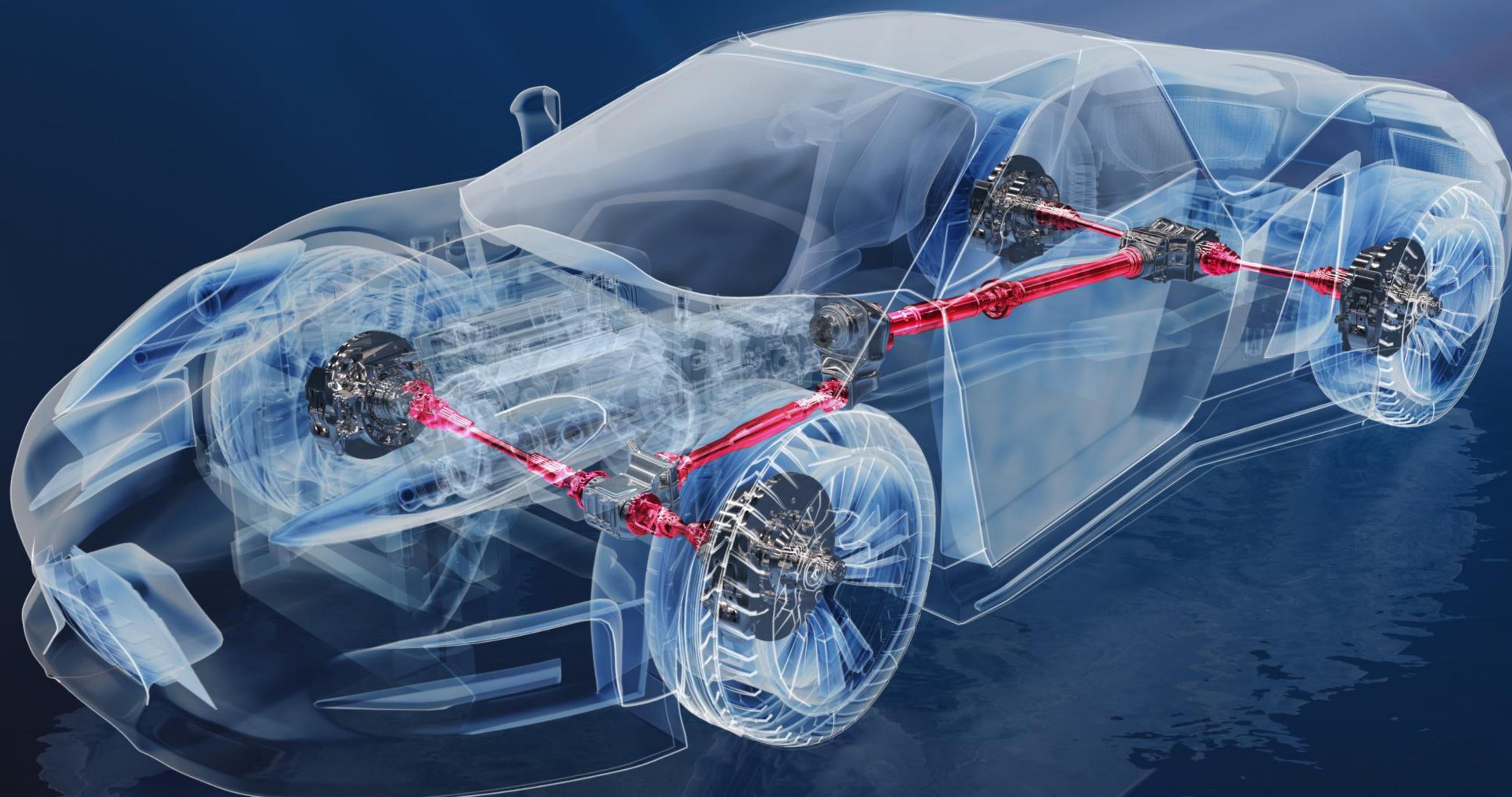
Parameter identification for an hyperelastic material model of an elastomer rubber boot



dynardo | presented at the 14th Weimar Optimization and Stochastic Days 2017
Source: www.dynardo.de/en/library

Content

- Motivation
- Parameter identification and curve fitting with optiSLang
- 2D – axis symmetric analysis of an elastomer rubber boot
- Summary

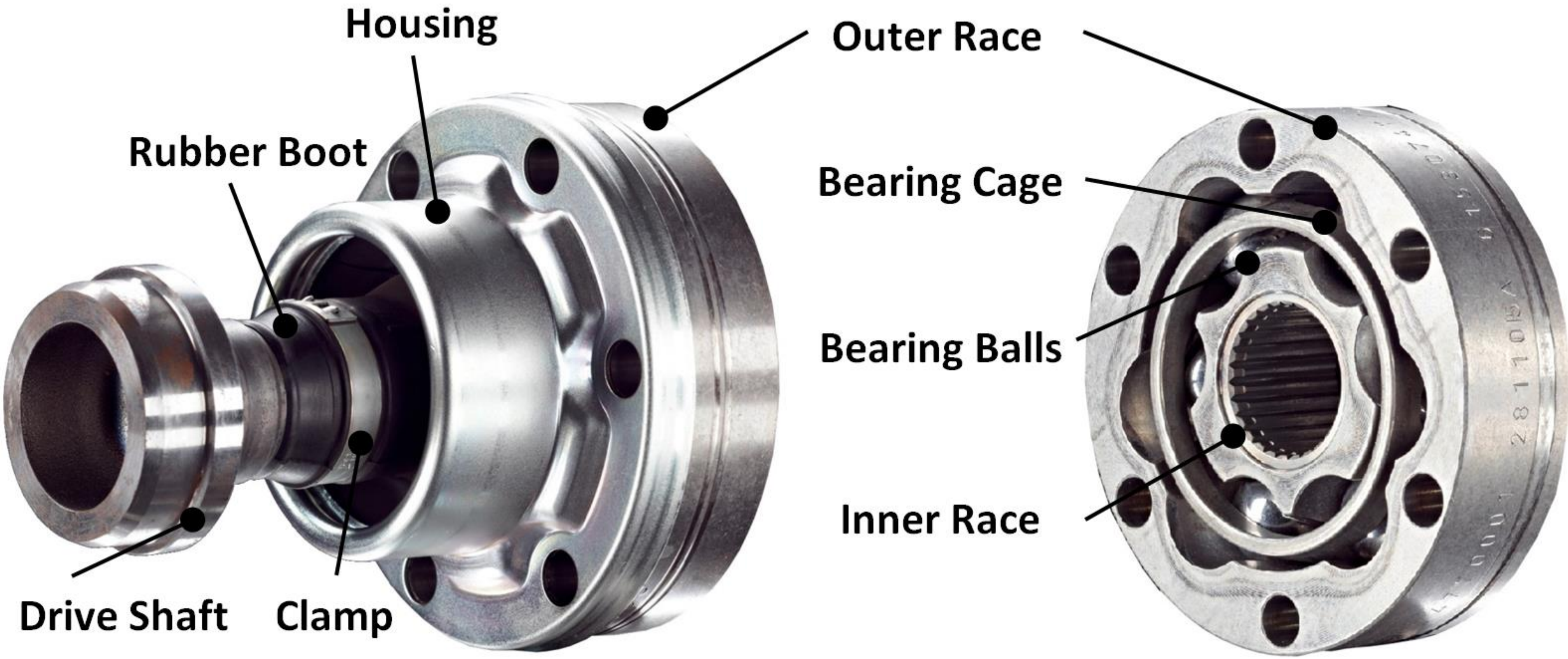
Motivation

Parameter identification and curve fitting with optiSLang

2D – axis symmetric analysis of an elastomer rubber boot

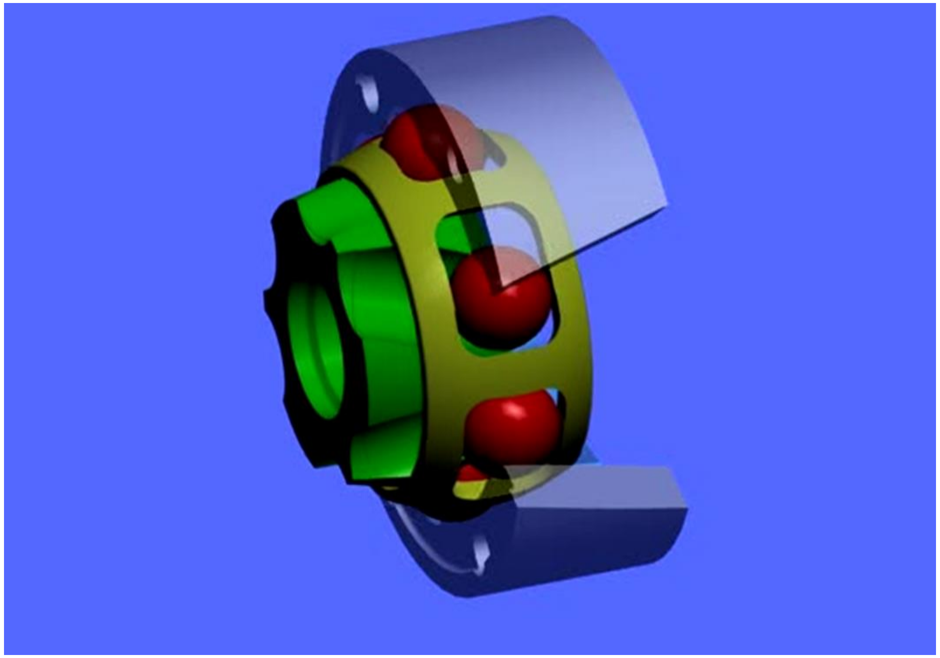
Summary

Constant velocity (CV) joint

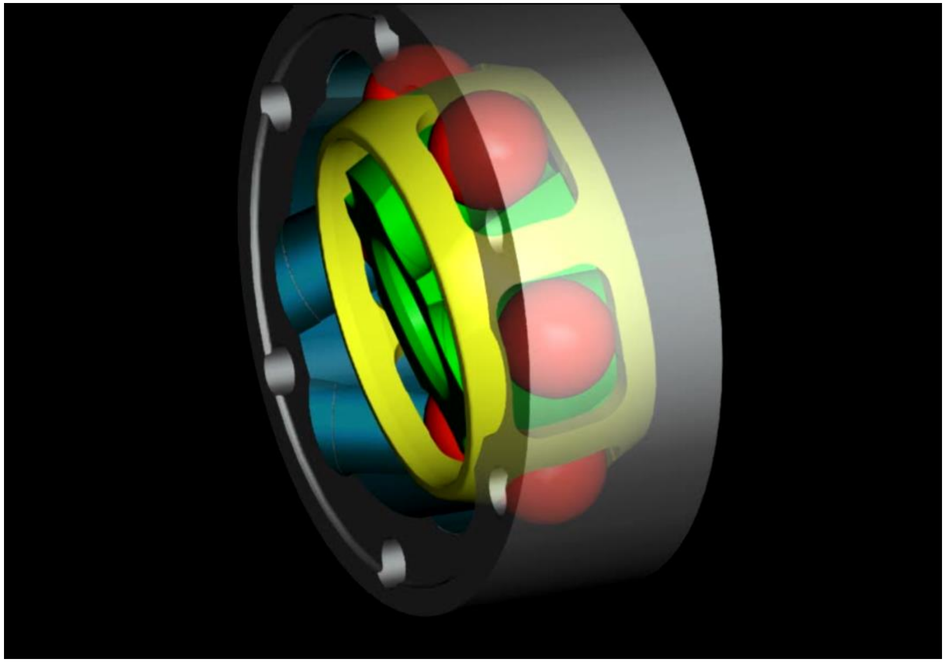


Constant velocity (CV) joint

Length compensation:



Flexion:



Pneumatic experiments

Damage symptoms

- Unintended "S"-shaped deformation by negative length compensation.

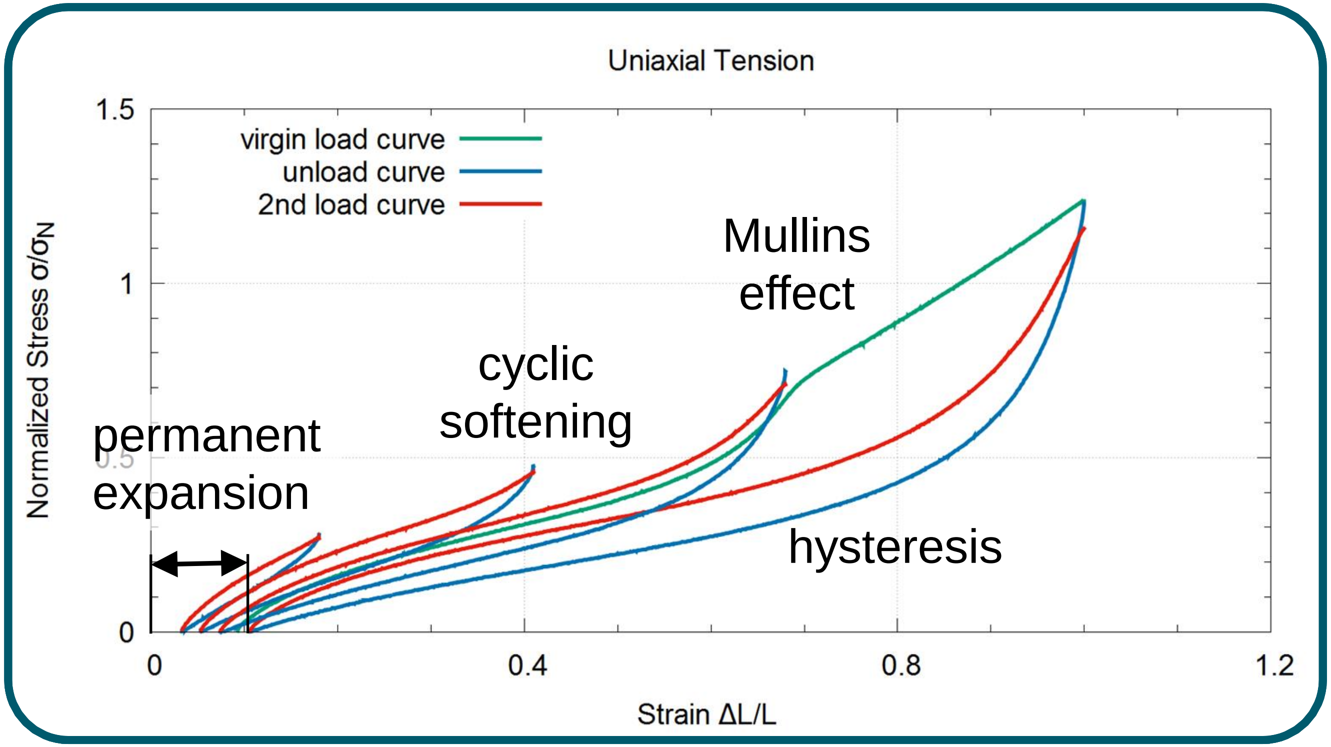
- Breakage caused by damage areas on rubber boot surface.

- Lost contact caused by fluid pressure penetration at housing site.

- Motivation
- **Parameter identification and curve fitting with optiSLang**
- 2D – axis symmetric analysis of an elastomer rubber boot
- Summary

Hyperelasticity - characteristics of rubber material

large deformation[1]



non-linear stress-strain behaviour

[1] http://www.instron.de/de-de/testing-solutions/by-material/biomedical/tension/bs-en-455-2

Modeling of hyperelasticity

- **strain energy potential W**

$$W = W(I_1, I_2, I_3)$$

- **invariants of strain tensor**

$$I_1 = \lambda_1^2 + \lambda_2^2 + \lambda_3^2$$

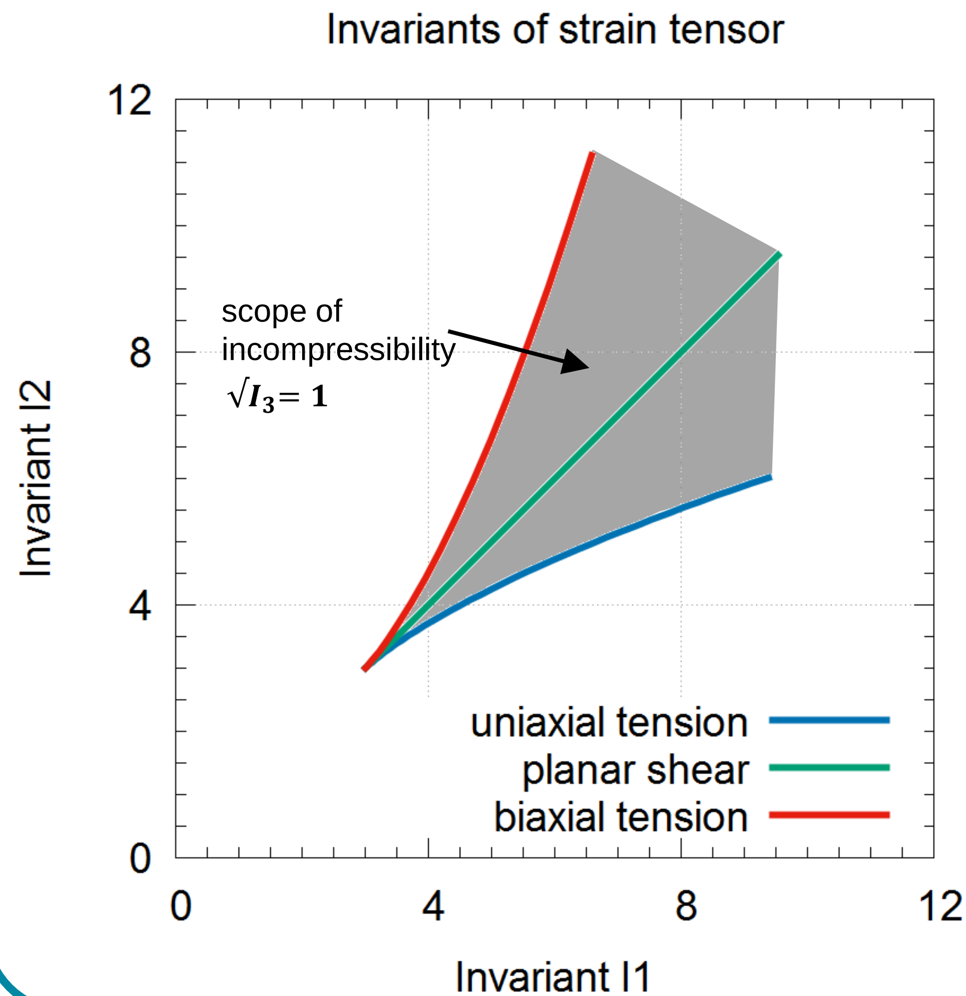
$$I_2 = \lambda_1^2\lambda_2^2 + \lambda_2^2\lambda_3^2 + \lambda_3^2\lambda_1^2$$

$$I_3 = \lambda_1^2\lambda_2^2\lambda_3^2$$

- **polynominal approach:**

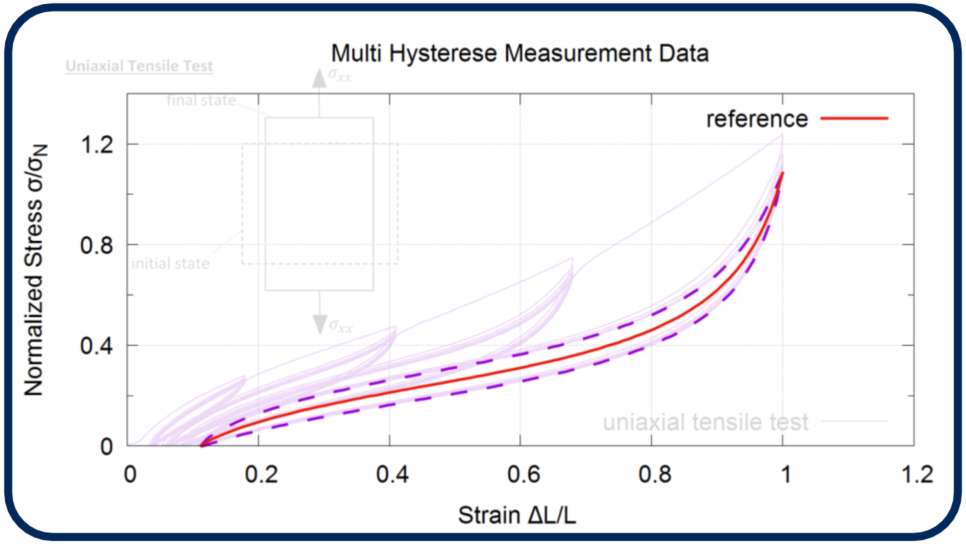
Ogden (6 parameter)

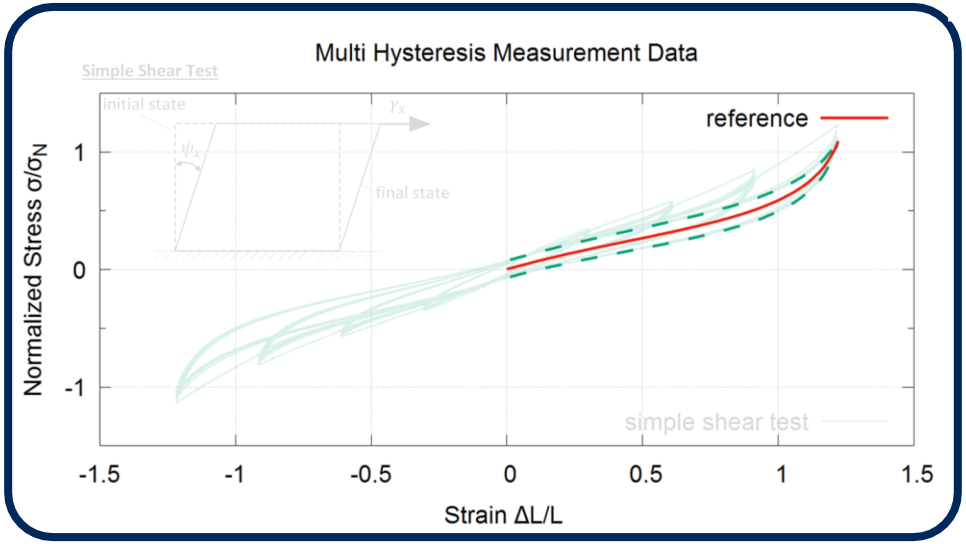
$$W = \sum_{i=1}^{N} \frac{\mu_i}{\alpha_i}(\lambda_1^{\alpha_i} + \lambda_2^{\alpha_i} + \lambda_3^{\alpha_i} - 3)$$

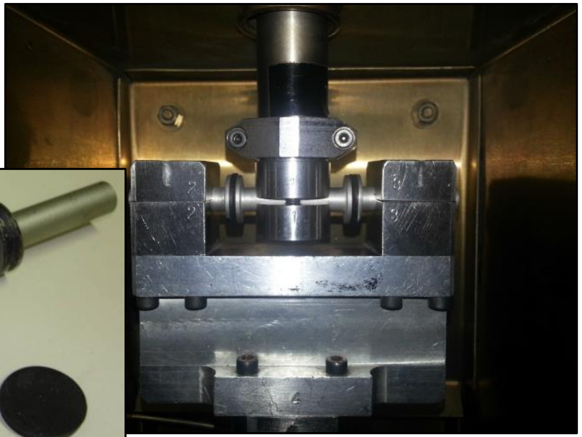


Modeling of hyperelasticity

- **measurement data** [2]







[2]: DIK – Deutsches Institut für Kautschuktechnologie e. V. 2015

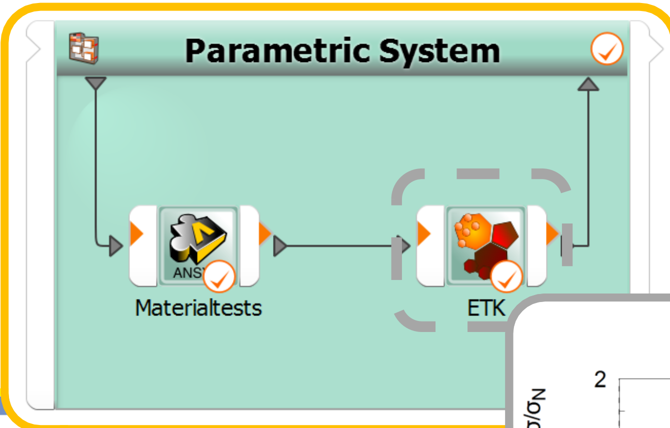
Project schematic

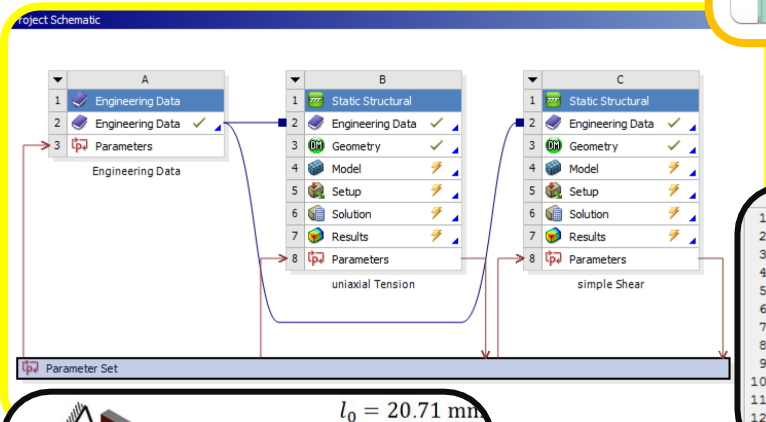
Input:

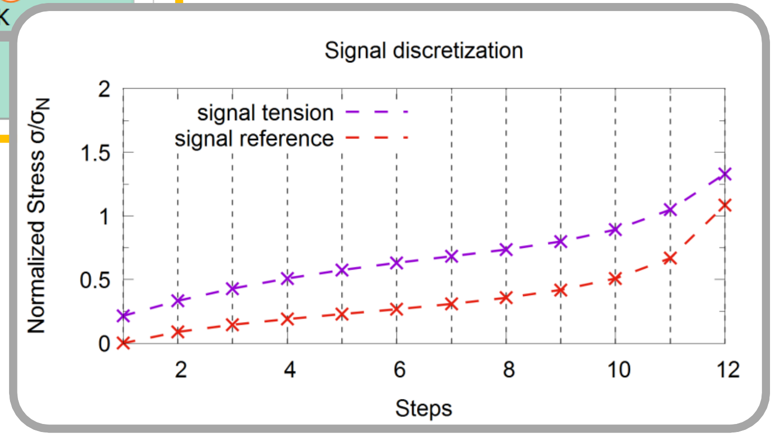
- Engineering Data
- material parameter α_i, μ_i

Output :

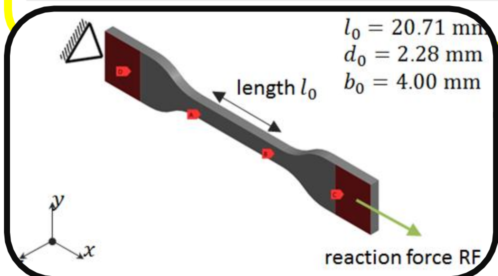
- Signal of stress-strain-curves

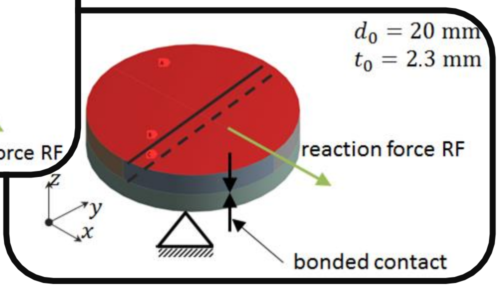






strain [1]	stress [MPa]
uniaxial Tension - Simulation	
0	0
0.02513	0.05192
0.05055	0.10075
0.07625	0.14671
0.10222	0.19001
0.12847	0.23084
0.15497	0.26939
0.18171	0.30586
0.20867	0.34043
0.23584	0.37330
0.26316	0.40466





strain [1]	stress [MPa]
simple Shear - Simulation	
0	0
0.02438	0.02053
0.04877	0.04105
0.07315	0.06154
0.09754	0.08199
0.12192	0.10239
0.14630	0.12272
0.17069	0.14298
0.19507	0.16315
0.21945	0.18323
0.24384	0.20321
0.26822	0.22309

Normalized **R**oot **M**ean **S**quare **E**rror:

$$NRMSE = \frac{\sqrt{\sum_{i=1}^{n}\left(\sigma_{ref} - \sigma_{sim}\right)^2}}{\left(\sigma_{max} - \sigma_{min}\right)}$$

Sensitivity analysis and direct optimization result

Parameter:

$$W = \sum_{i=1}^{3} \frac{\mu_i}{\alpha_i}(\lambda_1^{\alpha_i} + \lambda_2^{\alpha_i} + \lambda_3^{\alpha_i} - 3)$$

$$\alpha_i = 10^{\log \alpha_i}$$
$$\mu_i = 10^{\log \mu_i}$$

i	α_i	μ_i	$log\ \alpha_i$	$log\ \mu_i$
1	$2 \dots 4.5$	$0 \dots 0.3$	1	1
2	1	$50 \dots 100$	$-2 \dots -1.5$	1
3	$16.5 \dots 20.5$	1	1	$-6 \dots -4$

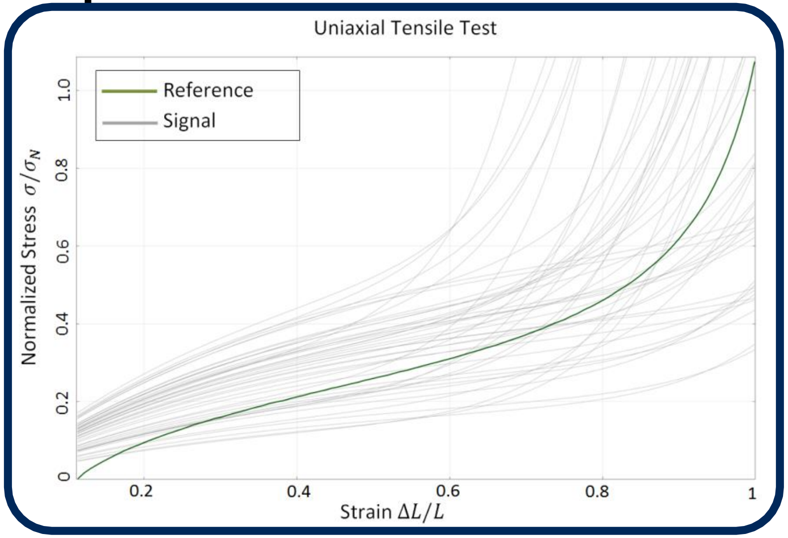
CoP-matrices:

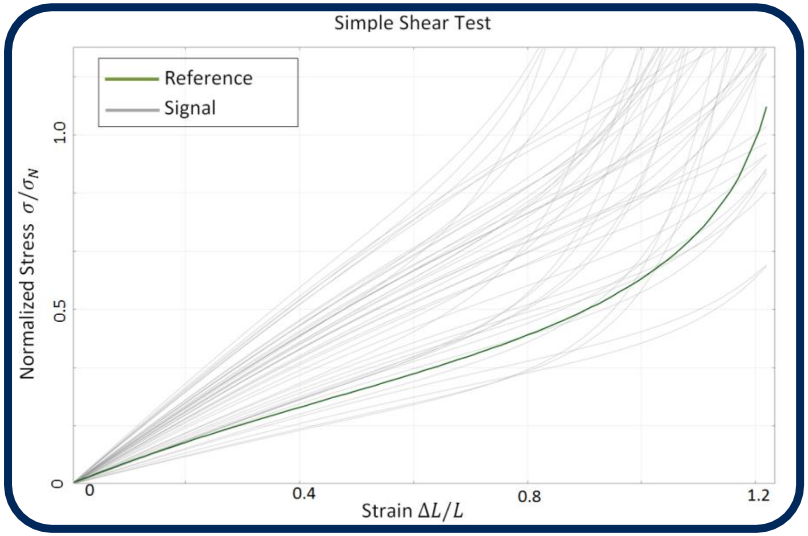
Models \ Parameter	MU1	A1	MU2	A3	logA2	logMU3	Total
stress_steps_uT[11]				42.6 %		84.0 %	99.7 %
stress_steps_uT[10]				41.2 %		82.9 %	98.8 %
stress_steps_uT[9]				35.4 %	5.6 %	80.5 %	97.7 %
stress_steps_uT[8]		6.2 %	0.0 %	25.6 %	11.1 %	66.7 %	95.1 %
stress_steps_uT[7]		7.8 %	5.9 %	13.1 %	29.0 %	40.4 %	90.8 %
stress_steps_uT[6]	0.5 %	13.5 %	17.0 %		51.6 %	12.7 %	94.7 %
stress_steps_uT[5]	0.0 %	15.0 %	16.6 %		59.4 %	4.4 %	98.4 %
stress_steps_uT[4]	2.5 %	17.7 %	17.5 %		58.4 %		98.6 %
stress_steps_uT[3]	2.6 %	17.3 %	16.8 %		58.8 %		99.2 %
stress_steps_uT[2]	2.4 %	18.4 %	17.3 %		59.6 %		99.3 %
stress_steps_uT[1]	1.9 %	18.8 %	17.0 %		60.9 %		99.3 %
stress_steps_uT[0]	2.3 %	18.0 %	17.1 %		59.3 %		99.3 %

Models \ Parameter	MU1	A1	MU2	A3	logA2	logMU3	Total
stress_steps_sS[11]				40.6 %		81.9 %	99.2 %
stress_steps_sS[10]				32.5 %	6.8 %	78.8 %	97.6 %
stress_steps_sS[9]		6.4 %	0.0 %	22.6 %	16.0 %	59.1 %	94.1 %
stress_steps_sS[8]	0.6 %	9.2 %	14.4 %	3.2 %	43.8 %	22.1 %	90.2 %
stress_steps_sS[7]	0.0 %	13.0 %	17.5 %		55.4 %	8.2 %	96.0 %
stress_steps_sS[6]	0.0 %	15.3 %	16.6 %		59.3 %	2.5 %	99.4 %
stress_steps_sS[5]	2.9 %	17.1 %	17.8 %		59.9 %		99.0 %
stress_steps_sS[4]	2.4 %	16.7 %	17.9 %		59.6 %		99.3 %
stress_steps_sS[3]	2.1 %	18.6 %	17.2 %		59.1 %		99.3 %
stress_steps_sS[2]	1.9 %	17.1 %	18.1 %		59.6 %		99.3 %
stress_steps_sS[1]	2.2 %	18.0 %	17.1 %		59.3 %		99.3 %
stress_steps_sS[0]	2.3 %	16.6 %	18.0 %		60.8 %		99.3 %

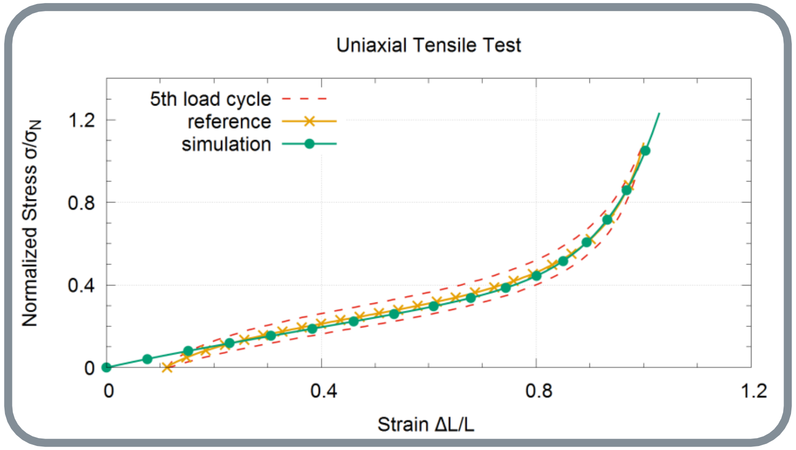
Sensitivity analysis and direct optimization result

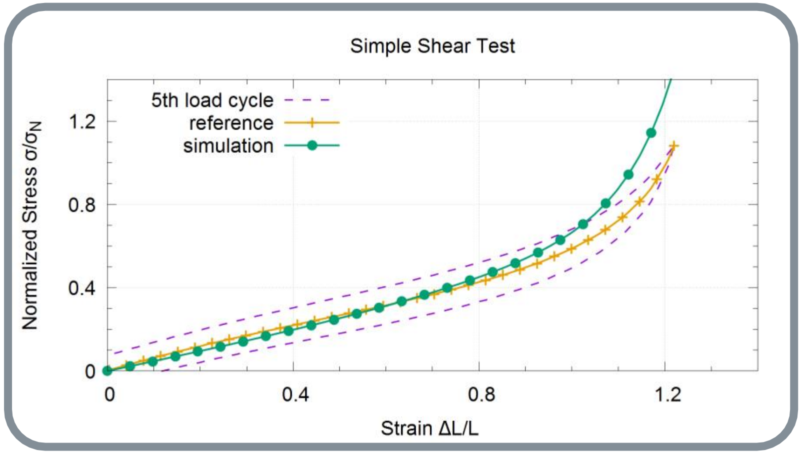
Signal plots:





Optimization result:

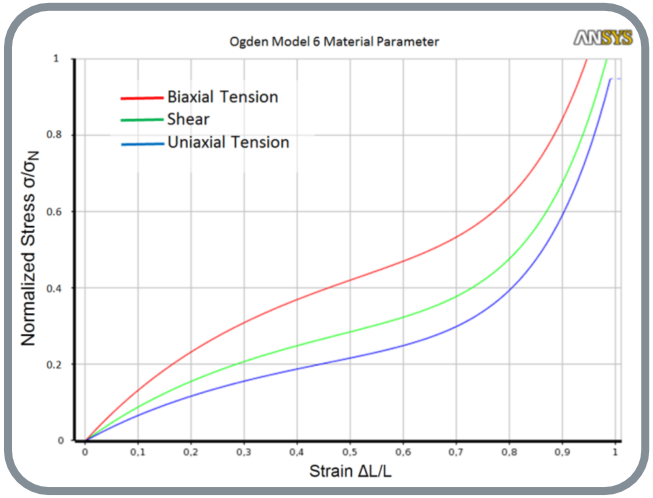




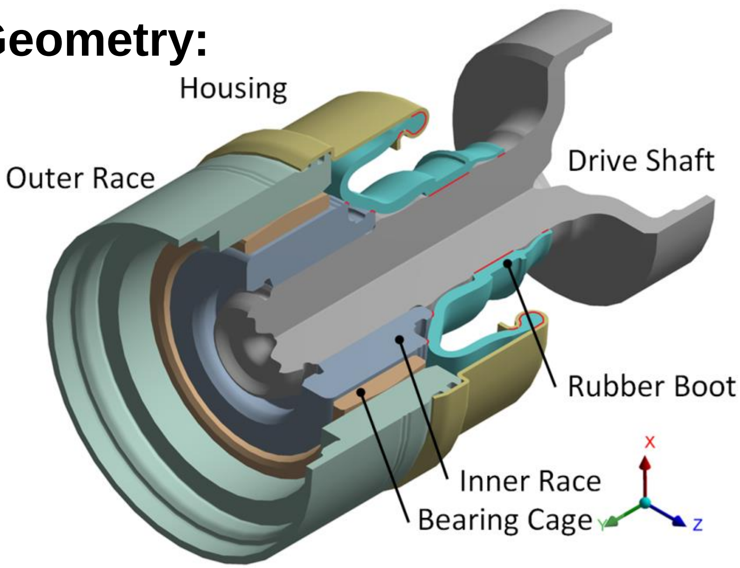
- Motivation
- Parameter Identification and Curve Fitting with optiSLang
- **2D – axis symmetric analysis of an elastomer rubber boot**
- Summary

FE model and positioning simulation

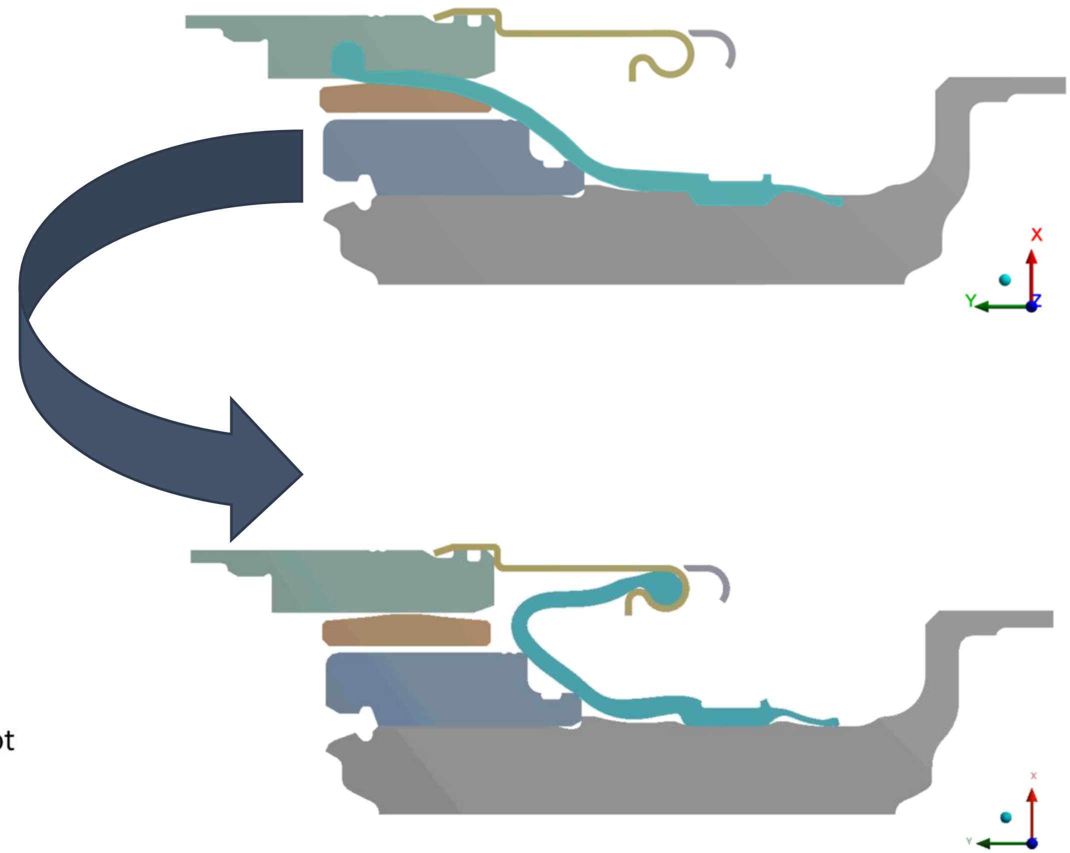
Hyperelastic material model:



Geometry:

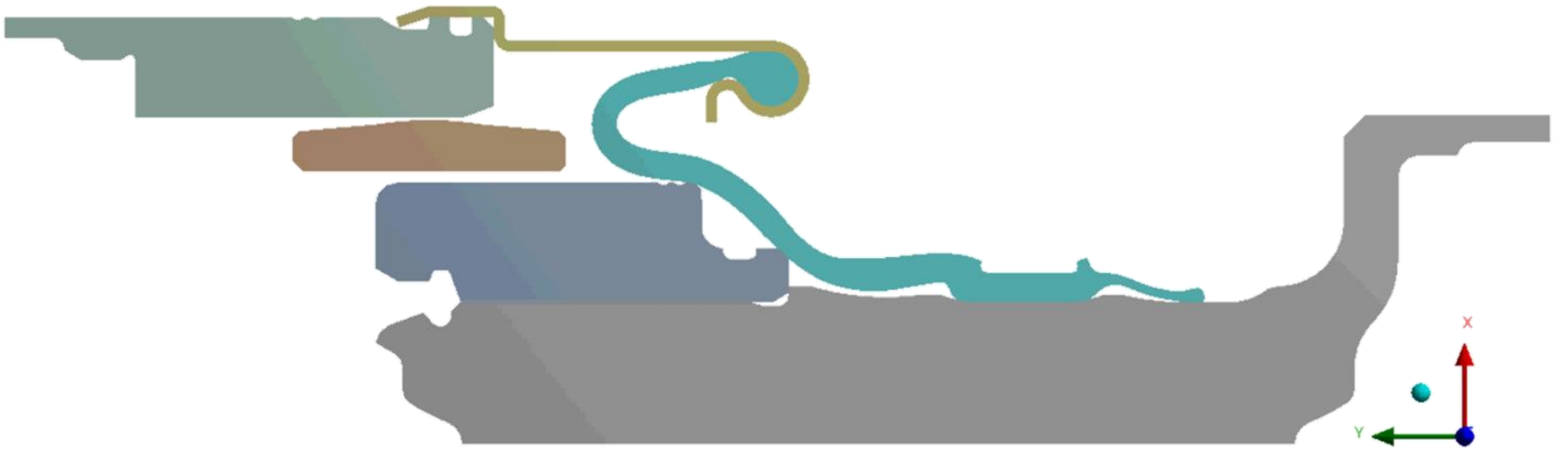


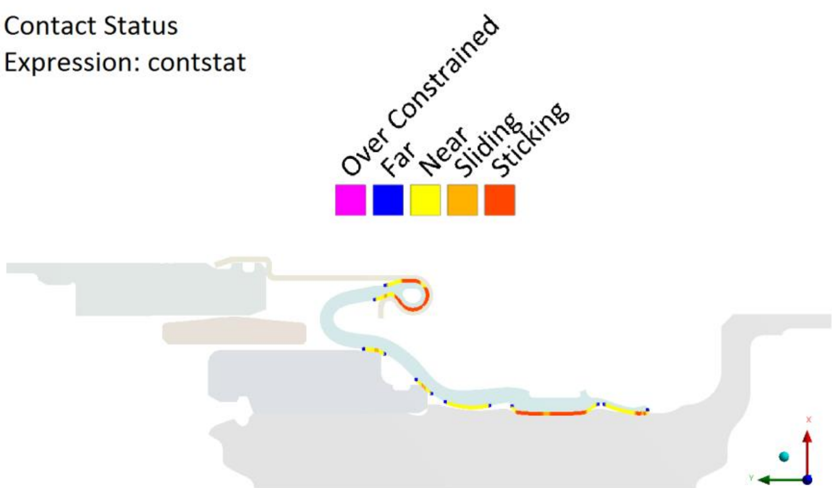
Rubber boot positioning:

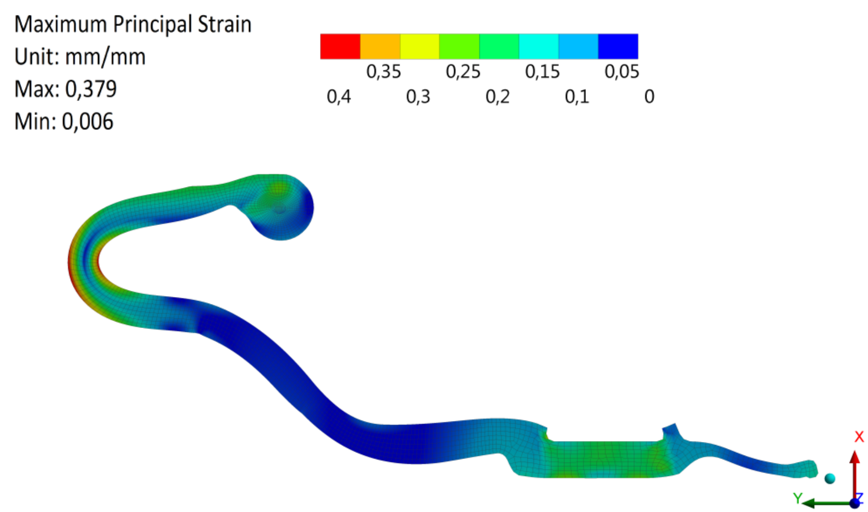


Length compensation and fluid pressure load

Positive length compensation
dy= + 15 mm:

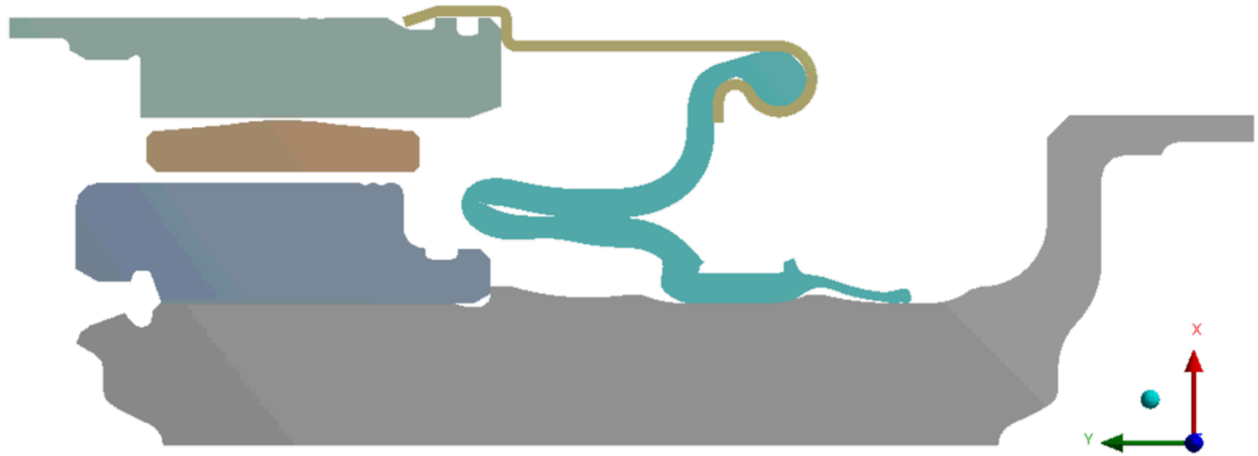


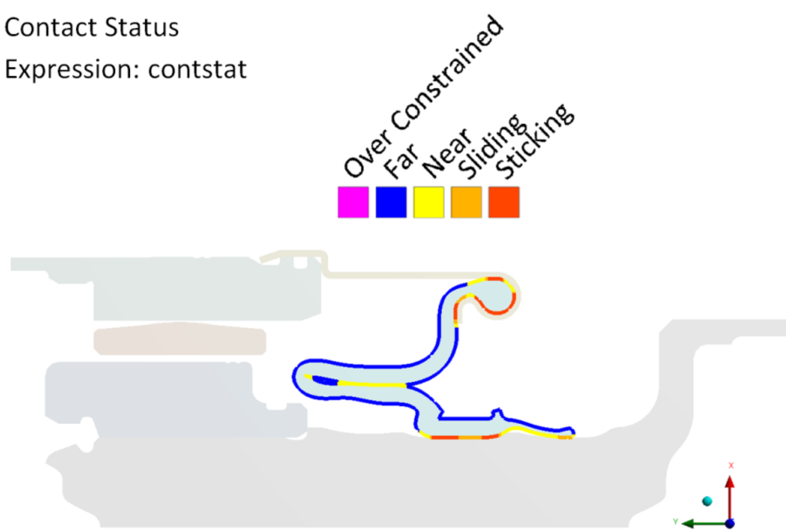


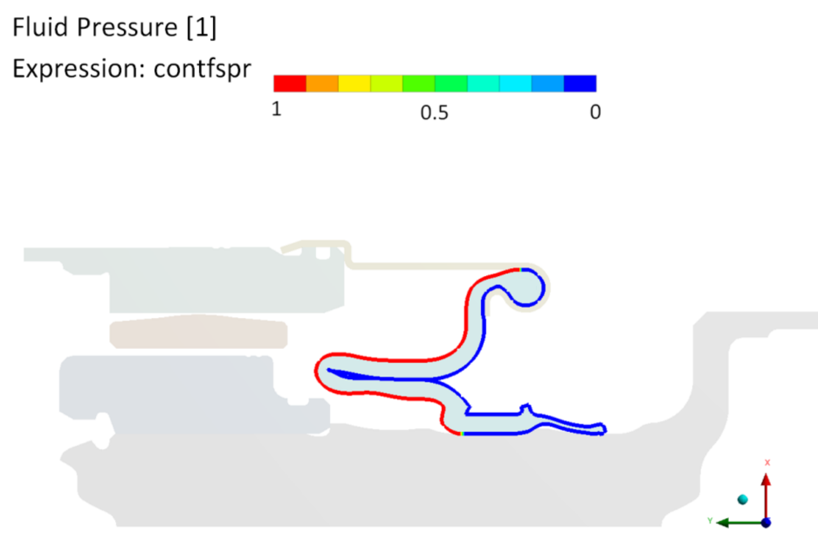


Length compensation and fluid pressure load

Negative length compensation
dy= - 15 mm:







Motivation

Parameter identification and curve fitting with optiSLang

2D – axis symmetric analysis of an elastomer rubber boot

Summary

Summary

- **Use optiSLang to fit a 6 parameter Ogden model on experimental data of uniaxial tensile test and simple shear test.**
- **Determined parameter set correlates well with experimental material data for strain range from 0 to 1.**
- **Deformation and seal function of rubber boot could have been predicted reliable by 2 dimensional axis symmetric fluid penetration analysis.**
- **Experiences will be used to develop a 3 dimensional FE model to investigate effects during flexion.**

Contact:

Ingo Grunow (M. Eng.) – Ingo.Grunow@ifa-group.com

Jean Lefèvre (Dr.-Ing.) – Jean.Lefevre@ifa-group.com