Design of Pressure Measuring Cells Using the Unified Material Law

Geometry Optimization for Better Sensor Sensitivity, Realistic Material Modeling for Burst Pressure Estimation

STW Technic, LP
Mobile Controllers and Measurement Technologies

Pablo Aguirre, Felipe Figueroa

Sensor Technik Wiedemann GmbH, Kaufbeuren, Bavaria, Germany

Introduction: Pressure sensors *(Figure 1)* are widely used in the automotive industry. Their main use is the dynamic monitoring of pressure inside combustion engines [1]. Normally the sensor measuring cells have small sizes up to one centimeter *(Figure 2)*. To achieve a good signal accuracy, the design of pressure sensors can be improved with FEM calculations of stress and strains on the measuring cell depending on their geometry and material properties. The geometry is adapted according to a desired nominal pressure and a limit rule of the stresses *(Figure 3)*.

***Figure 1**. Some STW pressure sensors*

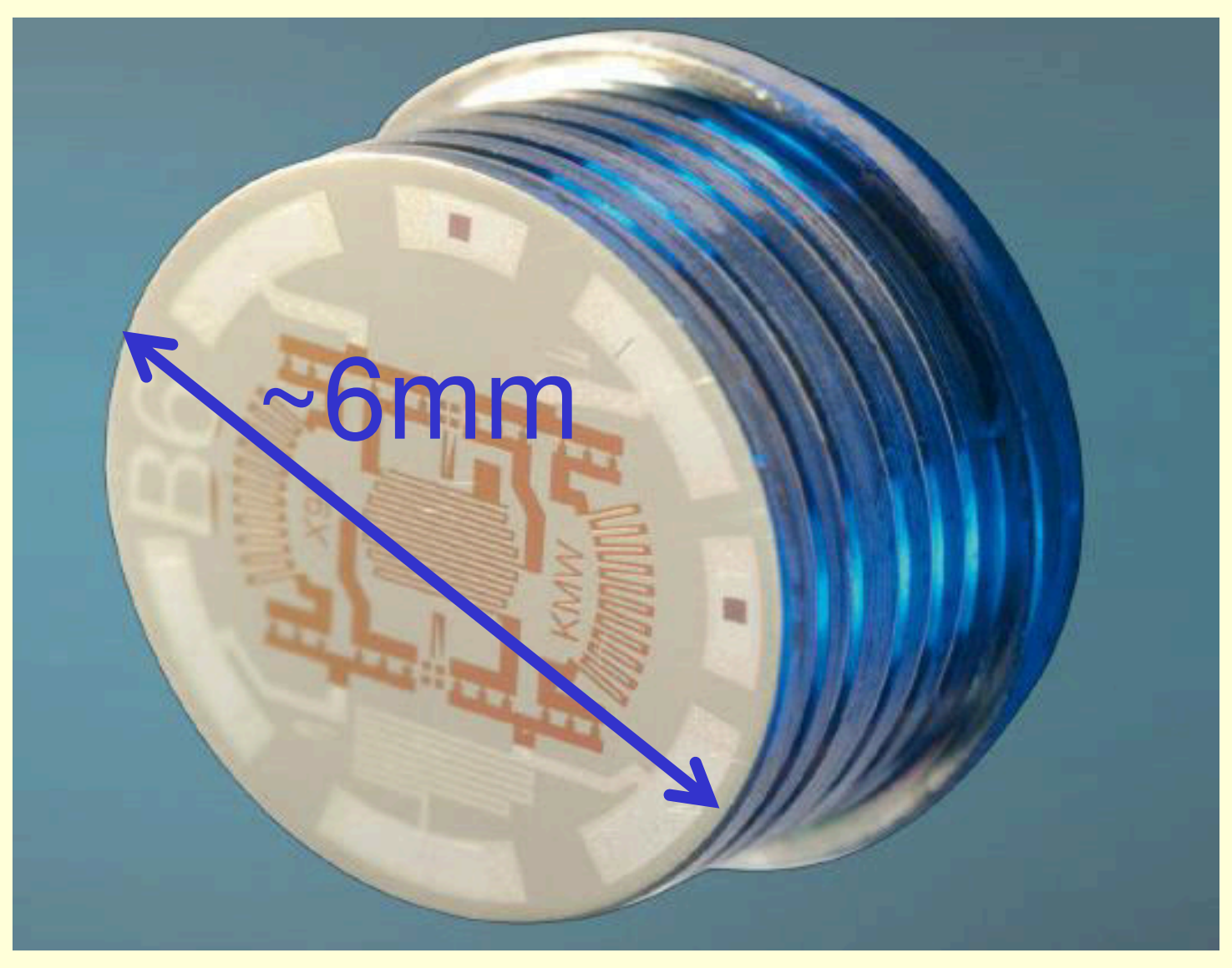
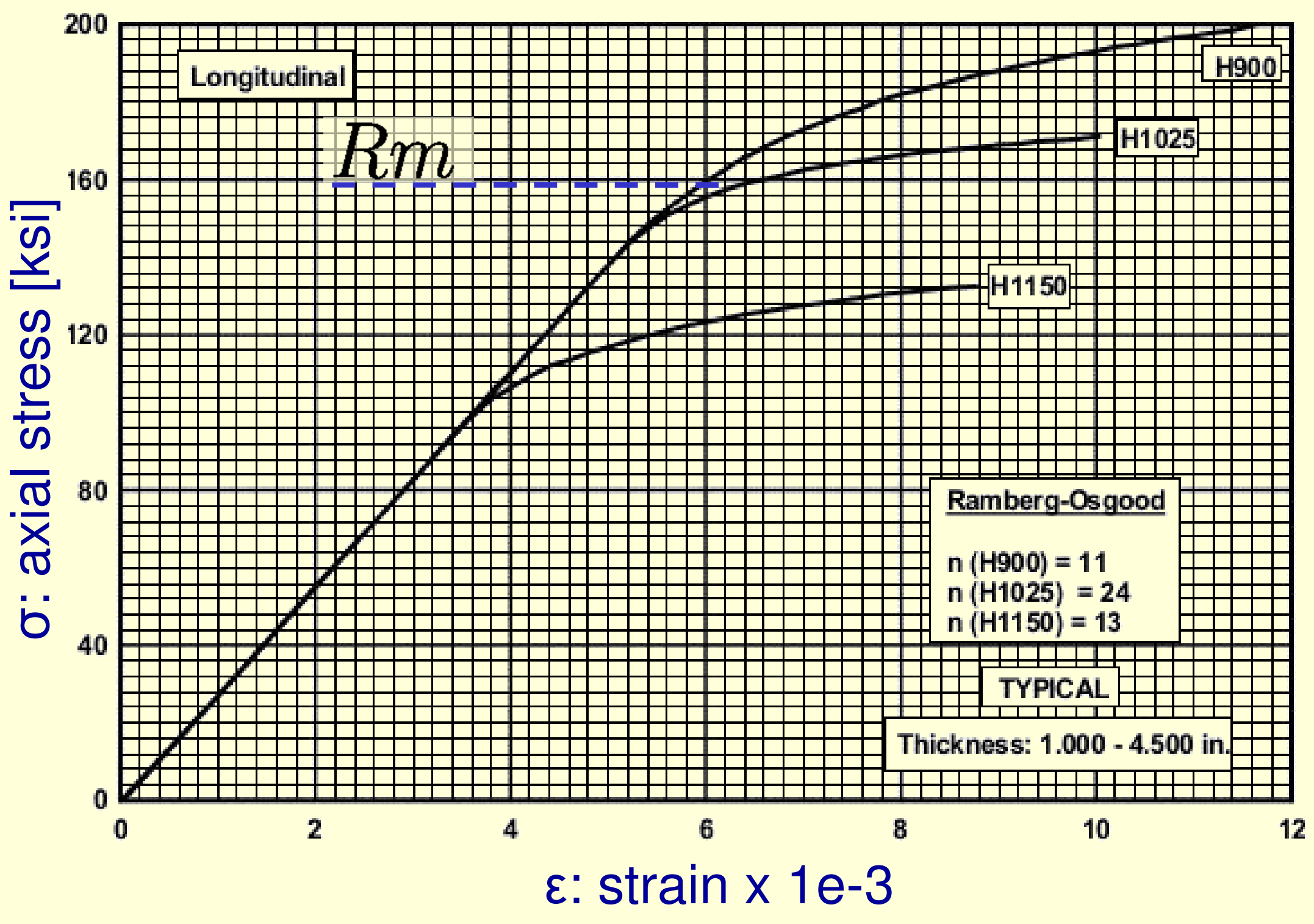


***Figure 2**. A measuring cell*

Computational Methods: A cylindrical measuring cell is modeled in 2D using the Solid Mechanics module in Comsol. The diameter, inner contour and membrane thickness are parameterized *(Figure 4)*. Material properties [5] of realistic material model "unified material law" (UML) [2] [3] equation for steels is chosen and implemented in Comsol *(Figure 3)*.



$$\varepsilon = \frac{\sigma}{E} + \left(\frac{\sigma}{1,65Rm}\right)^{1/1,65}$$

***Figure 3**: Typical tensile stress-strain curves at room temperature for various heat treated conditions of 17-4PH stainless steel bar [5]. UML equation: where "Rm" is the ultimate tensile strength.*

The cell is fixed on the bottom and loads on the inner surface are defined. The governing equation for the elasticity study $-\nabla \cdot \sigma = F_V$ is used by Comsol for the calculation of strains on membrane surface and the stresses *(Figures 5 to 7)* in the material. By defining a constant maximal limit of allowed stress *(Figures 3 & 7)*, and varying the geometry parameters *(Figure 4)*, it is possible to optimize the difference between maximal and minimal strains on the membrane surface *(Figure 6)*.

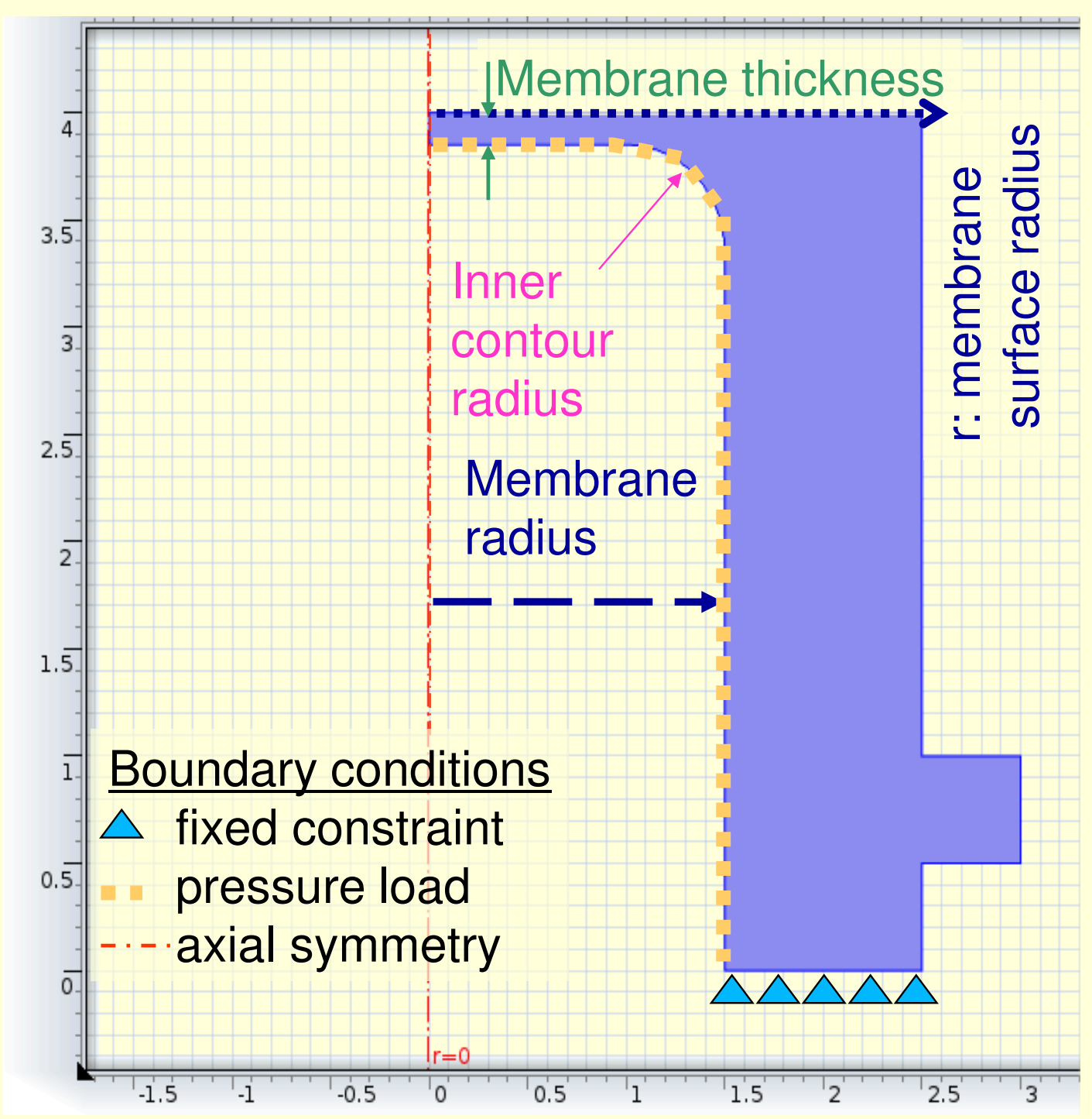


***Figure 4**. Cell model as 2D in cylindrical coordinates*

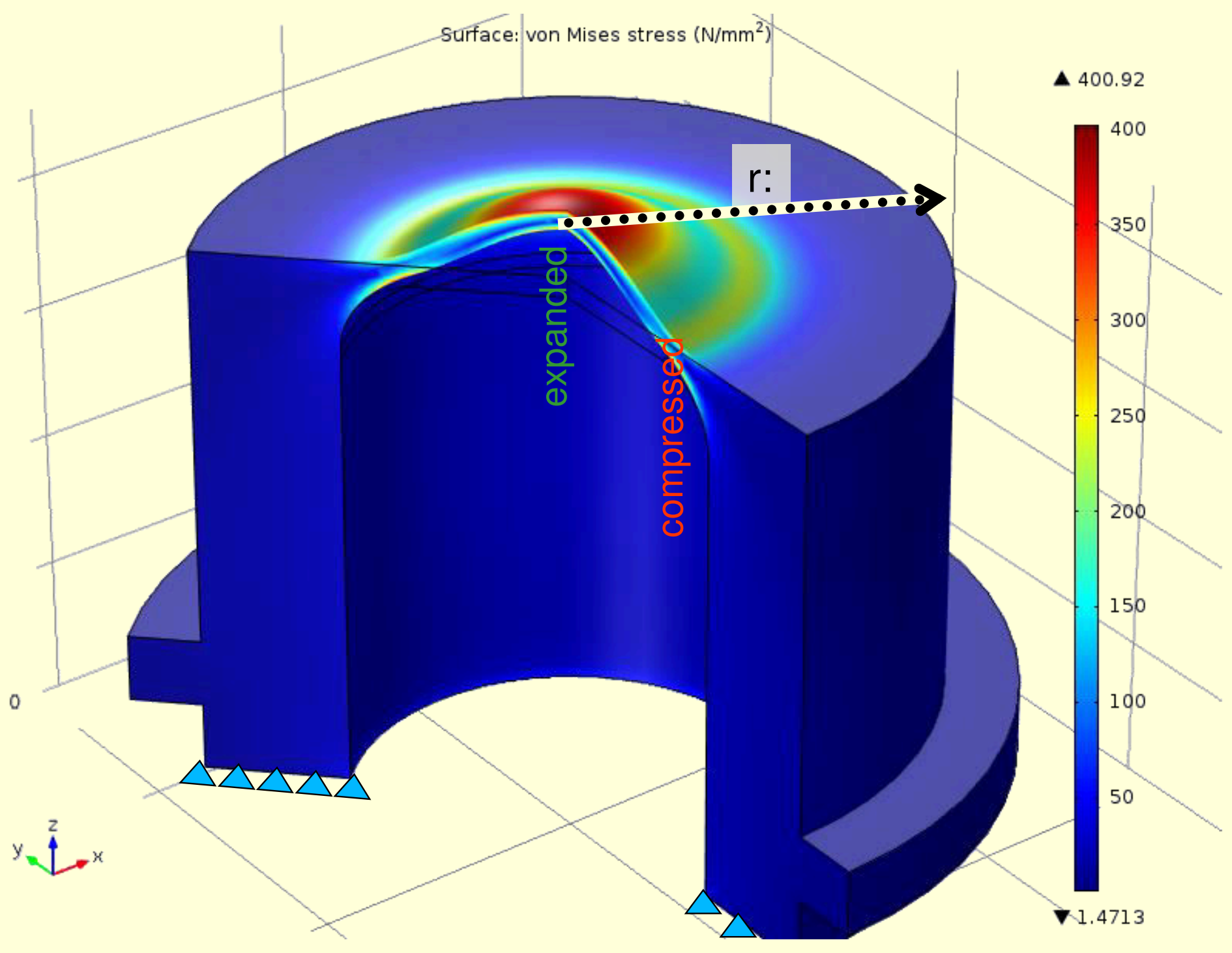


***Figure 5**. Von Mises stresses [MPa] 3D FEM reconstruction cell solid*

Results: A plot of the strains on the membrane surface as a function of the distance to its center, shows the surface regions which are compressed or expanded, allowing to determine the best places to allocate the strain-gauges for maximal signal sensitivity.

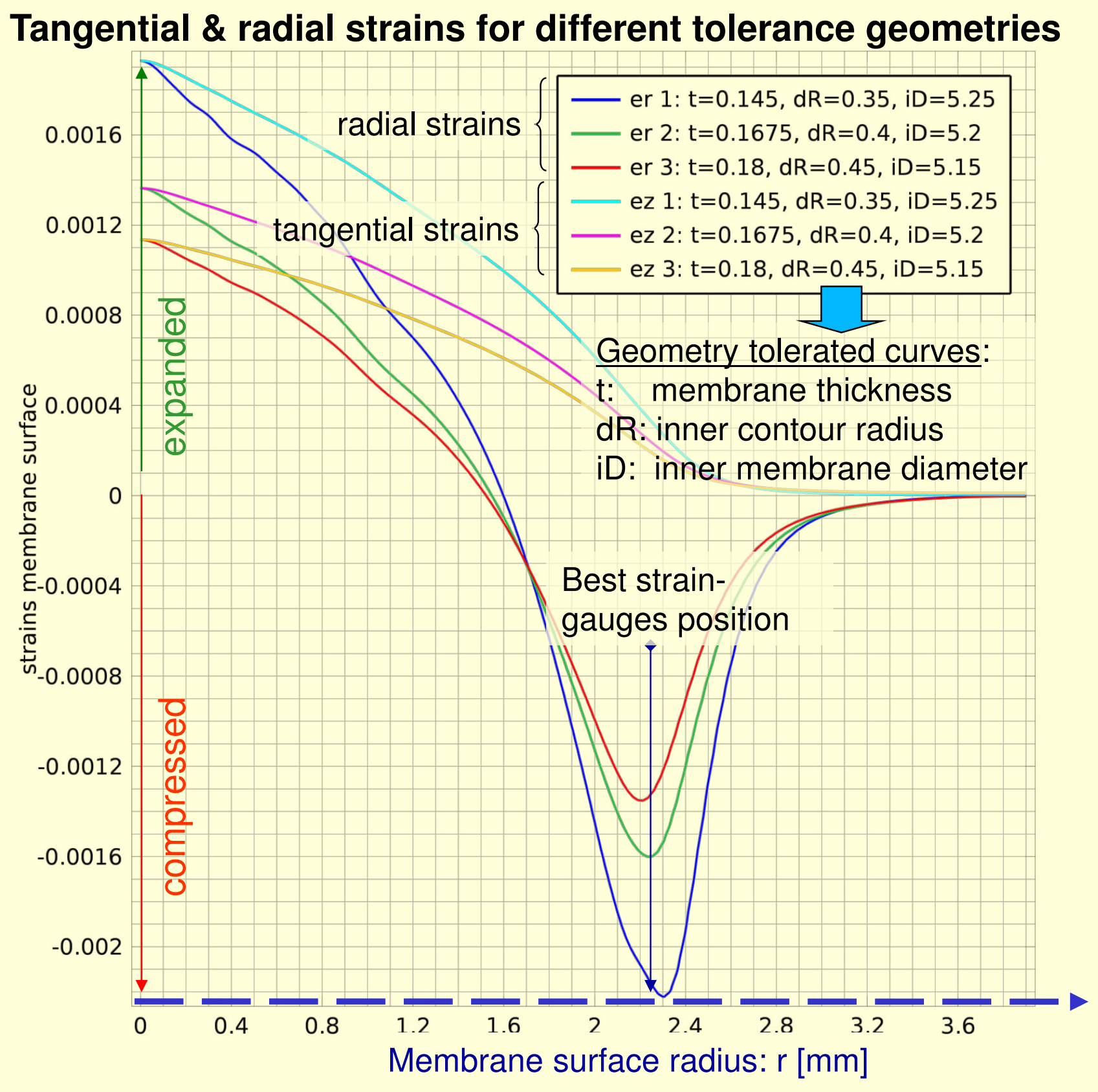


***Figure 6**. Calculated strains along radius (symmetrical line)*

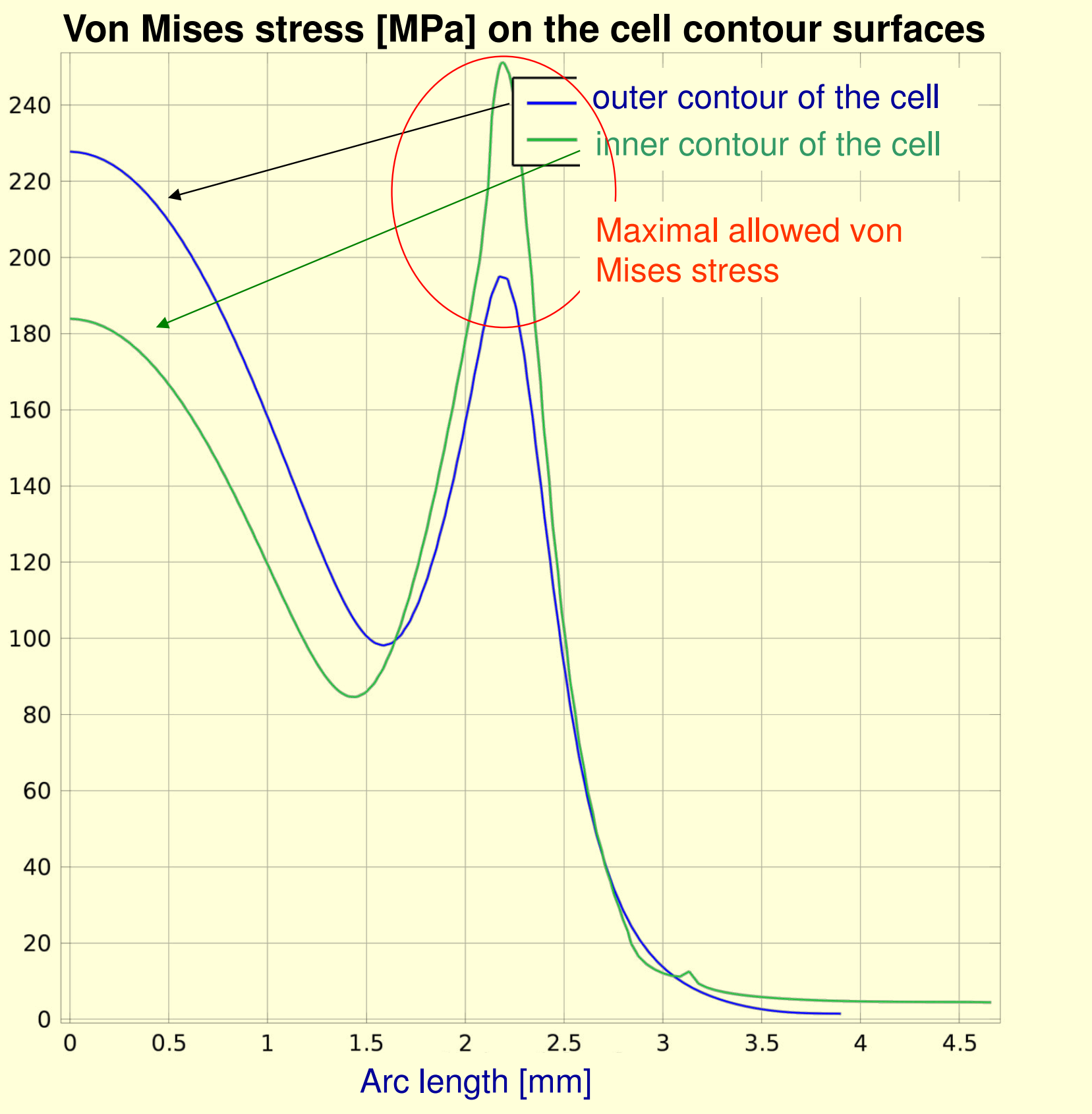


***Figure 7**. Calculated stresses [MPa] along inner and outer surface*

Conclusions: Signals are improved by changing the defined geometry parameters. The design with FEM tools allows us to analyze effects of tolerances in the geometry, affecting signal and mechanical stability of the sensor. Therefore, nonlinear effects *(Figure 8)* of each geometry can also be studied. The nonlinearity can be calculated from the gained signal of strain-gages on the membrane surface by defined material thin-film properties.

Burst pressure can be effectively estimated *(Figure 9)* with Comsol using UML [4] and a test-fail convergence algorithm, that stops when the equilibrium between loads and stresses by deformation cannot be more compensated. Results can be extended with a statistical variation of the modeled geometry parameters and be evaluated to estimate their effects in the calculated burst pressure.

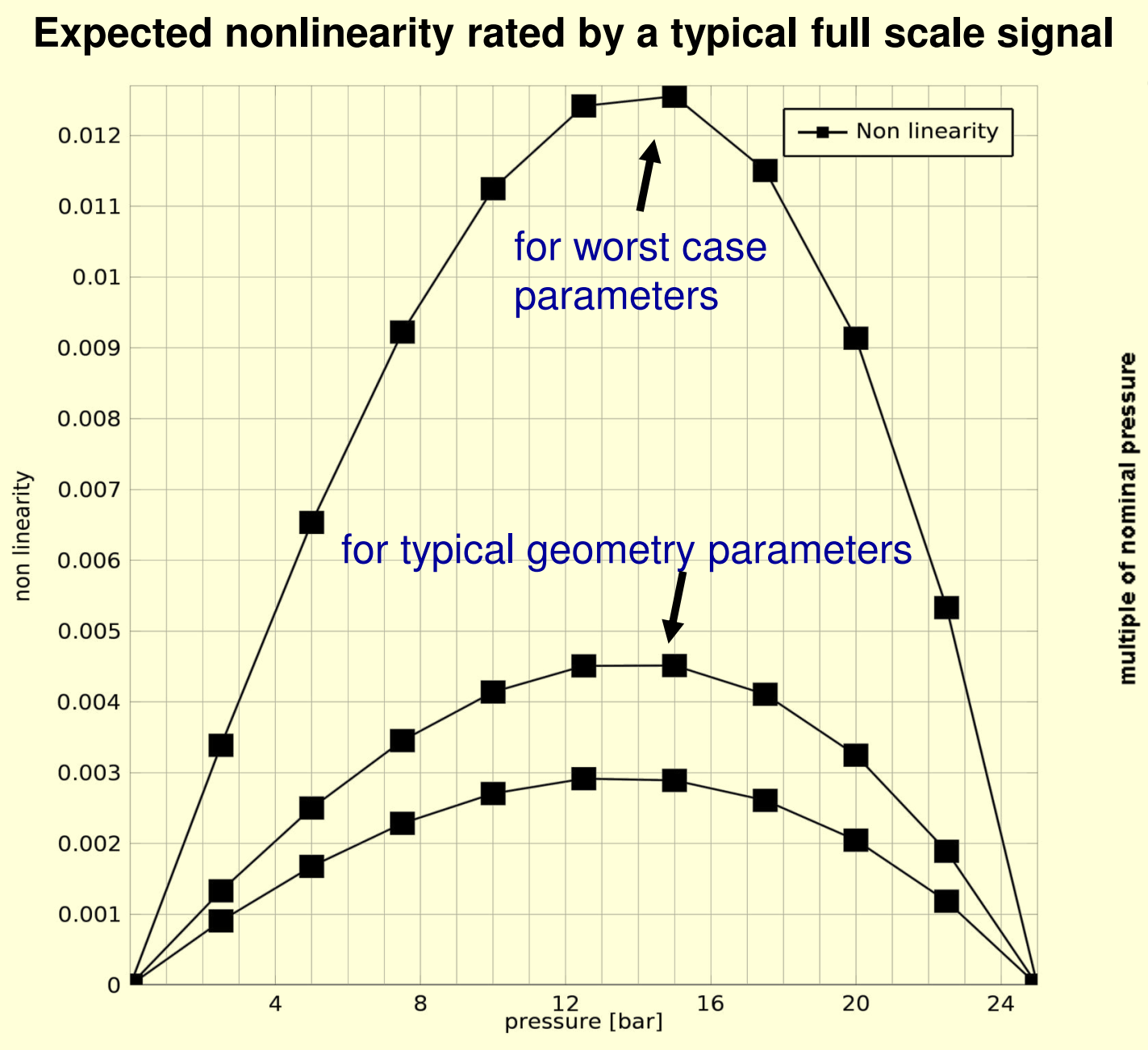


***Figure 8**. Nonlinearity estimation with statistical variation of the modeled geometry*

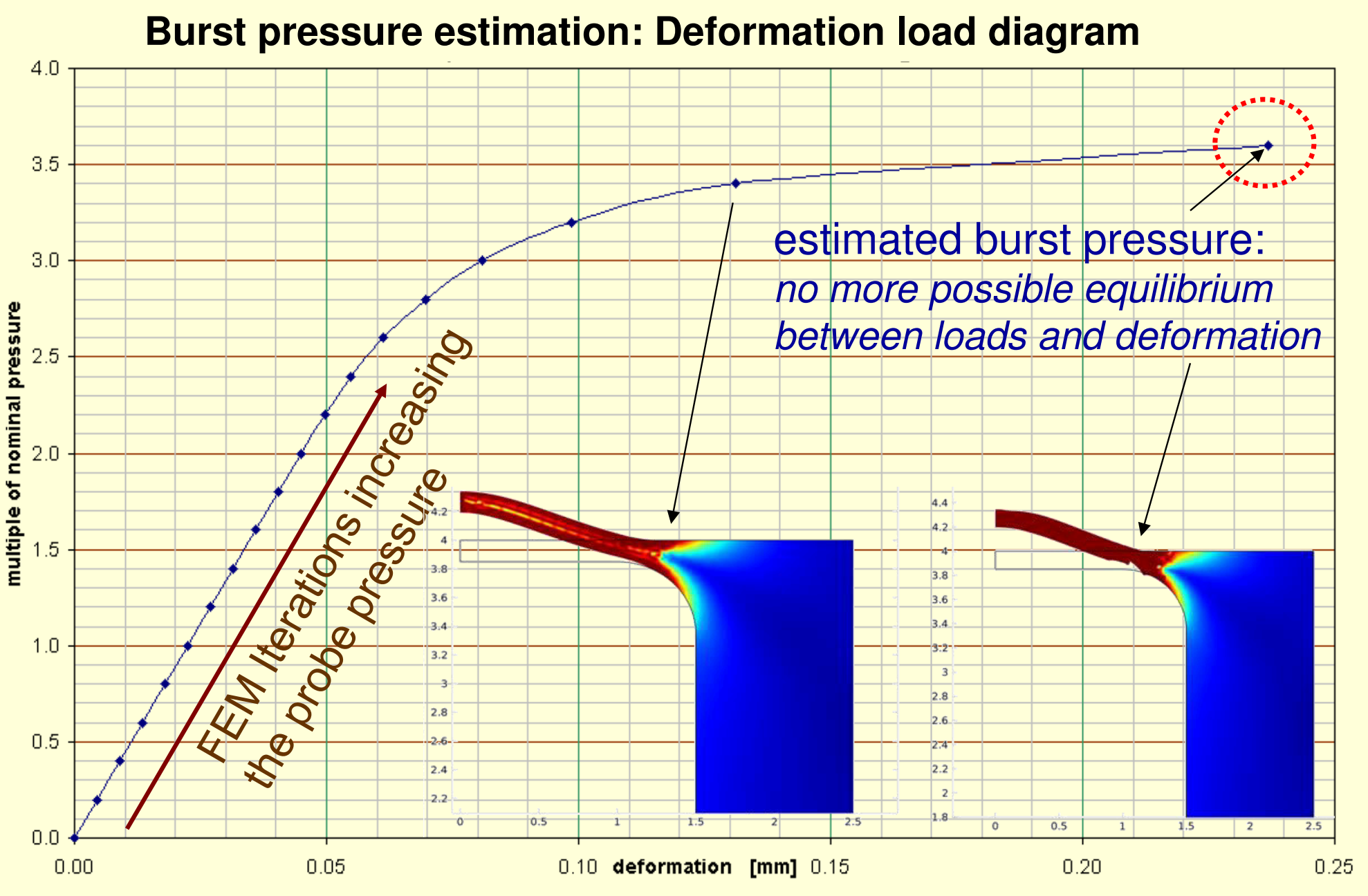


***Figure 9**. Burst pressure estimation using iterative convergence procedure until a FEM calculation loses the equilibrium between membrane deformation and stresses*

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