Simulation of contact between cam lobe and tube of assembled camshafts using module CAU

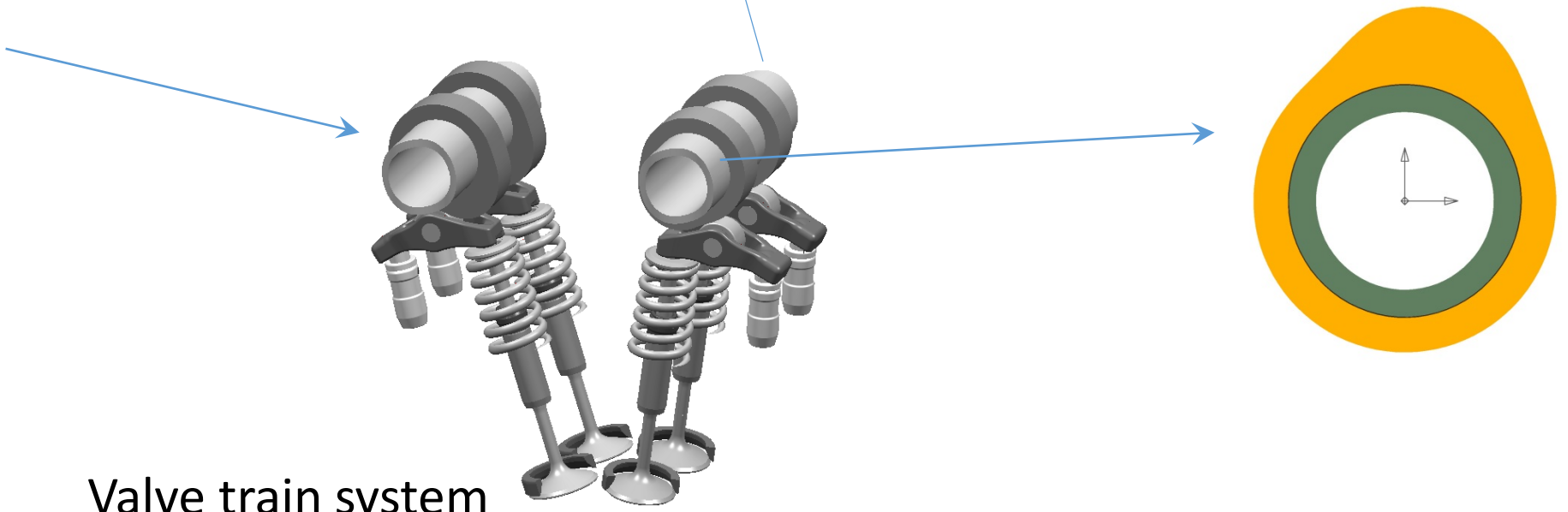
Dr. Walter Krepulat,
Florian Mohr
MAHLE GmbH

Where we are

Combustion engine LV

Pressfit
cam lobe – tube

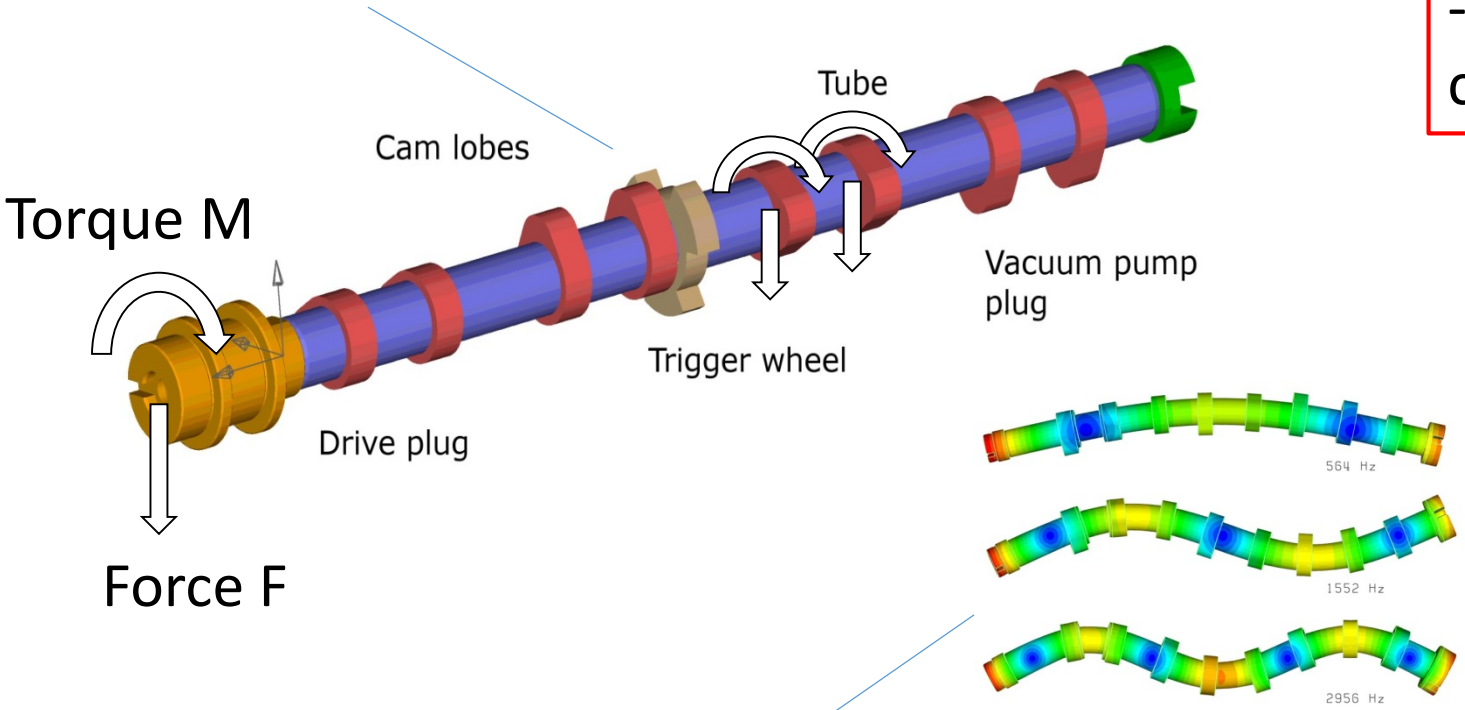
Assembled camshaft



Valve train system

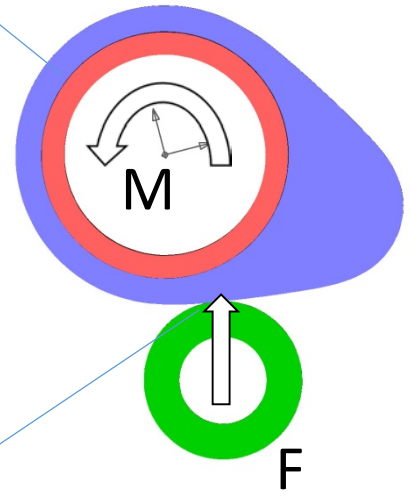
Loads

Load on camshaft -> torsion, bending, stress



Stiffness + natural frequencies influence on dynamic behaviour

M and F charge contact zone
-> sliding, risk of tribocorrosion, completely twisted parts



F + geometry -> contact pressure calculated with Hertzian equation

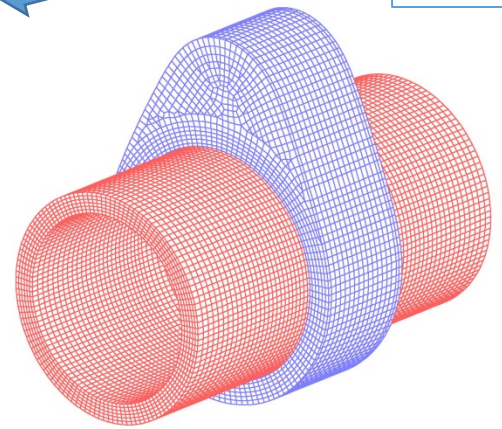
Pressfit design

PERMAS Users' Conference Stuttgart 2018

DIN 7190
+ simple and fast, analytical equations
- assumptions (round parts, same length)
- measured coefficient of adhesion

FEA normal contact
+ correct contact force -> M = F x R x μ
+ physical friction coefficient
- FEA model necessary
- parts assumed “stiff” (not correct)

FEA contact with friction
+ parts behave elastically
+ torque M direct FEA result
+ physical friction coefficient
- more calculation effort



“Roll over” simulation with FEA -> CAU module

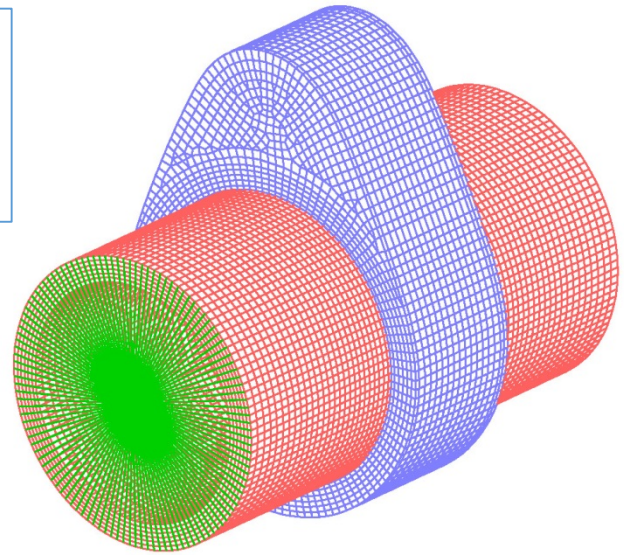
Same old problem: “true” friction coefficient = ?

Torque to turn

Calculation method	DIN7190	FEA_nc	FEA_fc
Sum contact force F	22.11 kN	29.243 kN	29.334 kN
Torque to turn M	61.92 Nm	81.88 Nm	82.14 Nm
Time	analytical	17 sec	27 sec

Delta shows the necessity to use with DIN a measured coefficient of adhesion

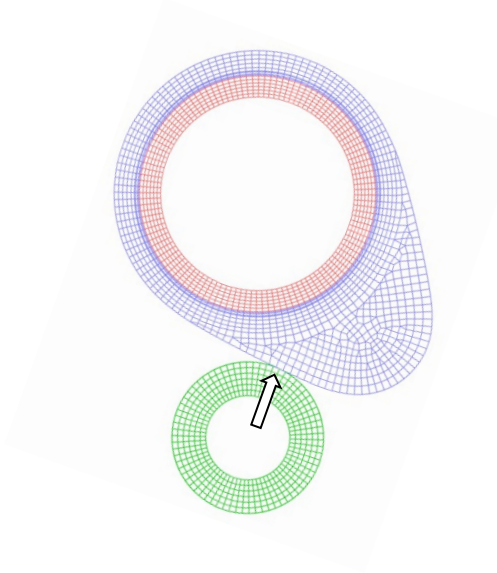
- normal contact
- node to node
- M = F x R x μ



- frictional contact
- node to node
- lobe with fixed rotation
- prescribed angular displacement 1° to tube end by rigid body elements
- reaction torque determined

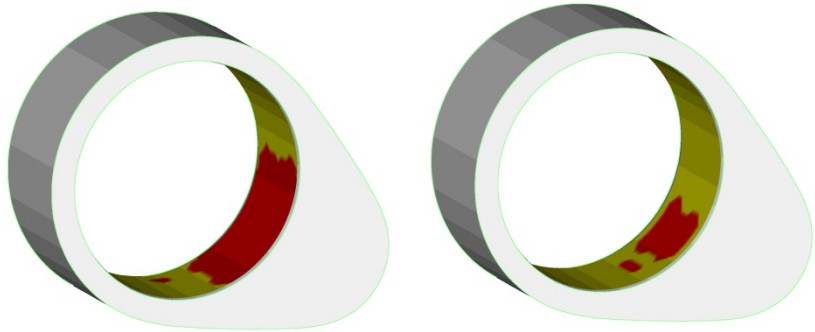
remark: supporting the cam lobe at only one point has an influence on sum of contact force and torque to turn

Real load - maximum force



- model with roller
- frictional contact
- max contact force 1.35 kN
- both tube ends supported

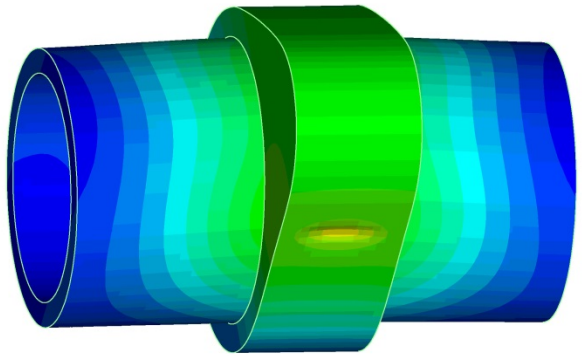
contact status



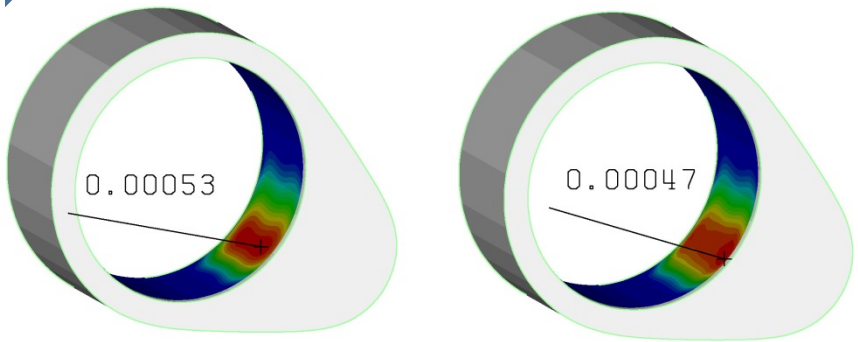
with force

force relieved

deformation



After taken away the load friction forces remain and keep parts in slided position

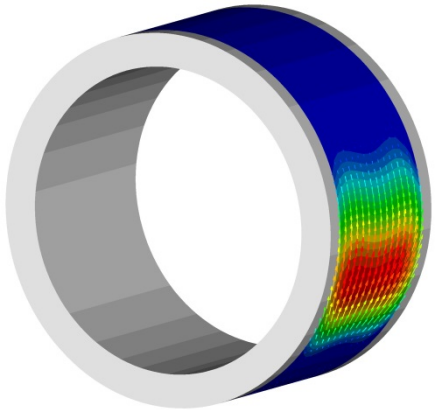


gap vector friction

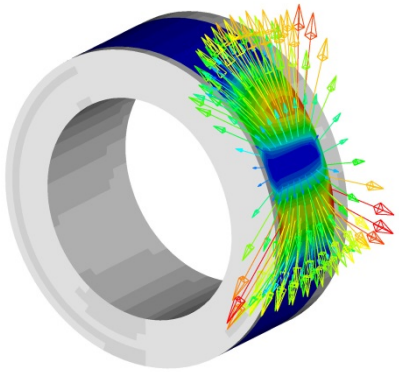
remark: the load has a small lever arm,
i.e. torque by real life contact force is small

Real life is moving

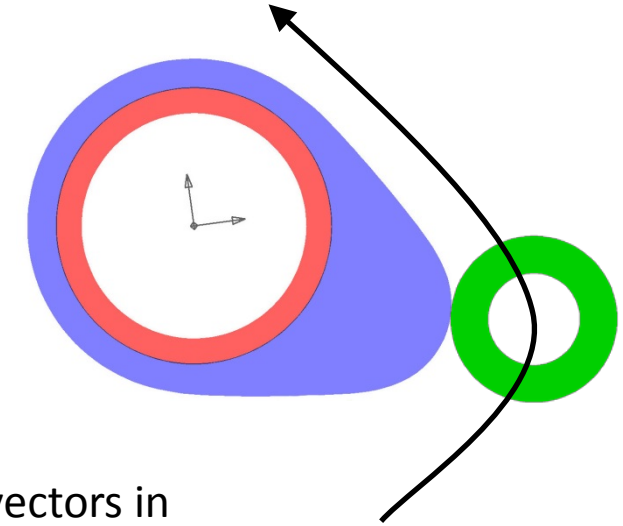
- Contact force, lever arm and torque are functions of rotation angle
- Roller is rolling around the cam lobe
- Contact status knows his load history !



example 1
gap friction vectors
all counter clockwise



example 2
gap friction vectors in
opposite directions !

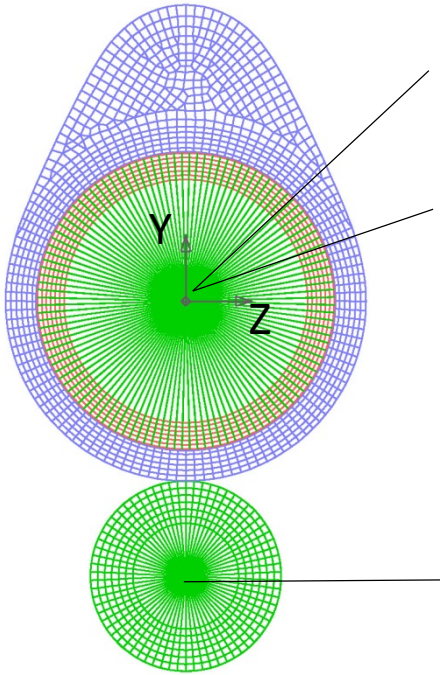


Idea: use contact update and simulate a „roll over“

First approach: rotate tube and lets move the roller only vertically

FEA model

- Rotation of tube by prescribed angles in 1° steps
- Provide the correct contact force between cam lobe and roller
- Roller should rotate freely and move vertically

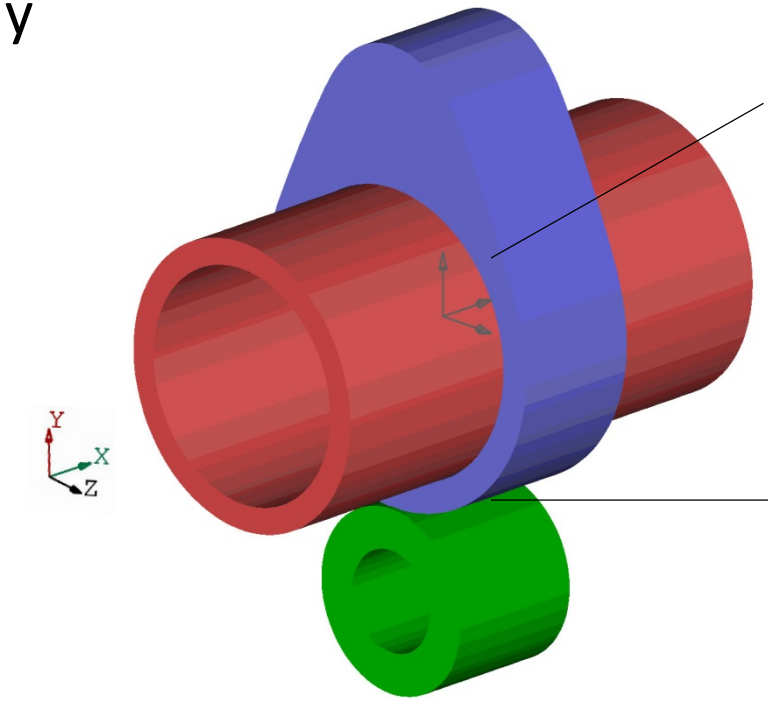


Tube end MPC Rigid
$u_{yz} = 0$

Tube end prescribed rotation
by $PREVAL via DAT file*

Tube and roller
center plane $u_x = 0$

Roller bore MPC Rigid
$u_z = 0$ and
load application



S2N contact
friction both
press fit $\mu_r = 0.2 / 0.18$

S2N contact
friction both
gap = geometry
$\mu_r = 0.1 / 0.1$

* not possible inside MEDINA

uci definition

- License for CAU module necessary ☺
- Contact update -> uci switch SET CAMAXGEOUP = Value (here 10 used)
- Great rotation-> NLMATERIAL with NLGEOM = YES
- Use of rigid body elements -> DEFAULT SET MPCUPDATE = COEFF
- Generate reaction forces for control purpose
- Switch NLGEOSTIFF = OFF is not recommended, the simulation has stopped with too much iterations

- Use of zero force elements CA1ZERF3 is necessary, node to ground springs had resulted in rigid body modes and simulation did not finish

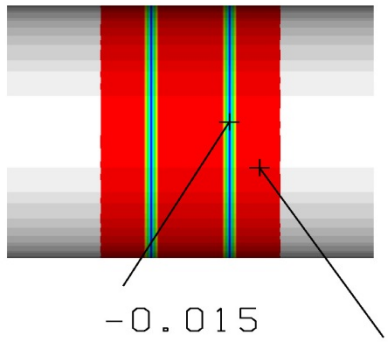
Contact definition

- Node to node contact is not possible with contact update !
- So use surface to node or surface to surface definition ?
- Intes recommends to use uci switch CASCOMPLEMENT = ALL when using contact update with surface to surface contact
- Cascomplement = auto together with surface to surface contact can give some unexpected result display
- Simulation time (model with 30 steps)

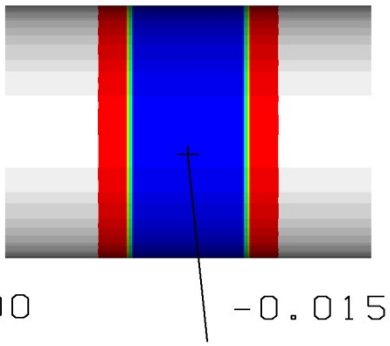
Contact definition	Elapsed time
Surface to node	6 h 49 min
Surface to surface and cascomplement = auto	12 h 40 min
Surface to surface and cascomplement = all	31 h 12 min

initial gapwidth on tube

cascomplement = auto



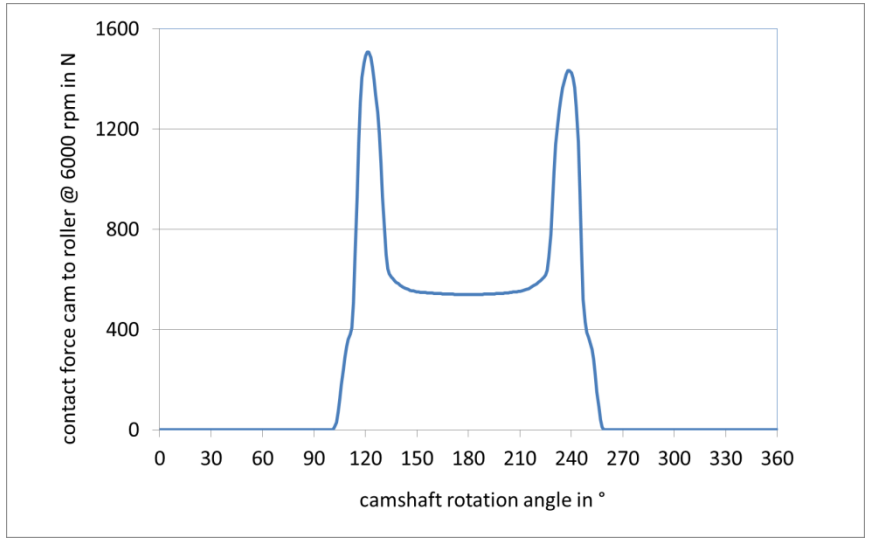
= all



Load definition

- Contact force is a function of camshaft rotation angle, peaks created by inertia force

- LPAT 1 = pressfit + spring pretension force
- LPAT 2 = friction on
- LPAT 3 = prescribed displacement 360° in 1°-steps via $NLRESULTS
- LPAT 4 = contact force between cam lobe and roller also in 1°-steps via $NLLOAD and $FUNCTION Table



Remark: realize the contact force by a non-linear spring seemed too difficult, but should be also possible.

Load definition in dat file

```
   $CONSTRAINTS  NAME = SPCVAR_1
!
      $PRESCRIBE  DOFS = 4  DOFTYPE = DISP
           30 31
!
   $END CONSTRAINTS
!
   $LOADING  NAME = LOADVAR_1
!
   $CONLOAD LPAT =  1  DOFTYPE = DISP
           40  2 : 250.0            ! valve spring pretension
!
   $PREVAL  LPAT = 3  DOFTYPE = DISP
           30 4:  6.28319           ! = 2 * pi = 360° rotation
           31 4:  6.28319
!
   $CONLOAD LPAT =  4  DOFTYPE = DISP
           40  2 : 1.0   ! true axial force on roller - function of angle
!
   $NLLOAD  TABLE  TIME = LIST  DOFTYPE = DISP
                1.0  2.0  3.0
      LPAT=1    1.0  1.0  1.0     ! pressfit = active + pretension
      LPAT=2    0.0  1.0  1.0     ! friction = active
      LPAT=3    0.0  0.0  1.0     ! prescribed rotation
!
   $NLLOAD  GENERAL
      LPAT=4  FUNCTION = 100        ! force in 1° steps by function table
!
   $END LOADING
!
   $RESULTS
!
     $NLRESULTS   STEPS = LIST   KIND = ABSOLUTE
      1.0
     $NLRESULTS   STEPS = EQUI   KIND = ABSOLUTE
      2.0 3.0 2.7778E-03            ! rotation stepwise by 1° steps
!
   $END RESULTS
```

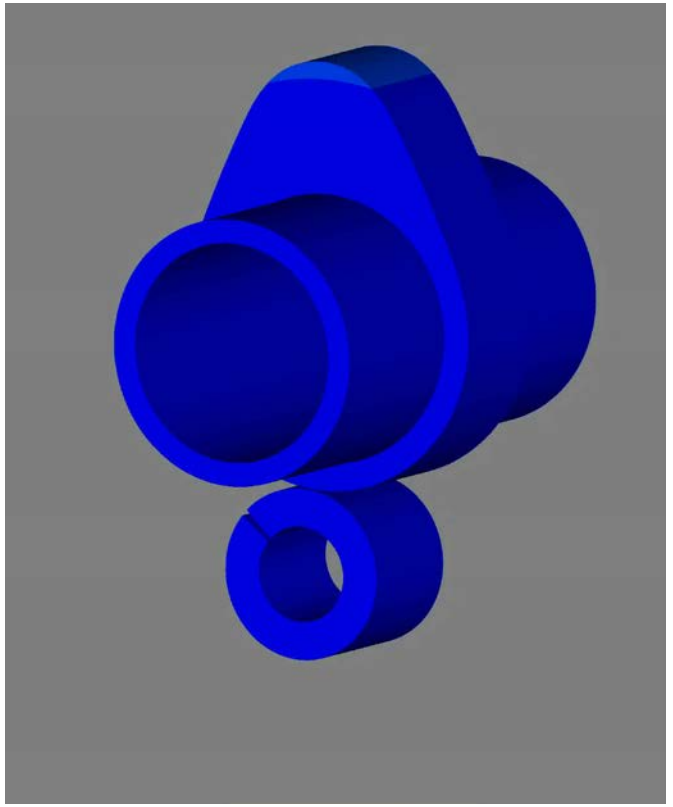
- Load definition is complex
- Contact definition done inside Medina
- Mixing of more than one definition is possible

```
$STRUCTURE
!
$FUNCTION TABLE FID = 100 EXTRA = LIN       ! axial force on roller / step 1°
0.00            :               2.000000E+00
0.00            :               2.002778E+00
0.00            :               2.005556E+00
0.00            :               2.008333E+00
0.00            :               2.011111E+00
...
407.77          :               2.311111E+00
504.84          :               2.313889E+00
691.58          :               2.316667E+00
924.69          :               2.319444E+00
1140.50         :               2.322222E+00
1300.63         :               2.325000E+00
1400.48         :               2.327778E+00
1455.27         :               2.330556E+00
1482.75         :               2.333333E+00
1494.08         :               2.336111E+00
1489.92         :               2.338889E+00
1466.26         :               2.341667E+00
...
0.00            :               2.991667E+00
0.00            :               2.994444E+00
0.00            :               2.997222E+00
0.00            :               3.000000E+00
!
$END STRUCTURE
```

Results – does it work ?

- Yes, it works,
- Cam lobe rotates, roller rotates
- Use Medina result type “non-linear statics”, select all load steps for displacement and animate (put some elements in noshow helps to see the rotation)
- Big result file for small model (9.5GB for 91000 nodes) –> use local file storage

result displacement

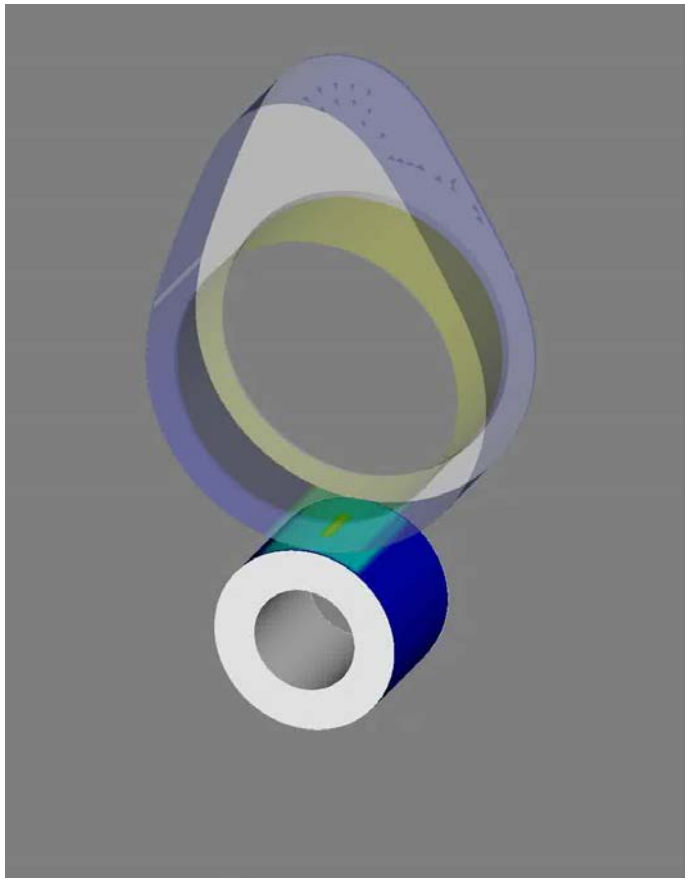


Results – contact status

- Gap between tube and cam lobe bore is always closed
- Sliding occurs as expected
- Position and size of sliding fluctuates quite a bit, this was not expected
- Sliding occurs and vanishes between two steps, see next page

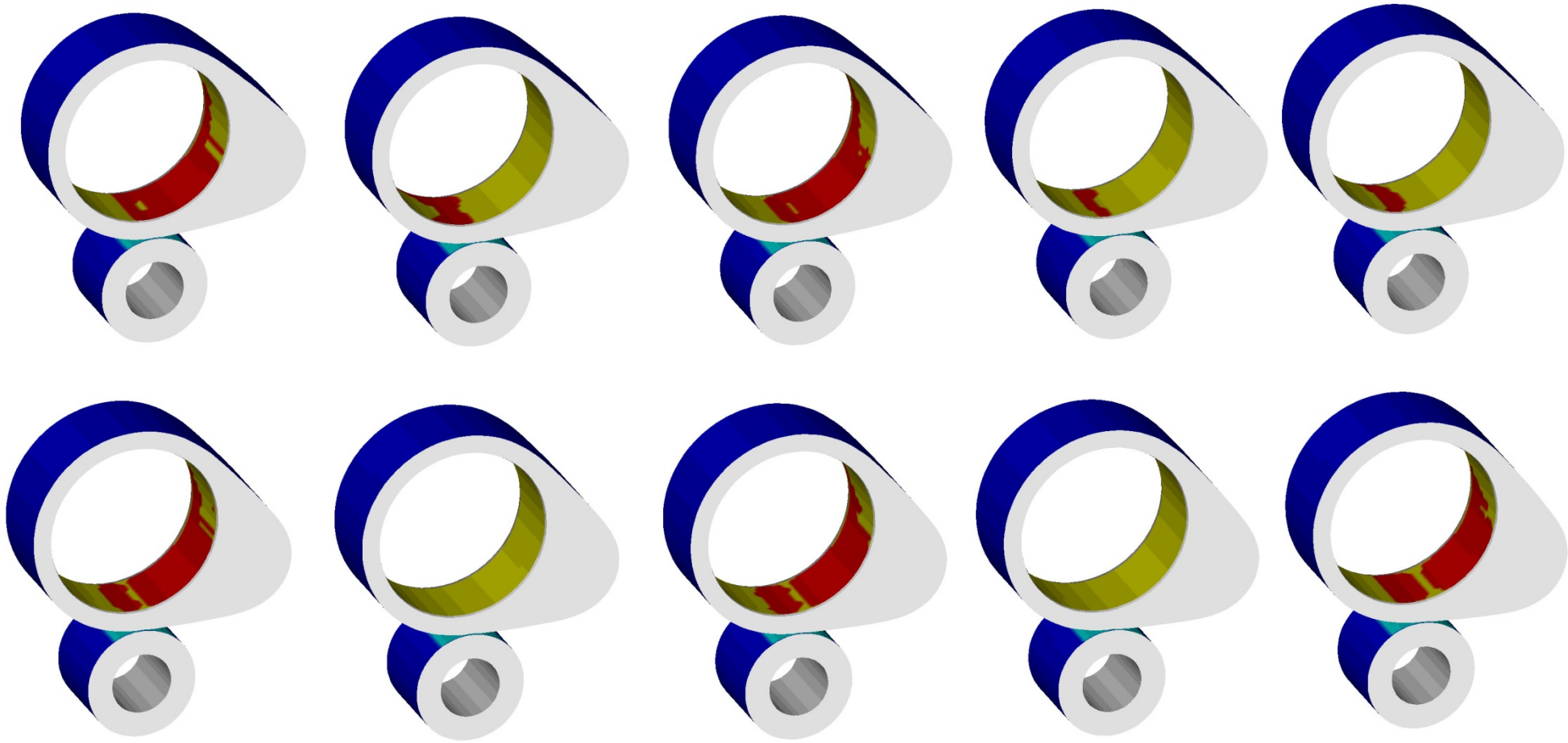
- Is this fluctuation realistic ?
- Further analysis necessary

contact status



Results – contact status

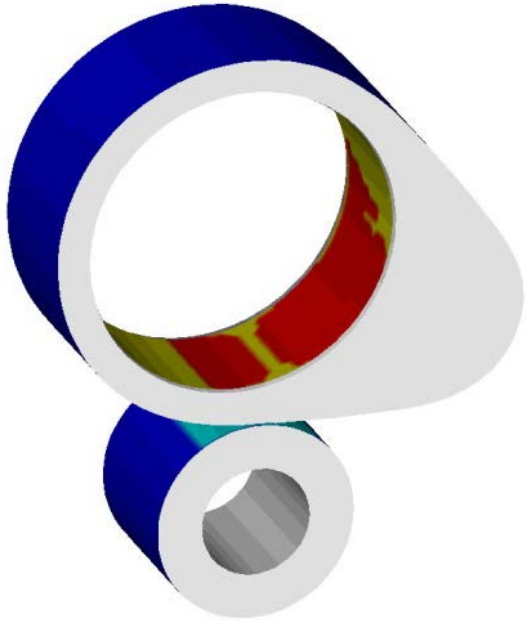
- load step 120 to 129, at opening flank, i.e. max contact force



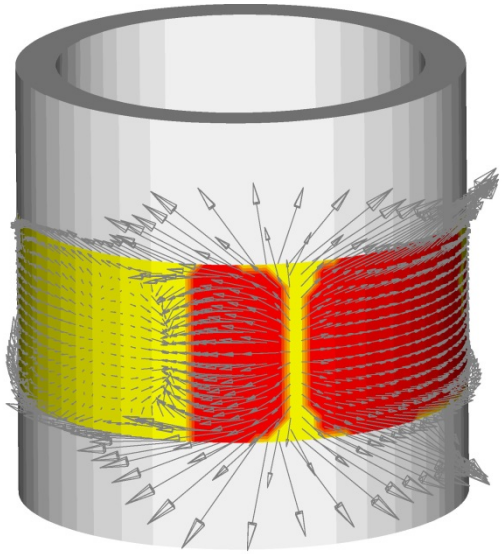
Results – contact status

- Load step 129
- Friction force vectors, i.e. sliding have opposite directions
- The amount of sliding alone gives no indication for the risk of twisted parts
- Difficult to get amount of sliding between two steps

It is necessary to read in the contact force together with the displacements and look at the deformed state, otherwise the vector direction is not correct



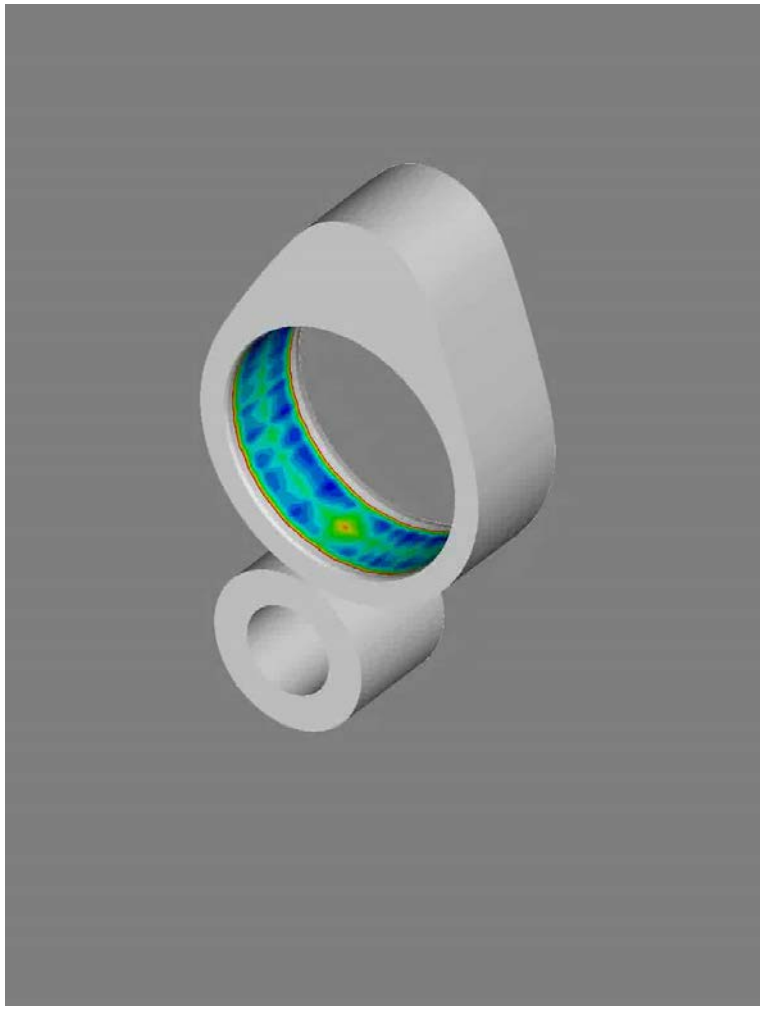
contact status at cam lobe bore



contact status at tube surface with contact force friction vectors

Results – contact force normal

- Distribution of contact force normal on cam lobe bore
- Roller has crowning -> force is higher in the middle
- Cam nose is stiffer -> lower contact force
- Contact force in opening and closing flank high because of inertia forces



- Distribution not so smooth
- FE mesh and 1°-steps too coarse ?

Conclusions

- When doing a new type of simulation, problems are to expect
  -> don´t give up and get support from Intes
- The model works, i.e. cam lobe rotates, roller rotates and moves up and down
- Some more analysis and variants could be done
- Sliding occurs between tube and cam lobe, but fluctuates unexpectedly
- Sliding directions are not all in one direction but can be opposite
- Maybe FE mesh and 1° load steps are too coarse
  (however it will be always discrete in time and mesh)
- CPU run time is long but okay for 360 loadsteps and full geometry
- Result evaluation becomes difficult with so many load steps if done manually
- Result evaluation is difficult (in Medina), small deformation vs big rotation