# Determination of the Pressure Curve to Control Strain Paths in Tube Hydroforming by Applying Restart Analysis

M.Sc. Trung-Kien Nguyen

Institute of Metal forming Technology (IFU), University of Stuttgart

# Content

1. Introduction

2. Restart analysis feature in LS-Dyna

3. Algorithm to control linear strain path

4. Validation through RSM-optimization and experiment

5. Conclusion and Outlook

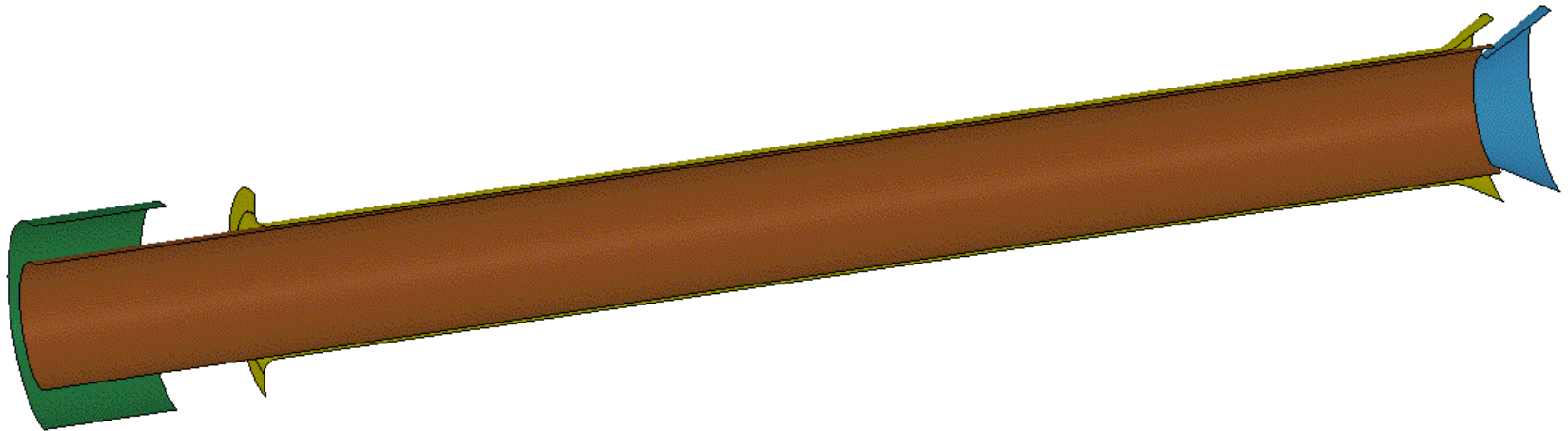Determination of pressure profile to control desired strain paths

**Tube hydroforming** (THF) is a forming process in which a metal pipe / profile is formed in the closed forming die by means of high pressure liquid. The most important process parameters are the internal pressure ($Pi$) and axial velocity ($Va$), which strongly depend on each other.
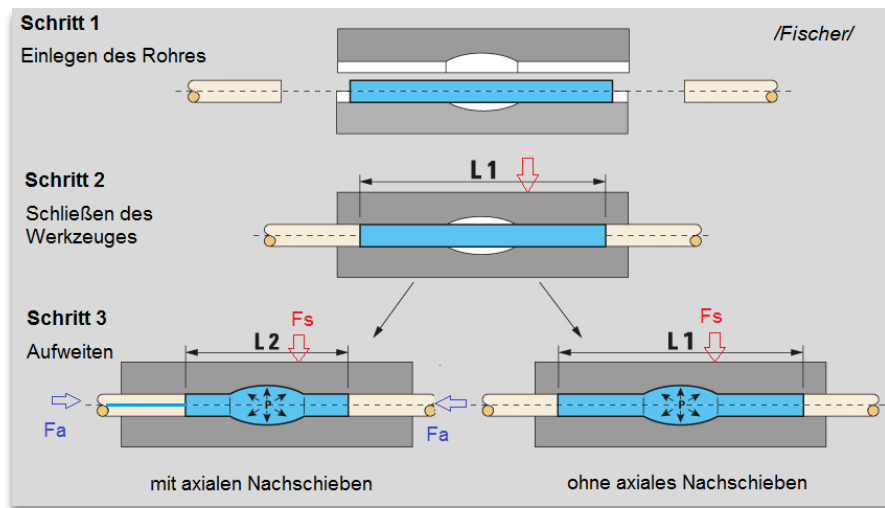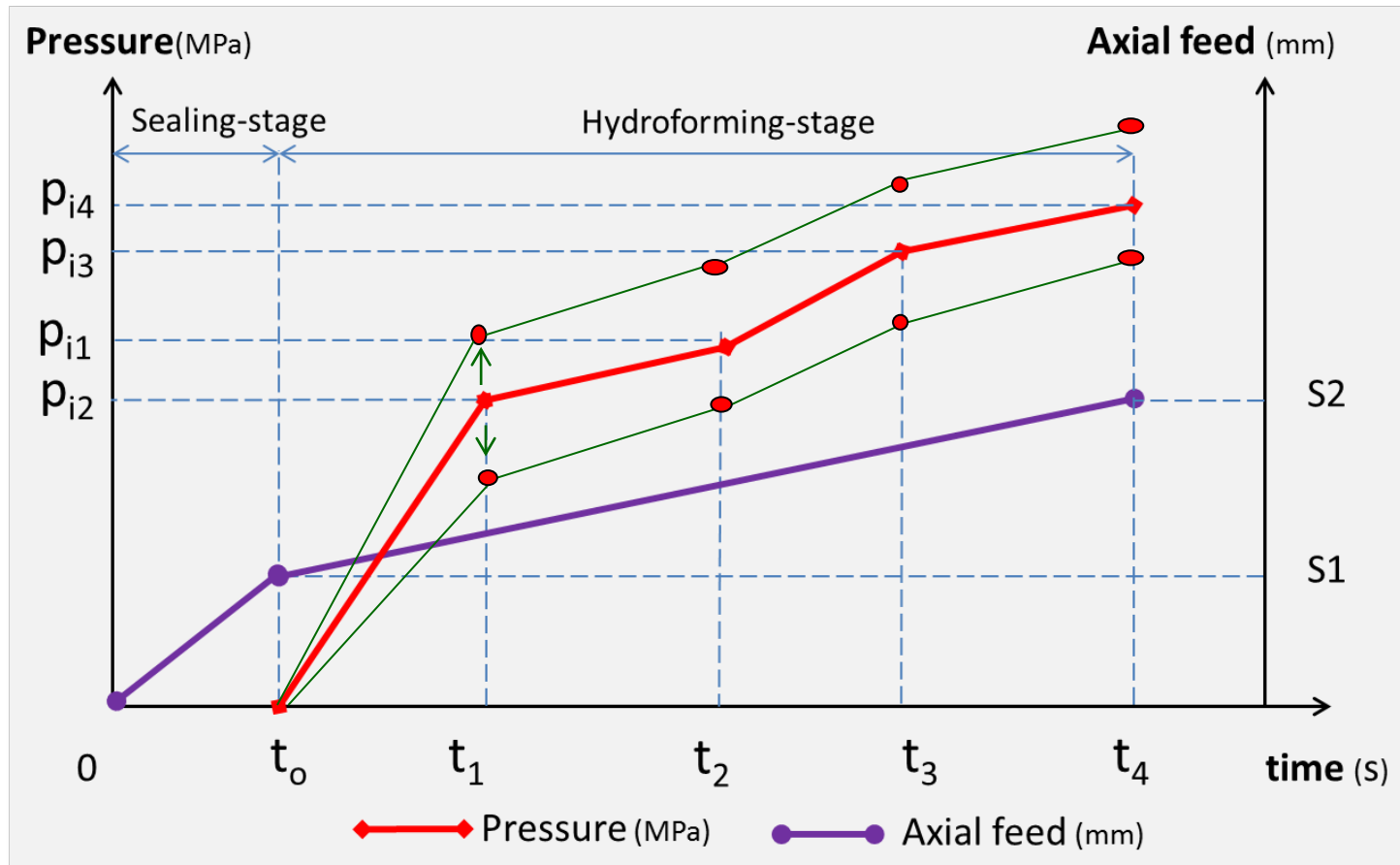
Seal-IHU 14301 ANISO
Time =      0

## Determination of Loading paths for THF-process



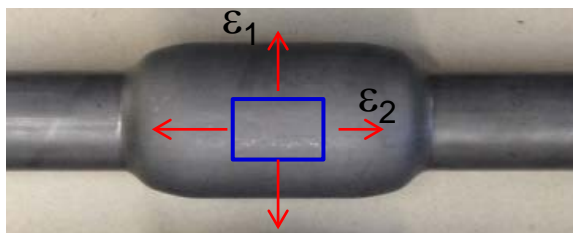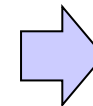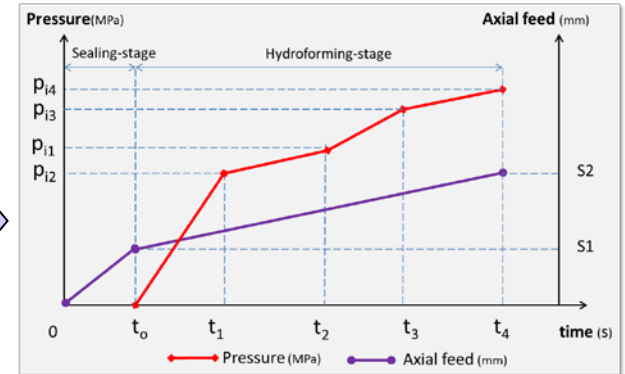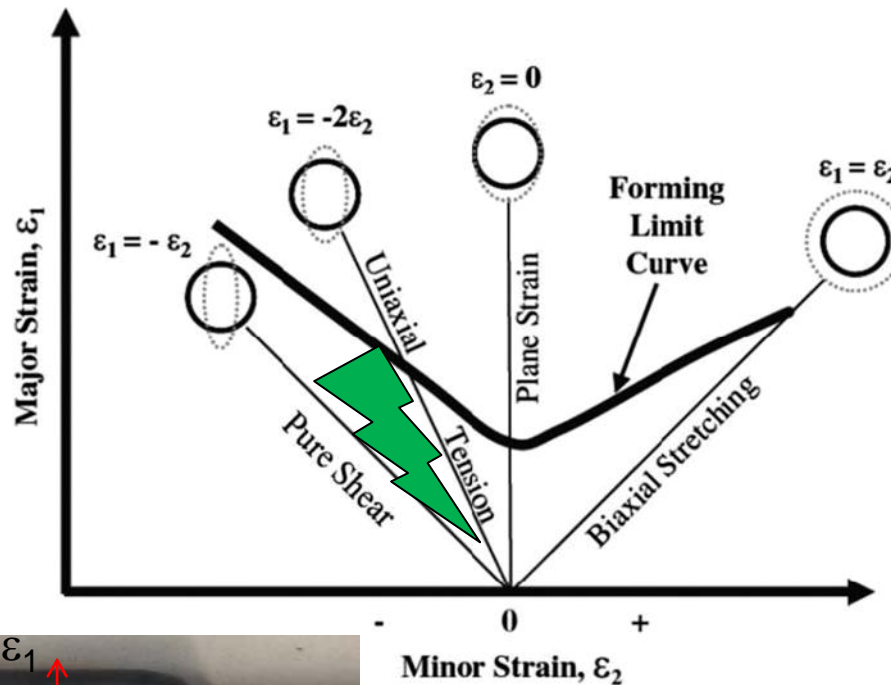Determination of pressure profile to control desired strain paths

**Determination & optimization of Loading paths for THF-process:**

- Analytical method: determination of some pressure points such as yield-, bursting-, and calibration pressure

- Experimental method: DoE and Regression

- FE-Simulation & EX-Validation: DoE and Regression

Determination of pressure profile to control desired strain paths
Institute of Metal Forming Technology | Trung-Kien Nguyen| 07.10.2014

**Aim of research:**

- Definition (Strain state) => Resulting (Loading paths)



Determination of pressure profile to control desired strain paths

# 2. Restart analysis feature in LS-Dyna

Setting up a Restart analysis:

Input deck     write dump file     time at stops

```
\ls971_s_R6.0.0_winx64_p.exe" i=E235R0.dyn d=d3dump Endtime=0.01
```

Restart
```
\ls971_s_R6.0.0_winx64_p.exe" i=E235R1.dyn r=d3dump01 d=d3dump Endtime=0.02
\ls971_s_R6.0.0_winx64_p.exe" i=E235R2.dyn r=d3dump02 d=d3dump Endtime=0.03
.
.
.
.
\ls971_s_R6.0.0_winx64_p.exe" i=E235R9.dyn r=d3dump09 d=d3dump Endtime=0.10
```

call dump file     write dump file

```
*CHANGE_CURVE_DEFINITION
      5
*DEFINE_CURVE
$PRESSURE
$     LCID      SIDR      SCLA      SCLO
       5         0
$                 A1                  O1
    0.0000000000E+00                  00
    1.0000000000E-02                  16
    2.0000000000E-02                  22
    3.0000000000E-02                  22
    4.0000000000E-02                  22
    5.0000000000E-02                  24
    6.0000000000E-02                  25
    7.0000000000E-02                  25
    8.0000000000E-02                  25
    9.0000000000E-02                  25
    1.0000000000E-01                  25
$---+----1----+----2----+----3----+----4-
```
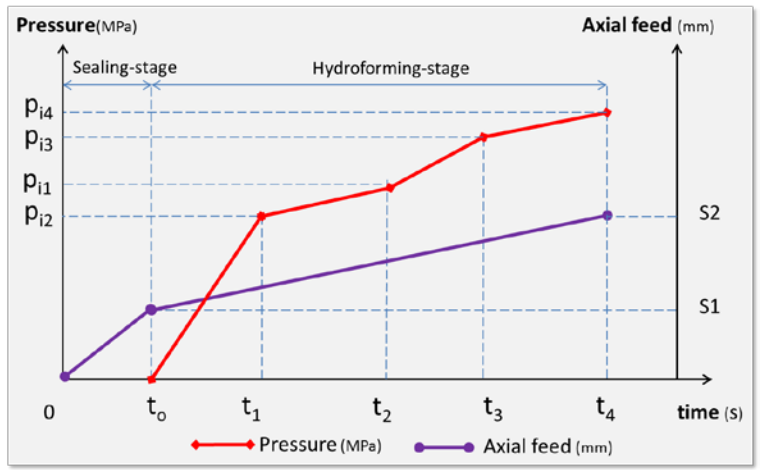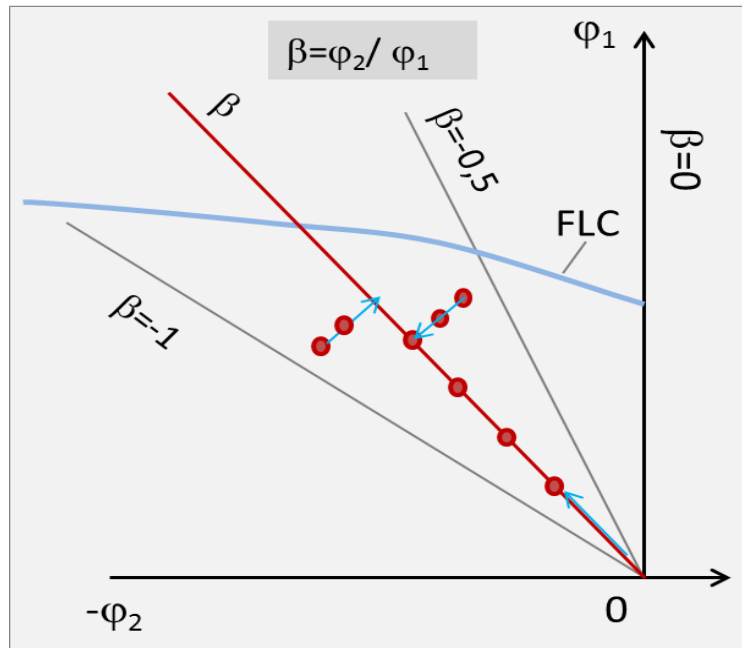


Determination of pressure profile to control desired strain paths

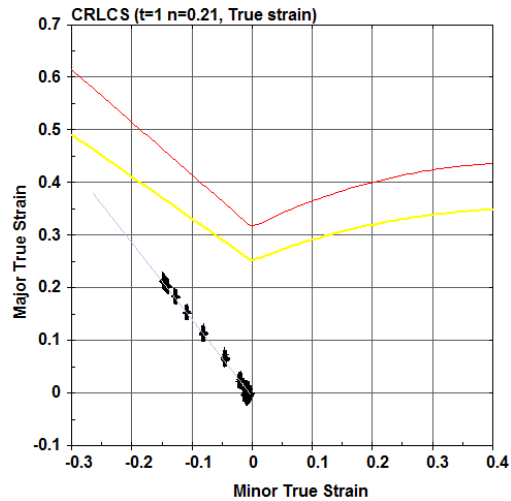# 3. Algorithm and case study

- Algorithm



*Schematically illustration of control the linear strain path on left side of FLD*

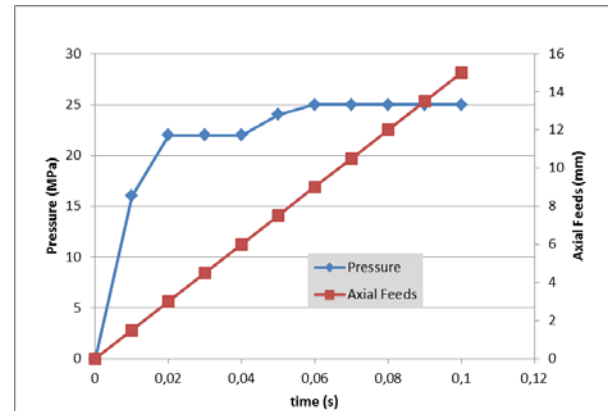Algorithm for control a linear strain path via FE-Simulation:

- Step1: Assign variables: $\Delta s$, $\Delta p$, i, k…
- Step2: Call LS-Dyna Solver
- Step3: Call LS-Prepost: Read results $\beta$
- Step4: Compare $\beta$ and change pressure $\Delta p$ and repeat Step 2 to 4 until $\beta = \beta'$
- Step5: Increase axial feed $\Delta s$
- Step6: Call Restart analysis and check FLC
- Step7: If $(\varphi_1, \varphi_2) >= $ FLC then End else repeat Step 2 to 5

Determination of pressure profile to control desired strain paths

- Adaptive FE-Simulation for case study $\beta$=-0.7



a) strain path $\beta \cong$-0.7

b) obtained pressure curve
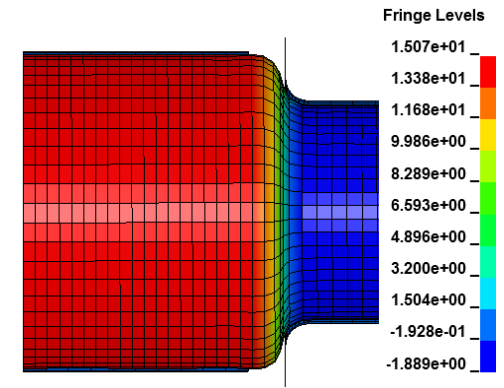
c) thinness distribution (%)

upper die

axial punch

Die insert

part

$t_0$

$d_0$

$pi$

lower die

initial tube

$l_0$

Determination of pressure profile to control desired strain paths
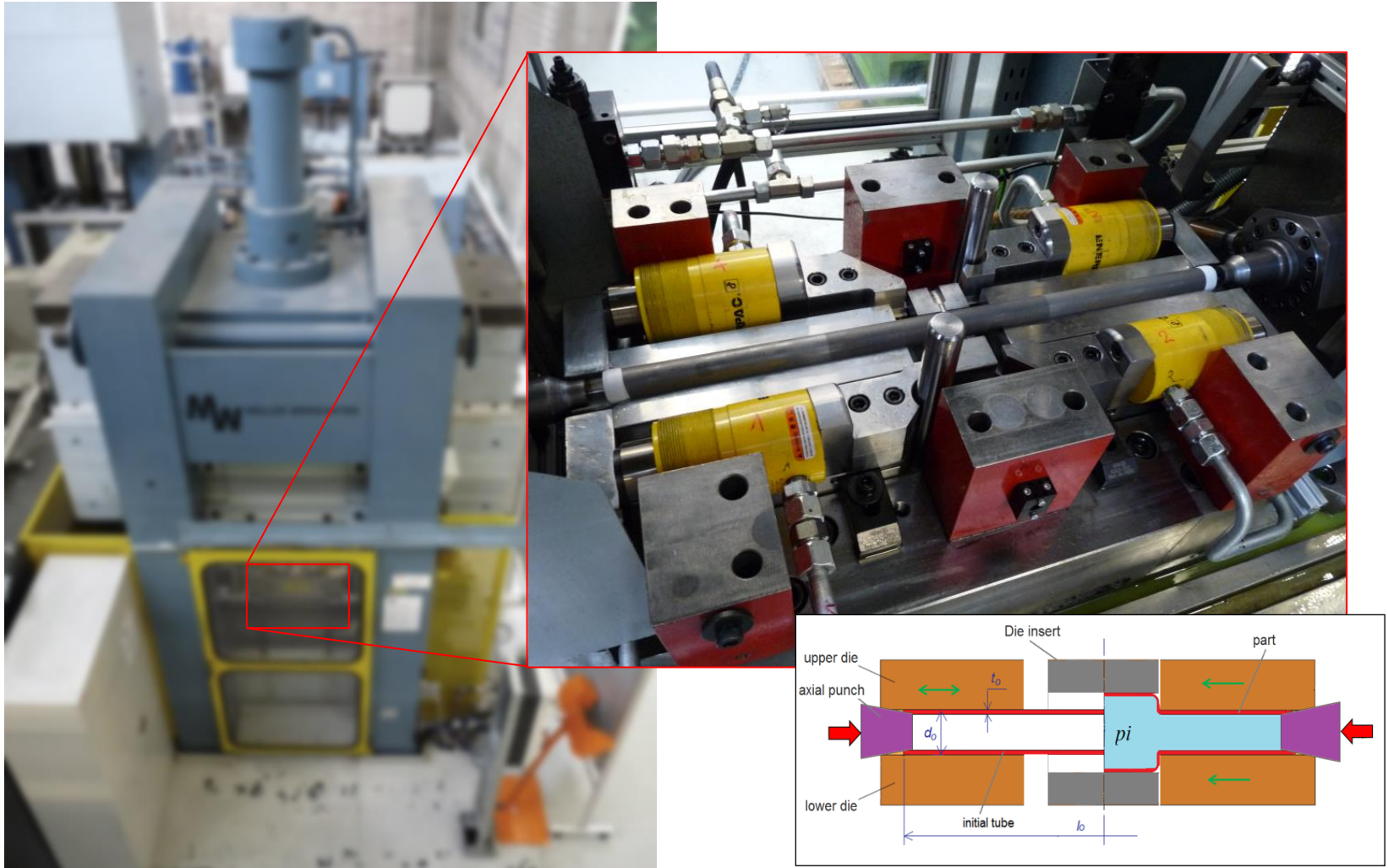
- Experiment vs. FE-Simulation

Weicher Stahl E235, $\varnothing_A 30 \times 1{,}0$

a) experimentelle Untersuchung
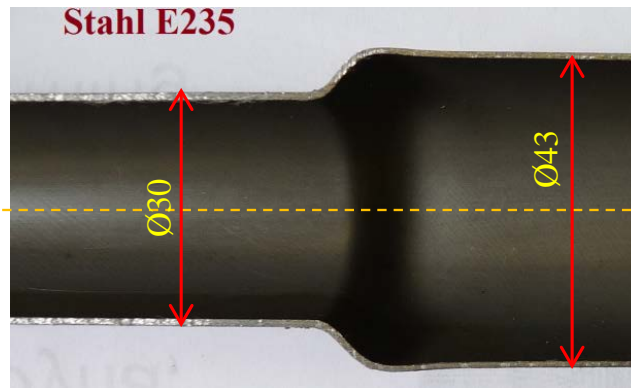
b) FE-Simulation



% Thickness Reduction- based on current z-strain

Fringe Levels

1.507e+01
1.338e+01
1.168e+01
9.986e+00
8.289e+00
6.593e+00
4.896e+00
3.200e+00
1.504e+00
-1.928e-01
-1.889e+00
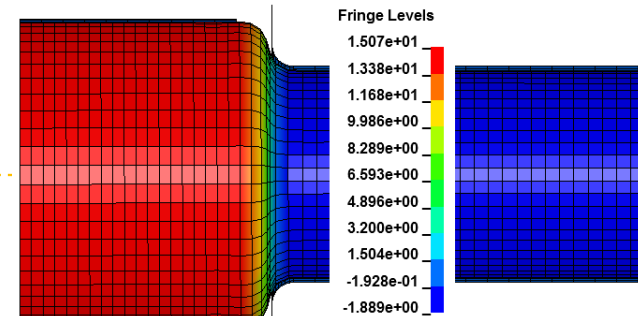
Reduzierung in Blechdickenrichtung [%]



13.5  14.6  15.7  16.8  17.8  18.9  20.0  21.1  22.2

Determination of pressure profile to control desired strain paths
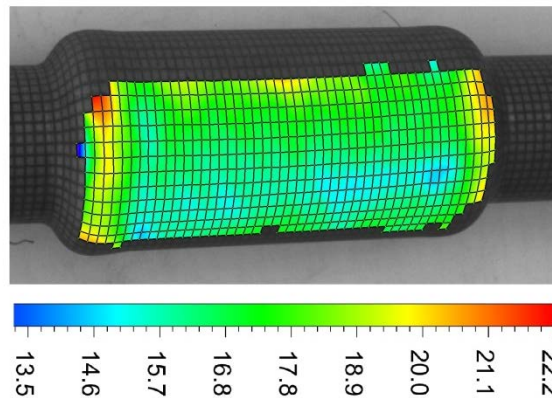
# 4. Validation through RSM and experiment

- RSM-Optimization vs. FE-Simulation

Object function $GE = \sqrt{(6{,}5 - a1)^2 + (6{,}5 - a2)^2 + (6{,}5 - a3)^2}$ minimal
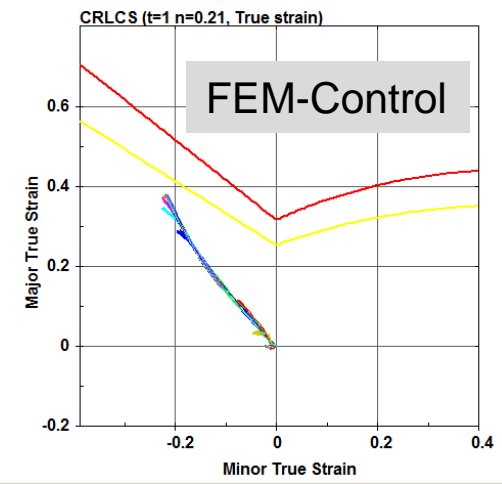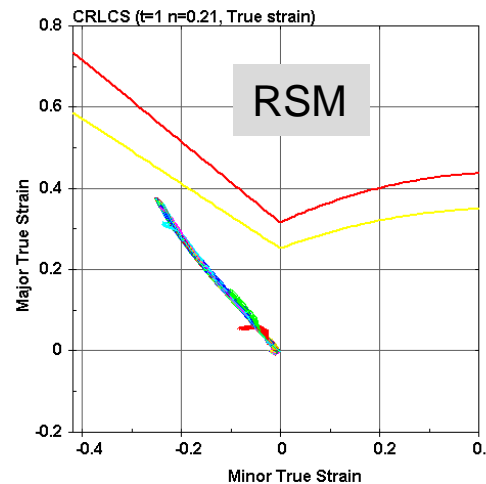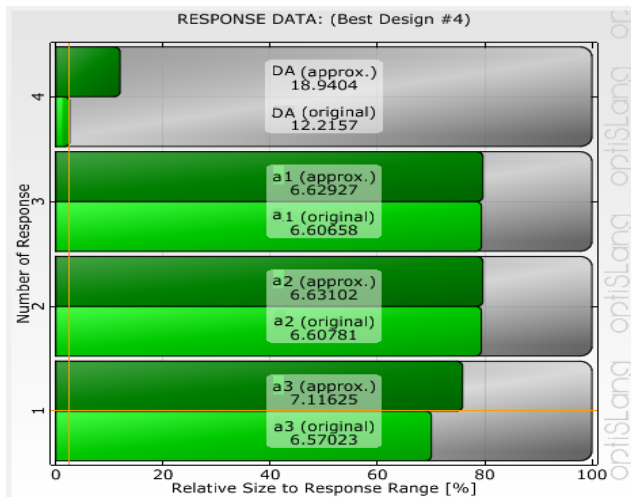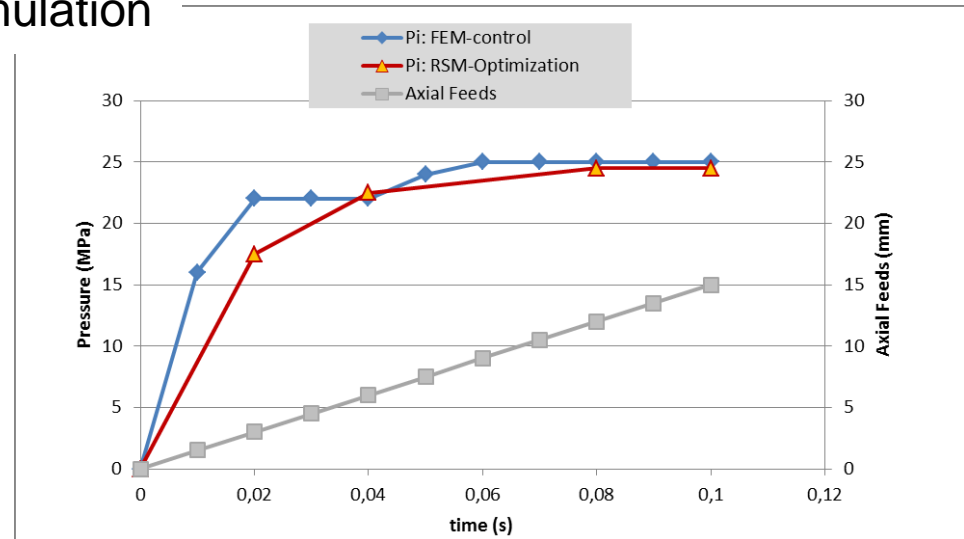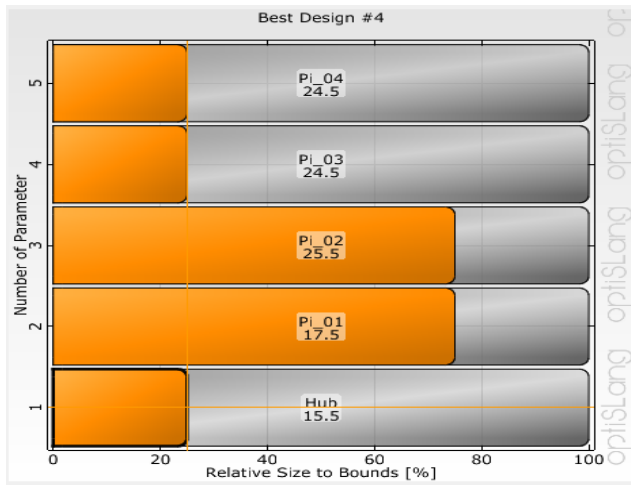
Constraints:
- Max. Thinning: DA < 20%
- Displacement a1 ≥ 6,4 mm
- Displacement a2 ≥ 6,4 mm
- Displacement a3: 6,0 mm < a3 < 6,7 mm
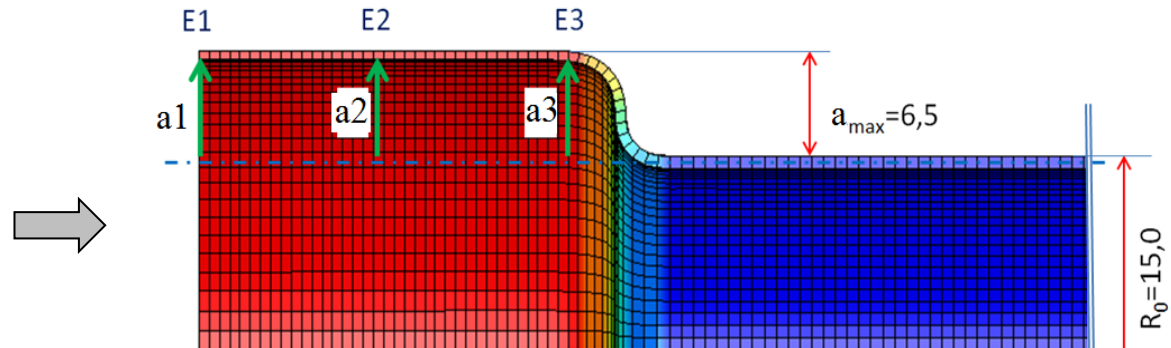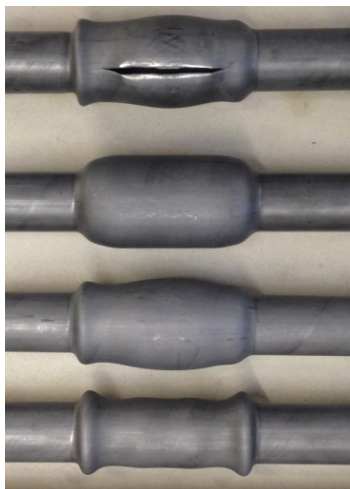


Determination of pressure profile to control desired strain paths

# 4. Validation through RSM and experiment
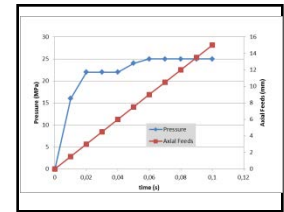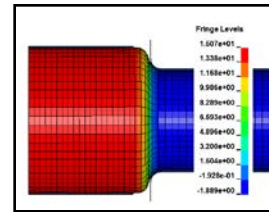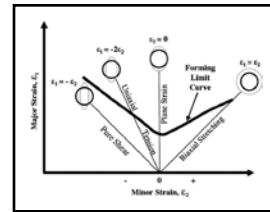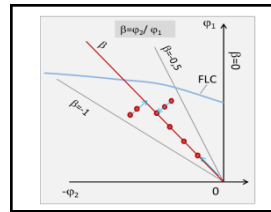
- RSM-Optimization vs. FE-Simulation





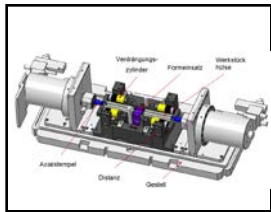

Determination of pressure profile to control desired strain paths

- Save simulation time significantly comparing to RSM and experiment
- It's useful for building of FLC for tubular material

Limits and Outlook:
- Axial feeds and strain paths are linear
- Suitable for specific case (THF with feeding)

# Thank you for your attention!

Determination of pressure profile to control desired strain paths