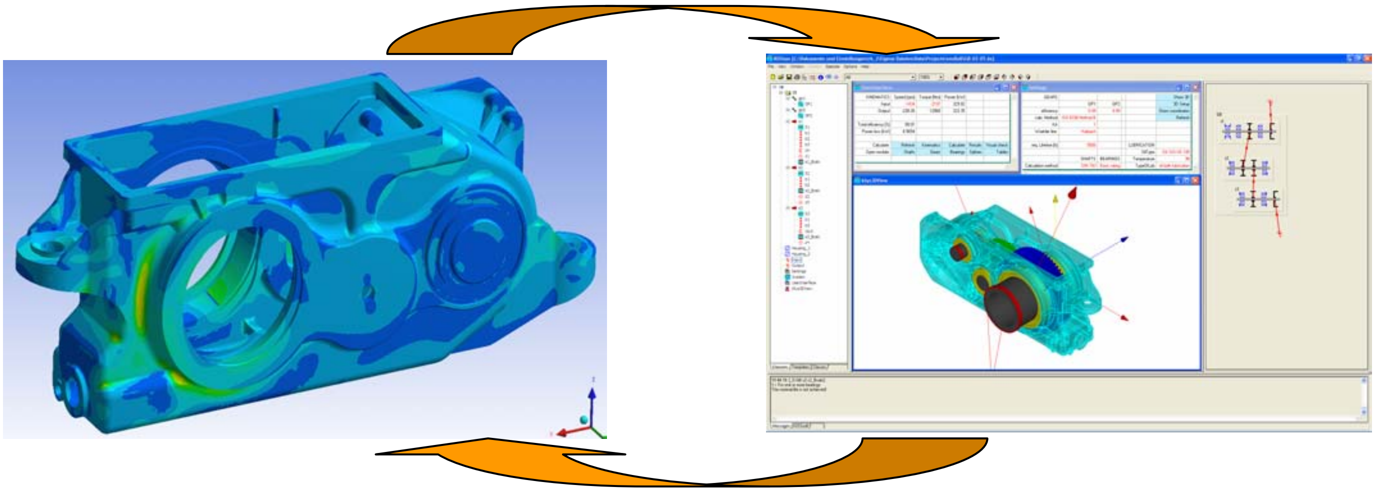
KISSsoft AG - ☏ +41 55 254 20 50
Uetzikon 4 - 🖷 +41 55 254 20 51
8634 Hombrechtikon - info@KISSsoft.AG
Switzerland - www.KISSsoft.AG

KISSsoft
Calculation programs for machine design

Combining KISSsoft&KISSsys with FEM analysis



In most cases, a combination of FEM calculation and standardised calculations leads to the most accurate results in the design process. Both methods have their unique strength and disadvantages; combining the two in a clever way is the most effective approach. While KISSsys and KISSsoft may be used to quickly and reliably generate load data to be exported to the FEM calculation, the resulting deformations as calculated may be used as an input into e.g. the bearing, shaft and load sharing calculation in KISSsoft. Furthermore, stress levels calculated in an FEM analysis may be transformed into a corresponding lifetime or safety factor using KISSsoft rating software.
Using the transmission error calculation in KISSsoft to find the variation of the bearing forces, the FEM analysis may be used to find the frequency response and sound pressure levels generated.
Natural frequencies of a housing calculated using FEM may be compared with e.g. meshing frequencies of the whole gearbox as calculated in KISSsys. In the same way, bearing fault frequencies may be compared with the natural frequencies found from the FEM analysis.

The below report is based on a joint project with VonRoll Casting for the development of a gearbox and its housing. We thank VonRoll Casting for allowing us to publish some results of our joint project. Visit www.vonroll-casting.ch to learn more about VonRoll Casting.

Customer	Supplier	Project	Document
	KISSsoft AG Uetzikon 4 8634 Hombrechtikon Switzerland www.KISSsoft.ch	Title: No.: Date: Manager: @:	Version: 0 Autor: Date: Approved: Date:

1. Document information

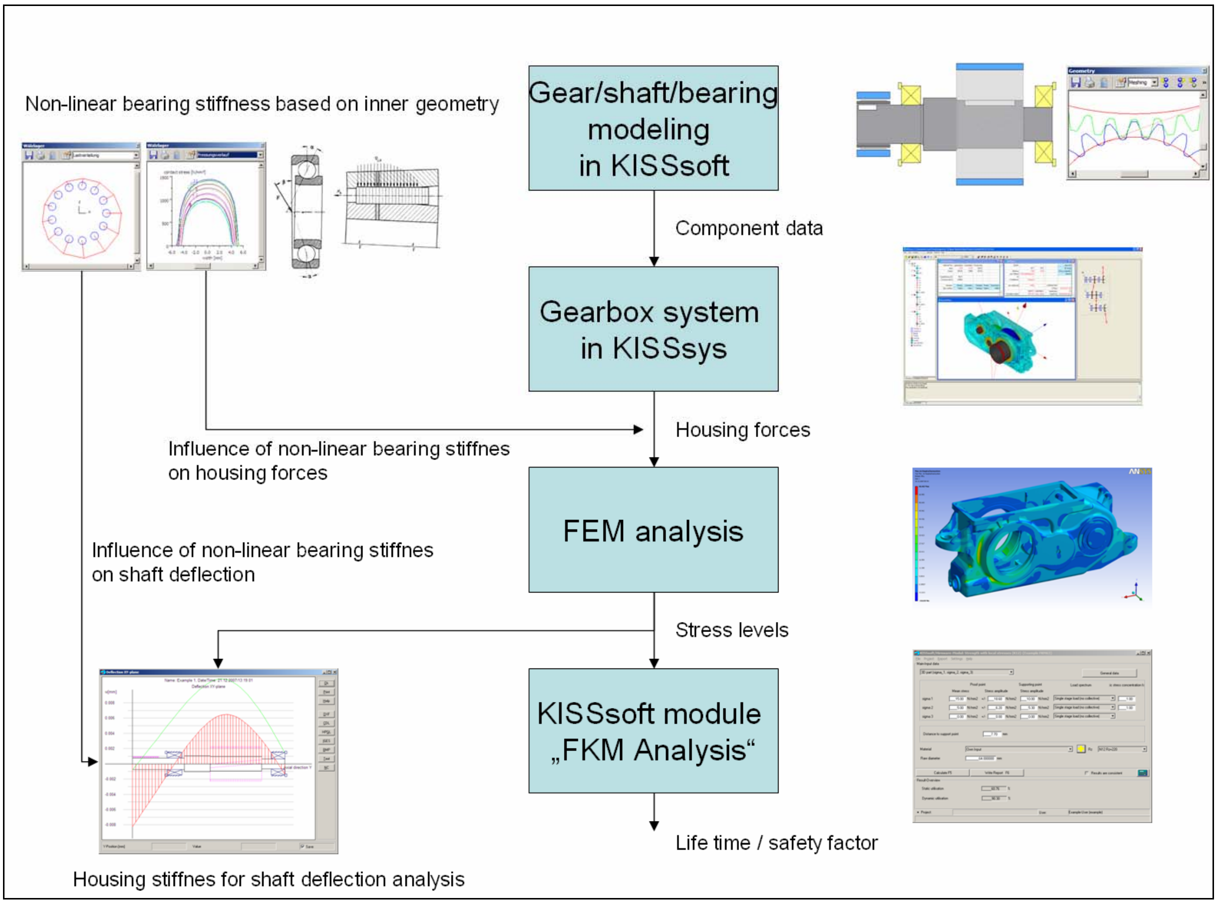
1.1. Table of content

1.2. Document change record

Document version	Dated	Who	Comments
0	28.1.2008	HD	Original document

2. Procedure

It is noteworthy that FEM analysis and the calculations in KISSsoft/KISSsys can interact at different levels of the analysis. Standardised calculations as implemented in KISSsoft are very fast to use and generate input in the form of housing forces for the FEM analysis at no additional modelling effort (see section 3). The housing deformation in return does influence the boundary condition formulation in the KISSsoft shaft analysis, influencing e.g. the gear corrections proposed there (see section 4).
Furthermore, parameterised KISSsys models allow for the immediate calculation of exciting frequencies, which may be compared to the natural frequencies obtained from the FEM model (see section 5). Finally, for a given stress distribution calculated in the FEM analysis, KISSsoft can be used to convert stress levels in to a part lifetime or strength (see section 6).
The methodology described below is independent of the FEM software used.



3. Housing forces

Using an in-built function in KISSsys, all housing forces may be exported for a given load case into a text document or Excel file (see Figure 3-2). The housing forces may also be calculated for a single shaft or a system of concentric shafts using KISSsoft shaft calculation. The housing forces thus documented may then be added in the FEM calculation as shown below (see Figure 3-3).

Housing forces are calculated based on meshing forces and element masses. Bearing stiffness (non-linear, including clearance) are considered for statically over-determined systems, bearing pre-tension is considered too. Both the absolute values as well as the direction of the force acting are given as output in tabular form.

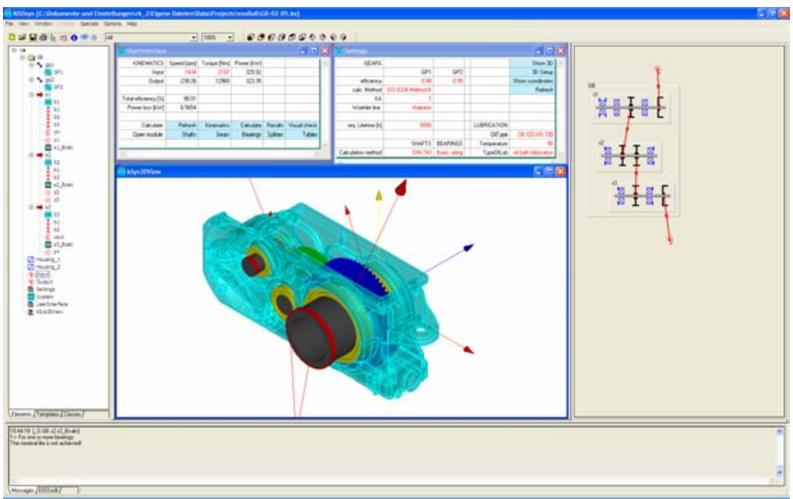


Figure 3-1 KISSsys model of transmission including housing data, display of housing forces

Forces acting from the bearings on the casing						
Bearing Name	Global x-coord.	Global y-coord.	Global z-coord.	Force Fx [N]	Force Fy [N]	Force Fz [N]
_O.GB.s1.b1	-551.93	-2	-20	0	7020.05	0
_O.GB.s1.b2	-551.93	-28	-20	-8693.41	0	14514.6
_O.GB.s1.b3	-551.93	-130	-20	2727.25	0	12839.75
_O.GB.s2.b1	-299.63	-15	-57	-7459.41	62.53	-38607.64
_O.GB.s2.b2	-299.63	-223	-57	3465.16	0	-48492.31
_O.GB.s3.b1	0	-21.5	0	-7896.99	7468.26	17902.49
_O.GB.s3.b2	0	-231.58	0	17698.78	-14410.56	41516.62
Sum of all reactions, Fxtot, Fytot, Fztot				-158.62	140.28	-326.49

Figure 3-2 Housing forces exported from KISSsys into text or Excel file

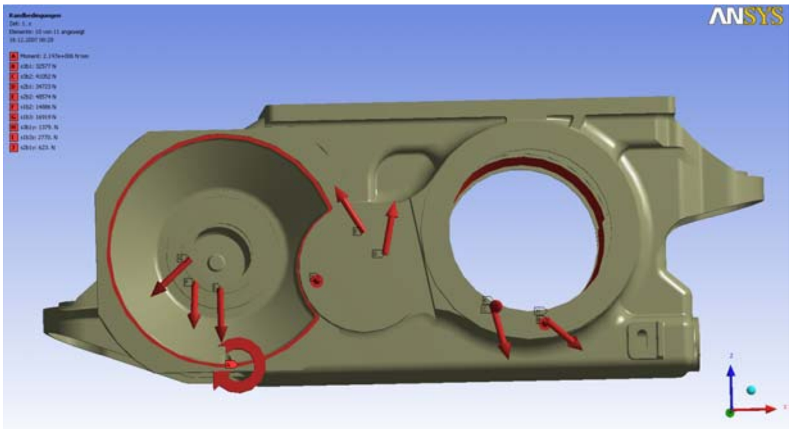


Figure 3-3 Application of forces and moments on geometry model in pre-processor

4. Bearing support stiffness

Import of bearing support stiffness (expressed through housing deformation compared to force applied) (see Figure 4-2) from FEM model (see Figure 4-1) into KISSsoft bearing/shaft calculation helps to improve the shaft deflection calculation as it is superimposed to the bearing stiffness calculation. The improved accuracy is relevant for the calculation of crowing/modifications to be applied in the gearing to improve the load sharing. Furthermore, any misalignment of the bearing supports calculated as bearing hole displacements may be directly added in the shaft calculation.

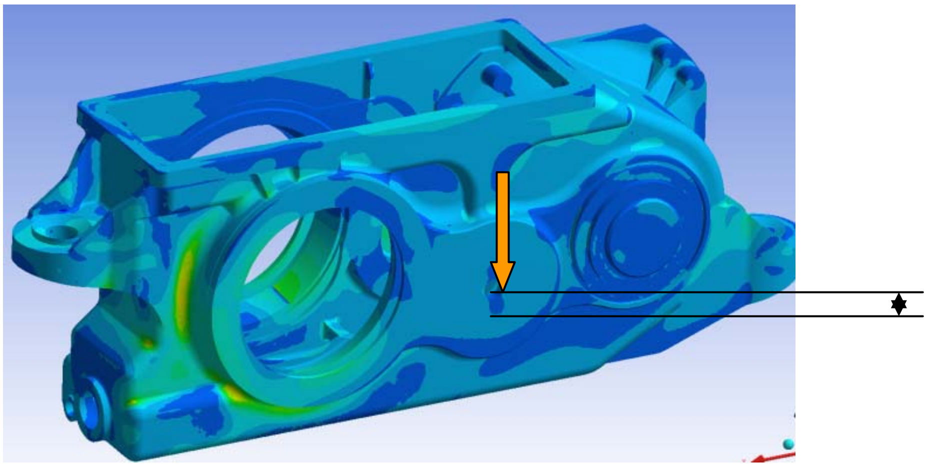


Figure 4-1 Results of FEM analysis, housing deformation is also calculated. Calculate housing stiffness from load applied and displacement calculated.

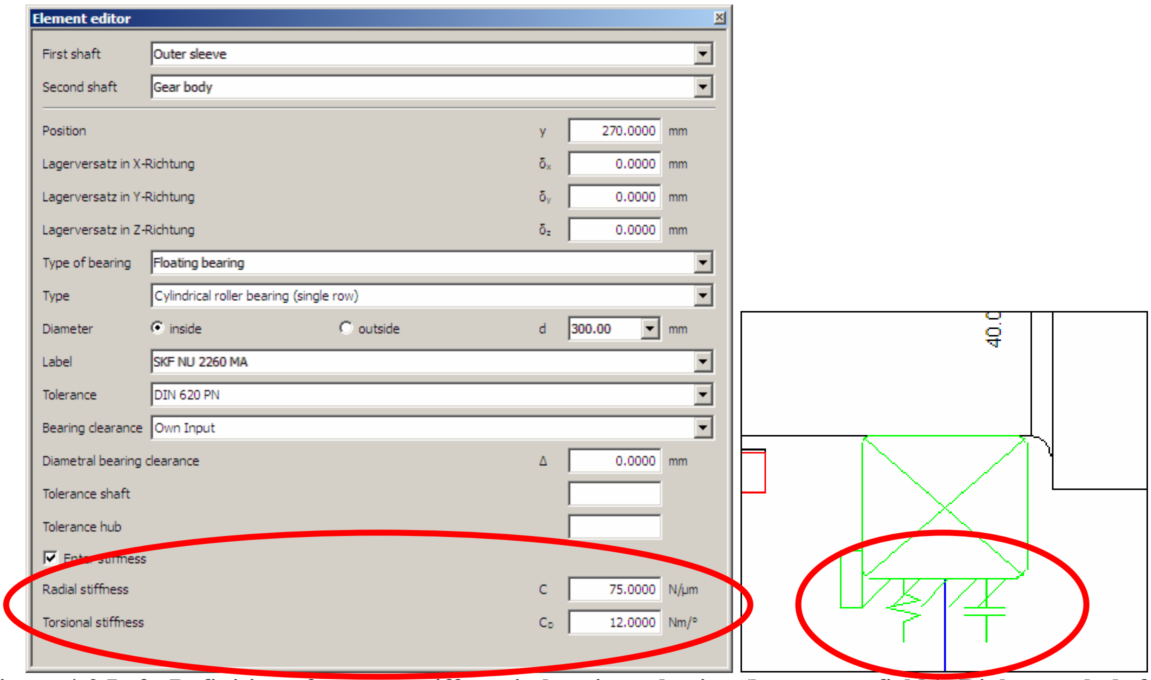


Figure 4-2 Left: Definition of support stiffness in bearing selection (lowest two fields). Right: symbols for bearing support offset and for bearing support stiffness.

5. Natural frequency analysis

Comparison of meshing and bearing fault frequencies from KISSsoft/KISSsys with natural frequency calculation / eigenform calculation in FEM (see Figure 5-1) will show whether a given gearbox housing is prone to vibration. For this, using the FEM calculation, the natural frequencies need to be calculated.
Using KISSsoft and KISSsys, the gear meshing frequencies are calculated based on shaft speeds and gear properties (see Figure 5-2). Furthermore, based on shaft speeds and bearing properties like number of rollers, bearing fault frequencies are calculated (see Figure 5-3). The natural frequency of an housing should then be different to the meshing frequencies present at the given operating speed. The bearing fault frequencies may be used for the set up of condition monitoring systems, measuring housing accelerations at the respective locations of the housing where large displacements occur in the eigenform.

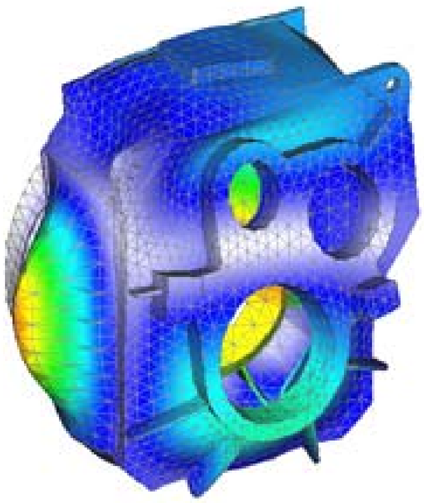


Figure 5-1 Eigenmode of a gearbox housing

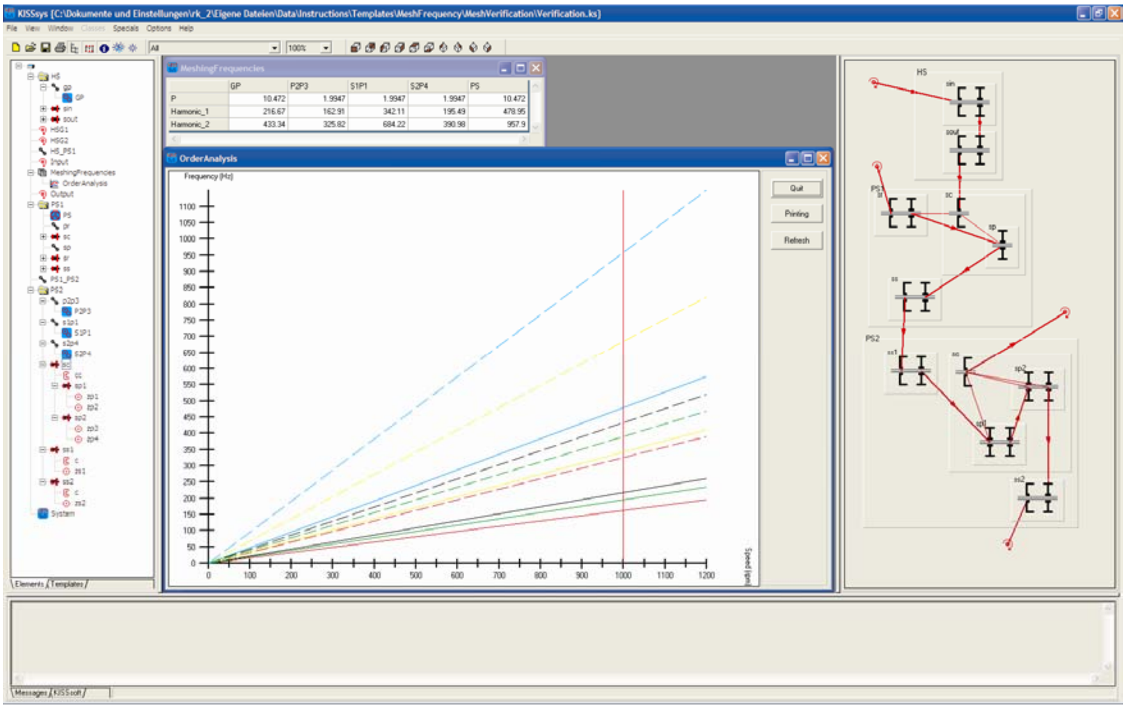
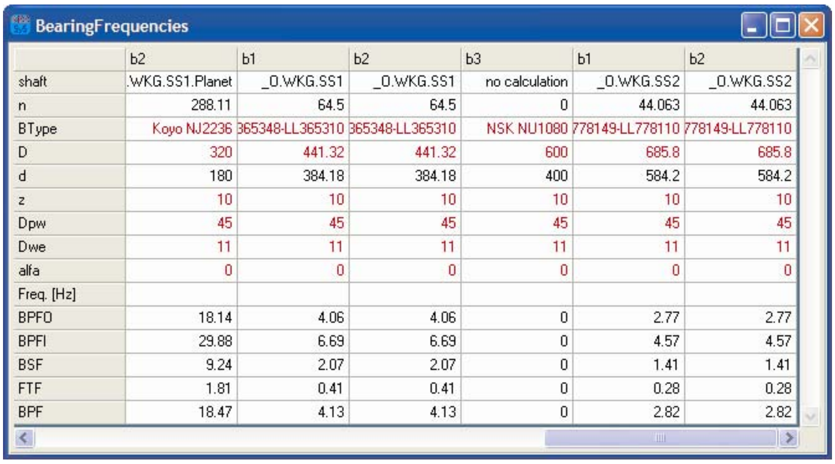


Figure 5-2 Meshing frequency analysis in KISSsys



BearingFrequencies

	b2	b1	b2	b3	b1	b2
shaft	.WKG.SS1.Planet	_0.WKG.SS1	_0.WKG.SS1	no calculation	_0.WKG.SS2	_0.WKG.SS2
n	288.11	64.5	64.5	0	44.063	44.063
BType	Koyo NJ2236	365348-LL365310	365348-LL365310	NSK NU1080	778149-LL778110	778149-LL778110
D	320	441.32	441.32	600	685.8	685.8
d	180	384.18	384.18	400	584.2	584.2
z	10	10	10	10	10	10
Dpw	45	45	45	45	45	45
Dwe	11	11	11	11	11	11
alfa	0	0	0	0	0	0
Freq. [Hz]						
BPFO	18.14	4.06	4.06	0	2.77	2.77
BPFI	29.88	6.69	6.69	0	4.57	4.57
BSF	9.24	2.07	2.07	0	1.41	1.41
FTF	1.81	0.41	0.41	0	0.28	0.28
BPF	18.47	4.13	4.13	0	2.82	2.82

Figure 5-3 Output of bearing fault frequency calculation from KISSsys

6. Stress level assessment

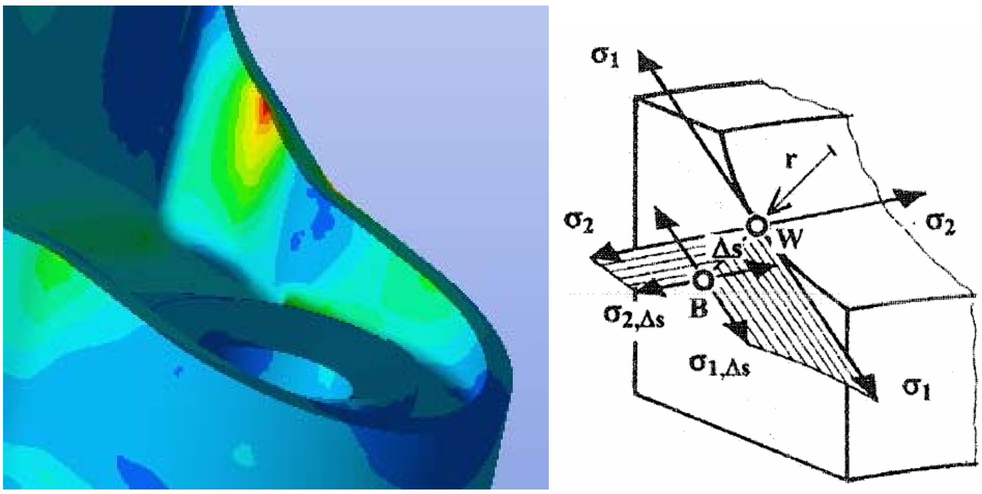


Figure 6-1 Left: Stress contour on housing, with various stress concentrations. Right: general describtion of a 3D stress state in a stress raiser.

For the final strength verification of the housing, the stress state calculated (see Figure 6-1) needs to be compared with a permissible stress state and transformed into a safety number using the part S-N curve. The calculation of the utilisation (a comparison between safety factor required divided by safety factor achieved) for a required lifetime, considering material properties (see Figure 6-2), stress concentration, stress state (see figure Figure 6-1, right) and part properties is implemented in KISSsoft as per the FKM guideline (see Figure 6-3).

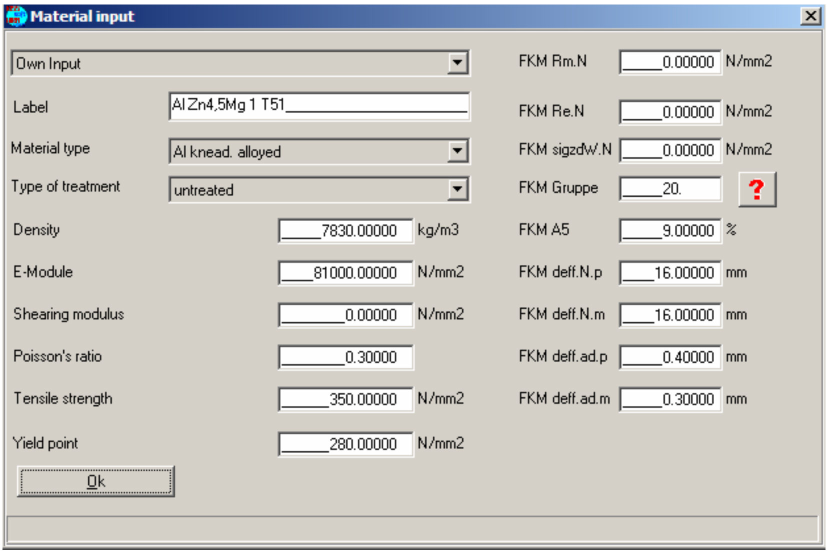


Figure 6-2 Definition of material properties for S-N curve along FKM guideline

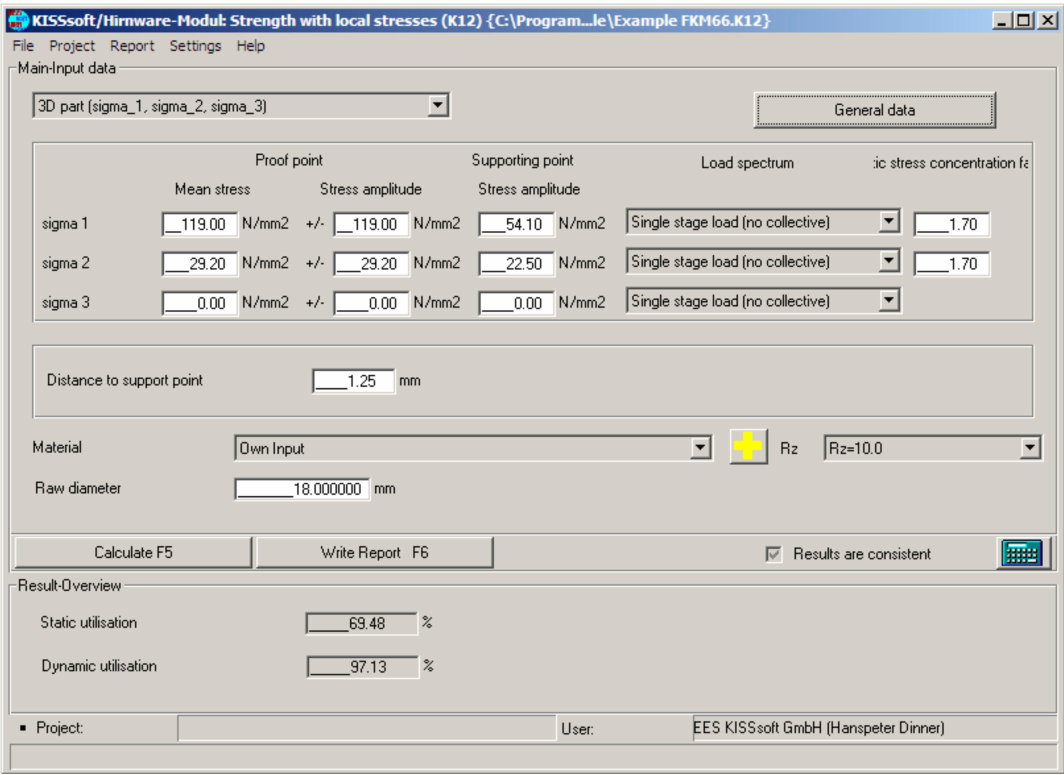


Figure 6-3 Conversion of a given stress state for a 3D part as calculated in a stress concentration using FEM into an utilisation value.

The analysis program delivers a complete, well documented proof of integrity for static and fatigue strength in a point of proof W. The proof is delivered along the local stress concept as described in the FKMguideline ”Rechnerischer Festigkeitsnachweis für Maschinenbauteile”.

The basic prinicple is to estimate the lifetime based on the elastic-plastic, local stress in the critical section compared to the S-N curve derived from the un-notched probe under uniaxial load. In the course of the FKM-guideline, the local stress concept is modified to a purely elastic load situation. Precondition for the use is hence an elastic material state. In this context, the concept used is not really a local concept as the elastic-plastic notch root strain concept but a concept close to the nominal stress concept except that the notch coefficient is "on the other side ofthe equation". It is a useful tool for the static and high cycle fatigue proof. Input: Stress amplitudes and stress ratio at the proof point and at a support point. Or the stress amplitudes / stress ratio at the proof point and an estimate for the support coefficient. Furthermore, for the calculation of the design factors, parameters like surface roughness, heat treatment and so on are required. Then, load data like number of cycles, temperature, collective are also required. Output: A static and fatigue utilisation (inverse of a safety number) is calculated. The proof is documented in detail.

```
KISSsoft Protokoll            21. December 2007, 13:00:01
―――――――――――――――――――――――――― KISSsoft/Hirnware Rel.  04-2006 ――――――
KISSsoft-Hirnware Evaluationsversion
File name    :                                 Example FKM63
Project      :
Date : 21.12.2007/12:58:11                        User : example
Description :        FKM Richtlinie 6.3  No.:
―――――――――――――――――――――――――――――――――――――――――――――――――――――――――――――――

Warning : Calculation not consistent.
          Results are probably not valid !


Proof of strength with local stresses
According to FKM-Guideline 4. edition (2002)

3D part

                                                sigma1   sigma2   sigma3
Stress at proof point (N/mm²)       [Sm]     15.000    5.000    0.000
Stress at proof point (N/mm²)       [Sa]     18.600    6.200    0.000
Stress at support point (N/mm²)     [S2a]    10.000    5.300    0.000
Distance to proof point (mm)        [deltaS]        7.700
Stress ratio                        [R]       -0.11    -0.11    1.000
Load spectrum                              Single stage load (no collective)
                                                   Single stage load (no collective)
                                                           Single stage load (no collective)


Material                 GG 30
Material type            Cast iron laminar graphite
Material treatment       untreated

Grey iron with laminar graphite (GG)


Base stress according FKM chapter 5.1:
Tensile strength (N/mm²)                 [Rm,N]              300.00
Yield point (N/mm²)                      [Rp,N]              195.00
Fatigue limit (N/mm²)                    [sigzdWN]            90.00
Reference diameter (mm)                  [deffNm, deffNp]   100.00   100.00

Load factor (static proof)               [fstat]           1.000
Number of load changes (Mio)             [NL]             10.000
Fatigue resistance for single stage use

Temperature (°C)                         [Temperatur]    380.000
Temperature duration (h)                 [TemperaturD]   100000.000
Temperature coefficients                 [KTm, KTp, KTD]  0.769 0.769 0.856
                                         [KTtm, KTtp]     0.512 1.000
Static stress analysis for higher temperatures: Only for short occurrence of stress.
Internal stress coefficient              [KEsigma, KEtau] 1.000 1.000
Additional coefficients                  [KA, KNL, KNLE]  1.000 1.050 1.025

Material properties:
          [fsigZ, fsigD, ftau, Rpmax]        1.000    2.500    0.850    320.0
                           [fWt, fWs]        0.850    0.300
                       [aM, bM, aTD]         0.00000   0.500    1.000
              [aG, bG, aRsig, RmNmin]       -0.050  3200.0    0.060    100.0
                             [MS, MT]        0.5000  0.4250
                  [ksigma, ktau, DM]            5        8        1
                   [kDsigma, kDtau]             0        0
                   [NDsigma, NDtau]         1e+006  1e+006
               [NDsigmaII, NDtauII]             0        0

Thickness of raw material (mm)           [d.eff]            64.00
Mean roughness (µm)                      [Rz]              220.00
```

Figure 6-4 Documented proof of integrity of the housing for a given feature and its stress state