technische universität dortmund

Fakultät Maschinenbau

Institut für Umformtechnik und Leichtbau

Process development for deep drawing with integrated electromagnetic forming

S. Gies, O. K. Demir, A. E. Tekkaya

October 06, 2015

Outline

- Introduction
- Electromagnetic Radius Calibration
  - Process Sequence
  - Results
  - Summary
- Electromagnetic Forming in the Flange
  - Process Analysis
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Introduction

Motivation: Increased design freedom in deep drawing

Problem:
→ min. edge radius
→ max. drawing ratio $\beta_{\max} = \frac{r_0}{r_P}$
→ max. drawing depth $h_{\max}$

Bottom tear at a cylindrical cup

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→ min. edge radius
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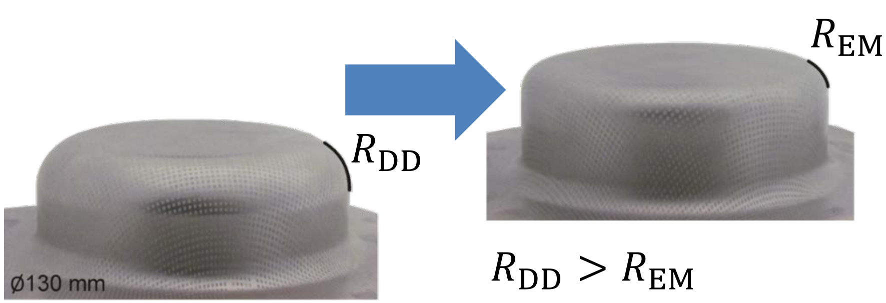
Bottom tear at a cylindrical cup

Electromagnetic Radius Calibration

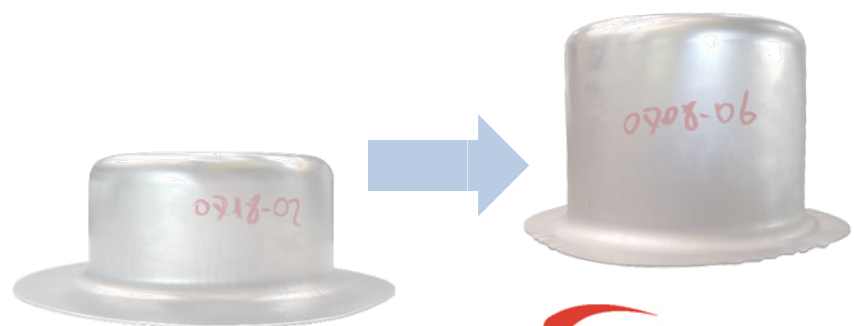
→ Decreasing min. edge radius



$R_{\mathrm{DD}} > R_{\mathrm{EM}}$

Electromagnetic Forming in the Flange

→ Increasing $\beta_{\max}$ and $h_{\max}$



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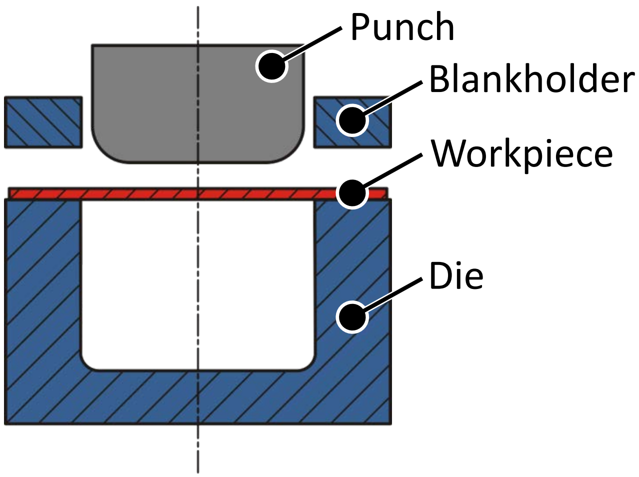
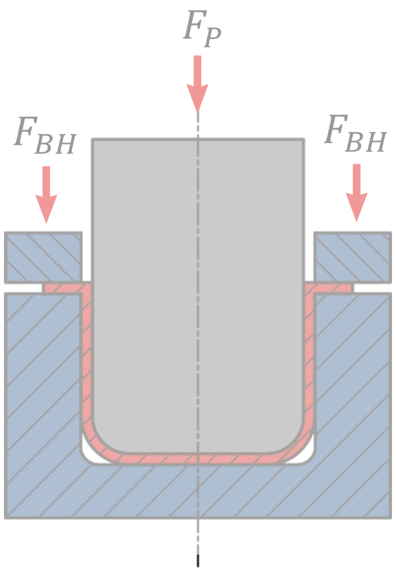
Electromagnetic Radius Calibration

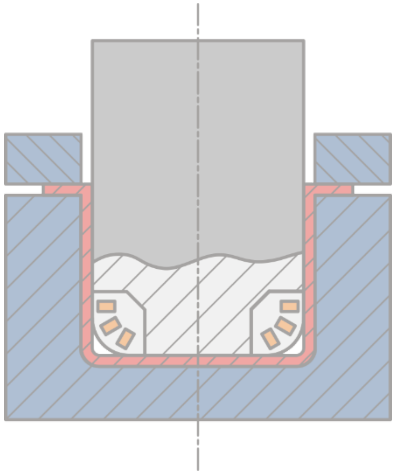
Process sequence



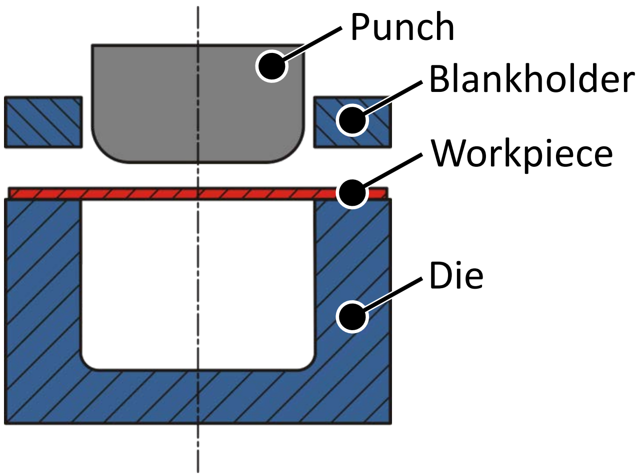
1. Deep drawing



2. EM Calibration



Process sequence



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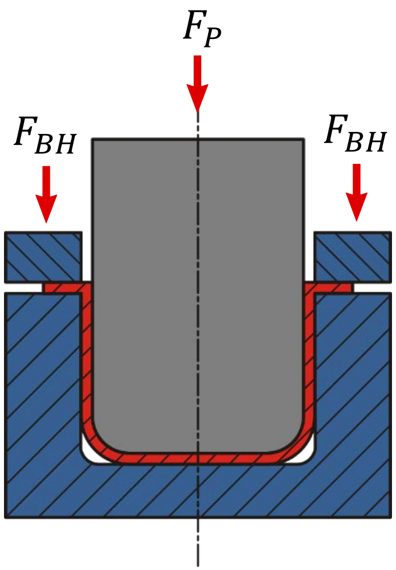

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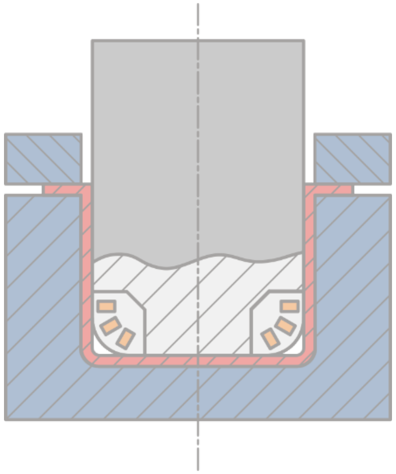

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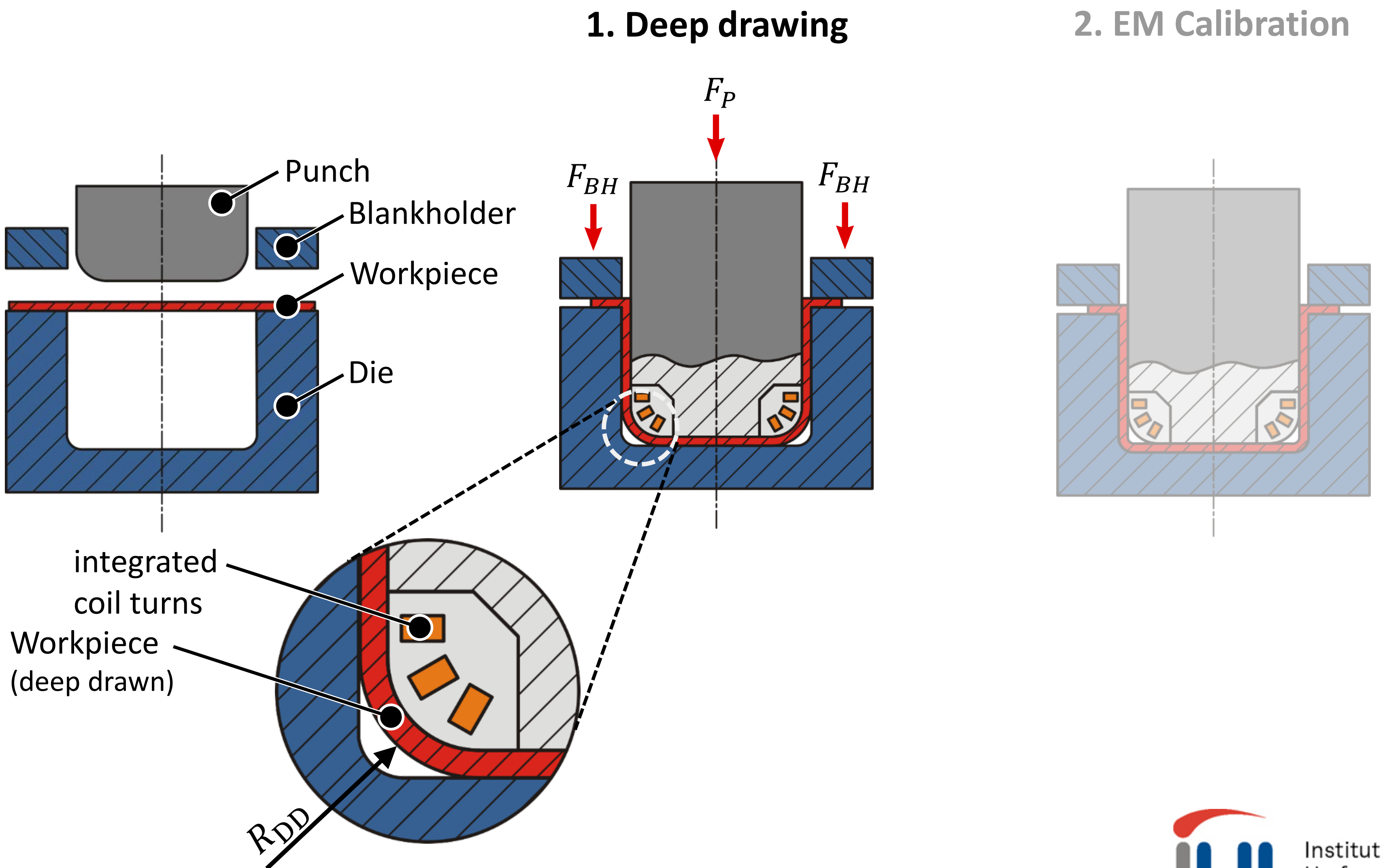
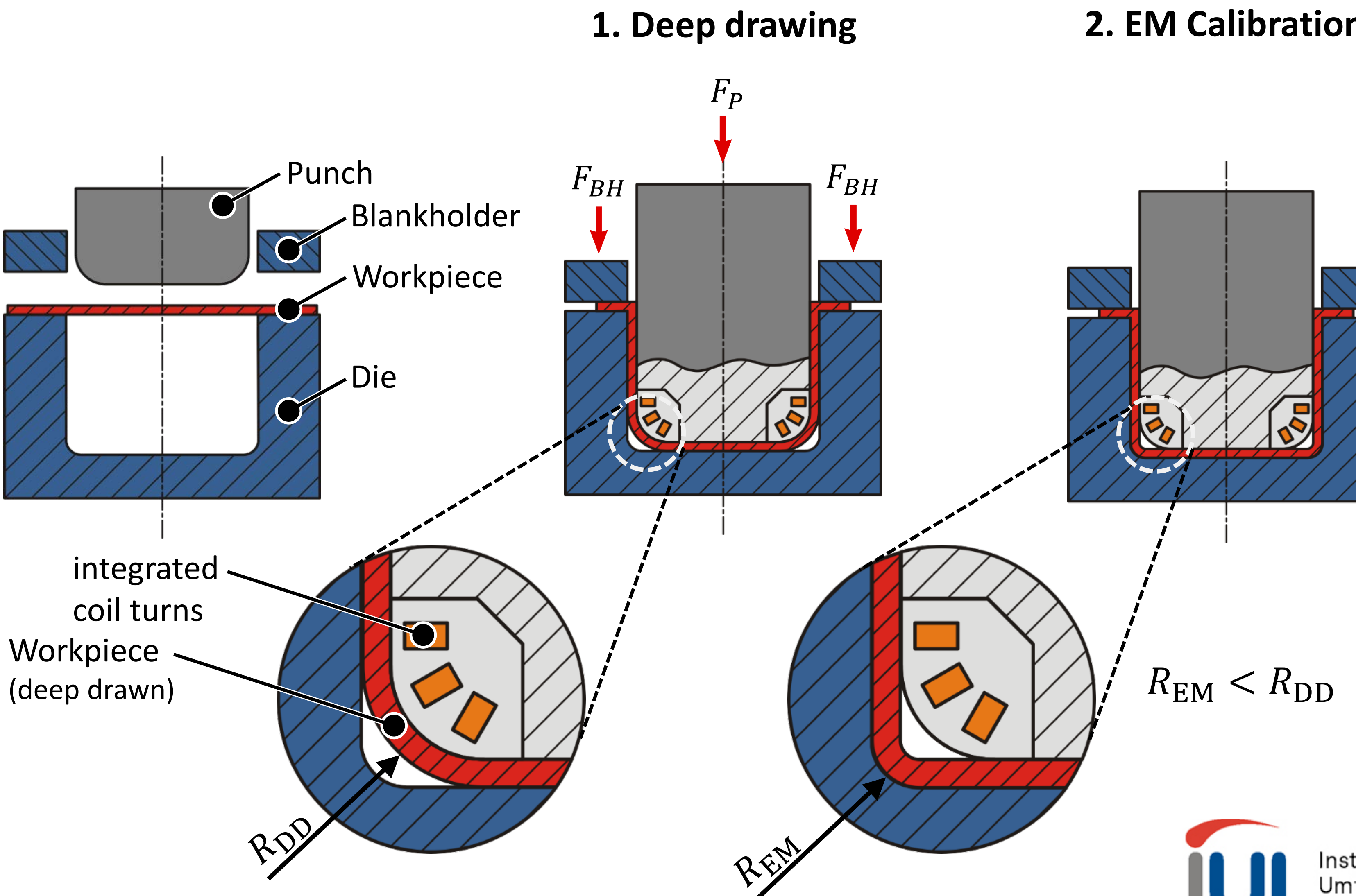
Process sequence



Electromagnetic Radius Calibration

Process sequence



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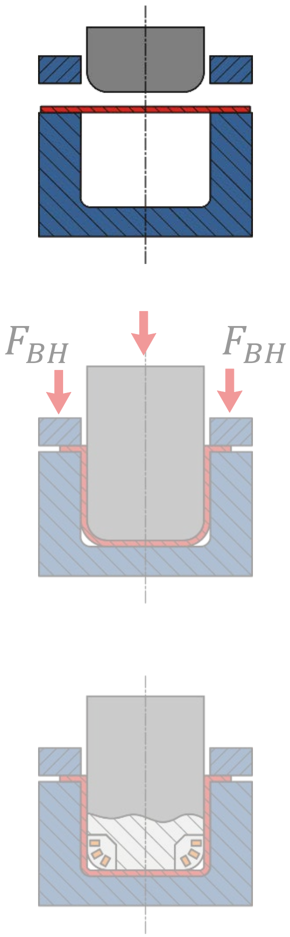
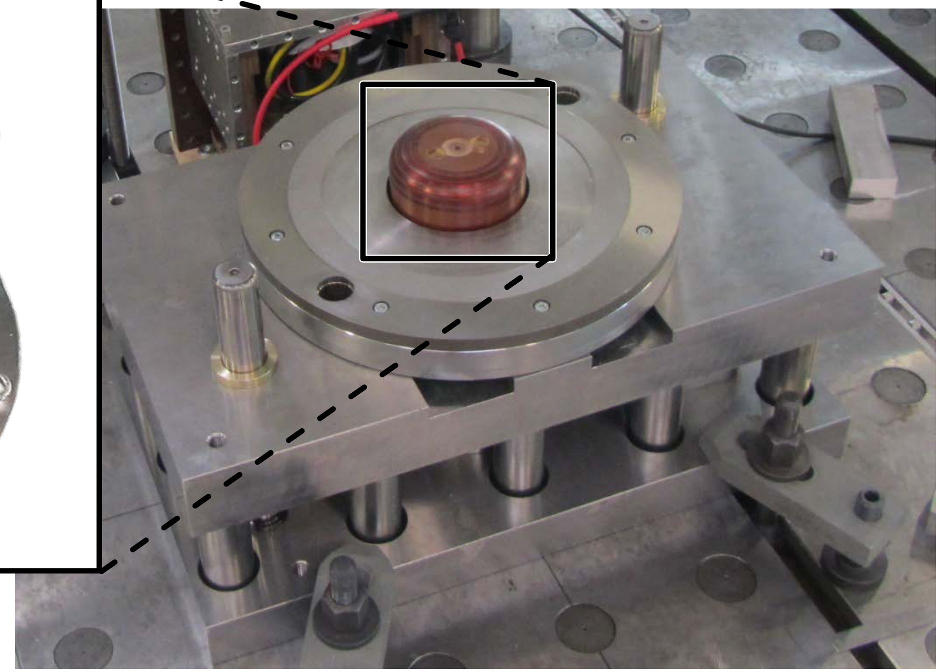
Electromagnetic Radius Calibration

Setup and Procedure





Punch with integrated coil turns

Deep drawing:	
Punch diameter:	130 mm
Punch edge radius:	20 mm
Die radius:	10 mm

Workpiece:	
Material	EN AW-5083
Geometry	t=1 / Ø260 mm
Yield stress	150 MPa

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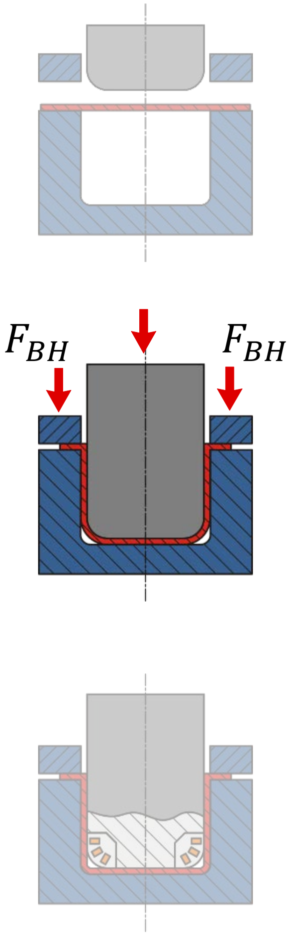
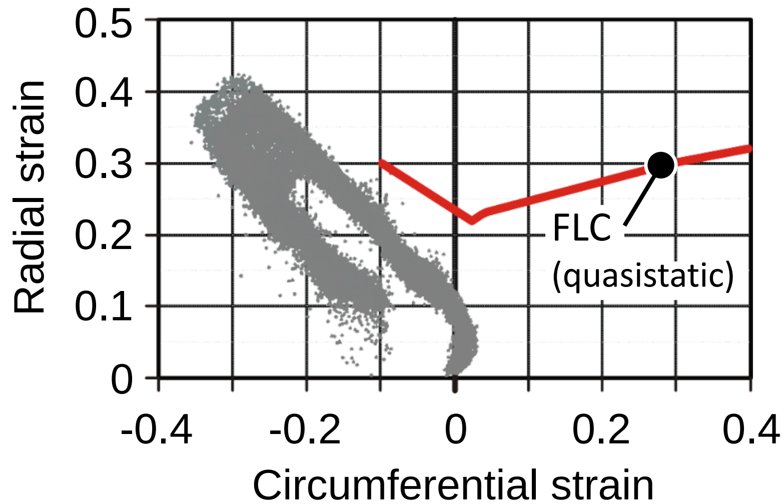
Electromagnetic Radius Calibration

Results: After deep drawing

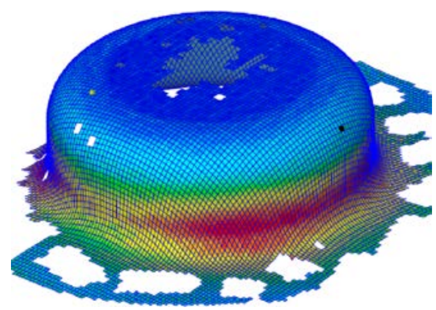




Punch/Sheet:
no lubrication

Flange/Sheet:
excessive lubrication

Blankholder force:
F_{BH} = 740 kN



Strain distribution after deep-drawing

R_{DD}=21 mm

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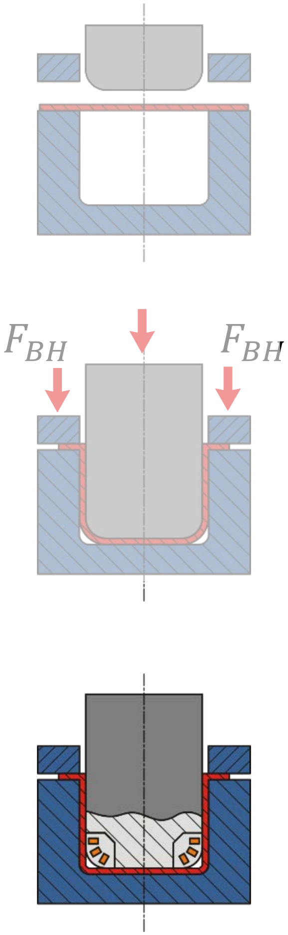
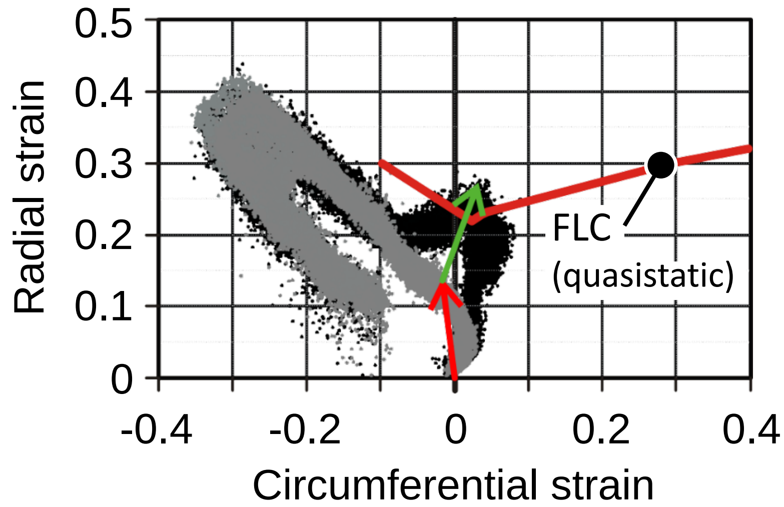
Electromagnetic Radius Calibration

Results: After EM-Calibration





Punch/Sheet:
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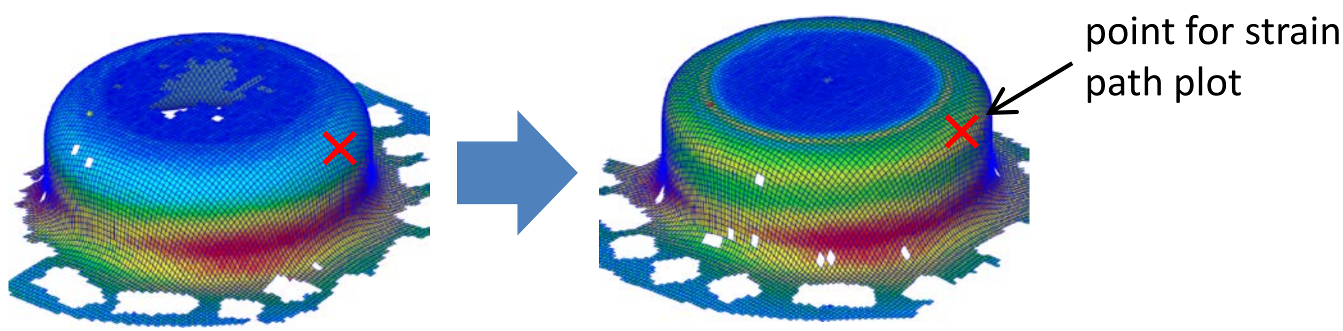
Blankholder force:
F_{BH} = 740 kN



Strain distribution after deep-drawing

R_{DD}=21 mm

Strain distribution after EM-Calibration

R_{EM}=13 mm

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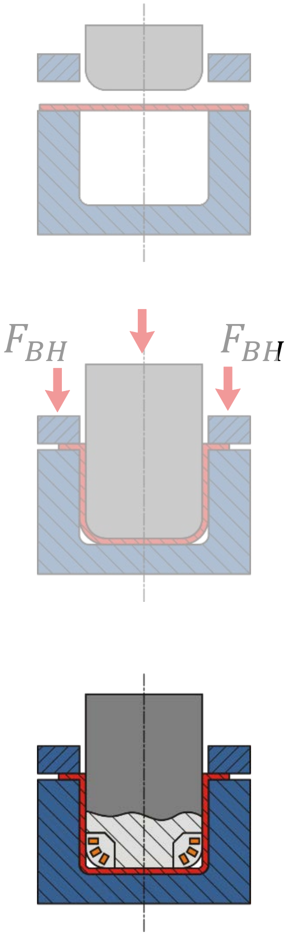
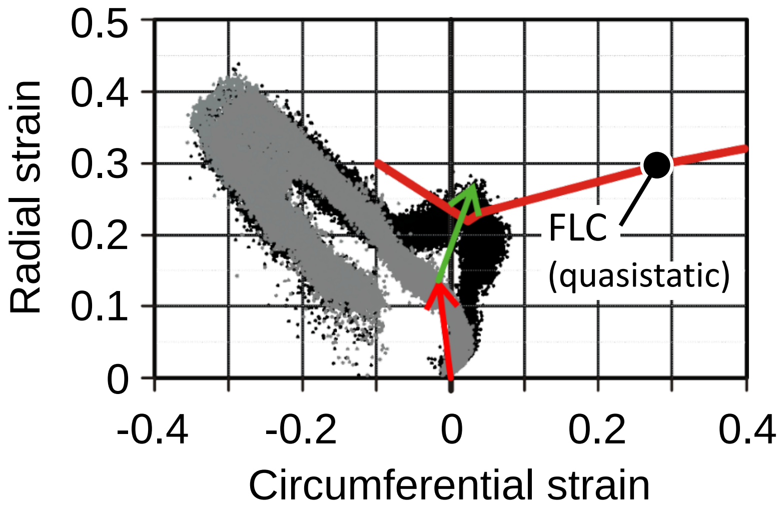
Electromagnetic Radius Calibration

Results: After EM-Calibration





Punch/Sheet:
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Flange/Sheet:
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Blankholder force:
F_{BH} = 740 kN

Requirements for increased forming limit:

- Strain rate change?
- Strain path change?
- Amount of prestraining?

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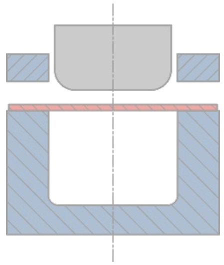
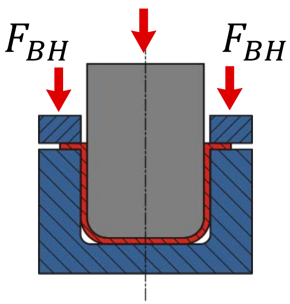
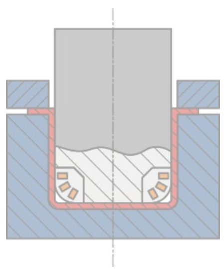
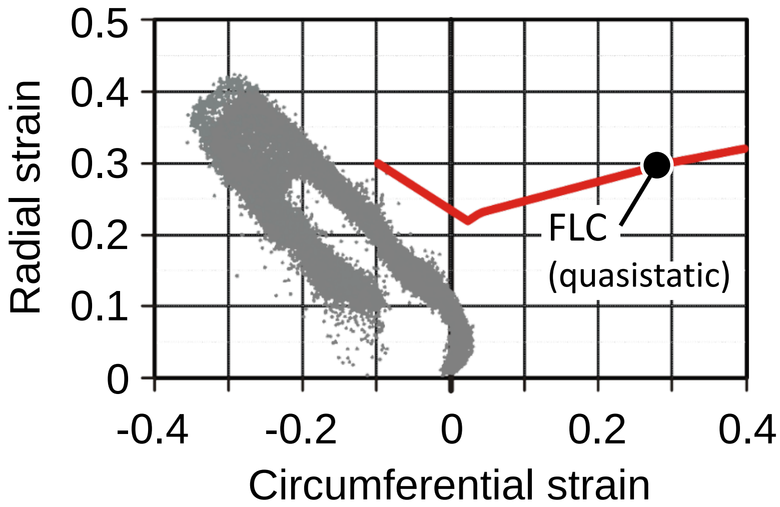
Electromagnetic Radius Calibration

Results: After deep drawing









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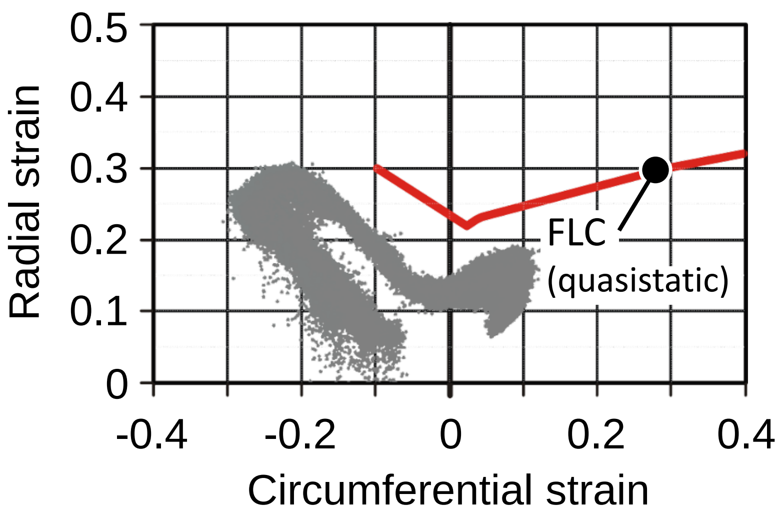

Punch/Sheet:
excessive lubrication

Flange/Sheet:
no lubrication

Blankholder force:
F_{BH} = 520 kN

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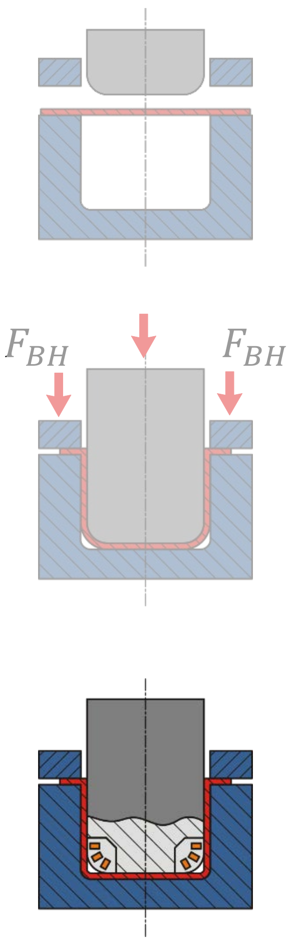
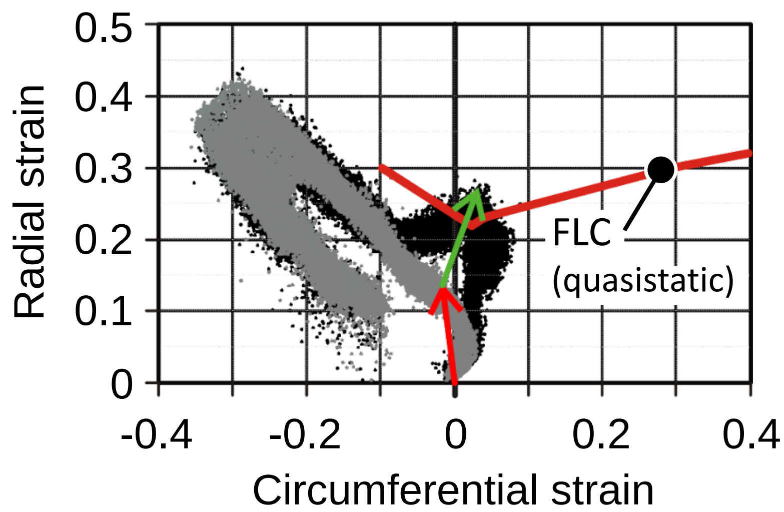
Electromagnetic Radius Calibration

Results: After EM-Calibration





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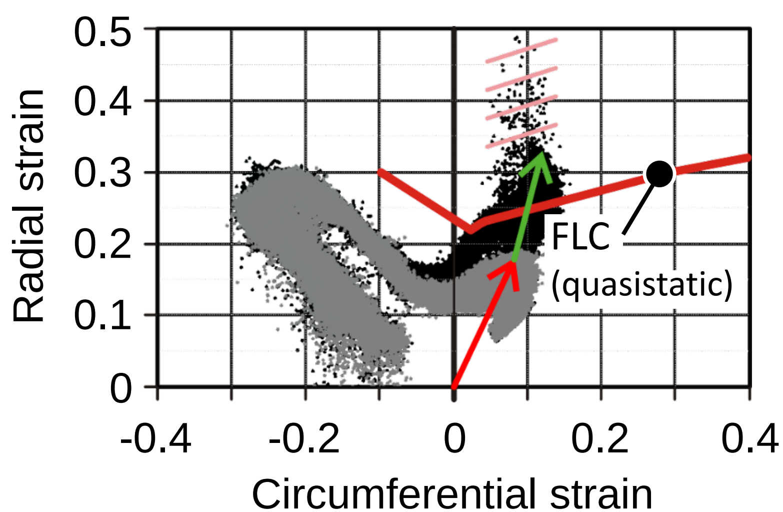

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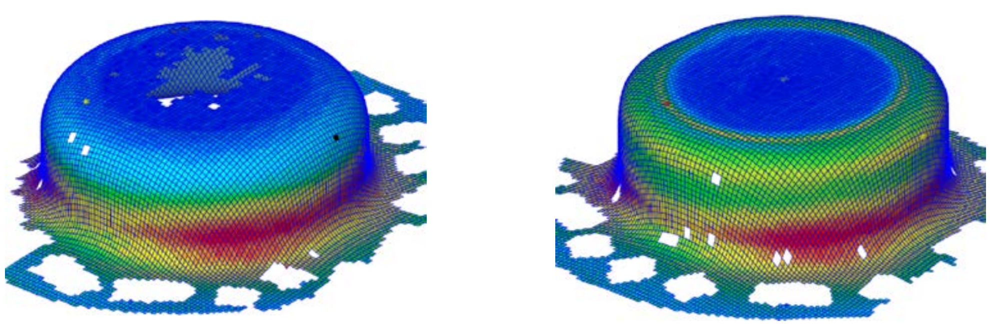
Summary

Electromagnetic Radius Calibration

- Increased forming limit
- Decreased cup radius ($R_{\mathrm{DD}} = 21\mathrm{mm} \rightarrow R_{\mathrm{EM}} = 13\mathrm{mm}$)
- Mainly caused by strain-rate change
- No strain-path change required
- No remaining quasi-static forming limit required

Workpiece after deep-drawing

Workpiece after EM-Calibration



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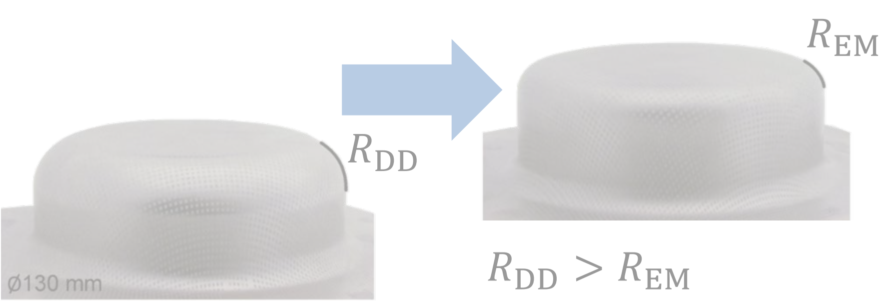
Bottom tear at a cylindrical cup

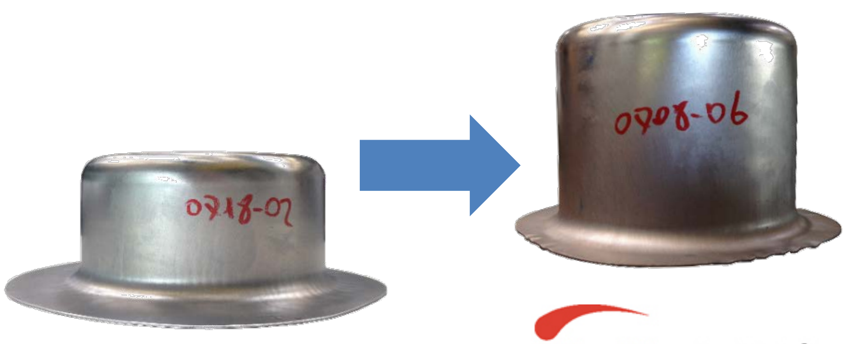
Electromagnetic Radius Calibration

→ Decreasing min. edge radius



Electromagnetic Forming in the Flange

→ Increasing $\beta_{\max}$ and $h_{\max}$



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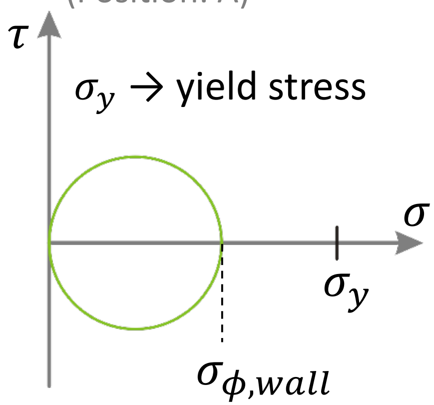
Electromagnetic Forming in the Flange

Process analysis: Failure mechanism

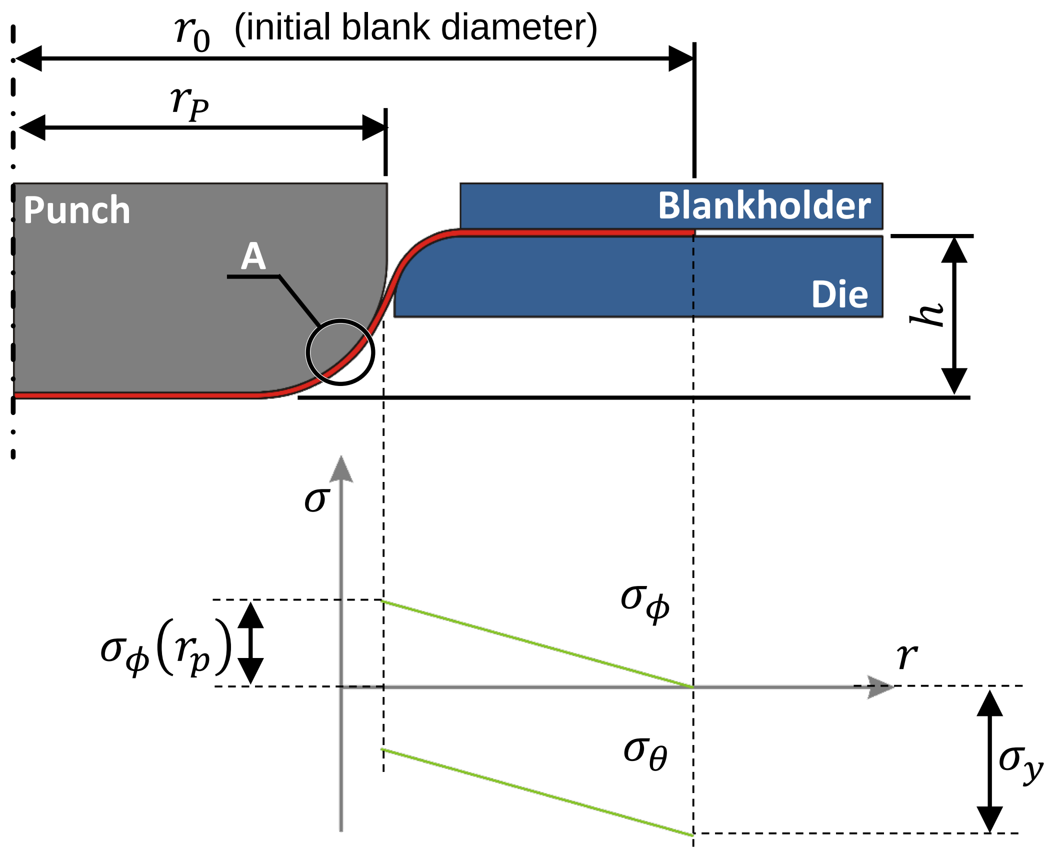


$$\sigma_\phi(r_p) = \sigma_{\phi,wall}$$

$$\sigma_\phi(r_p) = \sigma_y \cdot ln(\beta)$$

$$\beta = {}^{r_0}/_{r_P}$$

(no friction, no work hardening)



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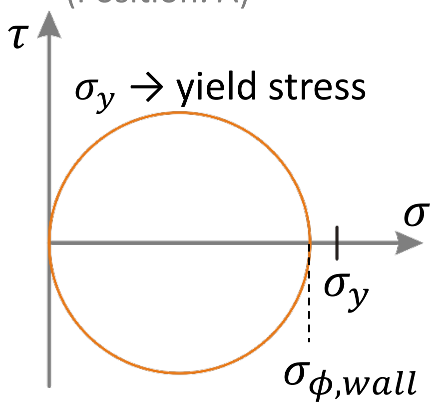
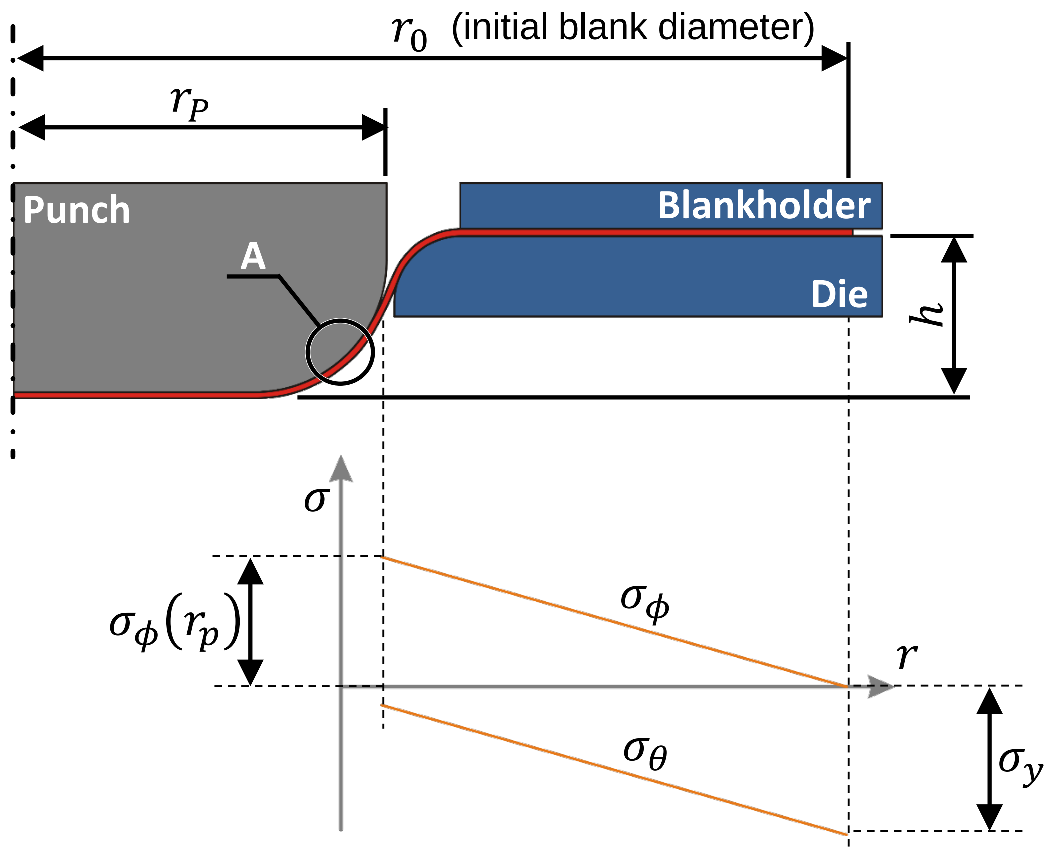
Process analysis: Failure mechanism

Stress state cup wall
(Position: A)





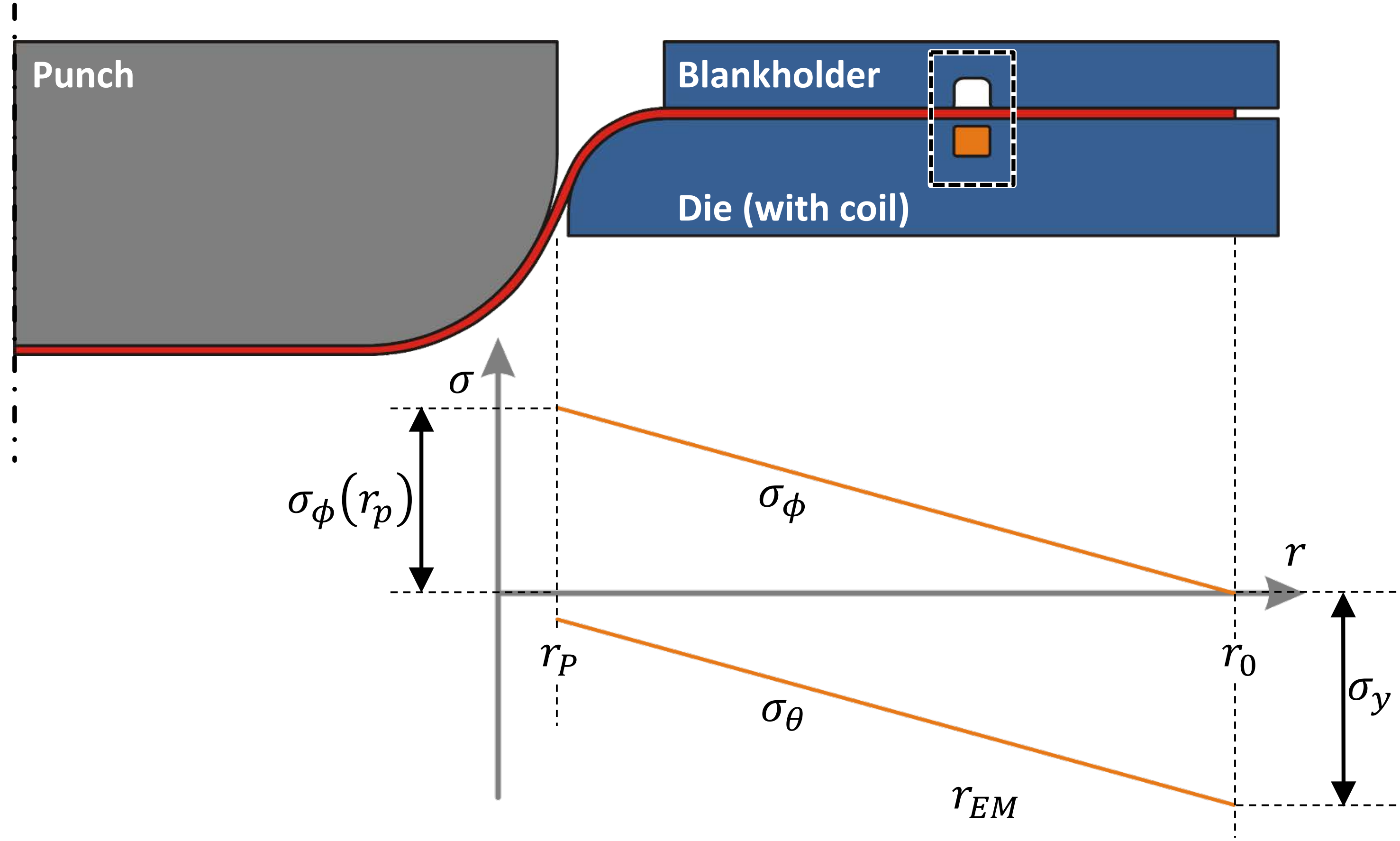
$\beta > \beta_{max}$

$\sigma_{\phi,wall} = \sigma_y$

Bottom tearing

Process analysis: Reduction of meridional stresses

EM bulge forming in the flange[*1]

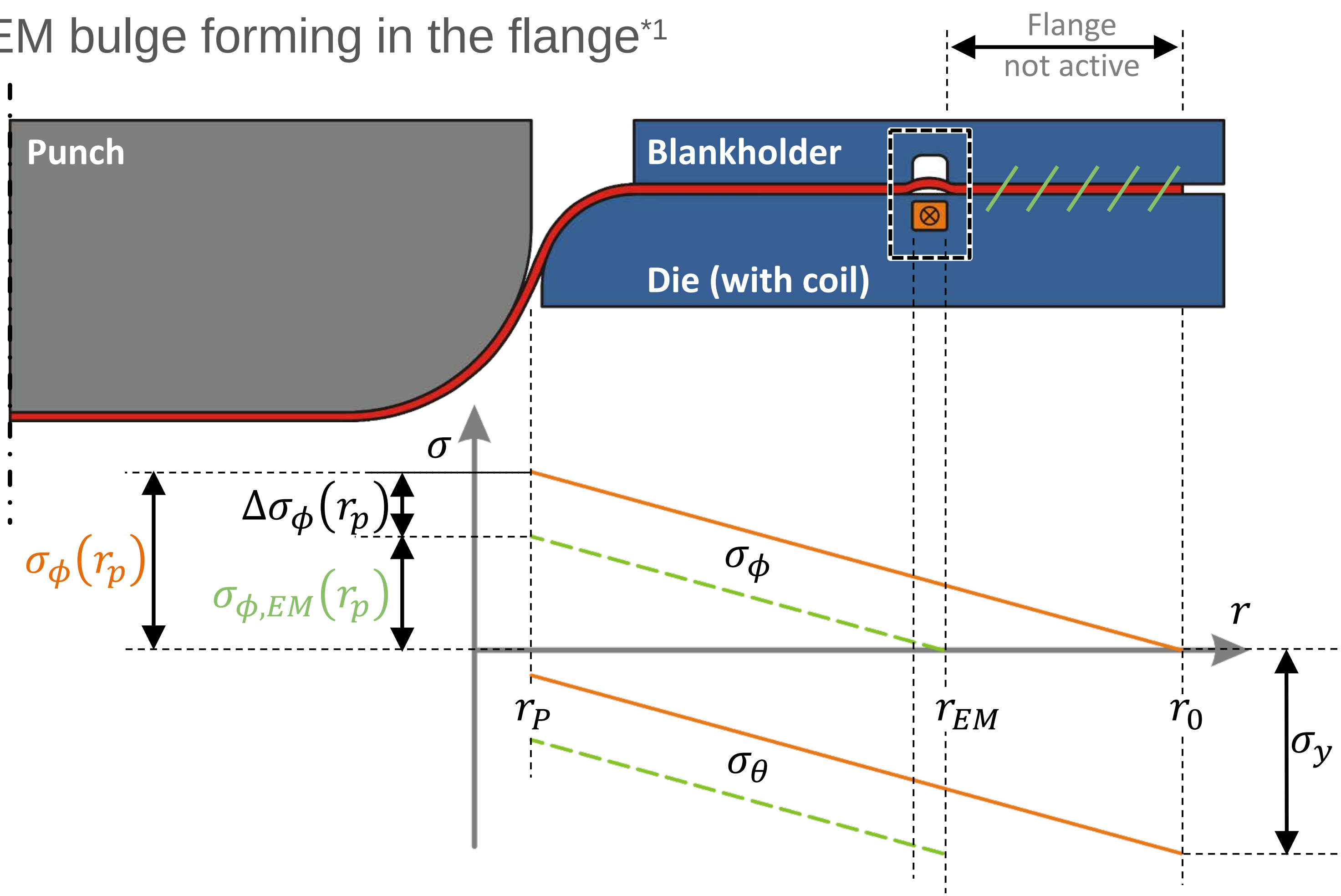


*1 *Shang, J.: Electromagnetically Assisted Sheet Metal Stamping, 2006*

Electromagnetic Forming in the Flange

Process analysis: Reduction of meridional stresses

EM bulge forming in the flange[*1]



*[*1] Shang, J.: Electromagnetically Assisted Sheet Metal Stamping, 2006*

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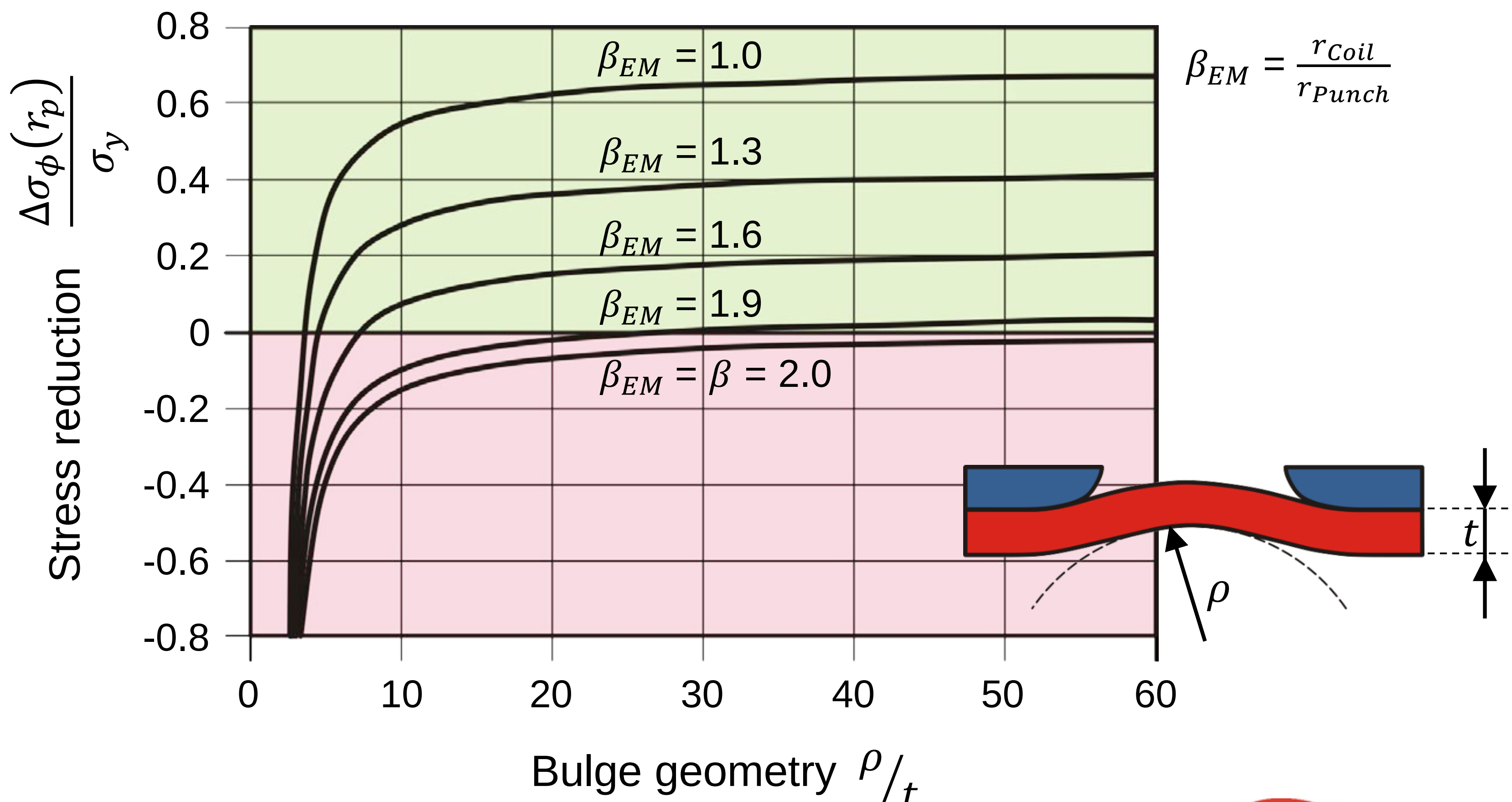
Electromagnetic Forming in the Flange

Process analysis: Reduction of meridional stresses

Derivation of coil position



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Electromagnetic Forming in the Flange

Process analysis: Reduction of meridional stresses

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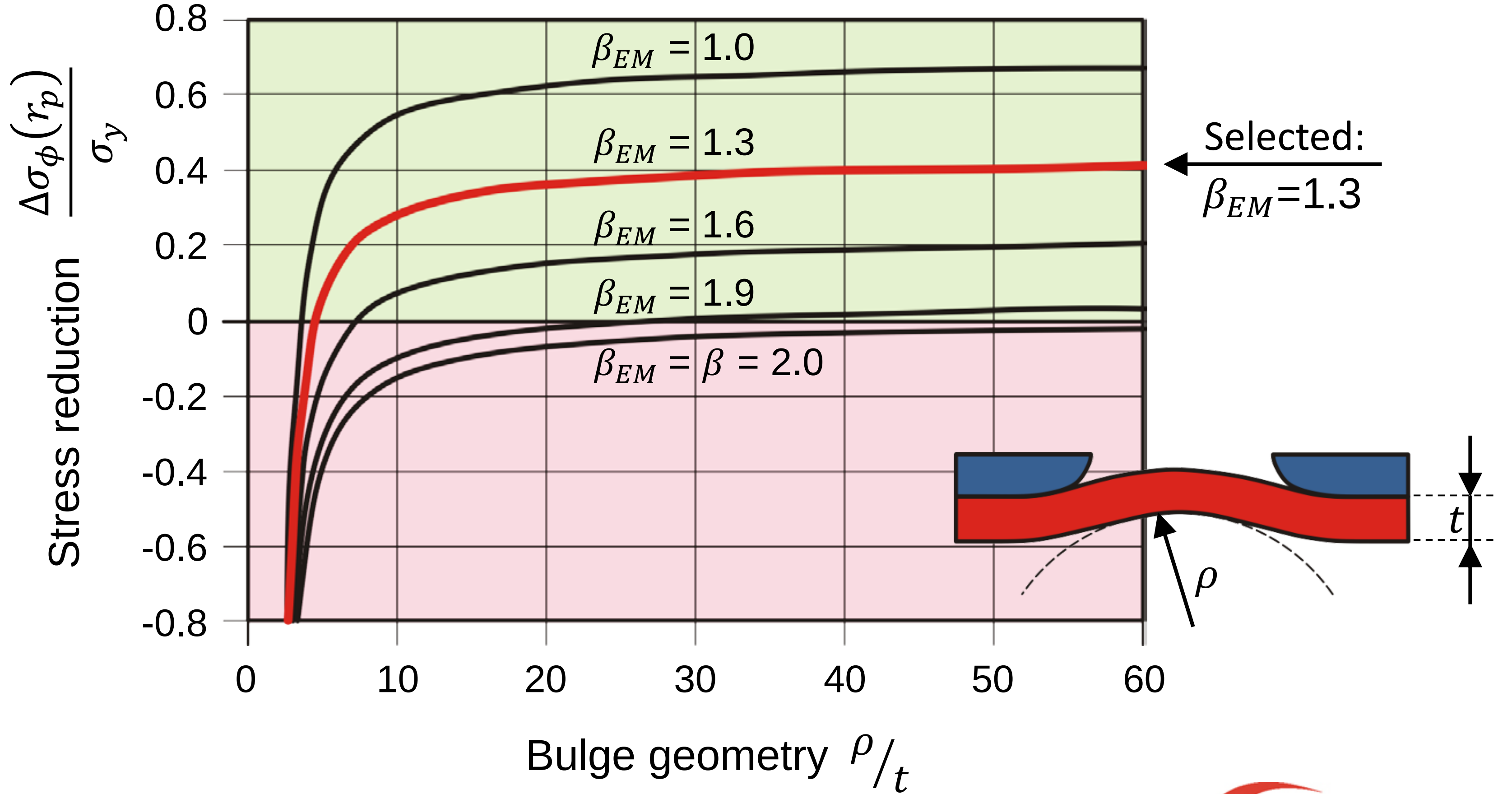

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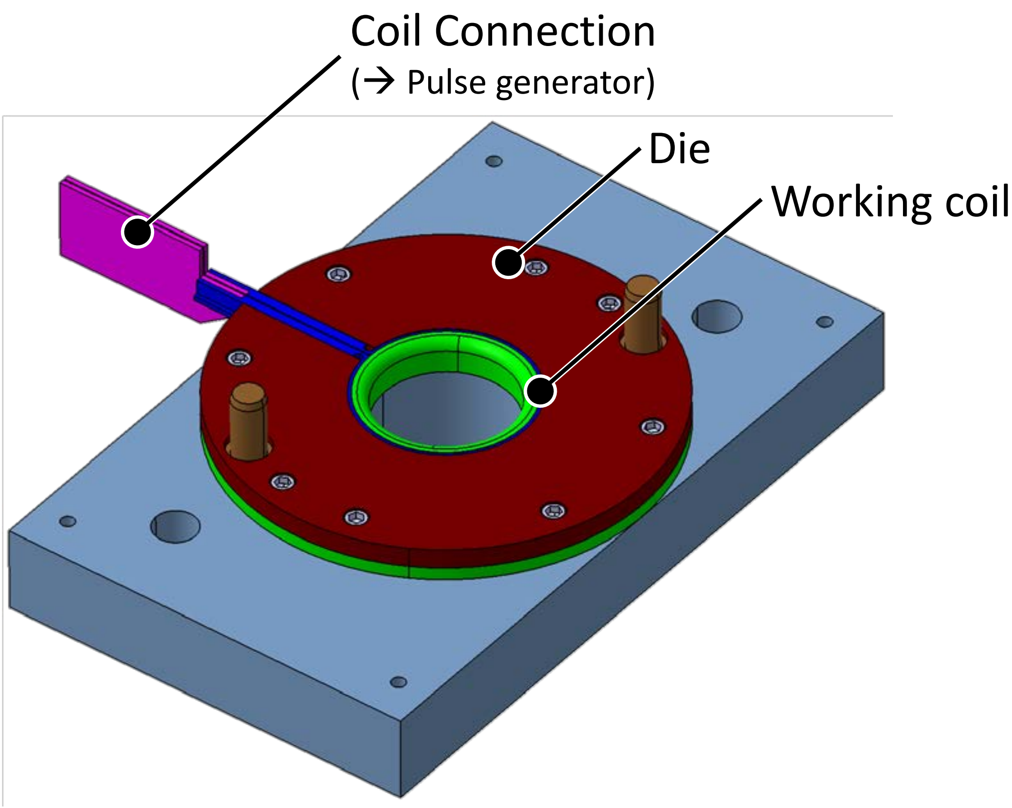
Electromagnetic Forming in the Flange

Setup and Procedure



Deep drawing

Punch diameter:	130 mm
Punch radius:	20 mm
Die radius:	10 mm

Electromagnetic forming

Coil diameter:	162 mm (inner)
Coil turn width:	3.35 mm
Pulse generator:	Maxwell 7000
	$R_{\mathrm{i}} =$ 3.3 mΩ
	$L_{\mathrm{i}} =$ 50 nH
	$C =$ 992 μF

Workpiece:

Material	EN AW-5083
Sheet thickness	1mm
Yield stress	150 MPa

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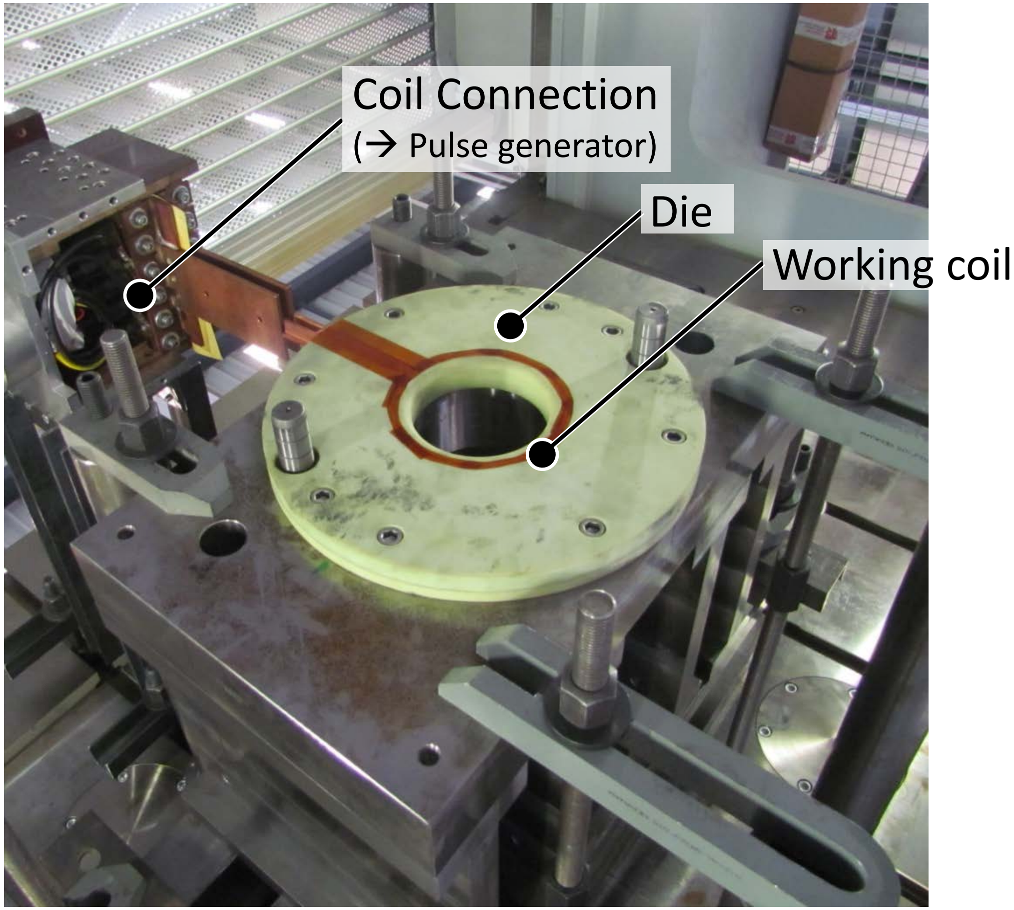
Electromagnetic Forming in the Flange

Setup and Procedure



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Electromagnetic Forming in the Flange

Results: Overview

1. **Limit of conventional deep drawing → β_{max} = 2.0**

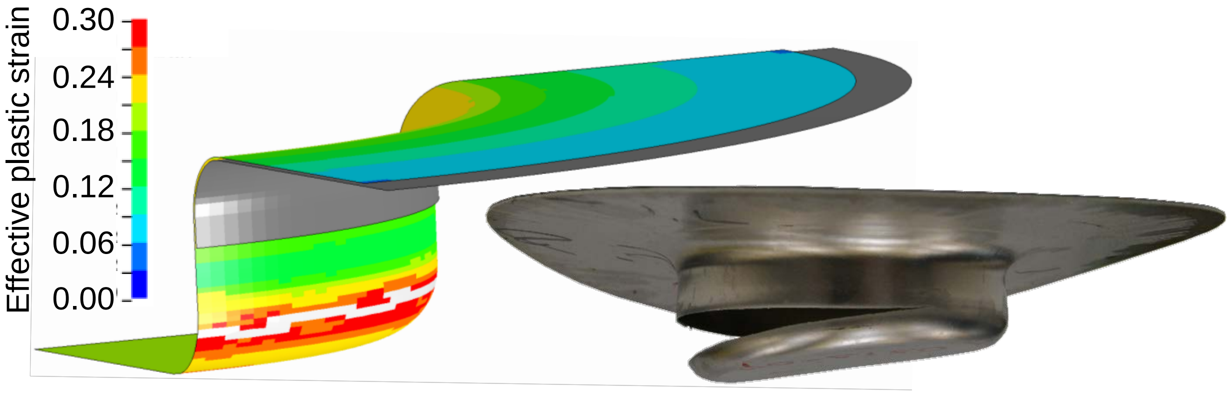

Figure: *Material failure in simulation and experiment (β=2.1)*

Results: Overview

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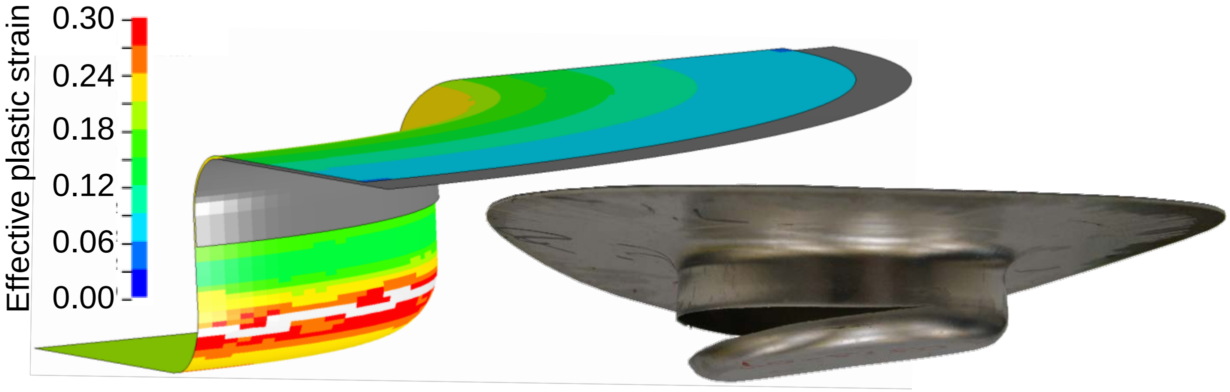
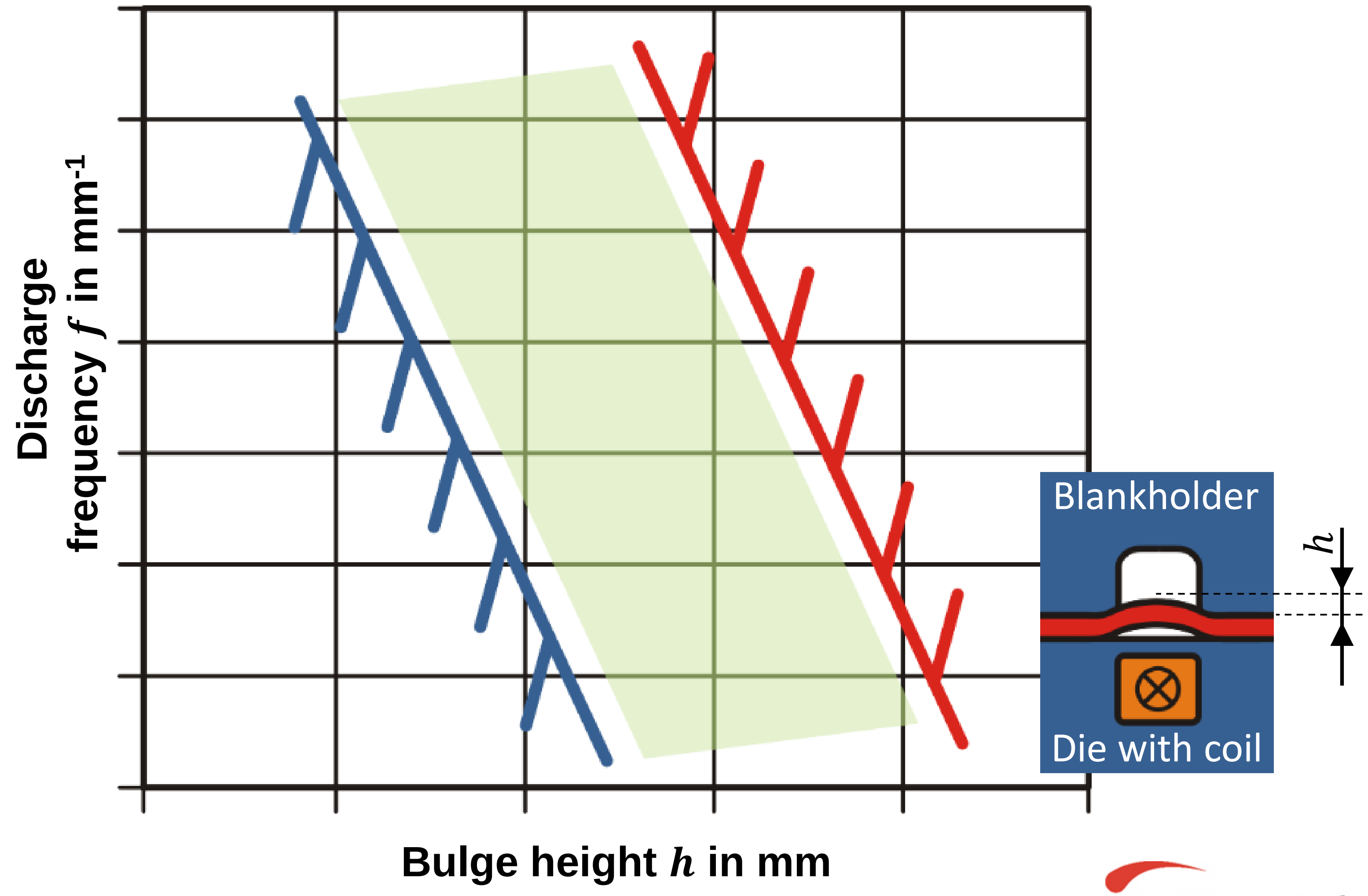


Figure: *Material failure in simulation and experiment (β=2.1)*

2. **Process window for EM-assisted deep drawing**

Electromagnetic Forming in the Flange

Results: Determination of process window



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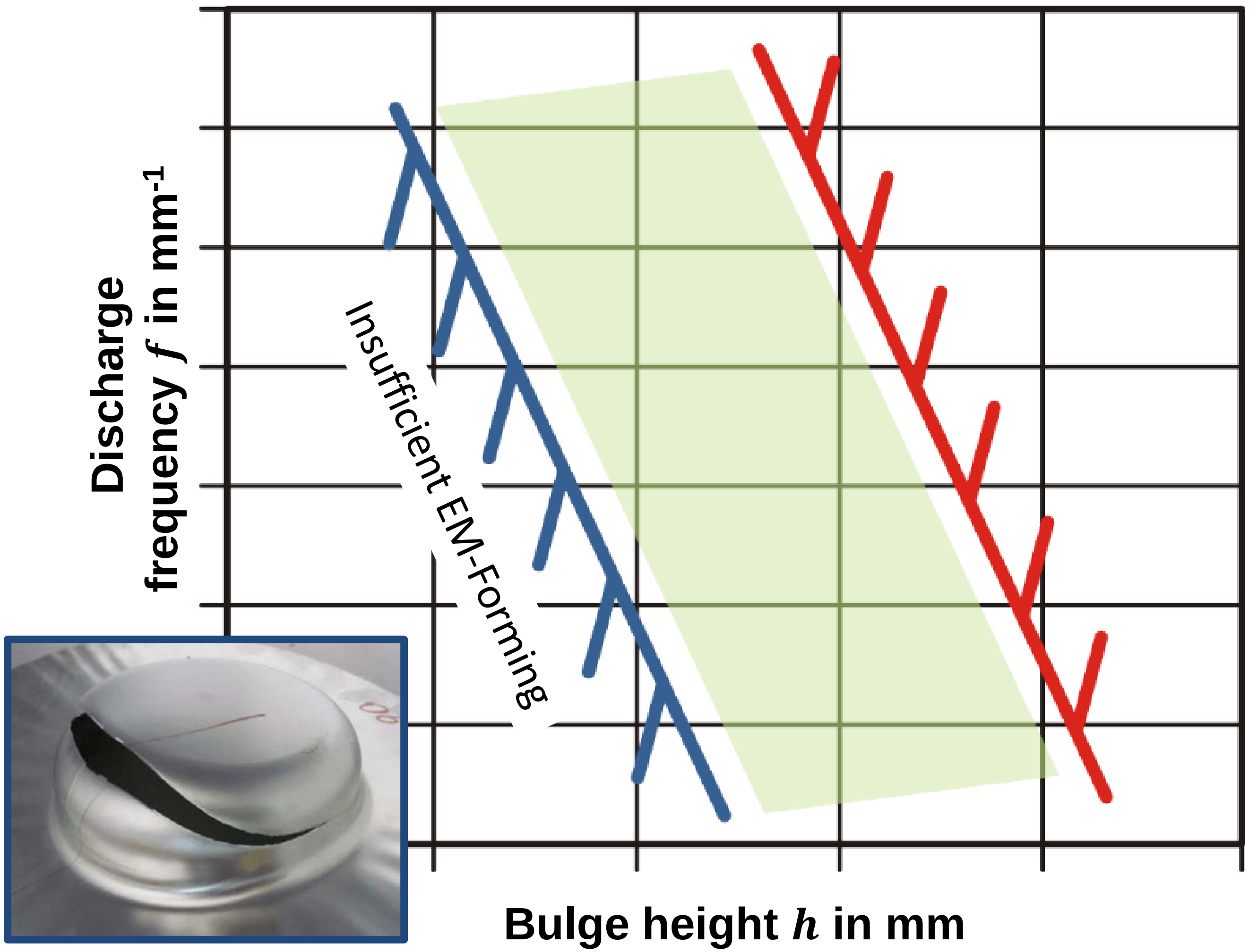
Electromagnetic Forming in the Flange

Results: Determination of process window



Bottom tearing

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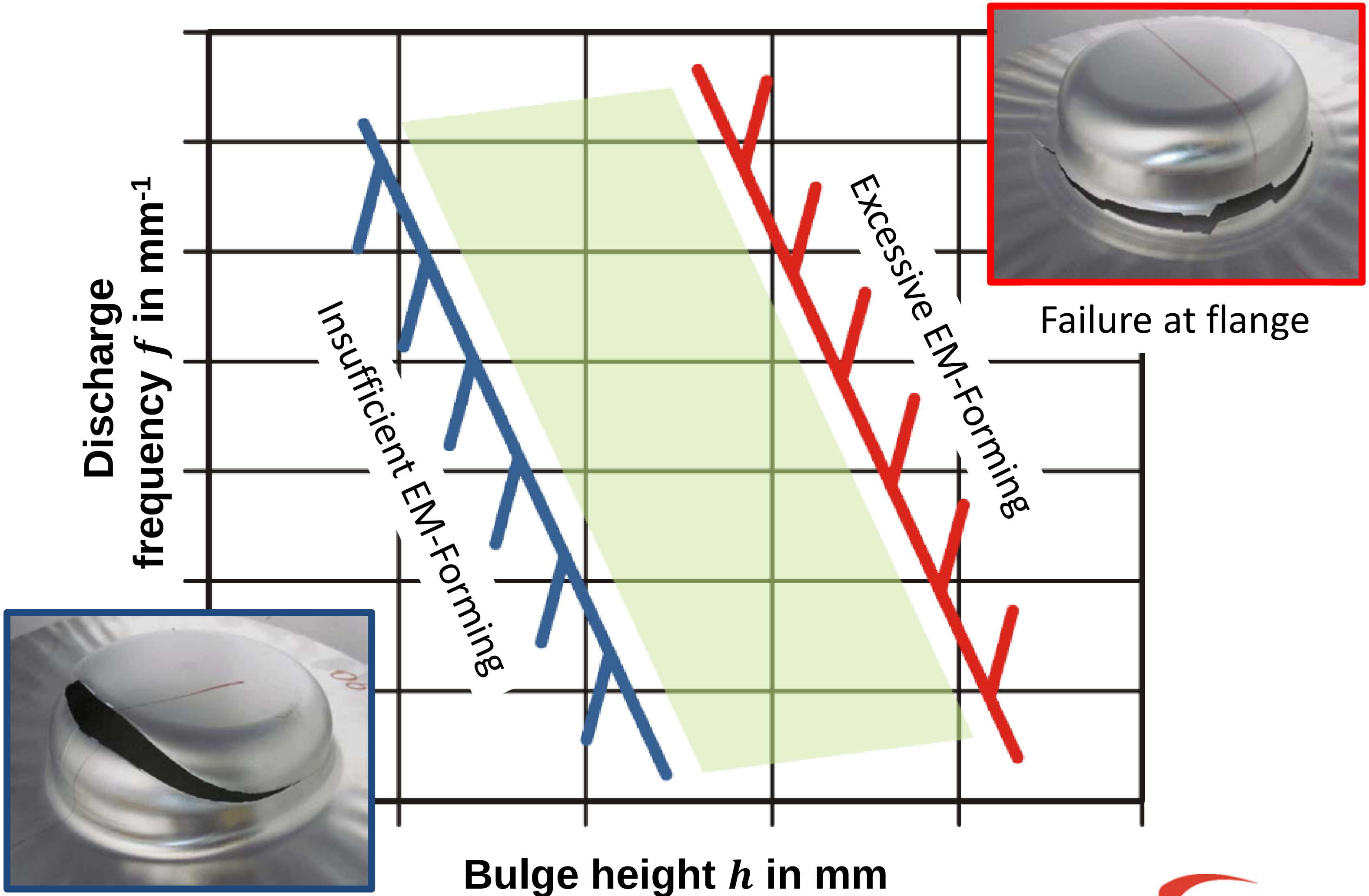
Results: Determination of process window

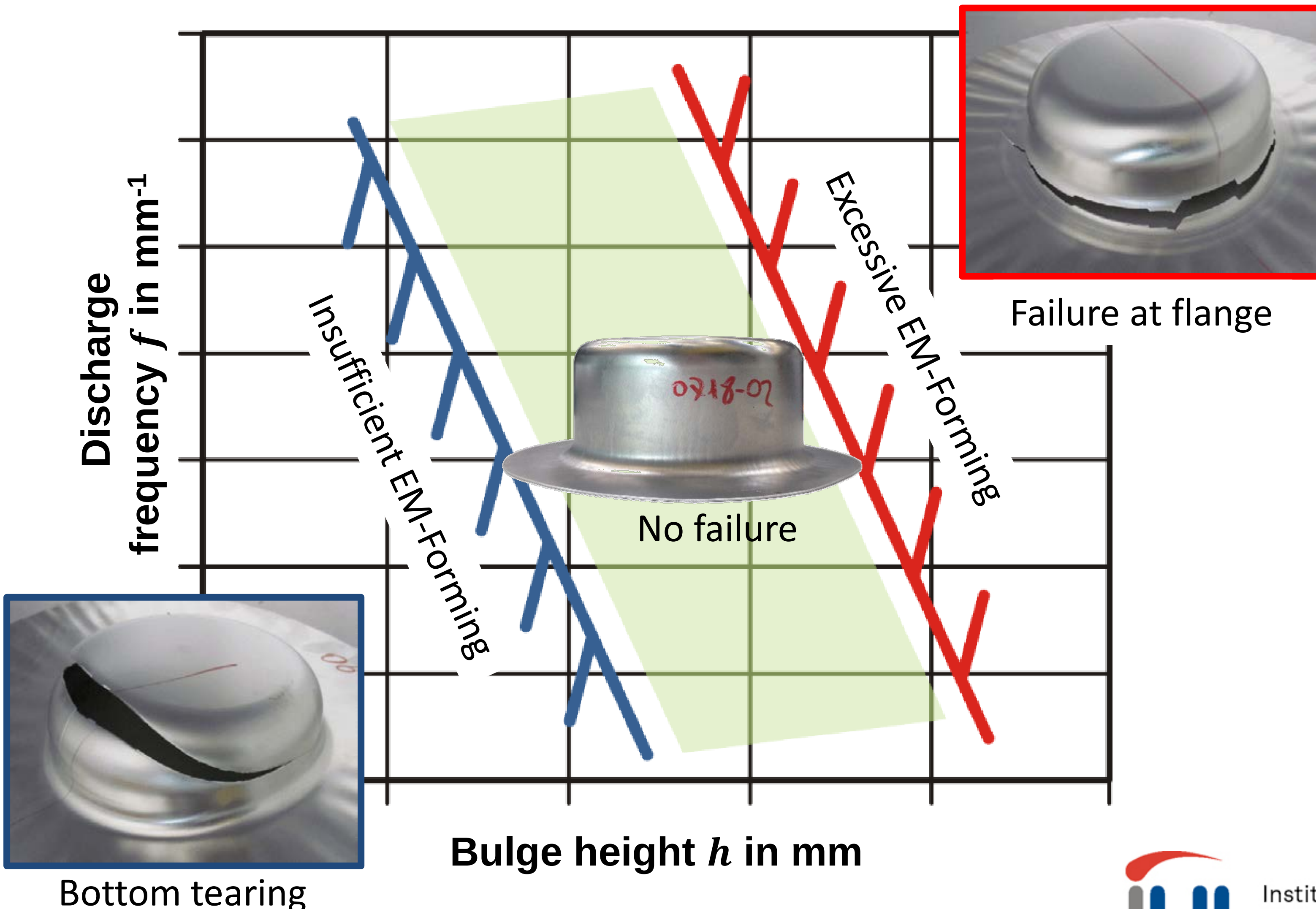


Failure at flange

Bottom tearing

Electromagnetic Forming in the Flange

Results: Determination of process window



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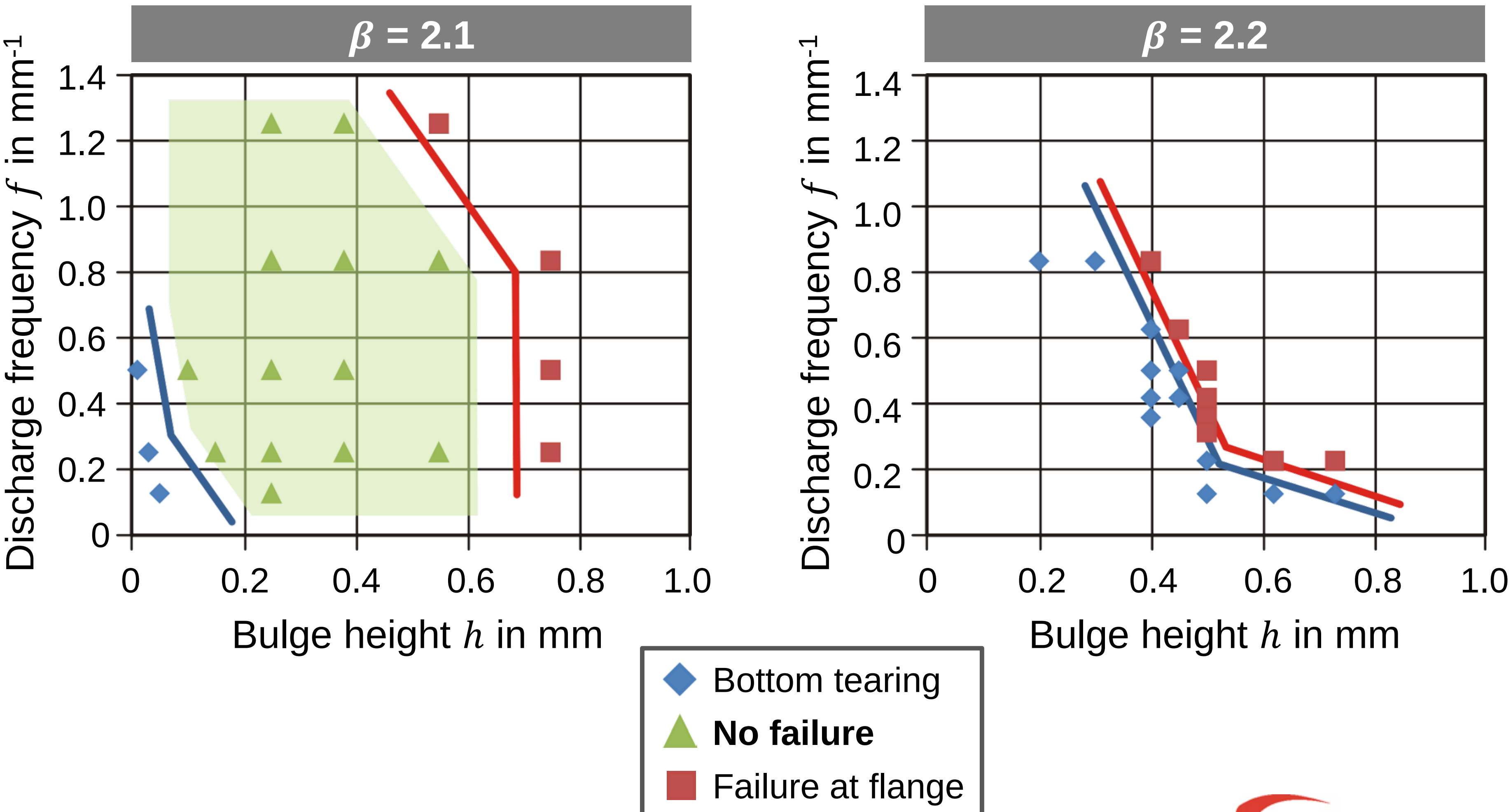
Electromagnetic Forming in the Flange

Results: Determination of process window



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Electromagnetic Forming in the Flange

Results: Overview

1. **Limit of conventional deep drawing → β_{max} = 2.0**

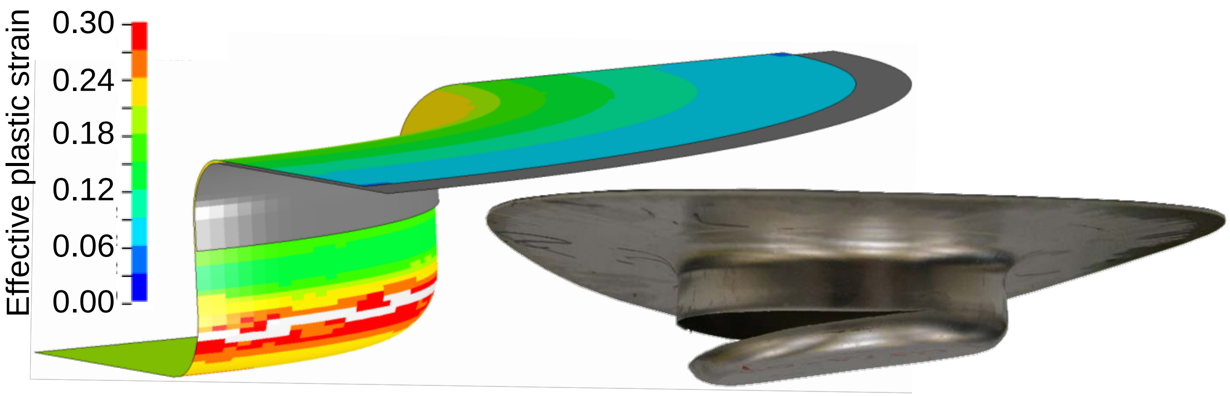

Figure: *Material failure in simulation and experiment (β=2.1)*

2. **Process window for EM-assisted deep drawing → $\beta_{\mathrm{max,EM}}$ = 2.1**

3. **Increase of the drawing depth h_{max}**

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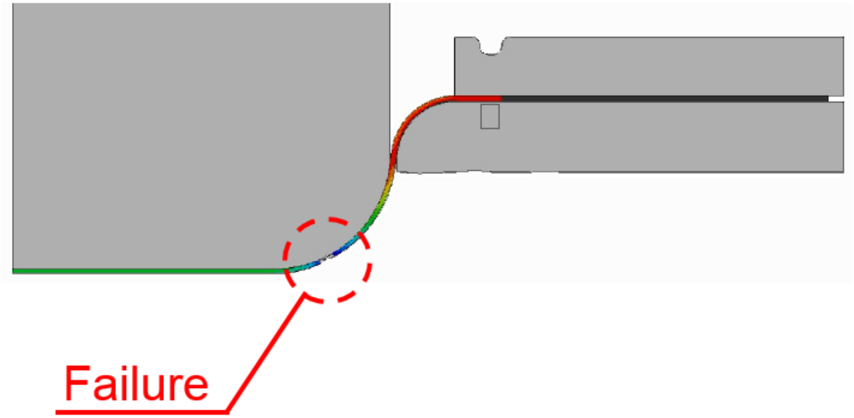
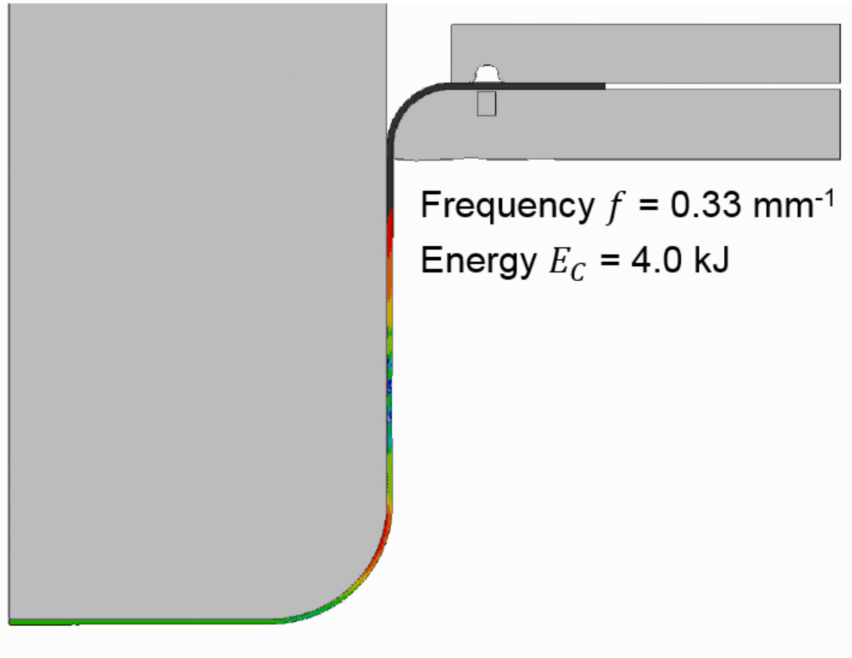
Electromagnetic Forming in the Flange

Results: Increase of the maximum drawing depth $h_{\max}$

Conventional deep drawing (β=2.1)



EM-assisted deep drawing (β=2.1)



$h_{\max}$ = 33 mm ⟵ β^*= 2.2 ⟶ $h_{\max,\mathrm{EM}}$ = 57 mm **(+73%)**

$h_{\max}$ = 36 mm ⟵ β^*= 2.5 ⟶ $h_{\max,\mathrm{EM}}$ = 41 mm **(+14%)**

(* → drawing process not completed)

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Summary

Electromagnetic Radius Calibration

- Increased forming limit
- Decreased cup radius ($R_{\mathrm{DD}} = 21\mathrm{mm} \rightarrow R_{\mathrm{EM}} = 13\mathrm{mm}$)
- Mainly caused by strain-rate change
- No strain-path change required
- No remaining quasi-static forming limit required

Electromagnetic Forming in the Flange

- Process analysis: Effect of coil position
- Process window: Discharge frequency f vs. Bulge height h
- Increased drawing ratio ($\beta_{\mathrm{max}} = 2.0 \rightarrow \beta_{\mathrm{max,EM}} = 2.1$)
- Increased forming depth (up to 73%)

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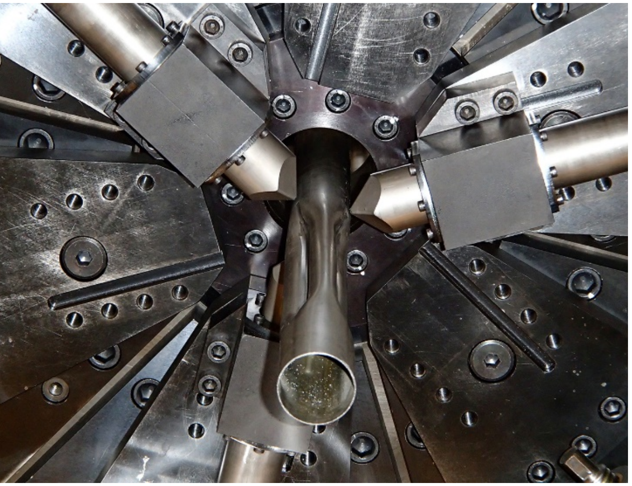

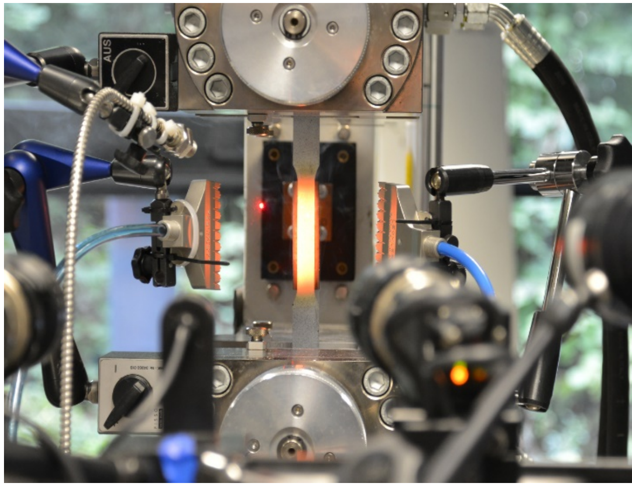

Thank you for your attention.

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