Rapid Control Prototyping for the Production of Functionally Graded Materials with Tailored Microstructural Properties utilizing COMSOL Multiphysics

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Overview

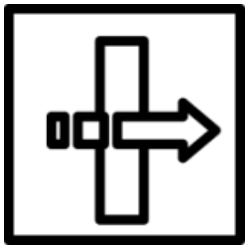
Tailored Microstructural Components

Wear-optimized tailored components

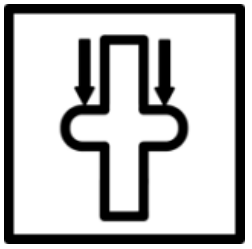
Load-optimized tailored components

Process Challenges

Heating Strategy



Transfer

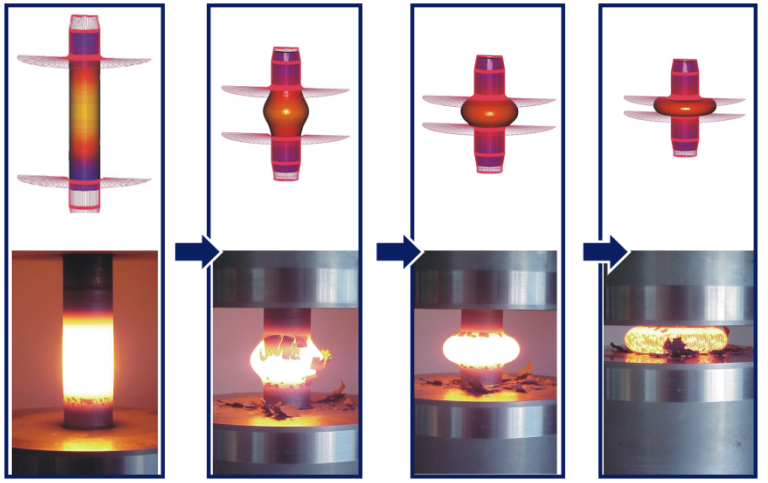


Forming Process

Cooling Strategy

Radiative and convective losses

Intra-billet heat flux

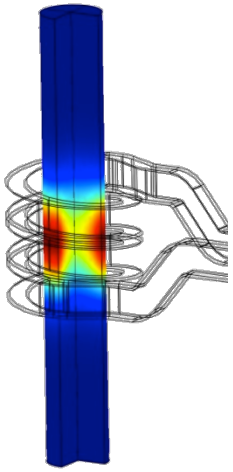


Source: Metform – University of Kassel

FEM Simulation

Geometry

FE Modeling



Simplifications:

- 2D axissymmetric model
- Inclination of coils neglected

Coupled Differential Equations

Maxwell equations:

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \cdot \mathbf{D} = \rho_{elec}$$

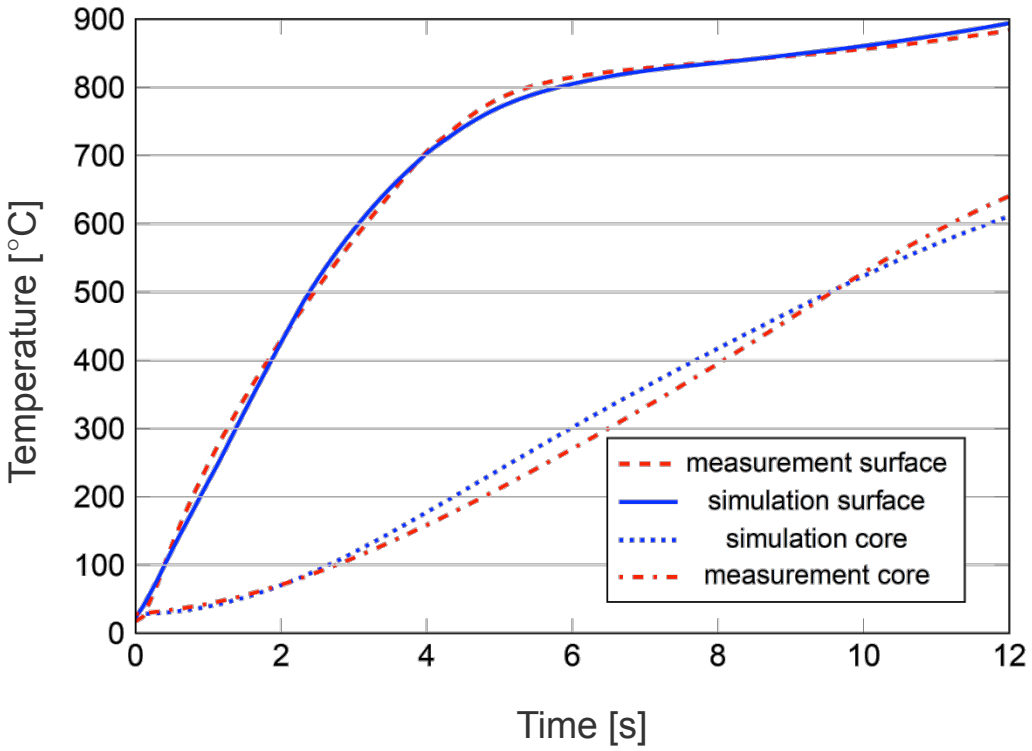
Induced current density:

$$J = -\frac{\partial}{\partial r} \frac{ber(\sqrt{2}\frac{r}{\delta}) + \jmath\, bei(\sqrt{2}\frac{r}{\delta})}{ber(\sqrt{2}\frac{R}{\delta}) + \jmath\, bei(\sqrt{2}\frac{R}{\delta})} H_s$$

Coupled thermo-electrical system (intra-billet heat flux):

$$\rho C_p \frac{\partial T}{\partial t} - k\nabla^2 T = Q_{source}$$

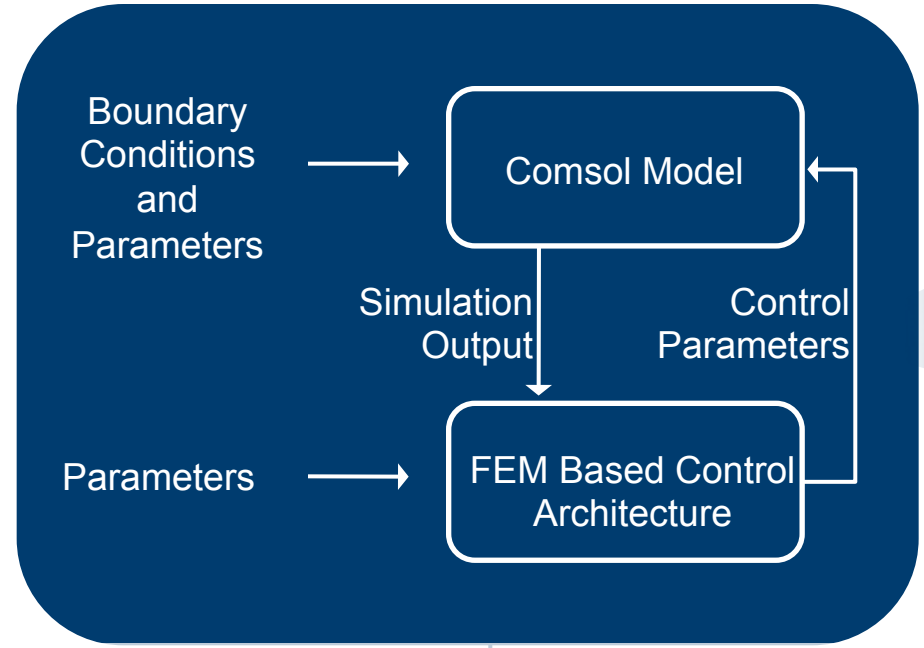
Model Verification



Specifications

power (P_{ind})	=	18 kW
frequency (f)	=	8 kHz
time (t_{ind})	=	12 s

Matlab and Comsol




```
1. fem1.sol = asseminit
   (femmodel,
   'init',femmodel.sol);

2. fem.sol=femtime
   (fem,'init',fem1.sol, ...
   ,[…]);
```

FEM Verification

Mapping

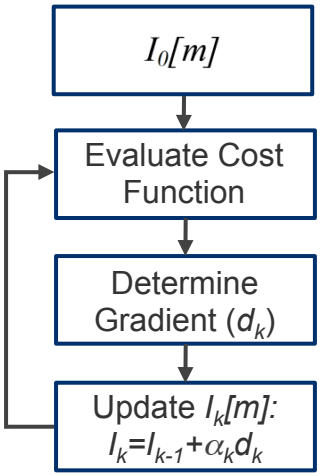
SPS Control Architecture

Sensors and Actuators

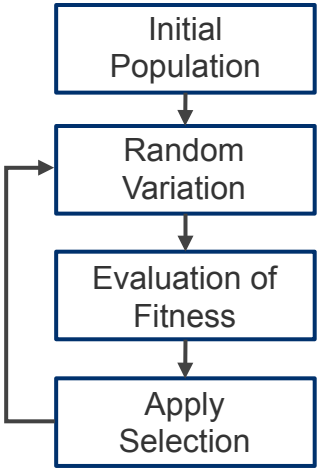
Metal Forming Process

Numerical Optimization of the Heating Strategy

Steepest Gradient Descent



Genetic Algorithm



Cost function

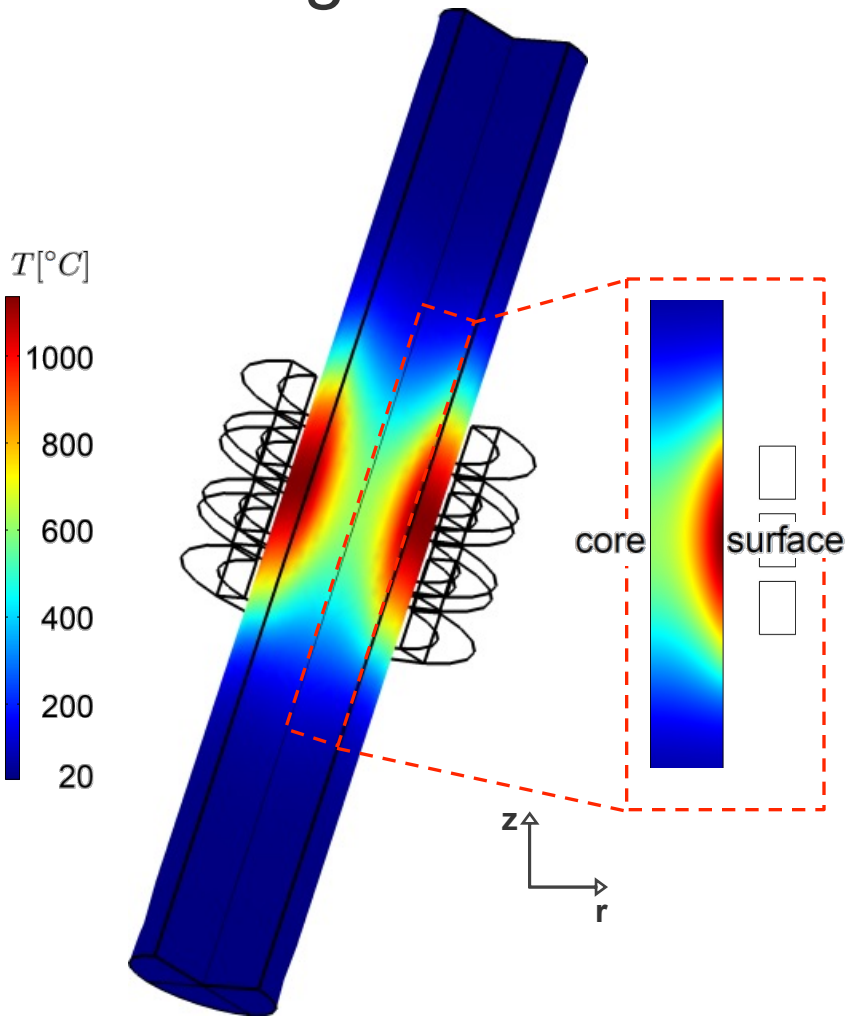
$$\varepsilon_{mse} = \frac{1}{N}\sum_{n=1}^{N}(T(r_n, z=0, t=t_{final}) - T_{defined}(r_n, z=0, t=t_{final}))^2$$

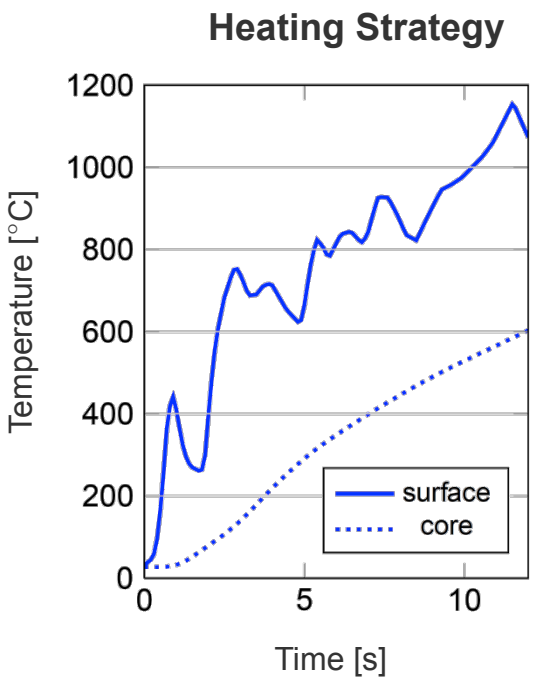
$$\varepsilon_{mse}(I_{opt}(t)) = min\ \varepsilon_{mse}(I(t))$$

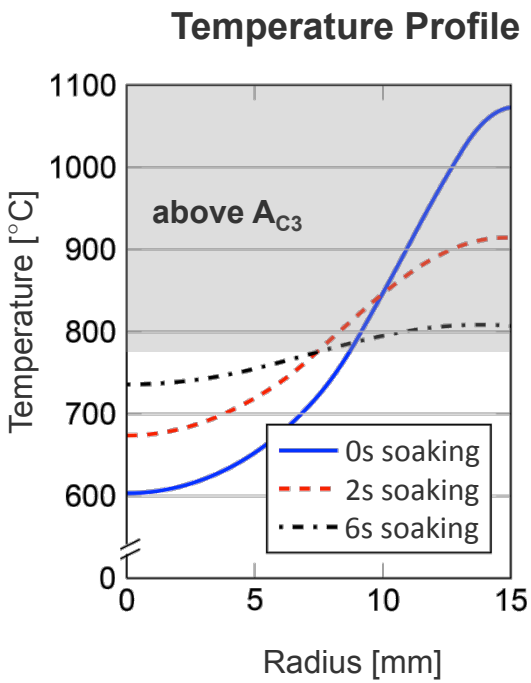
Advantages and disadvantages:
-Fast convergence
-Requires gradient
-Start-value dependent

Advantages and disadvantages:
-Suited for complex, nonlinear problems
-Stochastic search
-Usually slower

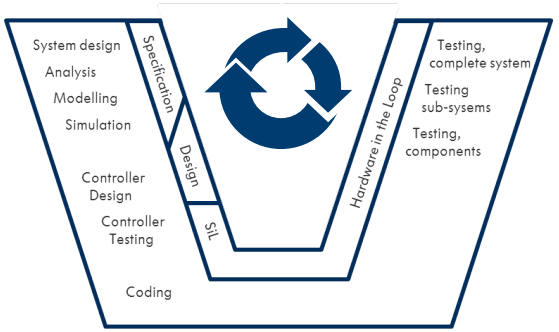
Strong Core-Surface Gradient Heating Strategy

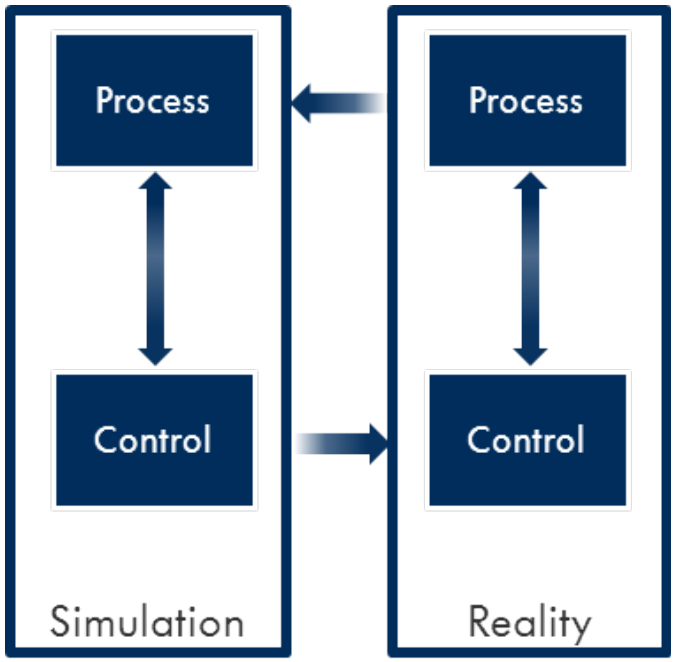






Rapid Control Prototyping

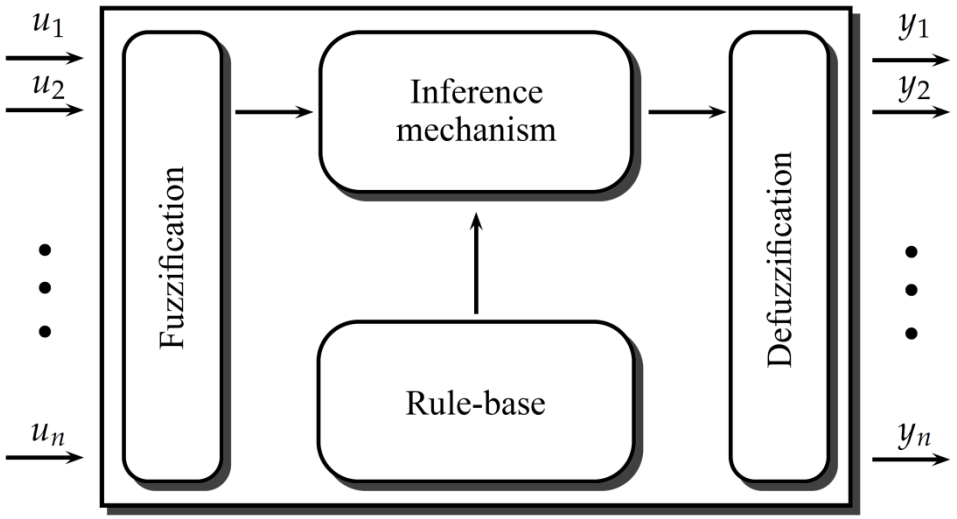




Source: D. Abel and A. Bollig, Rapid Control Prototyping, Springer 2006

Fuzzy Logic Controller

Fuzzy Logic Control



Online Adaption

$$\theta_{i,j}(k+1) = \theta_{i,j}(k) - \frac{w_{i,j}(k)}{\Omega}\frac{\partial J(\theta, x)}{\partial \theta}$$

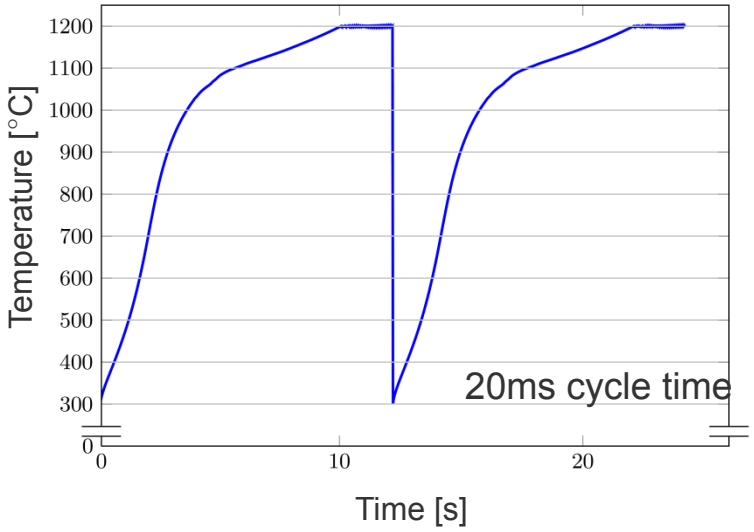
ε

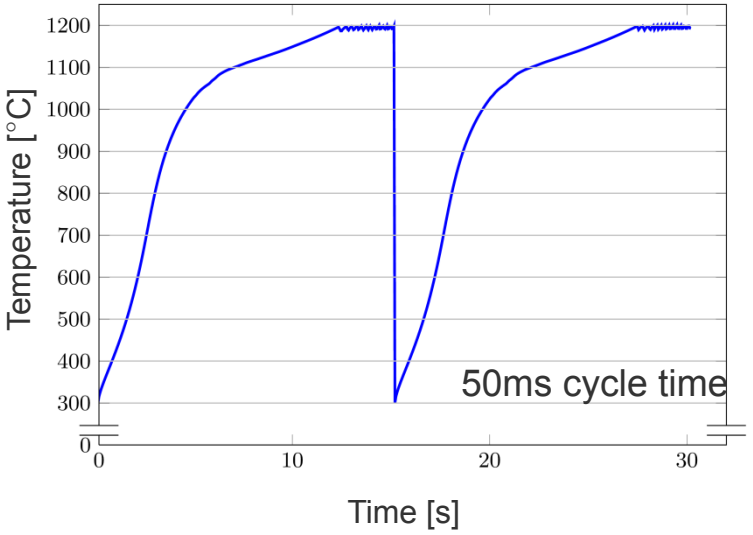
$R\downarrow init = [\blacksquare 0 \&0 \&0 \&0 \&0 \&0 \&0 @0 \&0 \&0 \&0 \&0$

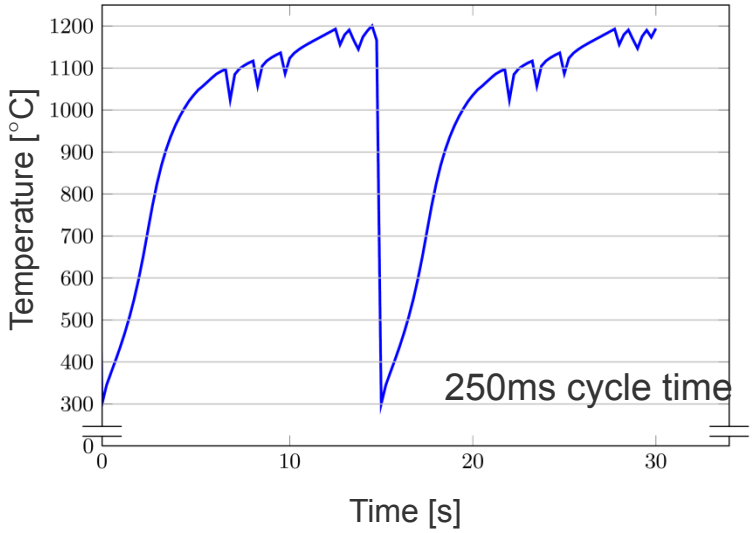
$\partial\varepsilon$

No pirior process information

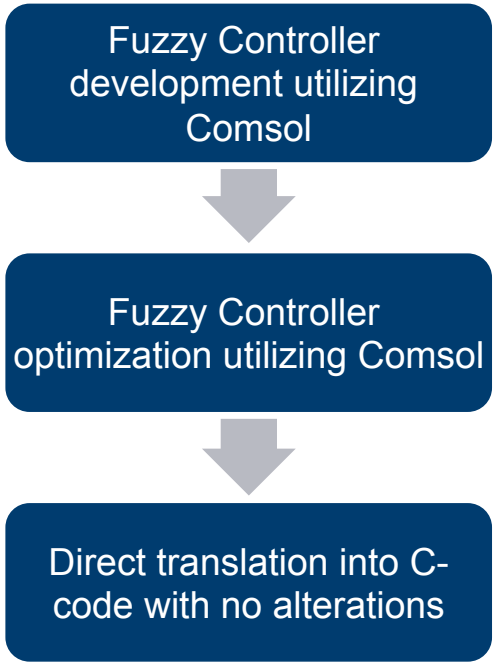
Simulative Evaluation of Cycle Time Impact







Application Results



Conclusion and Outlook

Conclusion

-Control of highly nonlinear system

-Complex optimization algorithms

-Implementation of complex, self adjusting control algorithms

Opportunities:

-Highly flexible production system for high precision mass customization

-Stable, tailored product quality properties (dimensions, microstructural distribution, etc.)

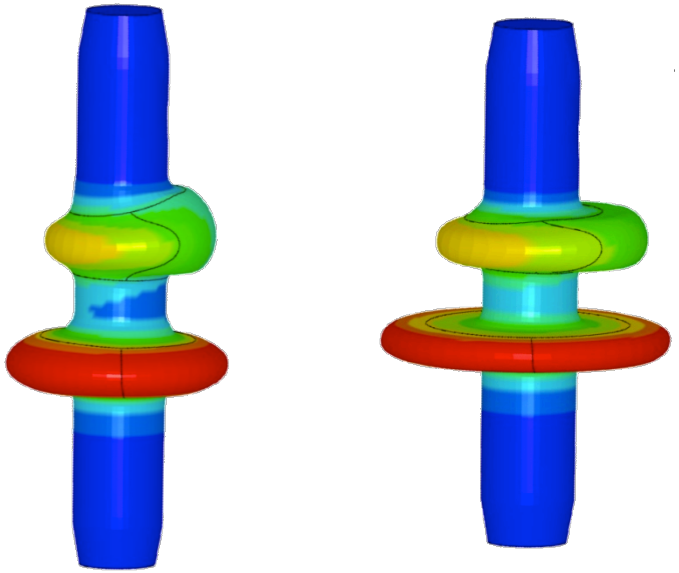
-Adaptable to all thermo-mechanical processes

Future Challenges:

-Multi-form flanged shafts

-Complex geometries

-Mapping to sheet metal forming



Source: Institute of Mechanics –Chair of Numerical Mechanics

Thank you for your attention!