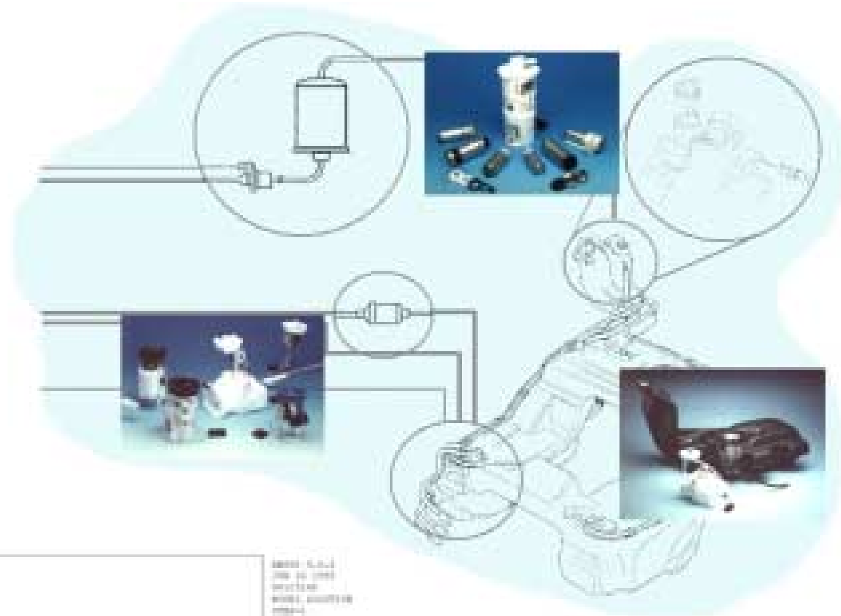
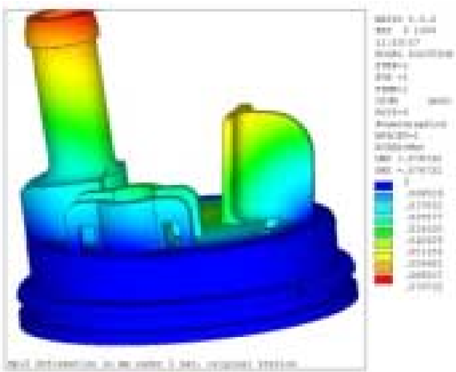
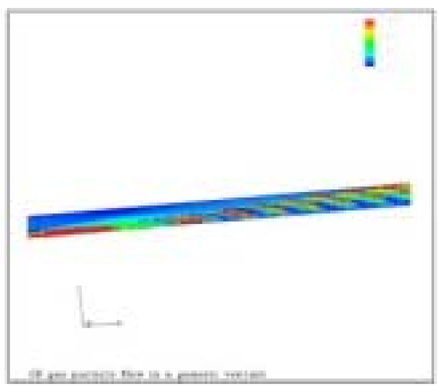
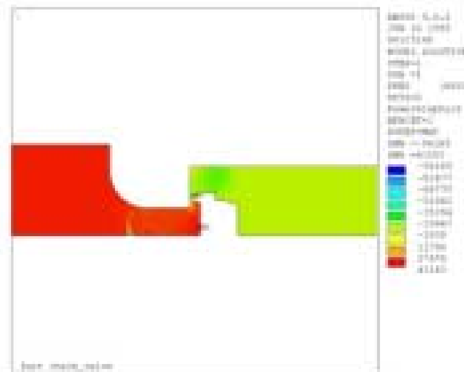
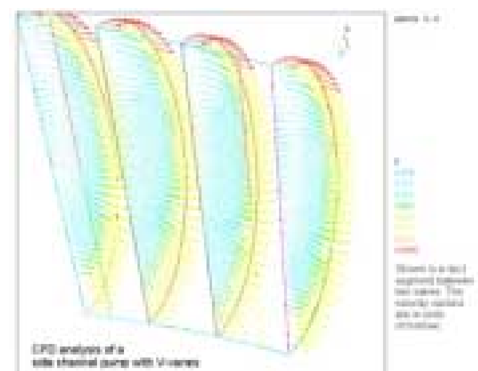
Finite Element Analysis at Mannesmann VDO Fuel Systems











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Car Management

Car Management

Engine Management

Intake-Pipe Adjust System

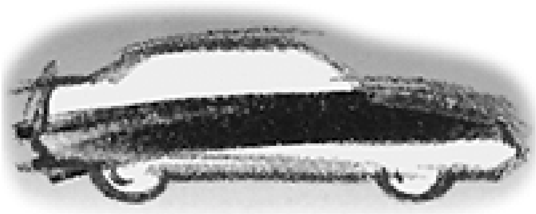
Sensors

Accelerator-Pedal Module

Intake-Manifold Module

Throttle Body

Electronic Control Unit



Fuel Management

Fuel-Supply Unit with Level Control

Fuel Tank

Information Management

Cockpit System

Instrument Cluster

VDO Dayton (Navigation)

Audio

Production facilities in Germany and Europe

World-wide production facilities

automotive
mannesmann
VDO

VDO Business in Figures
(m)

	1998	1999*	Change %
Orders received	3,400	3,531	+4
Sales	3,338	3,495	+5
domestic	1,757	1,503	-16
foreign	1,581	1,992	+26
Capital expenditure	603	224	-73
Depreciation and amortization	178	191	+7
Research and development	292	336	+15
Employees	23,157	23,825	+3

*) Excluding the Watches Business Area

ANSYS-FEA activity at VDO

automotive
mannesmann
VDO

About 20 ANSYS seats – tendency increasing

+ substantial part of FEA done by sub-contractors

- all kinds of ANSYS analyses employed –

Multiphysics:
mechanical, thermal, electro-magnetic, fluid (ANSYS/FLOTRAN)
and coupled effects.

In addition, crash (ANSYS/LS-DYNA).

ANSYS-FEA activity at VDO

- No central analysis department –
decentralized structure of FEA activity

- (in principle 1 – 2 person units, strongly integrated in the design and development teams).

- **Many advantages of this structure:** An analyst ”lives” with a product: From the conceptual phase, feasibility studies, optimization, up to fixing the final design and support at SOP.

Possibility to influence concepts!

ANSYS-FEA activity at VDO

automotive mannesmann VDO

- **Disadvantages of the decentralized organization:** In specific analysis problems analysts must seek discussion and advice from their colleagues company-wide.

Very well solved by a kind of self-organized ***neural-network-type of communication*** between all the analysts. Often telephone and e-mail conversations, sharing of computer resources and software licenses. Work-group meetings.

- **No formal, company-wide FEA organization, but it's working!**
(Of course, supported by the company management).

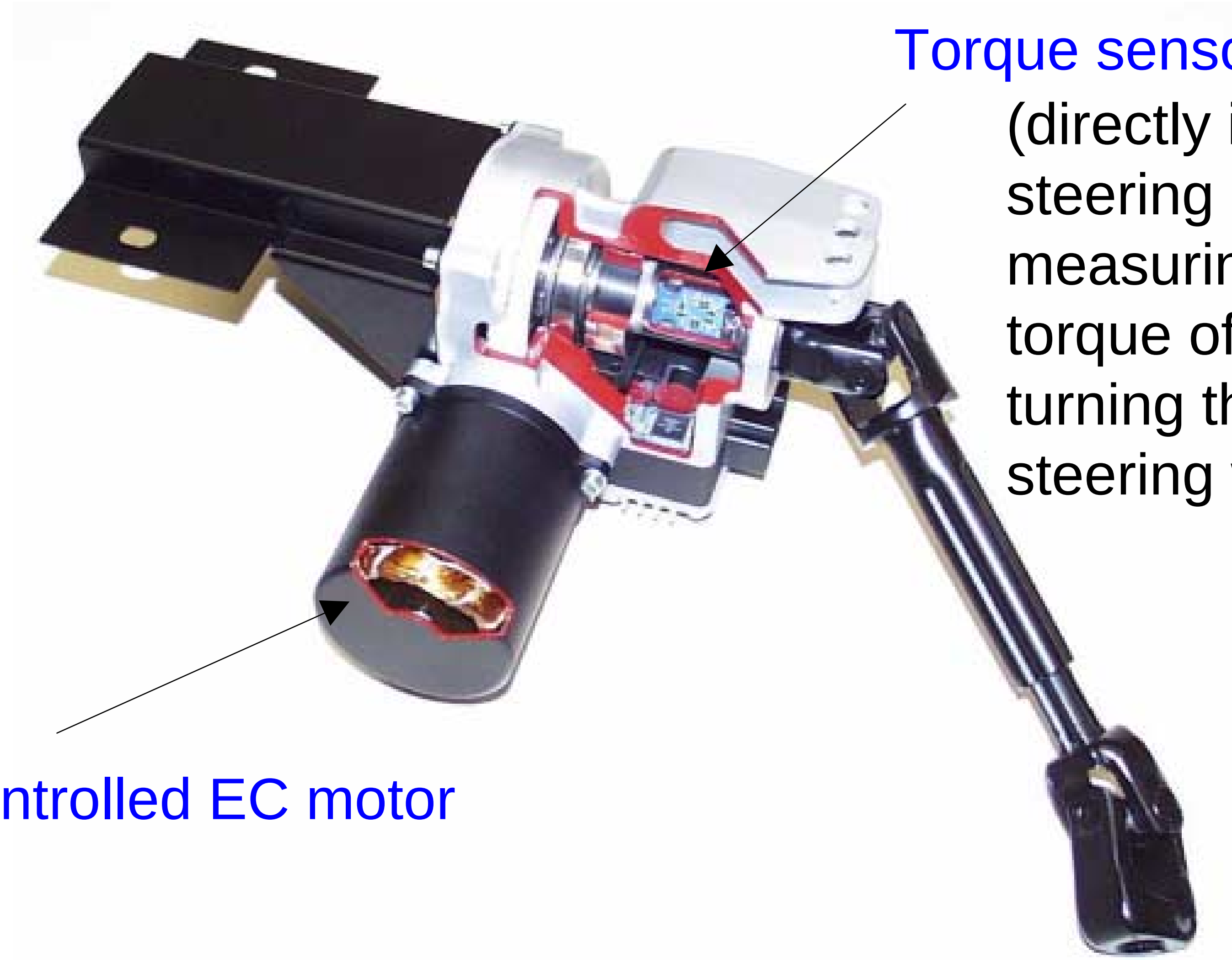
- Also excellent support by German ANSYS support distributor, CAD-FEM.

Now, first-hand,

real-life examples:

(personal reflections included)

Demand-controlled electrical VDO steering system



Torque sensor

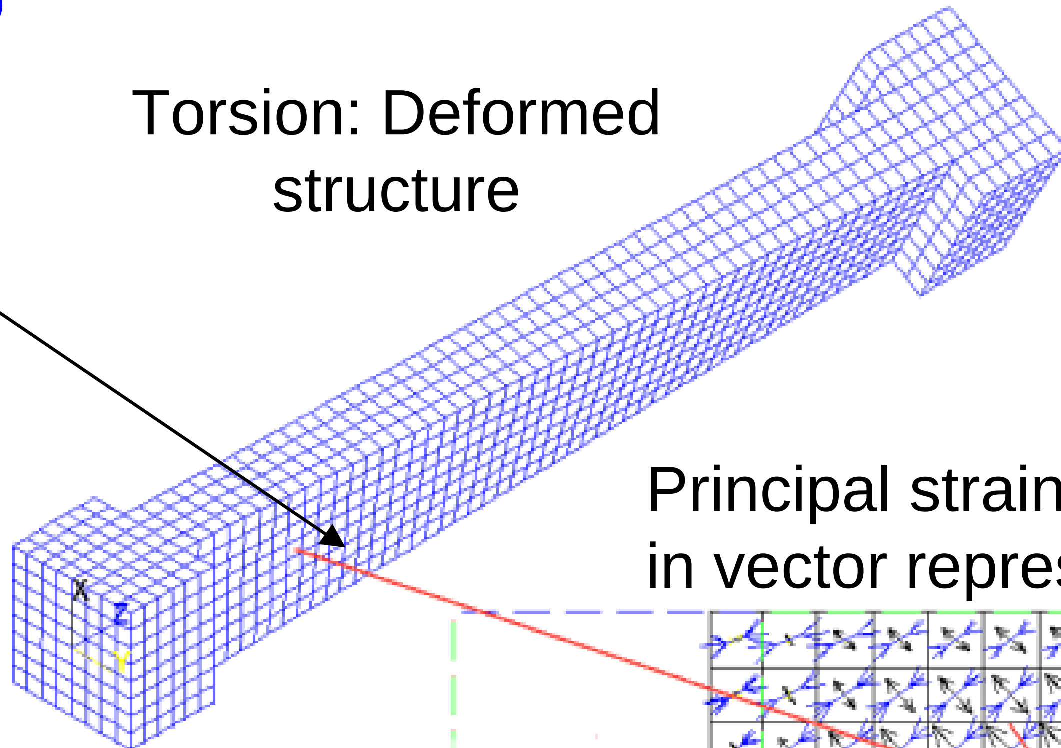
(directly in the steering shaft, measuring the torque of the driver, turning the steering wheel)

Demand controlled EC motor

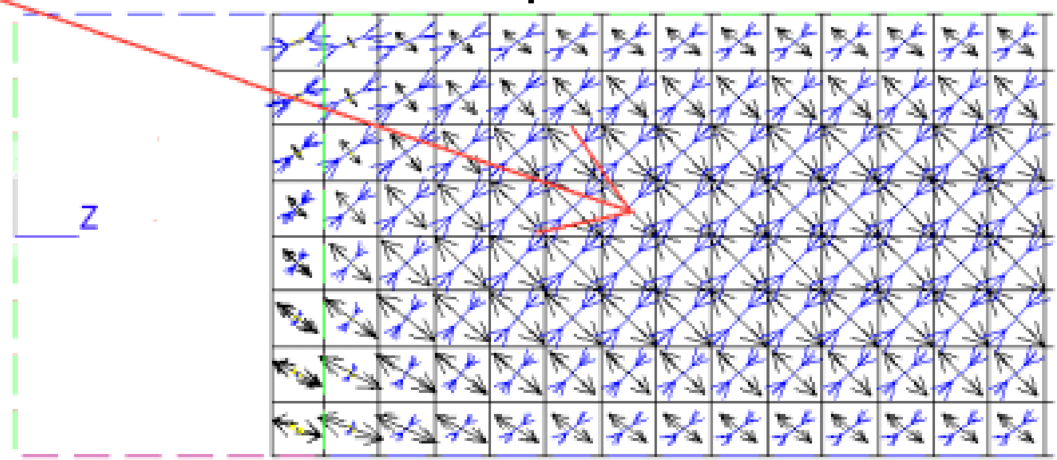
Starting structure
(steel slab)

Here, a ceramic, thick film resistor is to be bonded to the surface, acting as a strain gage.

Torsion: Deformed structure



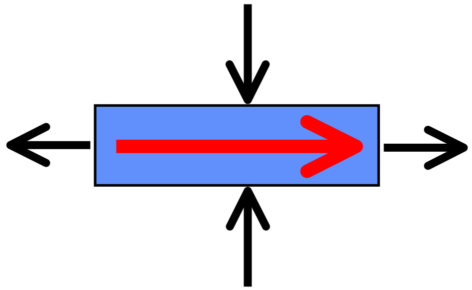
Principal strains at the surface in vector representation



Almost no signal!

Why???

ANSWER - through FEA:



Resistor with current direction

$\leftarrow \varepsilon_L \rightarrow$ Surface strain in the current direction (longitudinal)

$\downarrow$

ε_T Surface strain normal to the the current direction (transverse)

$\uparrow$

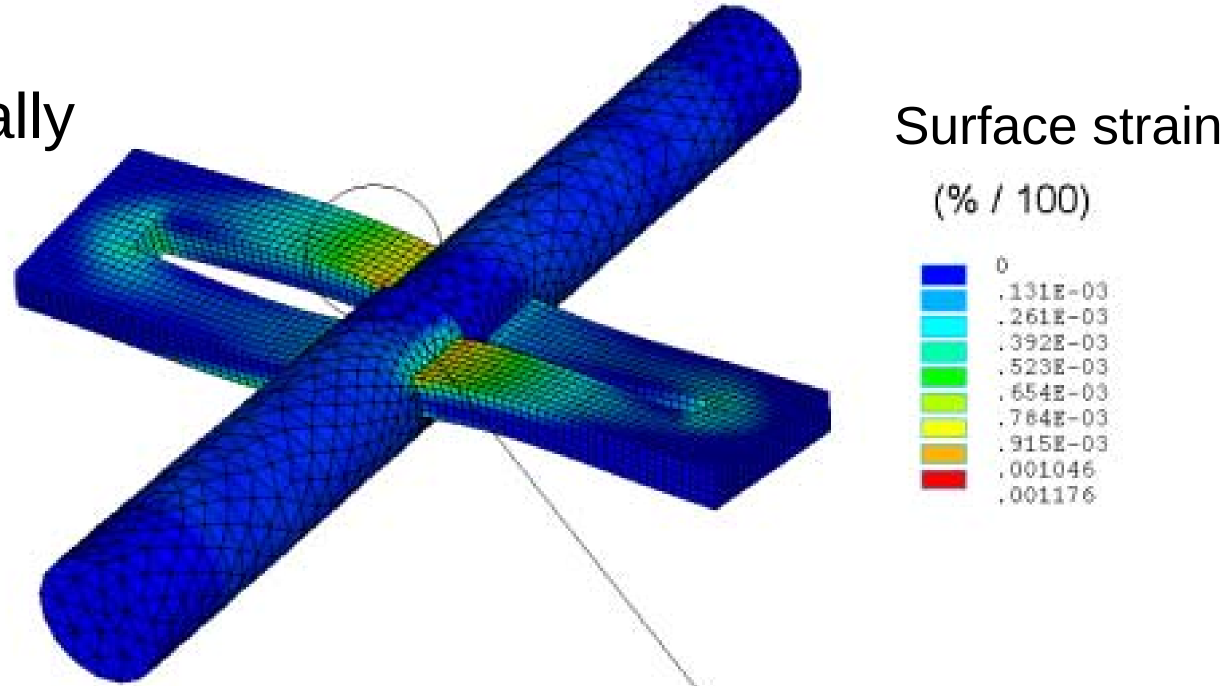
Relative resistance change on the resistor is:

$$\frac{\Delta R}{R} = \varepsilon_L \cdot K_L + \varepsilon_T \cdot K_T \qquad \text{(Eq. 1)}$$

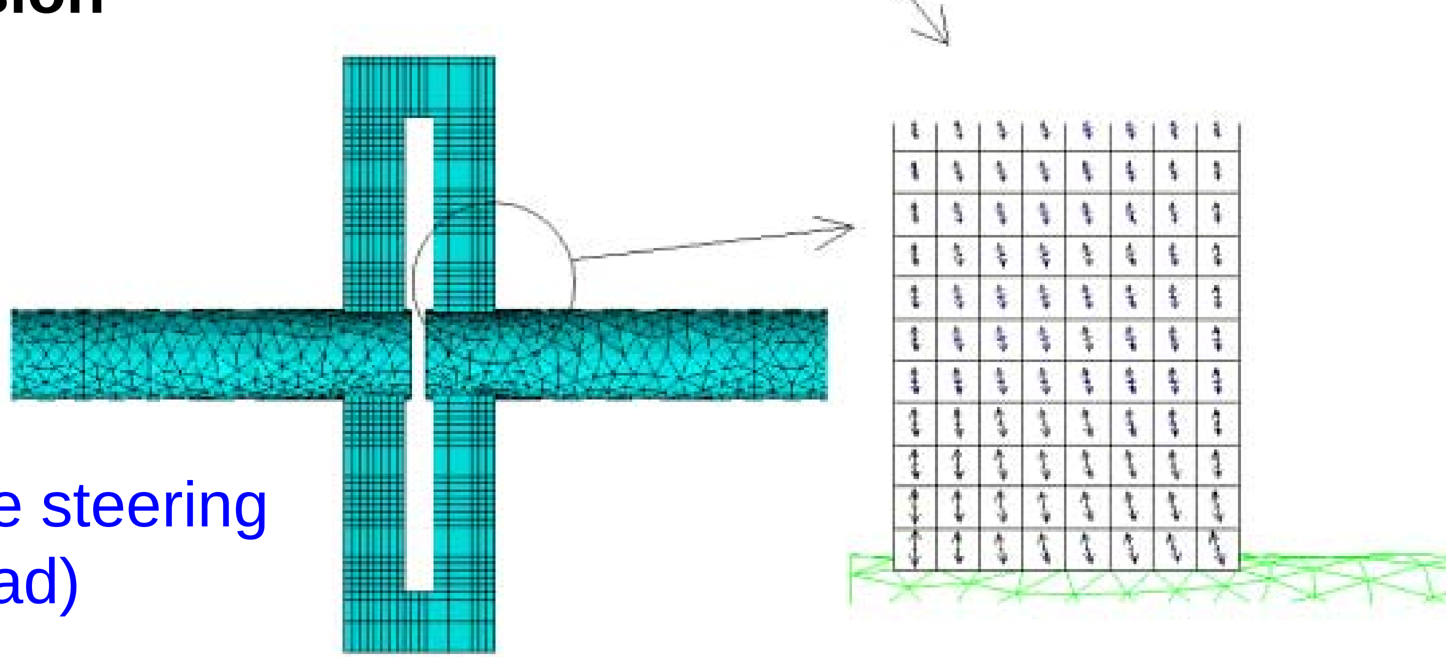
Typical values: $K_L = 13.5 \quad K_T = 11$

For pure torsion of a uniform slab $\varepsilon_L = -\varepsilon_T$ **: almost no signal!**

Solution: Enhance locally the longitudinal strain and suppress the transverse one!



This is typical for **bending:**
Transform torsion into bending!



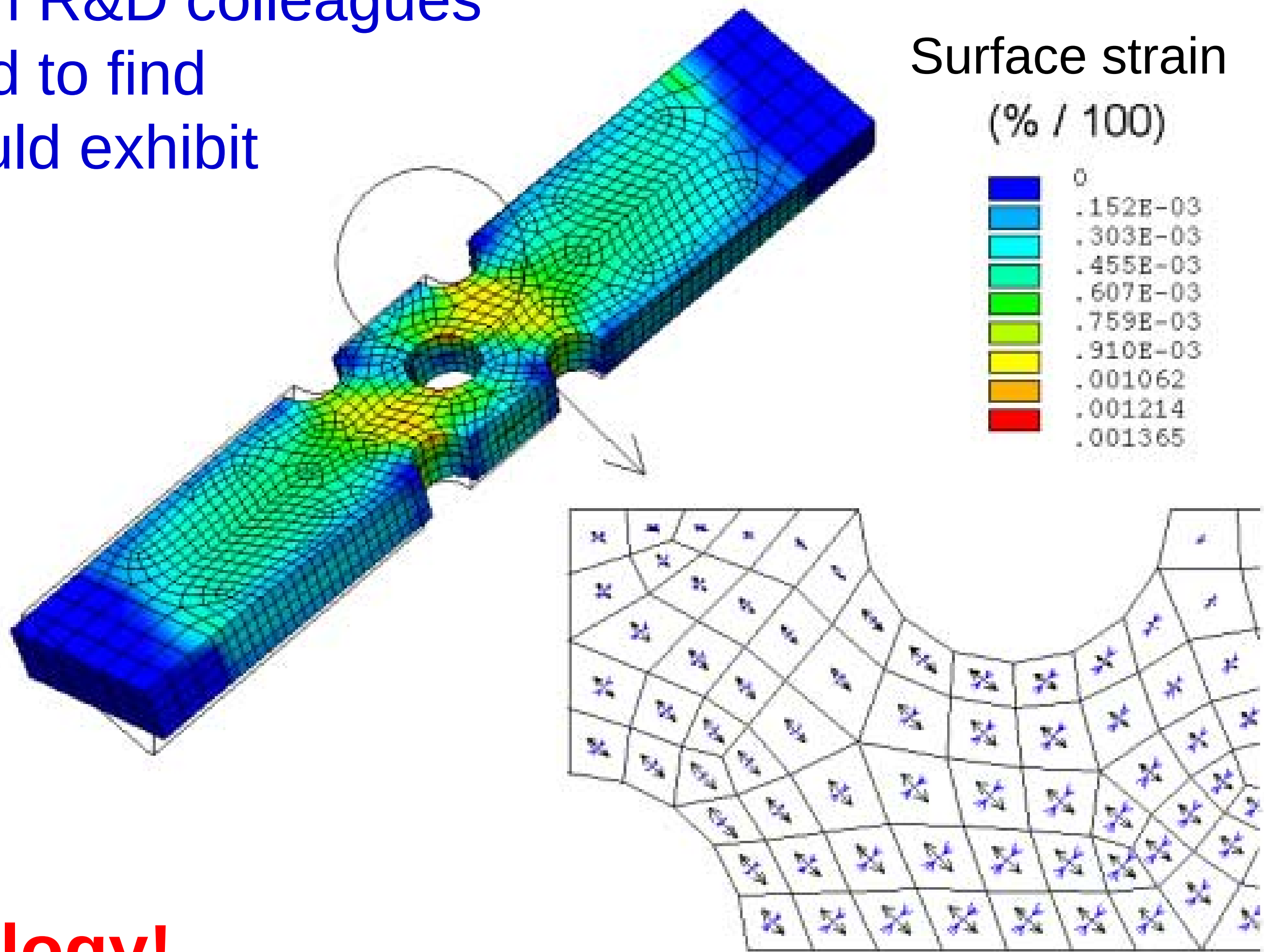
Excellent!

but useless!

(doesn’t fit into the steering shaft - far too broad)

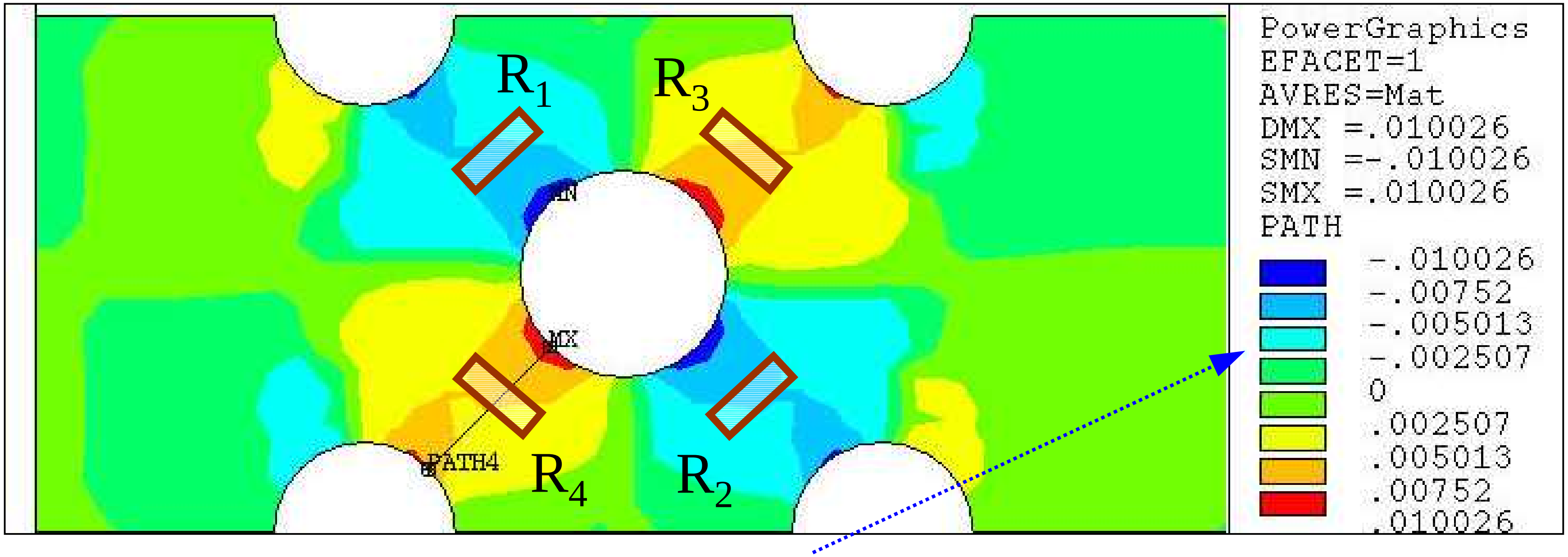
In a brainstorming with R&D colleagues and designers we tried to find a structure, which would exhibit the improvements we learned about and still be narrow enough to fit into the device.

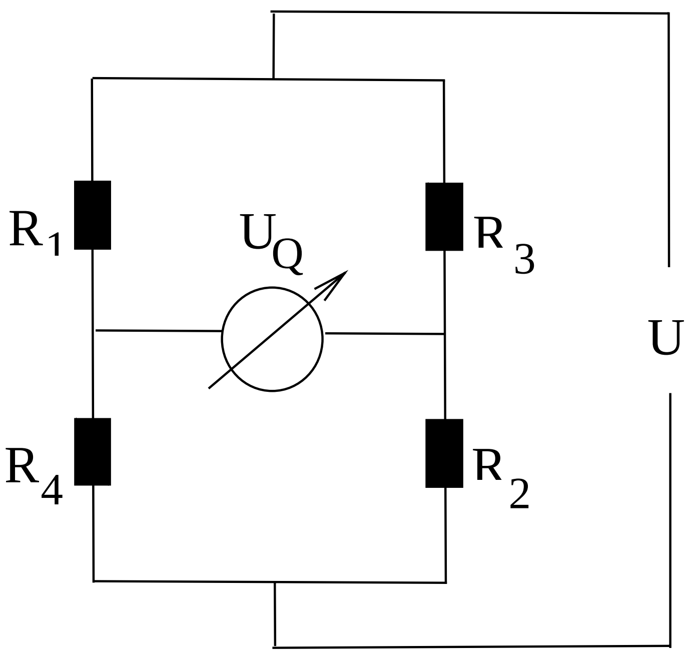
This came out:



Idea:

Preserve the topology!



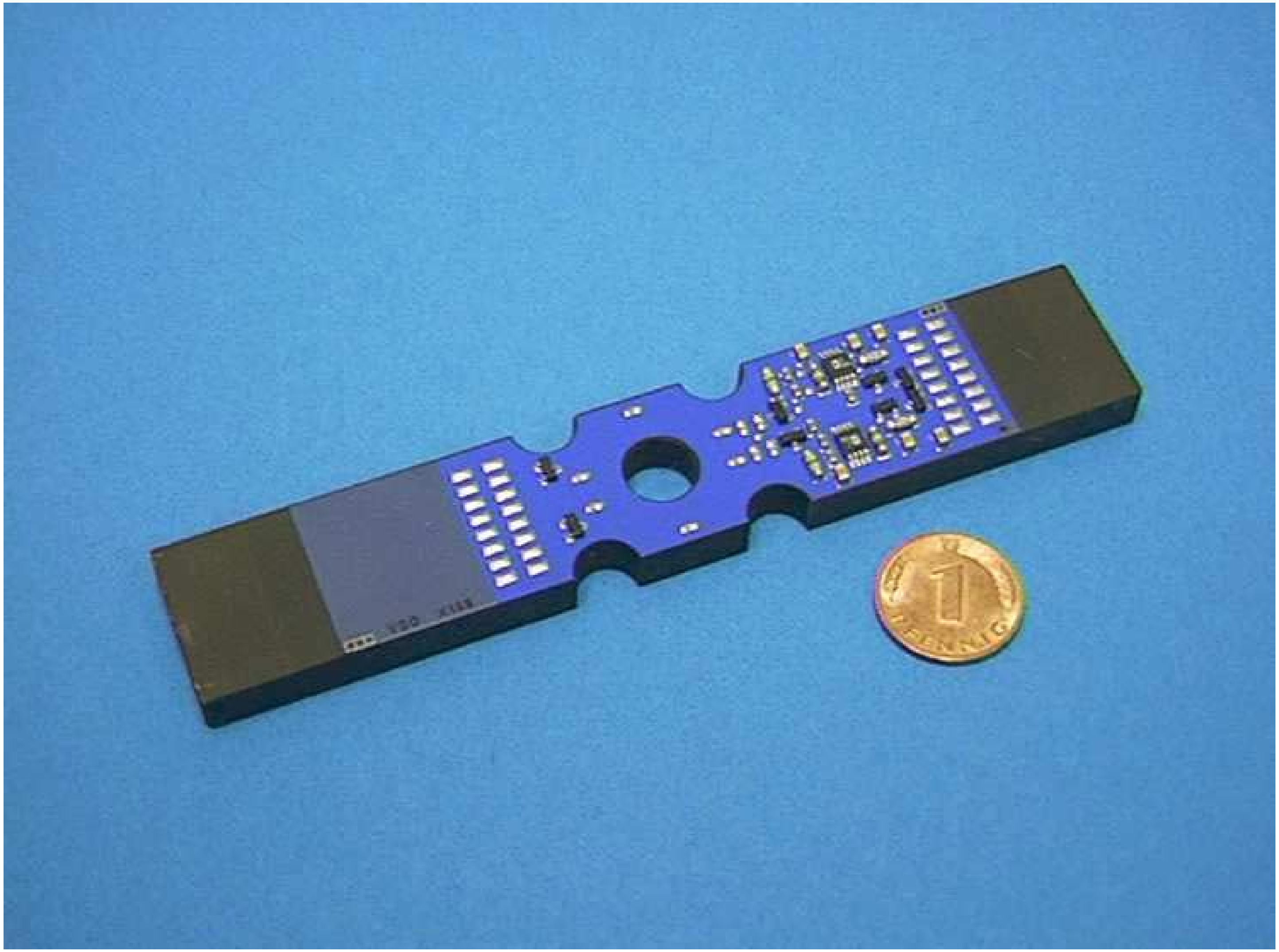


Simulated signal field (resistance change, a resistor would sense at any point on the surface), according to (Eq. 1)

R_1 to R_4 are four ceramic thick film resistors, connected into a Wheatstone bridge.

The signal of this circuit has also been directly simulated by ANSYS. This is the direct output of the sensor cell.

A new torque sensor in thick-film technology for a demand-controlled electrical VDO steering system



This slab is a FE-optimized shape, which **enhanced the signal by the factor of 5** in comparison to the first samples, improvised without FEA.

Moreover, this sensor is theoretically exactly insensitive to bending and shear forces, the usual ugly side effects of such sensors. This has also been exactly achieved through analysis!

The existence of the new power steering assembly is to a great part due to this sensor, in the creation of which our FEA played a crucial role.

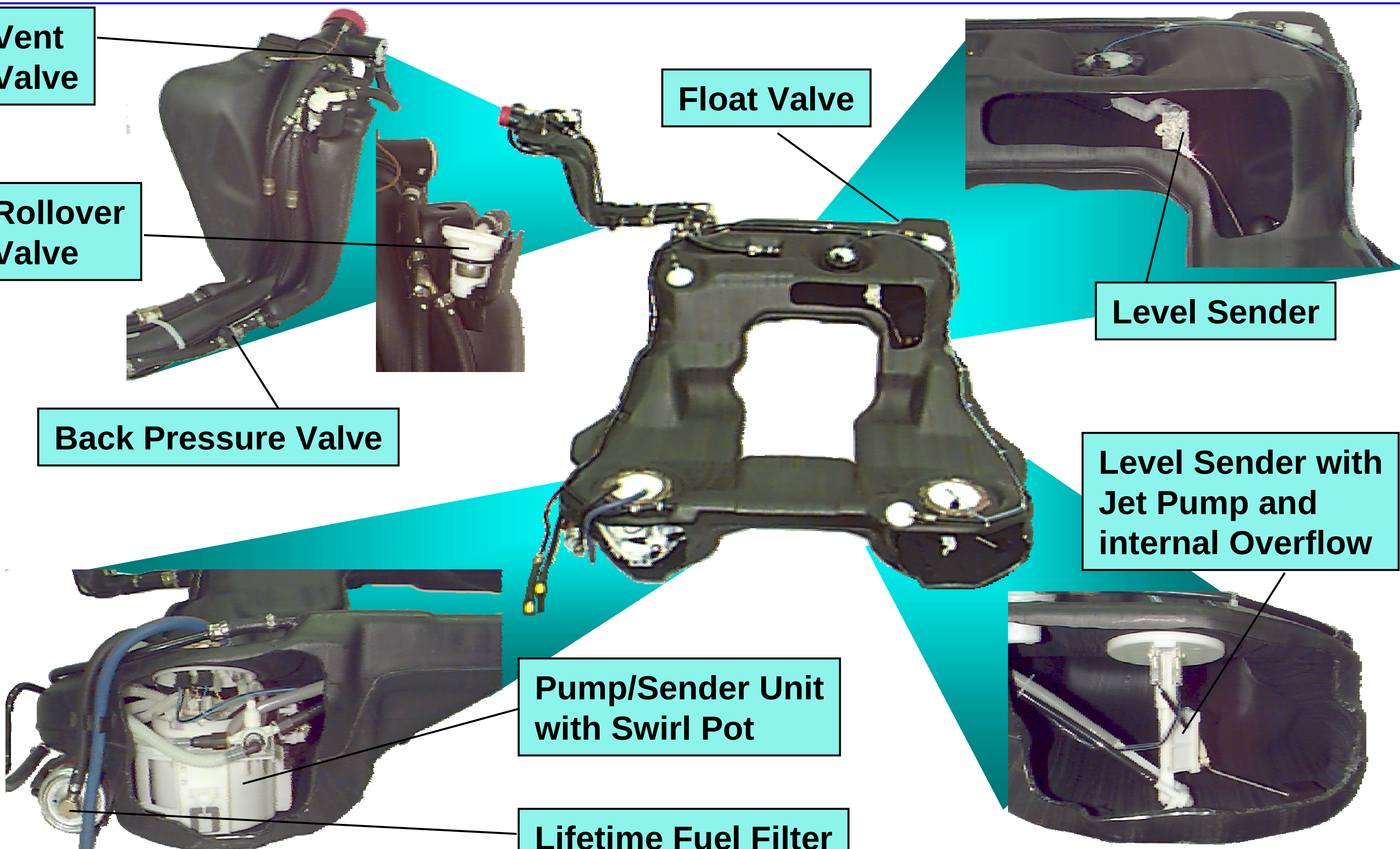
All of the improvements shown and the following fine optimization have been done only on the computer. At the very end, the best version was built.

It took **one to two days** to perform a FEA per variant, compared to **several weeks** to build one charge of equal samples.

We have “played” with at least 30 variants, some of them differing strongly, until getting a satisfactory solution.

Fuel tank module components

automotive mannesmann VDO



We design and produce **almost everything in the automobile fuel tank:** pumps, fuel gages and other sensors, pressure regulators, valves and fuel feed lines, all integrated into the assemblies: fuel delivery units.

As a system supplier we must also have a deep technical knowledge about the tank vessel itself, its periphery and the entire fuel management.

Working atmosphere: Very informal way of communication.
An analyst experiences and takes part in many discussions of day-to-day activities in R&D, designer and test engineer teams.

(Numbers: an analyst colleague of mine and I serve in various stages about 100 other R&D, test and design engineers, as well as project managers).

An example of a very lively communication:

At least three times a day our R&D head of department visits our simulation compartment with questions, comments and suggestions!

In a similar way the new analysis projects are born. An analyst is often present during discussions on the concept of a new product. In many cases, his main role in a whole project is to take part in the first brainstorming – through our experience we can often give good hints about the pitfalls at some design, or how to enhance a certain physical effect in a new device.

A second, very often class of problems for us is when several different alternative product concepts are born out of a brain-storming. Our colleagues ask us then for our help, in order to decide which concept to follow:

In that case we have to be FAST: We try to build a simple closed-form math effective model, or as simple as possible FEA model and simulate the features in question. Often, our R&D or designer colleagues continuously follow the progress of this preliminary analysis and add suggestions during the analysis process.

An analyst is not supposed to work alone until he finally comes out with a final, grand result!

We often check preliminary results by adapting them to existing prototypes and testing them. This gives a feedback for refining the simulation for the actual design.

In my view, FEA is an extremely strong tool in the **CONCEPT** phase of the product. One can very often, (and with relatively little effort) say: This is much better than that! Or, on the other hand: Changing in this direction will bring you virtually nothing!

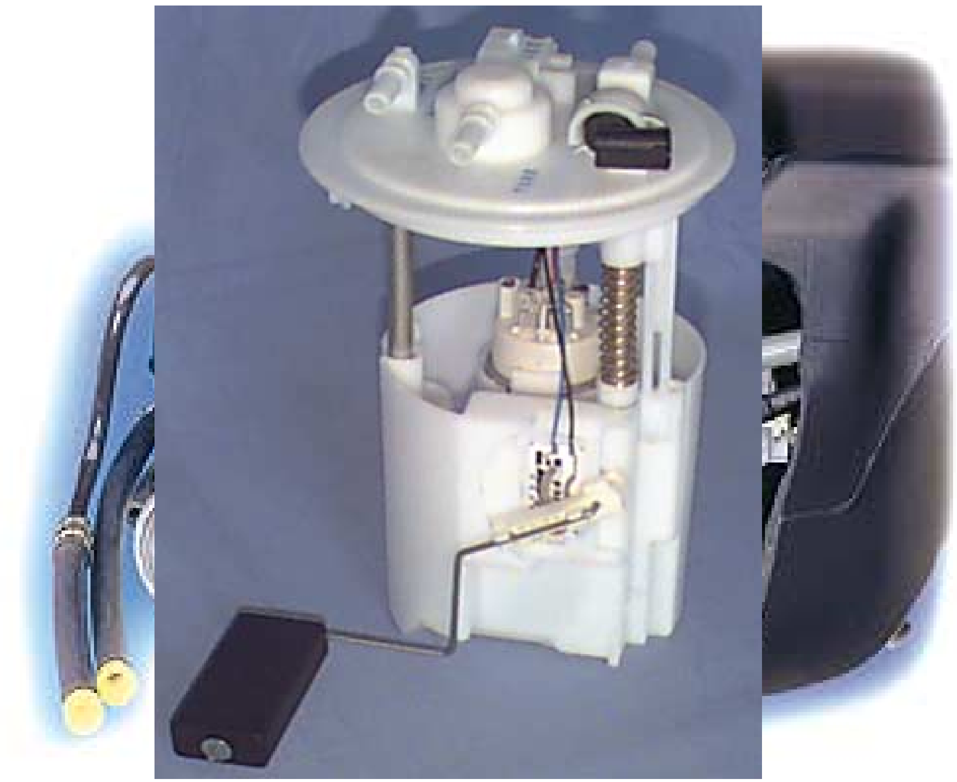
It is very sad, if one gets a task of improving a product which does not properly function shortly before SOP. At that stage the range of possible improvements is often very limited.

Example: Mechanical / crash

In designing a fuel tank, the car manufacturer noticed, that the fuel delivery unit can be directly hit through a deforming tank body during a side crash.

Position of a typical fuel delivery unit in a tank

(not the one discussed below!)



Example: Mechanical / crash

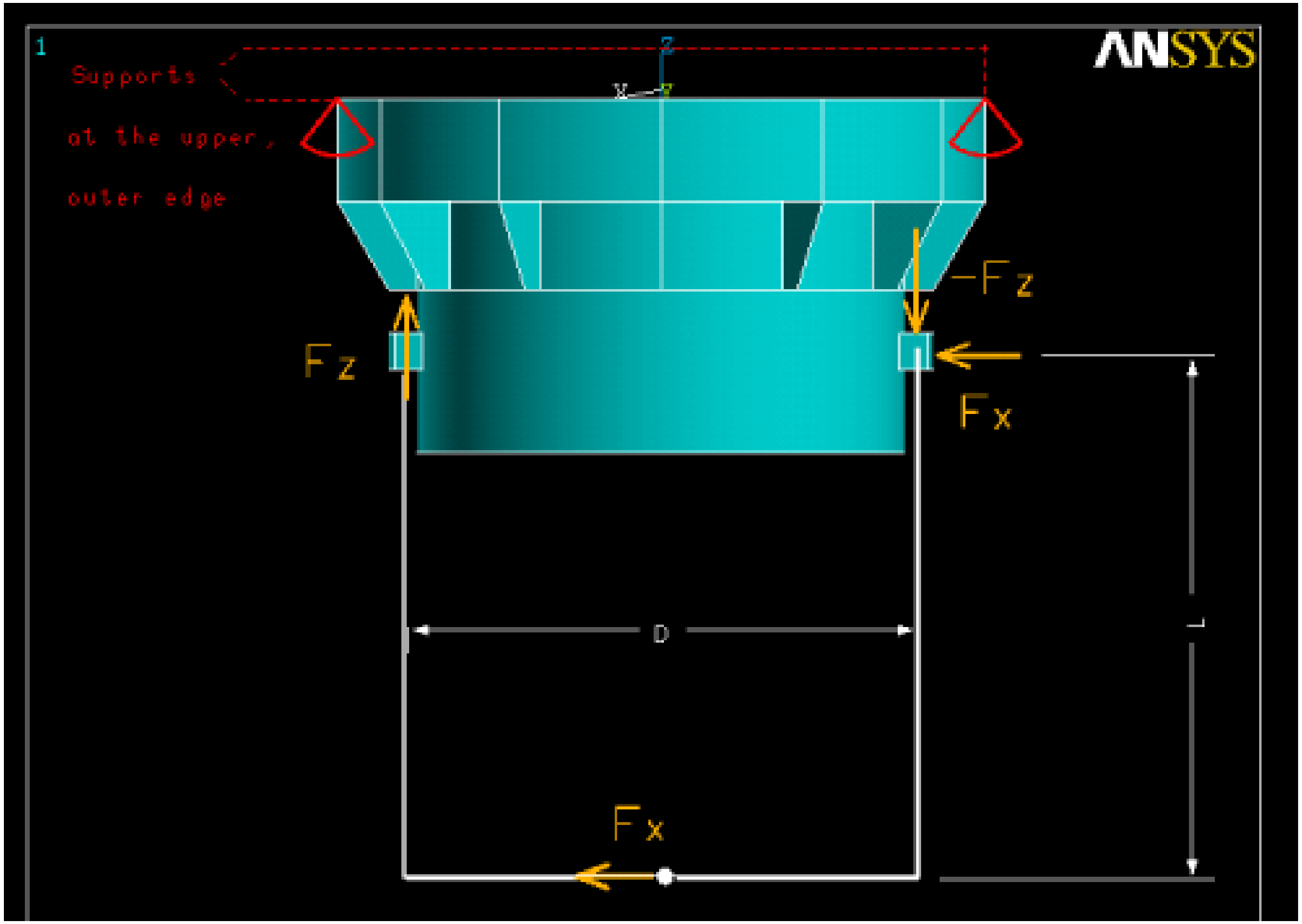
The question was: If a fuel delivery unit were hit by an undefined, strong force pulse and if it is going to break, how can you guarantee that the flange, sealing the tank would not break? Otherwise the fuel would pour out through the broken flange and this can cause a severe safety problem.

The question had to be answered within **three days** before an important meeting. The solution of that problem gives us an important leading advantage over our competitors.

Mechanical / crash
ANSYS/LS-DYNA

automotive mannesmann VDO

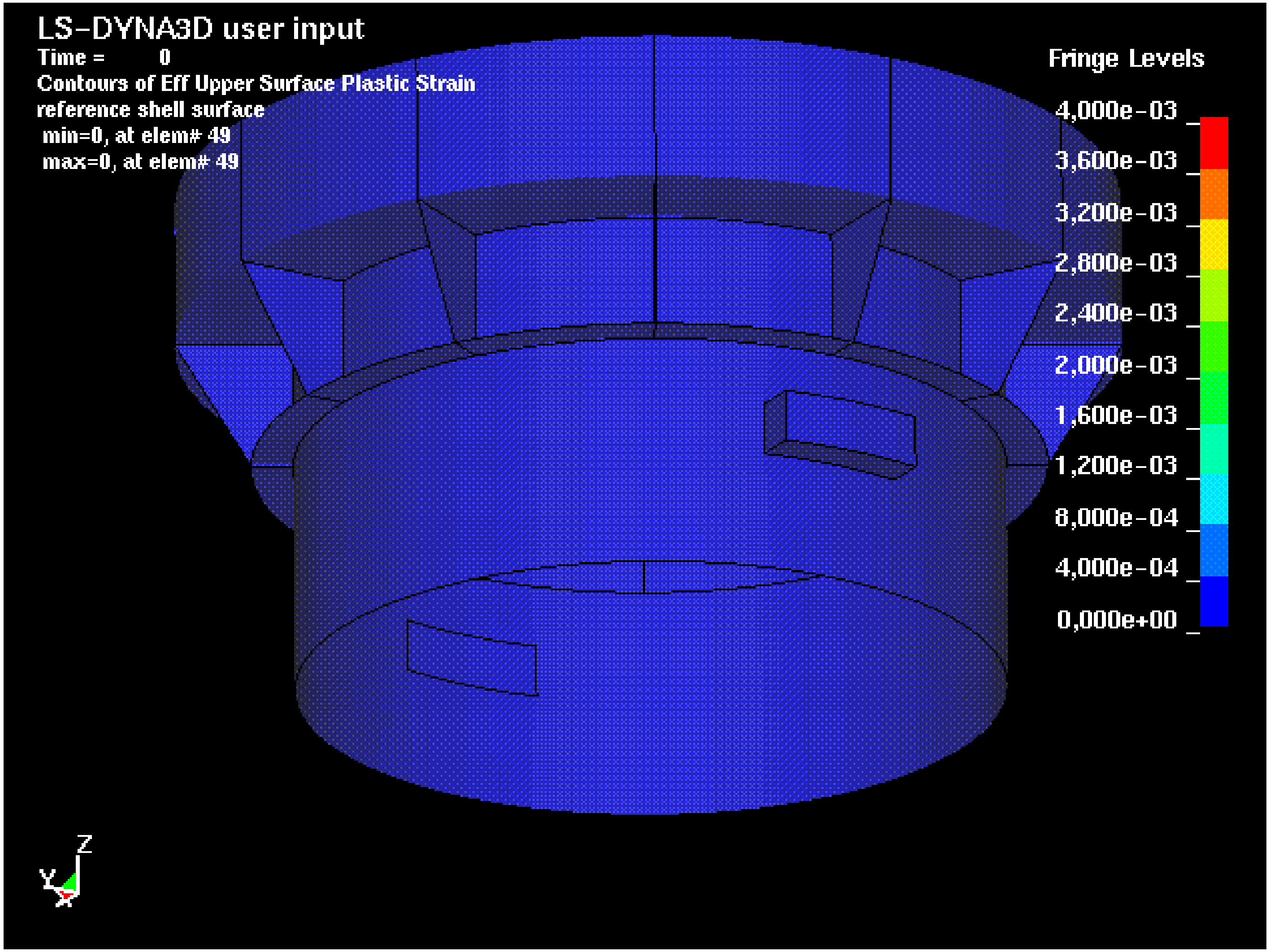
The time was too short to model everything in detail. However, the trends could excellently be distinguished through the effective model:



As an ultimate consequence of the complicated tank side crash scenario, a pair of forces acts to break a flange.

Mechanical / crash
ANSYS/LS-DYNA

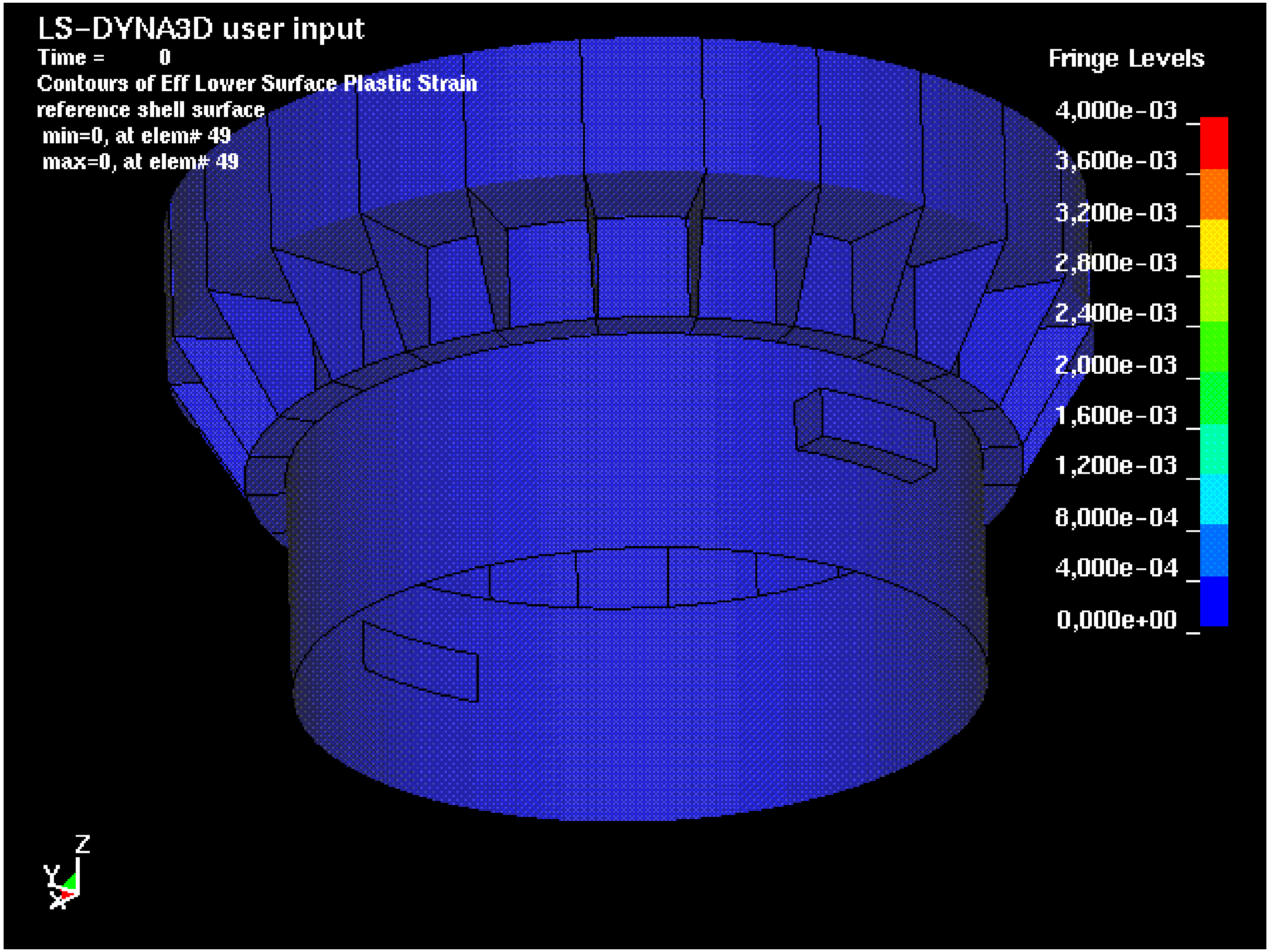
Original concept: A strong tendency that if it comes to cracking, a crack will be created at the edge between the stiff collar and the soft side wall of the flange.It will also propagate along this edge.



Mechanical / crash
ANSYS/LS-DYNA

An even better solution through enhancing the stiffness step between the rib structure and the soft wall region.

Conclusive!



Coupled field analysis: magnetic-mechanical

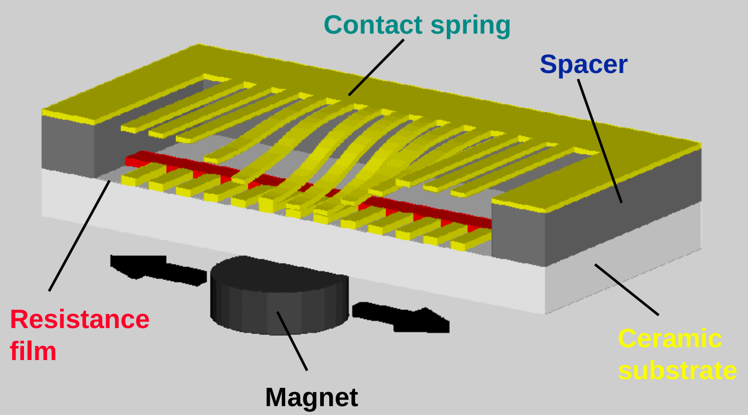
MAPPS: MAgnetic Passive Position Sensor

Operating principle

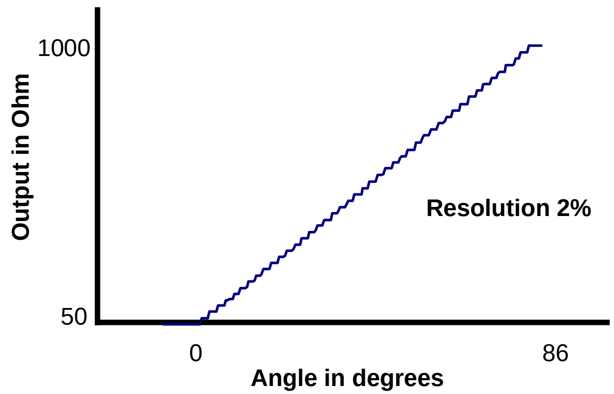
51 film resistors on a ceramic substrate are wired in series with individual contacts. A soft magnetic foil with a corresponding number of tongues is mounted a small distance above the contacts. A magnet below the ceramic substrate draws the tongues to the pads and thus closes an electrical contact.

The electrical output signal changes proportionally depending on the position of the magnet. Thanks to the magnetic coupling, the measuring system can be hermetically sealed. With this design no contamination of the microcontacts, even at extreme ambient conditions, is possible.

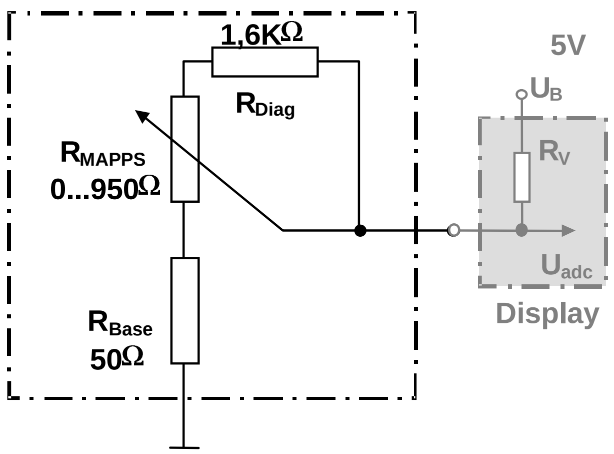
Schematic



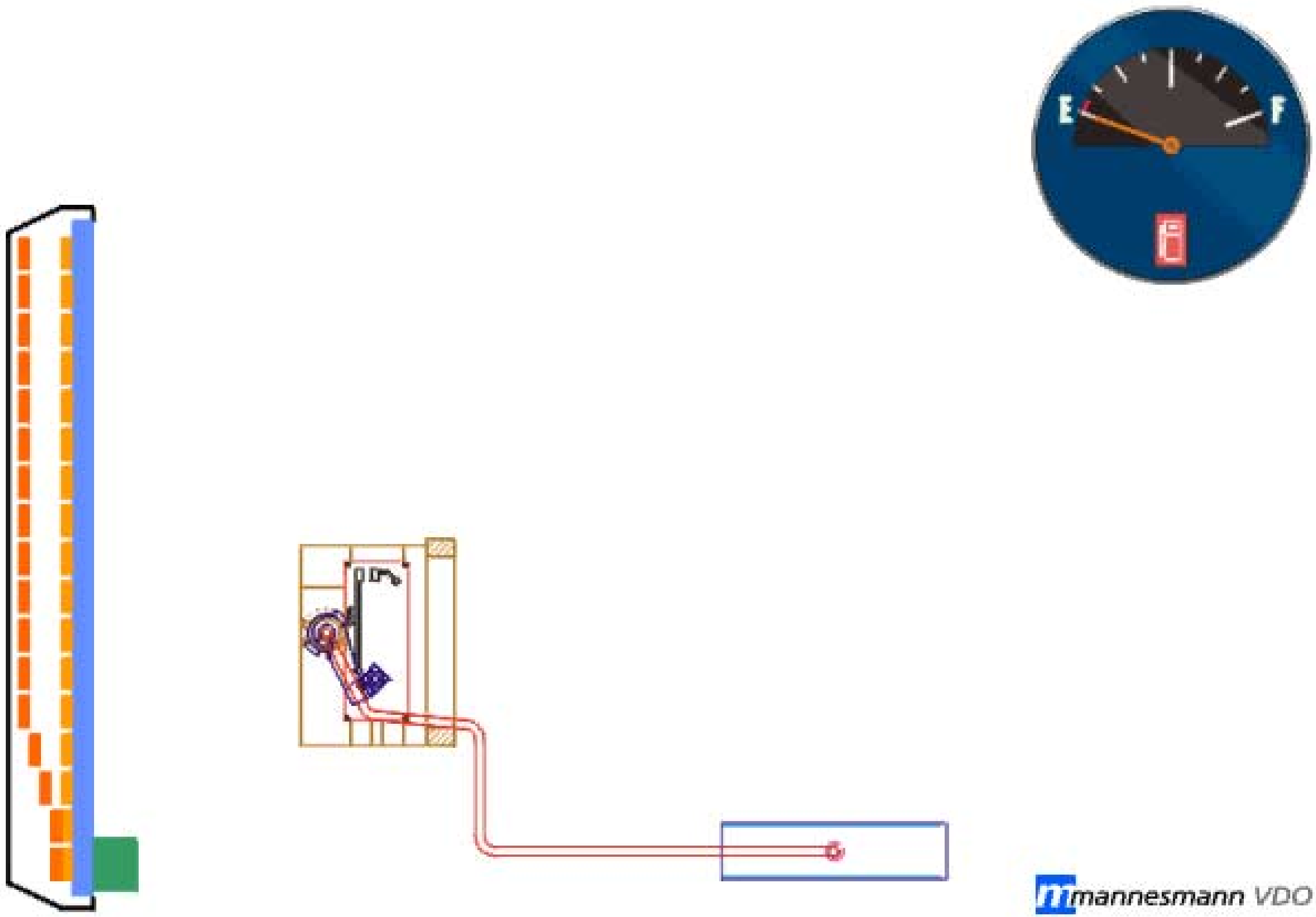
Characteristic



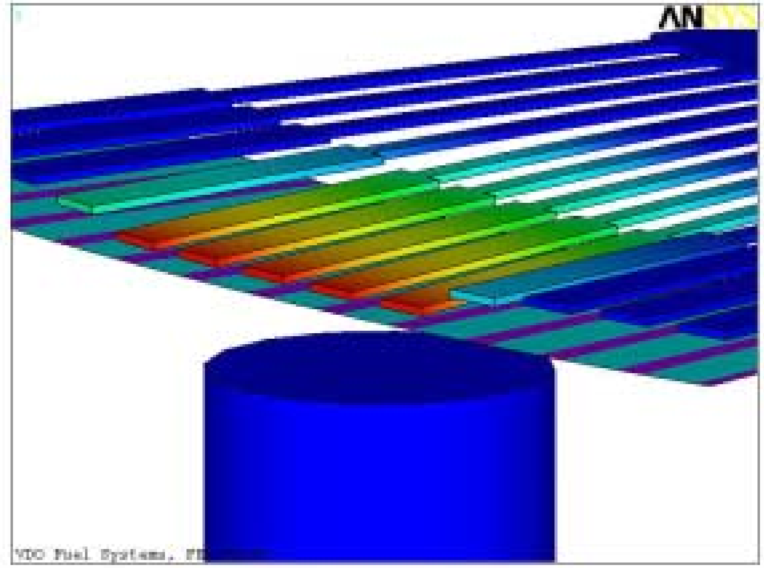
Level sensor



MAPPS operating principle



The task of optimizing the spring:



1) Maximize the contact force:

Contact force = magnetic attractive force **minus** the mechanical spring return force

2) Vibration eigenfrequency not below 1000 Hz (otherwise spontaneous contacting during the vibration of the vehicle – spurious signal).

These are two contrary optimization goals. For example:

a) Longer fingers **decrease** the spring return force ⟶ contact force increases. However, softer spring **lowers** the vibration frequency!

b) Broader contact pads **enhance** the magnetic attractive force (more material), but add more mass, **lowering** the vibration frequency!

c) Thicker metal sheet **enhances** the magnetic attractive force (more material), but **stiffens** the mechanical spring return force: **Counteracting** contributions to contact force. **Which one wins?**

Many parameters play an important role:

Metal sheet thickness, d

Contacting finger length, l

Contacting finger with, b

Contact pad area, A

Pad displacement up to the contact, u_Z

Material magnetic saturation flux density , B_S

Coercive magnetic field, H_C

Young's modulus, E

Metal density, ρ

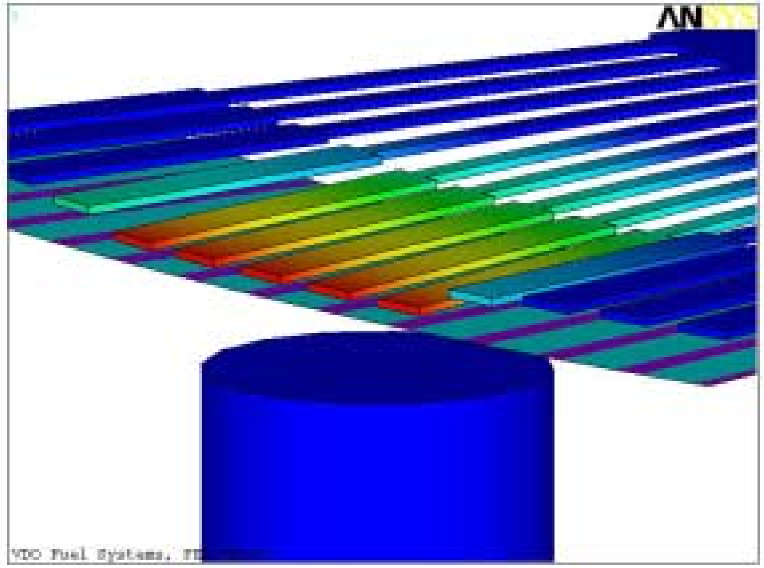
Gradient of the source magnetic field , B_e

All parameters strongly play against one another

What to do? To perform couple field magnetic-mechanical, modal and contact analyses and optimize all of these parameters through it?

A nightmare!

We tried to simplify the problem, separating out the leading effects.



In a brainstorming, a leading R&D engineer said: "A thin, isolated metal plate can be attracted by a magnet in probably very much the same way as our planned metal pads do. Could the rest of the structure therefore be neglected, when considering the source of the magnetic attractive force?"

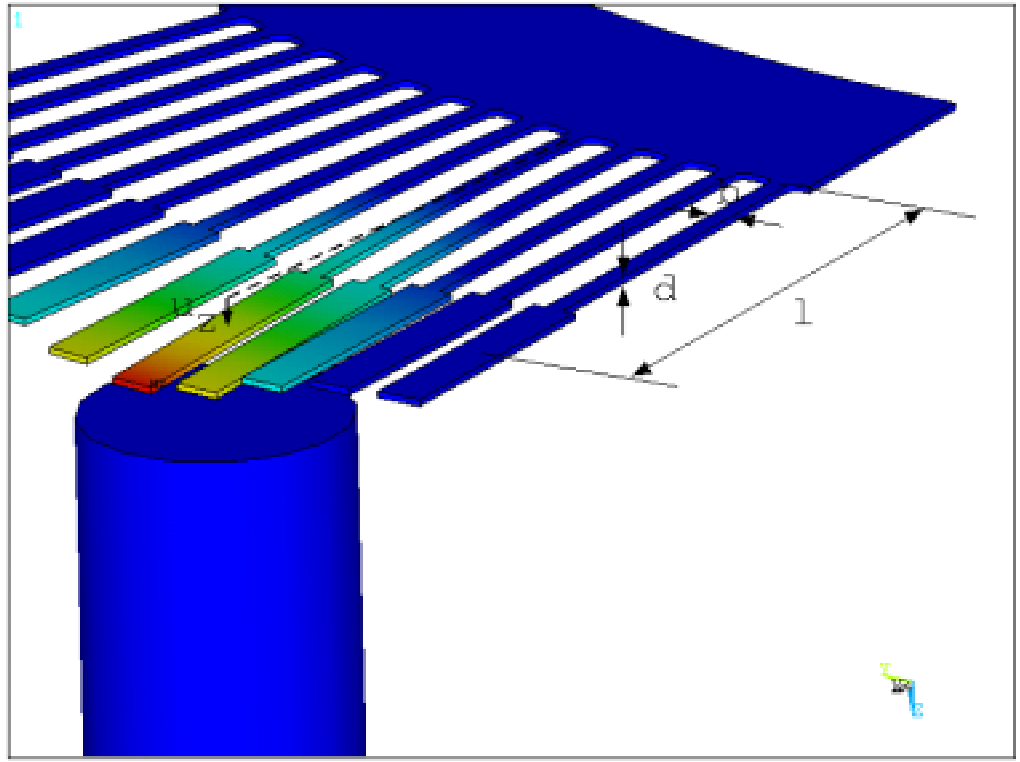
This was a trigger for me: Yes, not only that, but also the mechanics can be treated in such a way! :

- The elasticity of the contacting pads can be neglected when looking at the spring deformation. All the elasticity comes from the long, narrow fingers. Pads are rigid.
- On the other hand, due to the very long and tiny cantilever arms, all of the vibrational mass of importance is concentrated on the pads. Cantilever beams are massless, concerning vibration!

This brought about a simple closed-form-math model, based on:

Spring characteristics given by the cantilever beam formula.

Vibration characteristics:
Point mass in the middle of the contacting pad attached to a massless cantilever beam!



If the material is magnetically at saturation, the magnetic attractive force is only proportional to the volume of the pad!

This created simple, closed-form expressions, containing the relations between all the parameters.

In this way, the feasibility estimation and a fast pre-optimization have been performed.

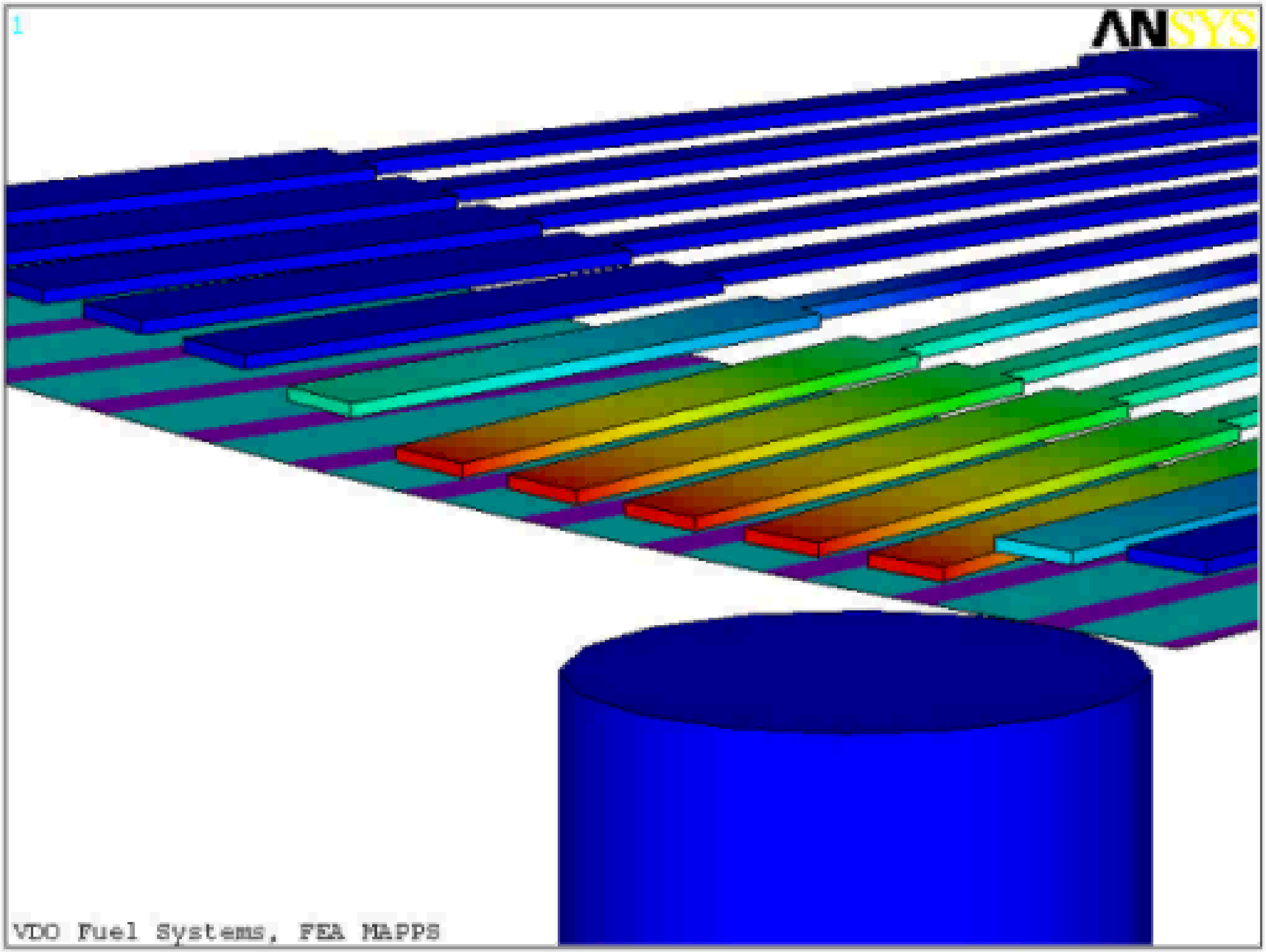
Moreover, these first information on the allowed spring thickness and other needed material properties (mechanical and magnetic) crucially defined the available sheet manufacturing technologies, and therefore also the **price**. At this stage, such information often strongly contribute to the decision on the very future of the project.

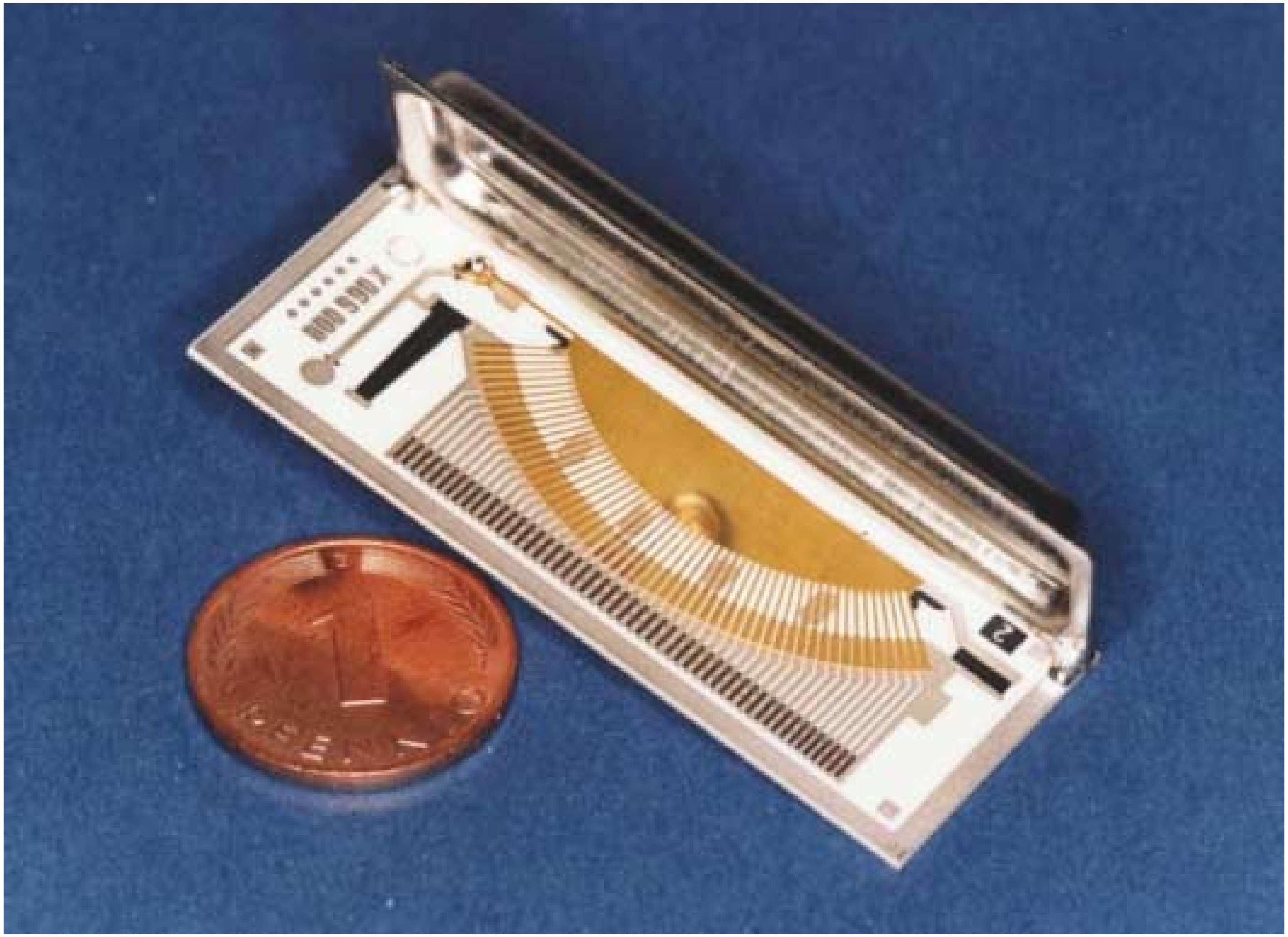
After a positive outcome of pre-optimization, ANSYS coupled-field magnetic-mechanical, modal and contact analyses have been performed in order to refine the judgements and precisely define the design.

Coupled field analysis: magnetic-mechanical with contact

Displacement of MAPPS contact fingers under the attractive force from the moving magnet.

red = contact with resistors on a ceramic substrate.





Coupled field analysis: magnetic-mechanical with contact

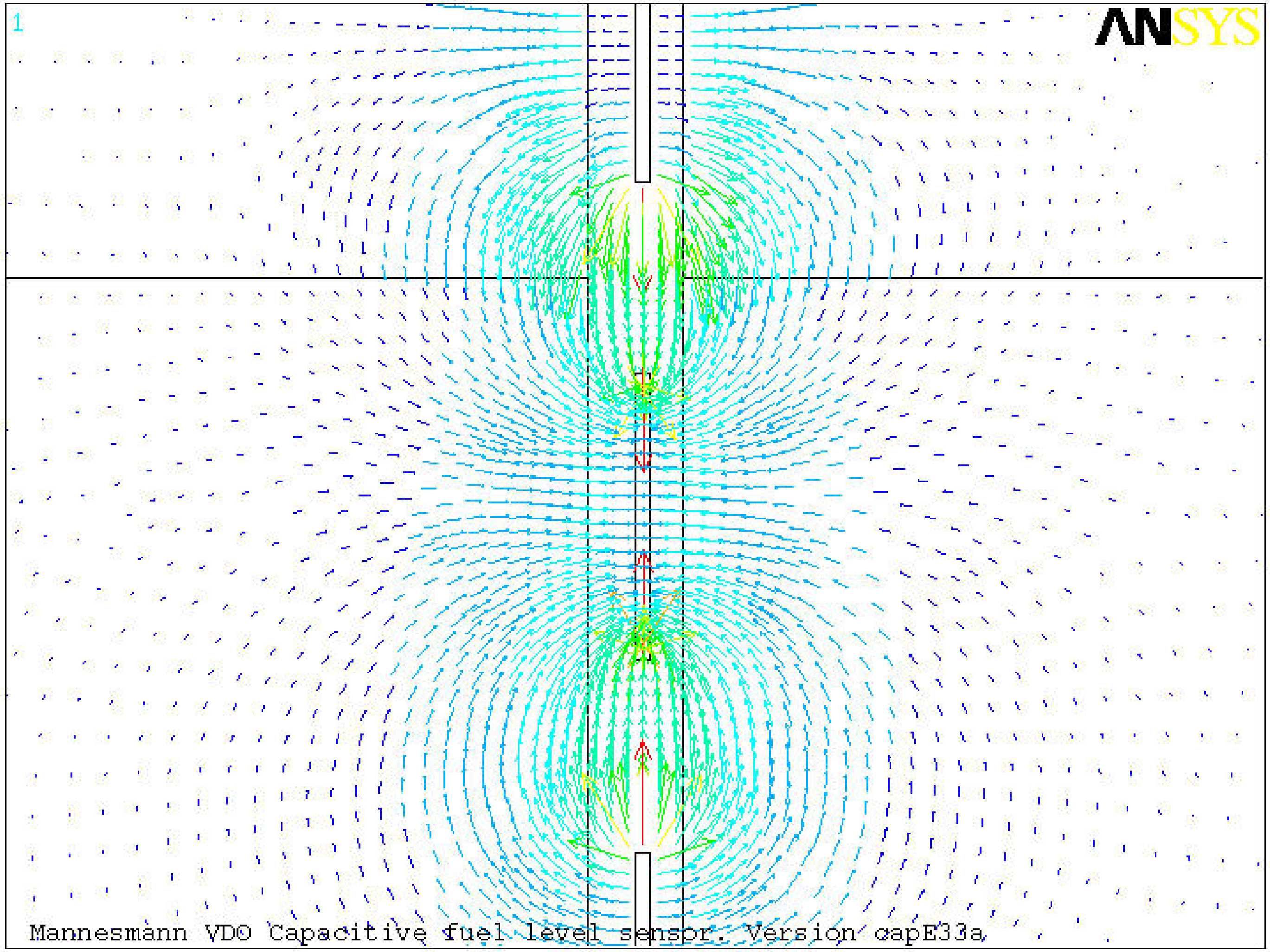
We optimized the magnetic spring within one man eight weeks work.
Our experience is that a hypothetical, comparable device would demand several years of a team-work development time, if done only in a laboratory, without FEA.

The SOP is due soon.

Electric field analysis:
A pilot study of a capacitive fuel level sensor

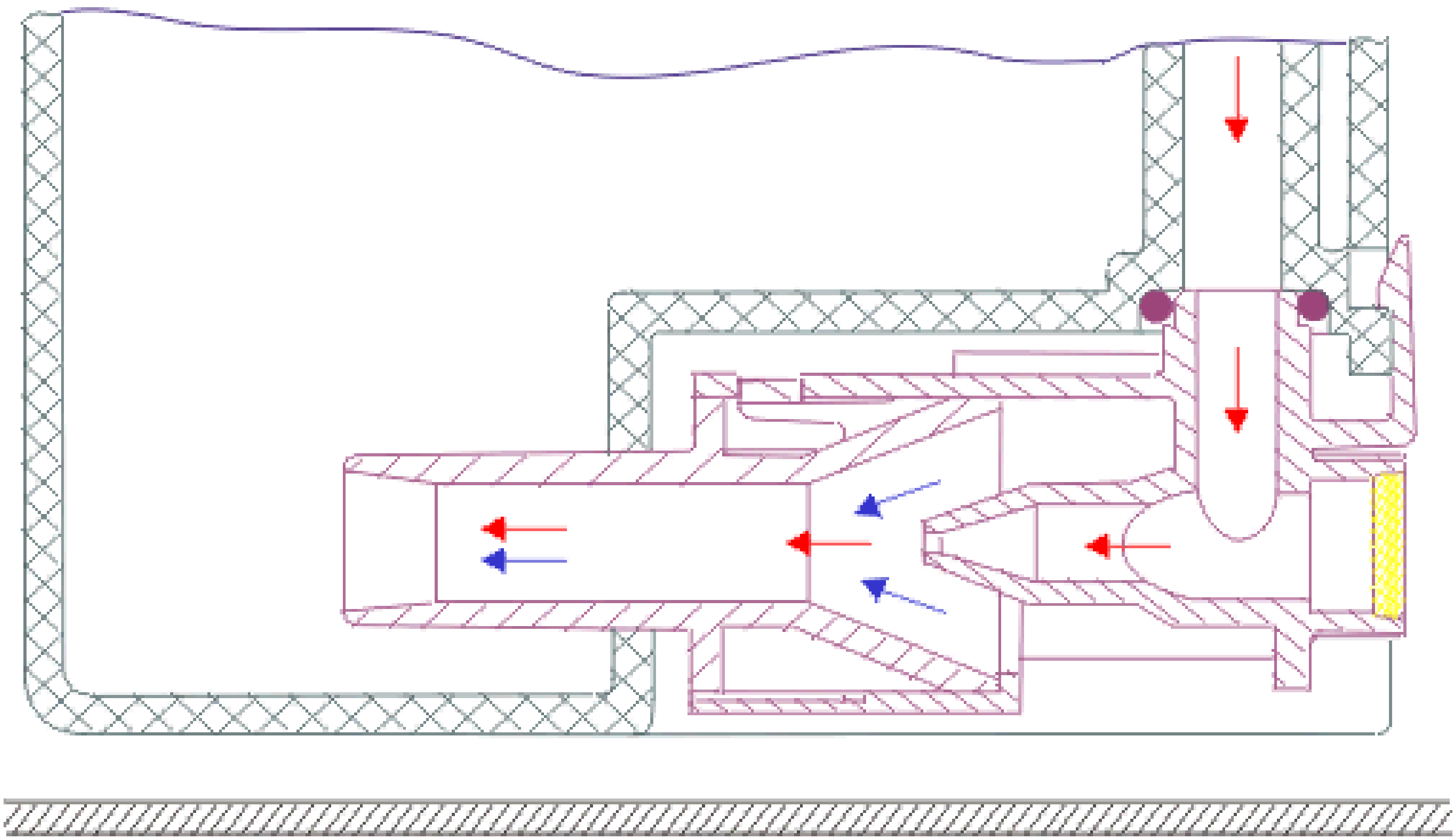
Capacitance changes if the sensor electrodes are covered by fluid.

The first FEA results on the capacitance enabled us to start the electronics development before any hardware was built, shortening the development time **by about one third**



What else are we doing?

Jet Pump - Functional Description



Jet Pumps

CFD (Computational Fluid Dynamics)
ANSYS/FLOTRAN

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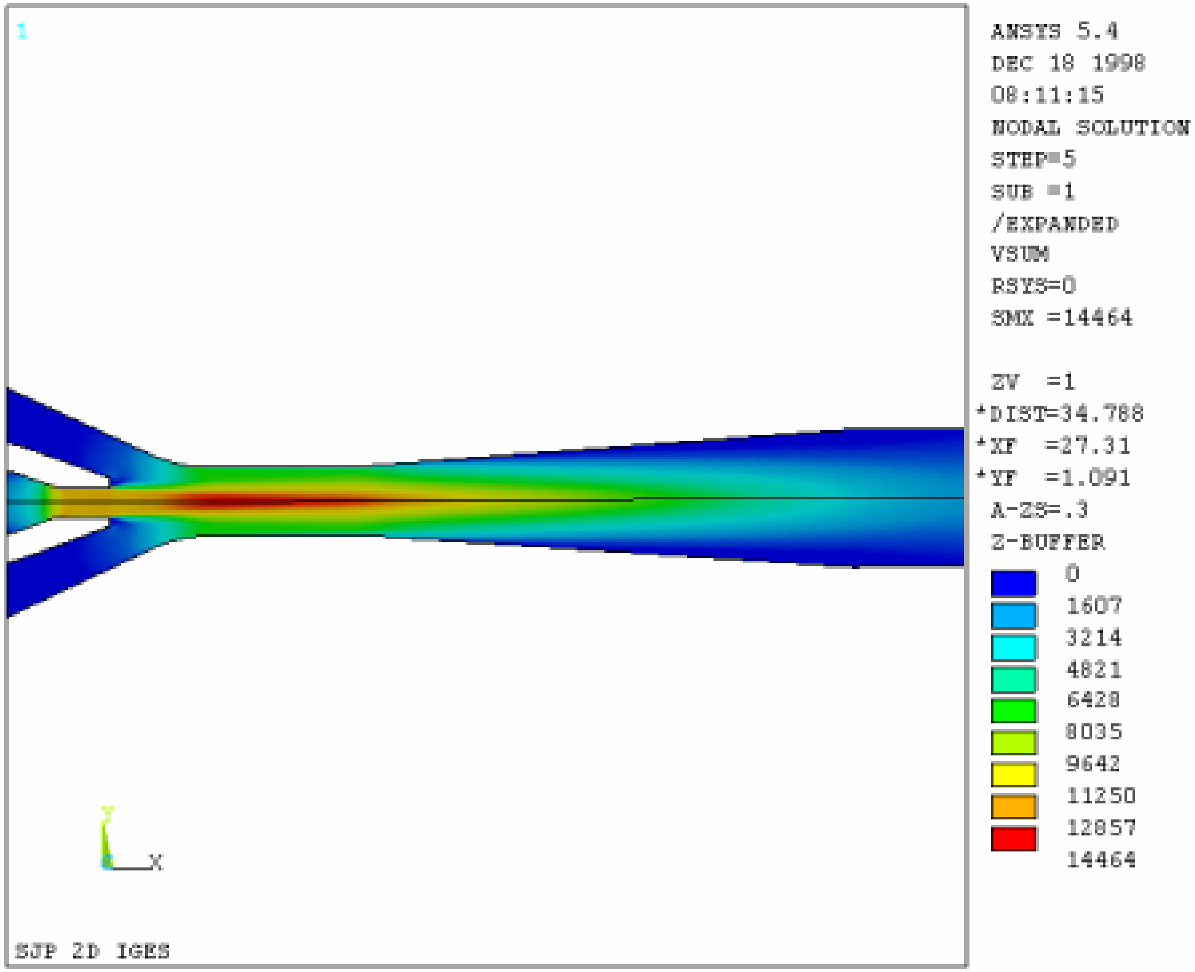
We designed a new generation of fuel Venturi pumps:

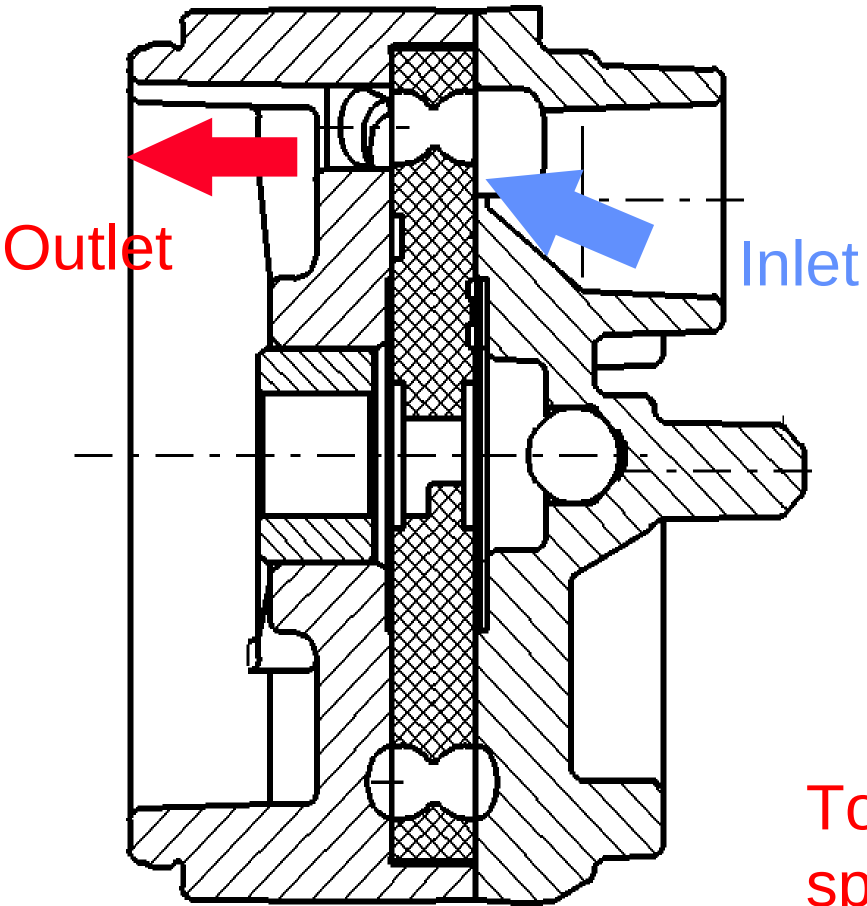
The relations between the diffusor and the mixing pipe are different than in any literature source available.

The pumps have better characteristics and are smaller at the same price!

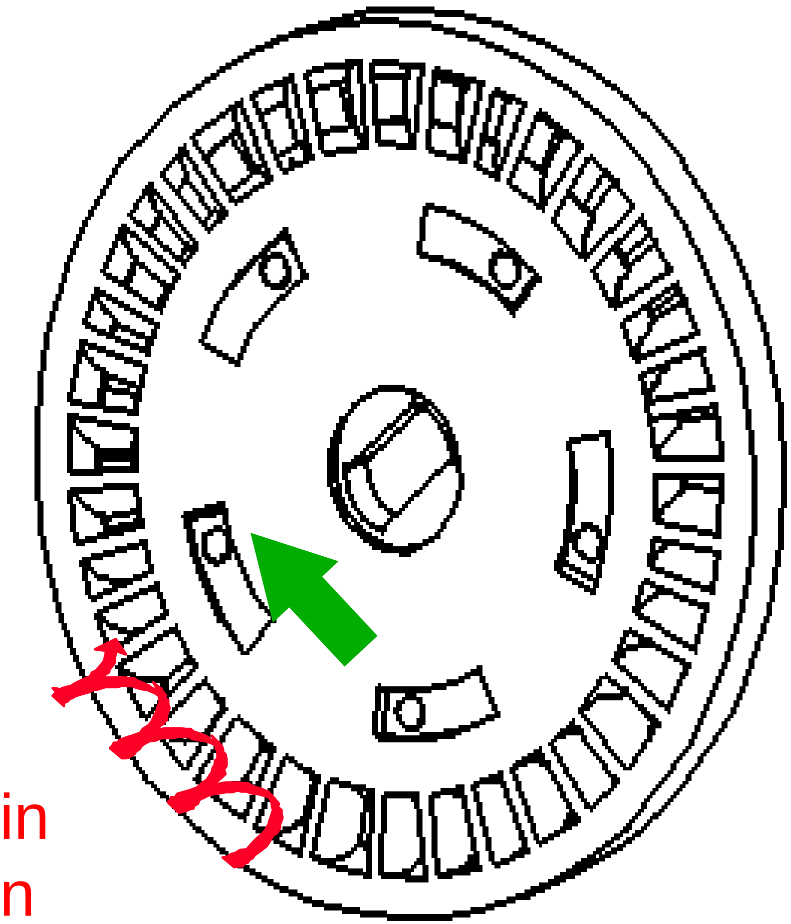


VDO Fuel Pumps

Lateral-Channel-Wheel with "V"-Profile-Paddle
VDO-Patent



Wheel with V- profile paddle

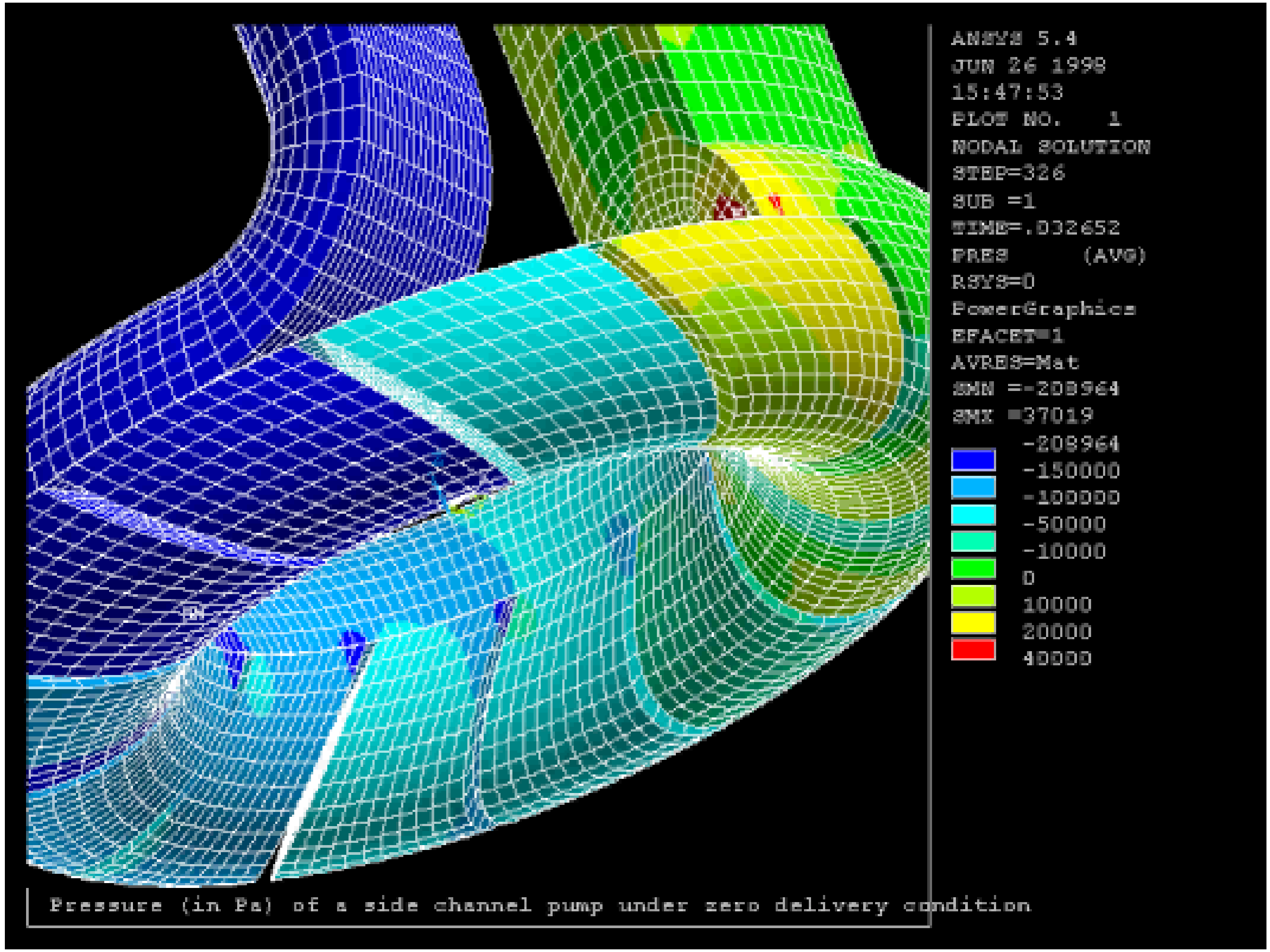


Total flow in spin motion

CFD (Computational Fluid Dynamics)
ANSYS/FLOTRAN

Pressure buildup in a fuel pump stage.

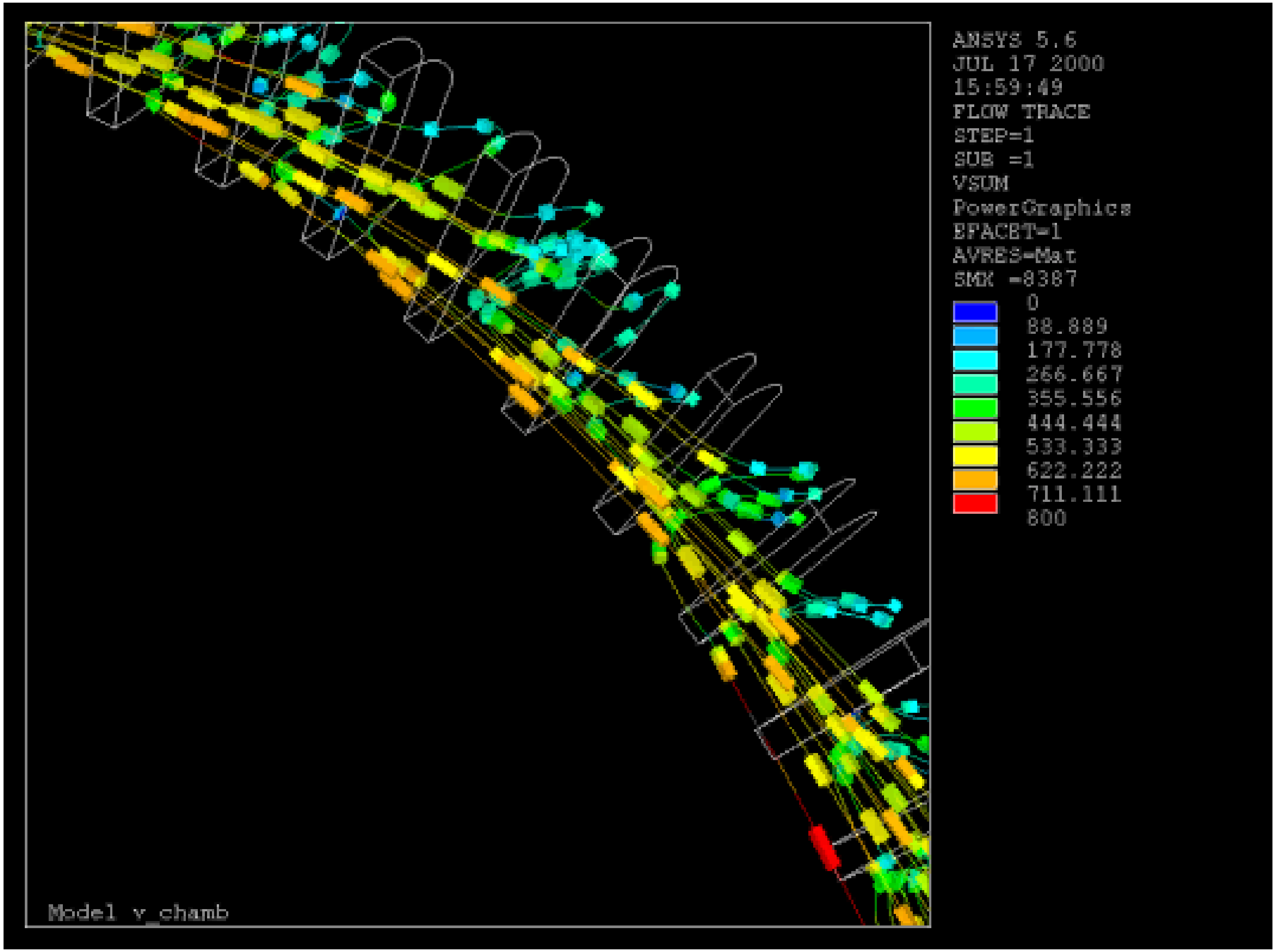
(shown is only a volume, filled with fluid)



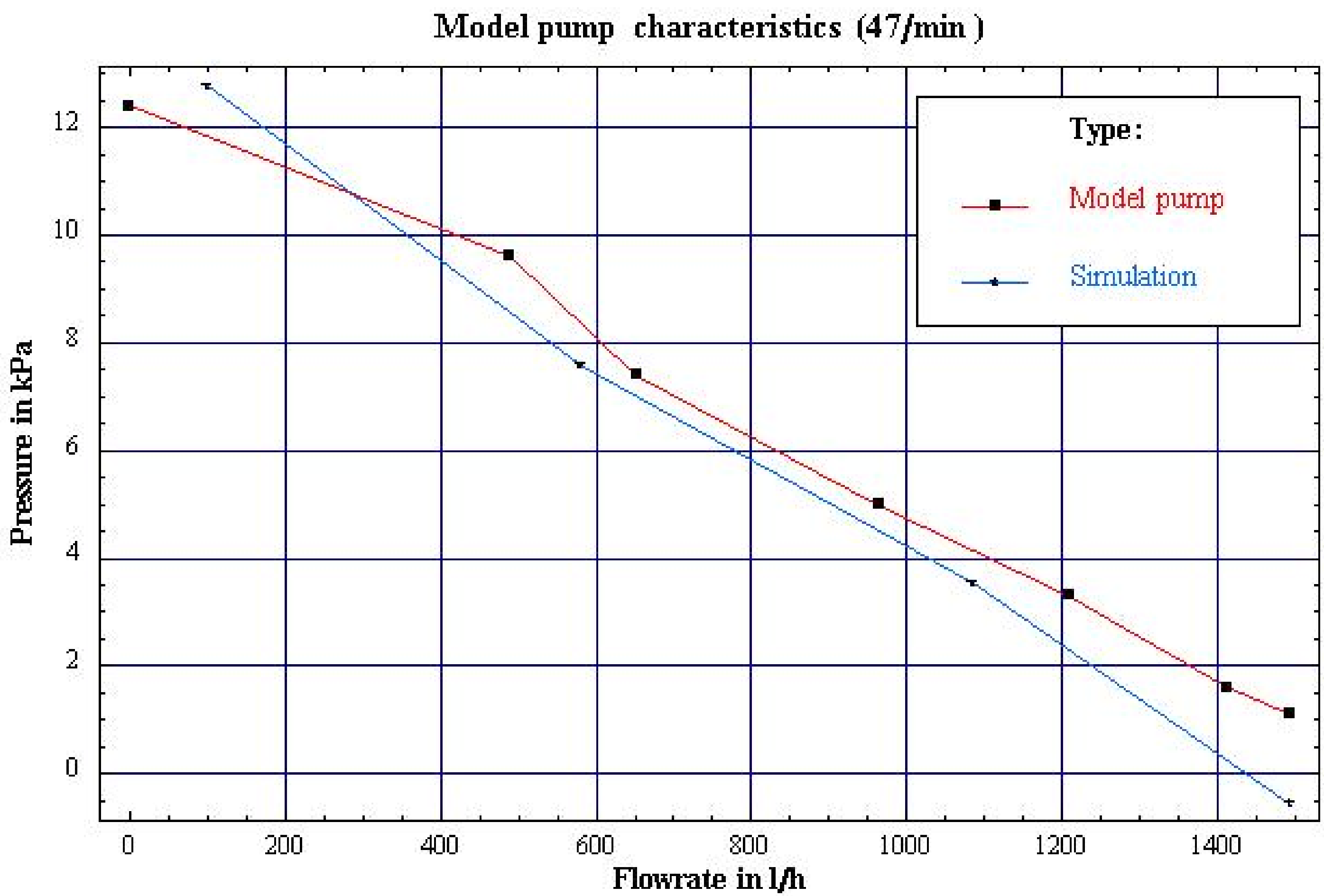
CFD (Computational Fluid Dynamics)
ANSYS/FLOTRAN

Fluid flow through a section of a fuel pump stage.

Particle traces.



Pump characteristics simulation:

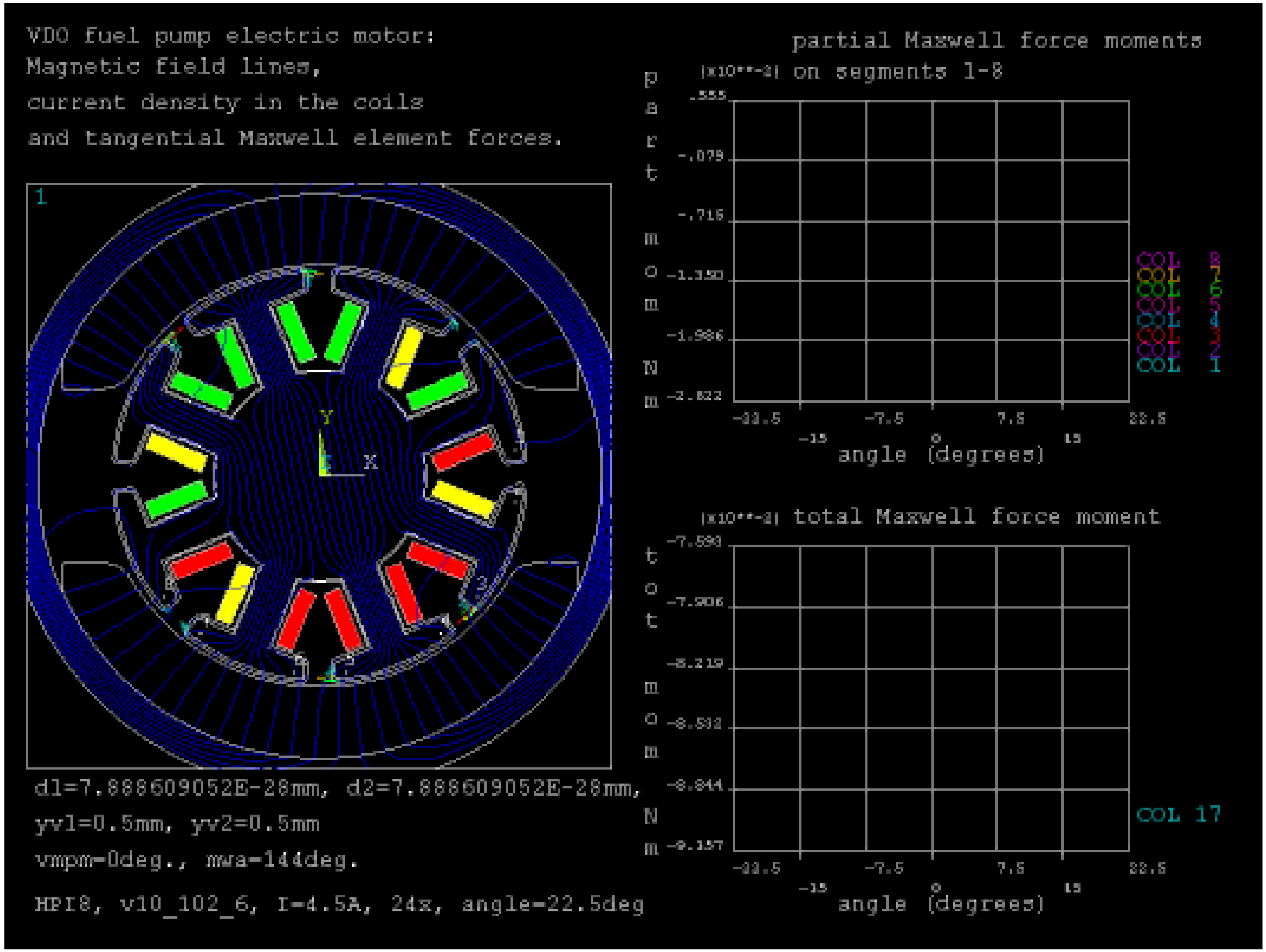


The characteristics can be influenced by changing the shape of vanes, chambers, pump duct etc.

Magnetic field

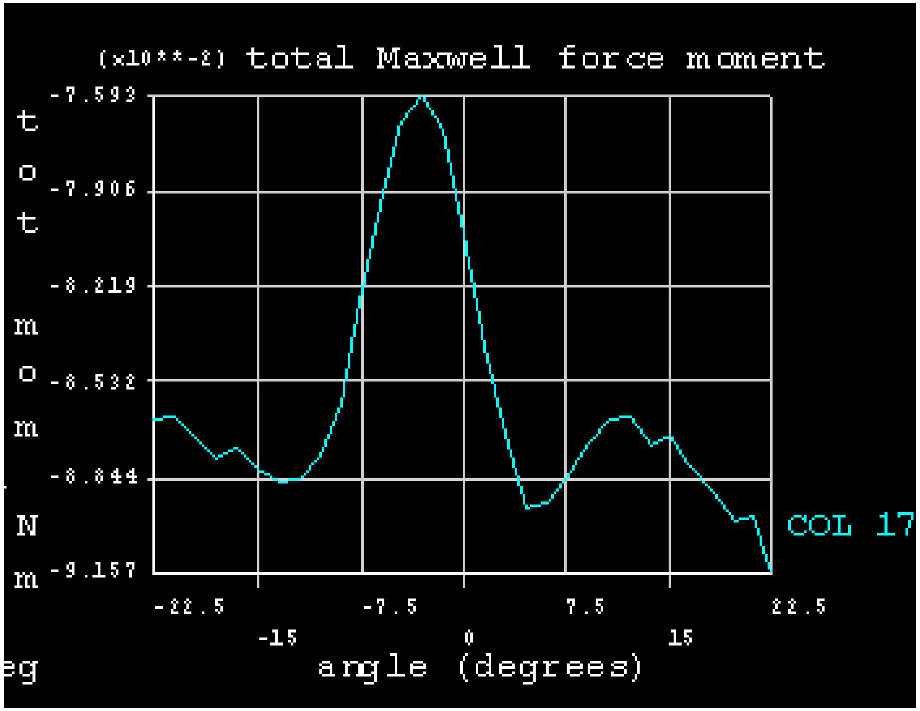
Magnetic field circuit and torque in a pump electric motor during commutation cycle.

Task: Optimizing an average moment value and achieving a more uniform time-dependent moment (less vibration, better acoustic properties).

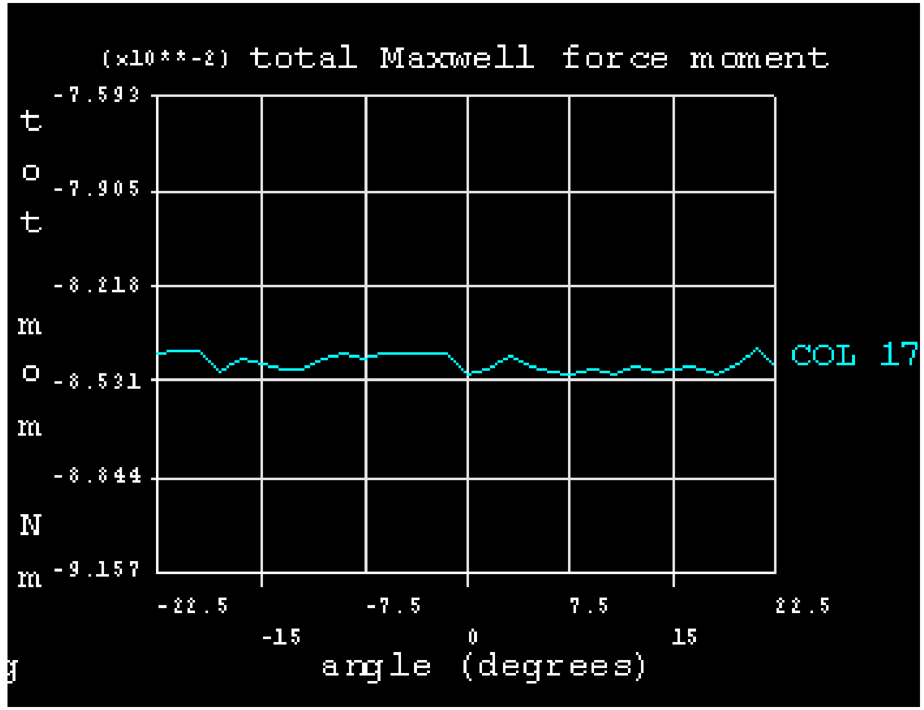


Magnetic field

Torque dependence on angle during one commutation cycle



start



FEA-improved

At the moment we are not yet allowed to show the improved magnetic layout, since this is in the stage of patent application procedure.

Coupled: CFD (Computational Fluid Dynamics) - thermal

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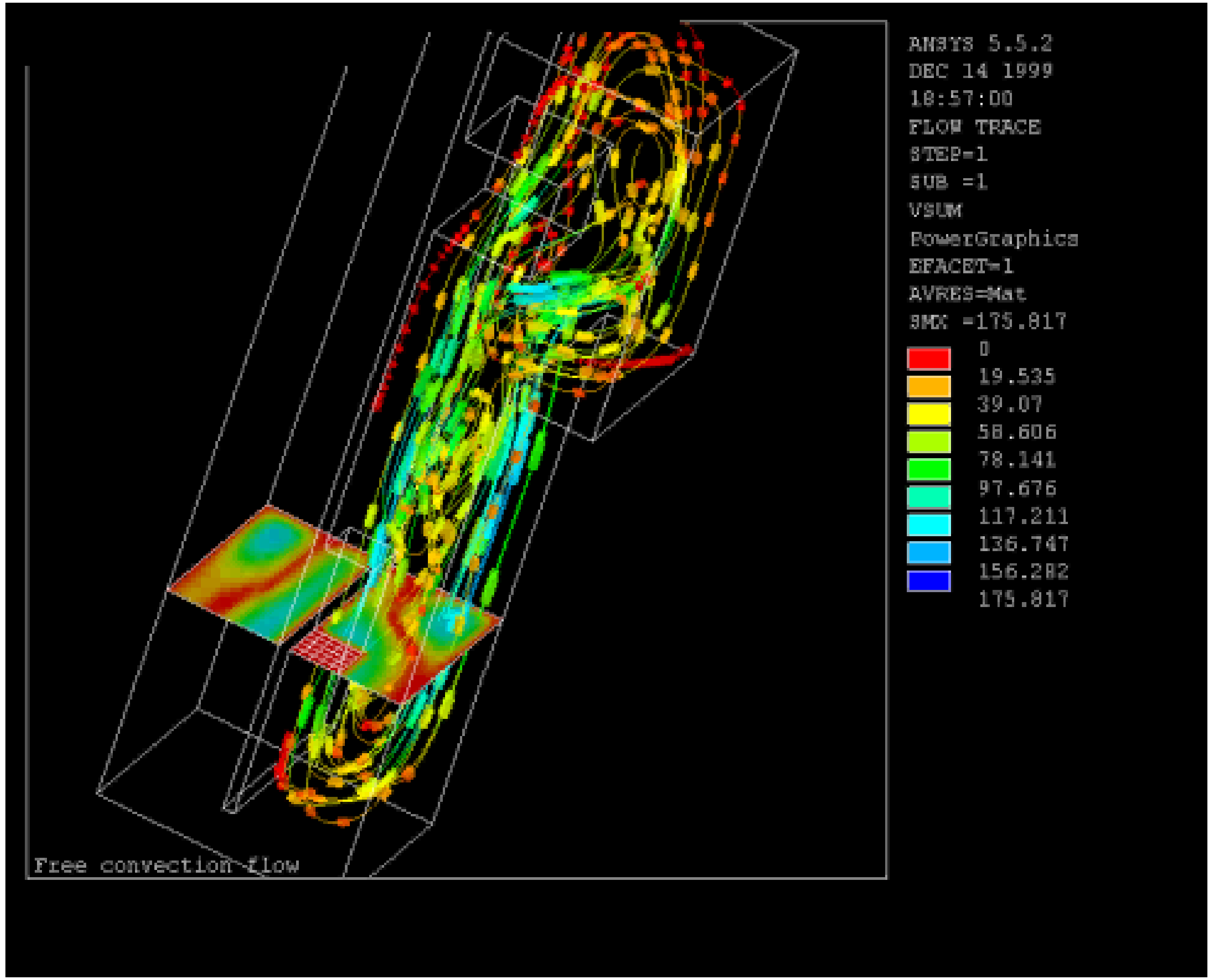
Particle traces: Free convection flow in the control electronics housing of an electronically commutated fuel pump.

Plane contours: absolute value of air velocity distribution



The managers usually ask: How can I quantify the benefits of the use of FEA in my company?

It is very difficult to give a clear cut, quantitative answer at every application case. The overall experience in our company is that under such a strong mutual influence of designers, R&D and test engineers, FE analysts and management, this has many advantages in:

•Better understanding of leading physical effects **(numerical laboratory)**. A simulation is comparable to fixing thousands of sensors in a device. One can clearly ”see” what is going on, especially on problematic places.

•Reduced lead-time with concurrent engineering.

•Reduction in cycle time for variant design studies.

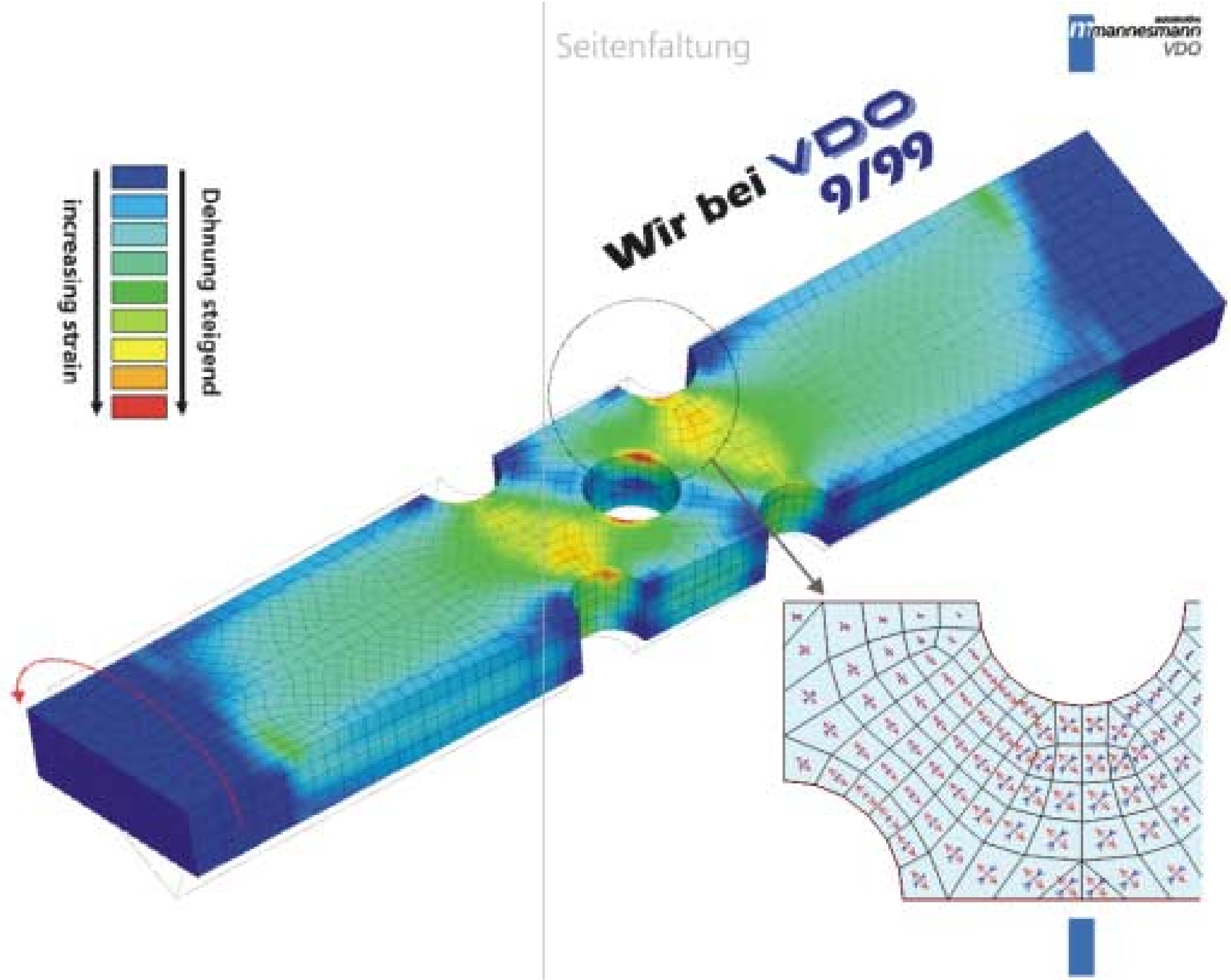
•Improved safety and reliability.

•Improvements in product quality.

Moreover, our customers, the car manufacturers and other system suppliers strongly appreciate, or even demand the FE-analyses. Sometimes, FEA is an important part of bidding for a new contract.

I hope to have also highlighted several examples from our experience, where our FE-analyses **decisively** contributed to the creation of new products:

Title page of our company's official magazine, No. 1, 1999



A few personal messages:

ANSYS is only a tool, not a magic box.

It can simulate ***enormously many things***, if you know in which direction to drive the technical improvement. Employ at least one excellently qualified or at least a very talented engineer per ANSYS team.
Saving money here is saving it in the wrong area.

Often FE-analysts have to solve very difficult problems - they begin at the point, where the other ones gave up. Therefore, my impression is that the following rule, otherwise known for medical doctors, can also be applied to us, FE-analysts:

Even the best ones are just good enough!

To finish with a short real life story, answering in part a question on the importance of the ANSYS-FEA:

A former manager in my business unit got promoted to a higher rank in another division of our company. He was very satisfied how we solved a problem of optimal dynamical damping in one of our devices, saying:
"In the two weeks work you have solved a comparable problem, for which I needed a whole year of trial and error in a laboratory."

One of the first investments in his new business unit were two new ANSYS seats!

End