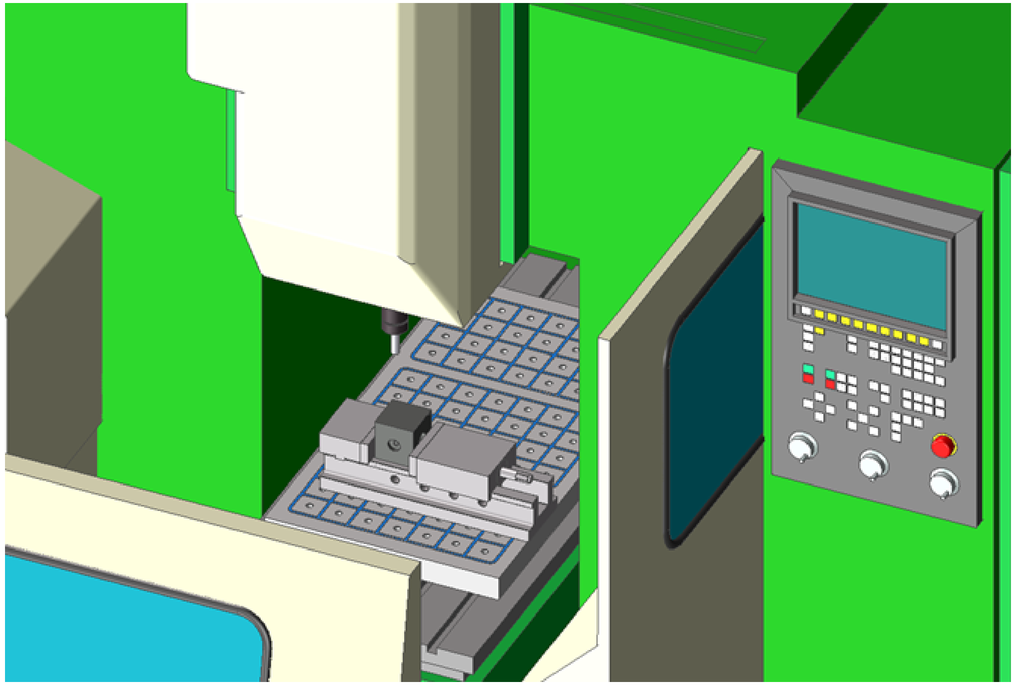
Tolerance assignment cycle





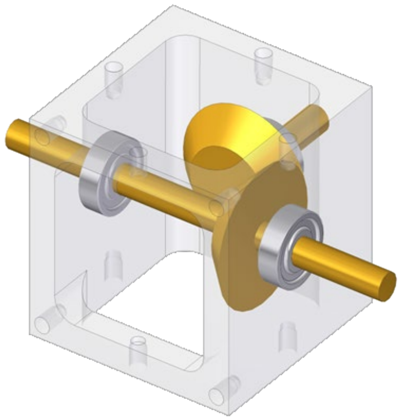
1st Choice: 5-axis machine tool

2nd Choice: 3-axis machine tool

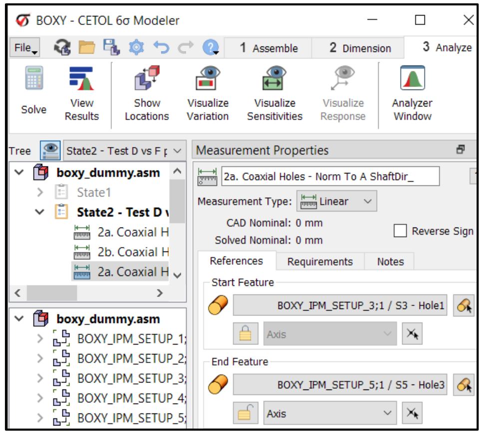


What we would like to achieve with simulation

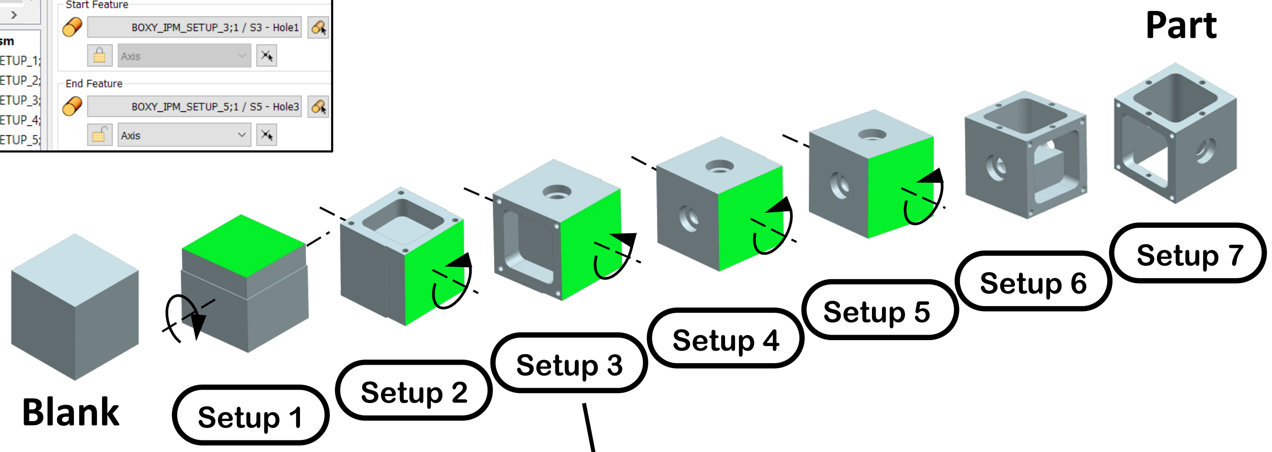
- Find generic approach for simulation
  - A structured way to build a tolerance/variation analysis model
  - A way to define what to analyze
  - Including all relevant tolerances/variations
- Analyze proposed methods
  - Method/methods first defined manually (based on previous experience, cost, etc.)
  - Simulation can verify a proposed method – assess the chance to be successful
  - Evaluate several different methods to find the best
    (evaluate full methods or e.g. just test small differences in datum positions)
  - Assess expected total variation from a method
  - Find critical features in a specific method (Need to loosen or tighten requirements?)



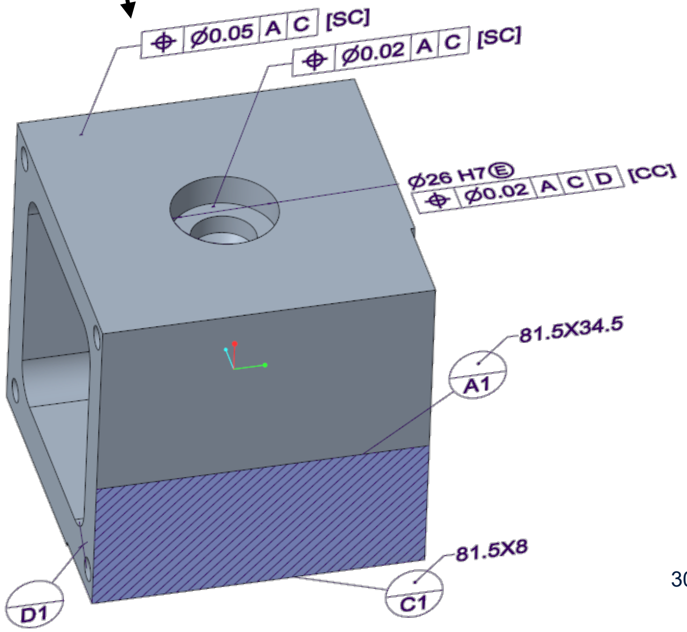
Inputs for simulation



- Tolerance analysis software (Cetol)
- 3D-models with finished geometry after each setup

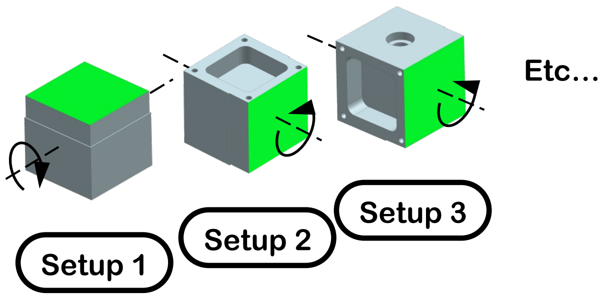


- Tolerancing/requirements for geometry created in each setup
  - Ideally a 3D model-based definition - MBD (2D-drawing works, but more hands on)
  - Ideally GPS-tolerancing with semantic connection (Machine readable)
- Information about clamping variation for setups
  - Physical surfaces used and size
  - Variation related to each surface (translations and rotations)



Two levels of variation

- **Level 1 - Operation variation**
  (machining or other process)
  - This is modeled as tolerances on “**component level”**
    (GPS tolerances inside each component: Setup 1, Setup 2, etc)
  - Accuracy of machine - Machine dependent, could vary with e.g. machine speed or distance from machine zero)
  - Requirement for allowed machining variation is defined as “tolerances”



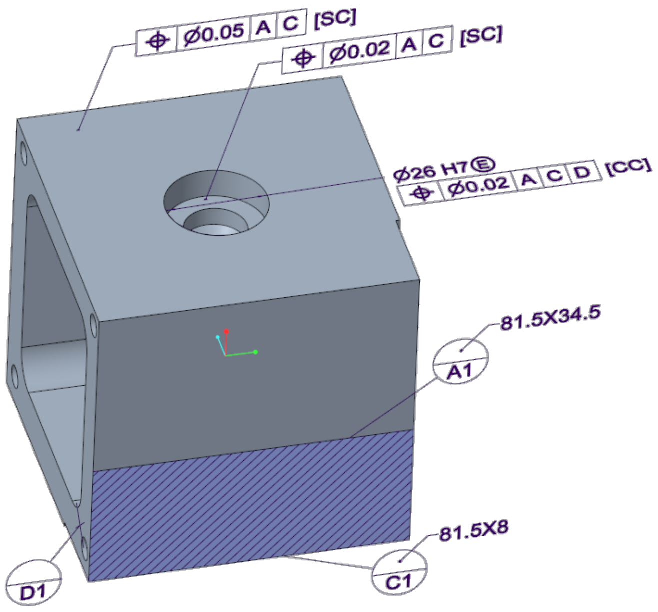
- **Level 2 - Clamping variation**
  (clamping or other fixation/handling process)
  - This is modeled as variation on **“assembly level”**
  - Accuracy of clamping equipment
  - Accuracy of manual/automatic setup handling
  - Requirement for allowed clamping variation is defined as “assembly tolerances”

1. Operation variation
“Components level” variation, in relation to clamped surfaces

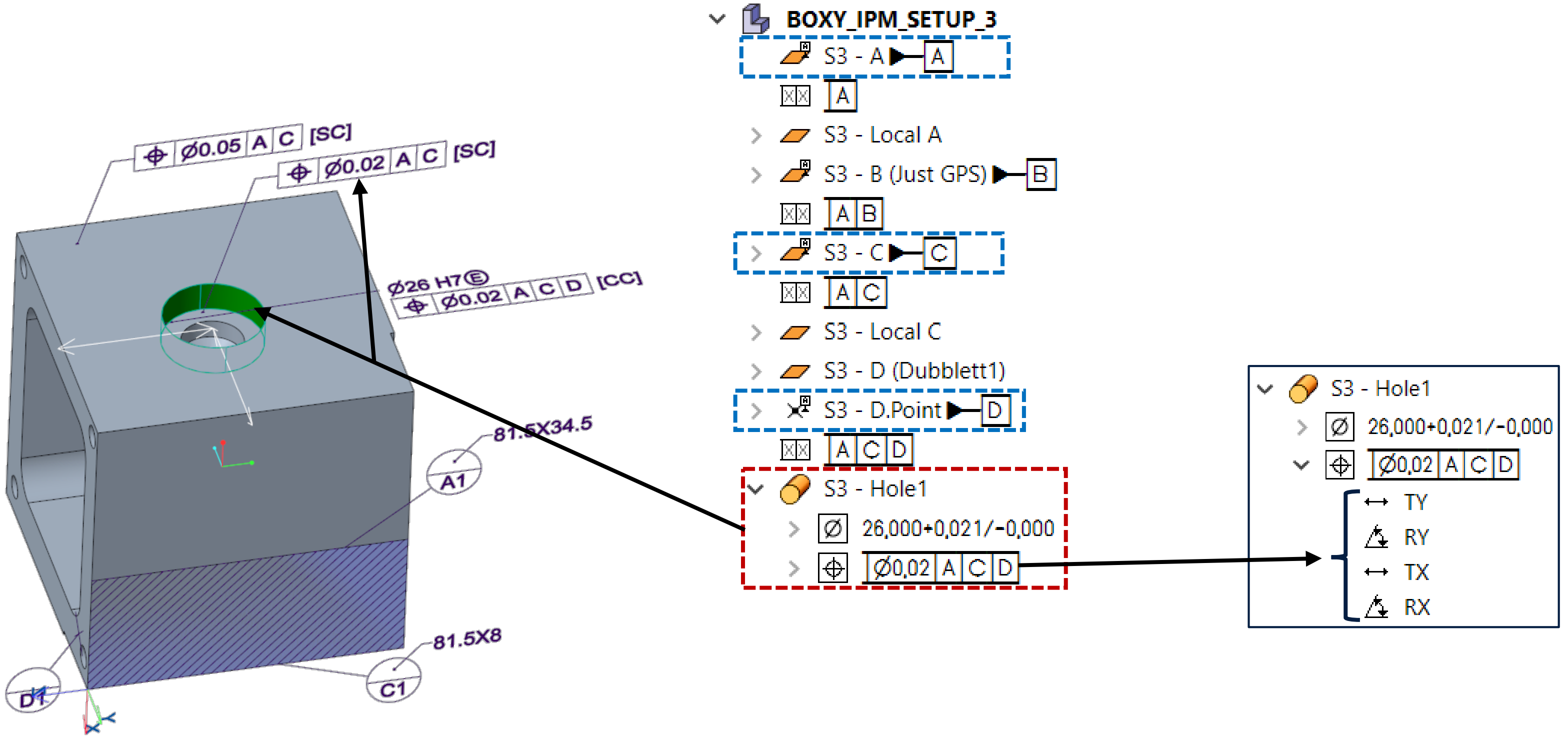
2. Clamping variation
“Assembly level” variation, between components

→ **Total process simulation**

Level 1
Operation variation - Definition

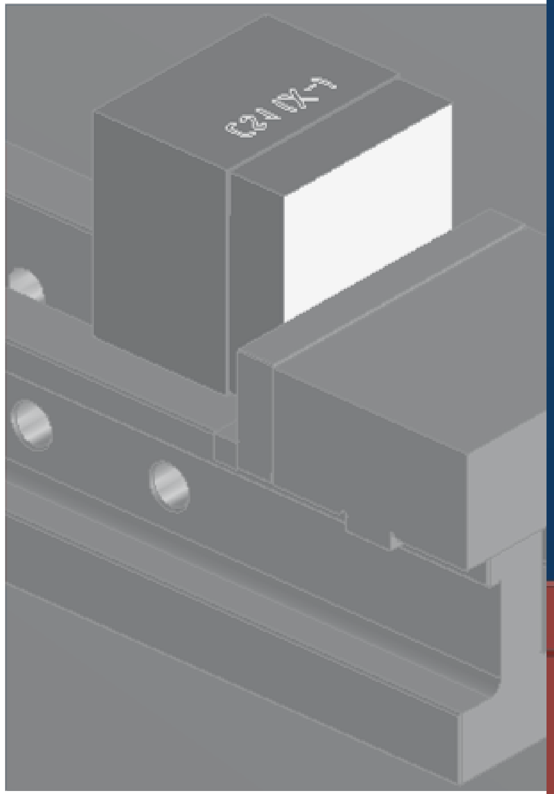


- Datums are defined – corresponds to clamping surfaces
- Variation for each "machined" surface is defined as a tolerance (including both allowed translations and rotations)

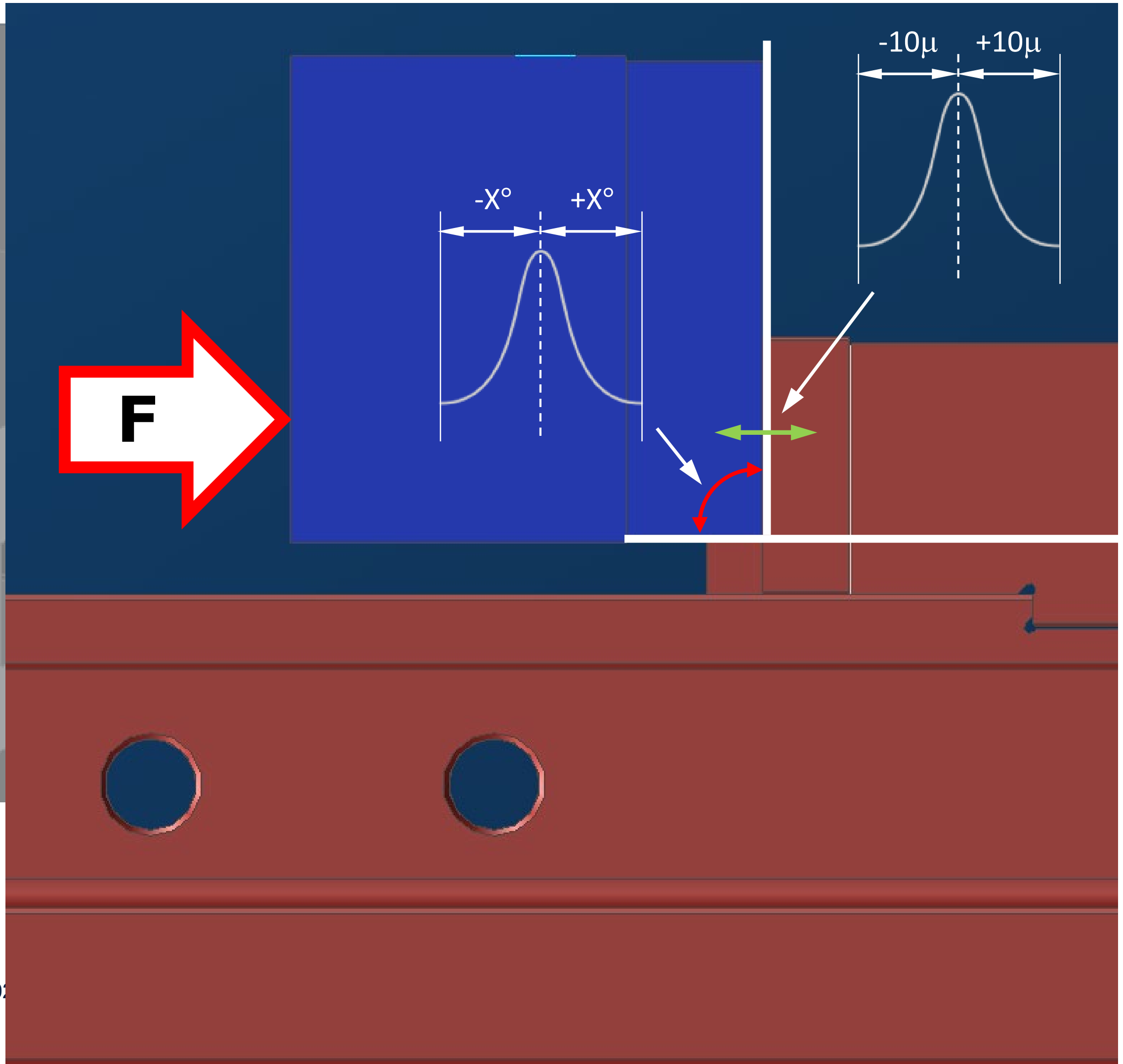


Level 2 - Clamping variation

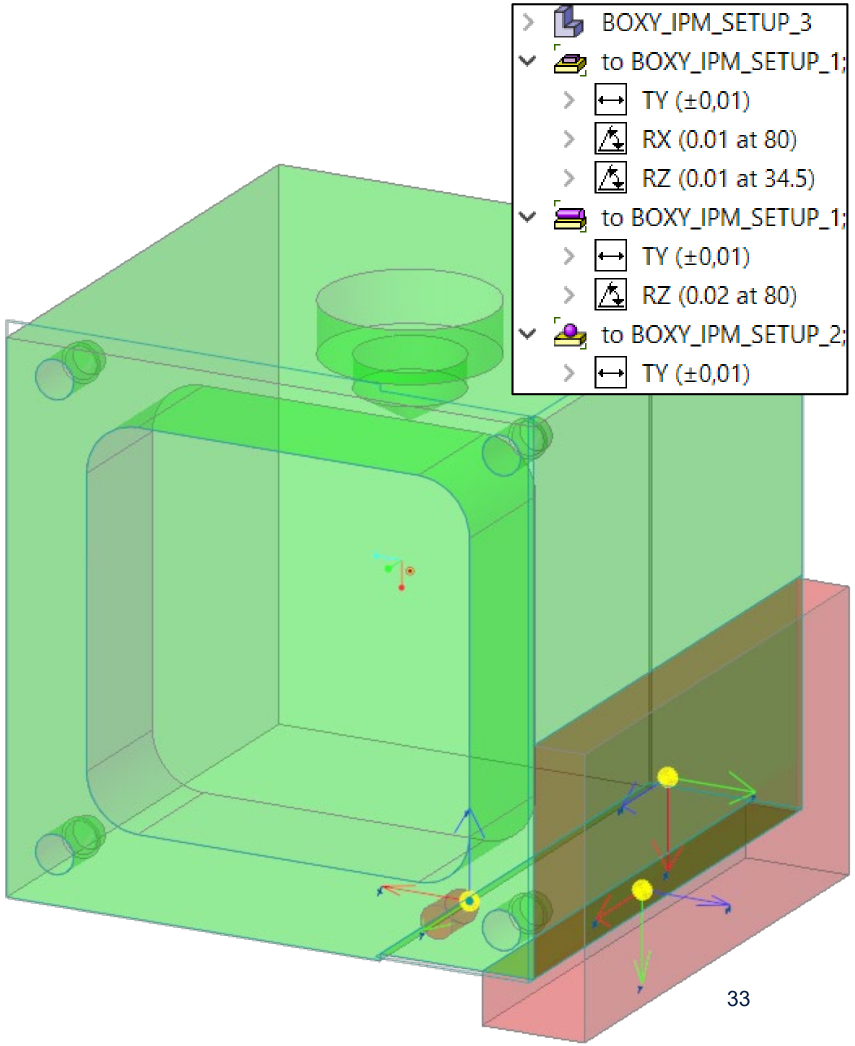
Clamping Equipment



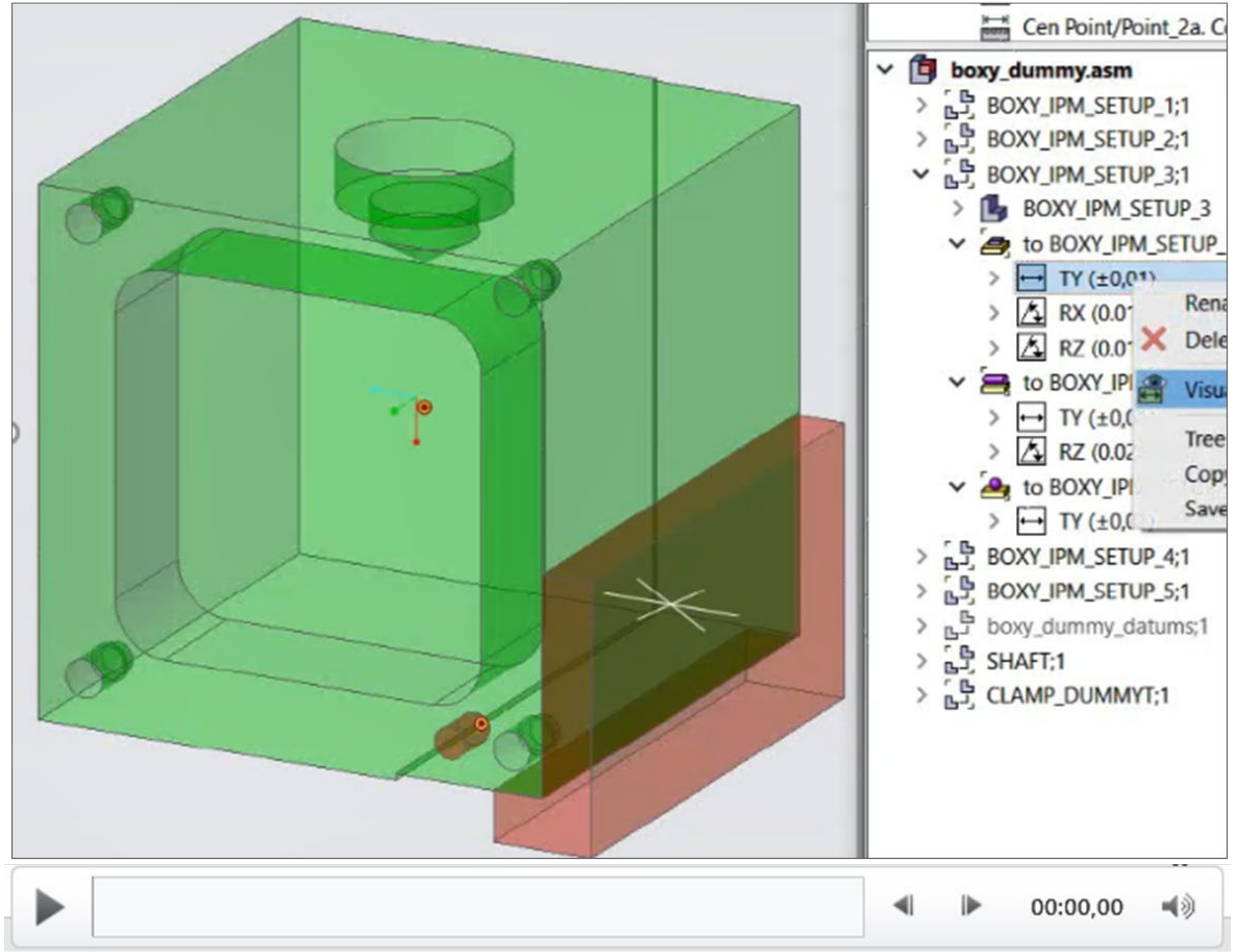
Clamping Variation

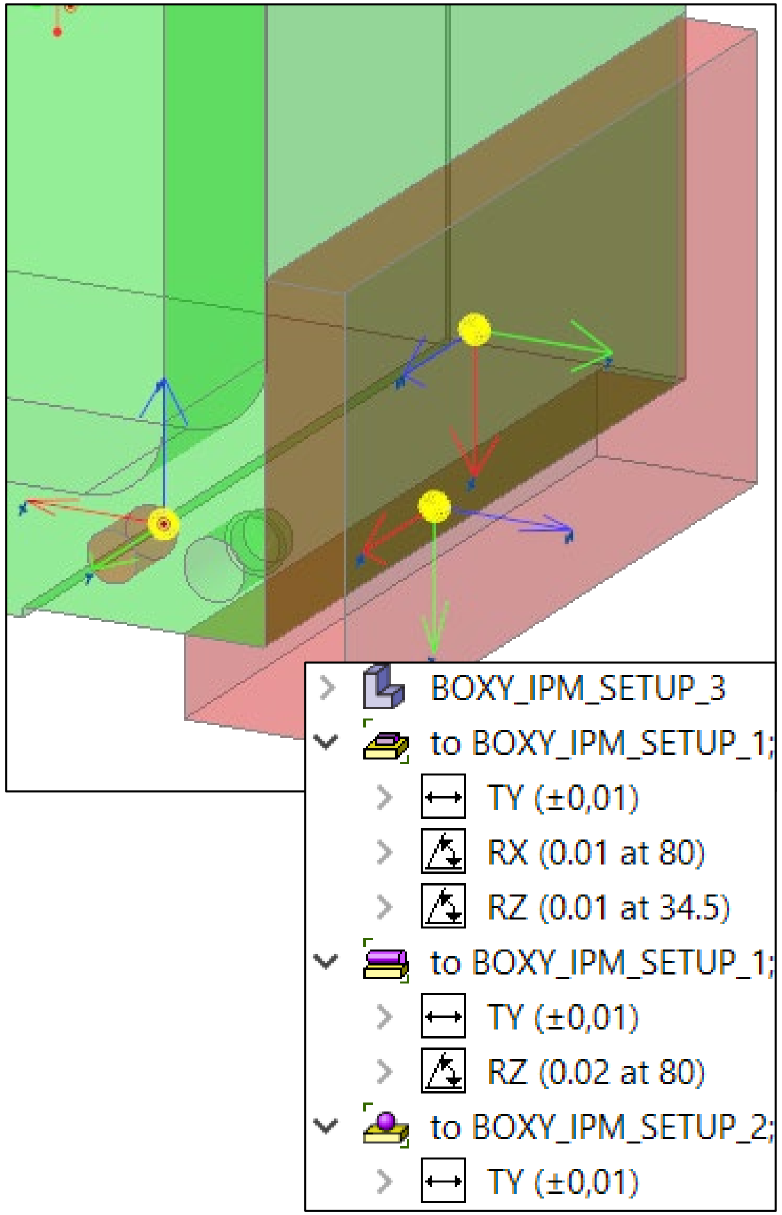


Clamping Variation Modelling



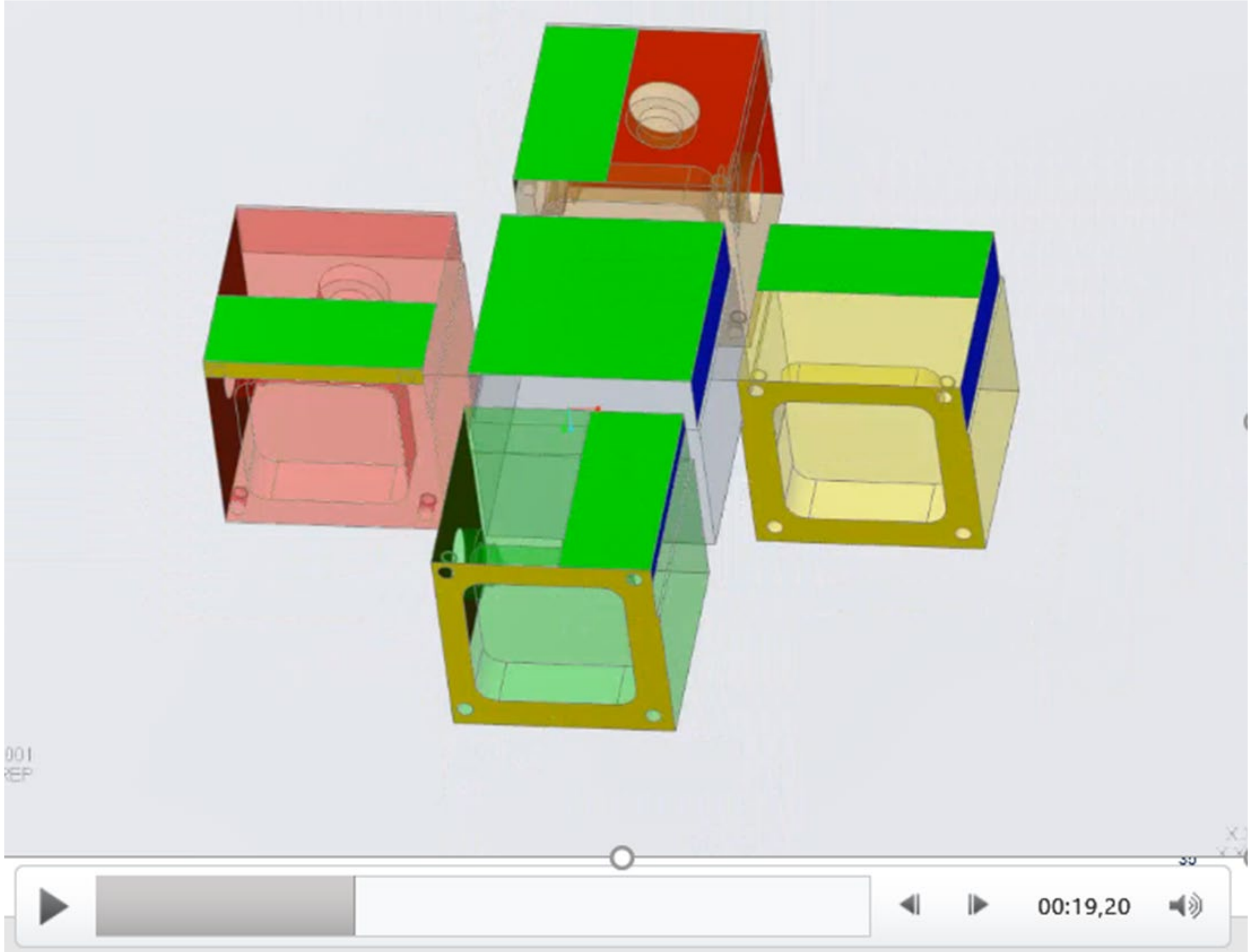
Simulate process variation – Clamping variation





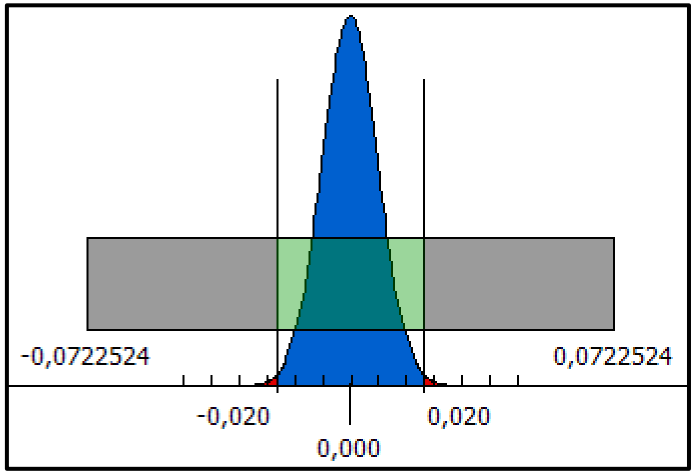
Simulate process variation – Assembly sequence

- Setup 1-5 components are included in analysis
- All components are assembled “on top of each other”
- Components for each setup are assembled according to clamping
- The component´s clamping surfaces are connected to corresponding surfaces in previous components (where it appears the first time)
- Color coding shows the assembly sequence

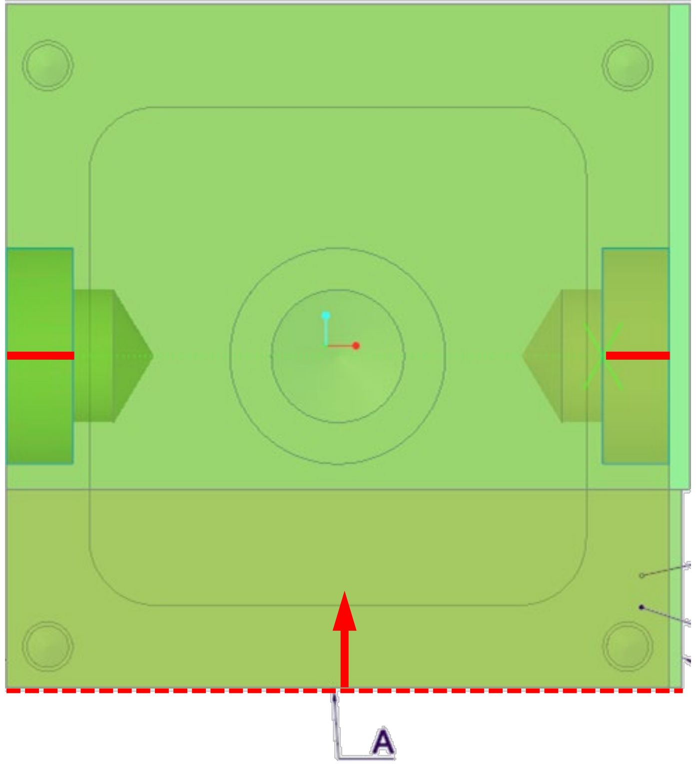


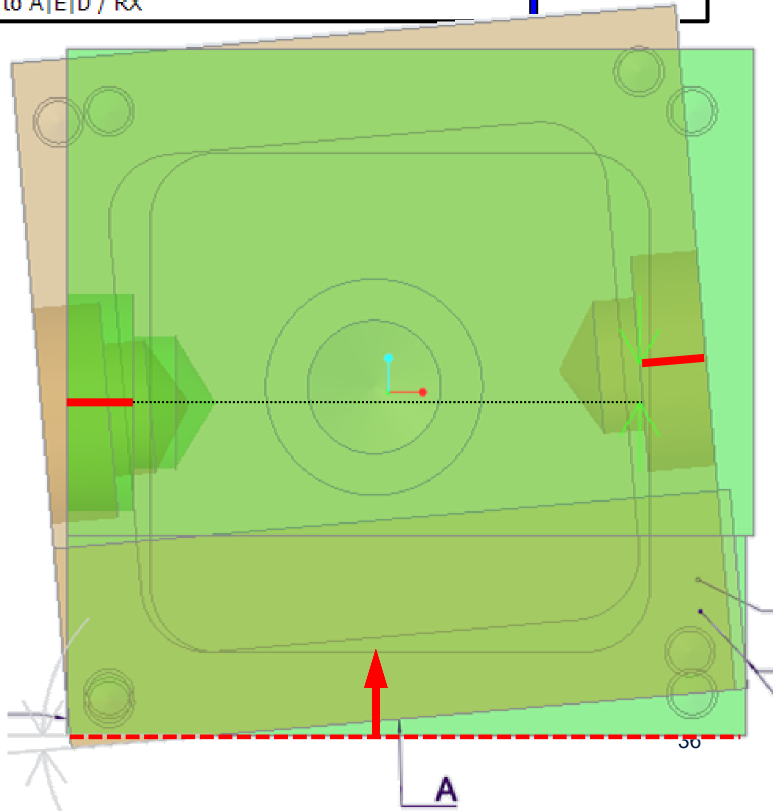
Analysis - Measurements

- Relevant measurements are defined
- Example: Vertical hole alignment (in relation to A, bottom surface)
- Results:
  - Total variation from used method
  - List of largest contributing variations
  - Identifying “critical features” (variations)
  - Identify feature sensitivities

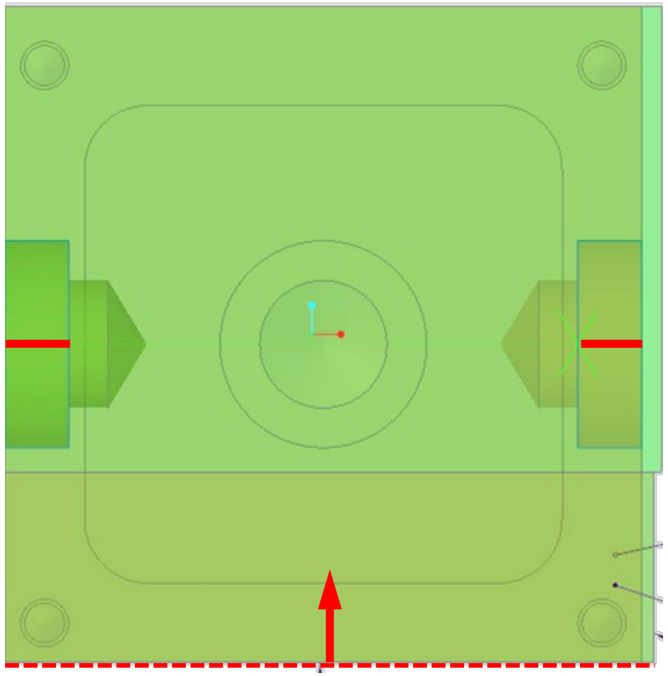


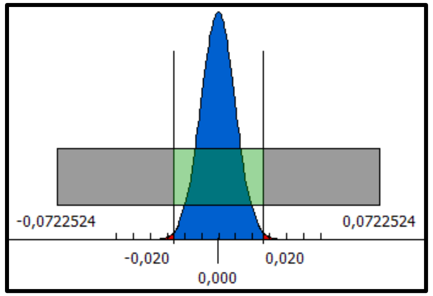
Name	Contribution
BOXY_IPM_SETUP_3;1 / to BOXY_IPM_SETUP_1;1,1 RZ (0.01 at 34.5) / RZ	28,96 %
BOXY_IPM_SETUP_5;1 / to BOXY_IPM_SETUP_1;1,1 RZ (0.01 at 34.5) / RZ	27,43 %
BOXY_IPM_SETUP_5;1 / to BOXY_IPM_SETUP_1;1,1 TY (±0,01) / TY	10,90 %
BOXY_IPM_SETUP_3;1 / to BOXY_IPM_SETUP_1;1,1 TY (±0,01) / TY	10,90 %
BOXY_IPM_SETUP_3;1 / S3 - Hole1 to A|C|D / TY	8,18 %
BOXY_IPM_SETUP_5;1 / S5 - Hole3 to A|E|D / TY	8,18 %
BOXY_IPM_SETUP_3;1 / S3 - Hole1 to A|C|D / RX	2,73 %
BOXY_IPM_SETUP_5;1 / S5 - Hole3 to A|E|D / RX	2,73 %





Simulation analysis – Results





Animation – Contributions 1 & 2

1. Clamp rotational variation 56%
2. Clamp translational variation 22%

(3. Hole position tolerances 22% - Not animated)

Name	Contribution
BOXY_IPM_SETUP_3;1 / to BOXY_IPM_SETUP_1;1,1 RZ (0.01 at 34.5) / RZ	28,96 %
BOXY_IPM_SETUP_5;1 / to BOXY_IPM_SETUP_1;1,1 RZ (0.01 at 34.5) / RZ	27,43 %
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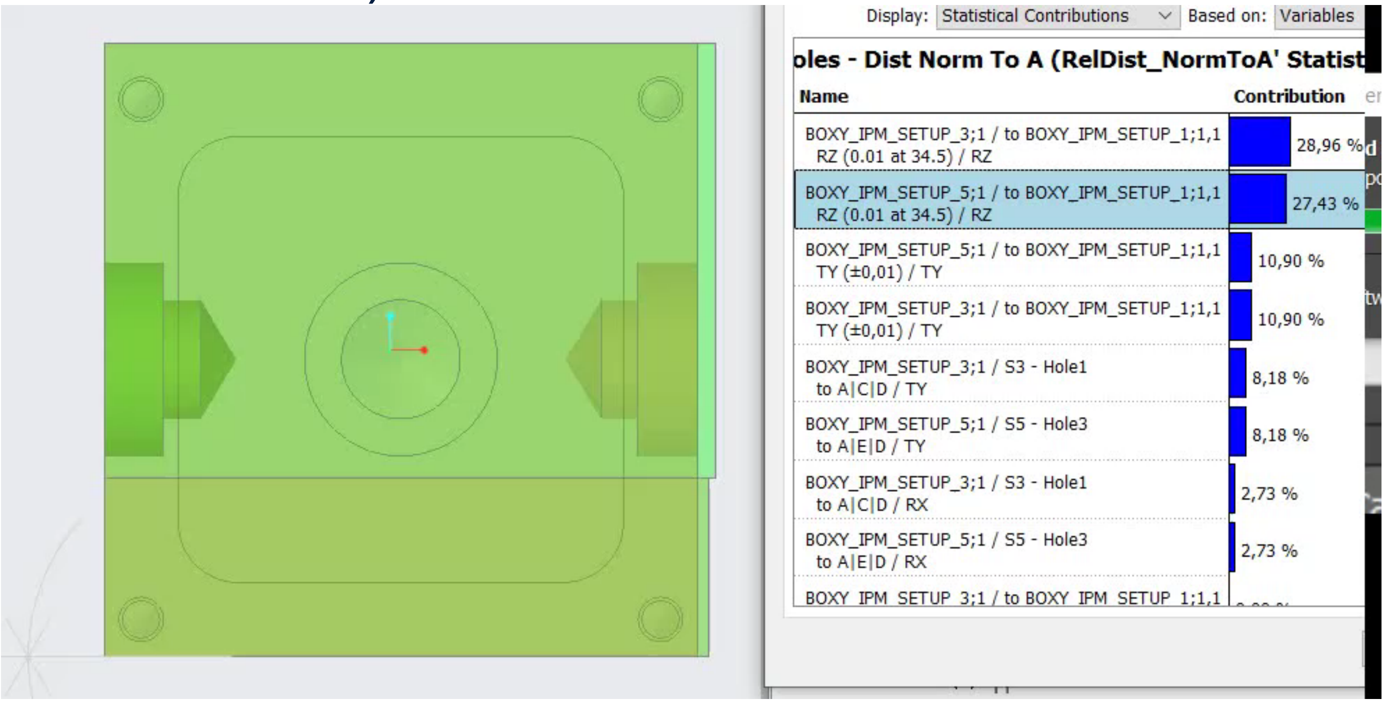
BOXY_IPM_SETUP_3;1 / S3 - Hole1 to A|C|D / TY	8,18 %
BOXY_IPM_SETUP_5;1 / S5 - Hole3 to A|E|D / TY	8,18 %
BOXY_IPM_SETUP_3;1 / S3 - Hole1 to A|C|D / RX	2,73 %
BOXY_IPM_SETUP_5;1 / S5 - Hole3 to A|E|D / RX	2,73 %

1. Clamp rotations

2. Clamp translations

3. Hole position tol. (rot. & transl.)



Find critical features

Name	Contribution
BOXY_IPM_SETUP_3;1 / to BOXY_IPM_SETUP_1;1,1 RZ (0.01 at 34.5) / RZ	28,96 %
BOXY_IPM_SETUP_5;1 / to BOXY_IPM_SETUP_1;1,1 RZ (0.01 at 34.5) / RZ	27,43 %
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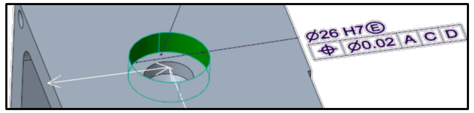
BOXY_IPM_SETUP_3;1 / to BOXY_IPM_SETUP_1;1,1 TY (±0,01) / TY	10,90 %
BOXY_IPM_SETUP_3;1 / S3 - Hole1 to A|C|D / TY	8,18 %
BOXY_IPM_SETUP_5;1 / S5 - Hole3 to A|E|D / TY	8,18 %
BOXY_IPM_SETUP_3;1 / S3 - Hole1 to A|C|D / RX	2,73 %
BOXY_IPM_SETUP_5;1 / S5 - Hole3 to A|E|D / RX	2,73 %

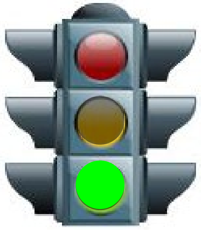
Clamp rotations

Clamp translations



Hole position tol. (rot. & transl.)

Hole position tolerance related 22%
(rotations & translations)

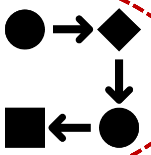


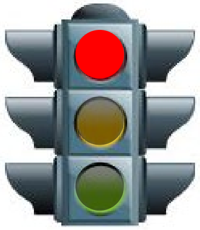
Tight tolerance/ surface requirement

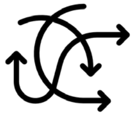
⌭	0,008
○	0,006

Clamping related 78%
(rotations & translations)

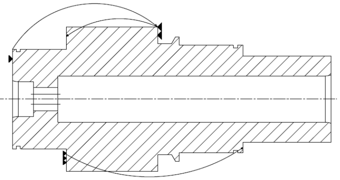
Is produced in several operations

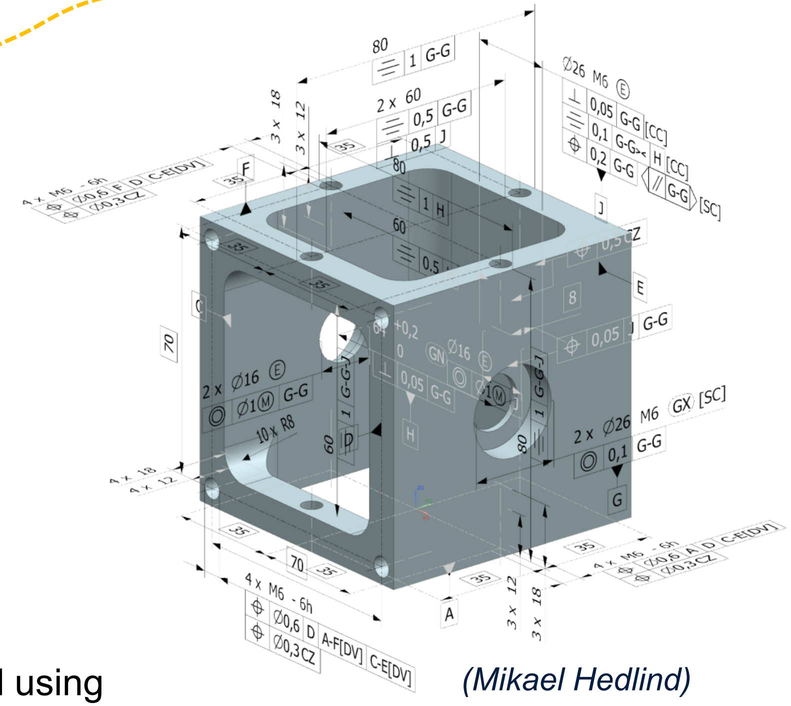






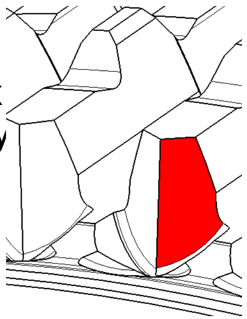
Different references in each operation



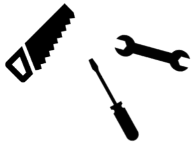


(Mikael Hedlind)

Complex geometry



Is produced using different tools



Affected by heat treatment

Outlook

- Conduct case studies to evaluate the effectiveness of the proposed method in improving product quality and reducing process planning time
- Develop a quality control plan based on the critical feature index
- Develop and validate new analytical methods and tools for tolerance allocation for IPPs
- Develop computer models/use software to simulate the tolerance chain analysis for IPPs

THANK YOU FOR YOUR ATTENTION