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KISSsys application:

Systematic gear design using modern software tools

1 Task

A complete, three-stage gearbox shall be designed, optimised and integrated into an existing casing.

2 Solution

When designing a gearbox, do you start with sketches and CAD or with formulas for strength and power flow analysis?

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2.1 Start with analysis...

Either you choose to start dimensioning the key parts like gears, shafts and axles, bearings and connective elements using formulas for strength and lifetime according to the relevant standards. To accelerate this process, software tools for calculation of machine elements are used. Even now, the engineer goes through several loops since most programs do not allow for analysis of a complete power train or gearbox but only of a gear pair or a single shaft.
Once the key parts are dimensioned, the resulting geometry is transferred to CAD drawings or models. To the engineers' disappointment, he will usually find that the parts do not fit into a design space or that they collide with each other. Back to start.

2.2 ... or with design?

Or: you start with drawing the casing, shafts, bearings and gears fitting the geometrical constraints. Here, the engineers experience and intuition helps a lot. Usually, one can start from an existing design. As soon as the drawings have reached a certain level of maturity, one has to check whether the parts designed will withstand the loads and reach the required lifetime. Usually they don't. Quite a bit of work lost then.

Both strategies have the disadvantage that the work is governed by only one aspect of the process of designing a gear box and that the other one is neglected. Loops in the process, a time consuming and de-motivating changing from CAD to CAE and back are the consequences. It would be much more efficient and satisfying to keep both aspects (drawing and analysis) in mind using the same engineering tool. With the existing tools available on the market this is difficult, when designing a complex power train or multi-stage gearbox it is hardly possible.

2.3 Systematic approach

Using KISSsys, the system program for KISSsoft, the engineer works on a system of machine elements – like a gearbox or a power train - instead of single elements. With KISSsys the power flow and the resulting loads on the elements of the system is calculated and the load data is available for analysis of single elements using KISSsoft automatically. The functions available in KISSsoft for dimensioning gears, shafts and other mechanical elements get much more powerful and flexible to use. When changing data on one element, the power flow is changed/recalculated and the changes in the lifetimes on other elements are visible immediately. Load spectra can be defined on a global level, several variants of a gearbox can be handled in the same model, differential gears and selector gearboxes are possible.
The time consuming iteration between different elements in the gearbox is reduced, repetitions of calculations are performed automatically and data handling mistakes are eliminated. The engineer has more time to concentrate on his important work: optimising the gearbox with respect to e.g. lifetime, noise or costs.

Furthermore, using KISSsys, both views on the gearbox (geometrical and analytical dimensioning) are handled simultaneously. In the same user interface where the strength analysis is performed, a 3D model of the gear box is available. Each step in the design and optimisation can hence checked for geometrical constraints.

A casing can be modelled using simple solids like cuboids and cylinders, to be positioned and arranged in space. Collision checks between casing and gears or shafts can be done in 3D viewer. Pre-defined views are helpful, panning, zooming and rotating is available. In case of doubt, the collision checks can be programmed in detail using data from the gears and casing (dimensions and positions). For this, KISSsys is equipped with a programming language and user interfaces with tables which can be programmed similar to Excel.

Standardised interfaces in KISSsoft (like dxf, step and iges) allow for an exchange of data (shaft, gear and bearing geometries) from KISSsys to CAD. Creation of drawings are hence much simplified. Furthermore, manufacturing parameters for gears can be printed automatically and added to manufacturing drawings.

3 An example

An example shall illustrate the advantages of this modern concept: a three-stage gearbox (with helical gears) shall be designed in an existing casing. The engineer has to start from an existing gearbox and optimise the efficiency.

3.1 Basis

In the following figure, the starting situation is shown. A small actuator with injection moulded gears, three stages, is built based on the data of the existing gearbox. The positions of the input and output shaft is to remain constant, the intermediate shafts are positioned automatically by KISSsys based on the centre distances of the gears. The shafts – steel – are supported by the casing directly (plain bearings). The casings made of plastic too.

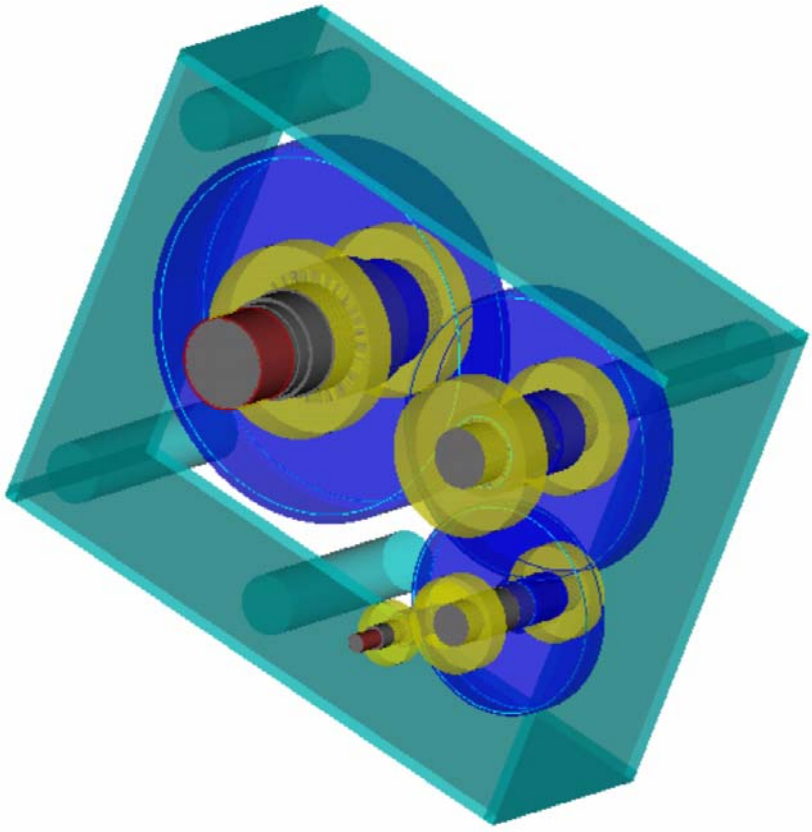

Figure 3.1-1 3D view of the gearbox with the three stages and the casing

The power flow of the gearbox is represented in KISSsys using a schematic (on the right side). The current power flow is highlighted in red, including power input and output. The mechanical elements and the bearings are shown as symbols, see below. When selecting a symbol in the schematic, an information box appears showing the name of the symbol/part and the respective element is highlighted in the tree structure. This helps when looking for a certain element since navigation in the

schematic is much more intuitive than in the tree structure. Furthermore, the element is marked in the 3D view by showing a local co-ordinates system.

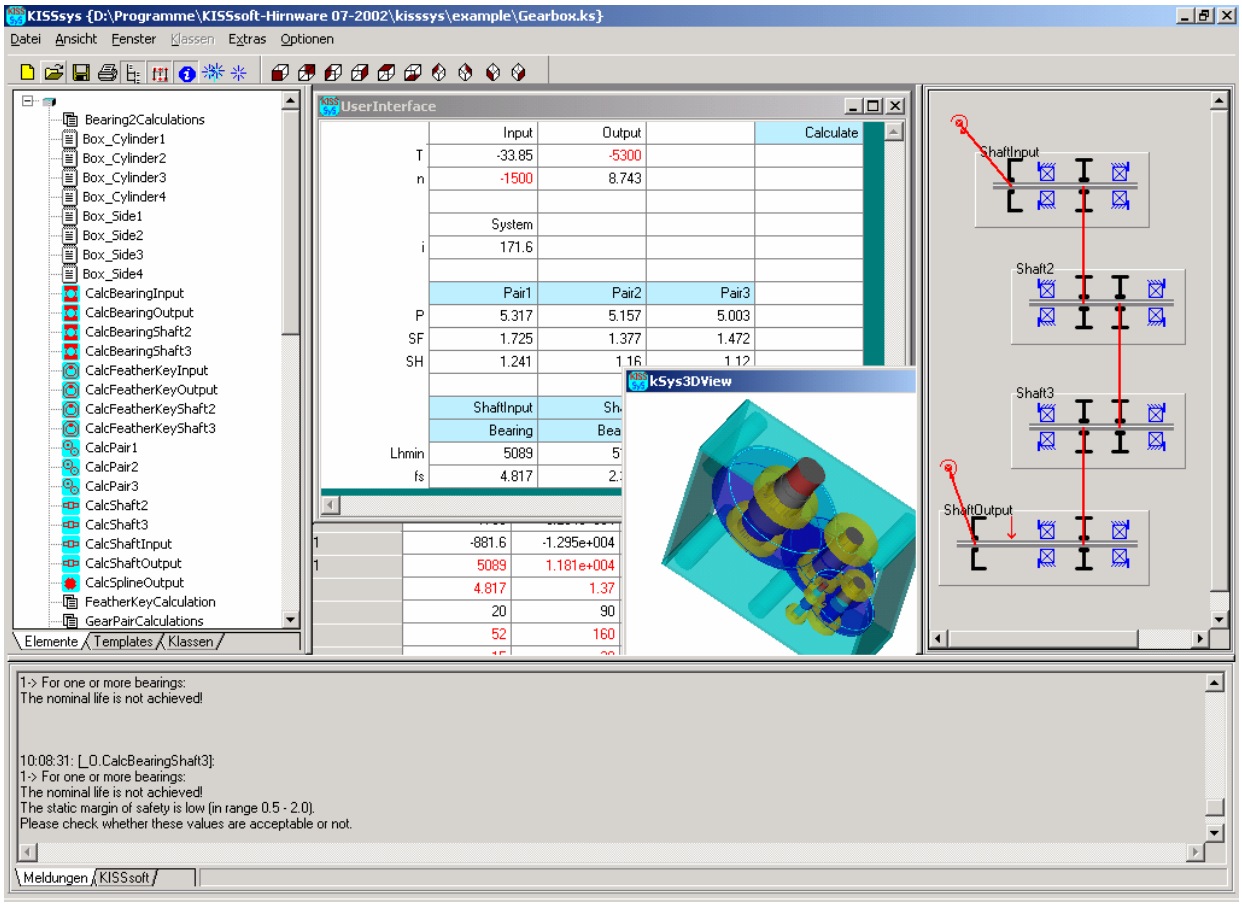

Figure 3.1-2 Tree structure, tables, 3D view and power flow schematic

3.2 Integrated analysis

For calculation of the efficiency of the gear box the friction in the gears and even more important the friction in the bearings is relevant. Since the materials for the gears are given, reduction of the friction is focussing on the bearings. The coefficient of friction between the plastic and steel is not known but the power loss of an existing, similar gearbox was measured. Using a separate KISSsys model for said gearbox, the coefficient of friction leading to the measured power loss could be determined for use in the current model. The corresponding value was found to be μ=0.36, see figures below.

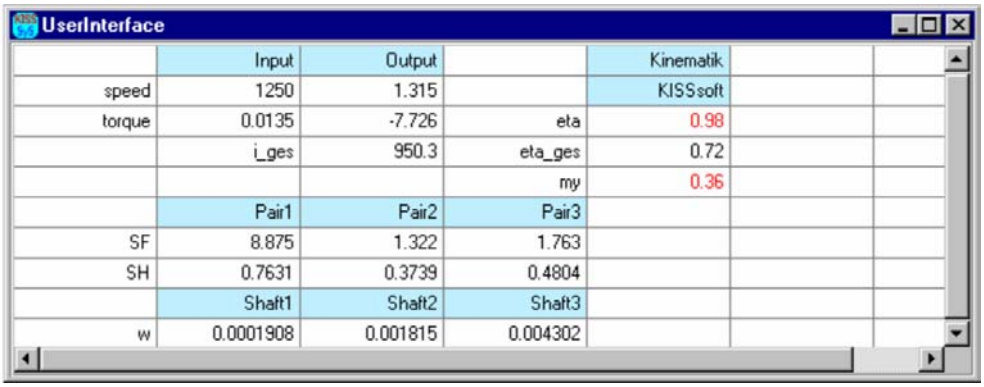

Figure 3.2-1 User interface for input of analysis parameters and execution thereof. Also, results are shown.

The power loss in the bearings is defined by the coefficient of friction and the diameter of the bearings. The smaller the shaft diameter, the smaller the resulting friction moment is. The objective hence was to reduce the shaft diameter for all shafts present. However, due to relatively high loads, the strength and deflection of the shafts was of concern. The diameter of the shafts was hence reduced at the ends of the shafts only. Strength analysis of shafts can either be performed according to the methods by Hänchen + Decker, DIN 743 or FKM Guideline 183 as available from KISSsoft.

In a 2D plot the efficiency of the gearbox and the safety against fatigue failure of the critical shaft is shown as a function of bearing diameter. By reducing the shaft diameter from 2.50 mm to 1.25 mm, the efficiency was increased by about 26% from 0.57 to 0.72. The safety factor against fatigue of the shaft was reduced from about 2.40 to a still acceptable value of about 1.95.

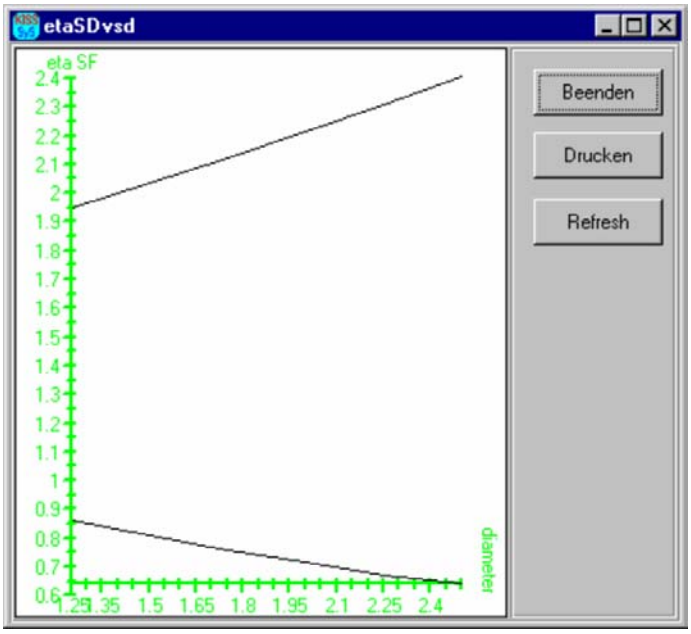

Figure 3.2-2 Factor of safety of the output shaft (upper line) and efficiency of the gearbox (lower line) as function of the shaft diameter

3.3 Building a KISSsys model

Building a KISSsys model usually is performed by an experienced KISSsys user with administrator rights. Standard users can then use the model and vary input data and optimise them e.g. by parametric studies. The kinematic of the model, the connections between the elements present however can only be changed by the administrator. The distinction between administrators and users ensures that the models are not damaged by inexperienced users.

Building a new system does require an amount of effort and profound knowledge of the program while using an existing model to perform an analysis is easy. Therefore, KISSsys models can also be used by e.g. sales representatives or even customers of gearboxes to study the behaviour of a particular gearbox under customer specific parameters (e.g. loads or lubrication). It is a most useful tool since it allows for access to expert know how. For example, a complete product line can be modelled in a single KISSsys model and is the available as a form of interactive product catalogue. The, e.g. during a sales presentation, the strength of the gears, lifetime of bearings or other technical aspects can be answered immediately by the sales representative using such KISSsys models.

4 Conclusion

Using this systematic approach to gear design, the following advantages are used:
Keep both aspects (geometrical and analytical design) of the complete gear box under control at any time
Collaboration between gear expert, design engineer and sales representative
Data exchange between CAE and CAD through standardised interfaces
Simple and safe management of design, manufacturing and strength/lifetime specific data
Optimisation and proof of integrity of all mechanical elements involved according to DIN, ISO and AGMA standard using state of the art analysis methods

Using KISSsys, the work of the gearbox designer is accelerated, simplified, less prone to errors and hence more interesting and rewarding.