Fast and Efficient: Integrated Fatigue Analysis in PERMAS

- Development Preview -

Jakob Häckh, Steinbeis Transferzentrum
Andreas Schünemann, Intes GmbH

PERMAS
Tech Meetings
2021

Motivation

Fatigue in PERMAS - WHY?

- Fully integrated Stress/Fatigue evaluation in PERMAS
- Highly performant implementation
  (optimized memory/runtime efficiency, parallelized)
- Classical approach via nodal stresses or SPR stresses/gradients
- avoids stress export/import; no external tool necessary
- GUI support by VisPER for pre and post processing

Cooperation of Intes with Steinbeis Verkehrszentrum:

Transfer of Know How
WinLIFE → PERMAS

Implementation directly in PERMAS (no code integration)

Combination:

Intes FEM/HPC capabilities
\+ WinLIFE Fatigue expertise

Options for further development

e.g. Optimization & Fatigue (Damage as design objective or constraint)

Content

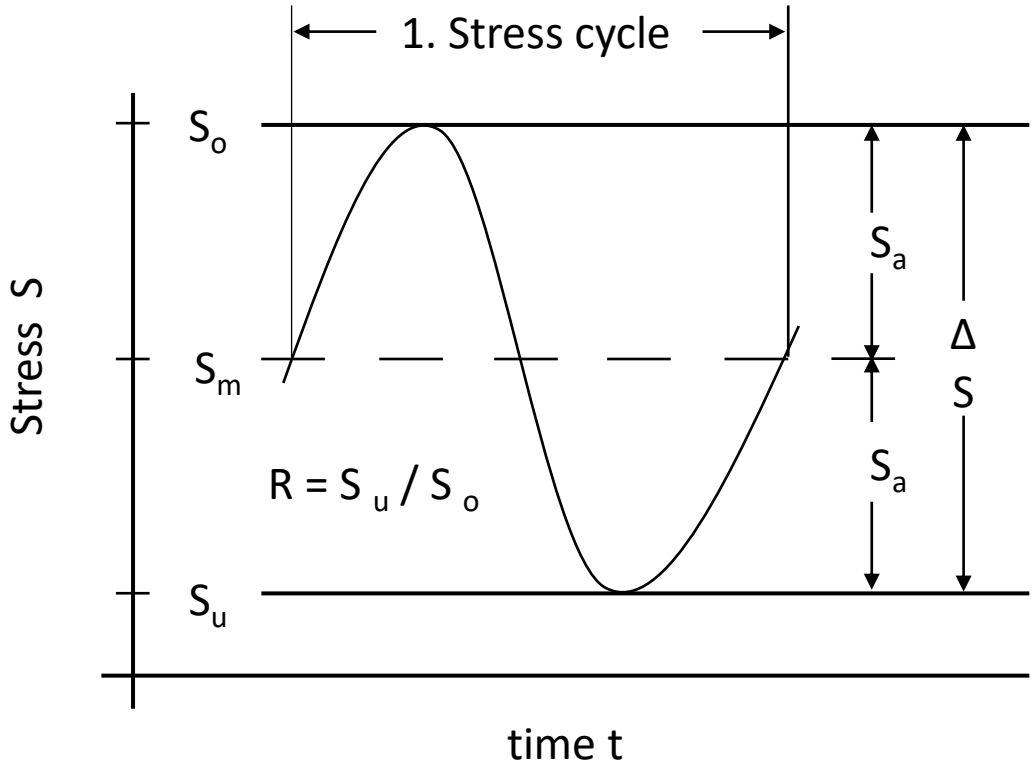
- Introduction to Fatigue
- The Fatigue Software WinLIFE
- Advantages of Direct Integration
- The Gain of Performance
- Comparison of Results
- Conclusion

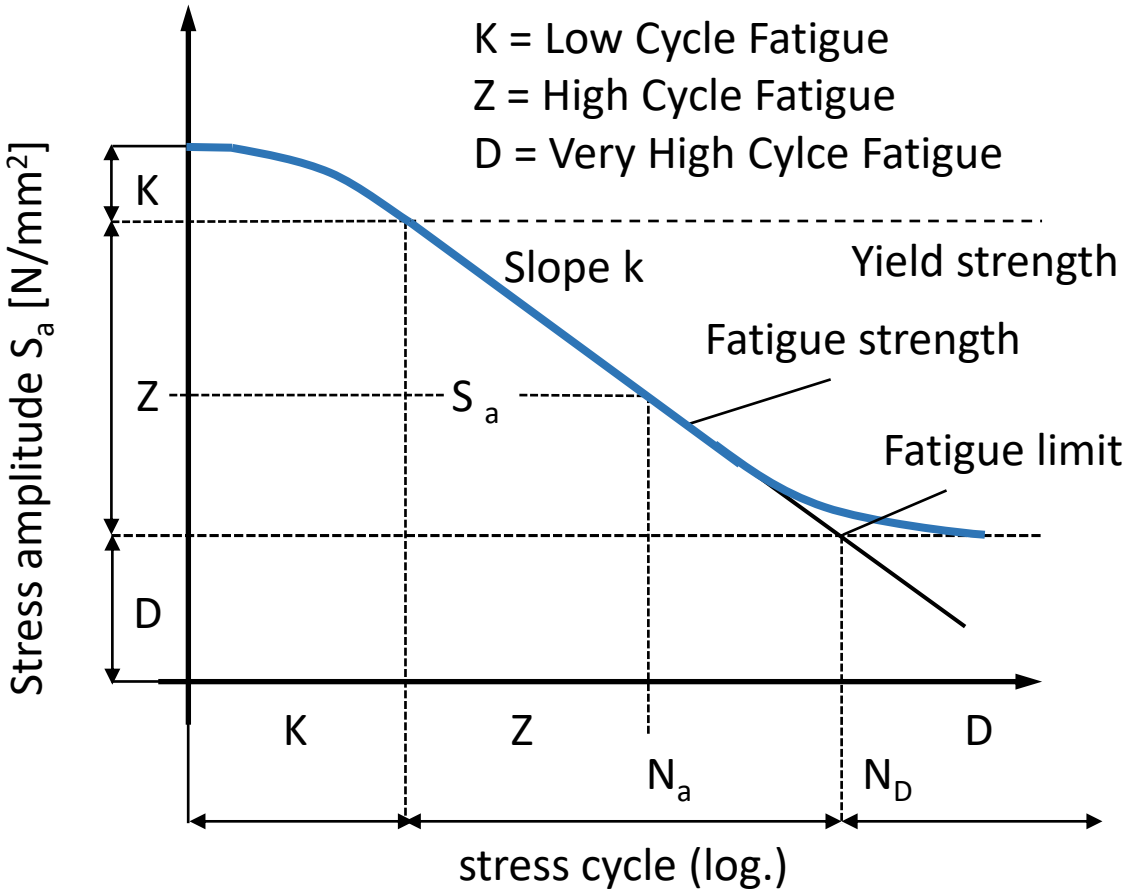
Why do I need a Fatigue Life Calculation?

ICE accident in Eschede:
A broken wheel tire gets blocked in a track switch and derails the train

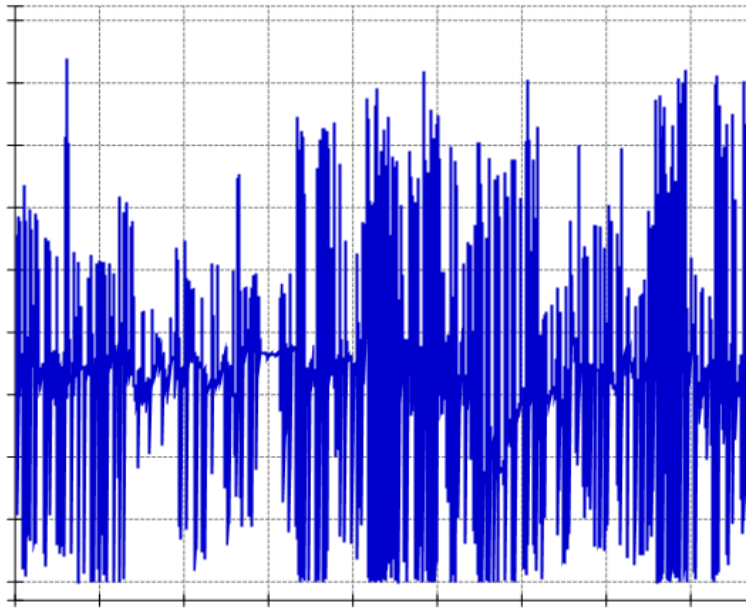
After approximately 20 000 km, the aluminum frame of a mountain bike broke.

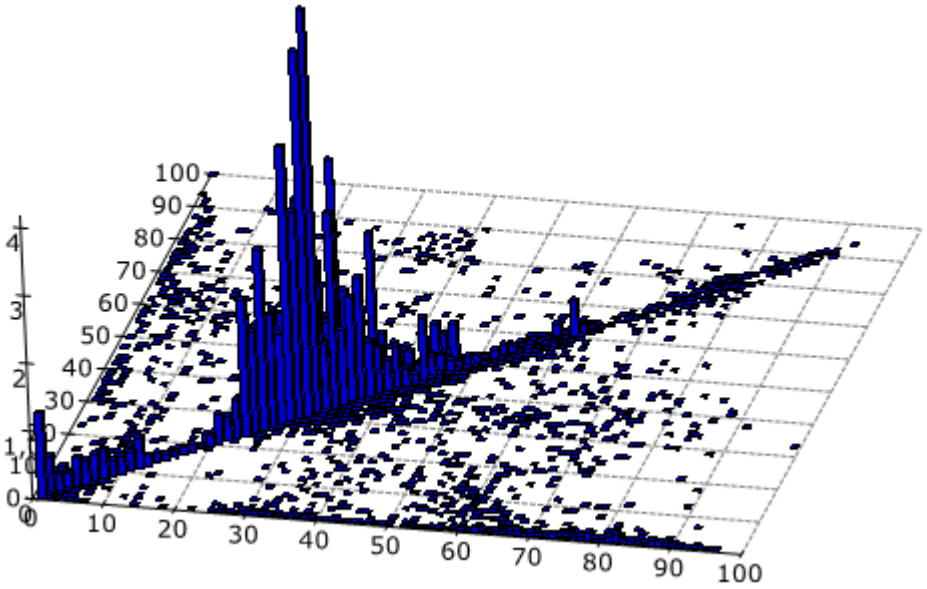
The Basis is the SN-curve Test

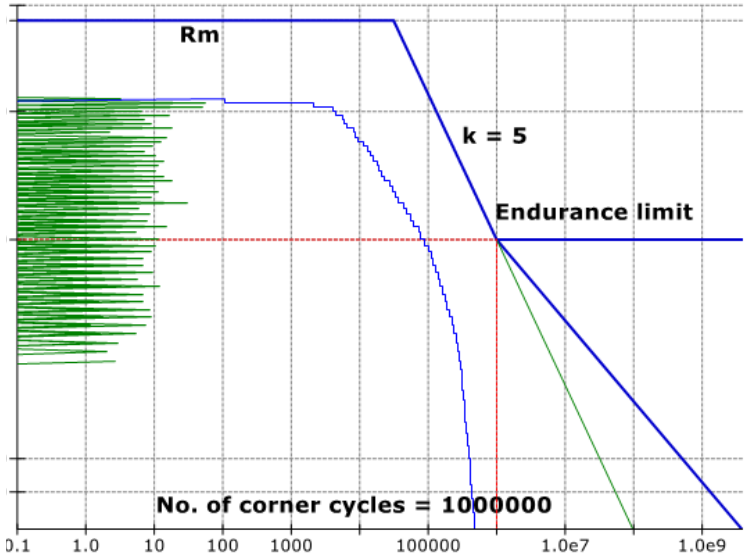




Load -> Damage Amount







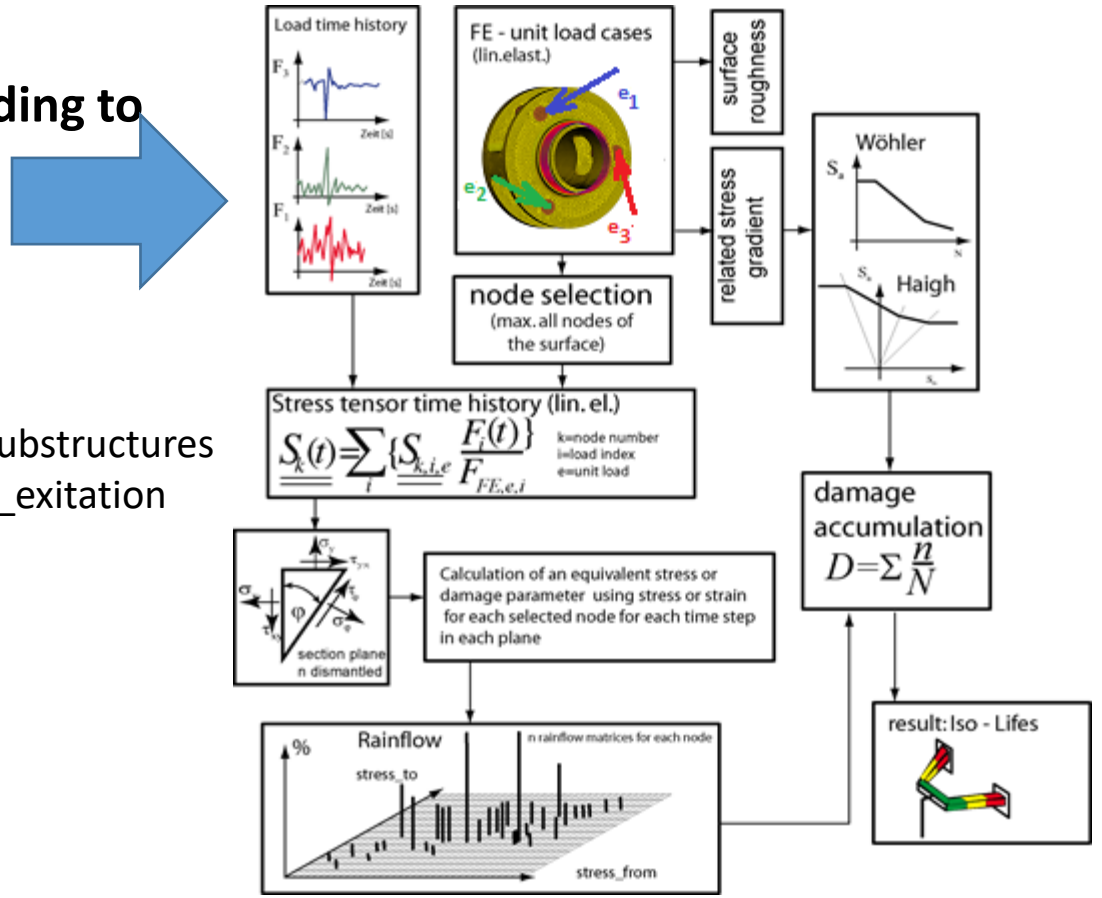
Rainflow Counting

A rainflow counting is an evaluation algorithm used to reduce a random stress-time history to a damage-equivalent stage collective. This can be used as a basis for a strength assessment by comparison with a corresponding Wöhler line.

Process of a Fatigue Life Calculation

BASIC Calculation methods of winLIFE:

- **Fatigue strength verification and static verification according to FKM**
- **Static superposition of load cases by scaling**
  - Mostly used method
  - High calculation speed
  - up to 200 loads histories
  - Non-linearity can be taken into account by dividing structure into substructures
  - Necessary condition: All natural frequencies of the structure > 3*f_exitation
- **Modal superposition**
- **Nonlinear calculation**



winLIFE 2021

winLIFE 2021

Founded 1989 from Prof. Dr. G. Willmerding -> **LIFE** (**L**ebensdauer (Fatigue) **I**nformation **F**inite **E**lemente)
-> renamed 1993 in TvLIFE -> 1996 renamed in winLIFE

Established for ofer 30 years with over 250 Installation worldwide

8 Moduls: FKM, BASIC, MULTIAXIAL, GEARWHEEL&BEARING, CRACKGROWTH, RANDOM, STATISTIC, VIEWER
All current theories implemented

Our customer: *Astrium, Audi, Arctic Cat, ALKO-Kober, Bayer, Bertrandt, **Bosch**, **Bosch Rexroth**, **Borg-Warner**, Doosan (Korea) EDF, ENO, Enercon, FAG, Fendt, **Daimler**, Eickhoff, Hitachi**, IVECO**, **Komatsu**, Krauss Maffei Wegmann**, Kögel**, Lürssen Werft, LBF, **MAN**, Müller Weingarten, MUZ Engineering, **Porsche**, Pfleiderer Verkehrstechnik Rheinmetall, Neumann & Esser, Terex, TEMIC, **ZF**, Zelter, Zollern*

More details see Lecture of 6th PERMAS Technology day 2019
or www.stz-verkehr.com

a product of:

Steinbeis-Transferzentrum
Verkehrstechnik.Simulation.Software

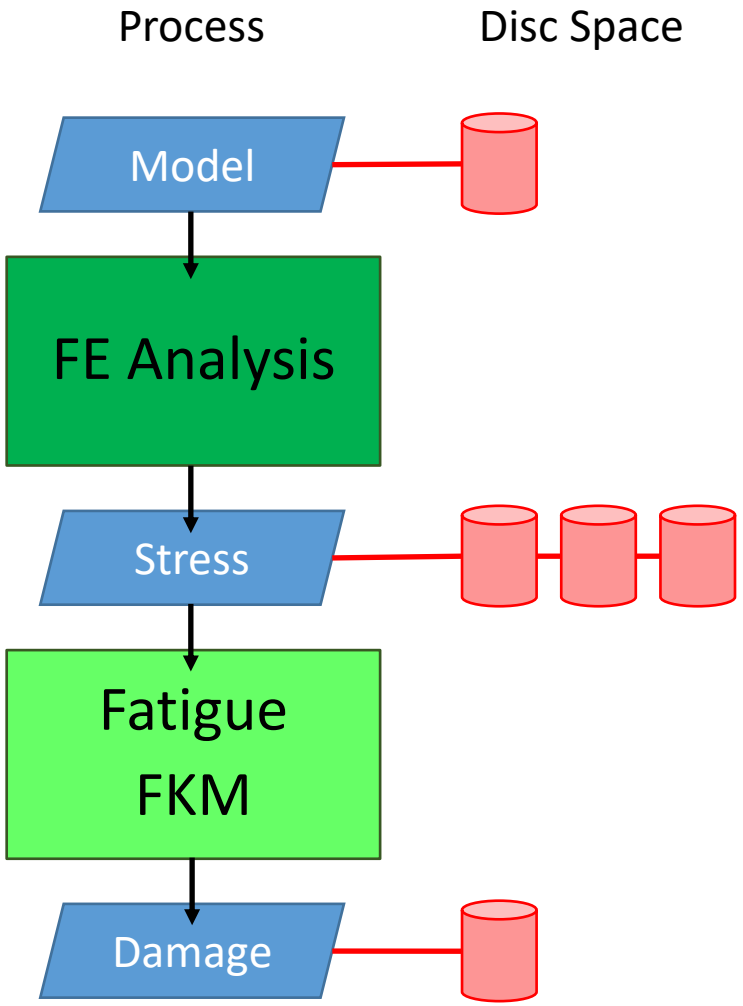
Content

- Introduction to Fatigue
- The Fatigue Software WinLIFE
- Advantages of Direct Integration
- The Gain of Performance
- Comparison of Results
- Conclusion

Process of Fatigue Analysis

Standard workflow in industry:

- Two separated software
  - Two independent analyses
  - Two different input syntaxes
- Inefficient data handling
  - File i/o is slow
  - Disc space required
- Only stresses at nodes are transferred
- All other valuable information is thrown away and not used

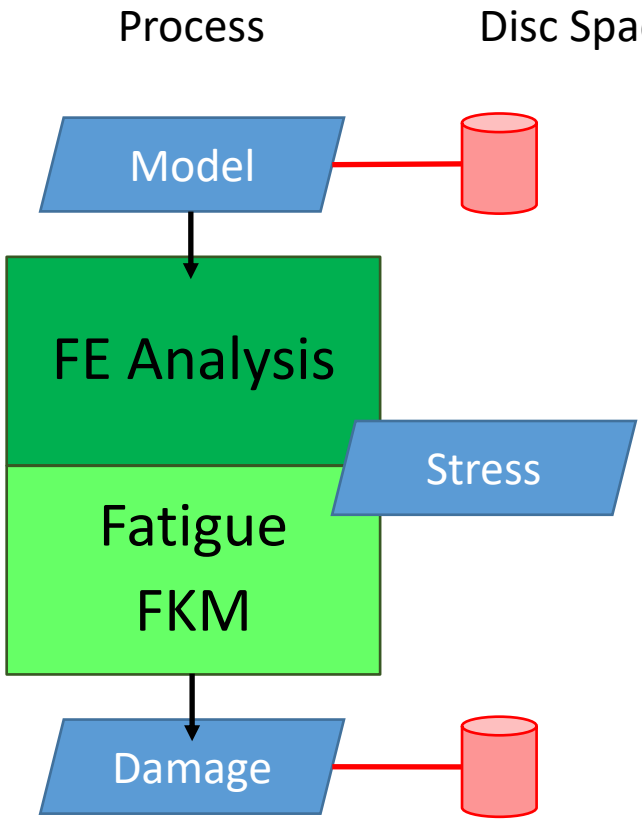


Common Software „Integration“

Simple put together of both software under an uniform cover:

- From outside: one software
  - Still two independent software kernels
  + one input syntax
- Maybe better data handling
  - Depends on software company

- Functionality added for advertising brochures
- Some advantages, but not a break through
- Significant possible benefits not implemented

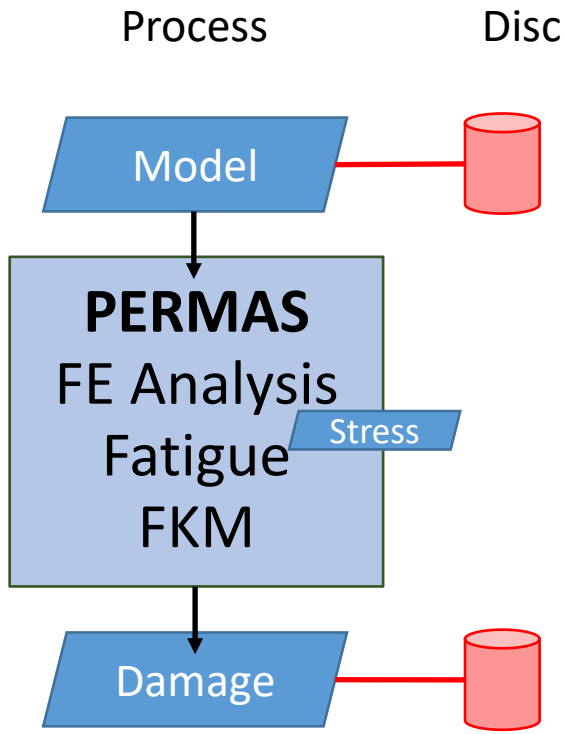


INTES Integration Approach

INTES advanced integration approach means:

Implementation of fatigue analysis in **PERMAS**

+ One software
  + One input syntax
+ Efficient data handling
  + Common data, no export/import of stress
+ Usage of PERMAS HPC strength:
  + Parallelization, data management, …
+ Usage of PERMAS internal model knowledge and of already computed information/results
  + E.g. stress gradients, normal directions, …
+ Knowledge (theory and long time experience) of experts (Steinbeis-Transferzentrum, winLIFE)



Significant advantages implemented:

- **Simplified, more reliable process**
- **Breakthrough in process acceleration**

Potential Advantages in Future

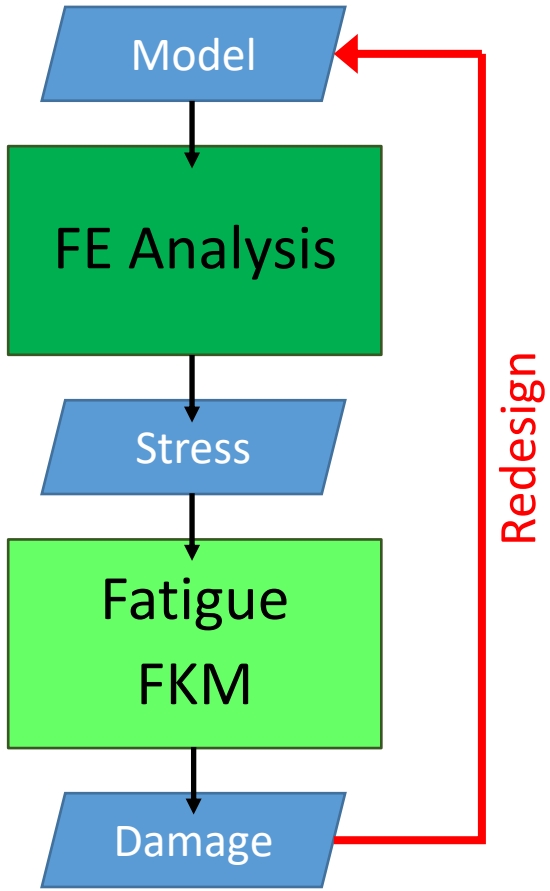
Significant advantages of integrated

- Fatigue analysis and
- Optimization

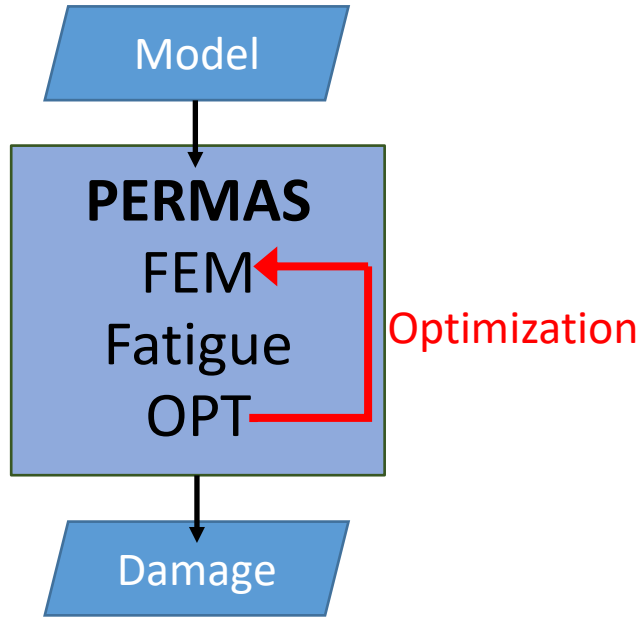
are door opener for further process improvements in future.

These innovations support your innovations towards best performance of your products!

Classic Development Process



Advanced Process



Fatigue Input in DAT File

Examples for preliminary PERMAS data file keywords

- Parameter for the SN-Curve which describes the magnitude of an alternating stress versus the number of cycles to failure (developed by August Wöhler):

```
$FATIGUE SNCURVE  METHOD = PARAM        NSET = FAT1  SNCNAME = C45R
!       DwTw    S02             IL      Rm      SD              K               ND                      M
        1.73    500.0           1       700.0   250.0           5.0             1000000                 0.15
```

- Description of roughness for the effect on the fatigue strength:

```
$FATIGUE NODEPROP  TYPE = ROUGHNESS  PDEF = NODE
!       Node/NSET  roughness
        1234567    0.15
        FRONT      0.05
        ...        ...
```

Fatigue Analysis in UCI File

- Simple extension of the UCI
- Just an additional result request with parameters required
- Based on nodal point stress results (explicit generate is optional)

UCI file excerpt:

```
EXEC
    ACTivate  SITuation = STATIC_FAT
    STATIC
    GENerate Nodal Point STRESS
    GENerate FATIGUE  FLSET = FAT1  SURFACE = 102  NCUT = 50  RFLDIM = 200  STRESS = NORMAL
```

Performance

FE Model Size:

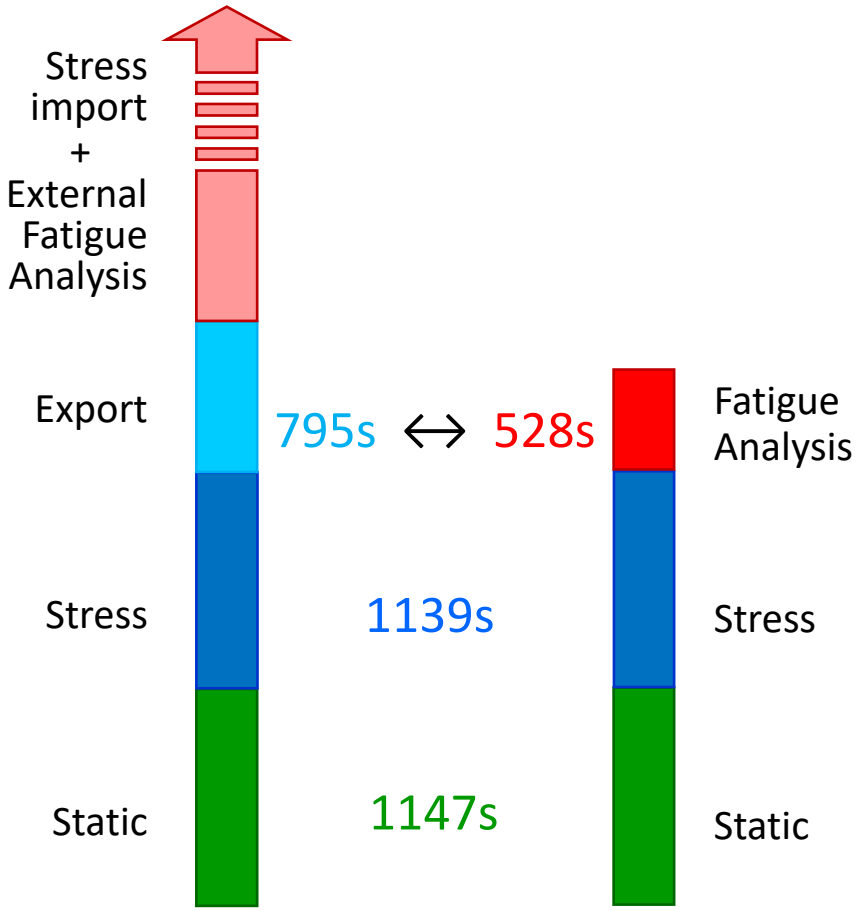
1506000 Nodes

1250000 Elements

Export Size:

Stresses: 48 GB (.bof)

Damage: 1.7 MB (.post.gz)



➔ PERMAS fatigue analysis is even faster than the stress export!

Performance: Parallelization

Fatigue settings for rainflow method

Hardware: 1 Socket, 18 cores, 192GB memory

		Fatigue Runtime	parallel speedup	GFlop/s
Rough sketch	10 cutting planes 40 rainflow stress classes	267s	4.3	4.7
Standard	40 cutting planes 200 rainflow stress classes	531s	8.9	6.5
High Quality	200 cutting planes 1000 rainflow stress classes	544s	10.9	19.6

Performance: Parallelization

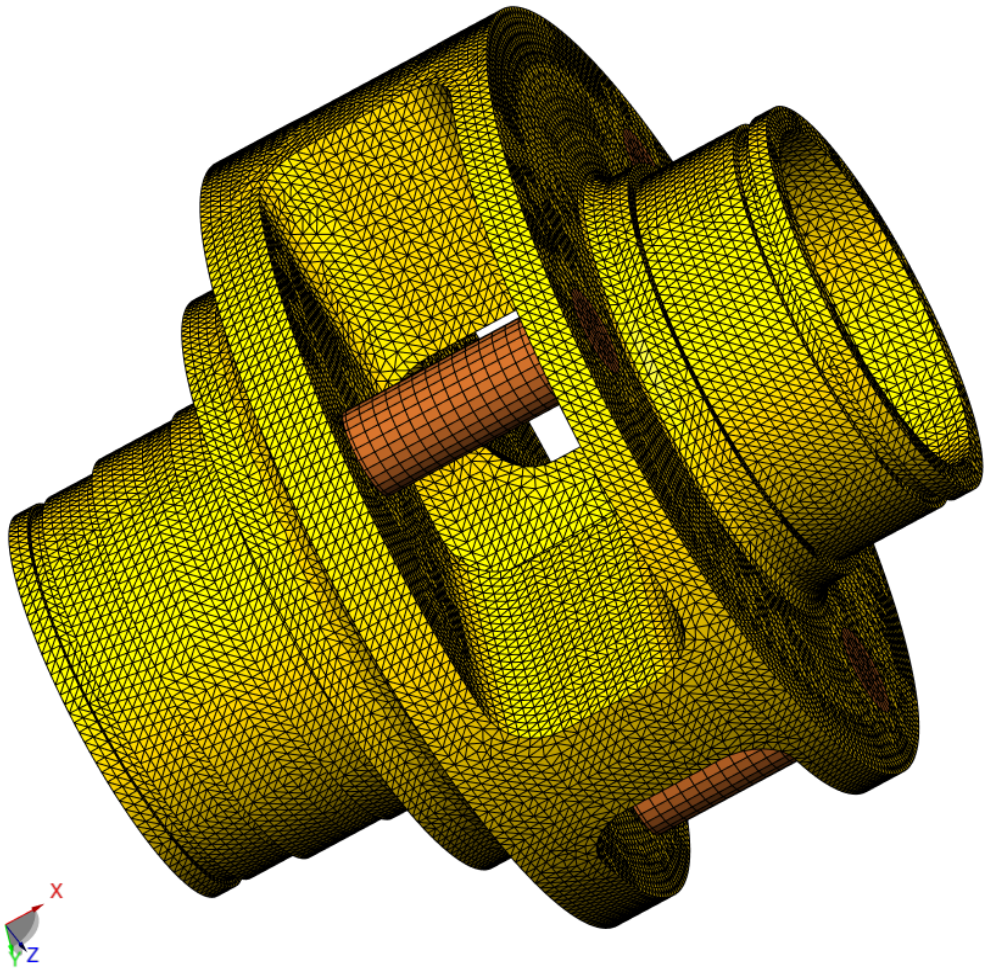
Fatigue settings for rainflow method

Hardware: 1 Socket, 18 cores, 192GB memory

		Fatigue Runtime	parallel speedup	GFlop/s
Rough sketch	10 cutting planes 40 rainflow stress classes	267s	4.3	4.7
Standard	40 cutting planes 200 rainflow stress classes	531s	8.9	6.5
High Quality	200 cutting planes 1000 rainflow stress classes	544s	10.9	19.6

Fully parallelized ➔ Higher result quality at small additional runtime

Planetary Gear Carrier

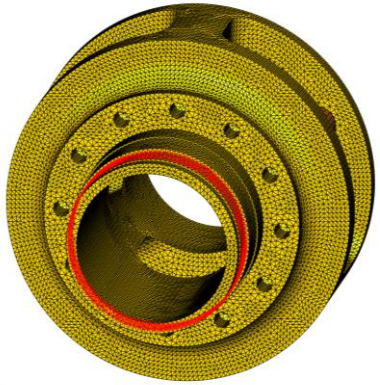


713377 Nodes
486355 Elements
16504 Fatigue Nodes

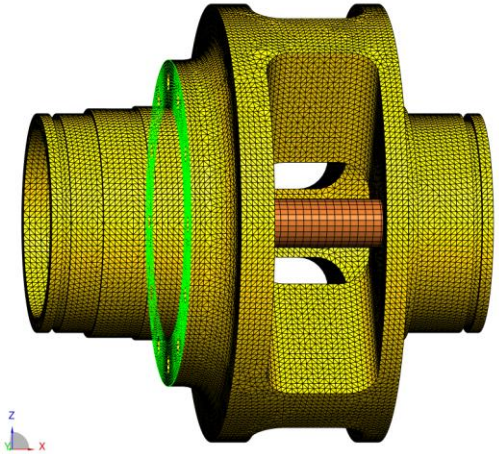
Rainflow method with
931 time steps
40 cutting planes
200 stress classes

Planetary Gear Carrier

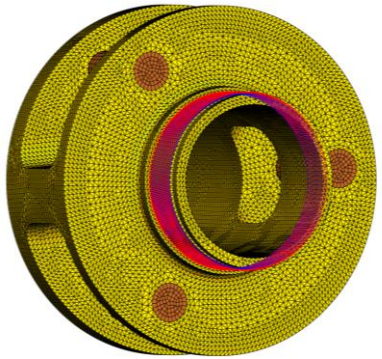
Kinematic conditions



radial

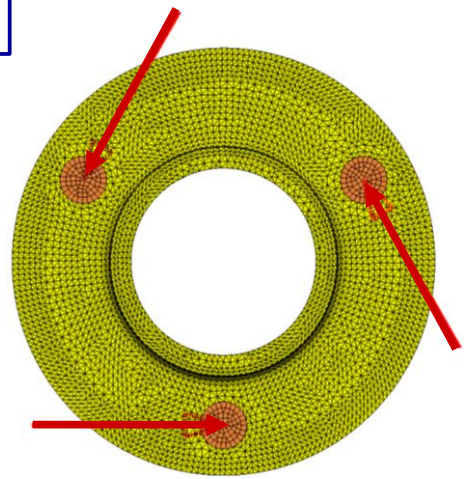


axial



radial +
tangential

Loads

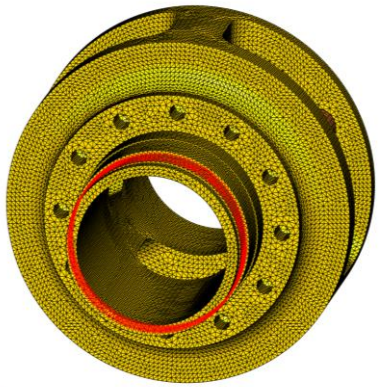


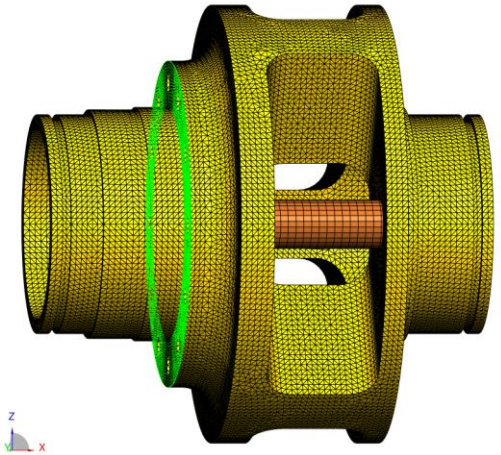
3 x 45 kN ⟶ 4725 Nm

Planetary Gear Carrier

Kinematic conditions

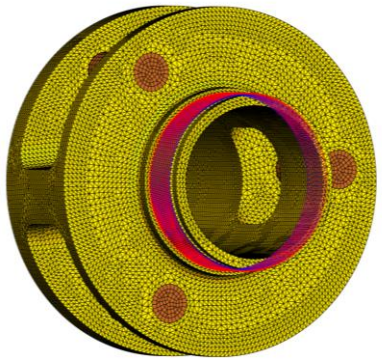
radial



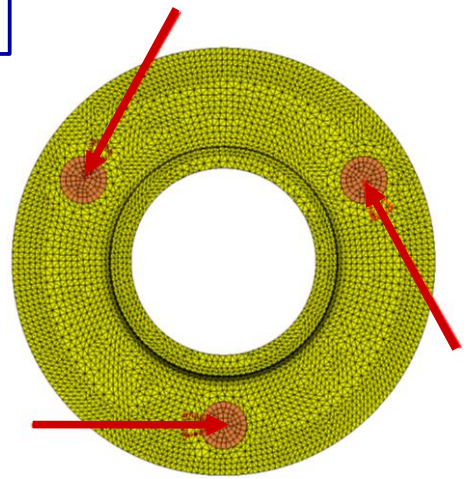


axial

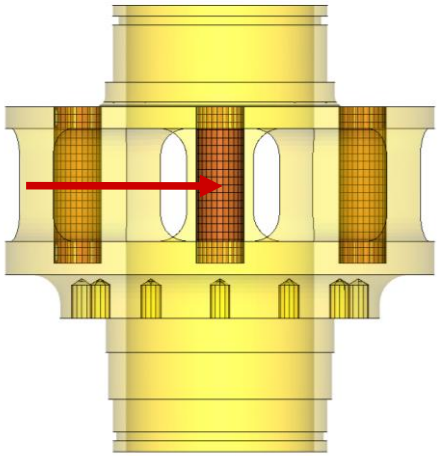
radial +
tangential



Loads

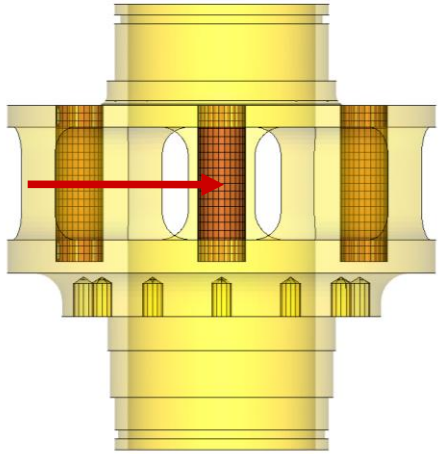


3 x 45 kN ⟶ 4725 Nm



Planetary Gear Carrier: Load Spectrum

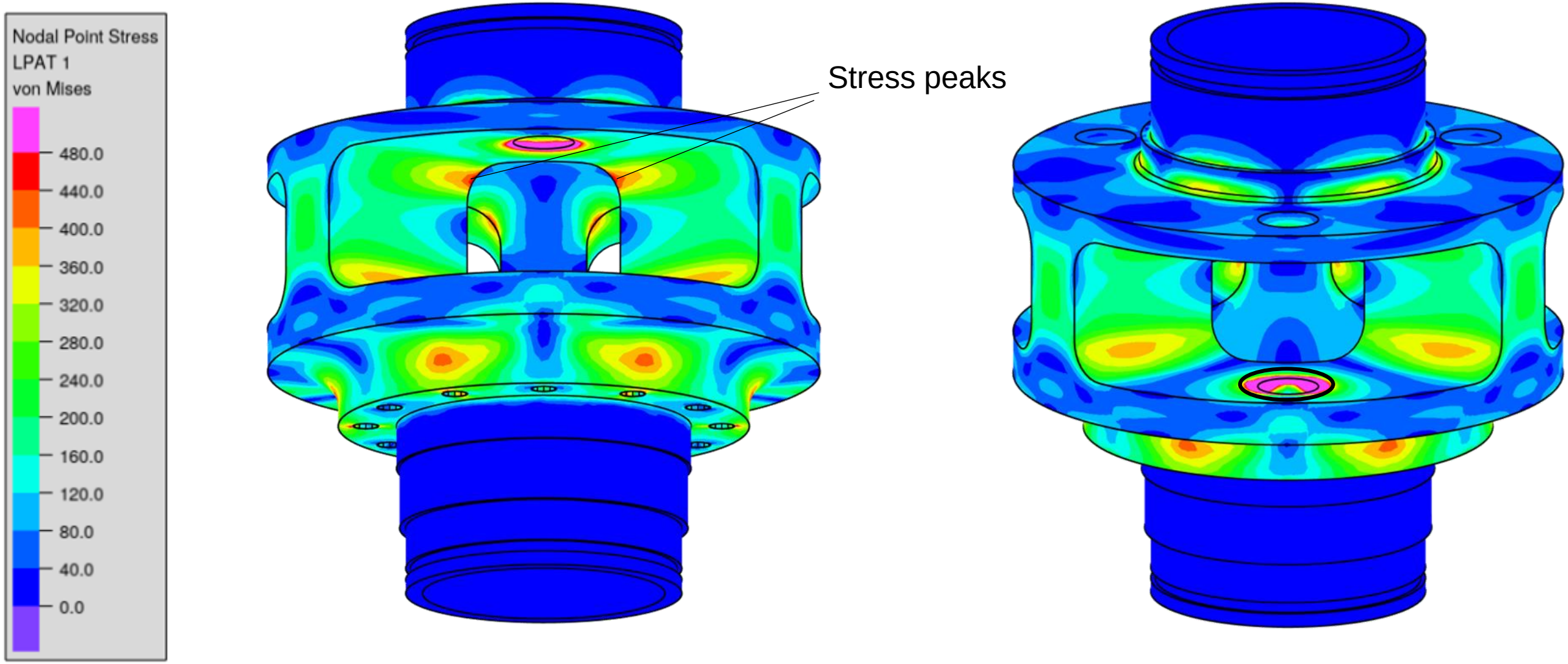
Load Pattern → Load Collective



LPAT 1
3 x 45 kN → 4725 Nm

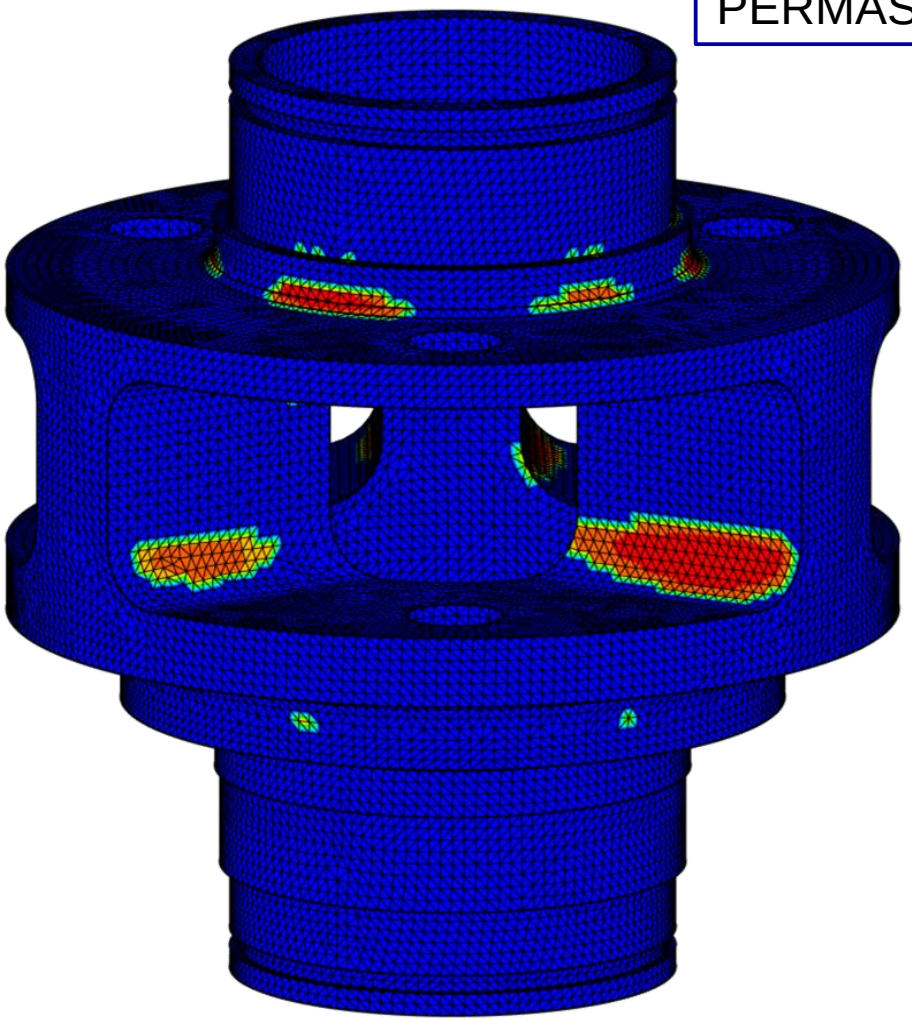
Factor	Loading cycles
1.0	3
0.9	21
0.8	63
0.7	105
0.6	273

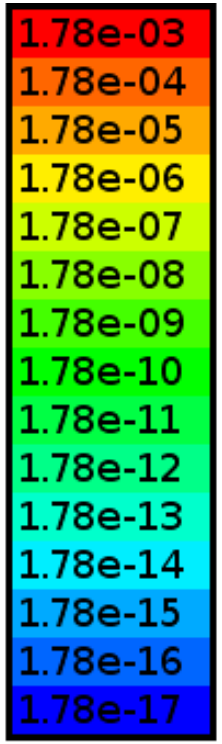
Planetary Gear Carrier: Stress Results



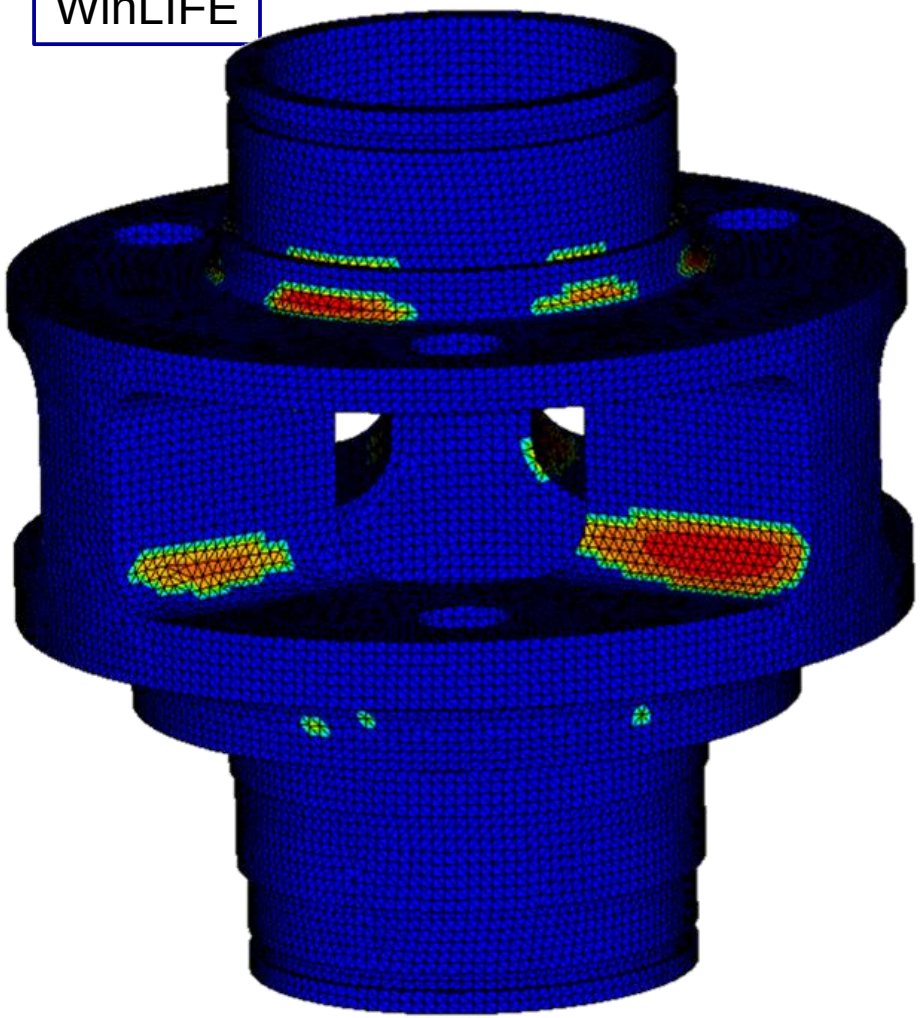
Planetary Gear Carrier: Damage Results

PERMAS



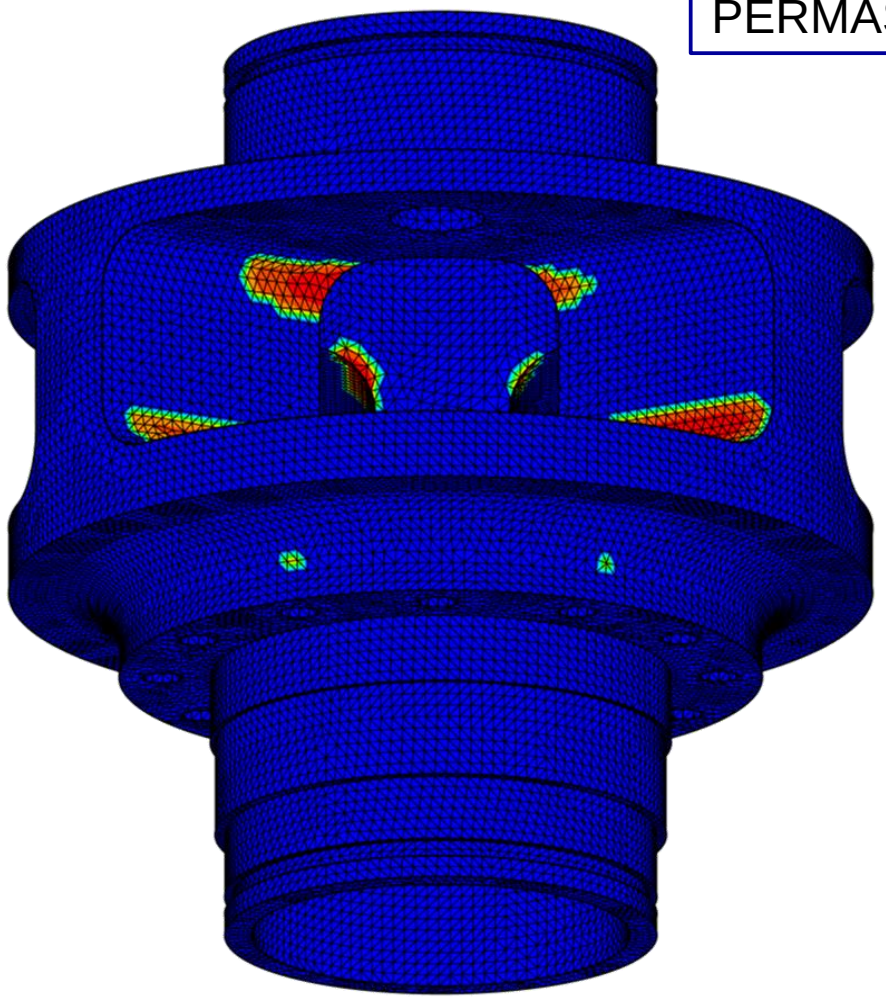


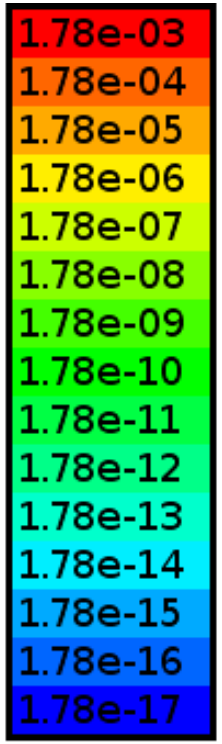
WinLIFE



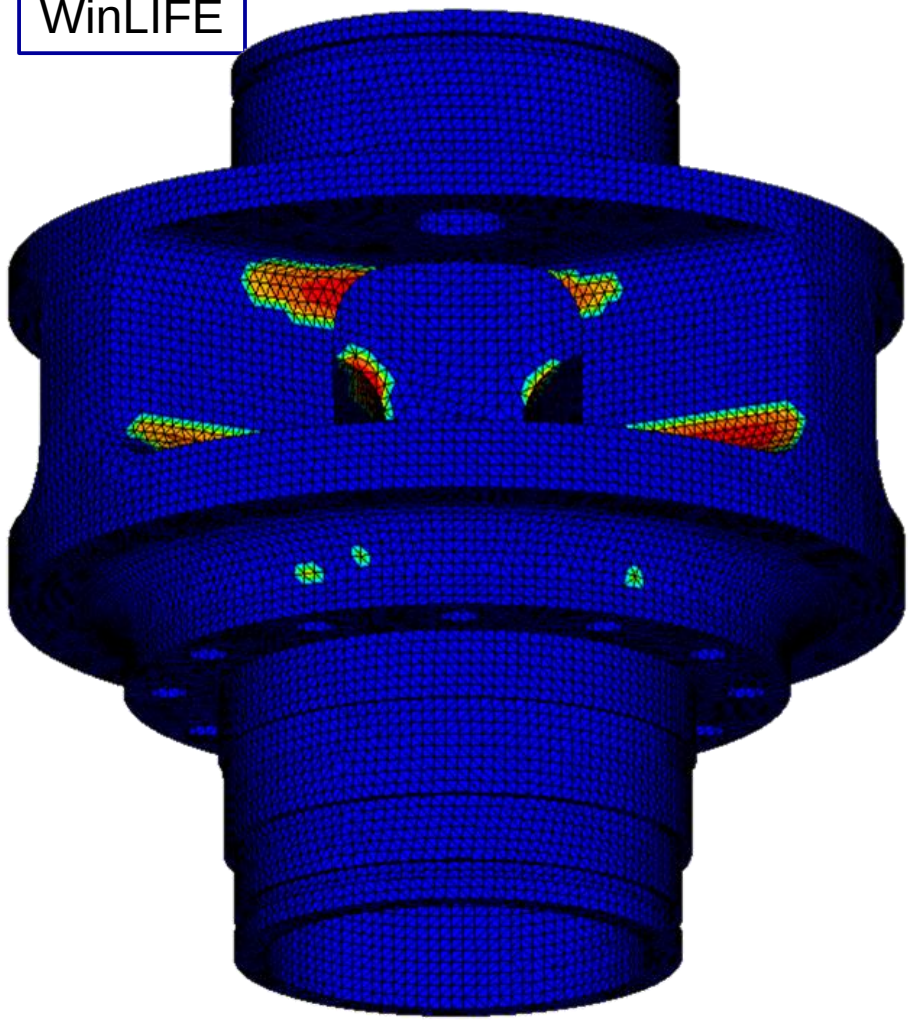
Planetary Gear Carrier: Damage Results

PERMAS



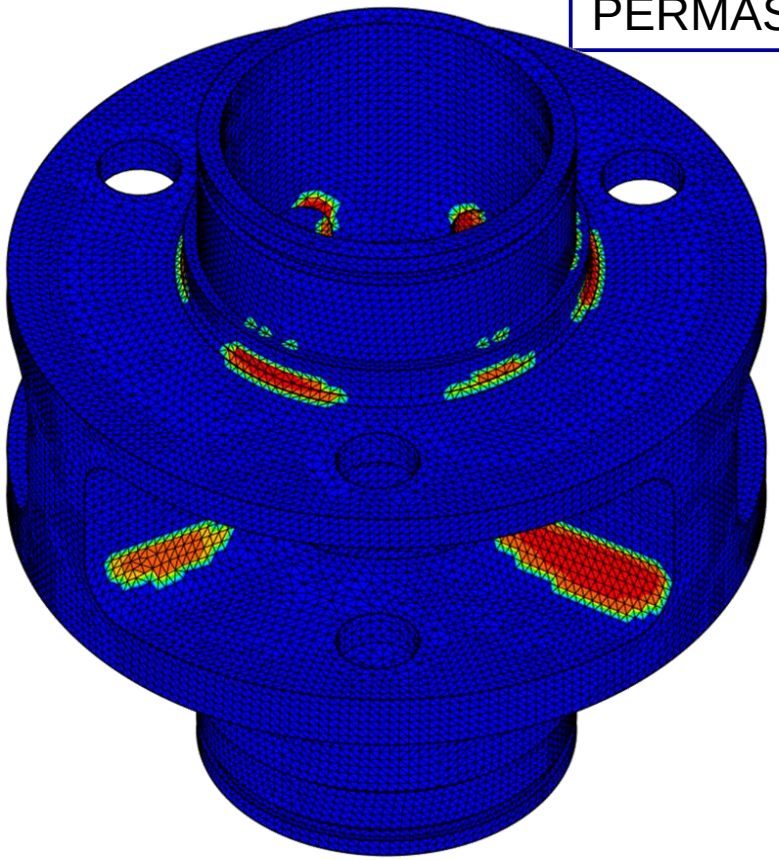


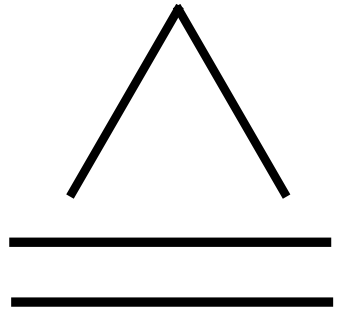
WinLIFE



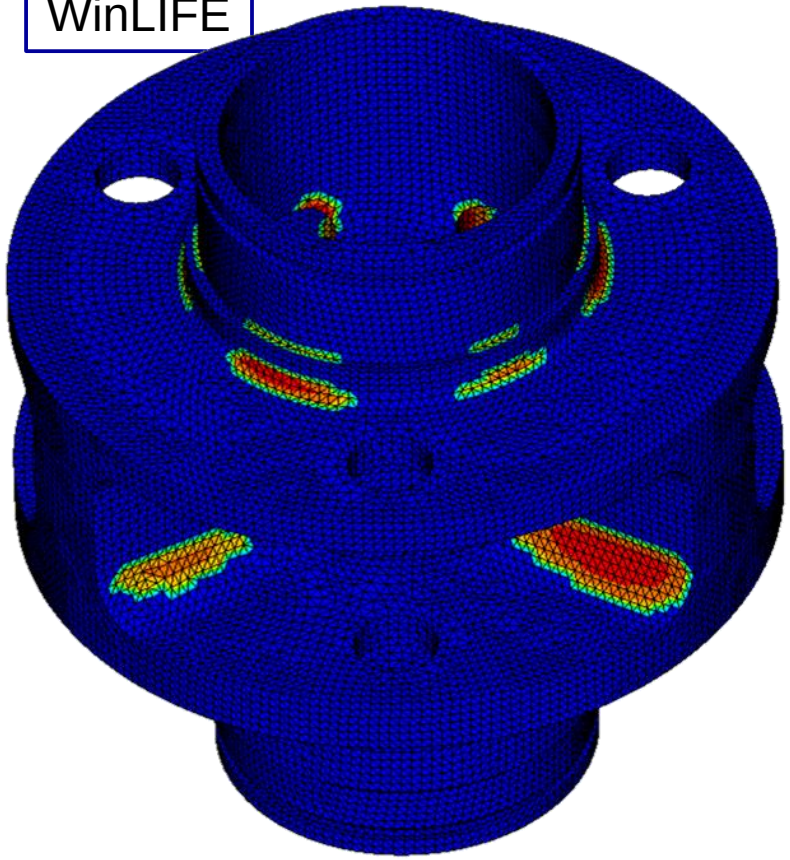
Planetary Gear Carrier: Damage Results

PERMAS





WinLIFE



Results are equivalent!

Conclusion

- Finite Element Analysis and Fatigue Analysis are based on the same model, but the established processes are to complex and time consuming:
  - Integration is a logical step
- Integration of fatigue analysis in PERMAS is in development
- The validity of the solution has been shown
- Deep integration of fatigue code leads directly to significant advantages:
  - Simplified, more reliable process
  - Breakthrough in process acceleration – shown: effort fatigue analysis ≈ effort stress calculation
- Further possibilities in future:
  - Improve the process from expensive redesign to fast optimization
  - Get better damage results by using more and more accurate FE-Solver information