Application of LS-DYNA Implicit for the Design of Plastic Components

Thomas Wimmer, Martin Fritz

4a engineering GmbH, Traboch - A

Abstract:

LS-Dyna is a common code in explicit analysis. Starting in 1997 the implicit capabilities are continuously being enhanced. Up from v970 most of the subroutines and data arrays can be used by both explicit and implicit. Switching between the codes can be done without overhead. In this presentation differences between explicit and implicit time integration are described and examples using the code in product development for plastic components are depicted.

Keywords:

Implicit, time integration, thermoplastics, nonlinear static, linear static

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T. Wimmer, M. Fritz (4a engineering GmbH, Traboch - A)

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Company Group

4a TECHNOLOGY GmbH

... in physics we trust

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What is Implicit (and Explicit) Analysis?

- It is one way of solving an ordinary differential equation

$$\dot{y} = f(y)$$

- Given $y^n = y(t^n)$, we can calculate $y^{n+1} = y(t^{n+1})$ in one of two ways

$$\frac{y^{n+1} - y^n}{\Delta t} = f(y^{n+1}) \qquad \frac{y^{n+1} - y^n}{\Delta t} = f(y^n)$$

Implicit equation for y^{n+1}

Need to solve an equation

Explicit equation for y^{n+1}

No equations to solve

References:
/Implicit Capabilities of LS-Dyna, Ushnish Basu, 2010/

Explicit vs. Implicit

Implicit and Explicit Analysis

- We want to solve the equations of motion:

$$ma^n + cv^n + f_{\text{int}}^n = f_{ext}^n$$

m	:	Mass
a	:	Acceleration
c	:	Damping
v	:	Velocity
f^{ext}	:	External forces
f^{int}	:	Internal forces
n	:	Indicates step n

The goal is to determine the displacement, u^{n+1}, at time t^{n+1}.

Implicit and Explicit Analysis

Explicit analysis is carried out as follows:

1. Compute accelerations from

$$ma^n = f_{\text{int}}^n - f_{\text{ext}}^n - cv^n$$

No equations are solved because mass matrix is diagonal

2. Compute velocities at half-step from

$$v^{n+1/2} = v^{n-1/2} + a^n \Delta t^n$$

3. Compute displacements as

$$u^{n+1} = u^n + v^{n+1/2} \Delta t^{n+1/2}$$

Explicit vs. Implicit

Implicit and Explicit Analysis

Implicit analysis is carried out as follows:

1. Approximate accelerations and velocities by Newmark method

$$a^{n+1} = \frac{1}{\beta(\Delta t)^2}\left[u^{n+1} - u^n\right] - \frac{1}{\beta \Delta t} v^n + \left(1 - \frac{1}{2\beta}\right) a^n$$

$$v^{n+1} = \frac{\gamma}{\beta \Delta t}\left[u^{n+1} - u^n\right] - \left(1 - \frac{\gamma}{\beta}\right) v^n - \Delta t \left(\frac{\gamma}{2\beta} - 1\right) a^n$$

2. Substitute into equations of motion

$$ma^n + cv^n + f^n_{\text{int}} = f^n_{\text{ext}}$$

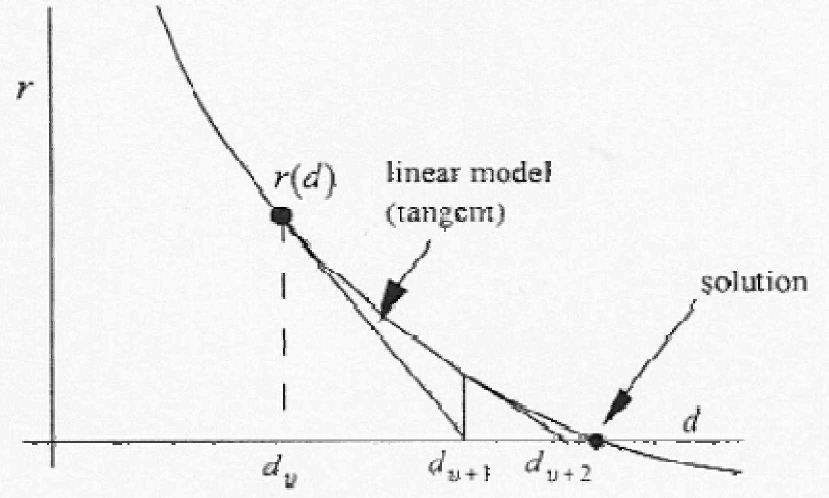
3. Solve for u^{n+1} using e.g., Newton-Raphson

   System of equatlons need to be solved

Implicit and Explicit Analysis

The Newton-Raphson method may be described as follows:

Solve: $r(d) = f_{ext}^{n+1} - ma^{n+1} + cv^{n+1} + f_{int}^{n+1}(d) = 0$ with $d \equiv u^{n+1}$



Solve a non-linear equation iteratively at each time step
Each iteration requires solving a linear equation

References:
/T. Belytschko et. al., 2000/

Explicit vs. Implicit

EXPLICIT

- Impact, penetration, high rate dynamics
- Many small time steps
- Courant condition limits langest stable time step
- Conditionally stable
- Robust, even for strongly non-linear models
- Low memory requirements
- Expensive to conduct long duration simulations

IMPLICIT

- Static, eigenvalue, low rate dynamic analyses
- Few large time steps
- Model size (degrees of freedom) affects wall time
- Can be unconditionally stable
- Eventually problematic for strongly non-linear models
- High memory requirements (inverting stiffness matrix)
- Relatively inexpensive for long duration analysis

Types of implicit analyses

Linear Analysis

– static, dynamic

Mode Extraction

– frequencies and mode shapes
– linear buckling loads

Nonlinear Analysis

– Newton, quasi-Newton, Arc Length solution options
– static or dynamic

Combined implicit - Explicit Analysis

– manual or automatic

Implicit Examples
linear statics jetski

Reference Vehicle

component testing– torsion test :
bottom-component
top-component

material testing– tensile test:
2 part regions
0° / 45° / 90°

simulation– torsion test:
bottom-component
top-component

Interpretation tensile tests:
micromec 2.1
3D orthotropic material model

simulation– reference vehicle (top and bottom component)
load case torsion
Load case pressure

Vehicle Update

material testing– tensile test:
0°/90°
+45°/-45°
0°/90°/+45°/-45°

Interpratation tensile tests:
micromec 2.1
3D orthotropic material model

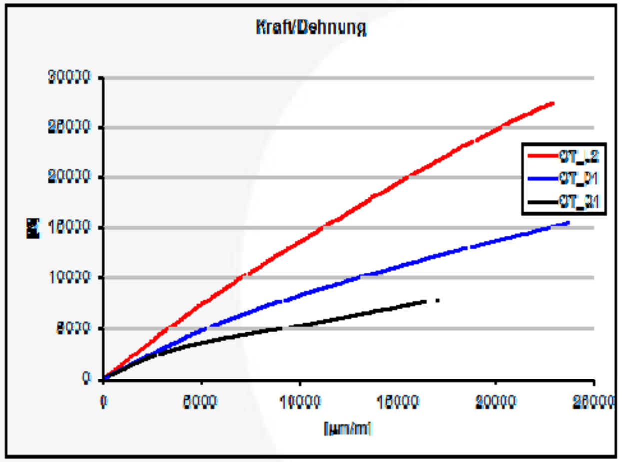
simulation – updated vehicle:
wall thickness adjustment to meet
torsion siffnes criteria
comparison pressure load case

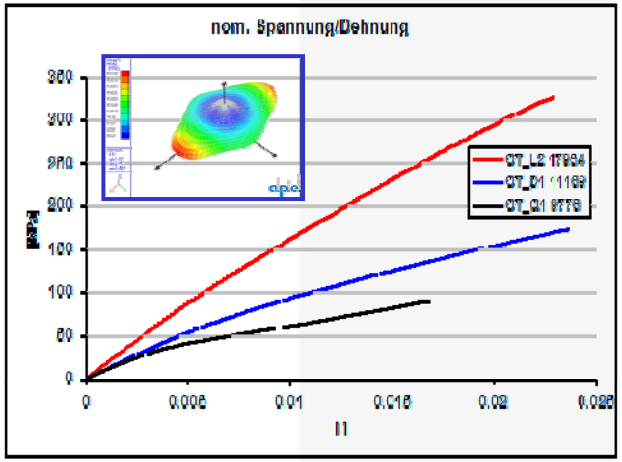
stiffnes requirements
torsion load

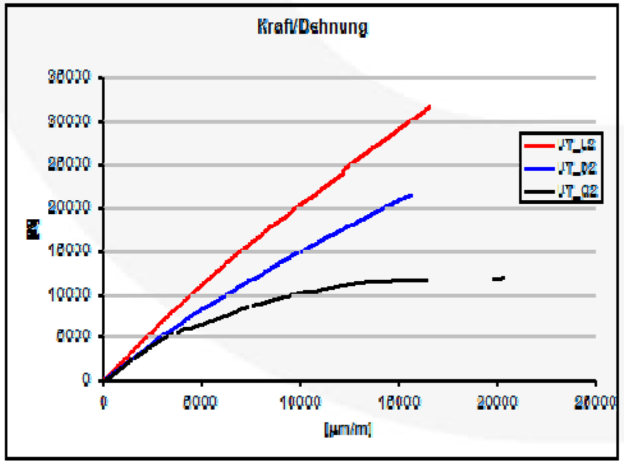
strenght requirements
pressure load

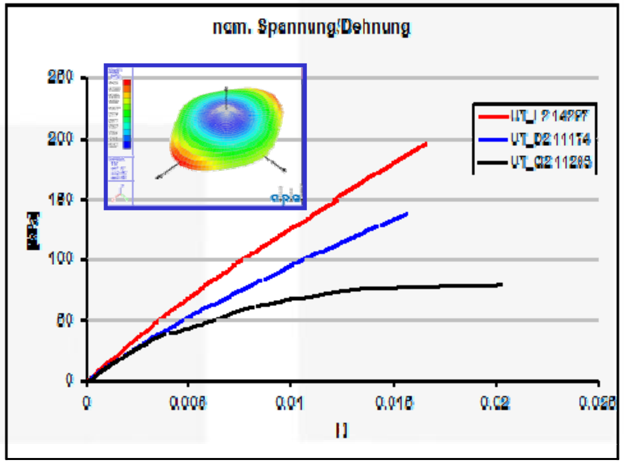
Implicit Examples
linear statics jetski

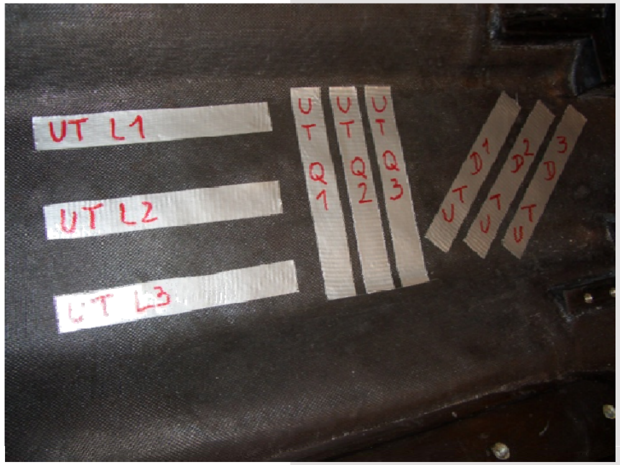
tensile tests and data fitting by micromechanics (MICROMEC)







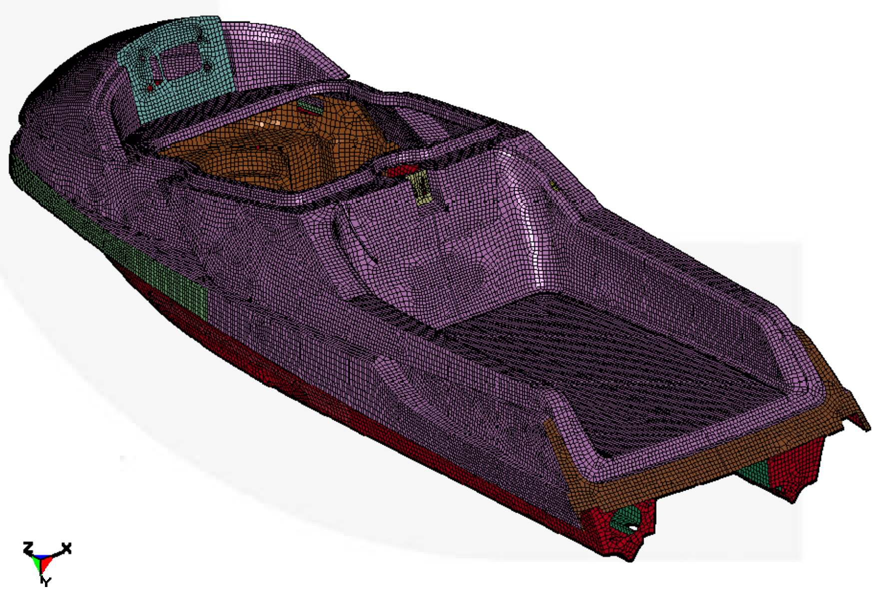


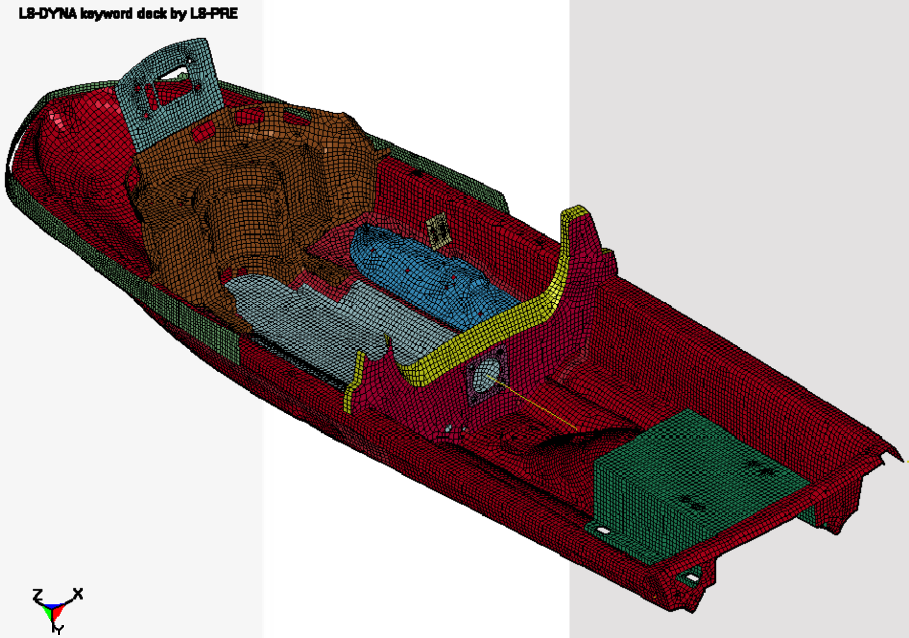


Implicit Examples
linear statics jetski

Modelling:

78529 shell elements (Type21)
3D orthotropic material model (Mat_002)





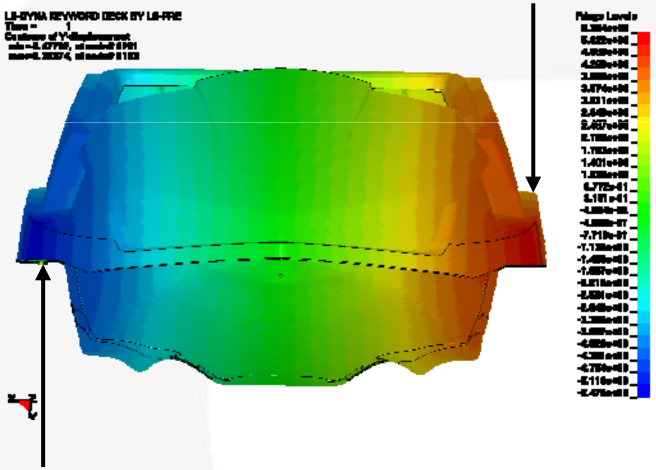
$$\mathbf{M}\Delta\mathbf{a}_{n+1} + \mathbf{K}\Delta\mathbf{u}_{n+1} = \mathbf{f}^{ext}_{n+1} - \mathbf{f}^{\text{int}}_{n} - \mathbf{M}\mathbf{a}_{n}$$

$$\Downarrow$$

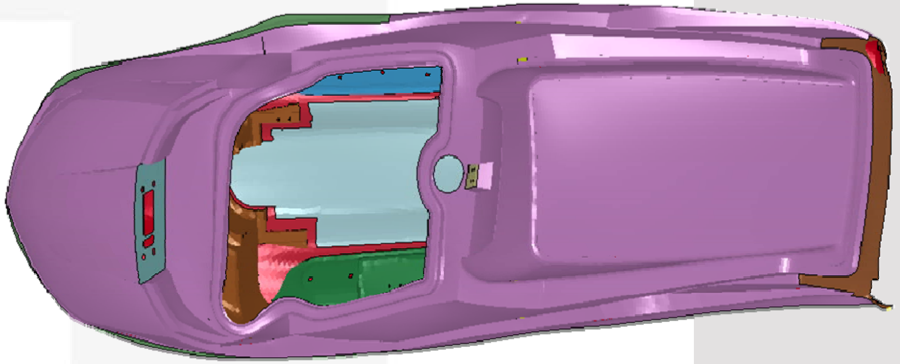
$$\Delta\mathbf{u} = \hat{\mathbf{K}}^{-1}\hat{\mathbf{R}}$$

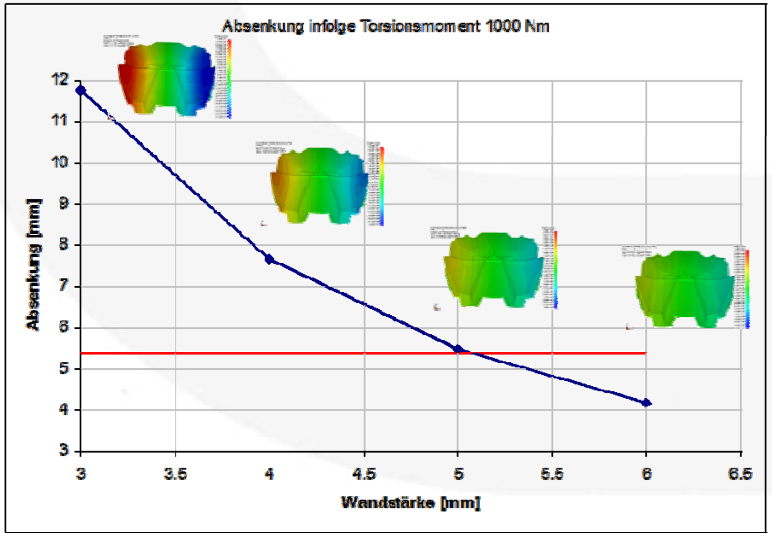
linear problem

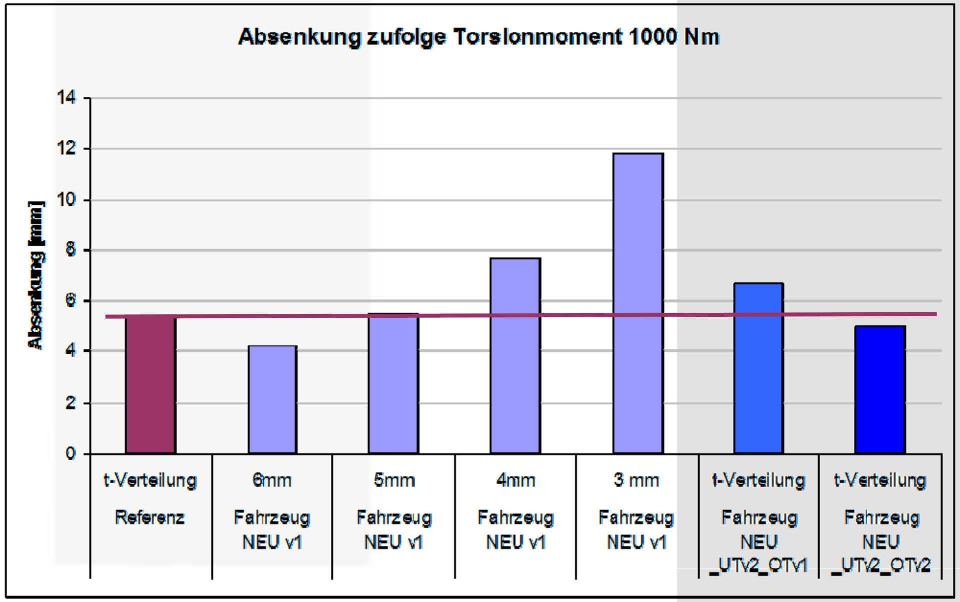
Implicit Examples
linear statics jetski



reference vehicle (deform x 50)

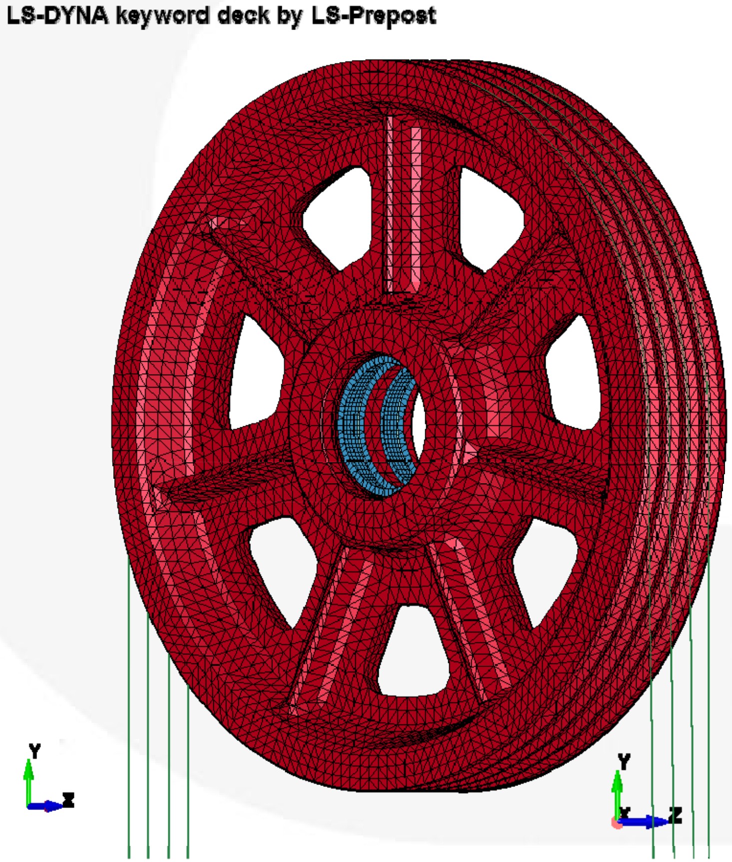


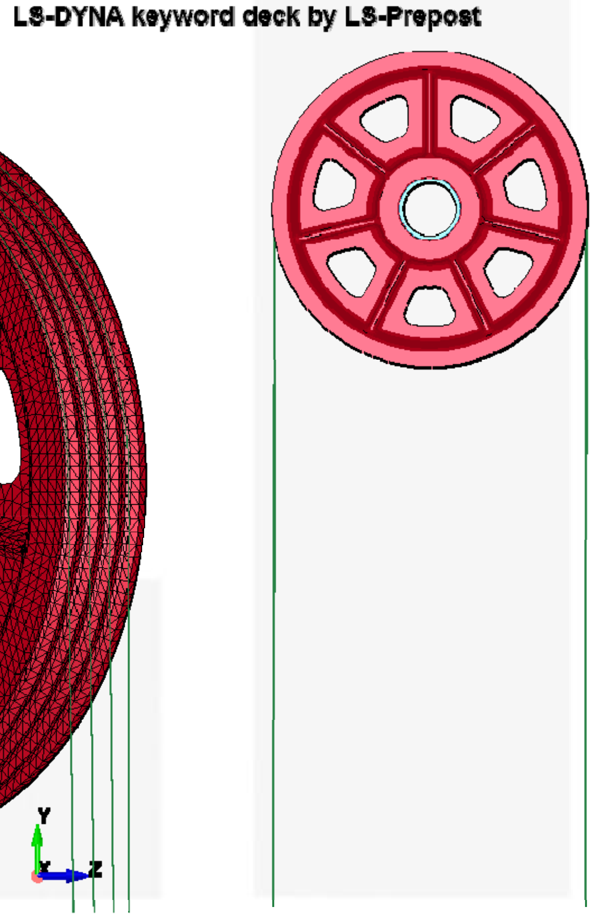


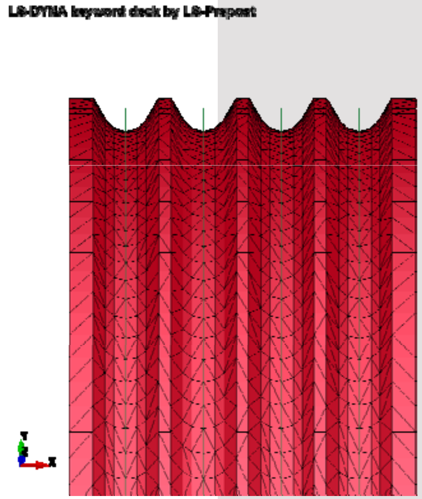


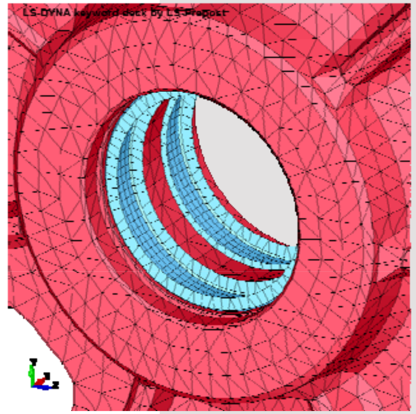
Implicit Examples
nonlinear statics pulley

5 POINT 10 NODED TETRAHEDRONS (ET16)
TRUSS ELEMENTS (no bending stiffness)
CONTACT_AUTOMATIC_NODES_TO_SURFACE

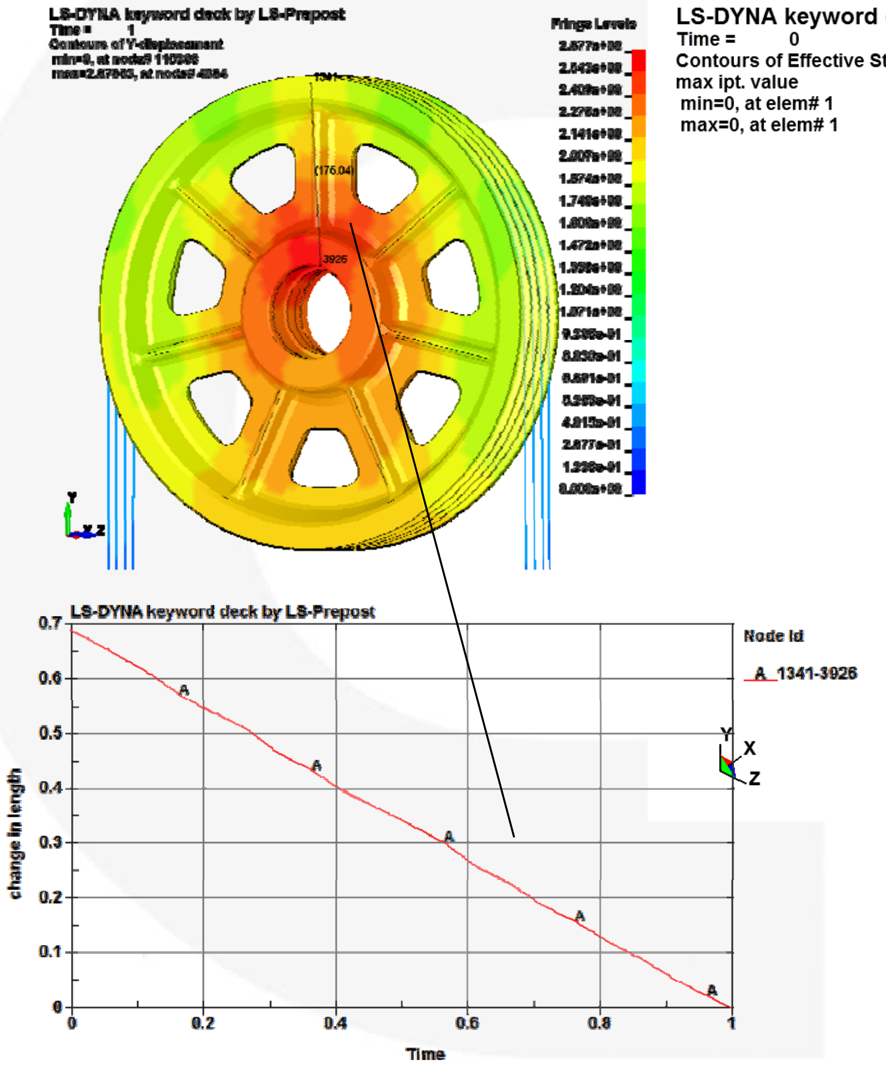


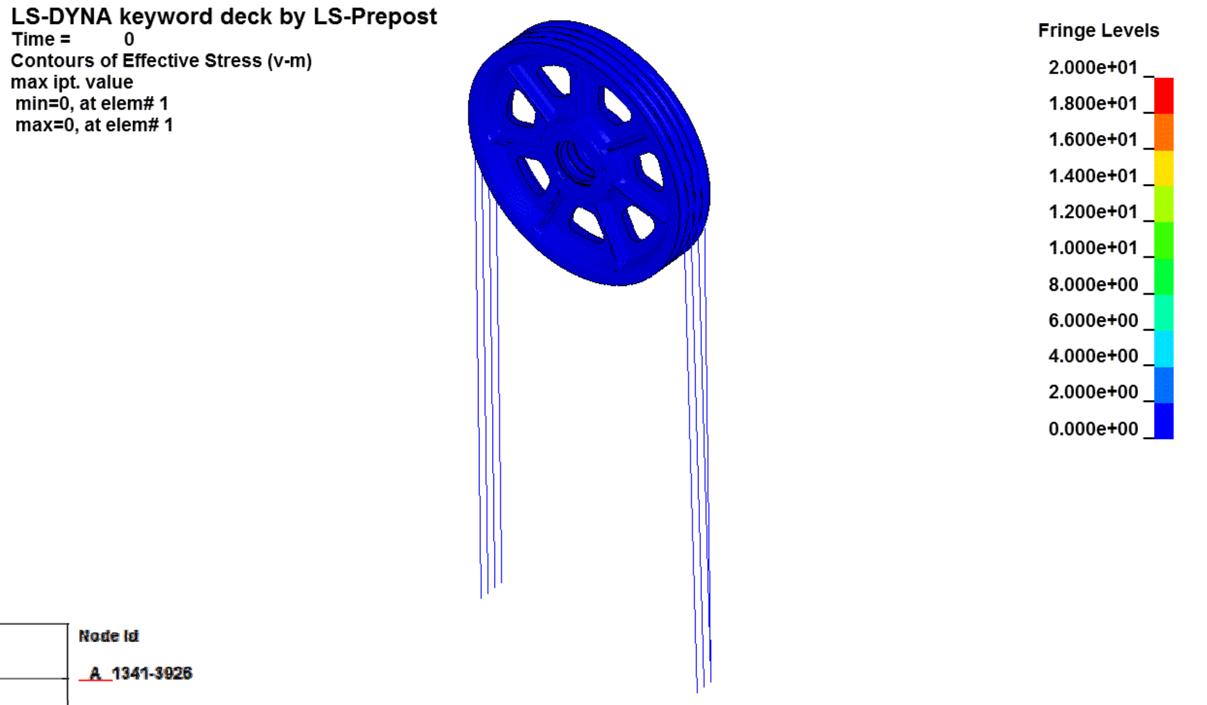






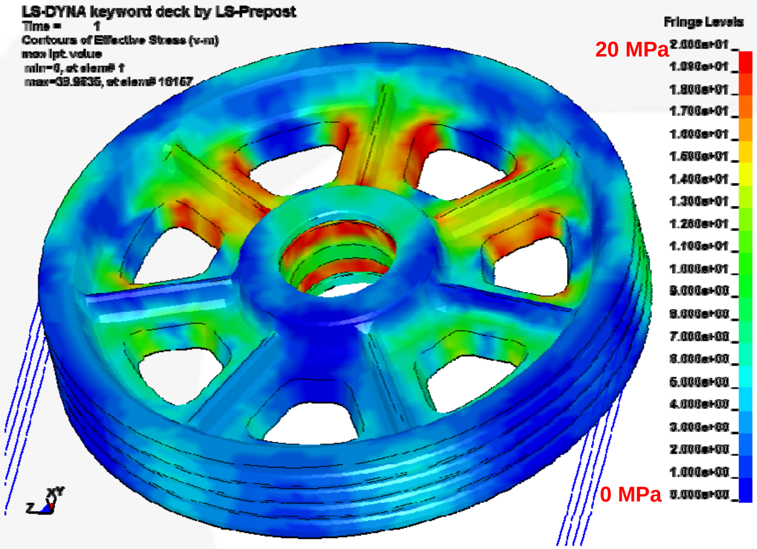
Implicit Examples
nonlinear statics pulley

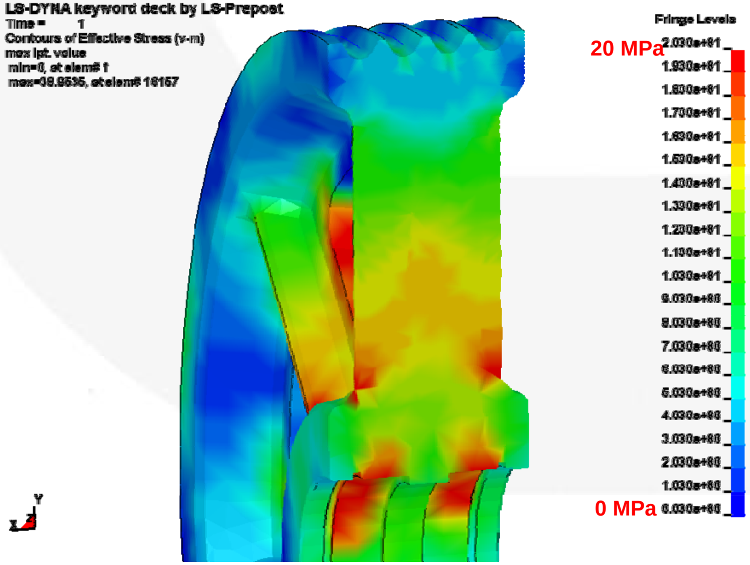




y-displacements[mm]

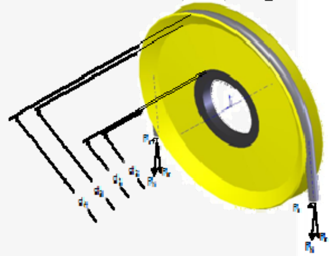
Implicit Examples
nonlinear statics pulley





SEILROLLENBERECHNUNG

Kunde:			
Ident. Nr:			
Bemerkungen:			
Geometrie Seilrolle:	Z.Nr.:	15783012	
Lageraußendurchmesser	d_1	90.00	[mm]
Durchmesser der Nabenbohrung	d_2	90.00	[mm]
Durchmesser der Seilrolle	d_4	454.00	[mm]
Durchmesser d. Seilauflage	d_3	439.00	[mm]
Nabenbreite	b	40.00	[mm]
Materialdaten:			
E-Modul der Seilrolle	E	3200.00	[MPa]
Querkontraktion	ν	0.39	[]
Belastung:			
Nennseilkraft	F_N	40000.00	[N]
Umschlingungswinkel	α	180.00	[°]
Maximaler Schrägzug bei FR	φ_1	0.00	[°]
Maximale Seilkraft (Sonderlastfall)	$maxF_S$	40000.00	[N]
Maximaler Schrägzug bei maxFR	φ_2	0.00	[°]



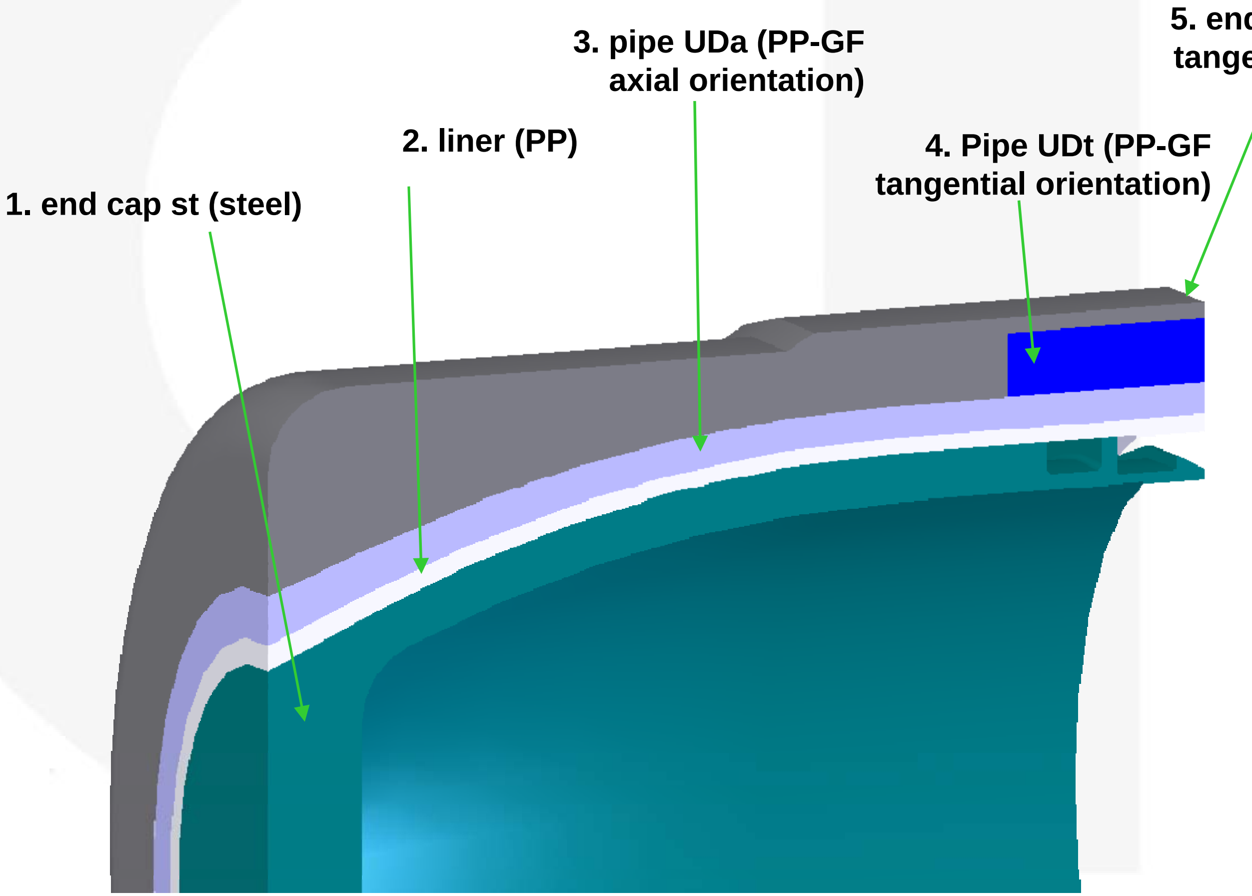
Ergebnisse:	für F_N und φ_1	für $maxF_S$ und φ_2	
F_x	0.0	0.0	[N]
F_z	40000.0	40000.0	[N]
Lagerbelastung F_L	80000.0	80000.0	[N]
Übermaß	0.00	0.00	[mm]
d_3/d_2	5.04	5.04	[]
Fugenpressdruck	0.00	0.00	[MPa]
σr_{max}	**0.00**	**0.00**	[MPa]
σt_{max}	**0.00**	**0.00**	[MPa]
proj. Fläche	3600.0	3600.0	[mm²]
Abminderungsfaktor	1.27	1.27	[]
eff. Fläche	2834.6	2834.6	[mm²]
σd_{max}	**-28.22**	**-28.22**	[MPa]
Biegemoment	0.0	0.0	[Nmm]
σb_{max}	**0.00**	**0.00**	[MPa]
σy_{Res}	**0.00**	**0.00**	[MPa]
σz_{Res}	**-28.22**	**-28.22**	[MPa]
Vergleichsspannung σv_{HMH}	**28.22**	**28.22**	[MPa]

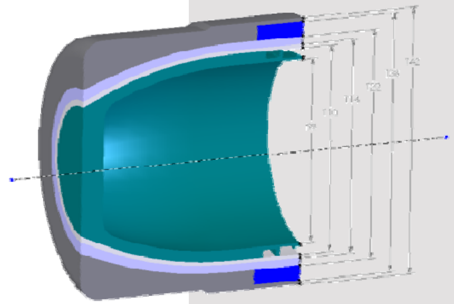
analytical solution

mises stresses [MPa]

Implicit Examples
nonlinear statics pressure tank

feasibility study pressure tank
composite with thermoplastic matrix



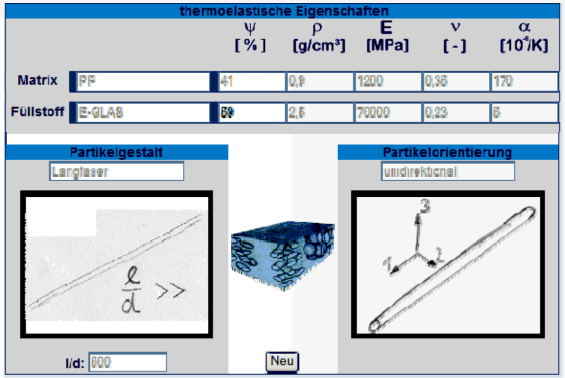


Implicit Examples
nonlinear statics pressure tank

MAT2-ORTHOTROPIC_ELASTIC (pipe)

Matrix	PP	1.2	kg/dm³
Faser	Glas	2.1	kg/dm³
Gew %		35.0%	%
Vol %		***23.5%***	%

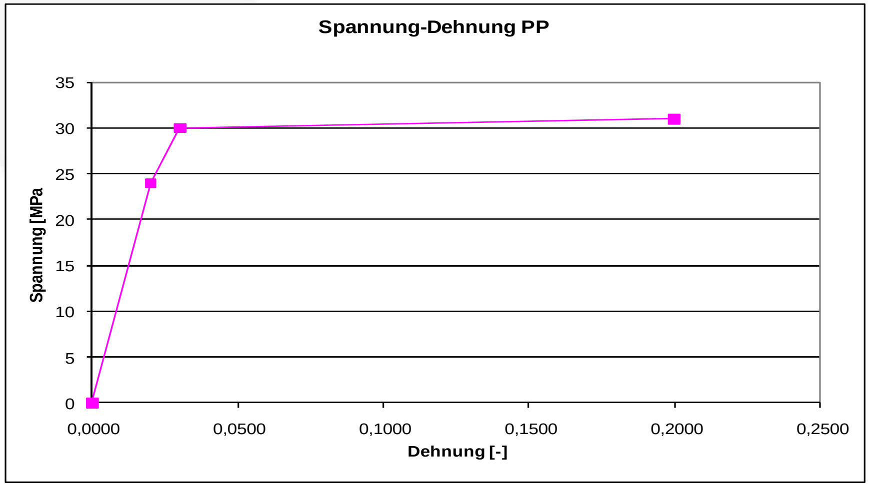
Matrix	PP	0.95	kg/dm³
Faser	Glas	2.5	kg/dm³
Vol %		35.0%	
Gew %		***58.6%***	



E [MPa]		G [MPa]		ν [-]		α [10^{-6}/K]	
1	24631	12	884	12	0,3	11	7
2	2396	13	884	13	0,3	22	90
3	2396	23	806	23	0,49	33	90
				21	0,03	12	0
				31	0,03	13	0
				32	0,49	23	0

ρ [g/cm³]
1,446

MAT24-PIECWISE_LINEAR_PLASTICITY (liner)



$$\mathbf{M}\Delta\mathbf{a}_{n+1} + \mathbf{K}\Delta\mathbf{u}_{n+1} = \mathbf{f}^{ext}_{n+1} - \mathbf{f}^{int}_{n} - \mathbf{M}\mathbf{a}_{n}$$

Nonlinear Equilibrium Problem:

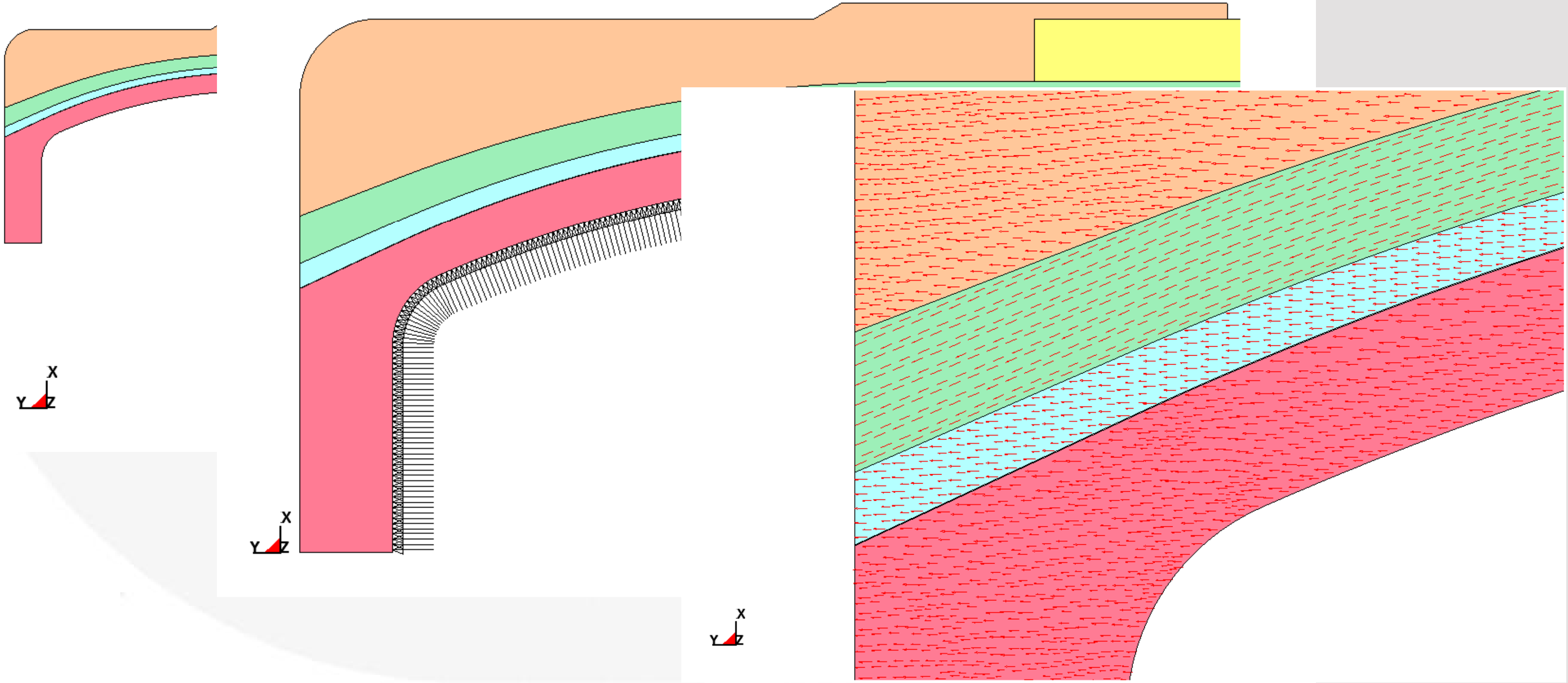
- find displacements **u** wich statisfy equilibrium $\mathbf{f}^{ext} = \mathbf{f}^{int}$
- both **K**, $\mathbf{f}^{ext}$ and $\mathbf{f}^{int}$ can be nonlinear functions of **u**
- iterative search using Newton-based method

Linear Algebra Problem:

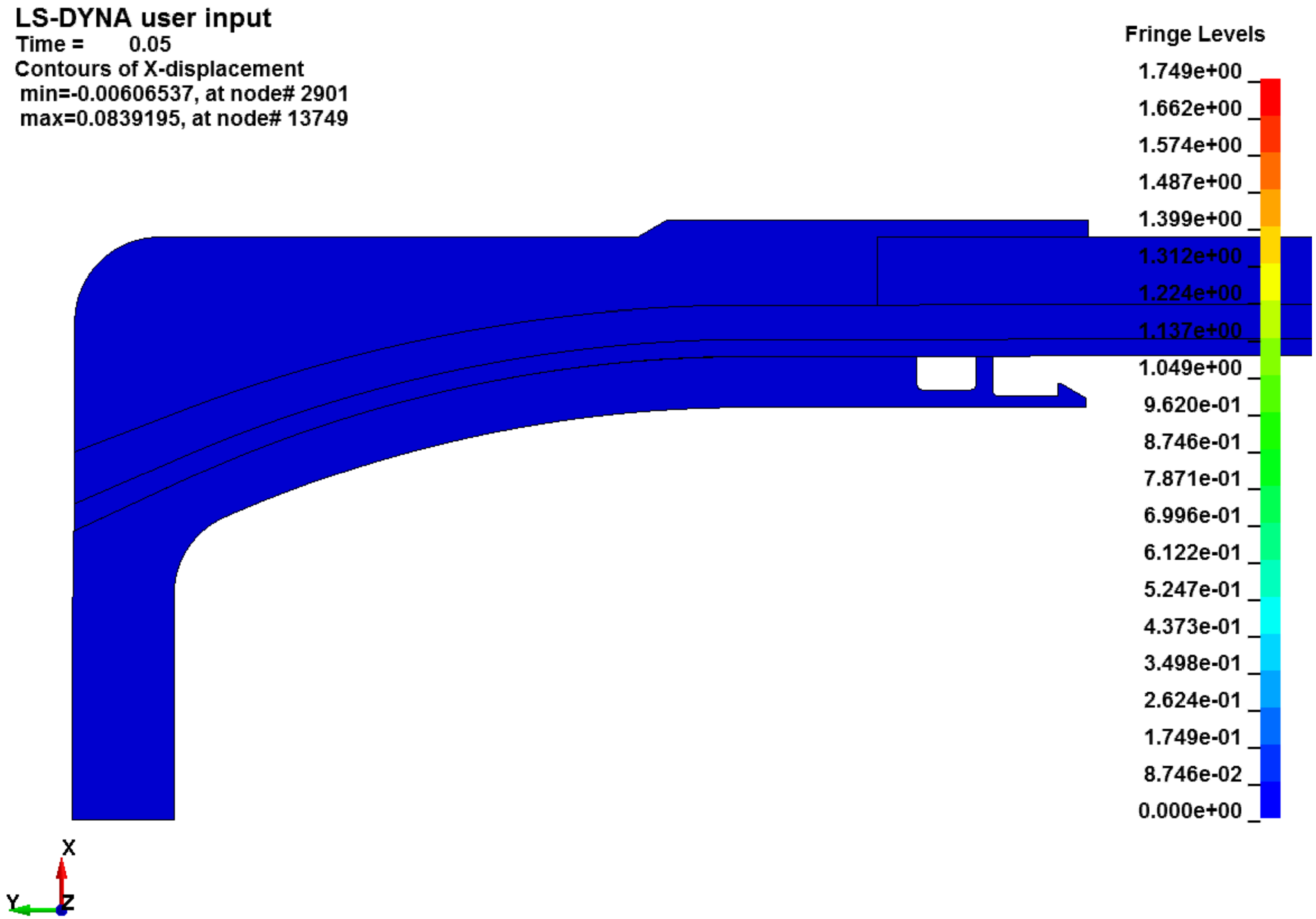
- solve system of linear algebraic equations $\mathbf{K}\Delta\mathbf{u} = \mathbf{R}$ every nonlinear iteration
- great CPU and memory cost

Implicit Examples
nonlinear statics pressure tank

ELEMENT_SHELL_BETA (Fiberorientation)
SECTION_SHELL ELEMENTFORM 15 (volume weighted axisymmetric elements)
CONTACT_2D_AUTOMATIC_SURFACE_TO_SURFACE

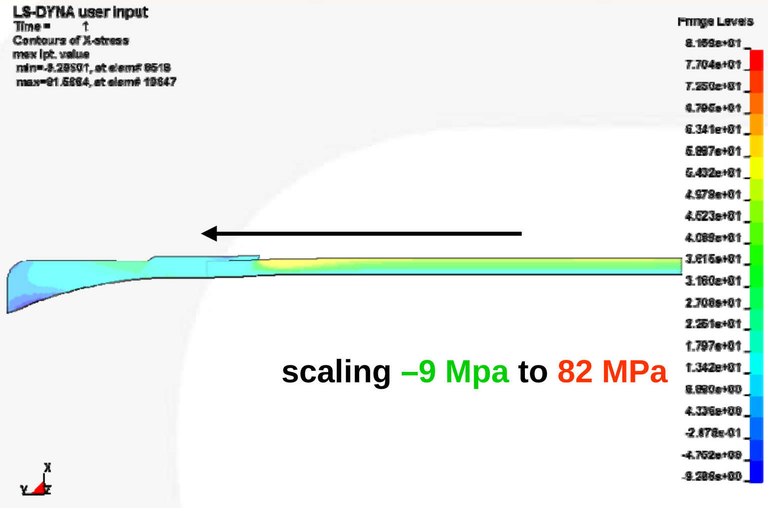


Implicit Examples
nonlinear statics pressure tank

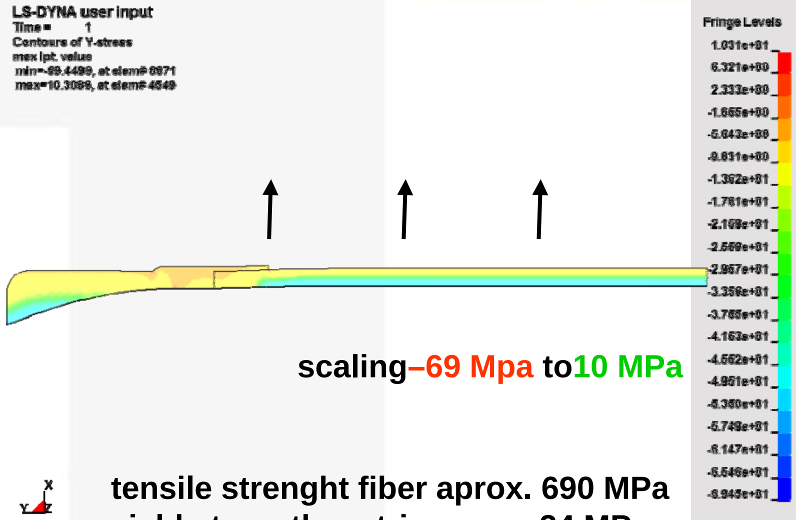


x-displacements[mm]

Implicit Examples
nonlinear statics pressure tank

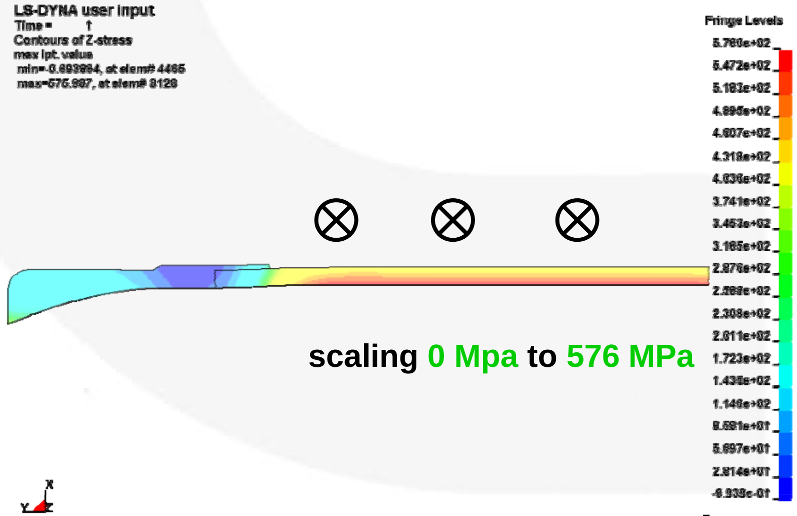


scaling **–9 Mpa** to **82 MPa**

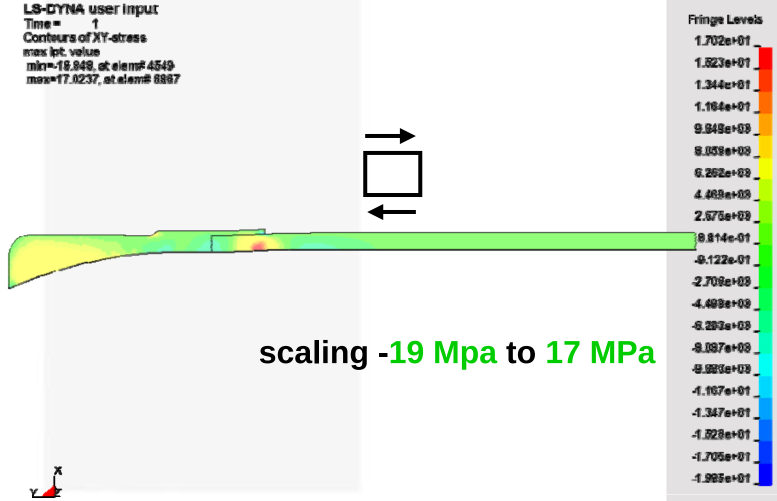


scaling **–69 Mpa** to **10 MPa**

tensile strenght fiber aprox. 690 MPa
yield strength matrix aprox. 24 MPa



scaling **0 Mpa** to **576 MPa**



scaling **-19 Mpa** to **17 MPa**

stresses pipe UDt components [MPa]