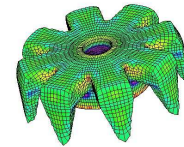
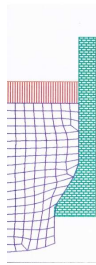
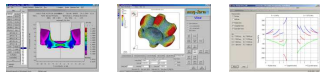


## 30 Years of FEM in bulk metal forming on the example of "eesy-simulation"

"From the idea in university to latest developments  
and applications"

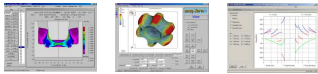


*Dr. Gerhard H. Arfmann, Dr. Michael Twickler  
CPM GmbH, Herzogenrath*



## 30 Years of FEM in bulk metal forming

1. Introduction
2. Developments
3. Applications
4. Application Tool Design
5. Future
6. Acknowledgements



## Introduction

### History

Since the 1980's CPM develops simulation systems.

1981 IBM PC



Typical work  
environment  
of an engineer

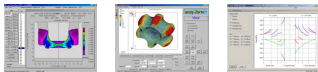


Wikipedia



Idea:

The „CA“engineer



## Introduction

History  
Since

1981



operations simulation systems.

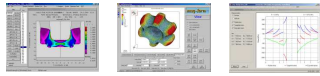


Wikipedia

Development of a „simple to use“  
**simulation system**  
to simulated metal forming and tool  
layout on personal computers

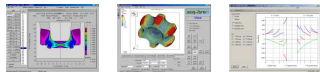


The „CA“engineer



## 30 Years of FEM in bulk metal forming

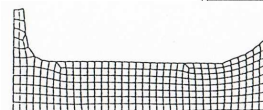
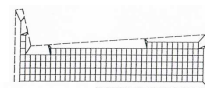
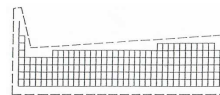
1. Introduction
- 2. Developments**
3. Applications
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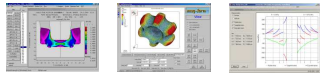


## Developments

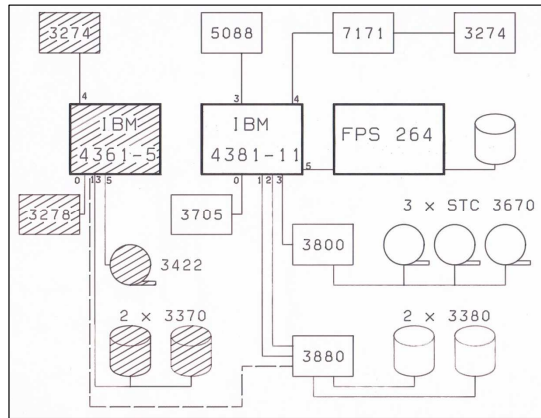
### Basic Developments FEA (2D)

- Element Types
- Contact Algorithm
- Solver for equation systems
- Meshing Methodes
- Material Laws and Data
- Simple User Interface



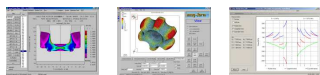


### Developments



**Development environment in the 1980's**

|                              |                |
|------------------------------|----------------|
| <b>Leistung</b>              | ca.. 60 MFLOPS |
| <b>Vergleich</b>             |                |
| <b>Core i7,</b>              |                |
| <b>3,47 GHz, 83,2 GFLOPS</b> |                |
| <b>6 Kerne</b>               |                |



### Developments

#### **First Prototype of an FEA System to be used on PC CAPS-Finel V1.0 (1989)**

2D Axis-symmetric, 2D plane

Integrated Modelling, Simulation and Post-processing in a single System

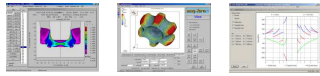
Simple interaction by a "question and answer" dialog

Rigid-plastic material law

Thermal – mechanical simulation

Automatic Meshing

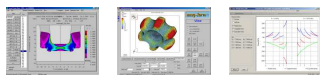
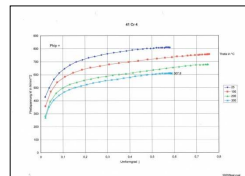
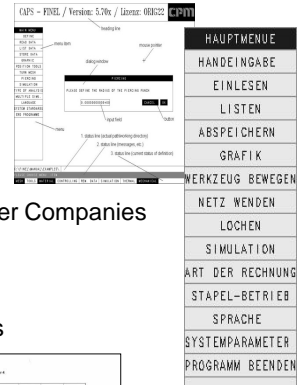




**Developments**

**Next Steps**

- Development of a graphical interface
- Development project with German Fastener Companies
- Improvement of technological modules
- Simple handling of Multi-station processes
- Elastic tooling
- Microstructure
- Material Data



**Developments**

**Next steps -2-**

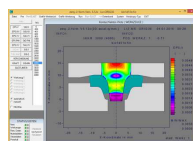
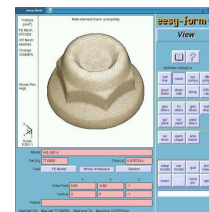
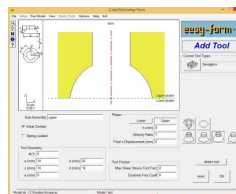
- New friction laws
- Failure analysis
- 3D Applications
- 3D Toolbox

**Friction**

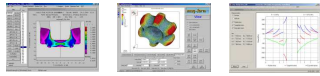
Coulomb  $F_r = \mu \cdot N$

Max. shear stress  $\tau = m \cdot k$

Combined  
Coulomb / max. shear stress

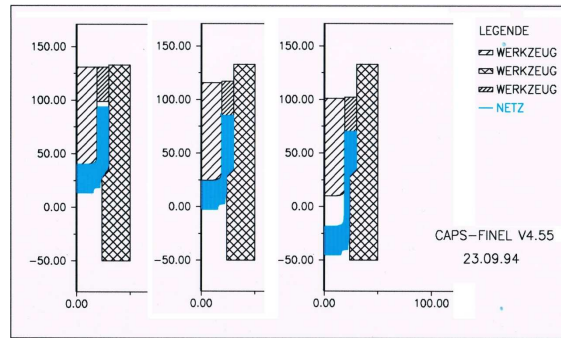
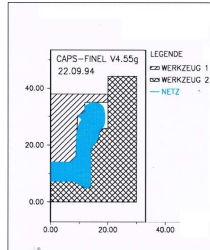


New „easy“ Windows Design  
(easy-2-form, easy-form)

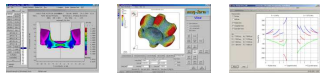


**Developments**

**Simulation of folding 1994**

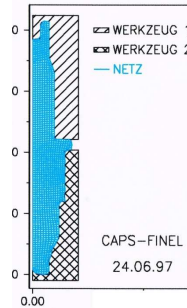
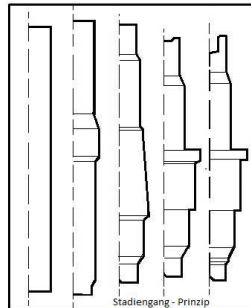


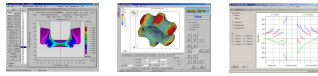
Tooling with spring



**Developments**

**Automatic simulation of multi station processes**

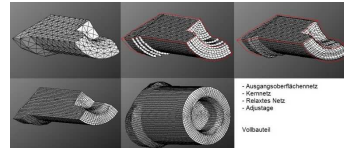




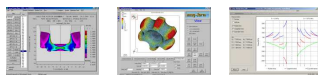
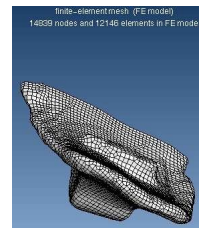
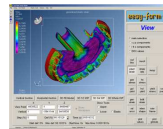
**Developments**

**Next steps -3-**

Push of 3D Simulation using



- Automatic meshing and re-meshing of Hexahedral elements
- Elastic-plastic Material law
- Interfacing with CAD
- ....



**Developments**

**Next steps -4-**

More and better technological modules

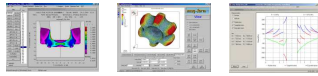
- Contact,
- Friction,
- Folding,
- ...



**Additional System easy-DieOpt for Design and optimization of tooling systems**

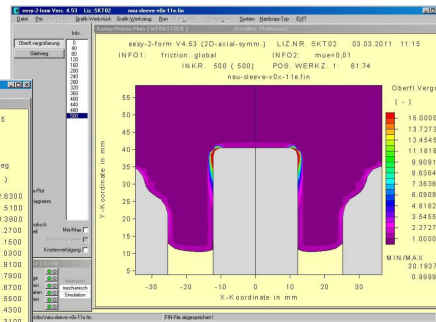
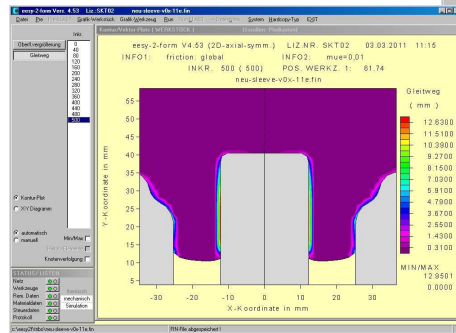
Local Description of friction

**Additional analysis of local surface properties -> Tribo-system**

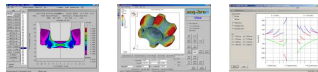


## Developments

### Surface enlargement



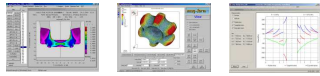
### Sliding distance



## 30 Years of FEM in bulk metal forming

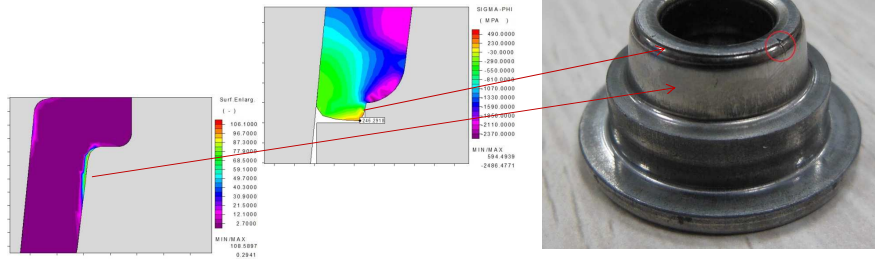
1. Introduction
2. Developments
- 3. Applications**
4. Application Tool Design
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### Applications

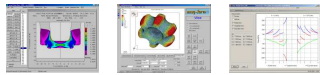
Rough surface and crack at a retainer



Surface enlargement

Tangential Stress

Retainer with failure

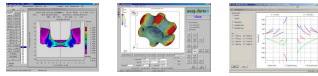


### Applications

Example of complex cold forging operations

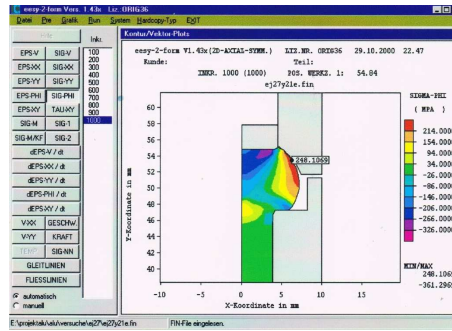


Hydraulic pivot element

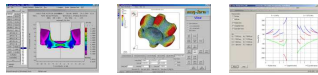


## Applications

### Damage analysis

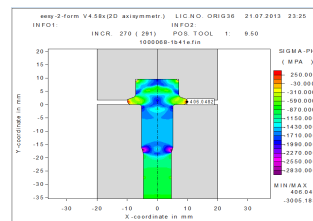
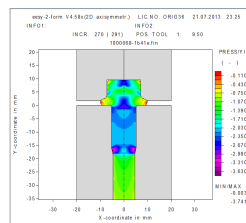


Cracks in a screw made from aluminum

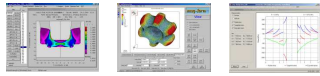


## Applications

### Damage analysis

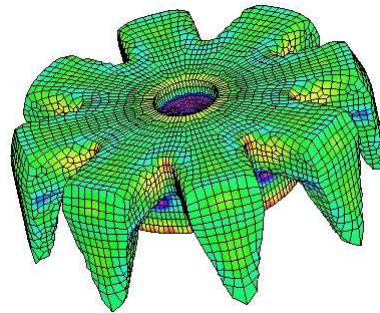
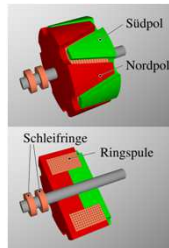


Crack in a screw (material failure)



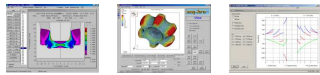
## Applications

### Example of complex cold forging operations



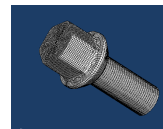
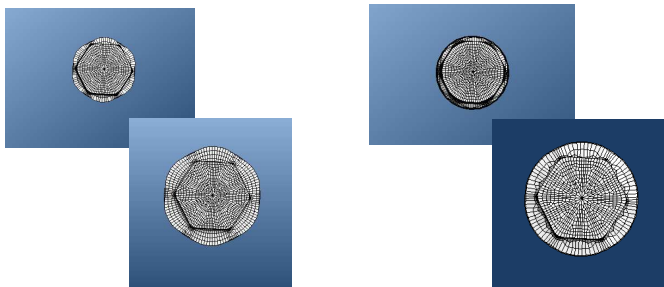
(Claw pole motor – Wikipedia)

Claw

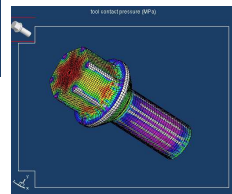


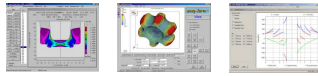
## Applications

### Example of complex cold forging operations



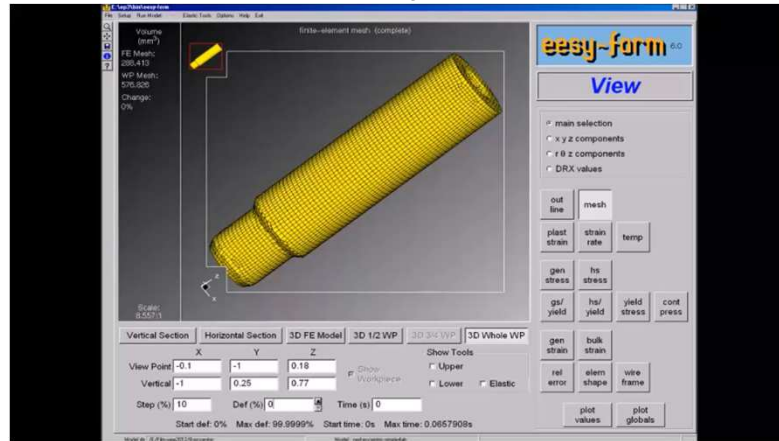
To avoid a „flower“ shape





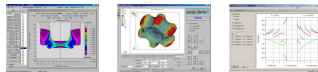
## Applications

### Eccentric pressing

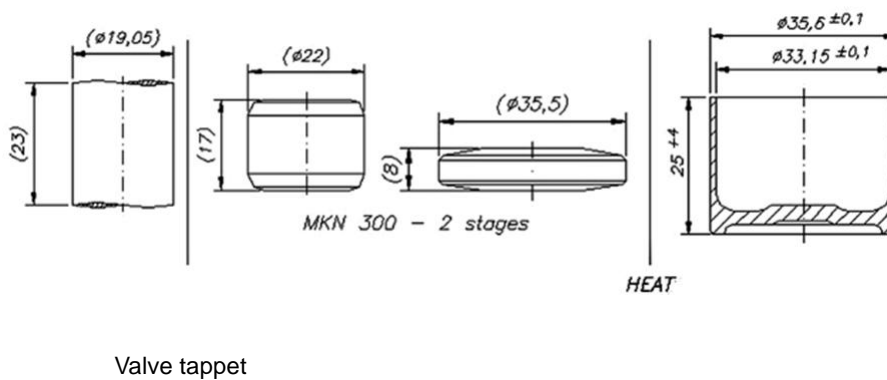


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35<sup>th</sup> Senafor, 07-09.10.2015, Porto Alegre, RS, Brazil

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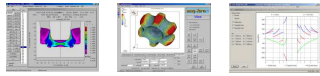
## Applications



Valve tappet

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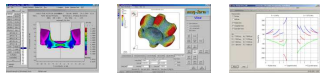
24



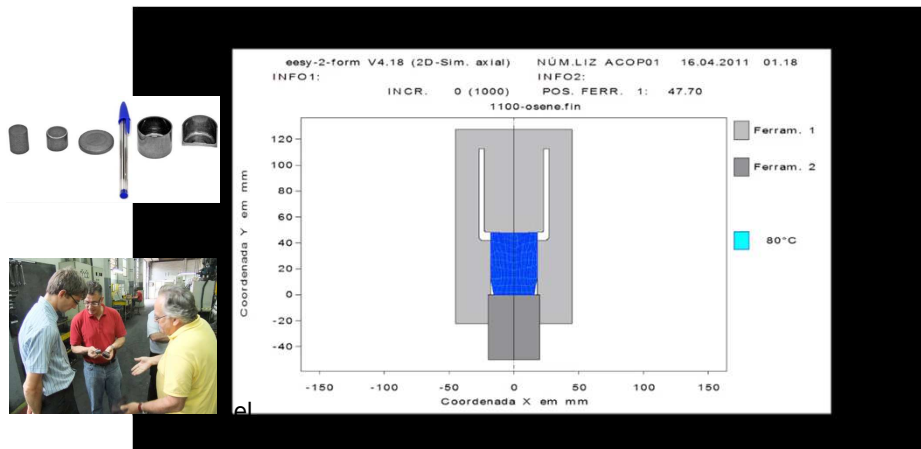
### Applications

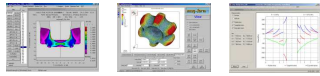


Valve tappet



### Applications





## Applications

This was a small overview about what can be done in simulation today.

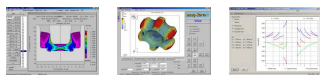
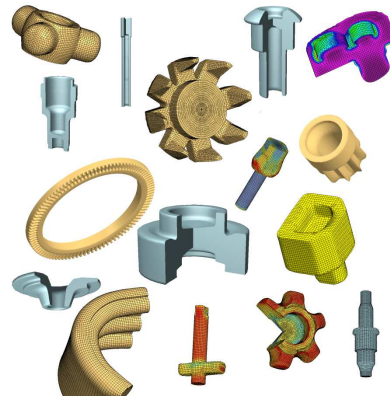
But besides the forming sequence the

### tool design

is decisive for a good productivity.

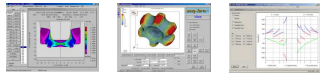
In the following is shown how

### Simulation can help with Tool design



## 30 Years of FEM in bulk metal forming

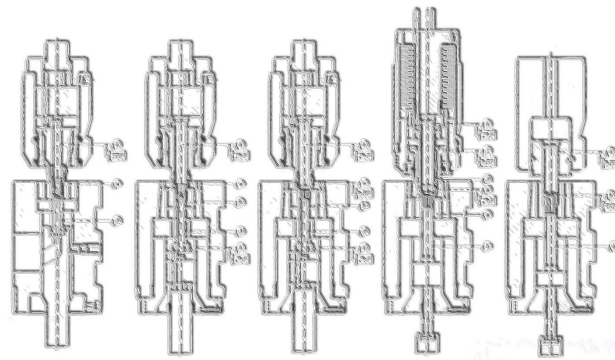
1. Introduction
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### Application Tool Design



Spark Plug

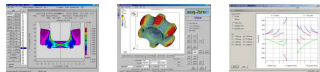


The idea how to make the tool design may be known in general.

Design by Nedschroef, Belgium

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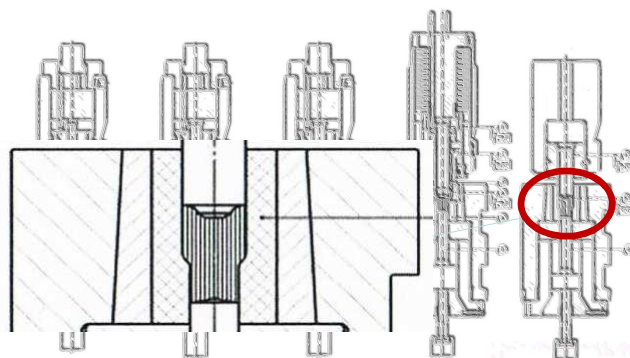
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### Application Tool Design



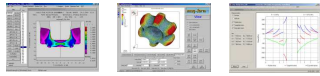
Spark Plug



How to do in detail ? Procedure will be explained in principle using similar examples

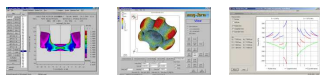
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## Application Tool Design

1. Analysis of punches
2. Analysis of a die insert (Carbide)
3. Design of an extrusion die
4. Example of a practical applications



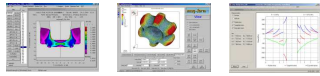
## Application Tool Design



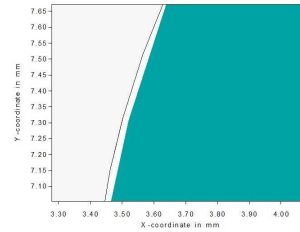
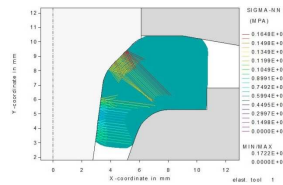
Examples of punch failure







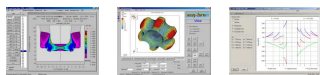
### Application Tool Design



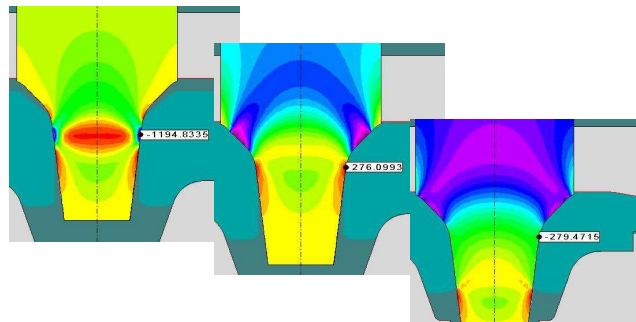
### Analysis

Pressure on the surface  
Alternating axial  
stresses in the punch  
and explanation  
Loss of contact  
during forming  
(no oil or air enclosure)

Punch failure during production of a retainer

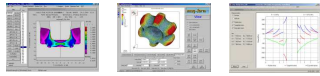


### Application Tool Design



Alternating Stresses

Failure due to fatigue

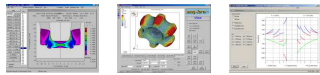


### Application Tool Design

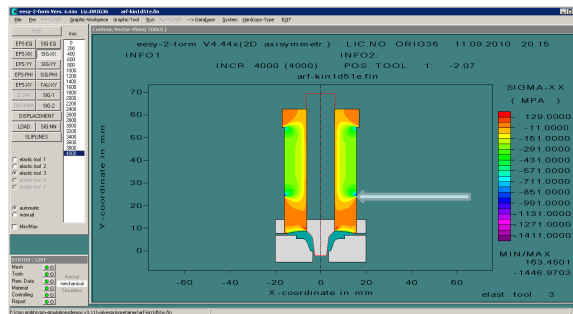


Fatal failure of a punch

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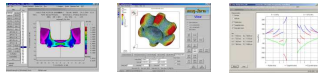


### Application Tool Design

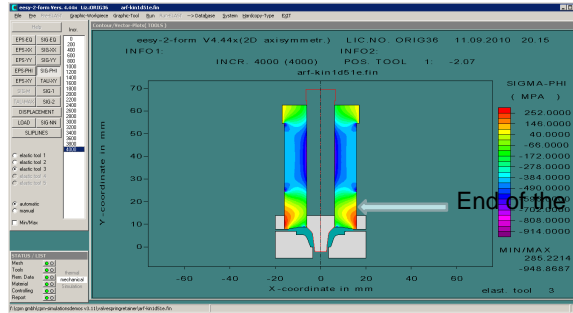


Stress concentration at the point of crack initiation (Sig xx)

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35<sup>th</sup> Senafor, 07-09.10.2015, Porto Alegre, RS, Brazil

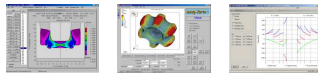


### Application Tool Design



End of the protecting tube

Positive tangential stress below the contact point

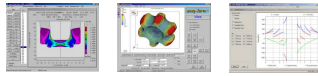


### Application Tool Design



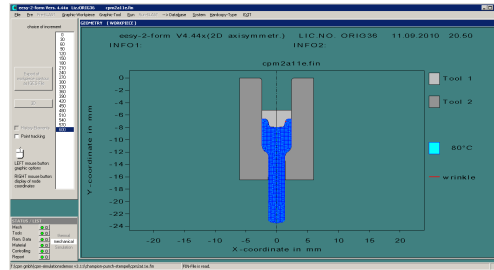
Punch failure during  
production of spark plug

Picture from a similar case (Picture ICFG Workgroup Simulation)

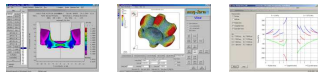


## Tool Design Task – Analysis of punches

Failure of punch during extrusion

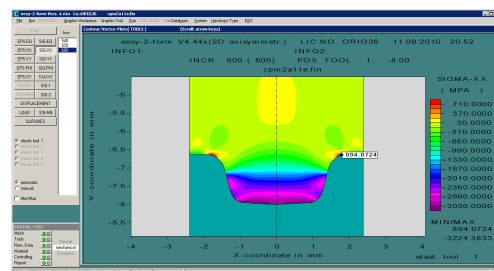


Punch failure during  
production of spark plug



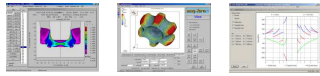
## Application Tool Design

Failure of punch during extrusion



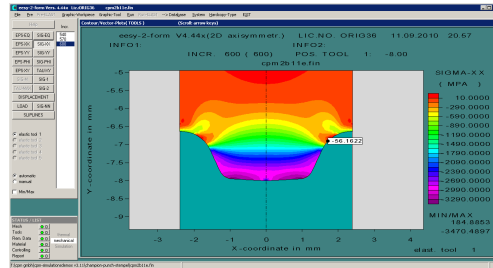
Punch failure during  
production of spark plug

High local positive radial stress -> punch failure



## Application Tool Design

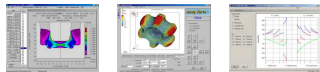
Failure of punch during extrusion



Punch failure during  
production of spark plug

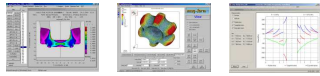
No concentration of positive radial stress after

Changing the radius -> no failure

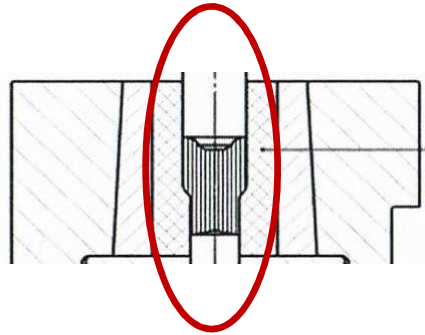


## Application Tool Design

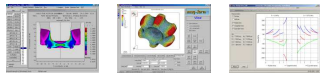
1. Analysis of punches
2. Analysis of a die insert (Carbide)
3. Design of an extrusion die
4. Example of a practical applications



### Application Tool Design



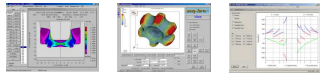
Die design



### Application Tool Design

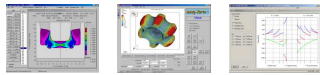
Horizontal split  
(breakage)  
due  
to axial stresses





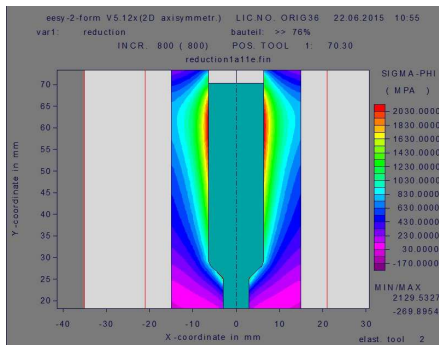
### Application Tool Design

Fatal cracking  
due to  
overloading

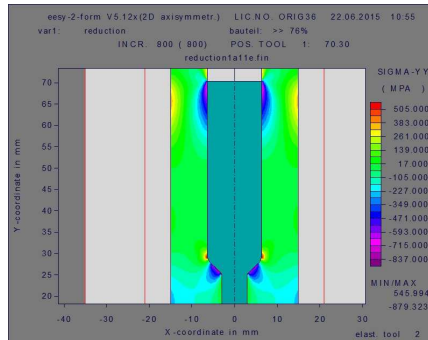


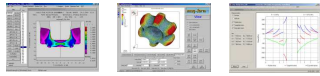
### Application Tool Design

Tangential Stress to be compensated  
by pre-stressing



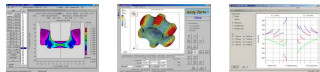
Axial stress to be avoided by split



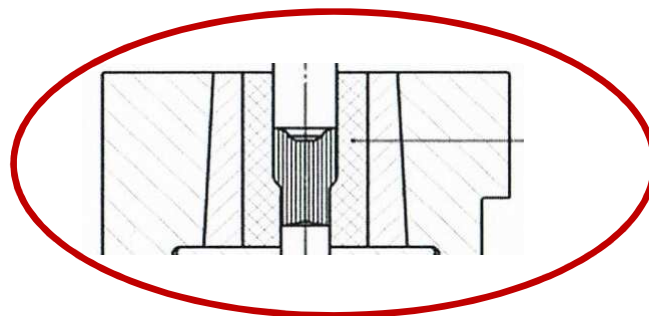


## Application Tool Design

1. Analysis of punches
2. Analysis of a die insert (Carbide)
- 3. Design of an extrusion die**
4. Example of a practical applications

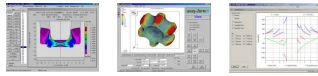


## Application Tool Design

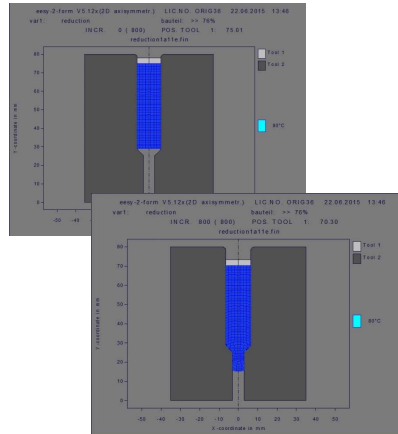


**Design of an extrusion die**

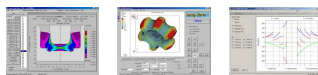




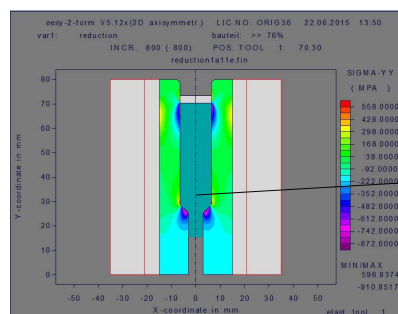
### Application Tool Design



## Simulation of an extrusion

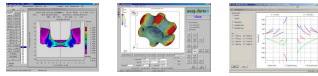


### Application Tool Design



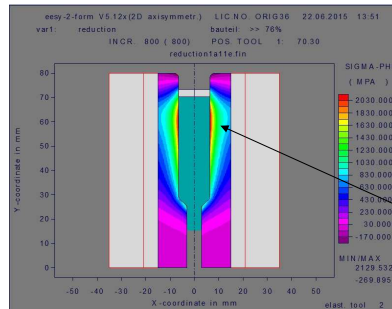
- Avoiding of failures (elastic analysis of the insert with FEM)

## Splitting of the die due to high axial stresses

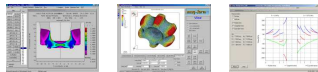


## Application Tool Design

### Tool design



Positive stress in  
the die without  
pre-stressing

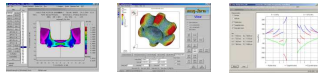


## Application Tool Design

### Procedure

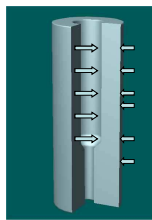
After the FEM analysis of the part an optimal design layout  
is calculated with the die-design system

The results (diameters, interferences etc) are provided to  
the FEM code with integrated die-design software



### Application Tool Design

### System to calculate and optimize the pre-straining in a die



easy-DieOpt Vers. 2.04 License for: 11-CPM GmbH, Herzogenrath, Germany

File 2-RING-SYSTEM (cold) 2-RING-SYSTEM (warm) 3-RING-SYSTEM 4-RING-SYSTEM Language System EXIT

3-RING-SYSTEM License for: 11-CPM GmbH, Herzogenrath, Germany

|                         | Insert | Sleeve     | Casing     |
|-------------------------|--------|------------|------------|
| Material name           | G55    | X40CrMoV51 | X40CrMoV51 |
| Material number         |        | 1.2344     | 1.2344     |
| Young's modulus [MPa]   | 450000 | 216000     | 216000     |
| Poisson's ratio [-]     | 0.25   | 0.28       | 0.28       |
| Tensile strength [MPa]  |        | 1900.0     | 1670.0     |
| Yield strength [MPa]    |        | 1700.0     | 1470.0     |
| Tempering temp. [°C]    |        | 550        | 600        |
| Equivalent stress [MPa] | 1462.7 | 1530.0     | 1323.0     |
| Tangential stress [MPa] | 0.0    | 571.1      | 893.6      |

Contraction (-) / Expansion (+): of D1 0.010 mm of Da 0.154 mm

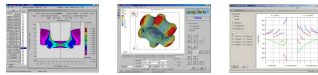
Assembly:  (Casing + Sleeve) <- Insert  
 (Insert + Sleeve) -> Casing  
 Without intermediate corrections

Buttons: New calculation, Optimisation (Interference), Optimisation (Complete), Optimisation (S1,D2,S2 only), Help, Graphic

22.06.2015 14:40

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### Application Tool Design

Interface

EESY-DieOpt

EESY-2-form

Tool Preloading

Type of tool assembly:

- Insert + Casing
- Insert + Sleeve + Casing (outside -> inside)
- Insert + Sleeve + Casing (inside -> outside)
- Insert + 2 Sleeves + Casing (outside -> inside)
- Insert + 2 Sleeves + Casing (inside -> outside)
- Insert + 2 Sleeves + Casing ((1+2) -> (3+4))

Function in tool assembly:

- Insert
- 1. Sleeve / Casing
- 2. Sleeve / Casing
- Casing

load easy-DieOpt Tool-Layout (\*.edo)

Inner Diameter given: 23.00 mm

Fitting Diameter D1: 23.00 mm

Fitting Diameter D2: 42.00 mm

Fitting Diameter D3: mm

Outer Diameter: 70.00 mm

Interference S1: 0.183 mm

Interference S2: 0.155 mm

Interference S3: mm

Material: G55, X40CrMoV51, X40CrMoV51

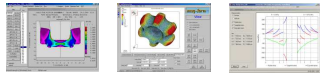
Poisson's Ratio: 0.25, 0.28, 0.28

Young's Modulus: 450000, 216000, 216000

Buttons: Cancel, OK

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35<sup>th</sup> Senafor, 07-09.10.2015, Porto Alegre, RS, Brazil

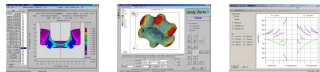
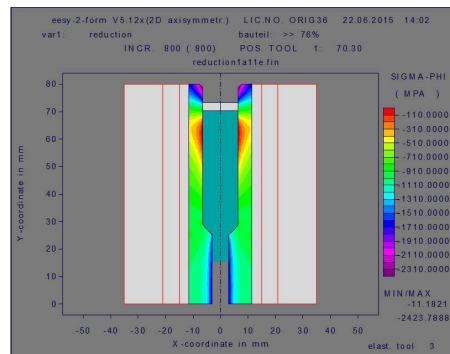
54



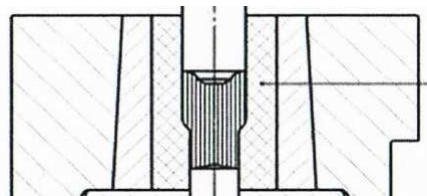
### Application Tool Design

In this case the result is ok.

Otherwise the engineer  
has to make changes in  
the design again.



### Application Tool Design



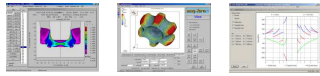
Final design:

inner dia: 12.83 mm  
outer dia: 70.00 mm

fitting dia: 23.00 mm  
interf.: 0.169 mm

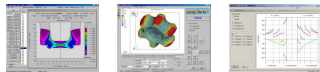
fitting dia 2: 42.00 mm  
interf: 0.168 mm

Mat insert: G55  
Mat sleeve: SKD61 HRC 54  
Mat body: SHD61 HRC 50

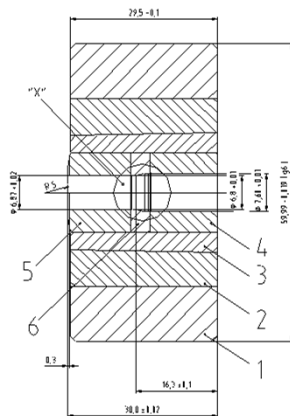


### Application Tool Design

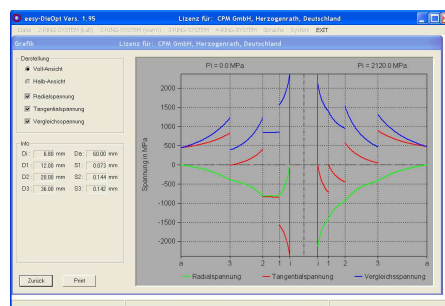
1. Analysis of punches
2. Analysis of a die insert (Carbide)
3. Design of an extrusion die
4. **Example of a practical applications**

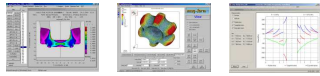


### Application Tool Design

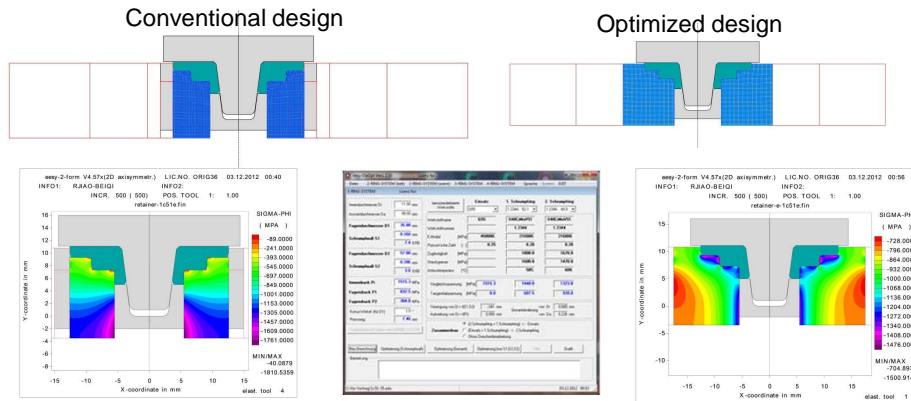


- Even complex design could be realised

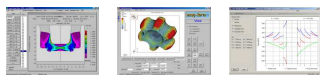




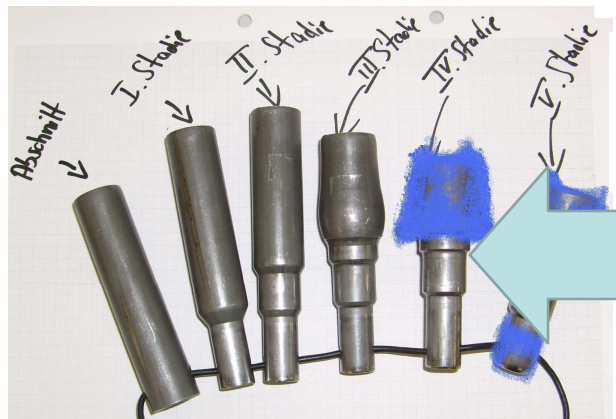
### Application Tool Design



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35<sup>th</sup> Senafor, 07-09.10.2015, Porto Alegre, RS, Brazil



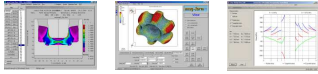
### Application Tool Design



5 station  
cold forging  
process

Location of the  
problem in the  
tooling

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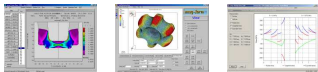


### Application Tool Design



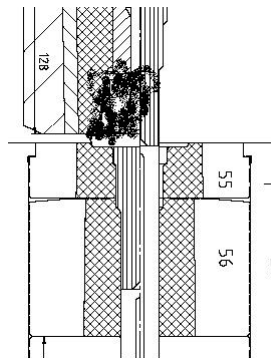
5 station  
cold forging  
process

Premature failure  
of the die

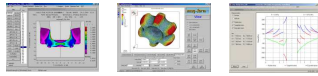


### Application Tool Design

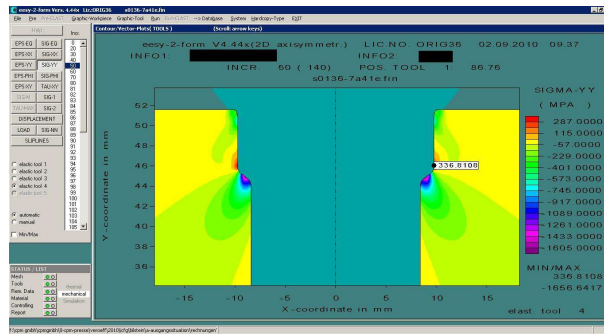
Initial design of the  
die in operation 4  
  
(Carbide –  
pre-stressed by  
one ring)



5 station  
cold forging  
process

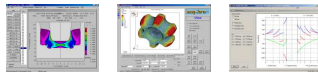


### Application Tool Design



5 station  
cold forging  
process

Positive stress in the carbide → failure



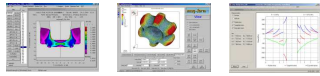
### Application Tool Design



5 station  
cold forging  
process

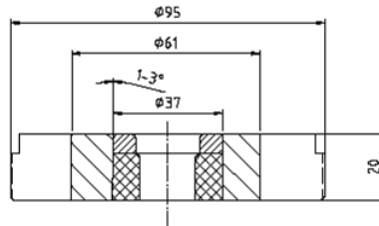
Prove of the failure in practical test



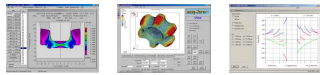


### Application Tool Design

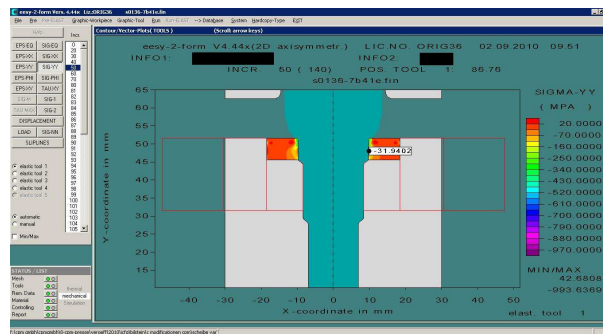
Final design  
of the  
die in operation 4  
  
(disc made out of  
ASP 30,  
Carbide split –  
pre-stressed by  
two rings)



5 station  
cold forging  
process

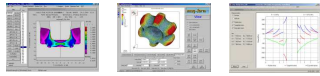


### Application Tool Design



5 station  
cold forging  
process

Stresses are compressive now  
**Tool life could be improved from 1000 pieces to 25000 pieces**

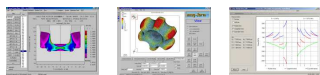


### Application Tool Design



5 (6) station  
cold forging  
process

Meanwhile the tool life  
could be improved to  
120000 pieces by  
introducing a further  
station before # 4.



### Application Tool Design



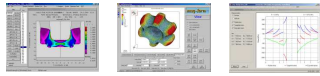
Pre-stressed punch to form  
a TORX® recess

After optimization

**a tool life of 2,5 Mio**

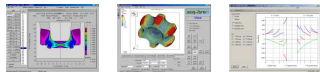
was reached

**(stable for more than  
10 years now)**



## 30 Years of FEM in bulk metal forming

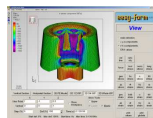
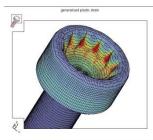
1. Introduction
2. Developments
3. Applications
4. Application Tool Design
- 5. Future**
6. Acknowledgements

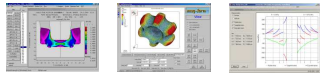


## Future

### Future developments

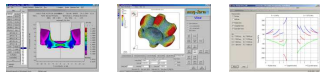
- \* Integration of the simulation in the entire production chain
- \* Completion of the material data needed
- \* Development of further technological modules
- \* Reducing the simulation systems to very specialized systems for industry sectors





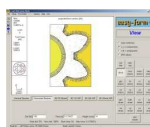
## 30 Years of FEM in bulk metal forming

1. Introduction
2. Developments
3. Applications
4. Application Tool Design
5. Future
- 6. Acknowledgements**



## Acknowledgements

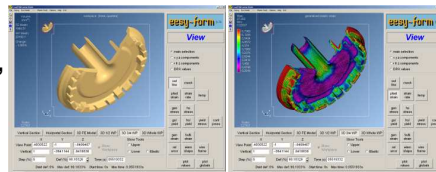
CPM is much obliged to their customers that provided relevant information to enable CPM to present successful applications of their simulation software.

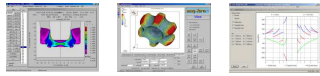


Such information is very helpful to promote CPM software and the application of simulation in general by presentations like this one.

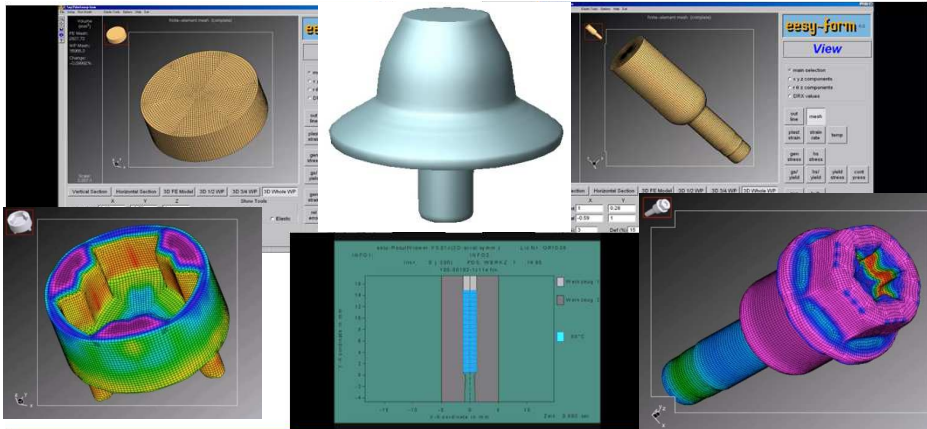
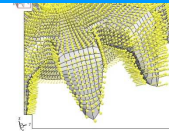


**Customers from Germany, UK, China, Brazil, Ireland Belgium and Swiss contributed to this presentation.**



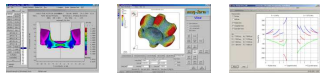


## Acknowledgements

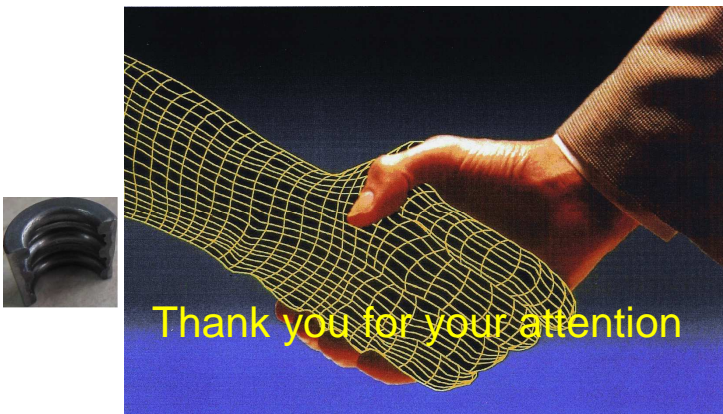


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35<sup>th</sup> Senafor, 07-09.10.2015, Porto Alegre, RS, Brazil

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## Trust in "easy" simulation



Customers are happy to work on their daily tasks  
with "easy" simulation

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