

# Fatigue Calculation Using

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## Summary:

 (Life Information using Finite Elements) can be used with or without finite elements for fatigue life prediction. The Nominal Stress Method, the Local Stress Method and the Local Strain Approach are implemented. Different modifications of the S-N-curve are supported. Generators exist for component S-N-curves and for material life curves according to the UML. Powerful tools to analyse and correct measured load time histories are included. There are three modules:-

-  BASIC:
-  MULTIAXIAL
-  GEARWHEELS AND BEARINGS
- 

The basic module can only solve proportional problems, but the multiaxial module can also solve non-proportional and non-synchronous problems. It is possible to connect to finite element programs and an interface for MSC/NASTRAN for windows is supplied with . Because FEMAP-Format is used, nearly all other FE-programs which run on Windows NT can be used.

Two examples using  are shown to demonstrate the use of the program.

## Keywords:

winLIFE, local strain approach, nominal stress method, multiaxial, gearwheel, bearing

# 1. Introduction

Light weight construction is becoming more and more important and the construction is often limited by fatigue life. **win LIFE** provides the well known and proved methods such as the Nominal Stress Method and the Local Strain Approach in a user friendly interface to relieve the user from complex mathematical operations.

The application of Finite Element Analysis is commonly used and in many cases indisputable. As a result **win LIFE** is designed to be connected to finite element programs running under Windows NT. To avoid any interface problems, it writes and reads files in the FEMAP-format and an access to nearly all FE-programs is possible.

**win LIFE** is distributed with MSC.Nastran for Windows by the MSC.Software Partner Solutions GmbH, Marburg. **win LIFE** is integrated into the user interface of MSC.Nastran for Windows.

The principal problems and faults that occur when predicting fatigue life are not solved by **win LIFE** but most of the common theories are implemented, so that in the hands of an experienced user **win LIFE** is a powerful tool for fatigue life prediction.

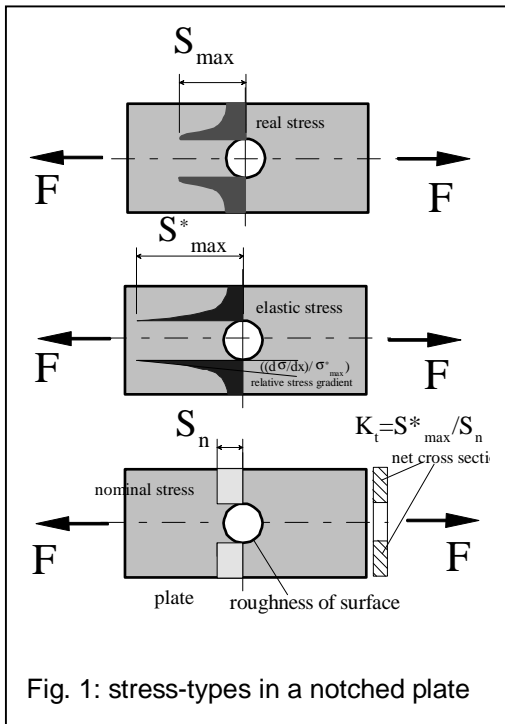


Fig. 1: stress-types in a notched plate

**win LIFE** is an open program, the data structure is documented to enable the user to access it for his own use or to implement additional features.

Here the theory is described and two examples are shown for fatigue calculation.

## 1 Proportional cases (**win LIFE** BASIC)

In the case of proportional loading there are many possible common solutions derived from the Nominal Stress Method or the Local Strain Approach, which are supported by **win LIFE**

The different types of stresses, which are used for fatigue calculation and the most important parameters are shown in figure 1, where a notched plate is loaded by a pull force.

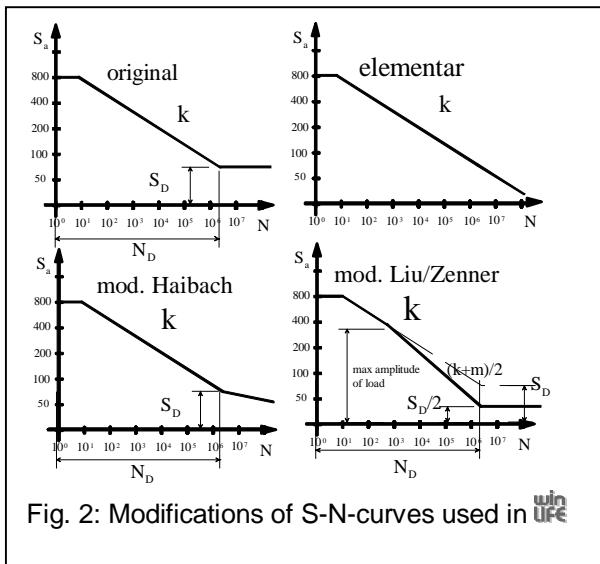


Fig. 2: Modifications of S-N-curves used in **win LIFE**

### 1.1 Implementation of the Nominal Stress Method in **win LIFE**

The traditional way of calculating fatigue life is using the Nominal Stress Method (fig. 1). This procedure has been proved in numerous experimental results and it has been shown that when used by an experienced engineer, this method leads to satisfactory results. This method is the foundation of many construction rules.

**win LIFE** uses component S-N-curves for fatigue life prediction. If the user knows the S-N data, he can enter them into **win LIFE**, if he does not, these curves can be generated using the following data according to [1].

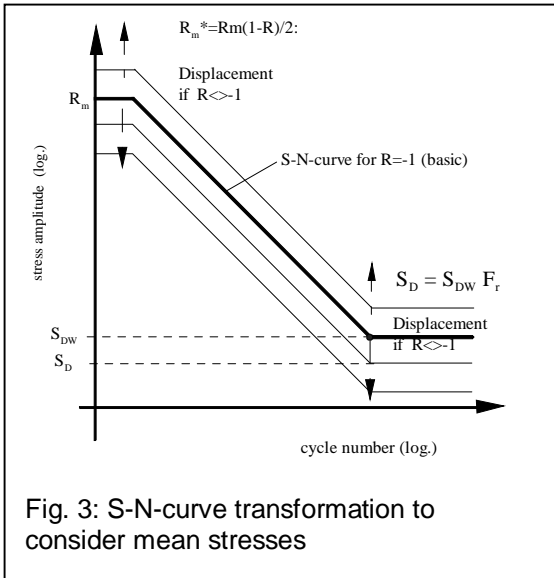


Fig. 3: S-N-curve transformation to consider mean stresses

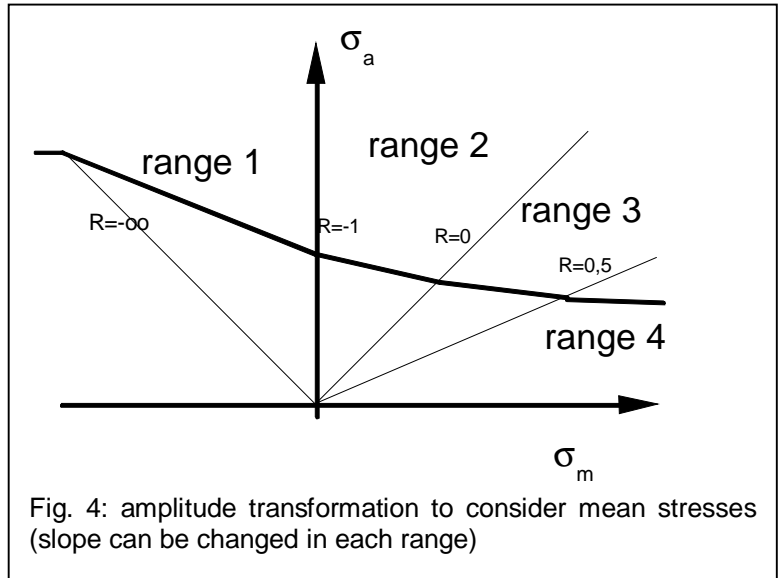


Fig. 4: amplitude transformation to consider mean stresses (slope can be changed in each range)

- static material data
  - $R_m$ ,
  - $R_{po,2}$
- component data
  - $K_t$ ,
  - material treatment,
  - roughness of the surface,
  - related stress gradient

Many different modifications of the S-N-curves (fig. 2) and consideration of the mean stress (fig. 3,4) is possible. According to the mean stress a transformation of S-N-curve (fig. 3) or stress transformation (fig. 4) is possible. The user can use the slope in the ranges one to four according to existing standards [3,4] or he can also enter his own data. Finally the damage accumulation is according to Miner's law.

The flow diagram in figure 5 shows how to use the Nominal Stress Method. It is possible to use local stresses in a similar way to the Nominal Stress Method. This procedure is also supported by **winUFE** and gains in importance in multiaxial calculations.

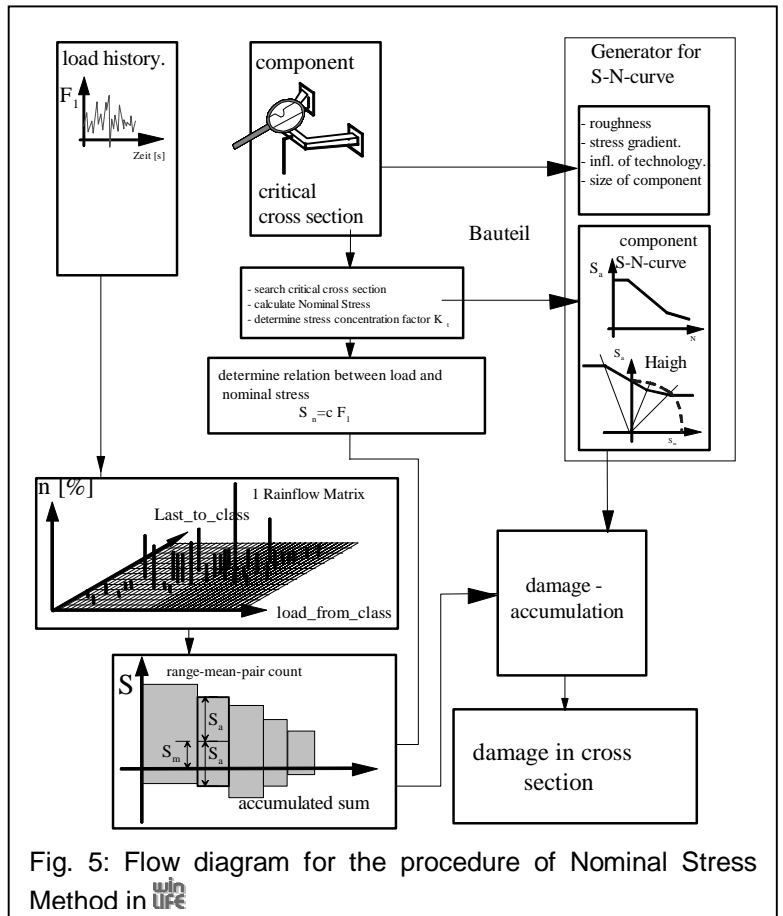
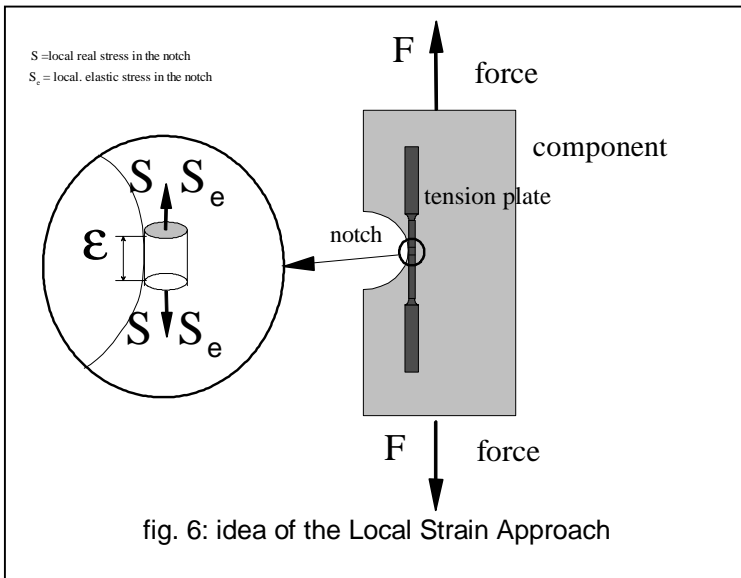


Fig. 5: Flow diagram for the procedure of Nominal Stress Method in **winUFE**

## 1.2 Implementation of the Local Strain Approach in **winUFE**

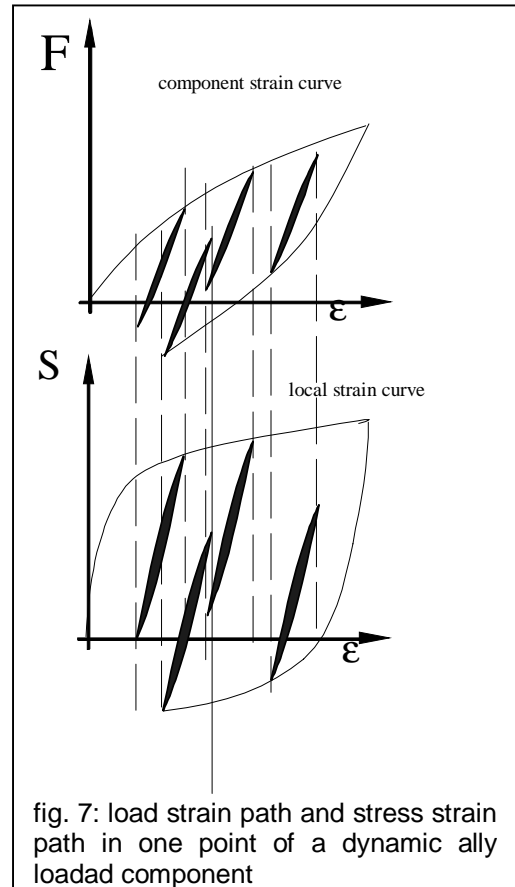
The Local Strain Approach takes into account the real local stress and strain just as if a local specimen in a component were to be subjected to a load. (fig.6). The relation between the turning points of the load strain path and the stress strain path enables the analysis of the load time history by rainflow count. It also enables the construction from the rainflow matrix and the cyclic material properties to the local stress strain path (fig. 7). The rainflow count algorithm includes the correction according to Clormann/Seeger [7] and has been extended to consider hysteresis and classes.



win LIFE uses the common equations according to Ramberg Osgood to describe the cyclic properties and the Masing behaviour.

$$\epsilon_a = \frac{S_a}{E} + \left( \frac{S_a}{K'} \right)^{1/n'}$$

$$\Delta \epsilon = \frac{\Delta S}{E} + 2 \left( \frac{\Delta S}{2K'} \right)^{1/n'}$$

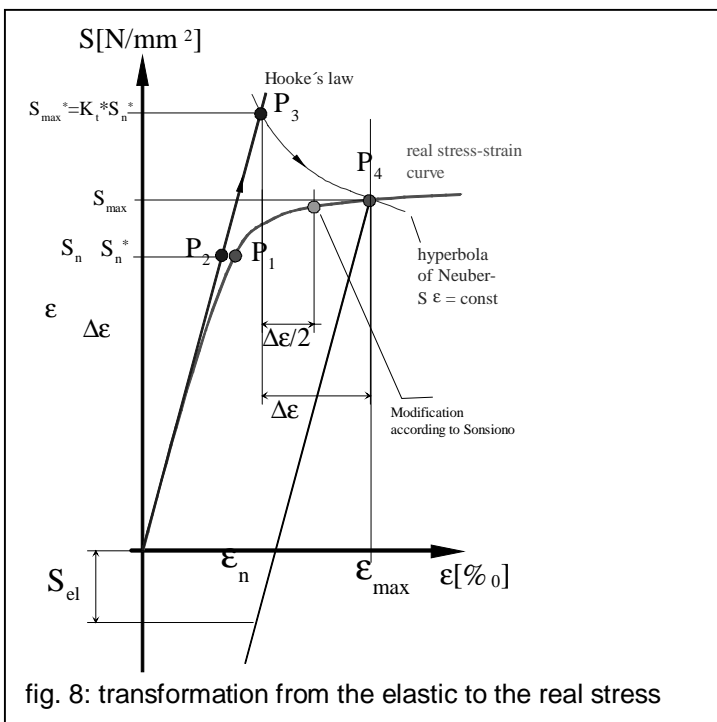


win LIFE carries out fatigue analysis based on elastic stresses. The transformation from the elastic stress to the real stress is done using Neuber's rule. The appropriate modifications can be selected (fig. 8). The damage is calculated according to the damage parameter of Smith, Watson and Topper.

$$P_{SWT} = \sqrt{(S_a + S_m) \epsilon_a} E$$

Further damage parameters are being worked on. Additionally an endurance limit can be used. The only limitation of the length of a time history is the disk space. Figures 9, 10 and 11 show a typical load history, the resulting rainflow-matrix and the calculated stress-strain-path.

For more in-depth interests, win LIFE supports the interactive construction of the stress strain path only with the help of



the material memory. So the user can move along the loading in both time directions step by step.

If the Local Strain Approach is used in conjunction with a finite element analysis, the calculation will be carried out as shown in the flow diagram (fig. 12). If win LIFE is used without finite elements, the user has to enter the elastic stress. In this way a nominal stress combined with  $K_t$  or an elastic stress from a traditional mechanical analysis can be the basis of the fatigue calculation.

win LIFE includes a material data bank and a generator for life curves based on static material data as is proposed in the NML (Uniform Material Law) [9].

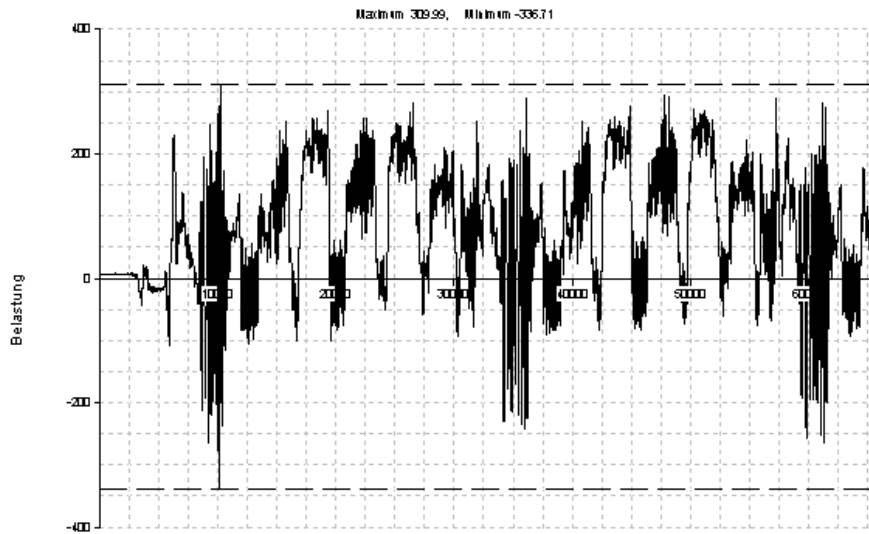


Fig. 9: Load time history of the forces in a heavy truck stabiliser (hardly any limit in length)

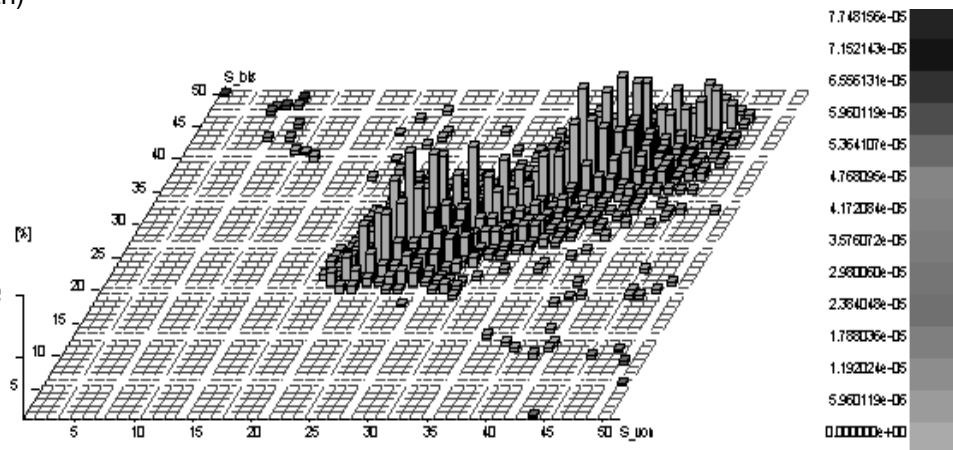


Fig. 10: rainflow matrix of the loading from fig. 9.

E-Modul : 214000  
 $K_t$  : 1.0000  
 $k$  : 988  
 $n'$  : 0.2070  
 Anz.Schleifen : 3193.5

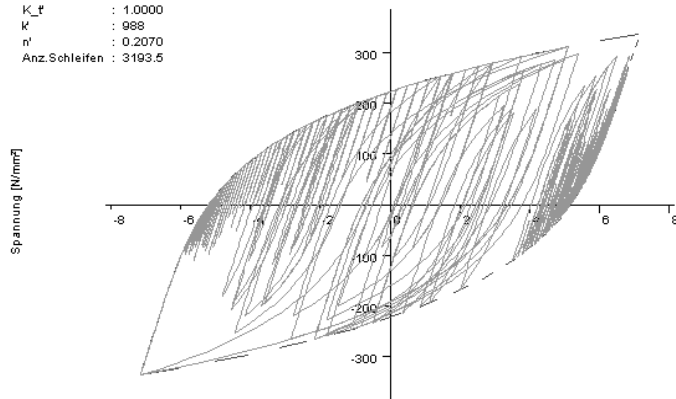
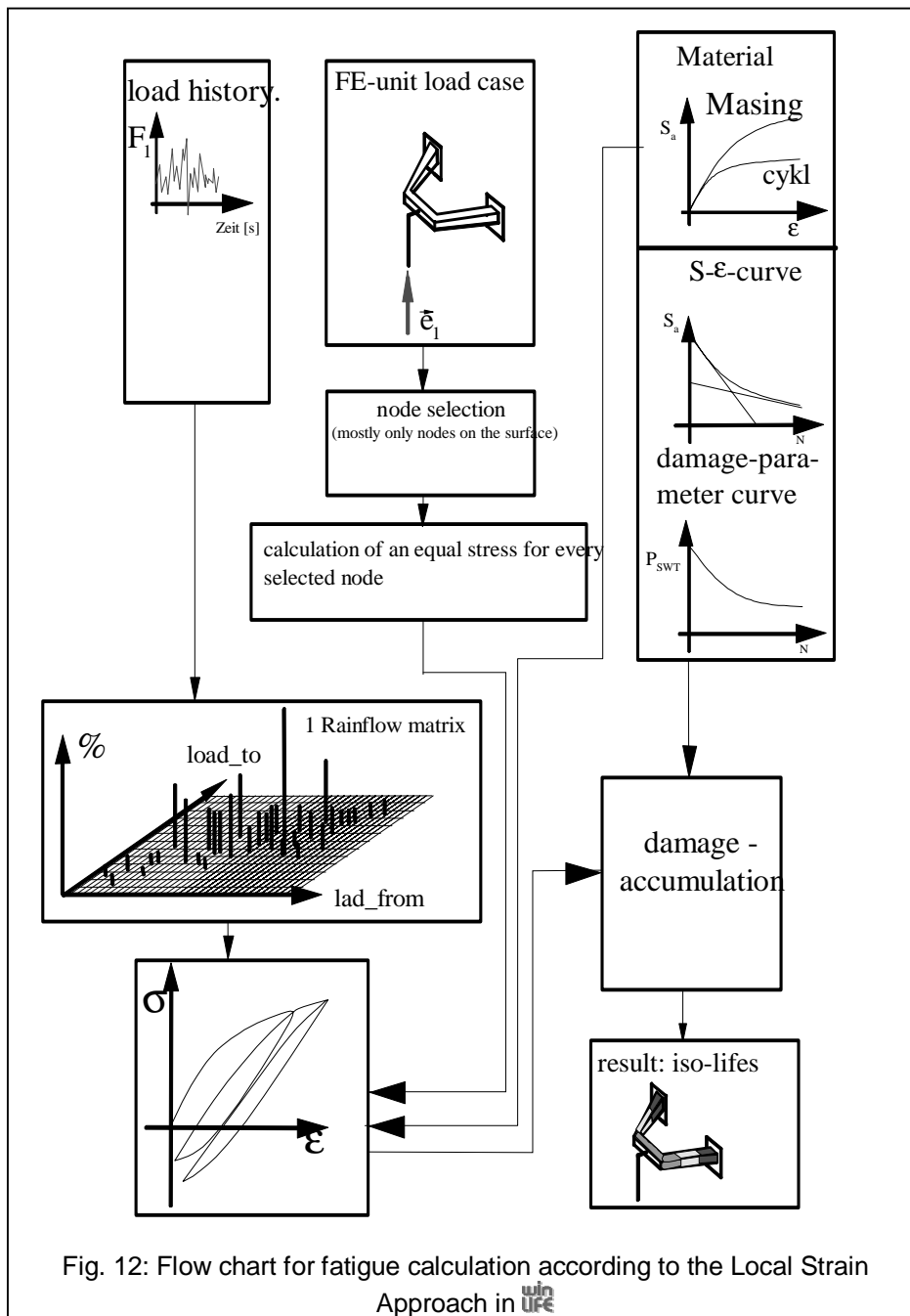


Fig. 11: Stress-strain path constructed from the rainflow-matrix and the cyclic properties of the material

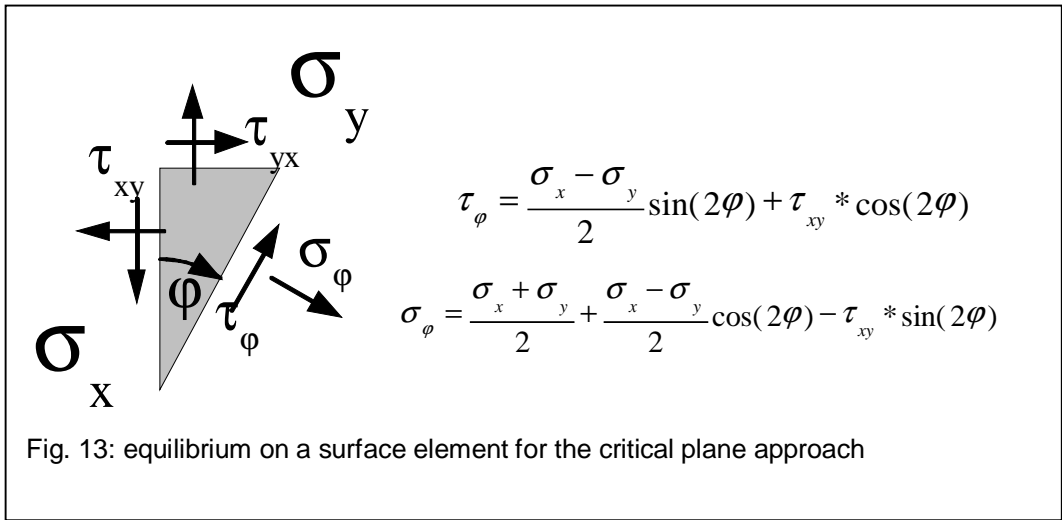


## 2 Changing directions of principal stresses (UFE MULTIAXIAL)

It is much more complex to calculate a fatigue analysis when the principal stress directions are changing than it is when they are constant. It is therefore important to establish first of all, whether the problem is really non proportional.

The table in fig 14 shows three cases and the parameters which help to identify whether a problem is non proportional or not. The angle  $\phi$  and the ratio  $\sigma_1/\sigma_2$  of the stresses are useful parameters which are calculated for all time steps. UFE uses these as shown in figures 15 and 16.

In some cases a problem of changing stress directions can be simplified by a proportional calculation. This results in a greatly beneficial reduction of calculation time. Two different cases in red and black colour are shown in the figures.



case	$\phi$	$\sigma_1$	$\sigma_2$	$\frac{\sigma_2}{\sigma_1}$	mohr`s circle	structure
<b>uniaxial</b> direction of principal stress and direction of loading are identical	=0	variable	=0	=0	<p>in every time step mohr`s circle touches zero point</p>	
<b>biaxial</b> proportional loading several loading are acting proportionally in different directions	const	variabel	variabel	const $-1 \leq \frac{\sigma_2}{\sigma_1} \leq +1$ and $>0$	<p>for every time step mohr`s circle is geometrical similar</p>	
<b>multiaxial</b> non-proportional loading several loading are acting independently in different directions	variable	variable	variable	variable	<p>geometry of mohr`s circle may change for every in any way</p>	

figure 14: classification of the possible cases

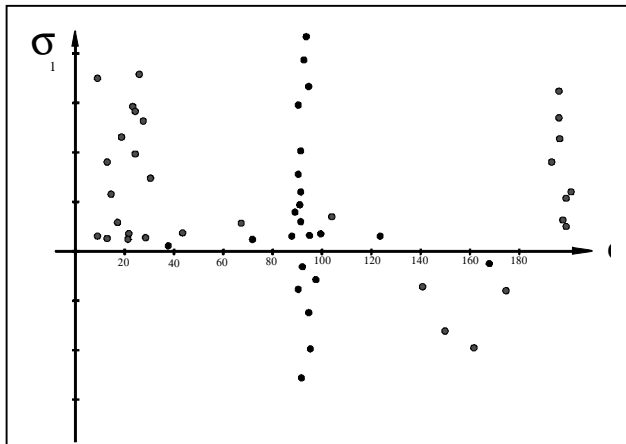


Fig. 15: largest principal stress over the direction angle (red dots=non proportional; black dots=proportional)

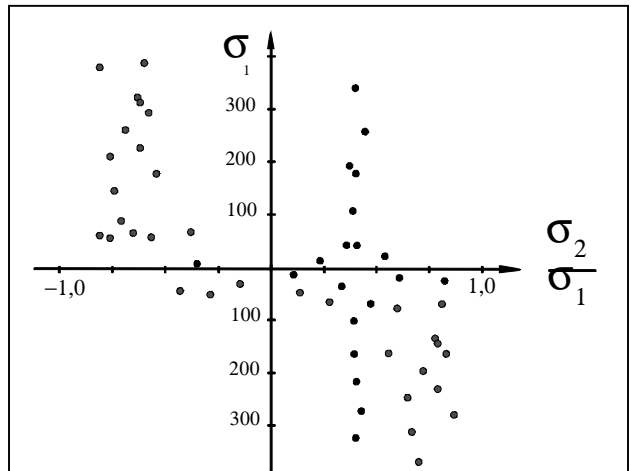


Fig. 16: largest principal stress over the stress ratio (red dots=non proportional; black dots=proportional)

## 2.1 Case 1: When the loadings are already available

If loadings are given, **win** **life** performs a fatigue calculation in combination with a finite element analysis if dealing with a non proportional case. This procedure is shown in the flow chart. There are usually a lot of non synchronous loadings acting on a structure.

Because in most cases damage starts from the surface, fatigue life calculation can be simplified by analysing only the surface. This means, that only plane stresses have to be considered. Figure 13 shows a triangle in the surface and the stresses in the x-,y and  $\phi$ -directions. Depending on the angle  $\phi$ , the stresses  $\tau$  and  $\sigma$  change.

The stresses in each plane are calculated for the total load history and an equivalent stress is also calculated for each plane based on the following formula:

$$\sigma_v = \text{MAX}(c * \text{sign}(\sigma_\phi), d * \text{sign}(\tau_\phi)) * \sqrt{a * \sigma_\phi^2 + b * \left(\frac{\sigma_w}{\tau_w}\right)^2 * \tau_\phi^2}$$

Depending on the material properties the factor a or b can be set to 0. A rainflow count of this time history in each plane is carried out and a damage calculation is done. A S-N-curve is used which has to be modified by local properties such as the related stress gradient and the surface property.

The flow chart of a non proportional fatigue calculation is shown in figure 19.

Calculation time can be a problem for long load time histories and in such cases the following two steps should be carried out when doing a fatigue calculation:

- a precheck estimate of all nodes on the surface to find the possible critical points,
- a final calculation just for the nodes to be considered which were derived from the precheck

During the precheck analysis a calculation is done:

- only for the common turning points of the load time histories (fig. 17 )
- using a hysteresis between 10 and 20% to reduce the number of turning points (fig. 18 ).

Both these simplifications of the precheck estimate lead to a remarkable reduction of calculation time. The nodes are sorted according to damage and the node number is written into a file. If the final calculation step is carried out for only a limited number of preselected nodes without these simplifications, the calculation times are largely acceptable.

The reduction in calculation time is proportional to the reduced number of nodes. More than 90% of the nodes are usually not of interest and are not calculated.

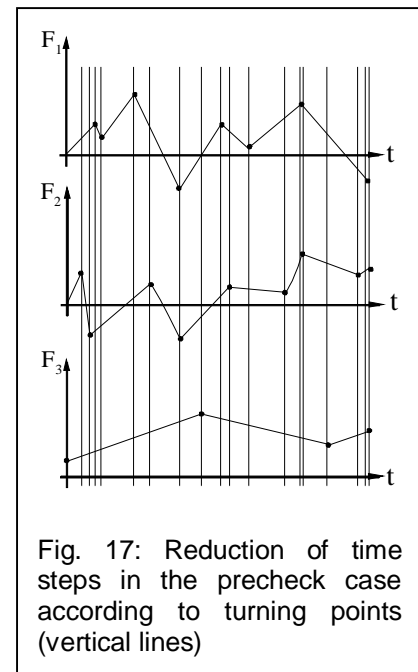


Fig. 17: Reduction of time steps in the precheck case according to turning points (vertical lines)

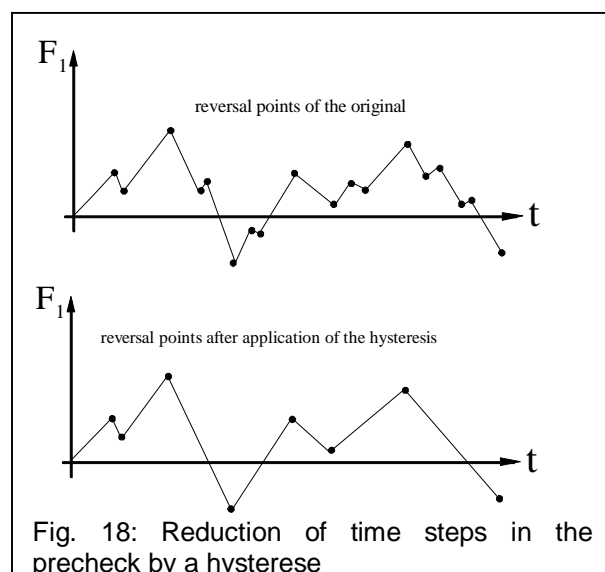
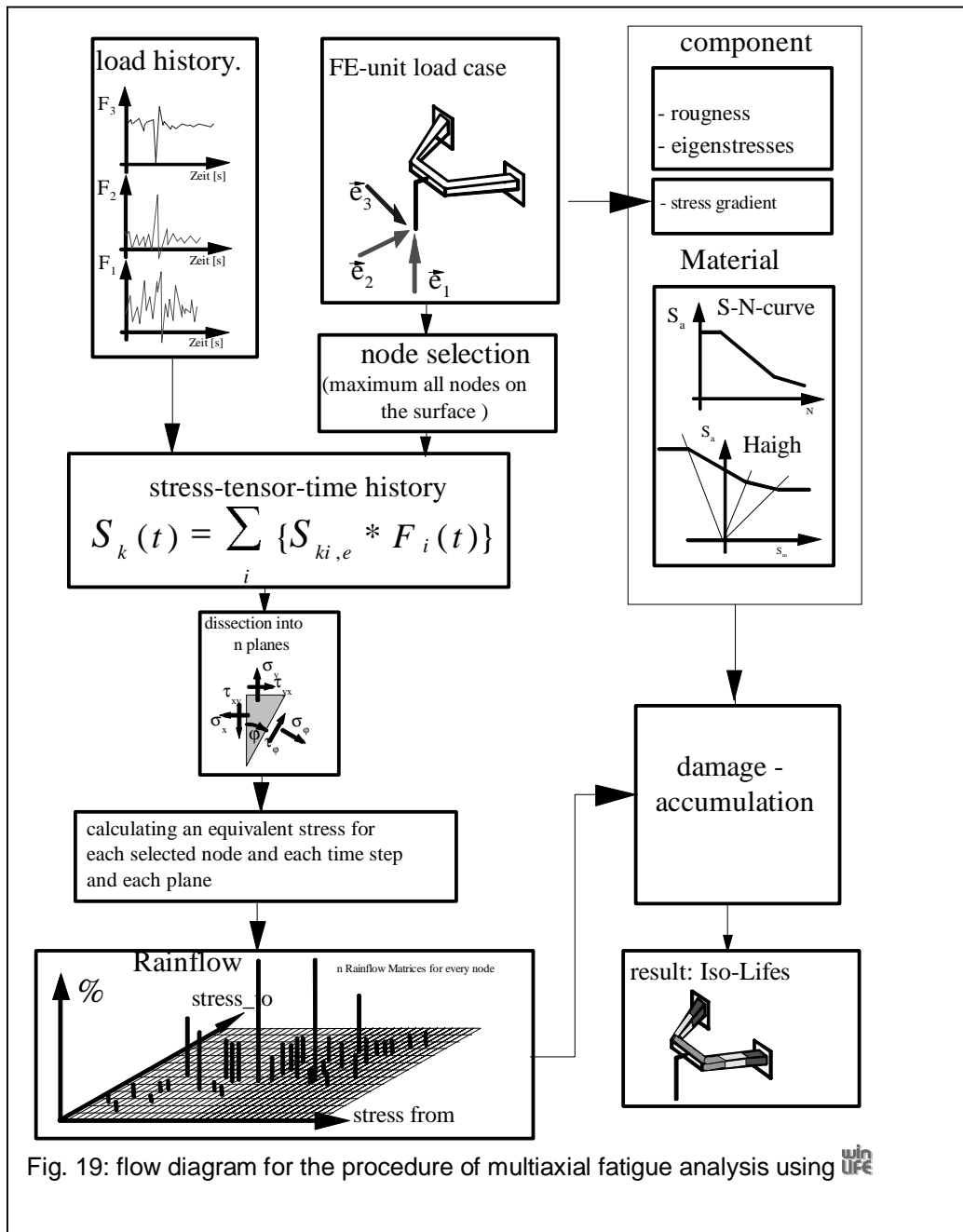


Fig. 18: Reduction of time steps in the precheck by a hysteresis





## 2.2 Case 2: When measured strains (gain rosette) are available

When measured strains are available, no finite element analysis is used and only the locus of measurement can be calculated. Mostly these data are got from a strain rosette. A model of Mros`z is used to make a prediction similar to the Local Strain Approach. This procedure will be available in the winLIFE version 2.1 and will released end of this year.

## 2.3 Data handling

winLIFE includes tools for graphically interactive data handling and data correction. Time histories can be corrected simply. Offsets can be changed, spikes removed, the drift corrected. It is possible to generate all types of spectra. The rainflow matrix itself can be changed interactively. Data from other programs such as measurement systems or Matlab/Simulink can easily be imported.

### 3 Gearwheel and bearing

Fatigue calculation of gearwheels and bearings is similar to that of the Nominal Stress Method. A user who is familiar with the basic module will soon be able to work with it. **win LIFE** supports common calculation methods based on DIN or FVA standards. These standards deal with life curves for different material

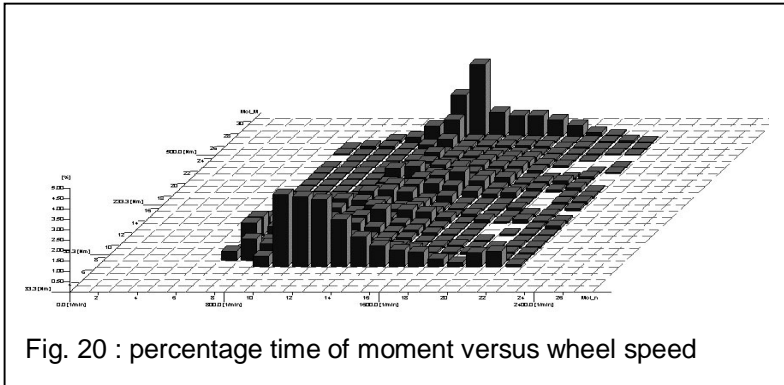


Fig. 20 : percentage time of moment versus wheel speed

and design parameters of wheels. The modifications of the life curves used in the basic module (fig. 2) are also used for gear wheels.

The loading is described in a different way: typically the torque time percentage (fig. 20) is used and is converted into a spectrum of torque over total number of revolutions.

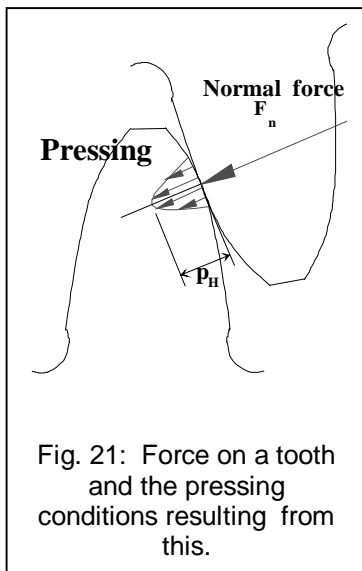


Fig. 21: Force on a tooth and the pressing conditions resulting from this.

#### 3.1 Gear tooth base fatigue

Gear tooth base fatigue occurs due to dynamic bending of the gear tooth base, which can result in a primary crack and finally to a tear in the tooth, depending on the roughness of the surface, the stress and the notch factor (figure 22).

#### 3.2 Tooth flank fatigue (pittings)

When the force of the tooth shifts to the tooth flank, it causes Hertz' Pressing which can lead to material fatigue in the form of pittings (Fig. 21). Fatigue life can also be described with S-N life curves according to FVA .

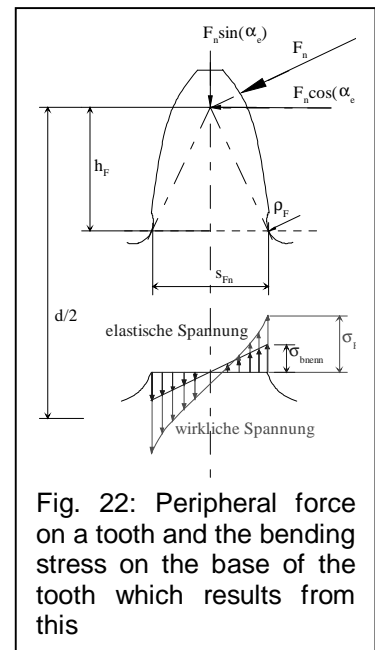


Fig. 22: Peripheral force on a tooth and the bending stress on the base of the tooth which results from this

#### 3.3 Bearings

The fatigue life calculation of bearings is also included. This is carried out based on information from the manufacturer and is available in catalogues.

### 4 Examples

#### 4.1 Retarder wheel for a hydrodynamic retarder brake

A Voith retarder shaft with a gearwheel which is used in heavy trucks is calculated. The torque was measured under different conditions for nearly 30 hours.

The shaft is pre-stressed by a pipe, and there is a helical gear on the right of the picture (fig. 23). To calculate the stresses caused by the rotation of the shaft, 4 load cases with a rotational angle of 0, 90, 180 and 270 degrees were created (fig. 24). The load-cases are worked through in this order and they are transformed by the measured torques to actual stresses. The number of cycles results from the shaft speed. The calculation was done with **win LIFE** MULTIAXIAL.

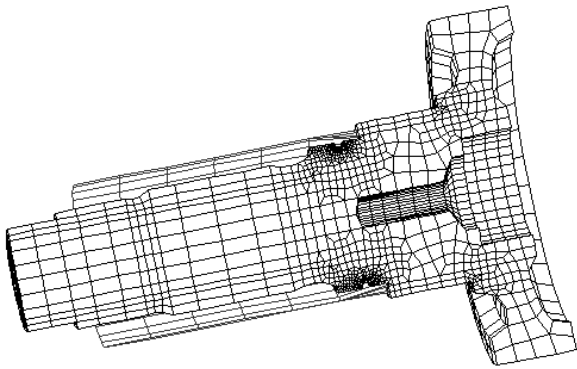


Fig. 23: Cross section of the calculated retarder shaft

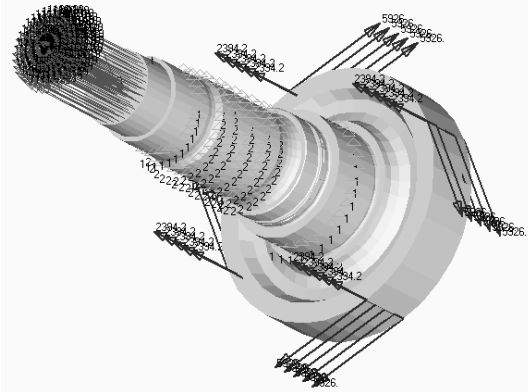
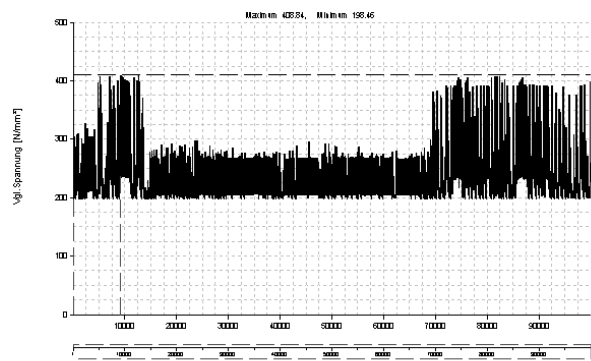
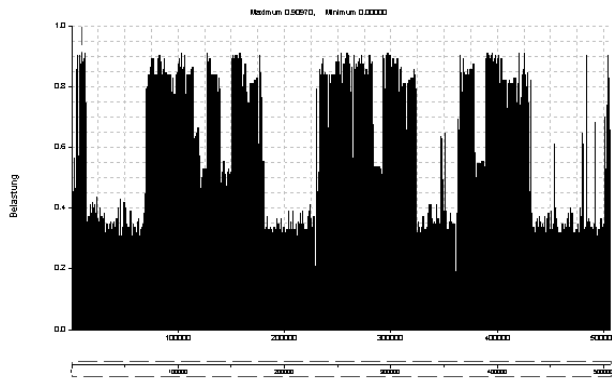


Fig. 24: Loads and constraints of the retarder shaft



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Fig. 25 : Measured Torque over time in a heavy vehicle (left), resulting stresses in the shaft notch (right)

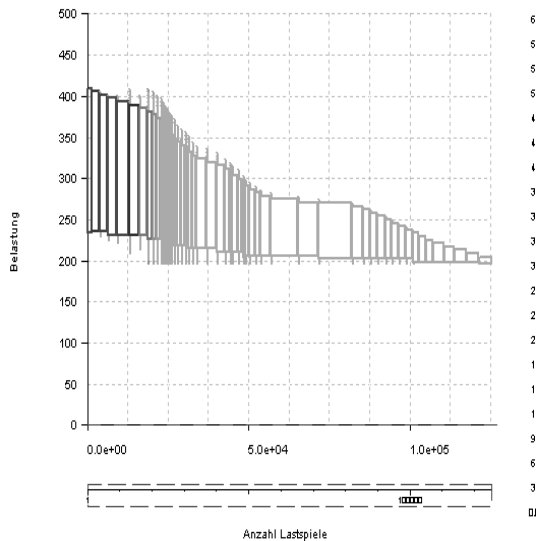


Fig. 26: range mean pair count of the stresses

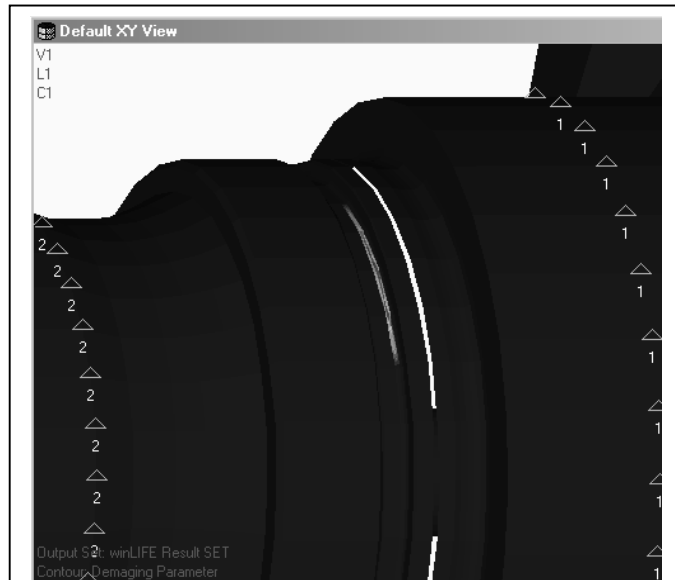
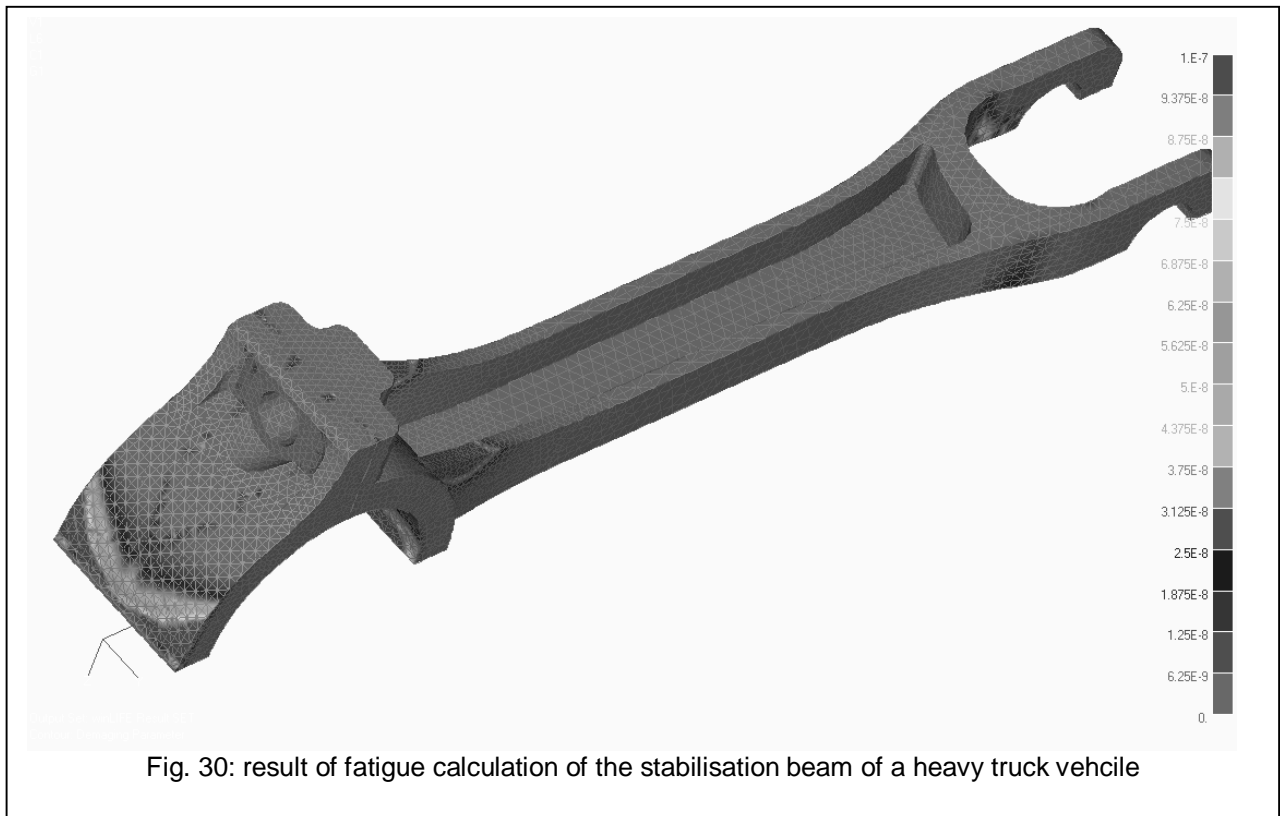
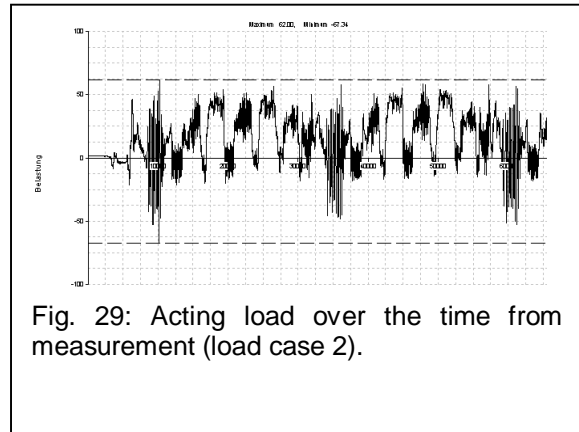
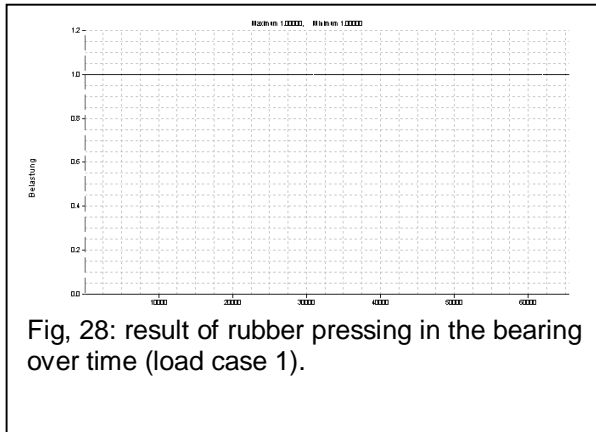


Fig. 27: result of winLIFE fatigue calculation: damage to the component

## 4.2 Stabilisation beam for heavy trucks

A stabilisation beam is used in a heavy truck vehicle suspension system. It is loaded lengthways by measured forces (fig. 29). Additionally a constant pre-stress is caused by an indented pressed rubber element into the bearing on the left of the picture (fig. 29). The rubber element was substituted by boundary conditions and resulting forces which act on the beam element bearing (fig. 28). Fig. 29 shows half of the FE-model. Because of the pre-stress, the fatigue calculation was carried out with **winLIFE** MULTIAXIAL.



## 5 Future outlook

**win**  
**LIFE** has been in use for more than 10 years (Version LIFE 1.0 dated 1986) for wide spread applications and has more than 60 customers. To start with, **win** was primarily a stand alone product without finite element analysis and was only used for proportional loading.

Since the cooperation with MSC.Software Partner Solutions (formerly CAE Partner) started in 1995 and since the integration with MSC.Nastran for Windows was achieved, many customers use **win** to solve complex projects such as shown in these examples. In the future **win** will be connected to a multi body analysis system which also allows for FE analysis and the range of use will increase even more.

The integration of fatigue calculation in the development process is beneficial for reducing the time of the development phase because different components can be compared reliably.

Despite all our enthusiasm, we have to keep in mind that a reliable quantitative fatigue life prediction is not possible by calculation alone and that parts critical to safety must always be tested additionally.

This means that the real benefit of fatigue life calculation will be achieved when it is performed over a long period of time and if the results are partially compared with test results. By doing this the user will be able to calculate a more reliable fatigue life prediction.

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