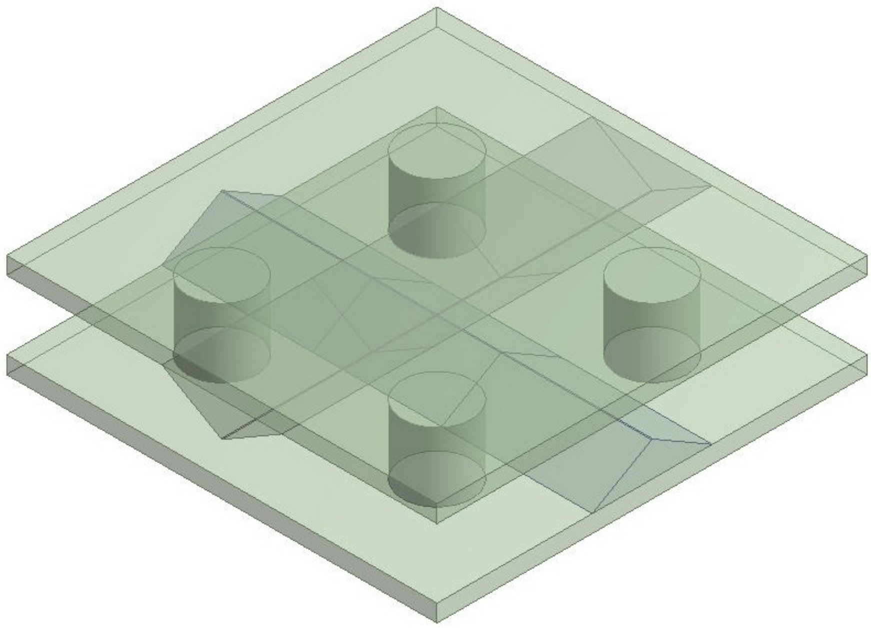
Structural simulation of the DLR "Artificial Skin" with ANSYS®



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1 Introduction

A silicon based 3D structure is intended to be used as a sensorgrid for robots, like an "artificial skin". Aim is to simulate the tactile sense of a human skin on a robot. To achieve an optimal sensor geometry, various test are carried out. Part of the test series is a structural simulation of the sensor with ANSYS®. In this document, the results of different structural simulations like

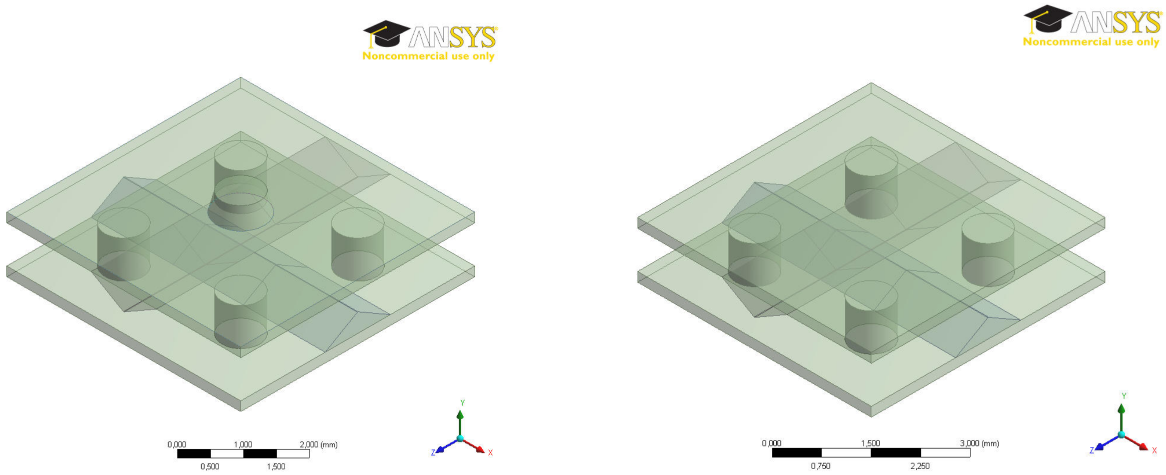
- pure displacement with three different electrode geometries,
- deformation of a Taxel with Bumper under external force,
- deformation of a Taxel without Bumper under external force

will be presented.

Initially pure displacement of the electrodes with different angles α (see figure 4) is simulated. Reason for this simulation is to evaluate the maximal contacting area between the electrodes dependent of the displacement. Next step is to simulate two different types of Taxel, one with Bumper[1] the other without, to compare the deformation of the Taxel and the contacting area between the electrodes under an external load.

2 Realization

An ANSYS simulation of a full 3D model requires high computing power and takes a long processing time. To reduce the processing time a symmetry model in xy- & yz-plane is calculated. The simulation is based on a 2x2 Taxel (see Figure 1a and 1b).



(a) With Bumper

(b) Without Bumper

Figure 1: 3D model of a 2x2 Taxel

The simulation itself is performed with ANSYS Workbench 13.0 and Windows 7, 64-Bit.

2.1 Material data

The material used in the structural simulation is a Silicon Shore A 50. To simulate the displacement of the electrodes and the Taxel, interpolated material curves are used in ANSYS. The ANSYS materialdata is based on two interpolated material curves. One curve represents the pressure test, the other curve a shear test. The interpolations are calculated with the Newton interpolation formula.

$$y = a_0 + a_1(x - x_0) + a_2(x - x_0)(x - x_1) + \ldots + a_n(x - x_0)(x - x_1)(x - x_2)(x - x_{n-1})$$

[1] *Bumper*: Name for a small attachment at the top of the silicon layer, placed above the crossing point the electrodes.

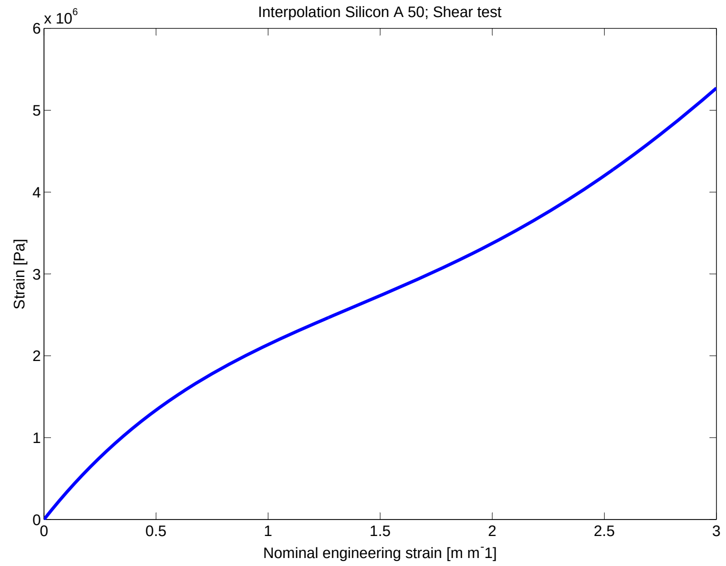


Figure 2: Newton interpolation for the silicon A 50 shear test

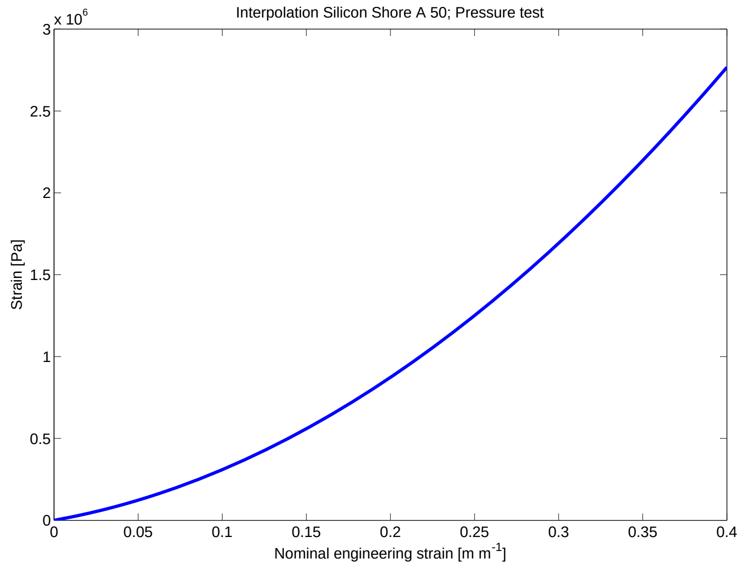


Figure 3: Newton interpolation for the silicon A 50 pressure test

After importing the material data a curve fitting (Mooney-Rivlin, five parameter) is done in ANSYS to get the hyperelastic material parameters.

Material constant C10:	$6,392 \cdot 10^5\,\mathrm{Pa}$
Material constant C01:	$-1,0619 \cdot 10^5\,\mathrm{Pa}$
Material constant C20:	$2174,1\,\mathrm{Pa}$
Material constant C11:	$-8908\,\mathrm{Pa}$
Material constant C02:	$10\,357\,\mathrm{Pa}$

Table 1: ANSYS material constants, Mooney-Rivlin five parameter

2.2 Requirements simulation pure electrode displacement

This parts represents a pure displacement of the electrodes against each other, without taking account of the resulting strain or the necessary force to compress the electrodes. The simulations of the electrode displacement were named according to the angle alpha (see Figure 4):

- Electrode 30°: alpha = 30°
- Electrode 45°: alpha = 45°
- Electrode 60°: alpha = 60°

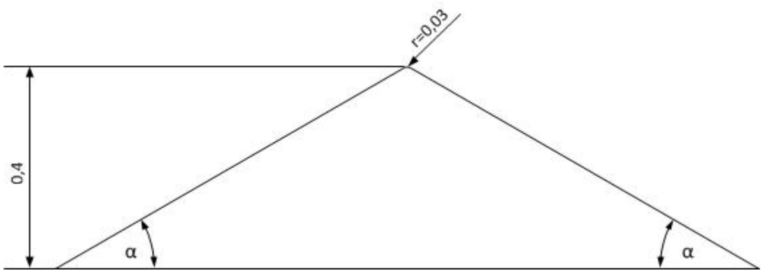
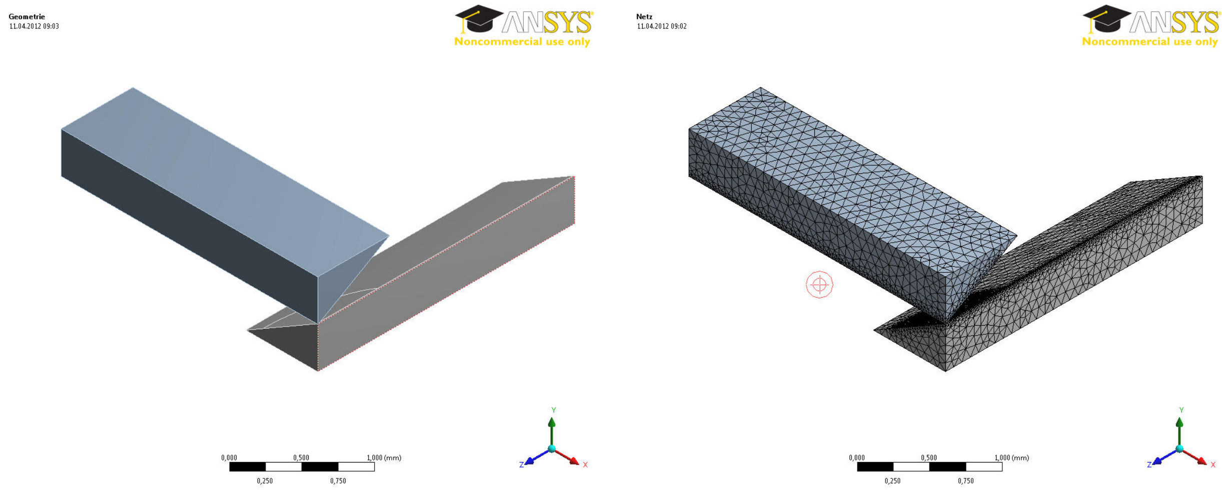


Figure 4: Cross section Electrode

Figure 5a and 5b stands exemplary for the "Electrode displacement simulation".



(a) Unmeshed electrode (b) Meshed electrode

Figure 5: Electrodes 30° in starting position (xy- & yz-plane symmetry)

Additionally the support and load of the electrodes is shown in Figure 6. Both symmetry areas (xy- and yz-plane) are per definition "frictionless support" after the suggestion of the ANSYS help. The bottom side was defined as "fixed support", the opposite layer was defined with the displacement C, direction to the electrodes.

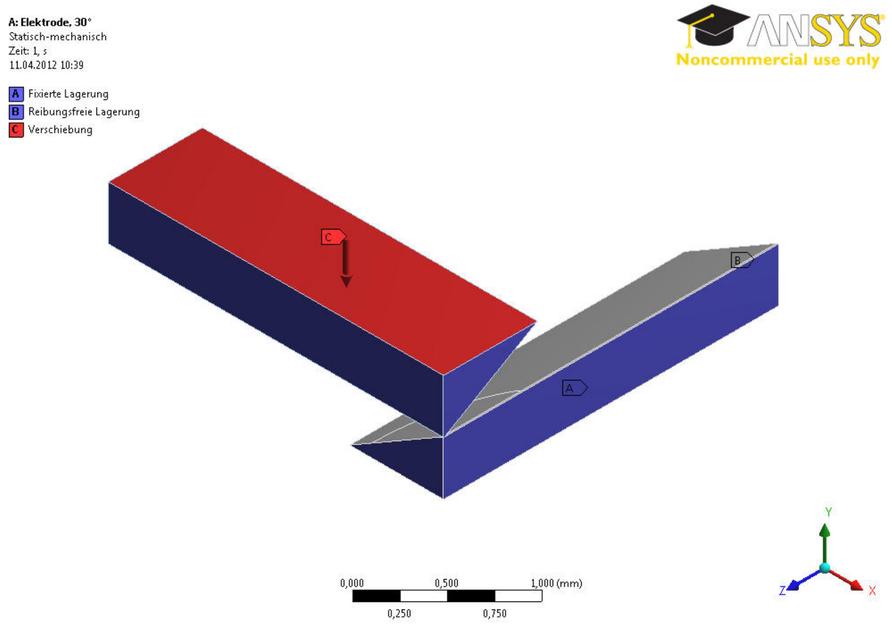
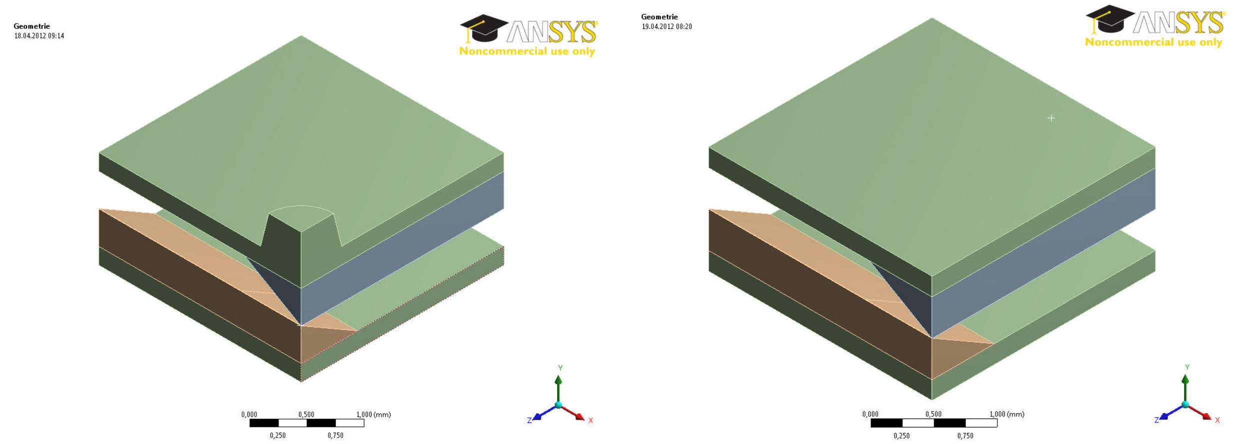


Figure 6: Electrodes 30° support and load for solution

Detailed information about all simulation settings are written in the report "Elektrode_30_Bericht" of the "Elektrode_30-45-60_Grad.wbpj" ANSYS Workbench project.

2.3 Requirements simulation Taxel deformation

Based on the results of the electrode deformation (see Table 2), the 30° electrode is choosen for further simulation because of the highest contact area between the compressed electrodes.
For detailed specification see the report "Taxel_2x2-30_bumper_report" of the "Pressure_Testing.wbpj" - Taxel with Bumper - and the report "Taxel_2x2-30_no-bumper_report" of the "Pressure_Testing_no_bumper.wbpj" - Taxel without Bumper - ANSYS Workbench project.



(a) Taxel with Bumper

(b) Taxel without Bumper

Figure 7: Taxel in starting position (xy- & yz-plane symmetry)

3 Results

3.1 Pure electrode displacement

All simulations end without any interruption. In average 10 Substeps per Loadstep are needed, no Bisection is shown.

3.1.1 Deformation

The following pictures shows the compression of each electrode type after a displacement of 0,2 mm.

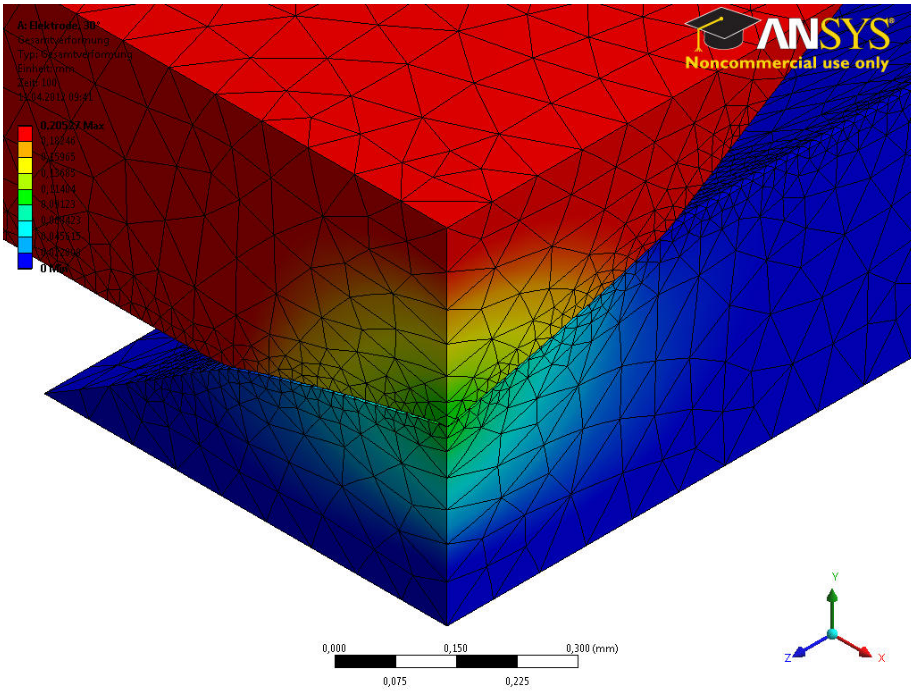


Figure 8: Pure Displacement, Electrode 30°

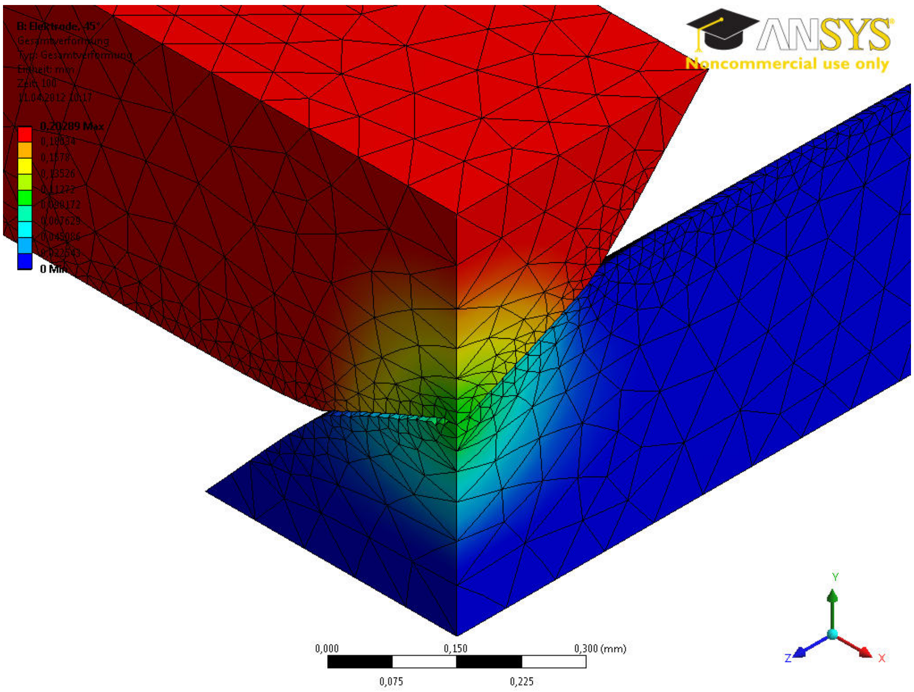


Figure 9: Pure Displacement, Electrode 45°

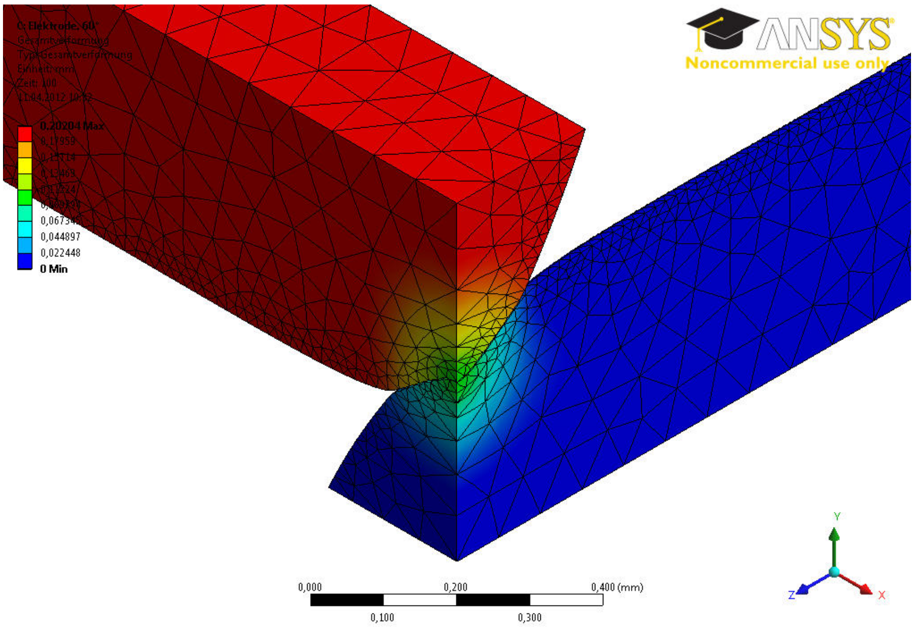


Figure 10: Pure Displacement, Electrode 60°

The edges of the electrodes inside the contact area is not planar. Instead it looks like that there are some "pores" inside the contacting area.

3.1.2 Contacting Area

The contact area in ANSYS is defined only over the sticking elements of the electrodes inside the specified contacting area. Inside the Workbench project "Elektrode_30-45-60_Grad.wbpj" the contacting area is selected by the rounded area (r = 0,03 mm) on top of the electrodes and the area on both sides of the electrode surface based in the center coordinate system with r = 0,4 mm (Electrode 30°) and 0,6 mm (Electrode 45° and 60°).

Electrode	Electrode 30°	Electrode 45°	Electrode 60°
Contacting area $[mm^2]$	$6,545447 \cdot 10^{-2}$	$2,143626 \cdot 10^{-2}$	$9,0477 \cdot 10^{-3}$
Displacement $[mm]$	0,20527	0,20289	0,20204

Table 2: Maximum electrode contacting area, ANSYS simulation

Electrode 30°

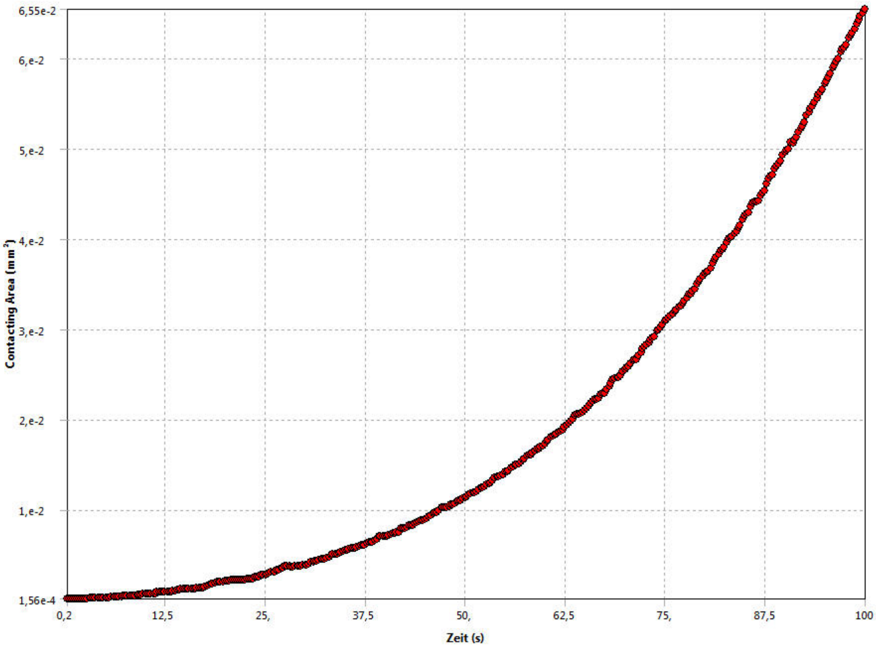


Figure 11: Contacting area, 30°

Electrode 45°

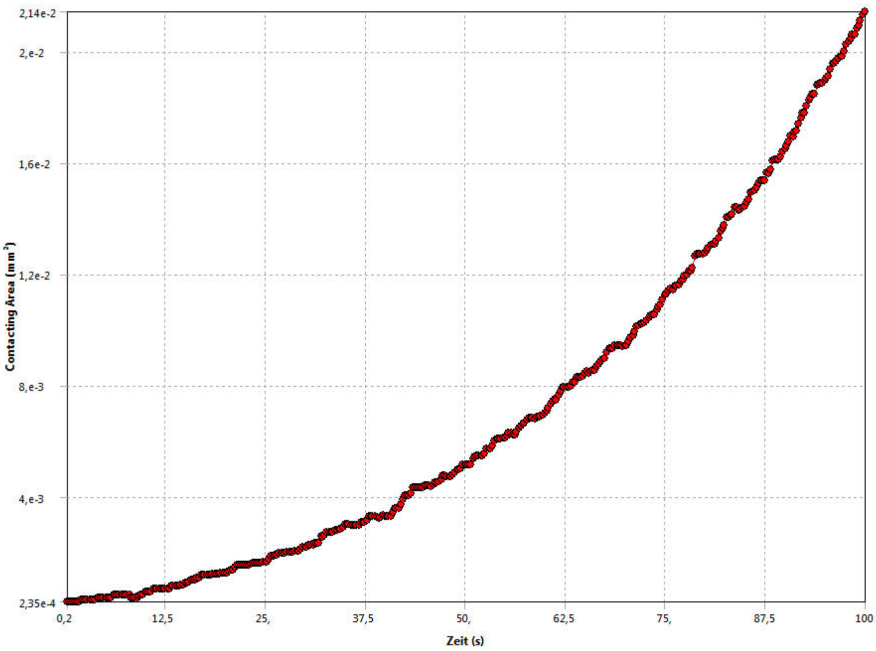


Figure 12: Contacting area, 45°

Electrode 60°

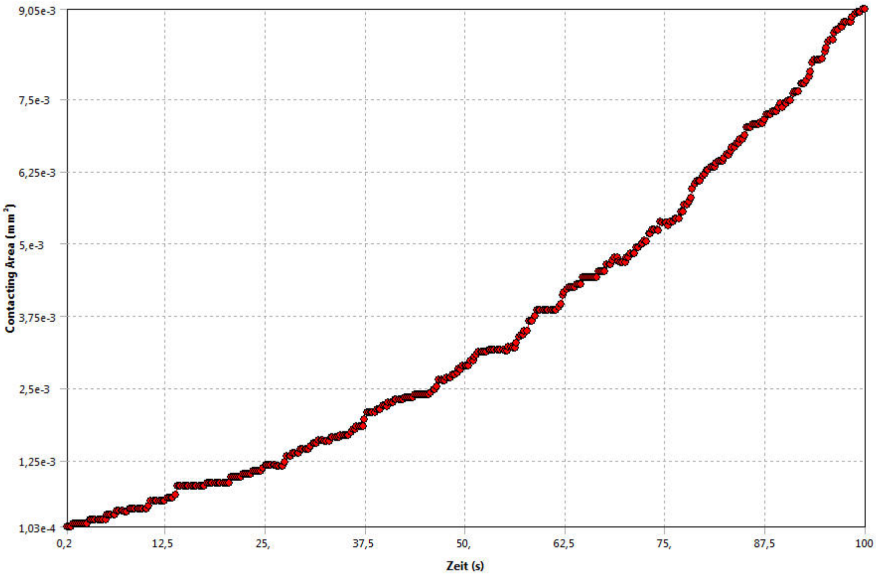


Figure 13: Contacting area, 60°

It should be noted, that the value of the contacting area in Figure 11, 12 and 13 is only for the symmetric model. To get the contacting area of the full electrode, the value has to be multiplied with four.

3.2 Taxel deformation

It is seen that there are two different types of deformation, depending on if the Taxel is with Bumper or without Bumper.

3.2.1 Deformation

Taxel with Bumper

In this case, the deformation of the Taxel is more located in the Bumper-area. Until the Test body does not reach the Taxel surface, only the Bumper itself is displaced. After contact between Test body and upper layer, the whole Taxel is deformed.

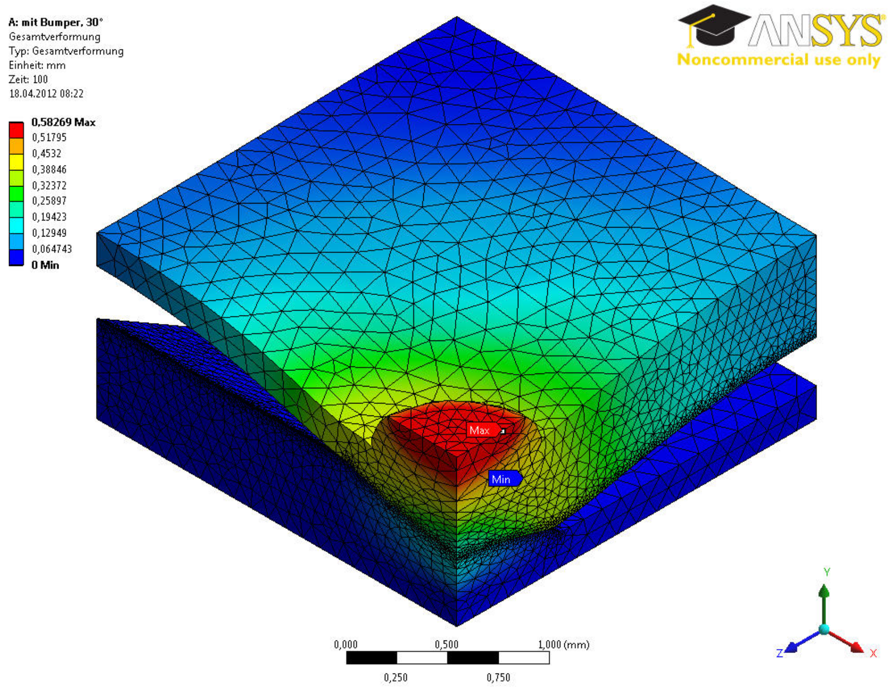


Figure 14: Displacement Taxel with Bumper after load of $F = 0{,}5\,\mathrm{N}$; isometric view

In Figure 15 it is seen, that the whole compressed Bumper is beneath the undeformed upper layer of the Taxel.

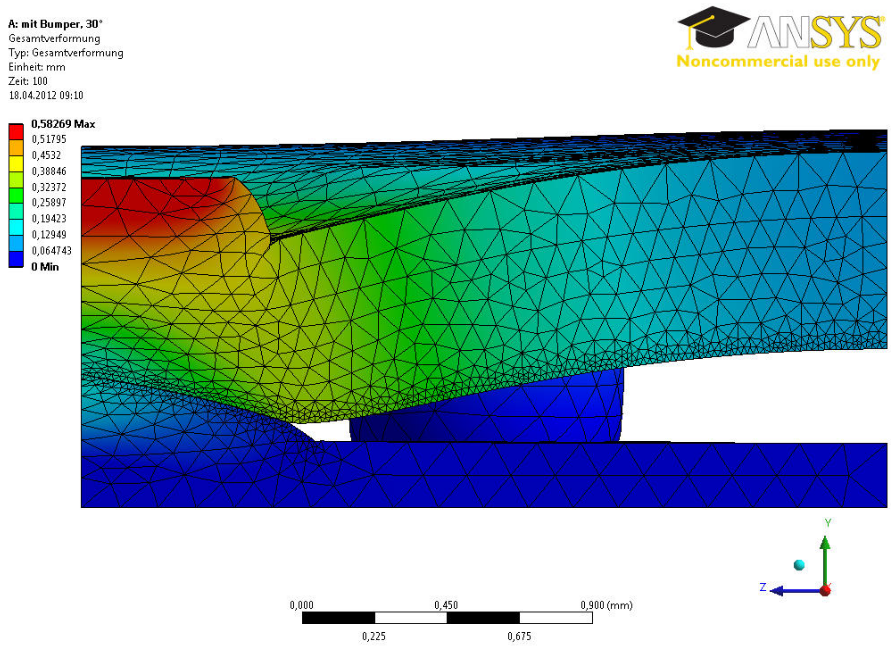


Figure 15: Displacement Taxel with Bumper after load of $F = 0{,}5\,\mathrm{N}$; close up, side view

Taxel without Bumper

In comparison to the Taxel with Bumper, the Taxel without Bumper shows a homogeneous deformation of the whole Taxel.

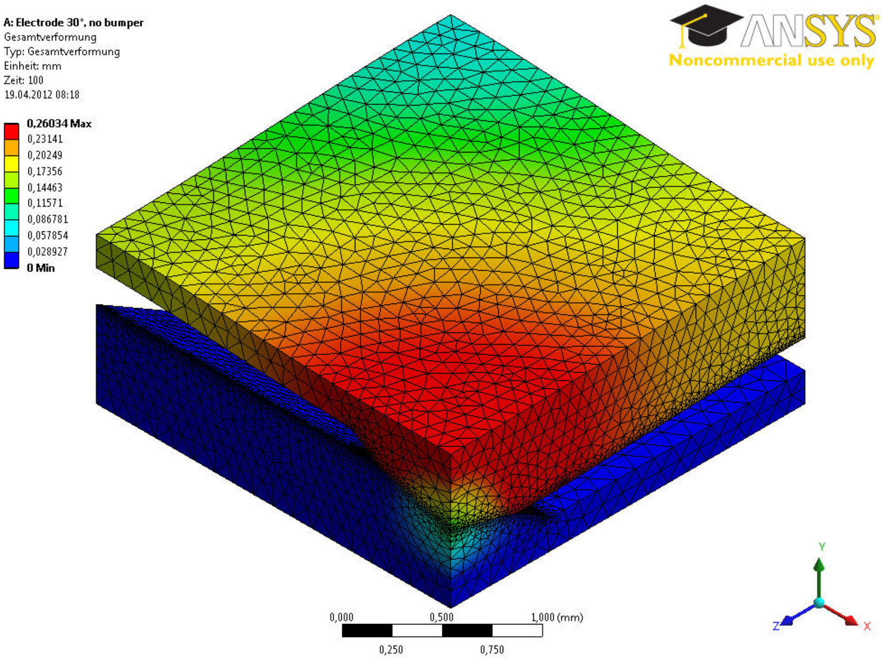


Figure 16: Displacement Taxel without Bumper after load of $F = 0{,}5\,\mathrm{N}$; isometric view

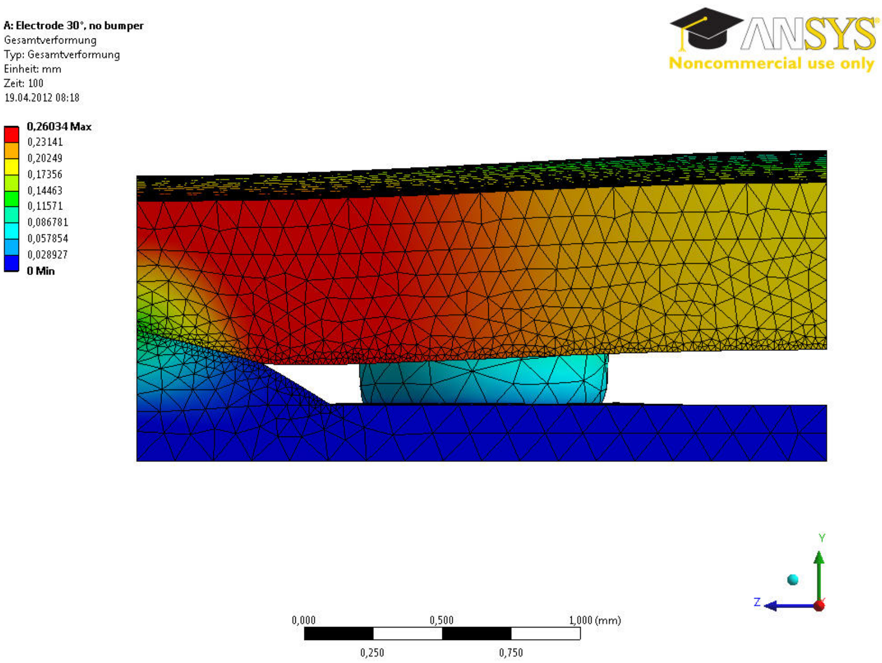
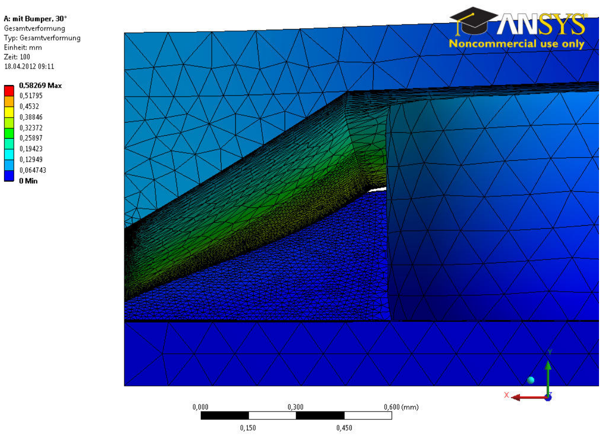
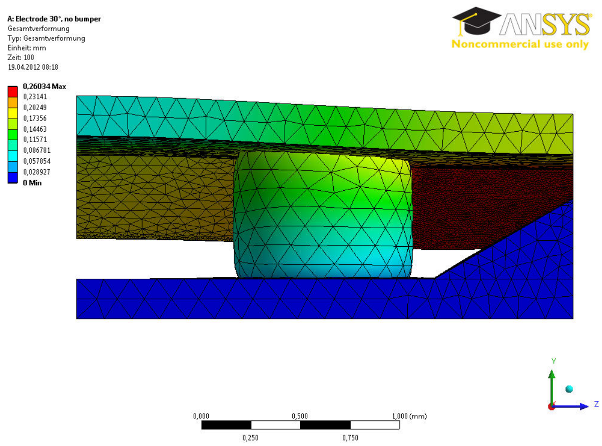


Figure 17: Displacement Taxel without Bumper after load of $F = 0{,}5\,\mathrm{N}$; close up, side view

The different effects of the Taxel geometry on the Spacer is shown in Figure 18. The Spacer in Figure 18a is less compressed than the Spacer in Figure 18b.



(a) Taxel with Bumper



(b) Taxel without Bumper

Figure 18: Displacement Taxel after load of $F = 0{,}5\,\mathrm{N}$; close up spacer

3.2.2 Contacting Area

The following figures relates to the same contacting area as described in chapter 3.1.2. The difference is that the contacting area results as a function of an external force, not of a parallel displacement.

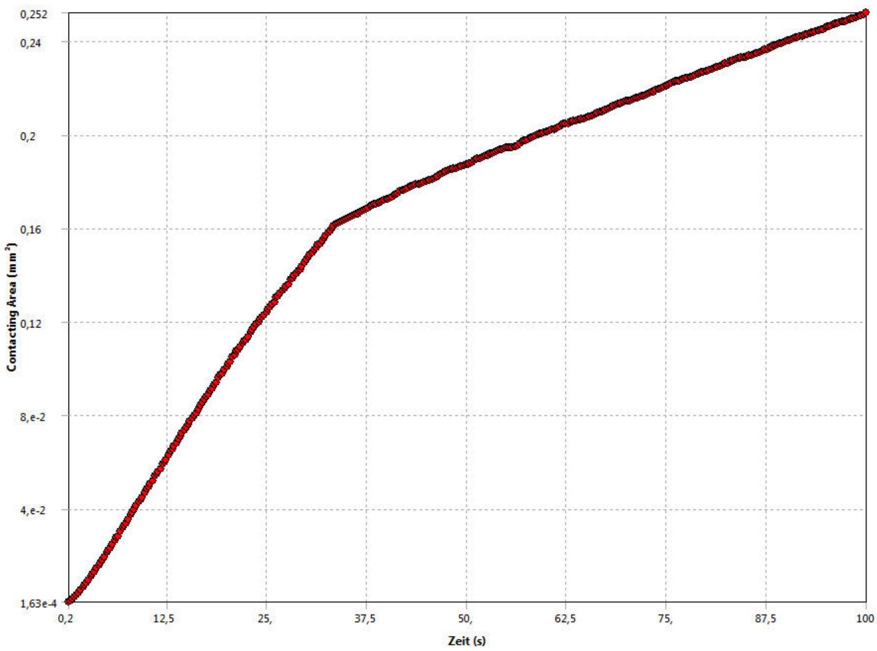


Figure 19: Contact are; Taxel with Bumper under constant increasing load $F_{max} = 0{,}5\,\mathrm{N}$

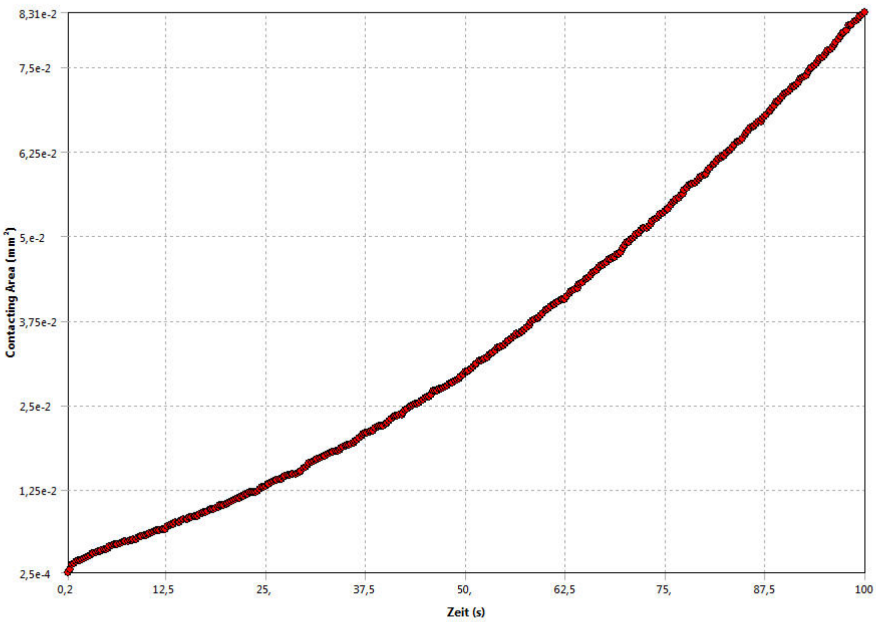


Figure 20: Contact are; Taxel without Bumper under constant increasing load $F_{max} = 0{,}5\,\mathrm{N}$

The contacting area of the Bumper system is greater than the area of the No Bumper system. Additionally the correlation of displacement and the calculated full contacting area between the electrodes, dependent of an external force is considered.
The displacement curve and contacting area curve in Figure 21 are almost parallel.

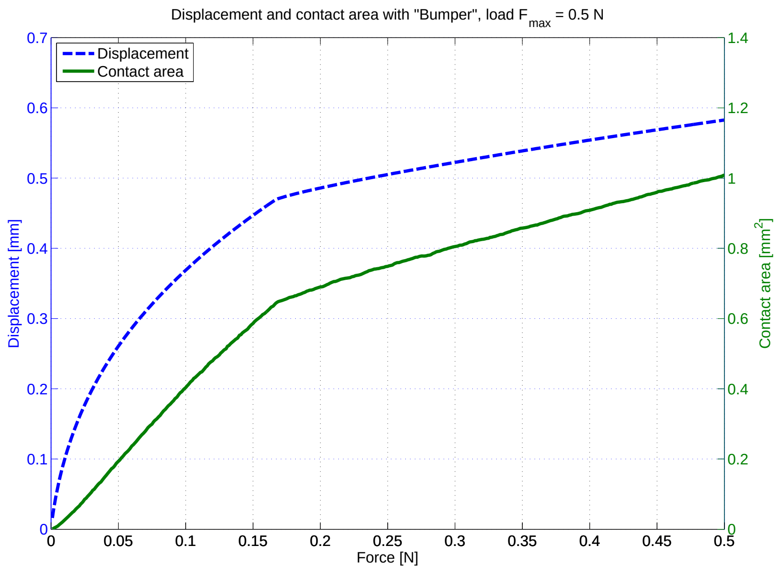


Figure 21: Displacement and calculated contact area of a Taxel with Bumper in dependence of external force F

In Figure 22 can be seen that the displacement curve and contacting area curve have an intersection at $F \approx 0{,}38\,\mathrm{N}$. After the intersection the contacting area rises more than the displacement.

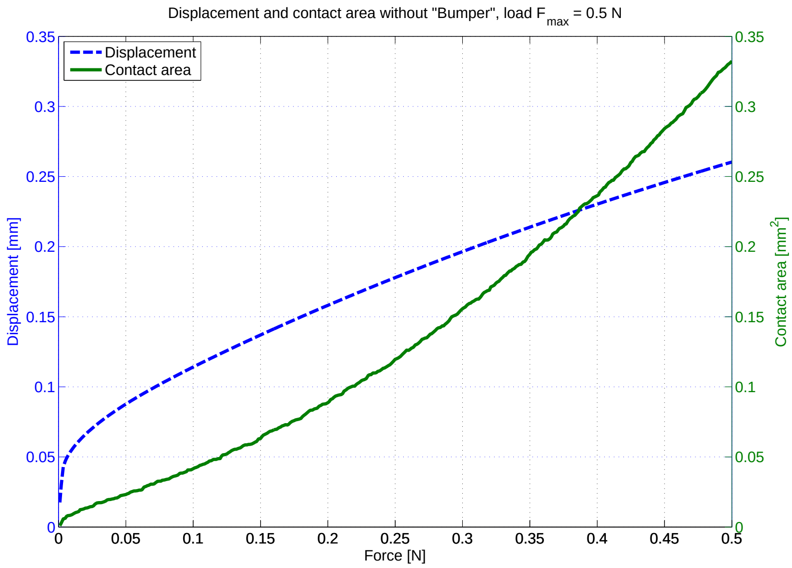


Figure 22: Displacement and calculated contact area of a Taxel without Bumper in dependence of external force F

4 Summary

A detailed view regarding the electrode deformation in Figure 9 for example shows a porous surface at the edges inside the contacting area. Most likely this is a result of the meshing method. Actually the mesh edge length in this area is $< 20\,\mu$m from node to node and it has yet to be checked if a more detailed mesh offers a more detailed result. As seen in Figure 11, Figure 12 and Figure 13 the contact between the electrodes gets smaller the higher the electrode angle α is. To evaluate the "real" contacting area (Figure 23, Table 3), the area of the ANSYS simulation has to be multiplied with 4, due to the symmetry during simulation.

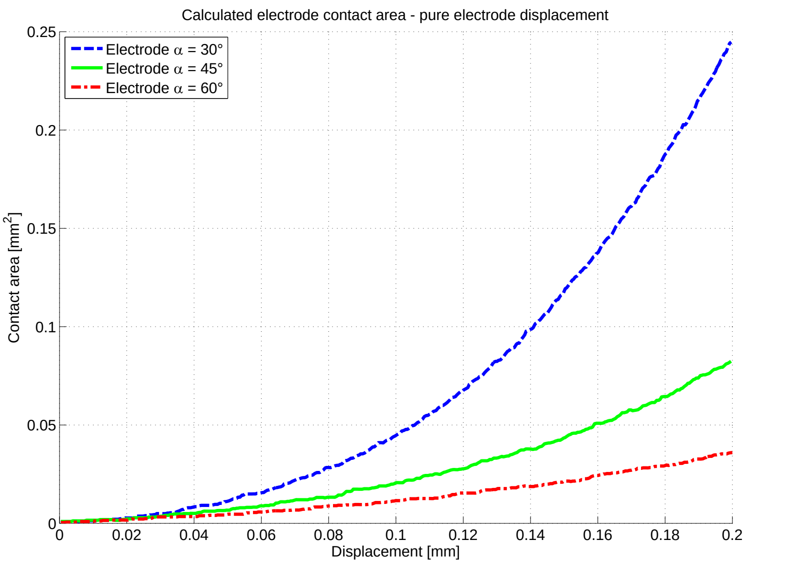


Figure 23: Calculated "real" electrode contacting area

Electrode	Electrode 30°	Electrode 45°	Electrode 60°
Contacting area $[mm^2]$	0,261819	0,085745	0,036191
Displacement $[mm]$	0,20527	0,20289	0,20204

Table 3: Maximum calculated "real" electrode contacting area

The most sensitive sensor resolution shall be obtained with the 30° electrode, due to actual electrode design. This type of electrode has the biggest contact area after a displacement of 0,2 mm (see Figure 23). To optimize the sensitivity a Bumper should be placed on top of upper layer. As seen in Figure 24 the curve from the Taxel with Bumper describes a higher gradient, especially in the range from 0 to 0,15 N.

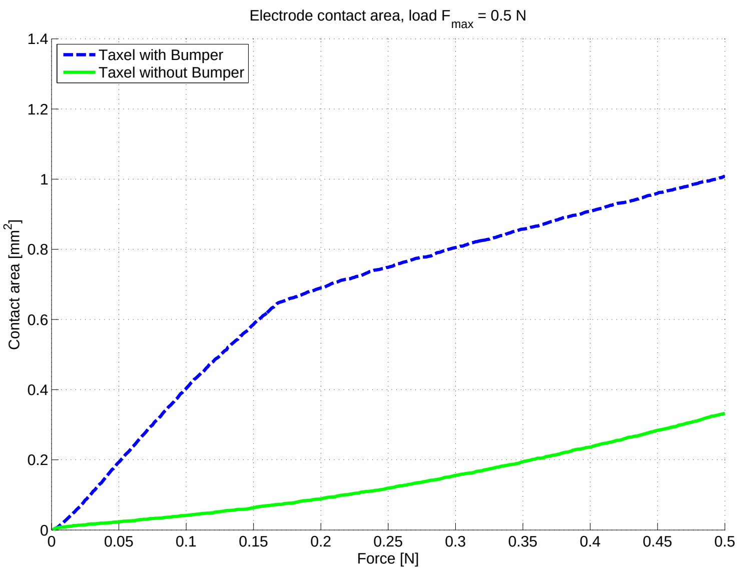


Figure 24: Comparison contact area of a Taxel with and witout Bumper

The simulation of the symmetric model under influence of an external force shows a serious difference between the deformation pattern of the Taxel. The Taxel with Bumper shows a local and centralized deformation above the crossing section of the electrodes until the test body has no contact with the upper silicon layer of the Taxel. After contact of the test body with the upper layer (see Figure 19, Time 33 s), the rise of the contacting curve flattens. This results from the influencec of the Spacer and has the consequence of a higher stiffness at this point of deformation.
The Taxel without Bumper results in a more homogeneous deformation due to the earlier influence of the Spacer based on the higher Taxel stiffness.

5 Additional documents

- ANSYS Protocoll "Elektrode_30_Bericht"
- ANSYS Protocoll "Taxel_2x2-30_bumper_report"
- ANSYS Protocoll "Taxel_2x2-30_no-bumper_report"