Fatigue Life calculation using winLIFE

1) Introduction

Light weight construction is becoming more and more important and the construction is often limited by fatigue life. winLIFE provides the well known and proved methods such as the Nominal Stress Method, Elastic Stress Method and Local Strain Approach in a user friendly interface to save the user having to carry out complex mathematical operations. In some industries technical standards for fatigue life design exist (wind-turbines (GL), ship-construction (GL), and civil engineering (FKM)) and the user has to follow these rules to get a certification. These standards represent the experience of decades and it is recommended to follow these rules. Because of the complexity a software-assistance is desired which winLIFE provides.

The application of Finite Element Analysis is commonly used and in many cases indisputable. As a result winLIFE is designed to be connected to finite element and multi body programs running under Windows operating system. To avoid any interface problems, the data transfer is done by data-import and data-export files, which are described in detail. Interfaces for FEMAP and other FEA products are shipped with winLIFE.

winLIFE 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. In this paper at first a short overview is given.

2) Overview winLIFE

winLIFE deals with the following capabilities and captures a wide range of fatigue life calculation possibilities:

2.1 Endurance Limit Certification (winLIFE FKM QUICKCHECK)

A first analysis step shall give information about the grade of utilization of the endurance stress. For this approach you only need the maximum load and its characteristic (alternating, pulsating, constant) for each load case. In a worst case scenario the maximum stress range is investigated and compared to the endurance limit. If the grade of utilisation is very much lower than 100% it may be possible to avoid further investigations.

2.2 Calculation Methods for proportional cases (winLIFE BASIC):

If there is no change in the direction of principal stresses (proportional case) the analysis can be performed with very high calculation speed. The following methods are available and in the proportional case only winLIFE BASIC is needed:

Nominal stress method (HCF=high cycle fatigue and VHCF=very high cycle fatigue)

Elastic stress method (HCF, VHCF). Local Strain Approach (LCF=Low cycle fatigue)

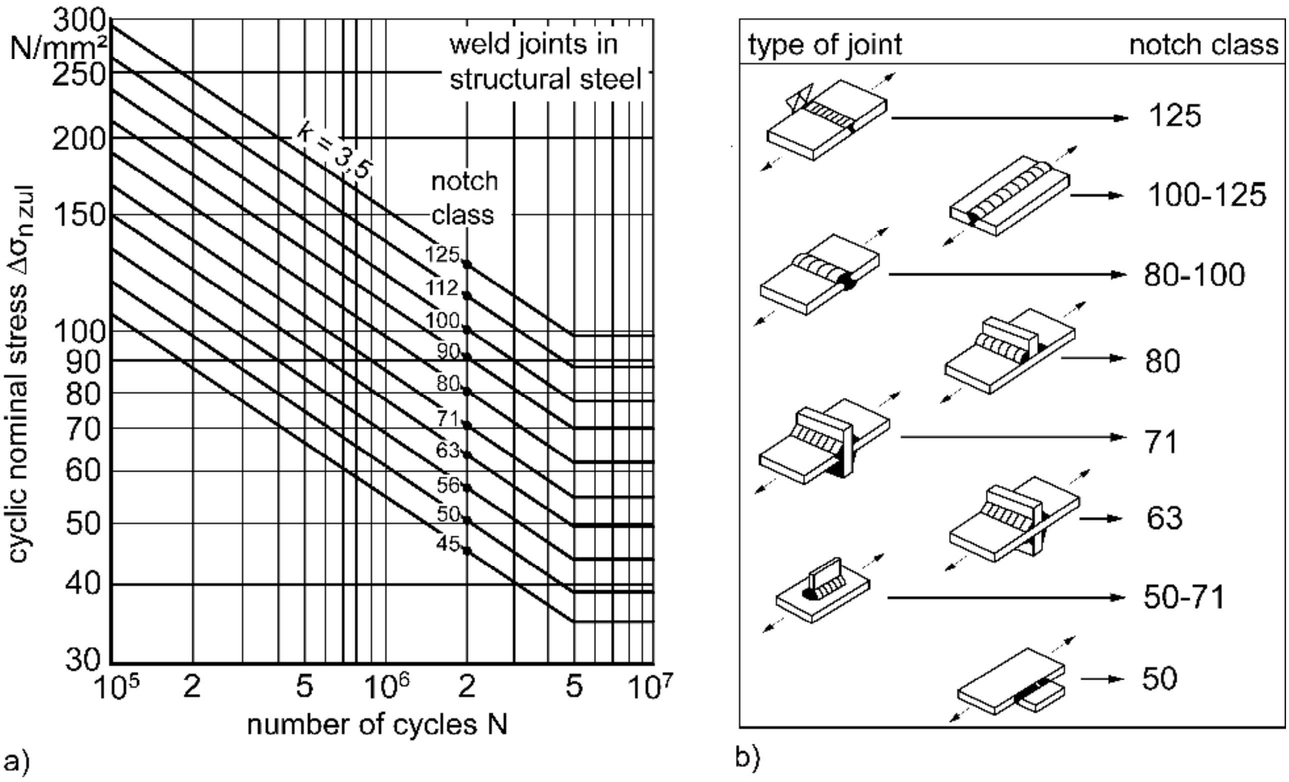
2.3 Calculation Methods for multiaxial cases (Critical Plane Approach) (winLIFE MULTIAXIAL)

In complex structures such as automotive bodies or gearbox housings there are often a lot of non proportional loadings acting which lead to a multiaxial problem. For such problems with up to 200 loadings winLIFE MULTIAXIAL has been designed. The critical plane approach is used which leads to time consuming calculations. For each (surface) node of interest in (typically 10…20) planes a fatigue life calculation has to be done. In each plane (of the surface) the normal and shear stresses are calculated and a stress time history is created. For this stress time history a fatigue life calculation is done and a damage D in each plane is ascertained. The plane with the maximum damage is the relevant plane.

2.4 Special Modules

The following special modules are available:

- **Seam weldings** (Nominal stress, structural stresses, Rx-concept) and **Spot weldings** included in winLIFE Multiaxial
- **Gearwheels and Bearings** (winLIFE GEARWHEEL AND BEARING)

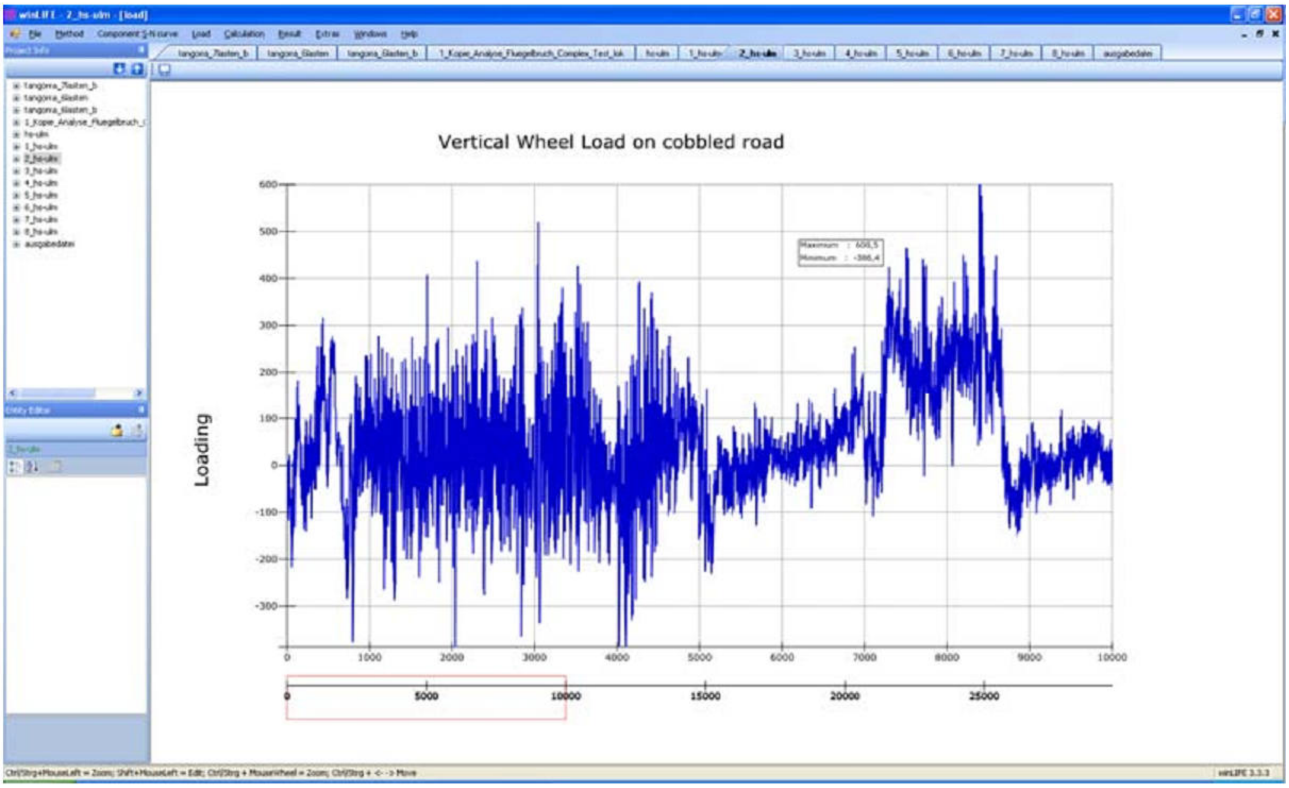


Standard S-N curves for weld joints in structural steel; permitted cyclic nominal stress $\Delta\sigma_{n\,zul}$ (failure probability P = 2,3 %) (a) for various notch classes (b); according to IIW-draft recommendation (simplified view)

2.5 Getting Loadings and load spectra

winLIFE can use up to 200 synchronously acting loadings without – disregarding the disk space – any limit in length. Powerful tools to correct or modify these data (remove spikes, drift) are available. In many cases the characteristic shape of the load spectra is known and instead of measured loadings a load spectrum is used.

winLIFE deals furthermore with a spectrum generator which can create common load spectra. A sinus-function generator is available too and helps to create typical rig-test-signals.



2.6 Creating of S-N / e-N curves according to standards

In many cases the life curves have to be created by material and component properties. The following procedures and standards are implemented in winLIFE. This enables the user in many industries to do his calculations according the established standards he has to follow.

Table 1: Life data creation by existing standards used in winLIFE

Objective	To be used with Method	According to Guideline	Materials and Alloys	Description
Creation of S-N component Life curves	Nominal Stress Elastic stress (not welded and welded)	FKM [2]	Steel, Aluminium, casted steel and Aluminium	Depending on Material, Component- and production properties a S-N curve is created
Creation of S-N component Life curves	Nominal Stress Elastic stress (only not welded)	Hück, Trainer,Schütz [3]	Steel, casted steel	Depending on Material-, Component- and production properties a S-N curve is created
Creation of strain life curves	Local strain approach (only not welded)	Uniform material law according to [5]	Steel, aluminium, titan	Established Method to create e-N curves based on static material data
Creation of S-N component Life curves	Nominal stress Structural stress (welded)	GL [4] wind turbines	For certification of wind turbines	Established standards to create S-N curves for weldings in Wind turbines
Creation of S-N component Life curves	Nominal stress Structural stress (welded)	GL Ship design	For certification of ships	Established standards to create S-N curves for weldings in ships

2.7 Material databases which are included in the software

Many material data have been investigated and can be found in the internet. But to give the winLIFE user a fast access to a wide range of life data, databases for a lot of materials are included. Each concept - stress life and strain life – is supported.

Table 2: Life data creation by existing standards used in winLIFE

Data type	Source	Number of data	Availability
Material stress life data	FKM guideline [2]	2000	Shipped on winLIFE
Material strain life data	Literature and winLIFE customers [5]	1400	Shipped on winLIFE
Component database	User-Data of competent life data are stored	10 example data	Shipped with example data. It grows depending on user demands

To establish a component life curve the life data coming from a specimen (strain life data, stress life data) must be combined with the properties of the component (surface treatment, roughness, Eigen stresses, size, related stress gradient). winLIFE assists the user with material databases (strain and stress life) for specimen and the rules to take the component properties into account. The result is a component life curve which is stored in the winLIFE user-database (see figure 2).

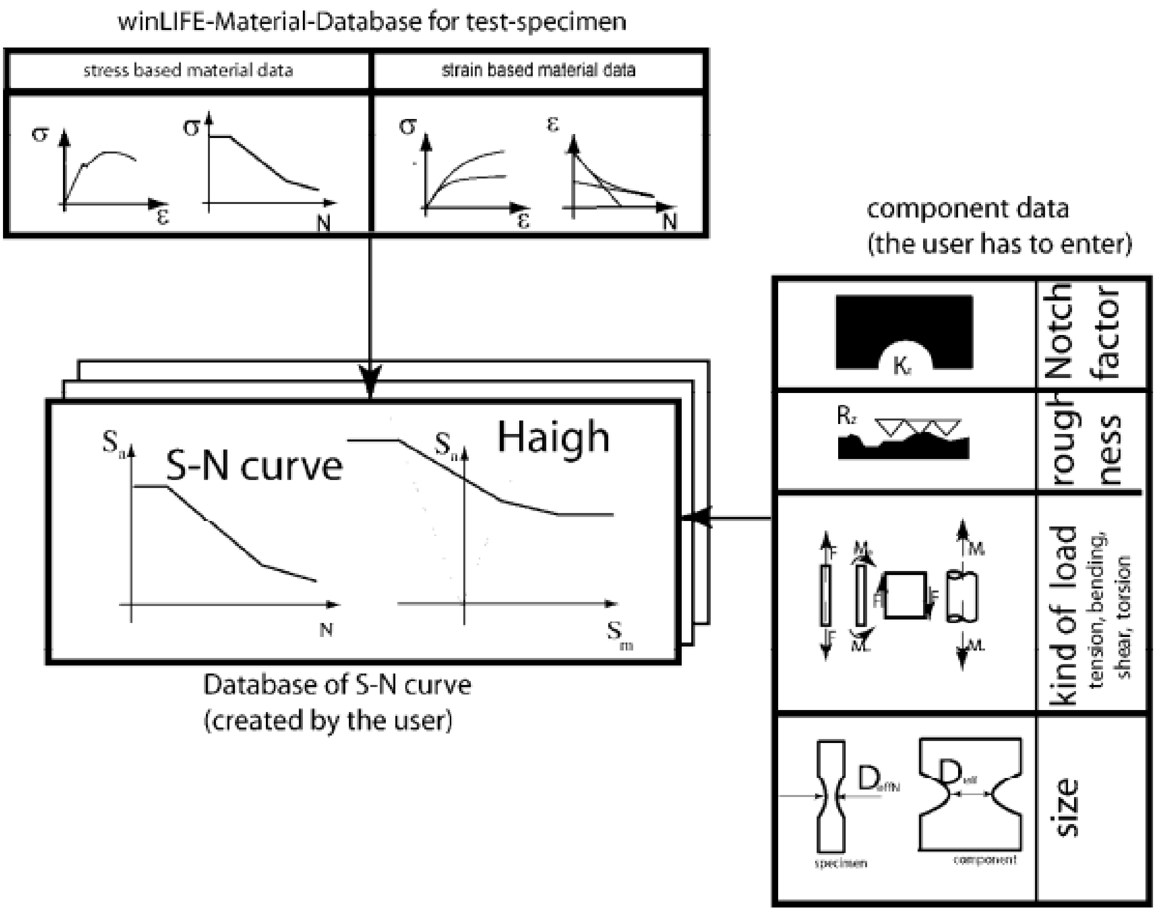


Figure 2: Interaction between material databases (strain , stress) and user component database

The stress life depends considerably on the related stress gradient, which is changing in a component especially in notches. winLIFE can automatically calculate the related stress gradient for all nodes and can change the S-N curves locally according to it.

2.8 Statistical Analysis

Based on some statistic parameters – scatter ratio - the user can transform a fatigue life curve to another failure probability he needs.

2.9 Investigating the Importance of loads

winLIFE is used to solve very complex problems with often dozens of loading histories. Beside of fatigue life estimation there is often the intention to simplify the problem for rig testing. For this it is helpful to know which loading is important for fatigue and which not. winLIFE automatically creates a Load Importance Analysis (LIA). This is easily done in the following way. In a first step a fatigue calculation for each single loading is done, the other loadings are set to zero. In the next step only one loading is set to zero while the rest of the loadings act unchanged. The damage results of these calculations help to find out the most damage relevant loadings.

2.10. Life prediction based on short-time measurements

A lot of different load scenarios in the wind energy industry - which are got from measurements typically for only 10 minutes - are used to superimpose and extrapolate for life prediction of 20 years. A problem results from the transition residuum which depends on the order in which the loading is acting. For example: load scenario A can interact in different ways with load scenario B. The figure shows that different combinations of A and B lead to different load histories, which will be found in the residuum. Because of these effects it is important to consider the residuum in a proper way. winLIFE deals with different procedures to take the residuum into account to get a proper solution.

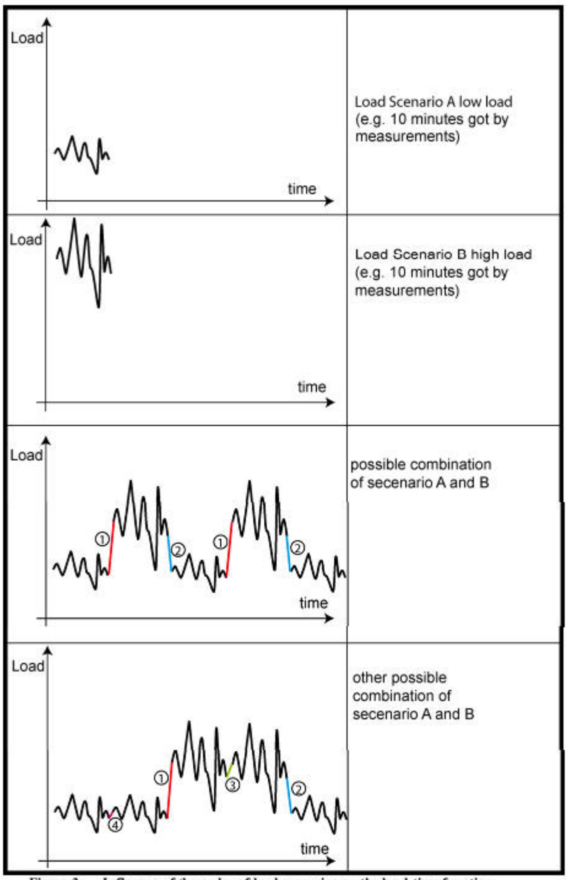


Figure 3: Influence of the order of load scenarios on the load-time function

2.11 Analysis of results

To understand the fatigue results graphics and reports are created.

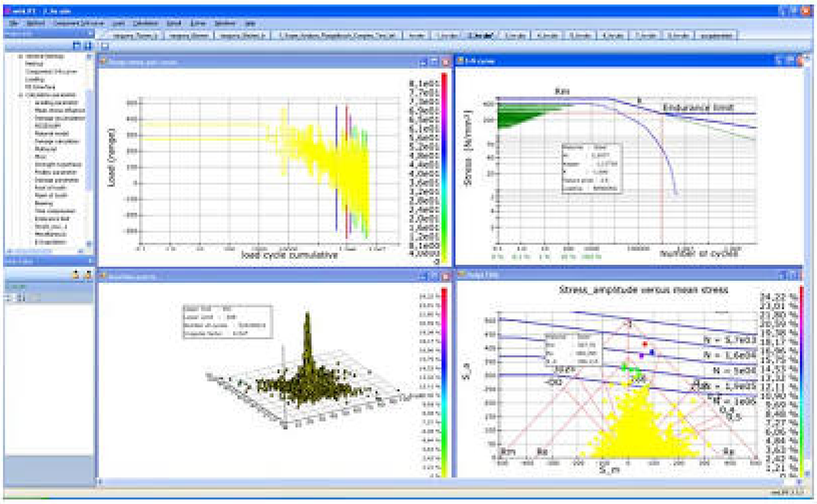


Figure 4: Result analysis range mean pair (above, left), S-N together with stress magnitude (above, right), Haigh-diagram including load (below, right), rain flow matrix (below, left)

2.12 Data Transfer between MBS/FEA and winLIFE

winLIFE is used as a post processor and picks up the results of FEA/MBS calculations. The results of the FEA/MBS-calculation are written into a file which winLIFE then has to access. The results of the fatigue life calculation are then transferred to the pre-processor and shown there as ISO-lines. The following figure shows the procedure.

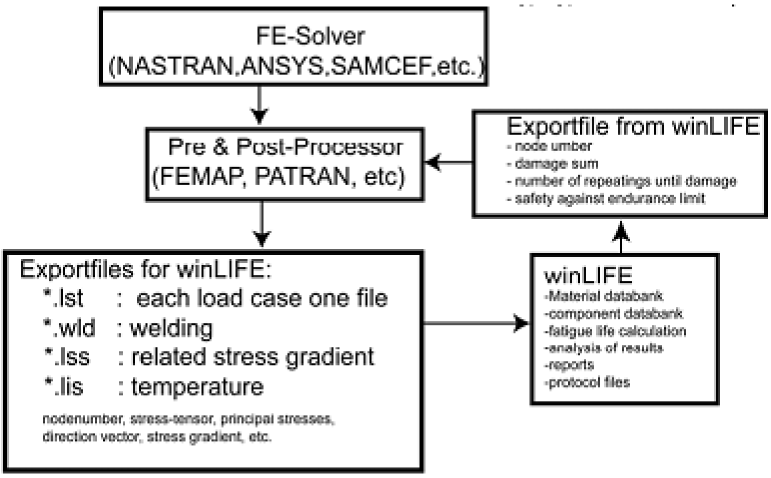


Figure 5: Data communication between FEA / MBS

3) Using Finite Element and Multi Body Systems for fatigue life estimation

3.1 Superimposing and scaling static unit load cases from FEA A very important procedure is to calculate the stress history of a structure by superimposing and scaling results from static unit load cases and (measured) load histories. This procedure is limited to only small deformations. The advantage is the high calculation time. The following picture shows the principal way:

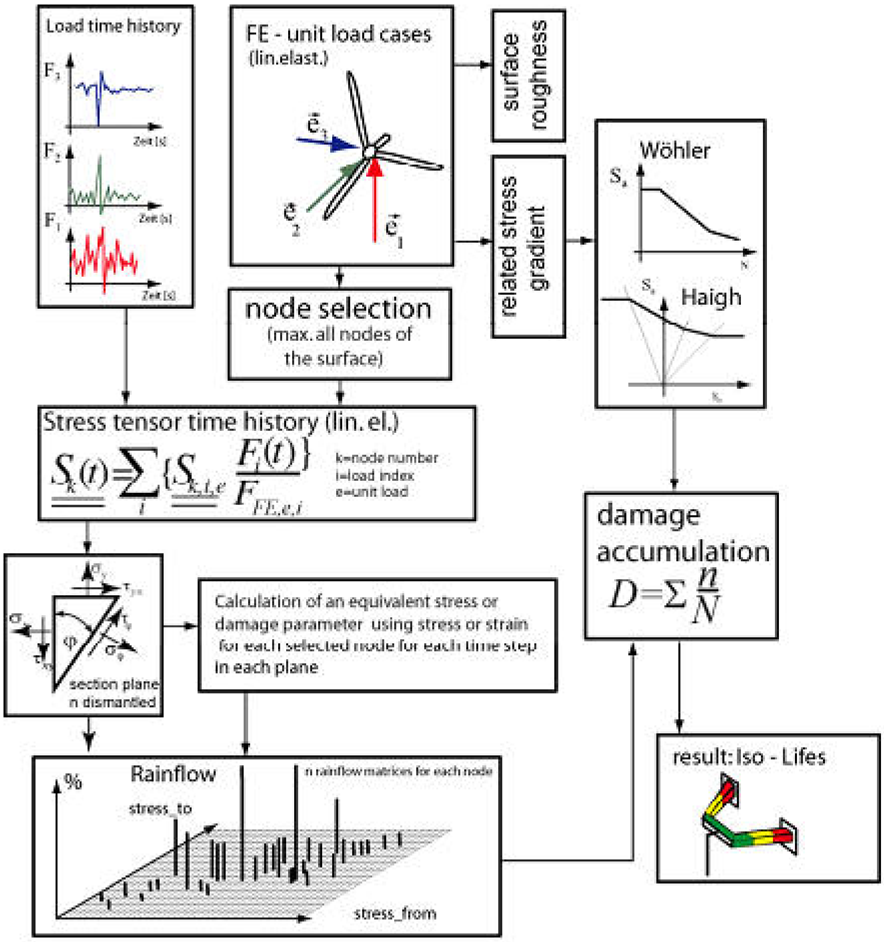


Figure 6: Procedure of fatigue life calculation based on static superimposing and scaling of static unit load cases

Note that there are used elastic stresses. In the case of Elastic Stress Method to get realistic results these have to be transformed by modifying the S-N curve by the related stress gradient. If the Local Strain Approach is used a stress transformation is done by Neuber´s rule.

Another problem is that in the case of contact or rotating parts, the unit load case and the corresponding loads must be divided into more than one to take the contact or rotating into account. winLIFE deals with powerful tools to transform problems with contact, nonlinearities or rotating parts into equivalent linear systems. This is done by separating the system in different part-systems and corresponding loadings. A detailed description of how to do this is described for wind turbines in [7]

4) Using MBS/FEA for fatigue life analysis

In the case of large deformations, nonlinear effects, dynamic forces static superimposing comes to a limit and it is more suitable to use a multi-body analysis in combination with FEA. In the MBS-model the total dynamic and nonlinear behaviour is solved. Compared to the static superimposing of unit load cases, there is no need to define separated unit load cases and split the load to take contact, rotation or nonlinear effects into account. But this method is much more time consuming. The procedure is shown in the following figure.

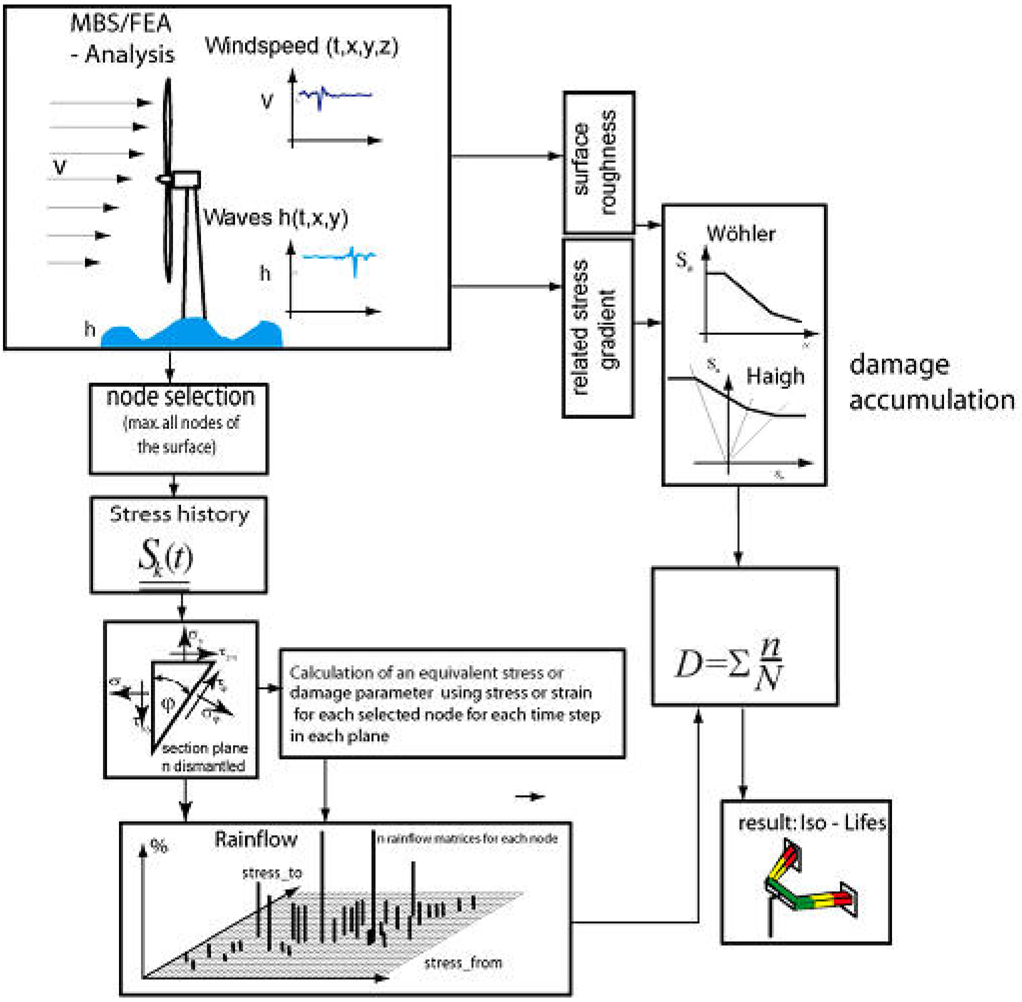


Figure 7: MBS/FEA in combination with fatigue life analysis

7) References

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[7] Weber, E.; Häckh, J.: Willmerding, G.: Fatigue Life calculation using winLIFE. NAFEMS conference Wiesbaden, 2010.

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