Numerical Identification of Optimum Process Parameters for Combined Deep Drawing and Electromagnetic Forming

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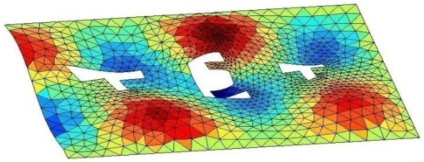
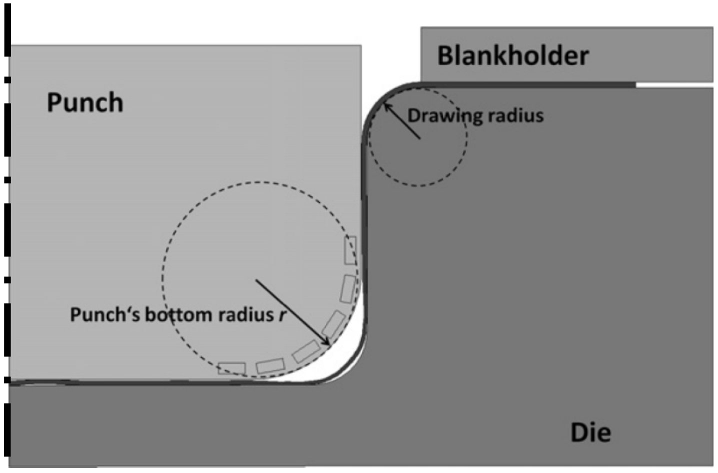
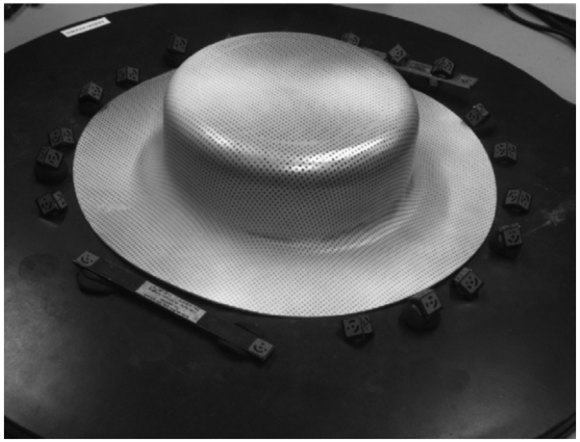


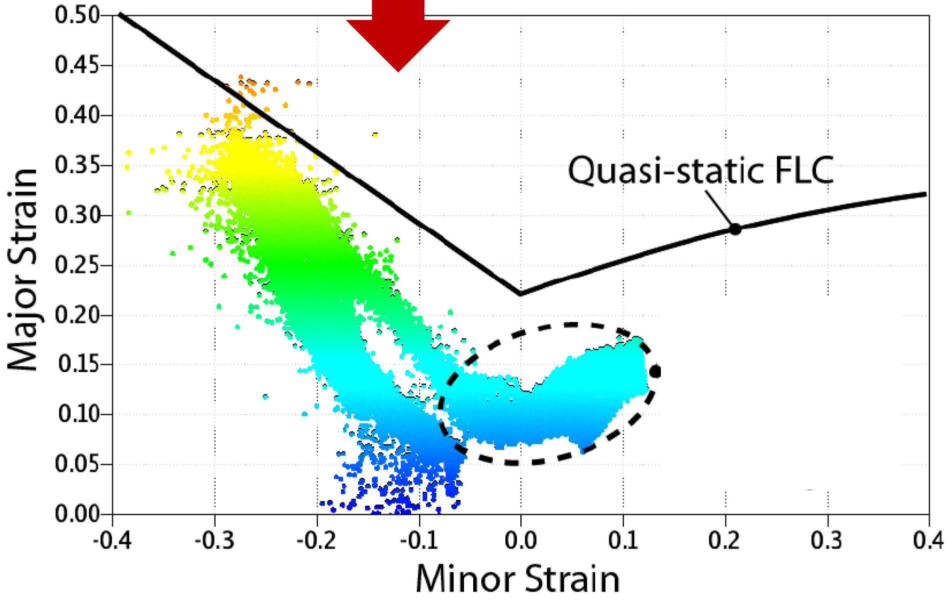
Forming limits of quasi-static processes



Deep drawing (axisymmetric)



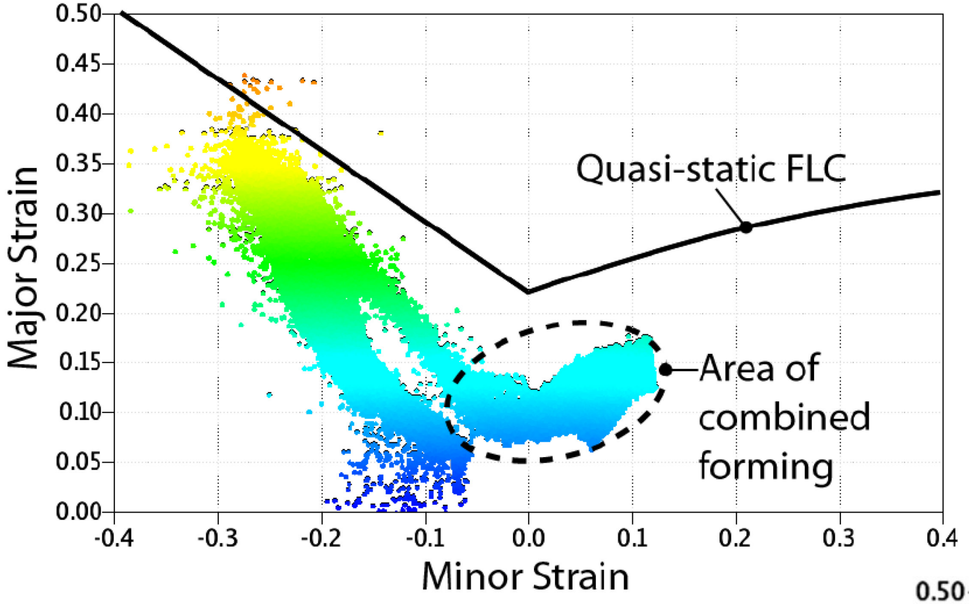
Grid of marked points on the work piece (IUL)



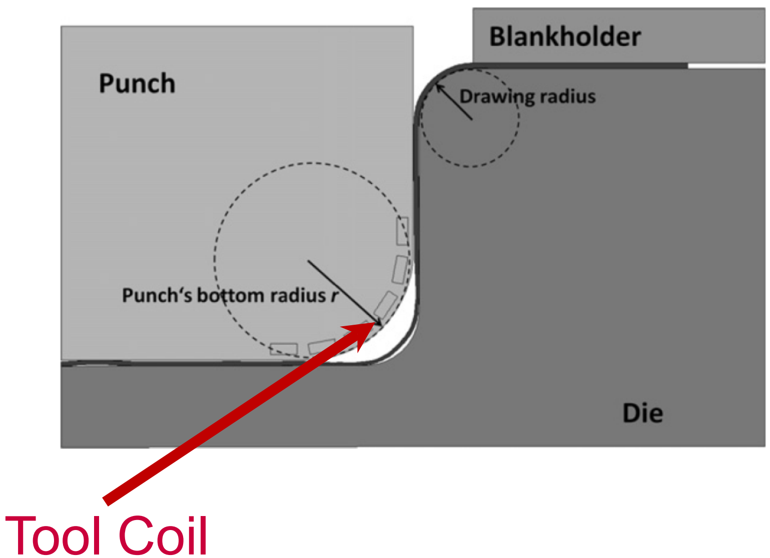
Larger principal value of the Hencky strain in the sheet plane (major strain) versus smaller (minor strain), obtained with the ARGUS-system (GOM) at the IUL, Dortmund

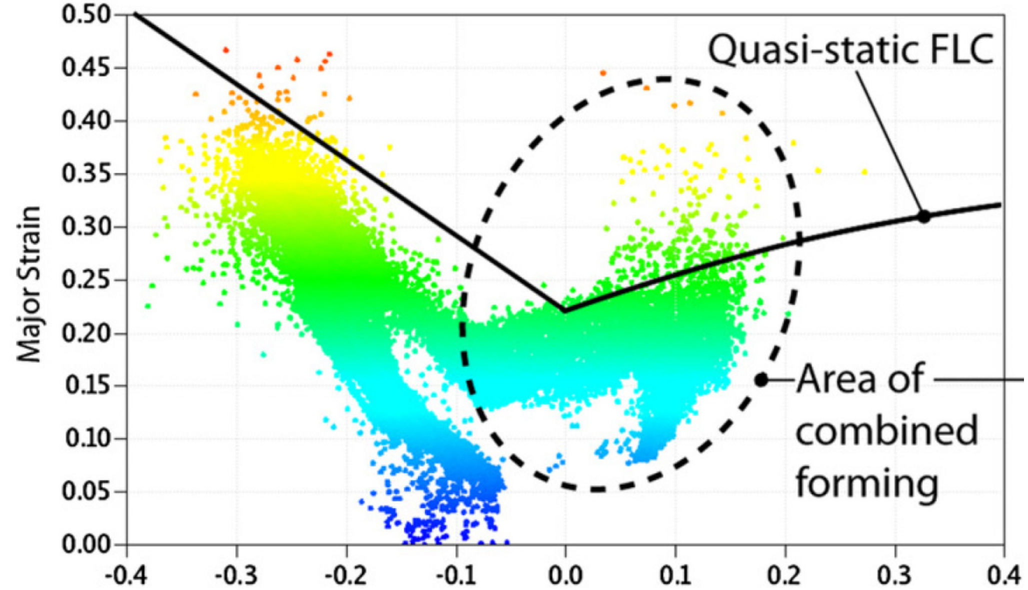
Forming Limit Diagram (FLD)

Extension of forming limits by combination with impulse forming

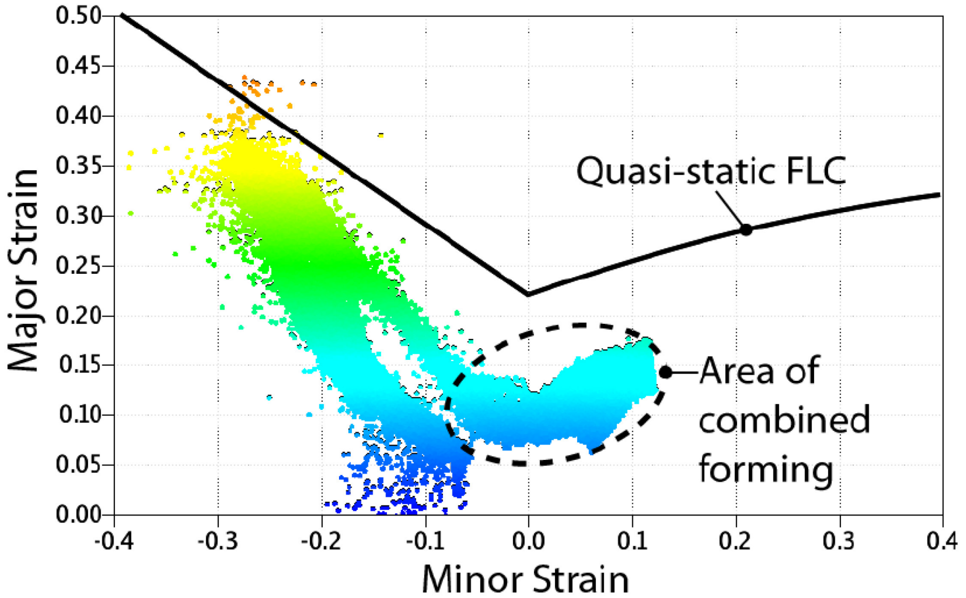


Extended formability by combination of deep drawing and electromagnetic forming (K. Demir, IUL)





Extension of forming limits by combination with impulse forming



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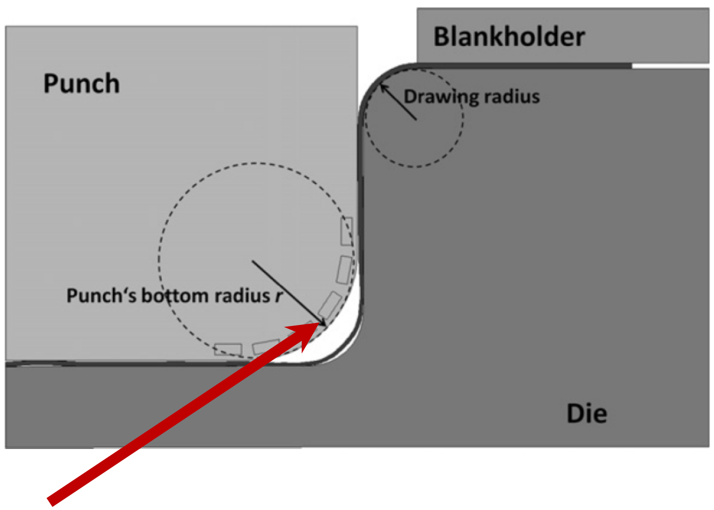
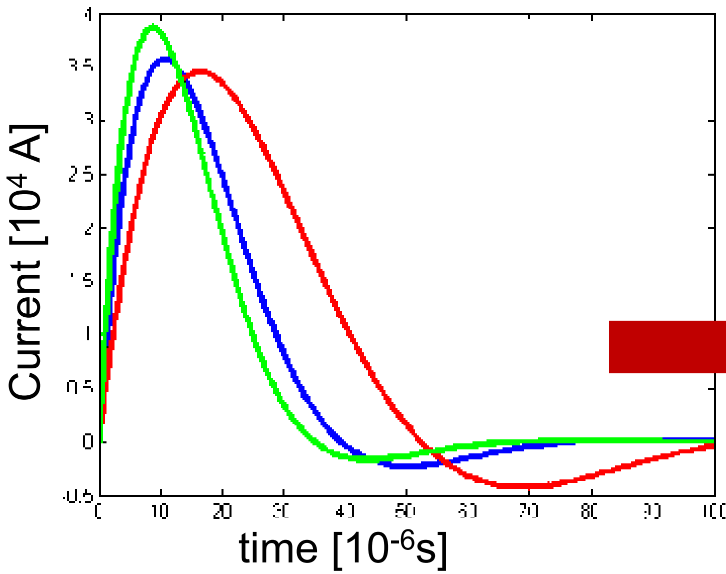


Tool Coil

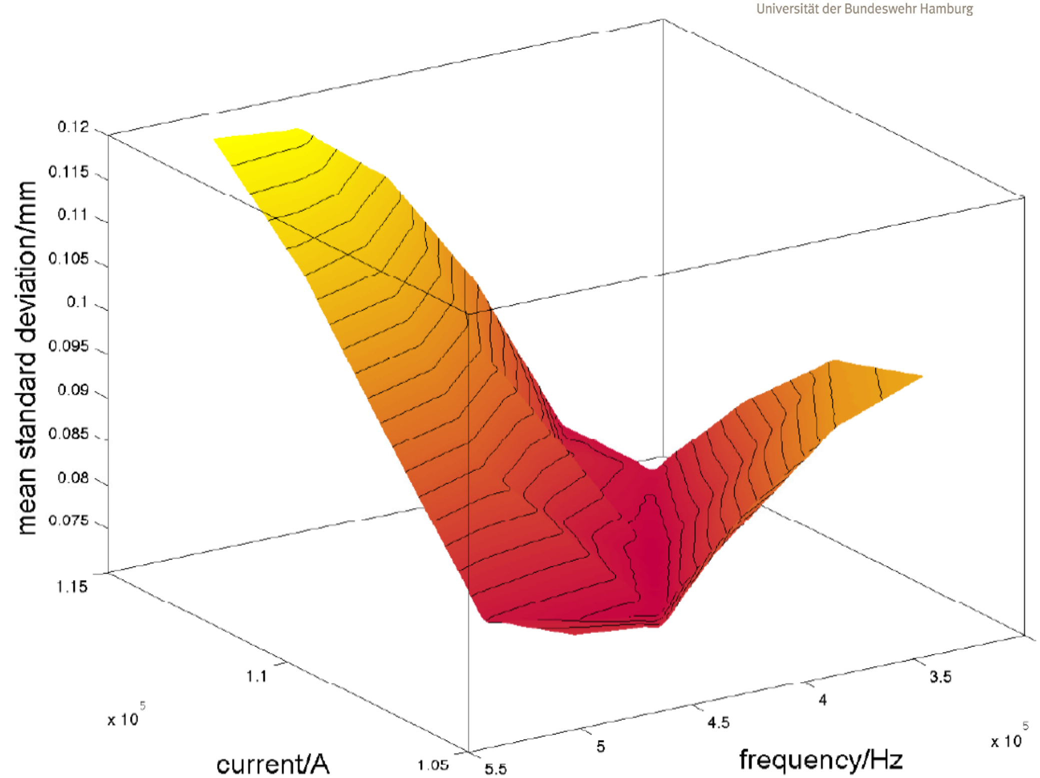
Classical Forming Limit Curve is meaningless for combined and dynamical processes

Identification of suitable parameters



$$I(t) = I_0 e^{\beta t} \cos(\omega t + \varphi)$$

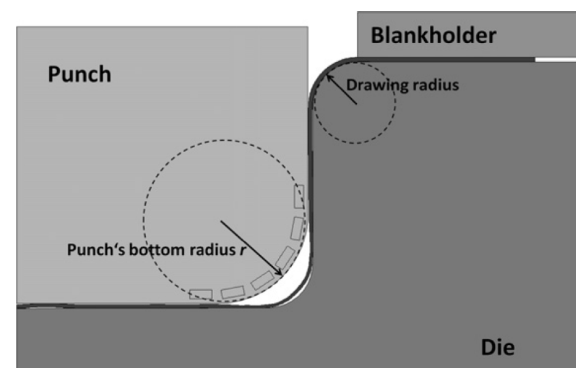
Input parameters for the numerical optimization (example)



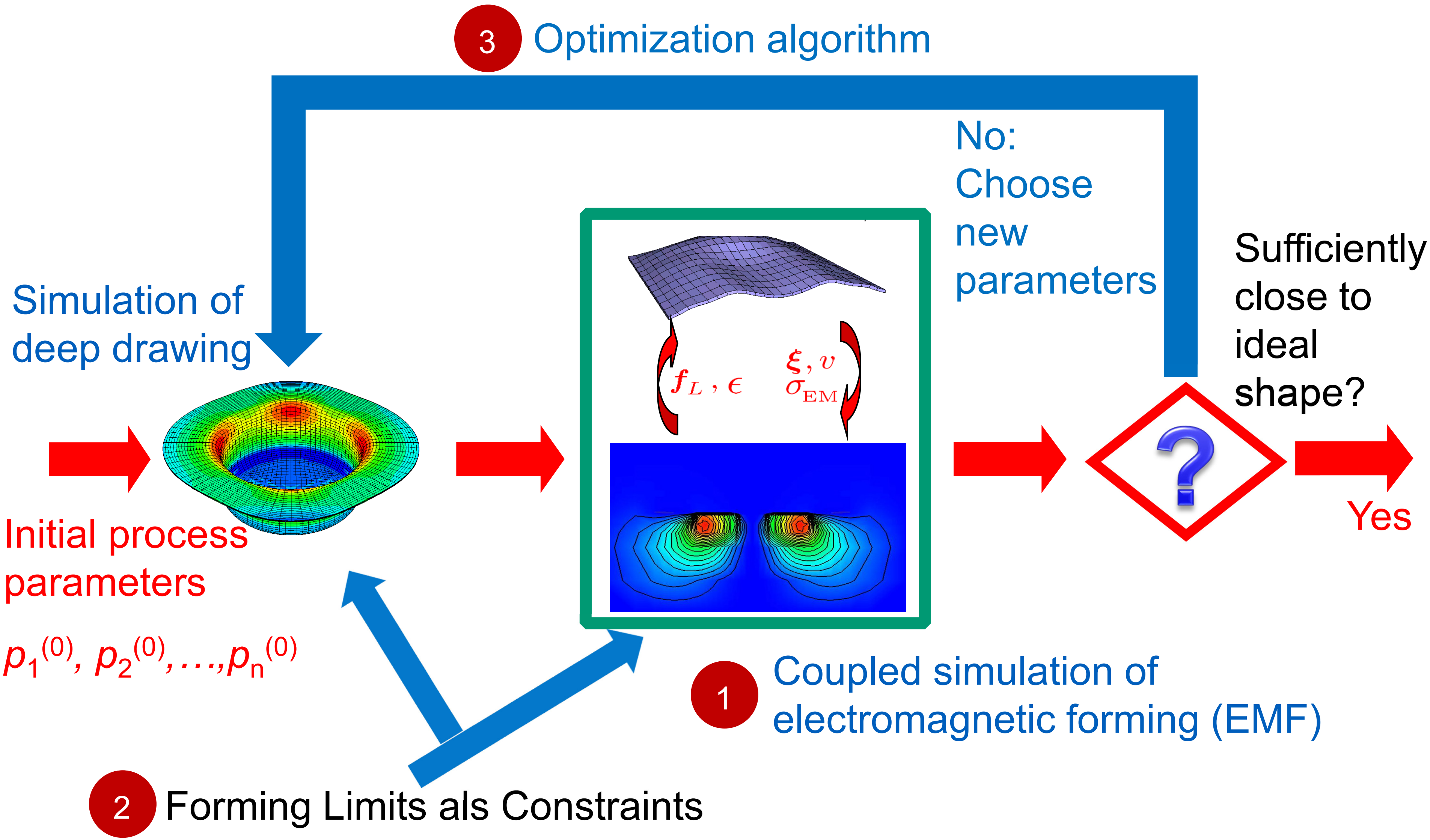
Objective function to be minimized:

$$\min_{\lambda \in \mathbb{R}^n} \quad \frac{1}{\text{meas } S} \int_S |s(\lambda, x) - s_{\text{opt}}(x)|^2 \, dx$$

$$\text{s.t.} \quad \text{dist}\left((\epsilon_1(\lambda, t), \epsilon_2(\lambda, t)), \partial F_t(\epsilon_1(\lambda, t), \epsilon_2(\lambda, t))\right) \geq 0$$



Process design by mathematical optimization



PAK343 Methodenplanung

1. Coupled simulation of EMF

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Universität der Bundeswehr Hamburg

Weak form of electromagnetic field equation

$$0 = \int_R \{(\dot{\boldsymbol{a}} - L^T \boldsymbol{a}) \cdot \boldsymbol{a}_* - \nabla(\chi - \boldsymbol{a} \cdot \boldsymbol{v}) \cdot \boldsymbol{a}_* + \mu_{\mathrm{EM}}^{-1} \sigma_{\mathrm{EM}}^{-1} \, \mathrm{curl}\, \boldsymbol{a} \cdot \mathrm{curl}\, \boldsymbol{a}_*\}$$

$$0 = \int_R \nabla\chi \, \nabla\chi_*$$

$$\boldsymbol{f}_{\mathrm{L}} = \det(\nabla\xi)\,(\boldsymbol{j} \times \mathrm{curl}\, \boldsymbol{a})$$

Lorentz force

Joule heating

$\boldsymbol{\xi}, v$

$\boldsymbol{T}$

Unknown fields

$\boldsymbol{a}$	vector potential
χ	scalar potential
$\boldsymbol{\xi}$	deformation

Weak form of momentum balance

$$0 = \int_{B_{\mathrm{r}}} \{\varrho\, \ddot{\boldsymbol{\xi}} - \boldsymbol{f}_{\mathrm{L}}\} \cdot \boldsymbol{\xi}_* + \int_{B_{\mathrm{r}}} \boldsymbol{K}(\nabla\boldsymbol{\xi})^{-\mathrm{T}} \cdot \nabla\boldsymbol{\xi}_*$$

Thermo-elasto-viscoplastic electromagnetic material law (Svendsen and Chanda, ´03, ´05)

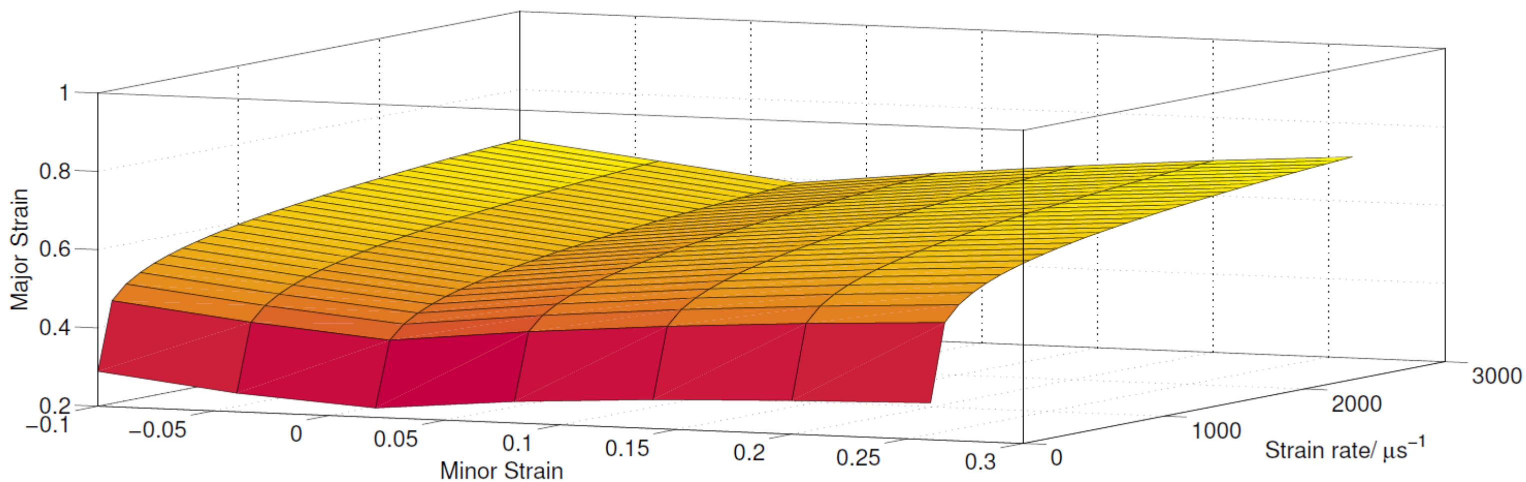
2. Forming limits as constraints

The optimization algorithm has to care that forming limits are not violated.

How can forming limits of combined and dynamic processes be implemented?

1. Damage model
   - universal
   - accurate if well identified
   - expensive evaluation

2. Forming limit surface (FLS)
   - Depending on the process
   - fast computable



Forming limit surface (FLS) for the alloy EN AA-5083

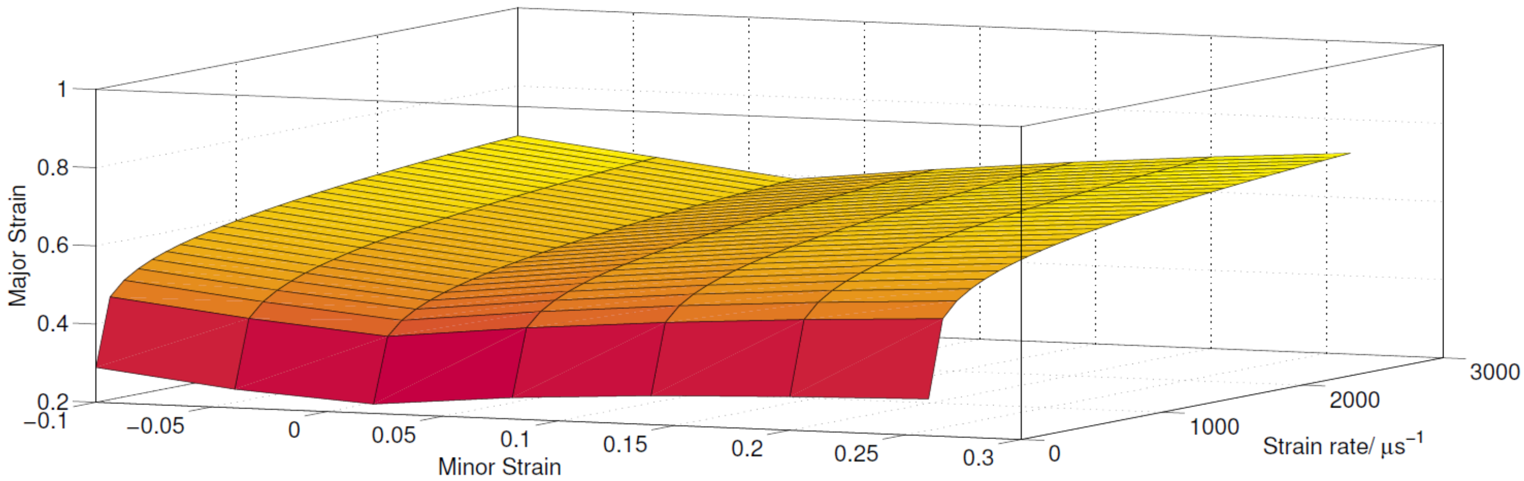
Determination of a Forming limit surface

Adapt a mathematical or physical model to experimental data.

Here: Johnsen-Cook type fracture model by Clausen et al. (2004)

$$\varepsilon_f = (D_1 + D_2 e^{D_3 \sigma^*})(1 + \dot{\varepsilon})^{D_4}$$

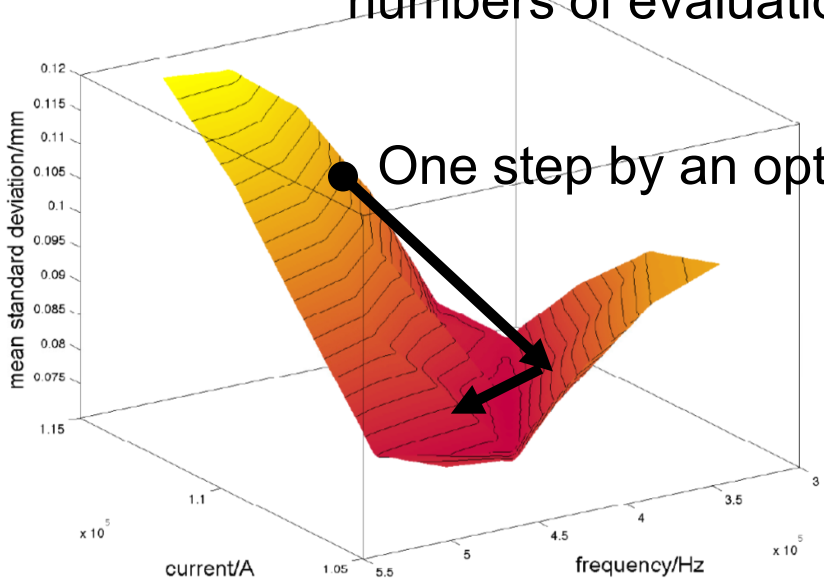
with D_1, D_2, D_3, D_4 parameters, ε_f strain at fracture, $\dot{\varepsilon}$ relative plastic strain rate, σ^* stress triaxiality ratio



Forming limit surface (FLS) for the alloy EN AA-5083

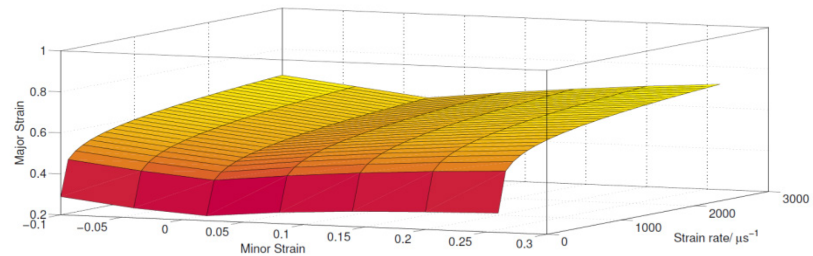
3. The optimization algorithm

Basic Idea: Use a method of descent to avoid large numbers of evaluations of the objective function

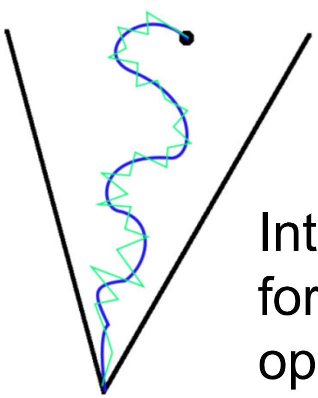


One step by an optimization method of descent

‚Landscape‘ of the object function



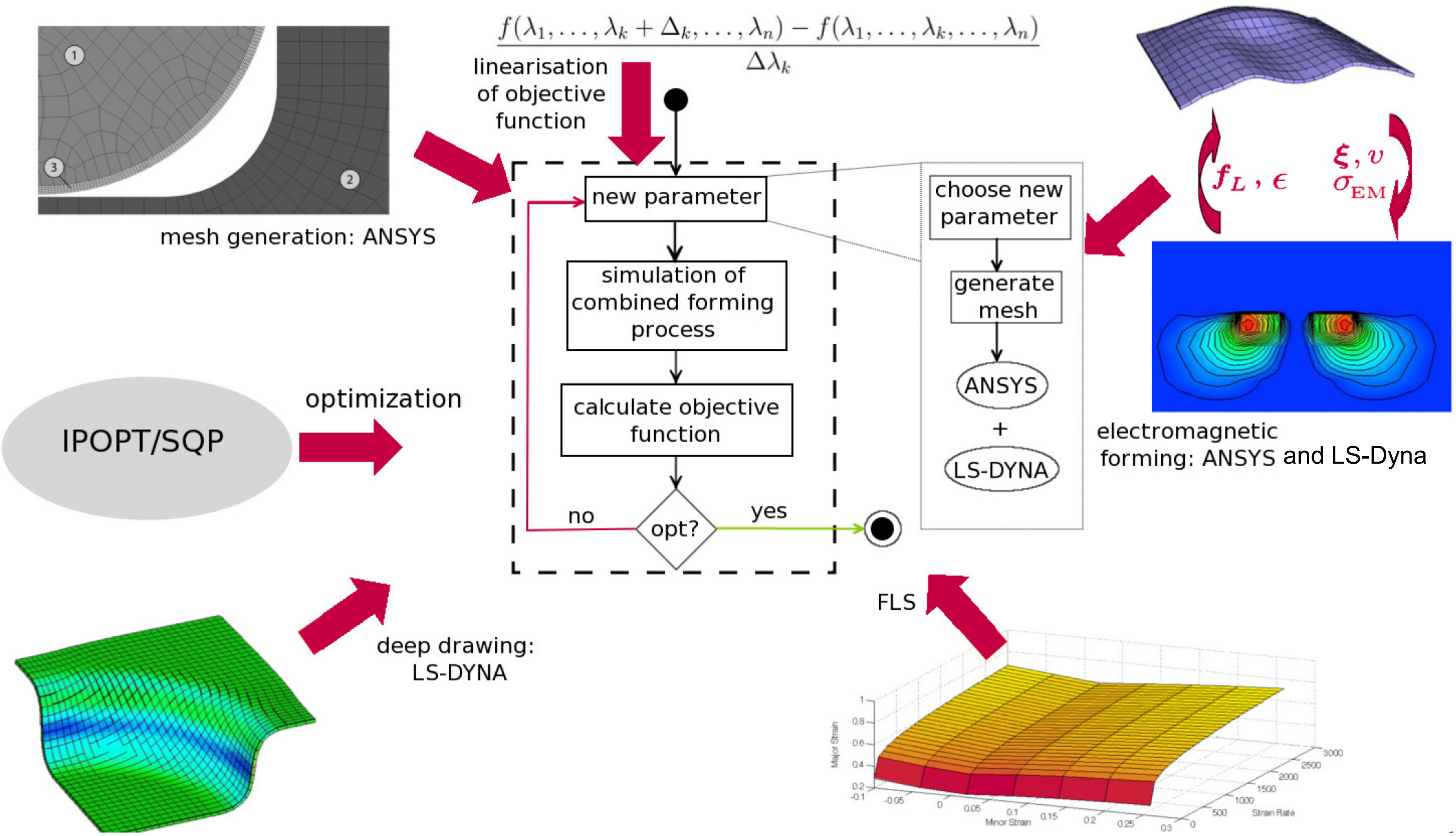
The decending step has to be carried out such that relevant forming limits are respected



Interior Point Method for constrained optimization

Problem: Derivatives of both objective function and constrains are required

The complete algorithm



An example

Given Data

Sheet metal diameter:	130 mm
Sheet metal thickness:	1 mm
Drawing distance	55 mm
Drawing radius:	10 mm
Blank holder force:	300 kN
Work piece material:	EN AA-5083
Punch bottom radius:	20 mm
Friction in the flange region:	$\mu = 0.04$
Ansatz for coil current:	$I(t) = I_0 e^{\beta t} \cos(\omega t + \varphi)$
Phase angle:	$\varphi = -1.35381\ rad$
Damping parameter:	$\beta = -15467.3 s^{-1}$

Identified values

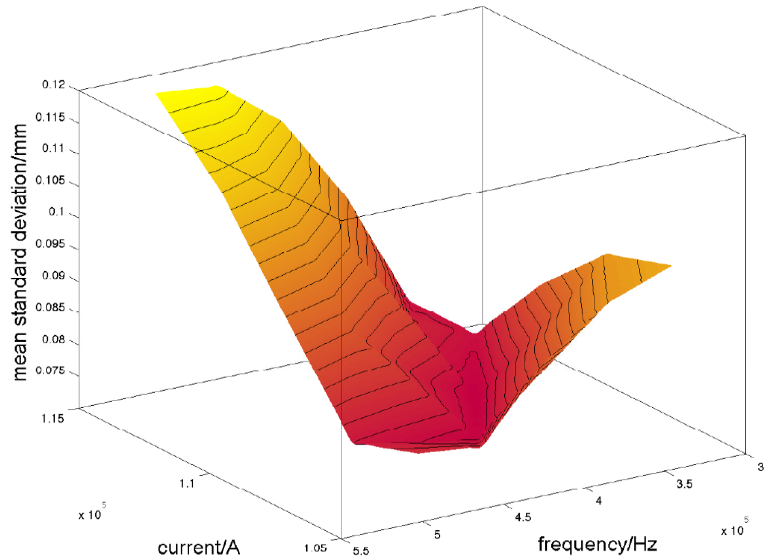
Amplitude:	$I_0 \approx 110\ 000$ A
Angular frequency:	$\omega \approx 3.8485 \cdot 10^5 s^{-1}$

Finite Element mesh of the work piece

Number of Elements:	1780 in 5 layers
Shape of elements:	quadratic

Simulation of EMF

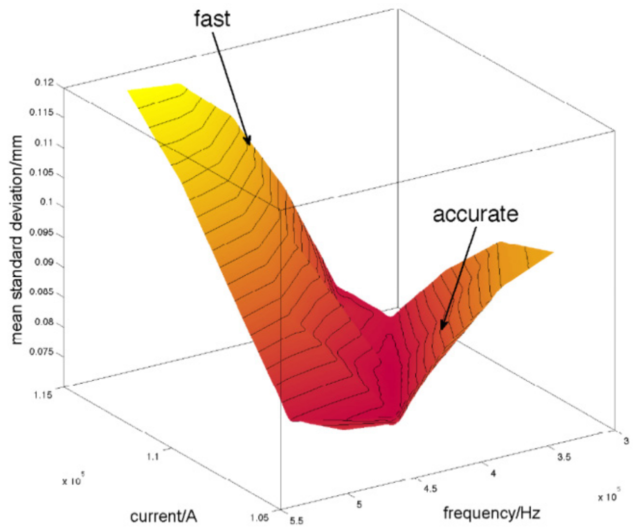
Time step size:	1 µs
Number of time steps:	55
Coupling:	sequentially



Efficiency, accuracy and robustness

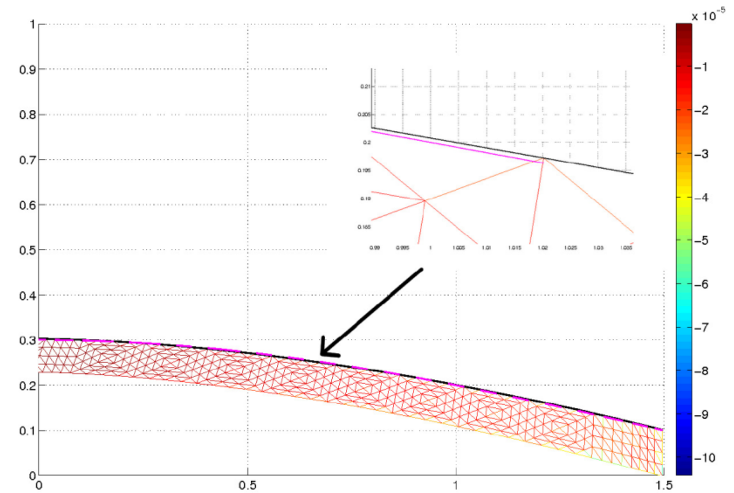
Controlling the algorithm

- Adapt mesh size in FE-simulation to duality gap of the optimization
- Apply trust-region type method on objective function
- Adaptive choice of the model for the constraints (FLS vs. damage model)



Derivatives

- Numerical linearization facilitates application to new problems
- However, required number of evaluations is increased
- Sometimes non-physical solutions have to be excluded by additional constraints



Summary and discussion

- Constrained numerical optimization has a potential to support the design of new forming processes
- In case of deep drawing with subsequent calibration by EMF, process chains depending on two parameters have sufficiently been identified
- The identified parameters led to extension of quasi-static forming limits
- The algorithmic framework is suitable for problems depending on larger numbers of parameters
- Simultaneous identification of both deep drawing and EMF parameters is possible
- A complete control of material flow is aimed at
- More experimental material data are required
- Many interesting questions on the mechanism of failure at high forming rates arise

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