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KISSsys application:

Lifetime analysis of a seven speed gearbox with reverse and helical gear differential

1 Task

A gearbox for a formula 1 car with seven forward and one reverse speeds is to be analyzed with respect to lifetime for several race tracks.
The different reduction stages are followed by a bevel gear pair and a single helical gear stage. Incorporated in the later is a helical gear differential. For the gears of the differential, a static strength analysis is performed only since this is the usual approach.
The objective is to compare different tooth form modifications in order to achieve a pre-defined lifetime and to obtain a complete analysis report on the push of a button.

Customer	Supplier	Project	Document
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2 Solution

In this application, several strengths of KISSsys are visible. The complete gearbox is being represented with it's kinematic for all seven forward and the reverse speed. Gears can be shifted (activated or de-activated) and using a damage accumulation procedure, the lifetime for all mechanical elements represented (mainly gears and bearings but shafts could also be analyzed) is calculated based on the load spectra selected and read from a text file. This is done by using KISSsys to control KISSsoft strength analysis by feeding KISSsoft with the applicable load data based on the current gear kinematic.

3 Description of the model

3.1 Structure of the gearbox

The gearbox features seven forward and one reverse speed using helical gears. The reverse speed uses an additional shaft. They are followed by a bevel gear stage and a single helical gear stage incorporating a helical gear differential.

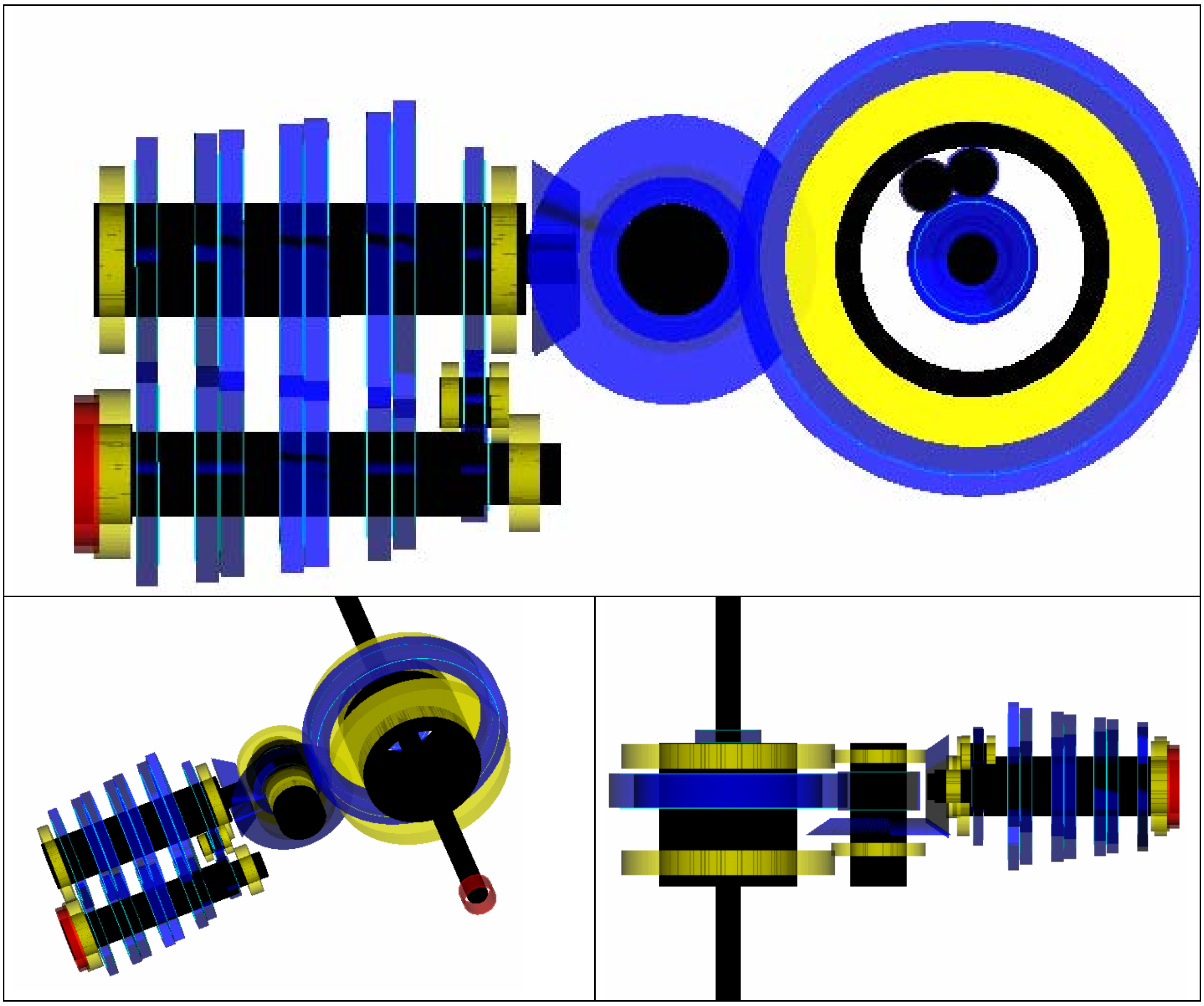

Figure 3.1-1 Structure of the gearbox: Black: shafts, blue: gears, yellow: bearings, red: power input or output. Of the differential only one pair of planets is shown.

The shafts, all of the hollow, are supported by cylindrical or ball bearings.

The kinematics on which the analysis is based includes all properties of the actual gearbox, especially the possibility to activate or de-activate gear pairs, depending on the speed selected. Also, the change in sense of revolution due to the reverse speed and the unequal power distribution in the differential is modeled:

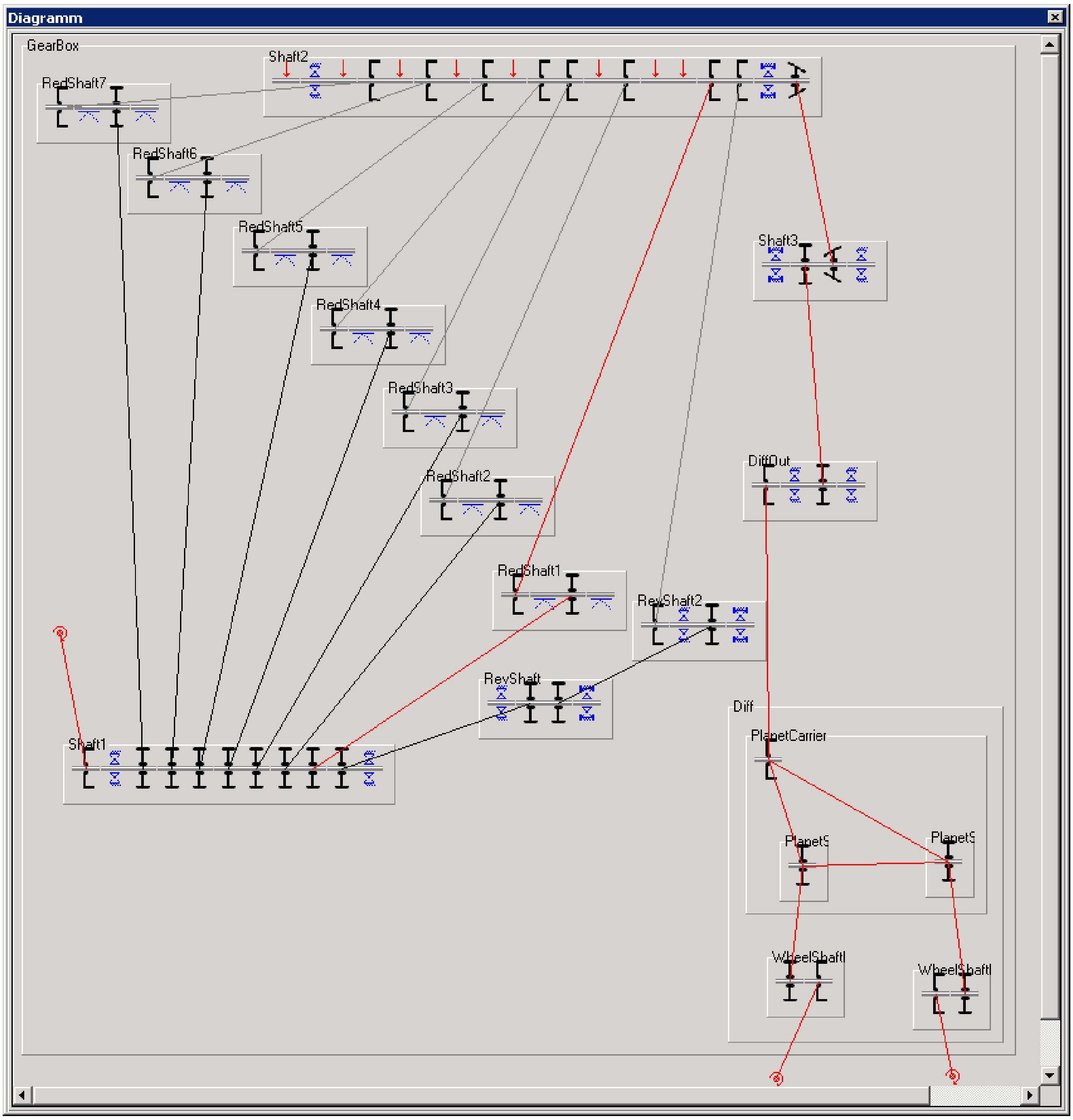

Figure 3.1-2 Schematic of the gearbox with power flow (red), mechanical elements (shafts, gears, couplings)(black), bearings (blue) and forces (arrows).

3.2 The user interfaces

KISSsys presents the user with different views of the model. The structure of the gearbox model is shown in the tree structure on the left side. Here, it is visible how the different parts are arranged with respect to each other. The tree structure is built by copy and paste from a library of elements, connections and KISSsoft analysis functions. Based on this tree structure, the power flow (top right) is derived and visualized. The 3D view shows the spatial arrangement of the parts and allows for a quick and simple collision check.

In- and output of data is through tables. They can be programmed freely using a built-in programming language and can be used to show results, select values from lists or enter data directly. For visualization of large amount of data, the 2D plot functions are very useful.

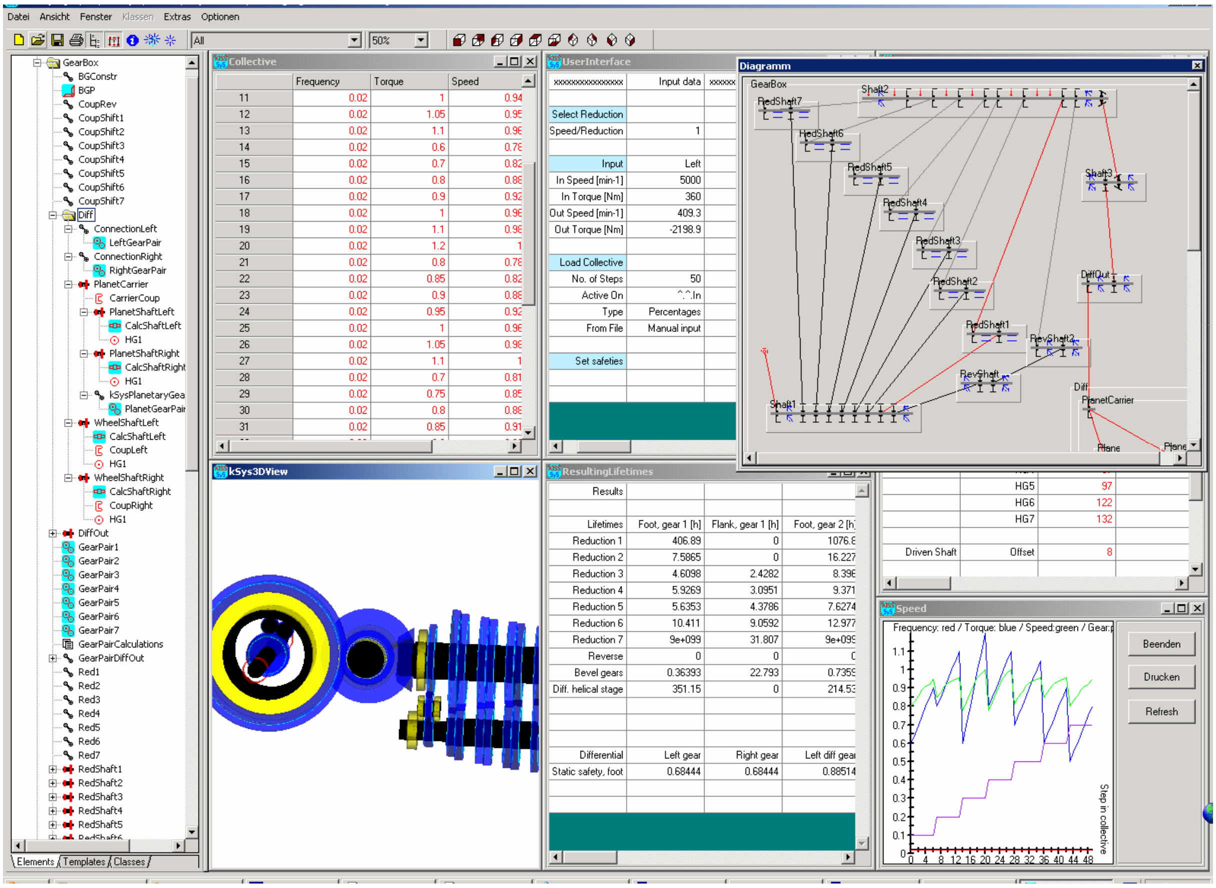

Figure 3.2-1 Views on the model. Left tree structure (logical structure). Top right: power flow. Bottom left: 3D view. In between: tables.

On the use of the tables and other elements, see below.

3.3 Execution of lifetime analysis

3.3.1 Lifetime analysis without load spectra

In this case, for a selected speed, torque and rpm, the lifetime for all gears and bearings is calculated. For this, the user has to define the following parameters using the tables / user interfaces:

- Selected speed
- Torque and rpm
- Rpm distribution at the differential
- Lubricant, temperature and lubrication mode
- Load factor and required safeties
- Type of bearing analysis (L_{10}, FAG, ISO281)

Once these parameters are set or selected, the lifetime analysis is started through a simple function call (double click on the field „Calc. Lifetime“). The definition of the nominal power and the selection of the active speed is by dialog functions:

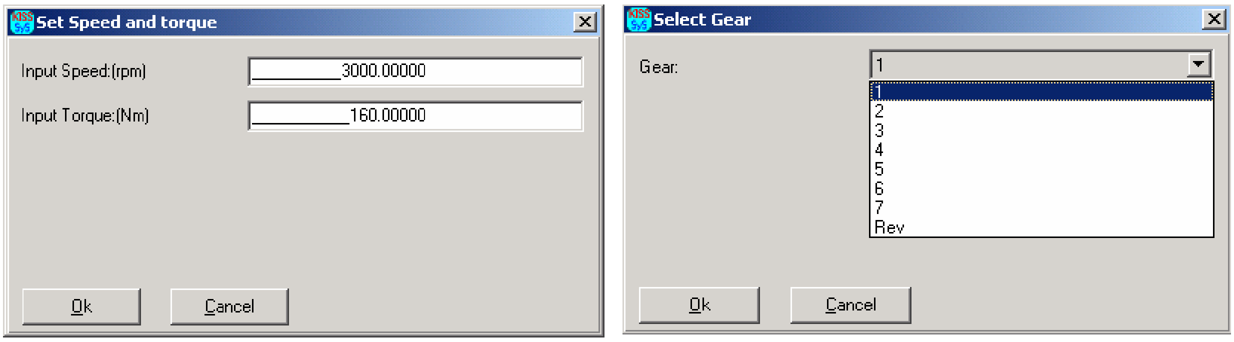

Figure 3.3-1 Left: Input of rpm and torque. Right: selection of active speed

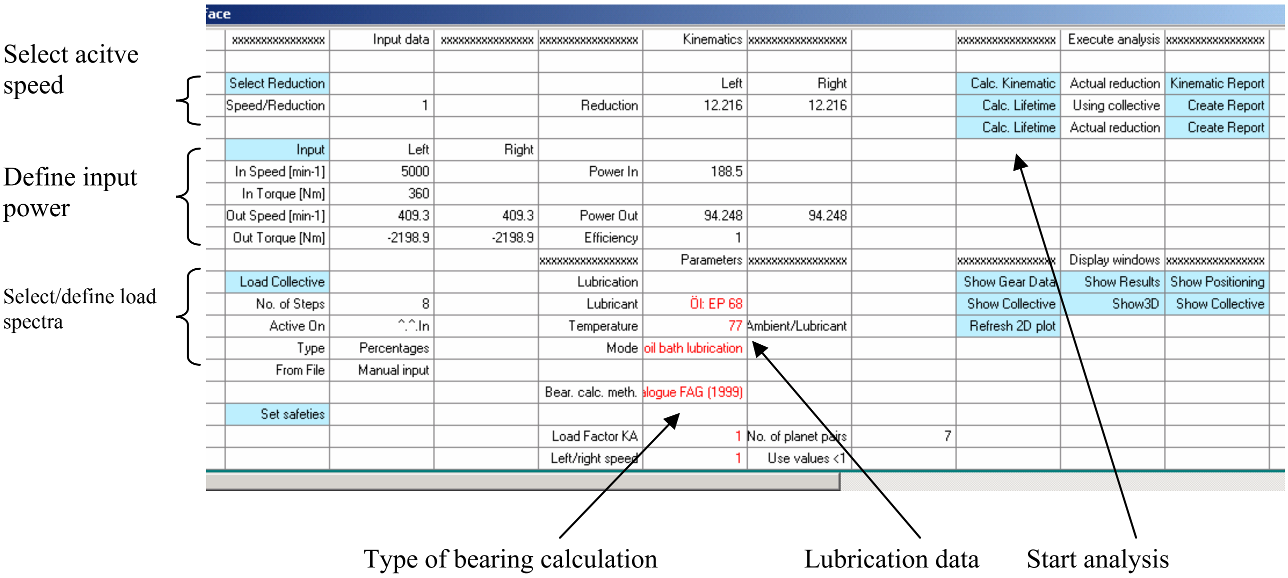

Figure 3.3-2 User Interface for controlling analysis

3.3.2 Lifetime analysis with load spectra

Besides the parameters mentioned above, a load spectra is to be chosen or defined. The user can choose to either import the load spectra from a file or define it manually in a table. The load spectrum is then stored in an array and can be represented graphically. Frequencies, rpm, torque and activated speed can be coded in this load spectrum. It is hence possible to simulate a complete race track in this load spectrum. The selection of a load spectrum again is done using simple to use dialogs:

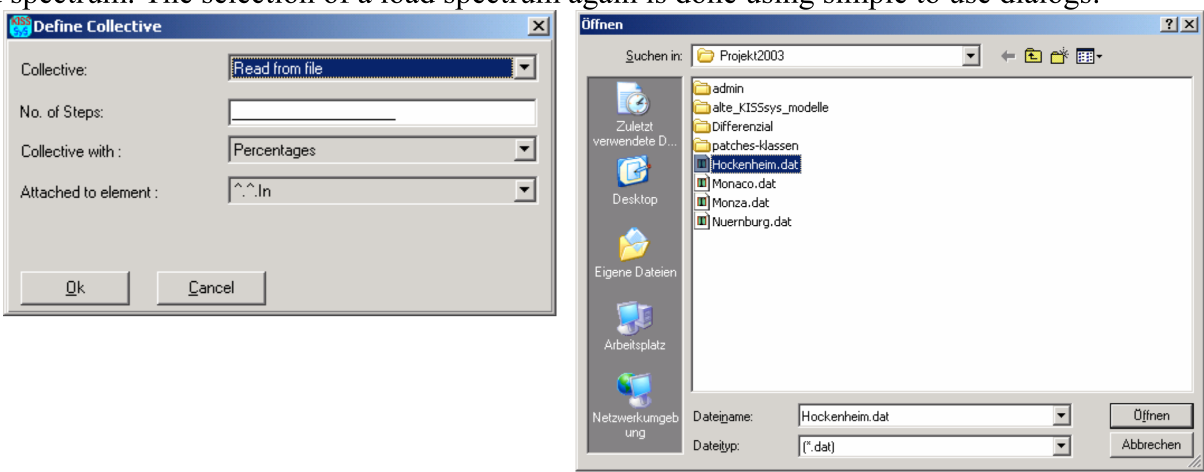

Figure 3.3-3 Left: Dialog for selection of spectra. Right: Select from different load spectra (here: race tracks) using a Windows Open File Dialog.

Collective

	Frequency	Torque	Speed	Gear
0	0.02	0.6	0.8	1
1	0.02	0.65	0.83	1
2	0.02	0.7	0.86	1
3	0.02	0.75	0.89	1
4	0.02	0.8	0.91	1
5	0.02	0.85	0.92	1
6	0.02	0.9	0.95	1
7	0.02	0.8	0.85	2
8	0.02	0.85	0.88	2
9	0.02	0.9	0.91	2
10	0.02	0.95	0.93	2
11	0.02	1	0.94	2
12	0.02	1.05	0.95	2
13	0.02	1.1	0.96	2
14	0.02	0.6	0.78	3
15	0.02	0.7	0.82	3
16	0.02	0.8	0.88	3
17	0.02	0.9	0.92	3
18	0.02	1	0.96	3
19	0.02	1.1	0.98	3
20	0.02	1.2	1	3
21	0.02	0.8	0.78	4
22	0.02	0.85	0.82	4
23	0.02	0.9	0.88	4
24	0.02	0.95	0.92	4
25	0.02	1	0.96	4
26	0.02	1.05	0.98	4
27	0.02	1.1	1	4
28	0.02	0.7	0.81	5
29	0.02	0.75	0.85	5
30	0.02	0.8	0.88	5
31	0.02	0.85	0.91	5

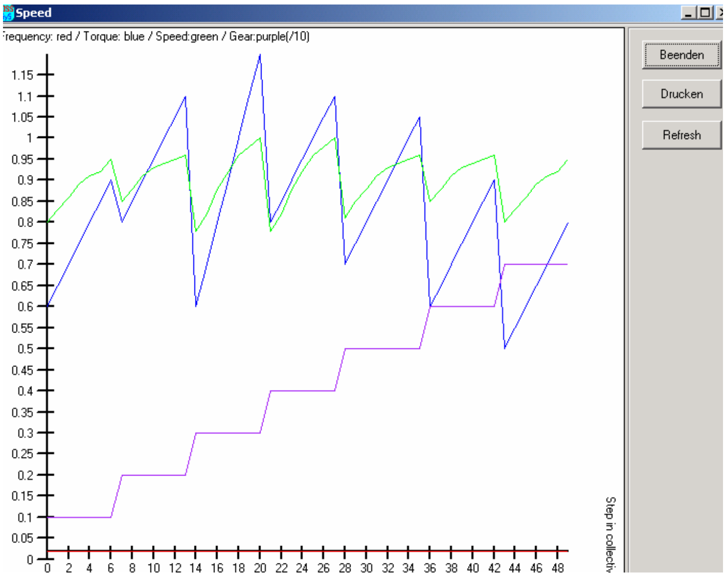

Figure 3.3-4 Left: load spectra in table form. Right: graphical representation (Due to confidentiality, values are fictive)

With these imported or manually defined spectra, a damage accumulation analysis is performed for the gears and bearings present. The selected speed is activated for each step of the load spectra and the power flow is recalculated.

3.4 Damage accumulation

The damage accumulation analysis first activates the current speed encoded in the load spectra, sets the input rpm and torque and then recalculates the power flow and the resulting forces. With the resulting loads on the mechanical elements (the deactivated speeds do not see any load) and considering e.g. load factors and required safeties, a partial damage is calculated. This partial damage is then accumulated over all steps of the load spectra. The calculation of an equivalent load is not sensible here since the slope of the S-N curve of the bearings and the gears is not equal and since the kinematic of the gearbox changes from step to step of the load spectra.

The calculation of the tooth root or flank damage/lifetime can either be performed according to DIN 3990, ISO 6336 or AGMA 2001. This is also true for the static analysis. The bearing analysis can either be according to standard L_{10} analysis, according to FAG method or according to ISO 281. The strength of the materials and lubricant properties are imported from databases available in KISSsoft.

3.5 Export of results, generation of reports

Again, using a table, the calculated lifetimes for the bearings and for the gears are shown. If more detailed information is required, then, for all gear pairs and bearings, detailed reports can be requested. These *.rtf files are then automatically compiled in a Word document, generating a 75 page report automatically. The time and effort needed for a comprehensive documentation is much reduced and errors are eliminated.

ResultingLifetimes

Results										
Lifetimes	Foot, gear 1 [h]	Flank, gear 1 [h]	Foot, gear 2 [h]	Flank, gear 2 [h]	Foot, gear 3 [h]	Flank, gear 3 [h]		Driving shaft	Front bearing	641.16
Reduction 1	406.89	0	1076.8	0					Rear bearing	131.18
Reduction 2	7.5865	0	16.227	17.185				Driven shaft	Front bearing	549.65
Reduction 3	4.6098	2.4282	8.396	6.953					Rear bearing	2.1626
Reduction 4	5.9269	3.0951	9.371	7.3777				Bevel shaft	Left bearing	4.2454
Reduction 5	5.6353	4.3786	7.6274	8.3943					Right bearing	1.7249
Reduction 6	10.411	9.0592	12.977	14.782				Differential	Left bearing	6750.5
Reduction 7	9e+099	31.807	9e+099	41.228					Right bearing	753.49
Reverse	0	0	0	0	0	0				
Bevel gears	0.36393	22.793	0.7359	35.066						
Diff. helical stage	351.15	0	214.53	0						
Differential	Left gear	Right gear	Left diff gear	Right diff gear						
Static safety, foot	0.68444	0.68444	0.88514	0.88514						

Figure 3.5-1 Calculated results for all bearings and gear (foot and flank). Furthermore, safeties against scoring could be shown.

4 Conclusion

The objective of a gearbox optimization of a race car is to achieve the required (in the range of a few hours) lifetime at minimum weight. Since the weight of the gears is linked directly to the dimensions of the gears, the focus is on having the width of the gears as small as possible. The effort for optimization of the gears is hence very high and a high number of optimization loops are performed. Hence, using a KISSsys model as shown above, saves a lot of time since the complete gearbox can be recalculated within minutes (when using a complex load spectra) after having modified e.g. the form of a tooth.
Furthermore, it is very useful for the customer to be able to analyze the gear box for different race tracks virtually simultaneously.
Influences of materials, toot shape modification or lubrication can be assessed quantitatively very quickly.