WILLKOMMEN ZU
WOST 2016
WEIMARER OPTIMIERUNGS- UND STOCHASTIKTAGE

dynardo | presented at the 13th Weimar Optimization and Stochastic Days 2016
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New geometrical product specifications (GPS*) and robust design

Univ.-Prof. Dr.-Ing. Peter Gust and M.Sc. Christoph Schluer

*Mechanical Engineering **worldwide**, needs the joint output of these standards committees **more than ever**.*

Source ISO/TC 213

Univ.-Prof. Dr.-Ing. Peter Gust
Chair of Engineering Design - University of Wuppertal June 23th 2016

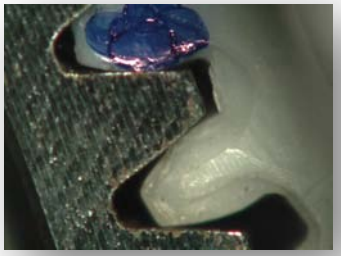
BERGISCHE UNIVERSITÄT WUPPERTAL

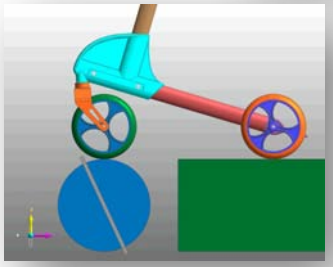
WILLKOMMEN ZU

WOST 2016

WEIMARER OPTIMIERUNGS- UND STOCHASTIKTAGE

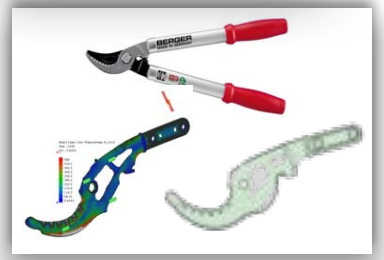
Main Reserach
Univ.-Prof. Dr.-Ing. Peter Gust
Chair of Engineering Design

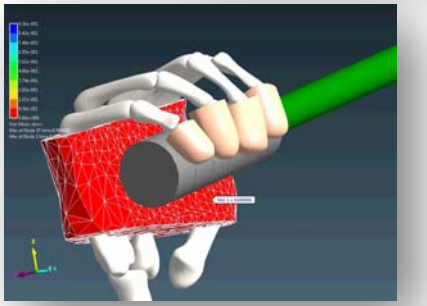


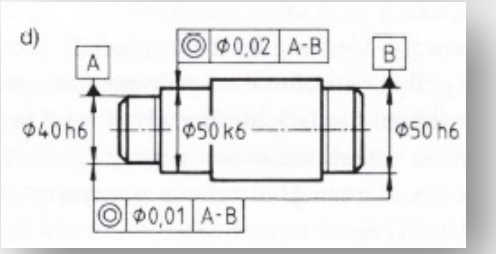


Product-development and Innovation-Management

„Robust Design“ Tolerance-analysis and -management







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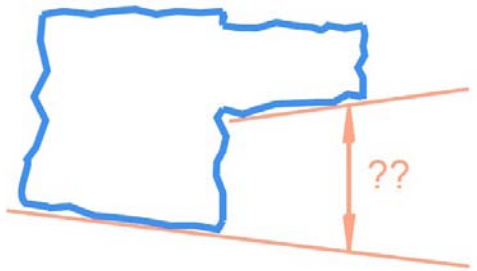
Global Problem*

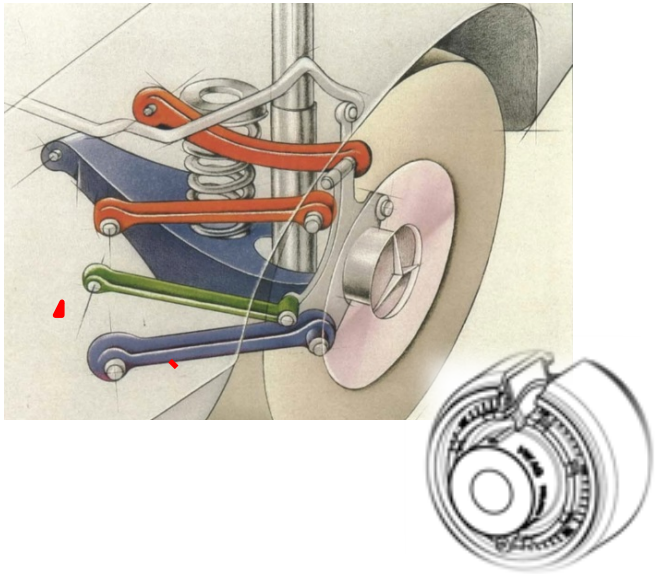
Specification inadequacy is the Achilles heel
for many of today's technologically advanced companies.

Tighter tolerances can often prove phenomenally expensive to apply

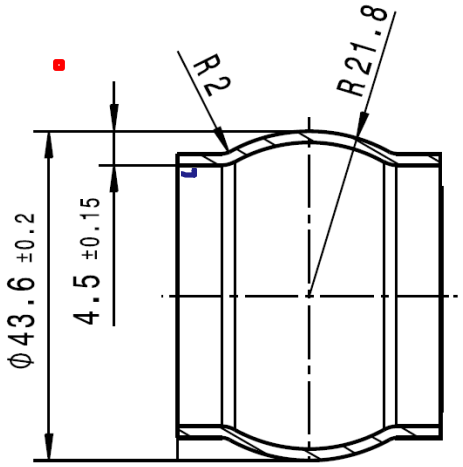
*Source ISO/TC 213



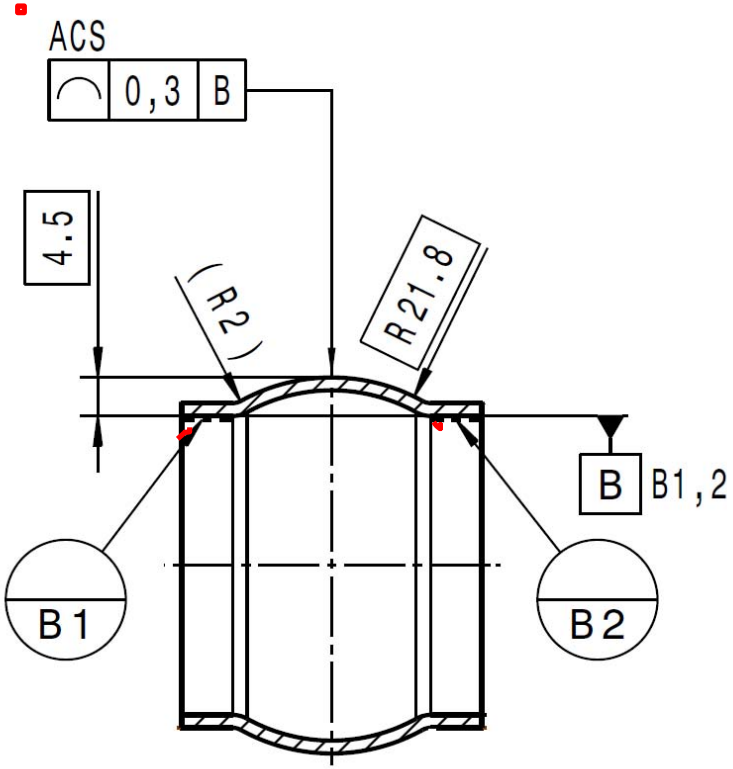
An example: **chassis bearing**



Typical Drawing



Drawing with GPS Spec's:



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State of the Art: New (?) Geometrical Product Specifications

Principle of Duality

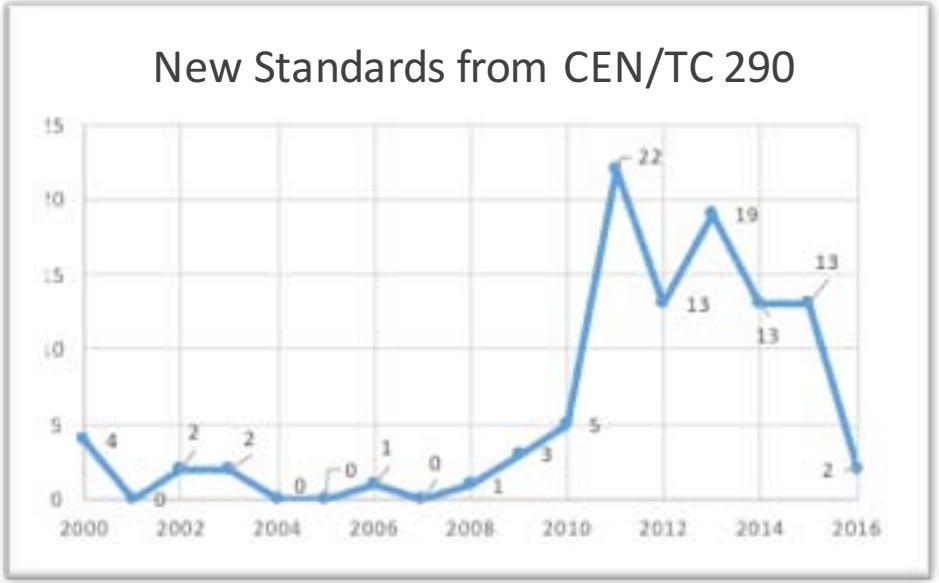
- The design engineer is responsible for the **specifications**
- Production and Quality Management are responsible for **validation**

Principle of Independency

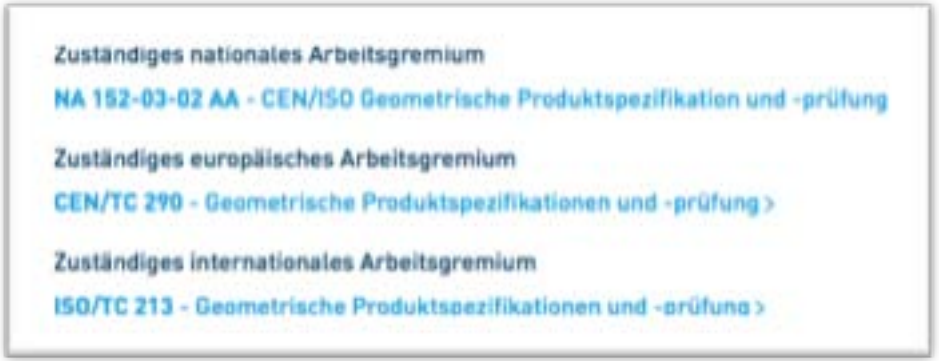
- Since September 2011 the new standard DIN EN ISO 8015 appeared, the **principle of independency** is the standard for geometrical tolerancing instead of the Principle of Envelope (Ⓔ)
- … except if you see the symbol Ⓔ (ISO 14405-1) for the envelope

Structuring all geometrical standards through the

- GPS-Matrix (at the end of each document – to locate the position of the single standard in the whole system)



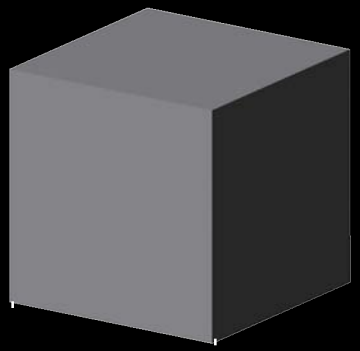
...since 2010 87 new specifications in Europa



IS THE WORLD PERFECT?

No!

Deterministic Approach



a

Statistical Approach
„Robust Design“

$a = f(\mu,\sigma)$

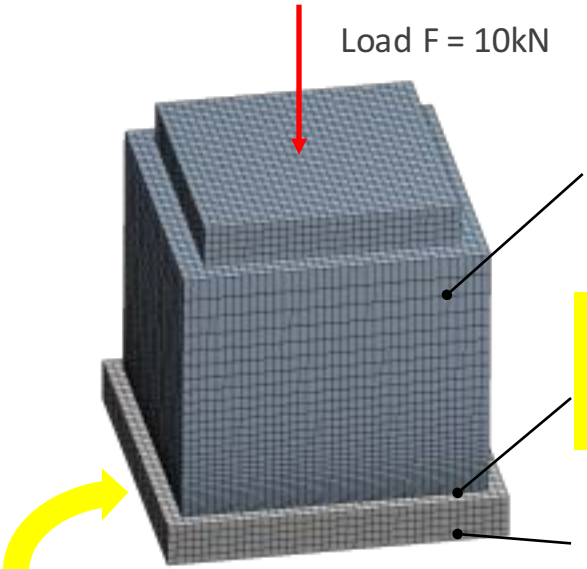
It is not the perfect, but the imperfect, who have need of love.

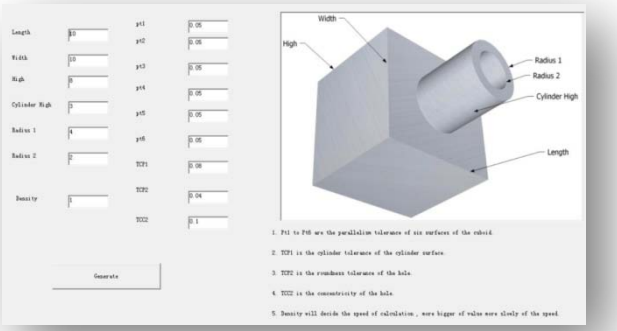
Charles Dickens

Randomly deformed bodies

For the reference case a FE analysis is performed to evaluate the influence of the shape and dimensional tolerances of parts on the stress distribution under load

1.Order: Shape Non Uniformity		linear, planar and roundness Non-Uniformity
2.Order: Waviness		Waves
3.Order: Roughness		Groves
4.Order: Roughness		Scratchs, Scurfs, ...
5.Order: Roughness	not presentable	Microstructur
6.Order	not presentable	Atomic Lattice

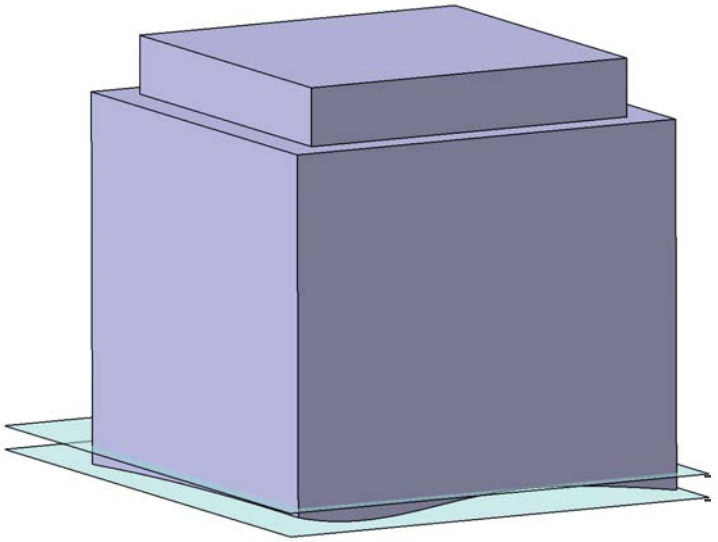




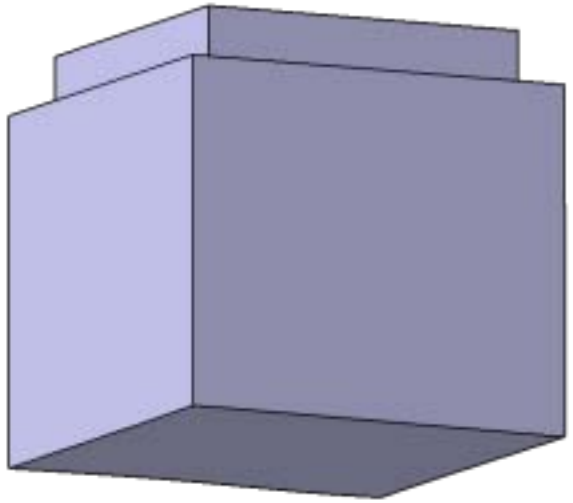
Inhouse Catia Module

Randomly deformed bodies

Contact surface with randomly deformed shape (inside the given tolerance!)



Surface Profile Tolerance (SPT) = 2mm

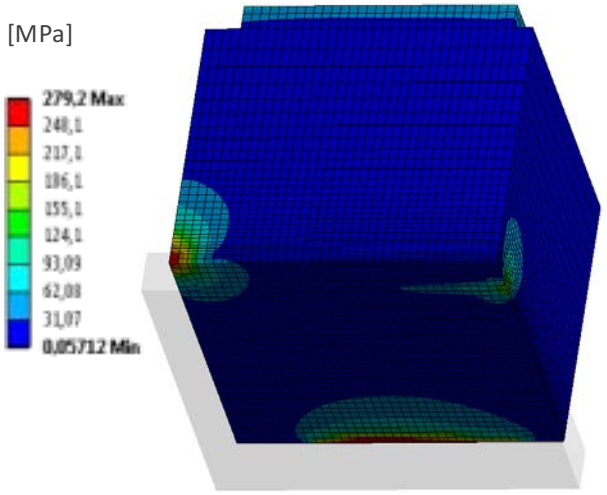


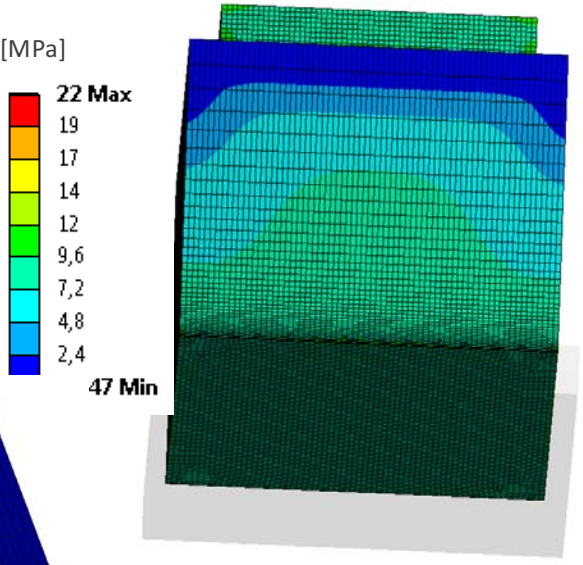
SPT = 0,2mm

Randomly deformed Bodies

First Result

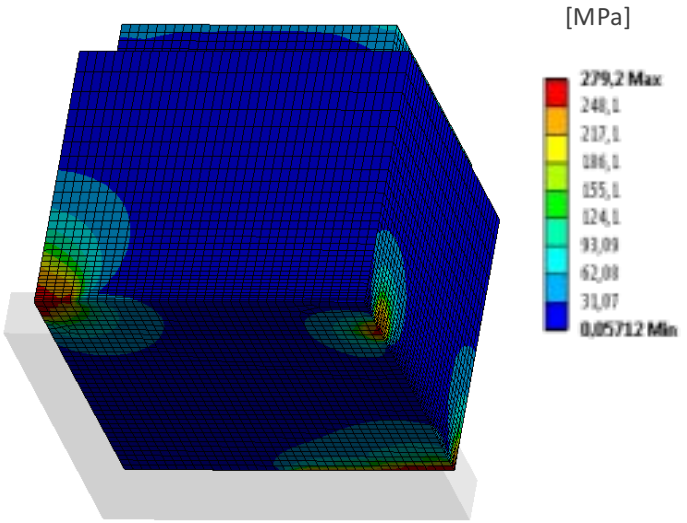
SPT = 0,1mm





SPT = 0,0mm
"Nominal Value"

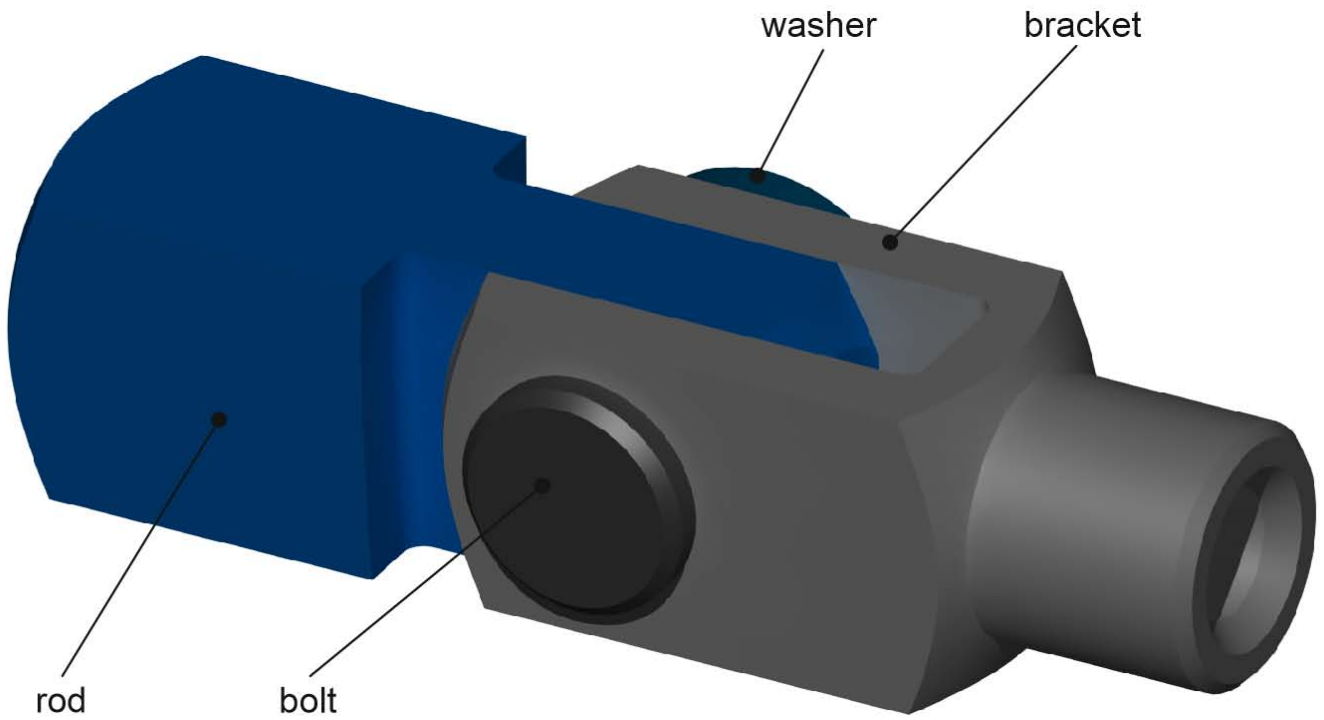
SPT = 0,2mm



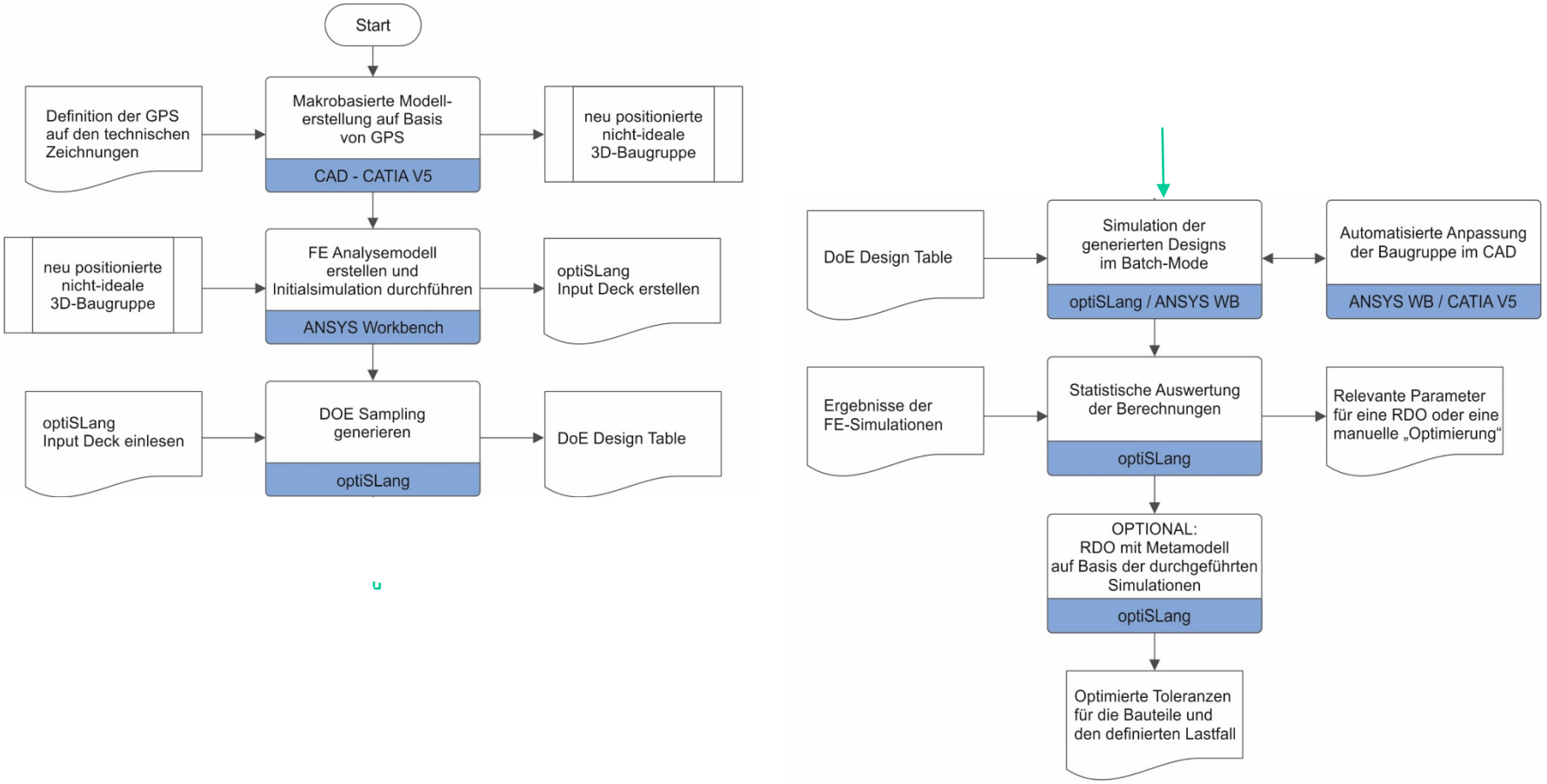
Original Test Object: Bracket-Bolt-Joint

Investigation of the stresses in an assembly with two contact regions and the possibility of experimental validation

Bracket-Bolt-Joint as a standard machine element

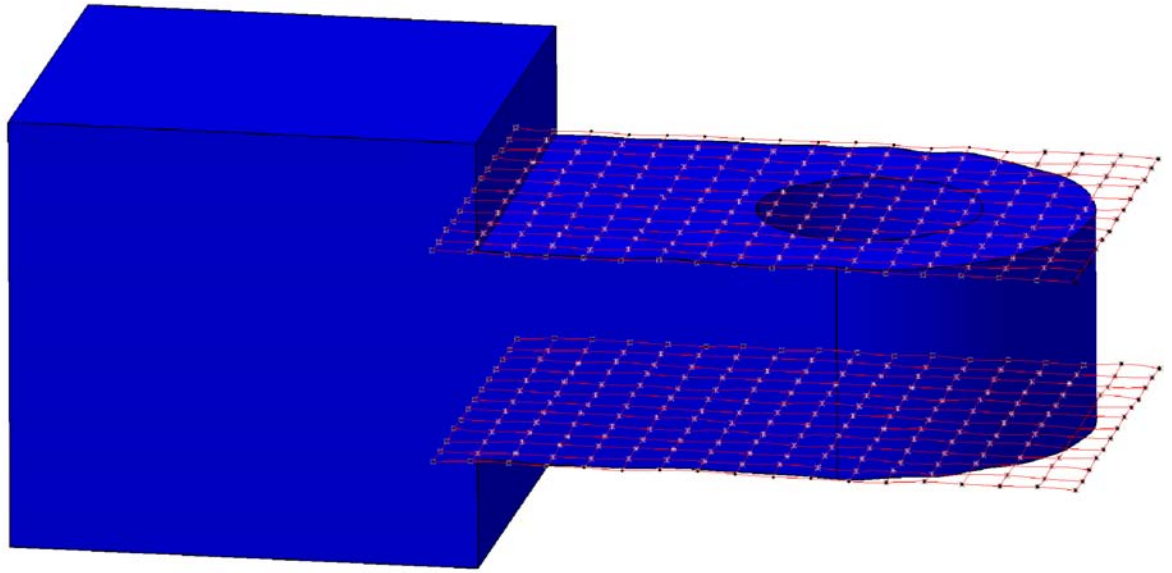


Workflow for consideration of non-ideal geometry in the product development process



Generation of the Non-Ideal-Geometry

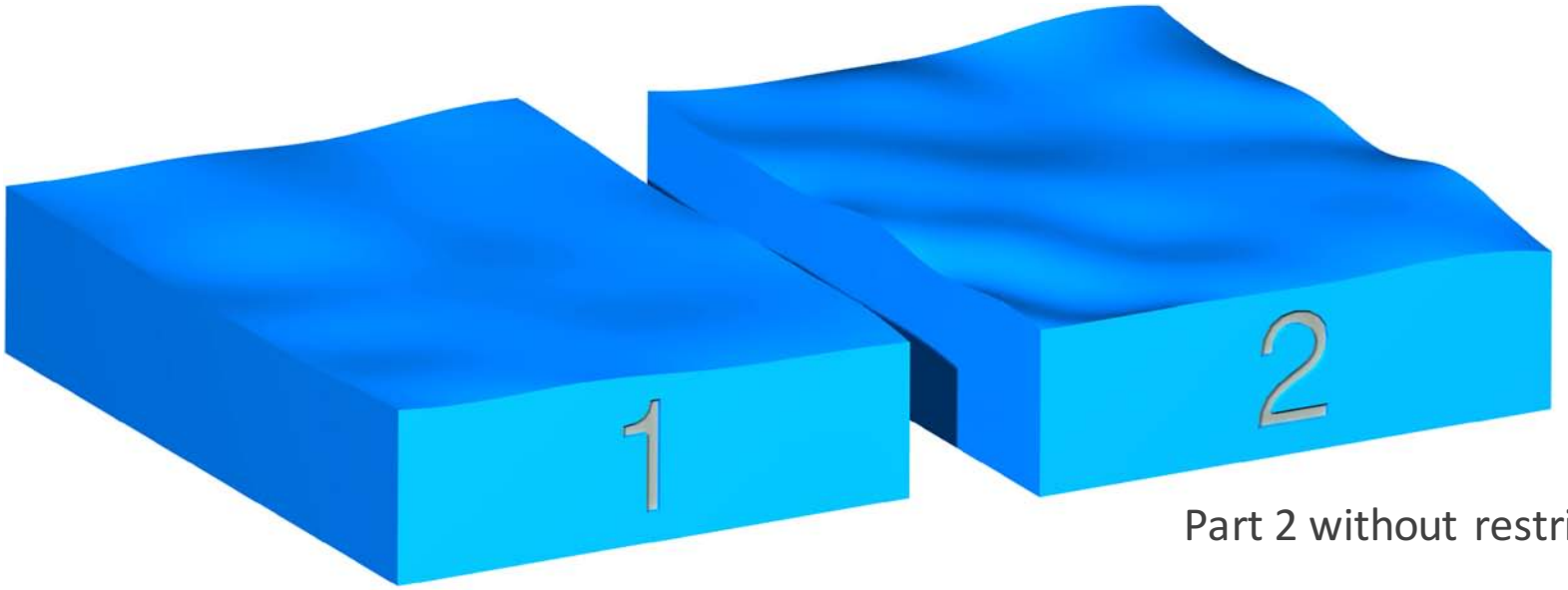
- The non-ideal model which is required for the simulation, is created in the CAD system.
- Dimensional an geometric tolerances are defined in advance.
- The geometry creation works with parametric point clouds, which form the basis for a surface model.



Generation of the Non-Ideal-Geometry

The generation of the data points in the predetermined tolerance field is carried out according to defined rules.

Among other things, the adjacent data points deviate not more than 20% of the permissible tolerance zone from each other → ensuring to get a realistic component surface.



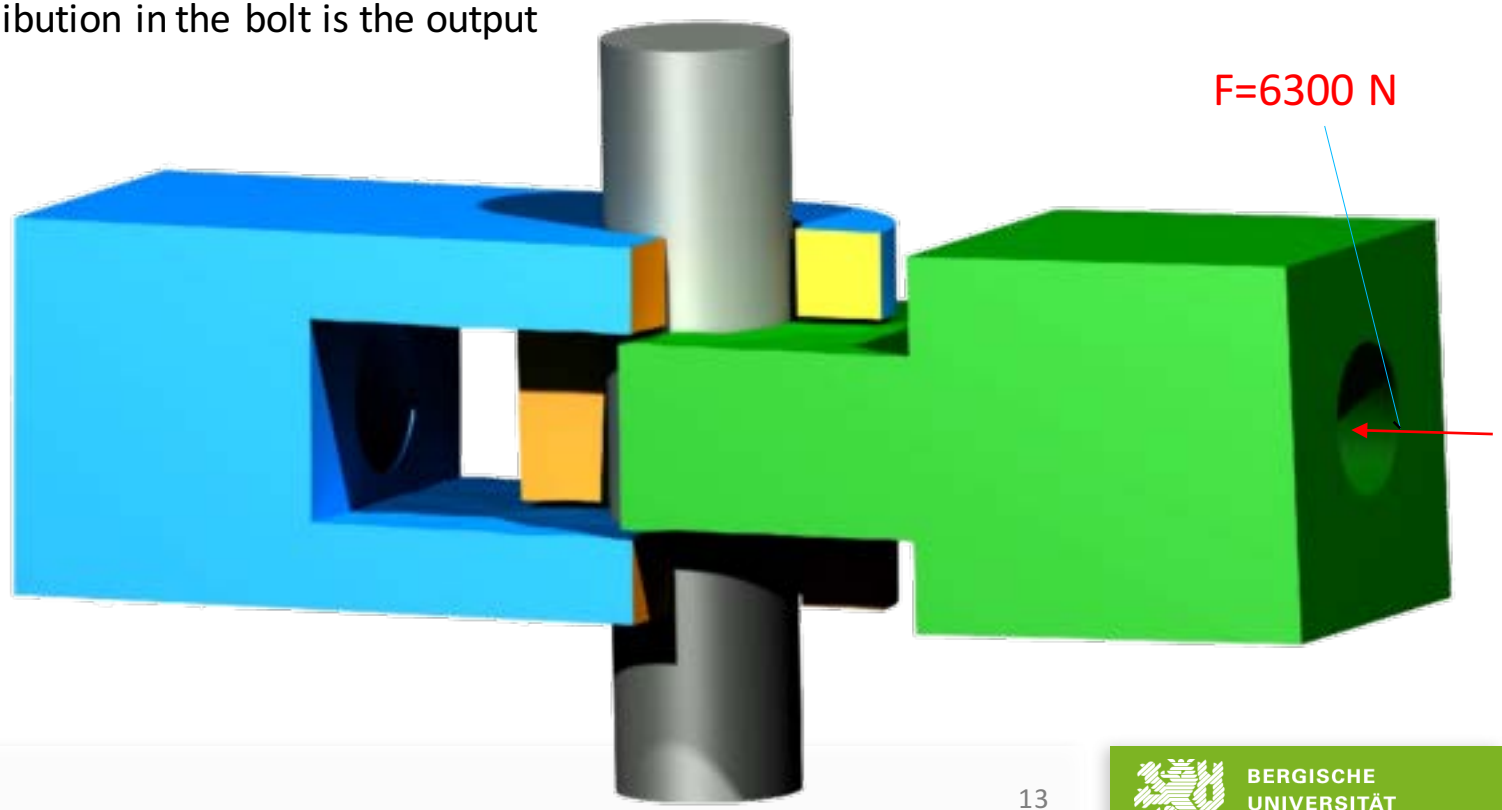
Part 2 without restrictions

Part 1 with restrictions

FEM-Model

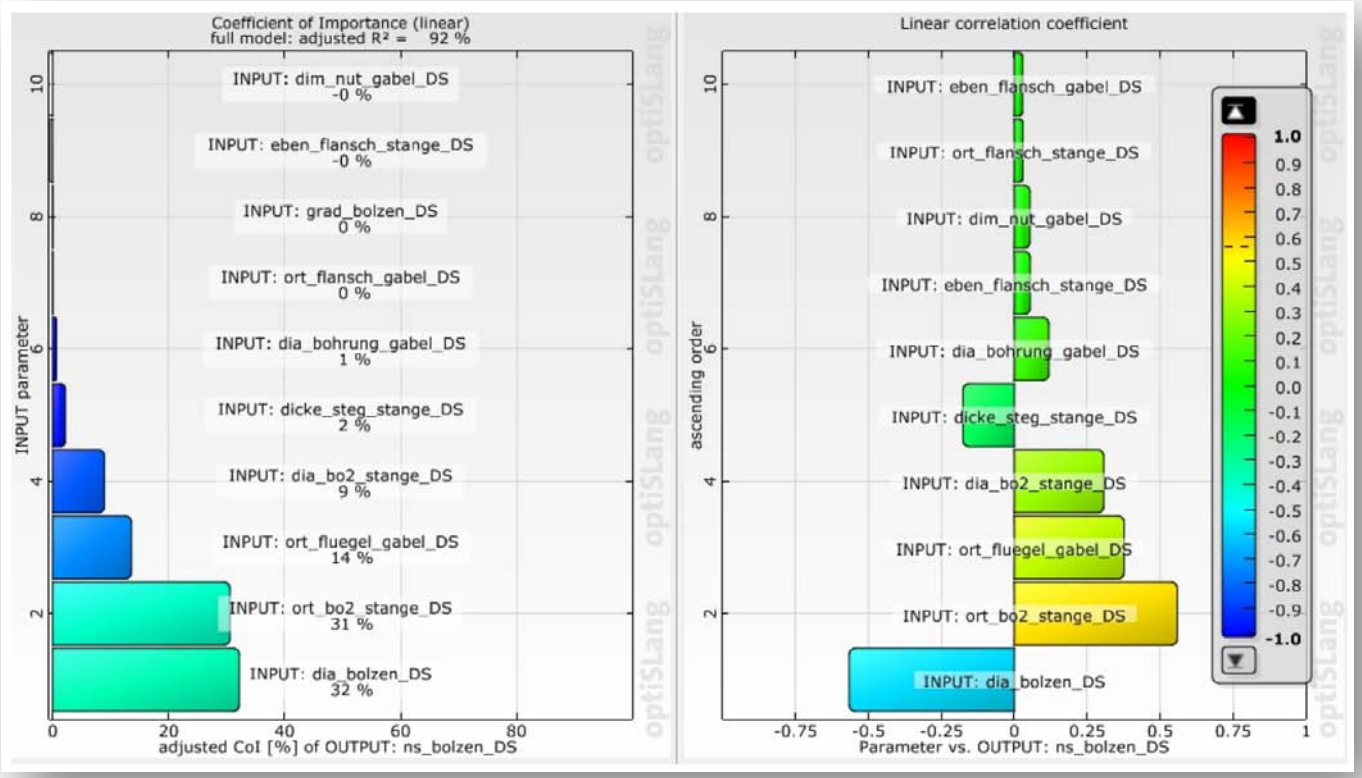
The non ideal Components cause complex contact behavior with clearance

- Bracket is fixed on the left side and the rod is loaded with 6300N.
- Friction in the contact regions with μ=0,1 non-linear material S235JR
- The tolerances of the components are the input
- The normal stress distribution in the bolt is the output



Sensitivity Study

Latin Hypercube Sampling with 120 designs shows the relevant parameters (tolerances) with respect to the normal stress in the bolt under load



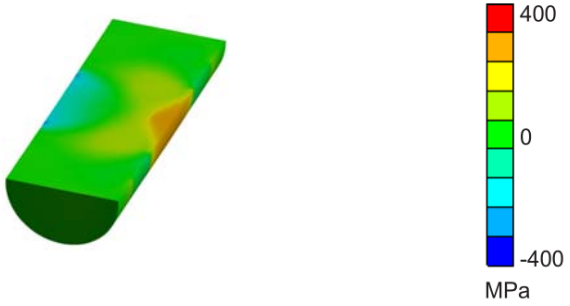
Parameters of the Bracket

Nummer ZB	Bolzen	Gabel			Stange		
		Flügel	Bohrung		Steg	Bohrung	
			Lage	Durchm.		Lage	Durchm.
1	min	max & parallel	gerade	max	außen max & innen min	max Winkel zu B	max
2	max	angestellt & parallel	max Winkel zu B	nominal	angestellt & parallel	halber Winkel zu B	max
3	konisch	außen max & innen min	gerade, quer zu $F_{Dirction}$ versetzt	nominal	außen min & innen max	nominal	nominal
4	ungerade	außen min & innen max	gerade	min	orthogonal	max Winkel zu B	max
5	ungerade	max & parallel	gerade	max	angestellt & parallel	halber Winkel zu B	min
6		außen min & innen max	gerade	min	außen min & innen max	nominal	nominal

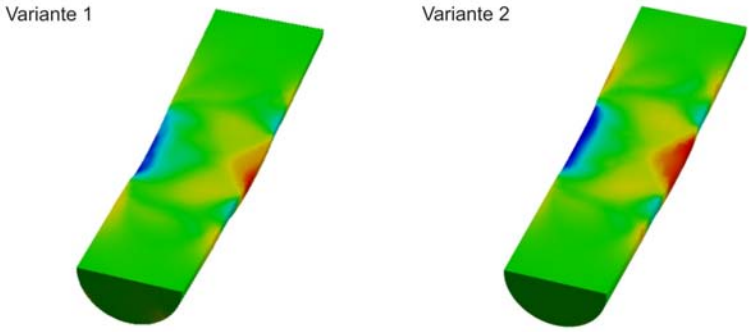
Begriffsdefinition:
min / max: Lage der Geometrie im Toleranzfeld
konisch: Bolzenform konisch
grade / ungrade: Ausnutzung der Gradheitstoleranz der Zylinderachsen
angestellt: Rechtwinkligkeitstoleranz maximal ausgenutzt

Comparison of the normal stress distribution for the different geometry variants

Ideal part

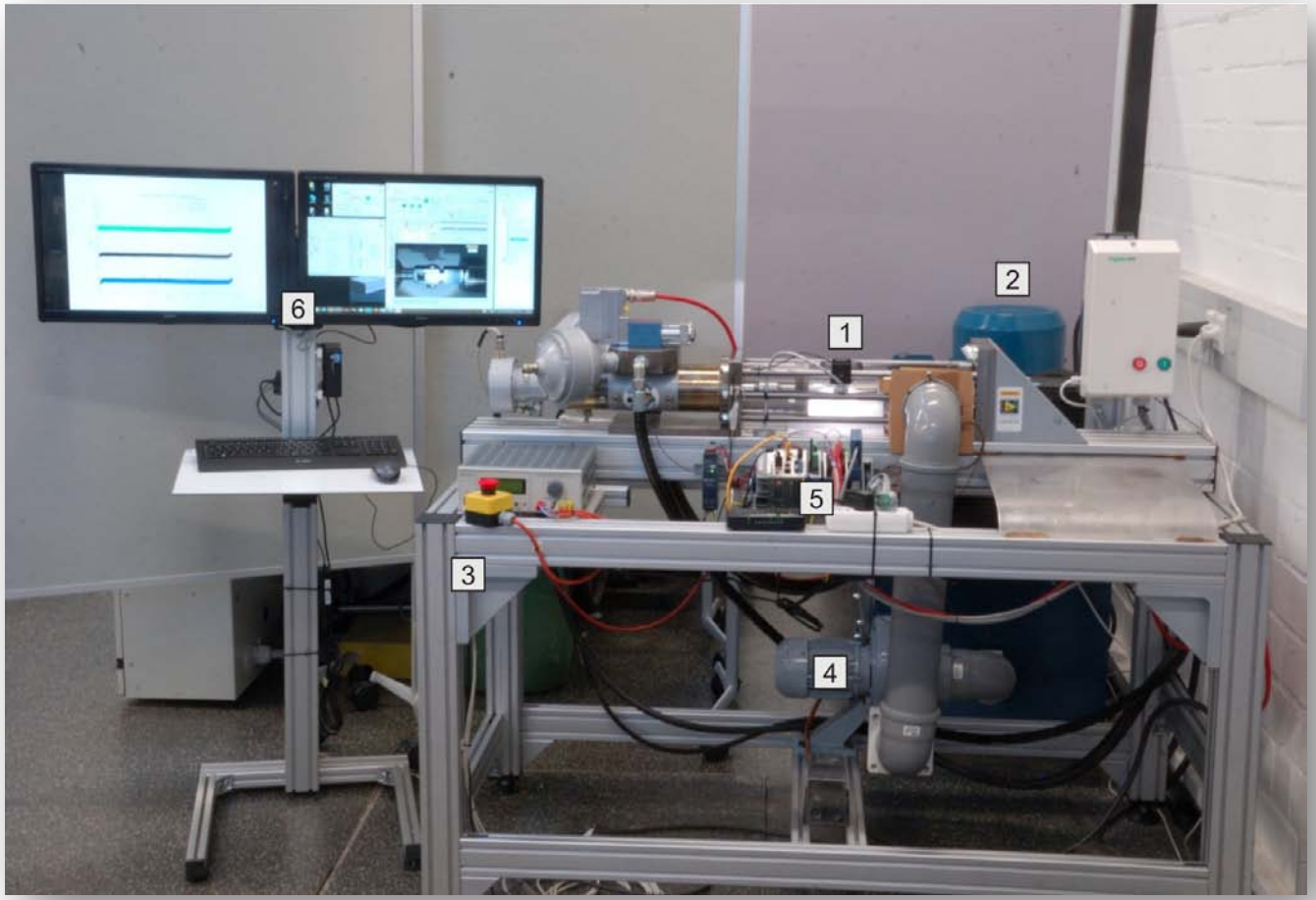


Non-ideal variants



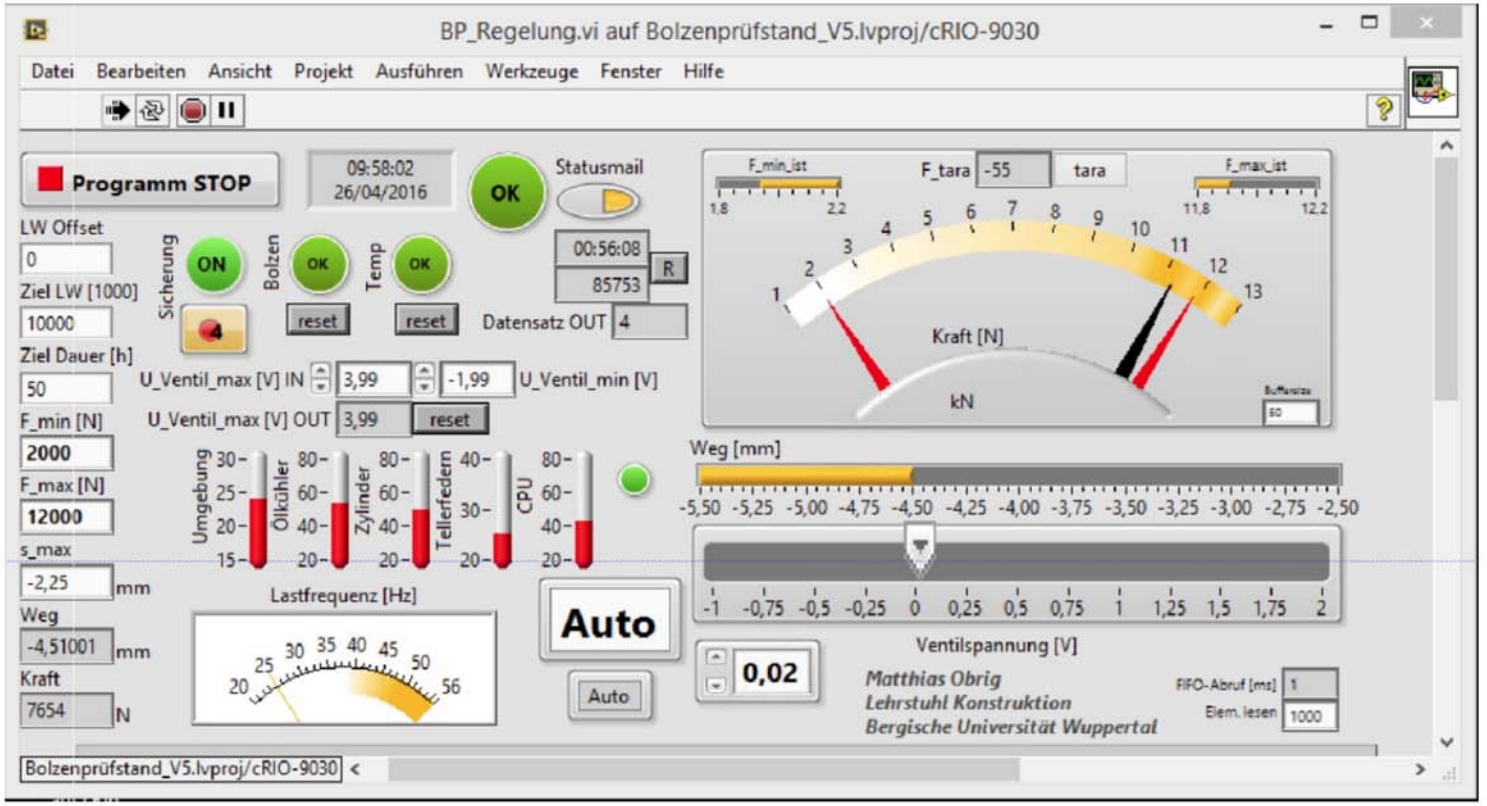
Variante nach Tabelle 4.1	Spannung im Bolzen in MPa	Abweichung zur Idealvariante in %
Ideal	248	0
1	326	31
2	300	21
3	315	27
4	312	26
5	304	23
6	292	18

Test Stand for Validation



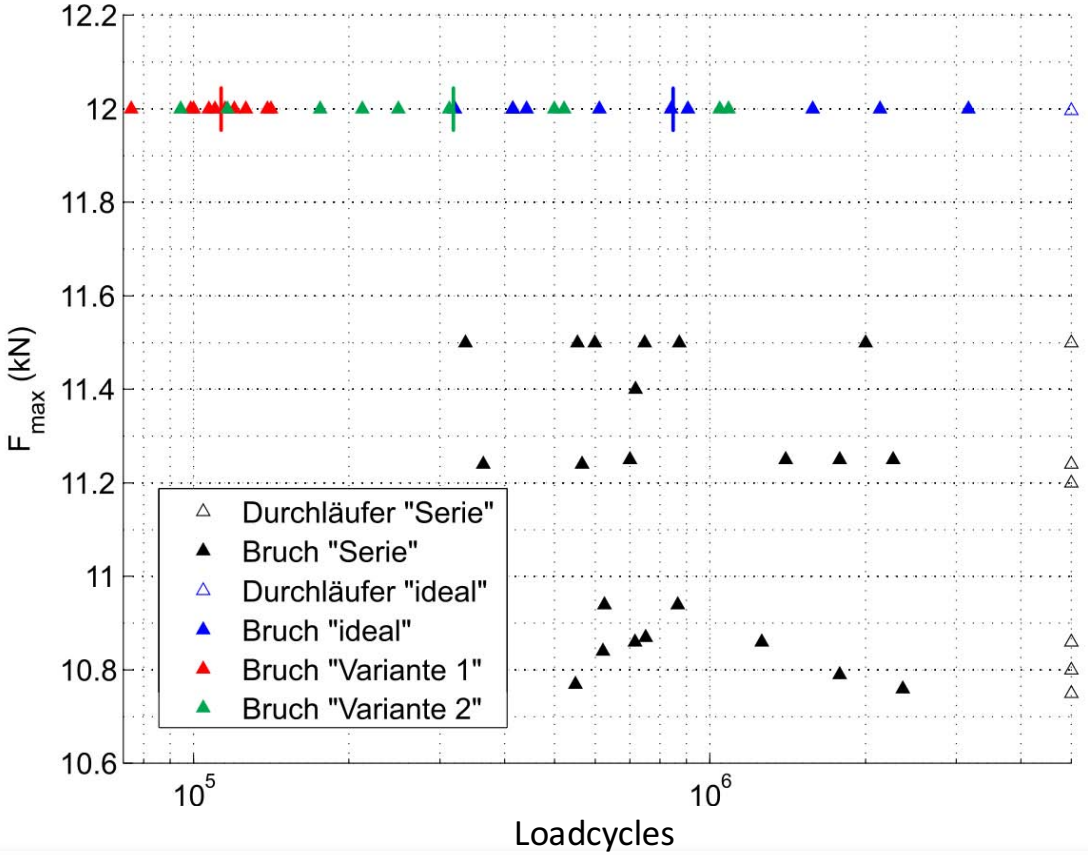
1. Test specimen
2. Hydraulic power unit
3. Mainframe
4. Cooling fan
5. Measurement Hardware
6. Graphical user interface

Validation Software/Control

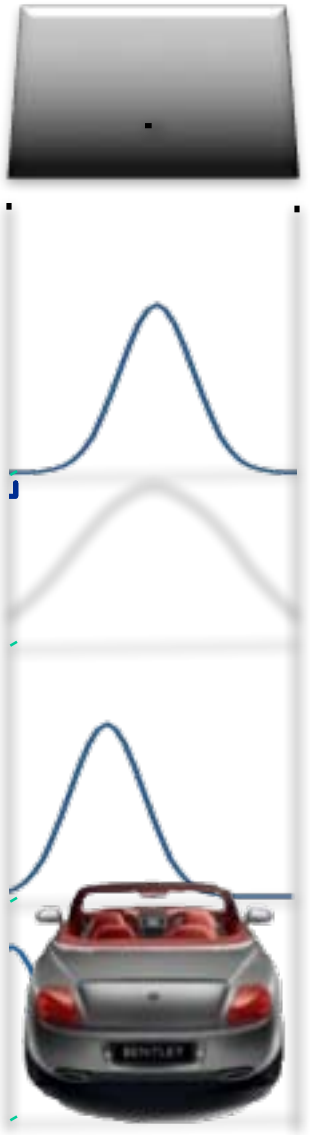


Final Results

After a period of initial tests, the ideal assemblys were tested (blue) in comparison to the non-ideal variants 1(red) and 2(green). The vertical lines represent the median of respectively 10 probes.



Actual evaluation of Process Capability



Process Suitability C_p: Is the process suitable?

$$Cp = \frac{T}{6s} = \frac{OTG - UTG}{6s}$$

with $C_p > 1{,}33$ the process is suitable!
... the car fits in your garage!

with $C_p < 1{,}0$ the process is **not** suitable!
... the car does not fit in your garage!

Process Suitability C_{pk}: Is the process controllable?

$$Cpk = \min\left[Cpo; Cpu\right]$$

$$Cpu = \frac{\bar{x} - UTG}{3s}$$

$$Cpo = \frac{OTG - \bar{x}}{3s}$$

with $C_{pk} > 1{,}33$ the process is controllable!
... the car strikes in your garage!

with $C_{pk} < 1{,}0$ the process is **not** controllable!
... the car does not strike in your garage

New extended Objectives

We need robust Processes

1. Suitable process,
2. Controllable processes
3. And new: centered Processes

The automotive working committee defined a new Index C_{pr}*:

- It is a value for the **robustness** and will be calculated through the average quadratic failure
- It can be easily calculated through 4 parameters
- It is suitable for all distribution shapes
- It included C_p und C_{pk}.

$$C_{pr} = \frac{T}{6 * \sqrt{\sigma^2 + (m - \mu)^2}}$$

T: Tolerance = difference OTG-UTG

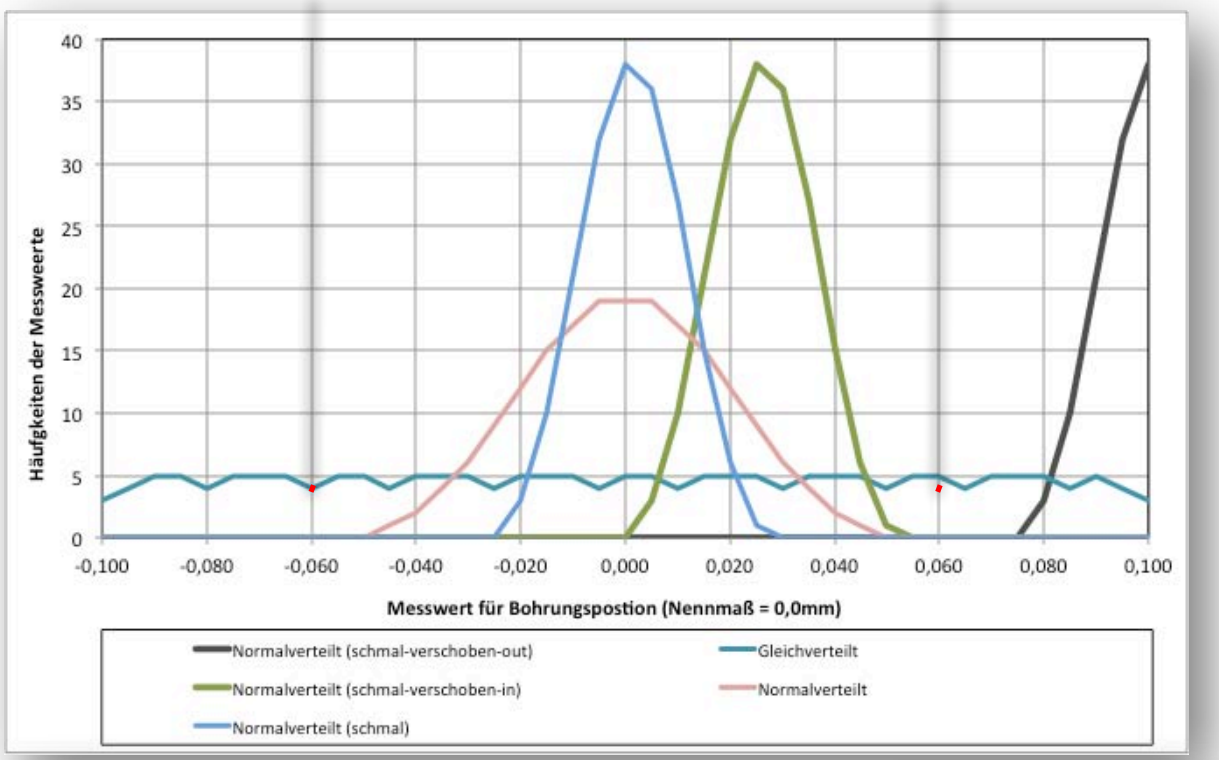
m: Mean Value of the tolerance

μ: Mean Value

σ: Standard deviation

* Quelle Summer School Toleranzanalysen, Uni Erlangen, W.R. Landschoff, VW, 2013

Index for Robustness C_{pr}



	Cp	Cpk	aktuelles Ergebnis	Cpr	neues Ergebnis
Normalverteilt	1,09	1,09	NIO	1,09	NIO
Normalverteilt (schmal)	2,19	2,19	IO	2,19	IO
Gleichverteilt	0,34	0,33	NIO	0,34	NIO
Normalverteilt (schmal-verschoben-in)	2,19	1,33	IO	0,75	NIO
Normalverteilt (schmal-verschoben-out)	2,19	-1,46	NIO	0,20	NIO

$$C_{pr} = \frac{T}{6 * \sqrt{\sigma^2 + (m - \mu)^2}}$$

- C_{pr}-Index is on his way to become a future part of the VDA
- Therefor existing „ok“ parts could be defective parts in future
- But the mounting processes is more „**robust**“ with less defective assemblies

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Chair of Engineering Design - University of Wuppertal June 23th 2016

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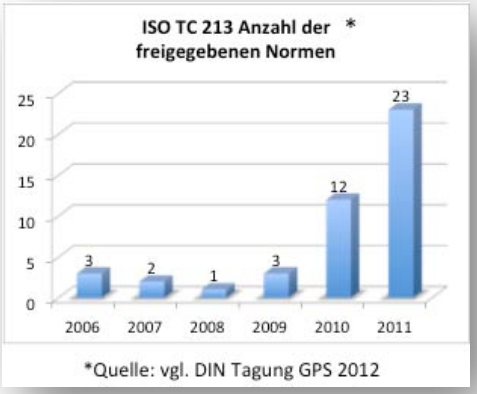
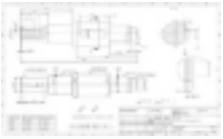
Outlook



Engineering Design



Production, Tooling

Quality Management

Idea: **The consequent usage of Tolerance-Management is capable for a significant cost reduction**

And How?

- Usage of the principle of Independency,
  (Envelope only for functional requirements (Ⓔ ISO 14405-1)
- Usage of Robust Designs (Optimization and Validation) and Tolerance-Management
- Reduction of failure expenses through definition of right references and clear dimensions
- Consistent level of competence through training and installation of internal **GPS Coaches**

Thanks for your attention, any questions - please?

Contact

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