KISSsys: Efficient Drive train Design

1 Abstract

The KISSsys software (Figure 1-1) combines kinematic analysis, lifetime calculation, 3D graphics and user defined tables / dialogues with a programming language. Due to it's flexibility, it is the tool of choice for strength and lifetime analysis of various kinds of drive trains and gearboxes. It is currently used in industries like: automotive, construction and agricultural, power tools, industrial gearboxes, power generation and many others. This software has been available commercially for three years now and the users community is growing steadily. KISSsys lets the user do quick yet detailed parametric studies of a complete power train in very little time to compare different variants of a concept. The machine elements calculated range from gears, shafts, bearings, shaft-hub connections to bolts. This will result in a more balanced starting design and fewer modifications will be necessary further down in the design process. Furthermore, documentation of the calculation is simplified and all calculation data for a whole drive train is stored in a single file. The purpose of this presentation is to explain the concept of the software and describe its many different uses. In particular, the experience and performance will be discussed using case studies from GETRAG and LIEBHERR.
KISSsys uses KISSsoft for the lifetime calculations of the various machine elements. KISSsoft is a CAE tool for the efficient and cost effective design of machine elements such as gears, shafts, bearings, bolts, shaft-hub connections and springs. KISSsoft focuses strongly on gearbox design and it is best known for its in-depth gear analysis capabilities.

The methods implemented for the calculations are all according to standards (ISO, AGMA, DIN) or well recognised and accepted literature. As well as the classical proof of strength against static and fatigue loads, the software features sophisticated functions for optimisation of the parts. One of the most powerful functions for helical gears iterates through a given set of parameters for spur or helical gears, determines the geometrically possible solutions and rates them according to several criteria such as strength, stiffness, noise or weight.

The software was originally developed by a Swiss gearbox company, but is now with an independent engineering consultant office specialising in mechanical power transmission software. During the last 25 years, the software has been constantly improved and more functionality is added every day. To ensure that the design engineer gets a practical tool for his daily work, the software is written by trained and experienced mechanical engineers. KISSsoft has established itself as Europe’s leading software for strength and service life calculation in the development of gear trains.

When designing a gearbox, an engineer must carry out an iterative process: Every change of an element of the gearbox (e.g. the helix angle of a gear) influences most other parts (e.g. the bearing loads). Checking these influences by manual calculation is slow and prone to errors. The objective hence is to have not only a pair of gears parametrised (like standard software does) but the whole drive train. This is achieved with KISSsys. Here, all parts (gears, shafts, bearings, connections) of the gearbox are linked and the strength/lifetime analysis is performed simultaneously for all elements. A
three dimensional graphical presentation of the current state of the system immediately shows the geometrical influence of every change in parameters (e.g. for collision tests). This approach greatly accelerates the design process and results in a much more balanced design even during the concept phase. KISSsys features:

**Kinematics calculation:**
- Connect bevel, helical, worm and face gears
- Epiciclic gears (planetary, Ravigneaux, Wolfrom, …)
- Model differential gears (bevel or helical type)
- Include chain and belt drives
- Activate / de-activate couplings, add slippage
- Add external loads and coefficients of efficiency

**3D modelling:**
- Automatic 3D representation based on the logical structure of the KISSsys model
- Graphics based on calculation data only, parameterized graphics
- Collision checks between parts and parts to casing
- Import gear box casings as STEP or IGES

**Special features:**
- Calculation of load spectra for all machine elements included in the model
- Use variants of a gearbox in the same KISSsys model
- Perform sensitivity analysis automatically
- Automatically generate documentation for a complete gearbox analysis
- Use scripting language for automatisation of routine tasks
- Interface to KISSsoft

Since the first version of KISSsys was released in 2001, it has been successfully applied to a wide variety of applications. In addition to those in the machine industry (including geared motors, wind turbines, power tools, actuators …) it has been used for wide-ranging projects in the automotive, agricultural and construction industry. Some examples of projects are:

### 2.1.1 Modelling of a leading Formula 1 team’s gearbox

This involved modeling the gearbox itself (7 forward and 1 reverse speed), the intermediate bevel-gear reduction and the planetary differential (Figure 2-1, left). The service life calculation is carried out for the gears, bearings and the shafts under load conditions measured during races. One element of the duty cycle is composed of the frequency of use, the engine speed and torque and the selected gear. This makes use of one of the very powerful properties of KISSsys: when determining the overall service life with duty cycles, the power flow is first set for each group of load conditions corresponding to the speed selected and only then the damage calculation for all elements is carried out. The result is an easily comprehensible table of the service lives of all parts calculated for the duty cycle. The critical elements (i.e. service life too short) and over-dimensioned elements (i.e. possible weight-saving) can then be picked easily.
2.1.2 Large mobile cranes

Large mobile cranes have eight or more axles, of which the greater part is driven. The axle distribution gear trains, with their connected differentials and wheel-hub gearboxes, are correspondingly complex. A calculation for various load conditions (e.g. to compare driving on road and off road) therefore results in a large number of calculations for individual machine elements to be performed. The structuring of these calculations with KISSsys saves a great deal of time and improves the clarity of results (Figure 2-1, right).

![Figure 2-1 KISSsys 3D view of Formula 1 drive train (left) and mobile crane drive (right)](image)

2.1.3 Development of new drive concepts for tractors

Power-split drives are used to achieve a continuously variable driving speed. To this end, a planetary gear set is used to divide the engine power into a hydrostatic and a mechanical component. In the hydraulic part, an axial piston pump drives a hydraulic motor with a large swash angle. The hydrostatic section thus acts as a CVT gearbox. The two power components are brought together on a summing shaft, fed to the centre differential, and then to the axle gear trains. The main tasks to be performed with KISSsys are the determination of the overall efficiency, the hydrostatic power ratio, and the service life calculation with customer-specific load conditions. Also of interest is the task of determining a load spectrum to be used in the tests that leads to the same degree of damage as the load spectra to be encountered in real world operation.
3 KISSsys in the development of manual automobile gear boxes

One area of application of KISSsys is the pre-development of automobile gearboxes. Often in the early stage of conceptual work, calculations have to be done quickly and for different configurations without the need for final results. With KISSsys, indications of service life can already be obtained in the first concept phase for all configurations considered. Various arrangements of bearings and gearing stages can be investigated very quickly. The influence of the variants on the bearing service lives and shaft deformation can be assessed with KISSsys.

For the purpose of this document, a simplified three-speed gearbox will serve as an example: Figure 3-1 shows an example of such a gearbox. The right side of the figure shows the schematic of the power flow. Bottom left is the input shaft, which can be directly coupled to the output shaft to provide third gear and drives the secondary shaft via a meshed pair of gears. On the secondary shaft above are two loose gears that can be locked to the shaft by clutches. The grey line in the KISSsys representation indicates an open clutch and the red line an engaged clutch that is transferring power. The bearing forces of the loose gears are represented as individual forces on the lay shaft.
Figure 3-1 Three speed gearbox (simplified example), the gear for the constant reduction on the secondary shaft overhangs the bearing.

With the above shown configuration (bearing on the right of the gear), the following resulting shaft deflections (angle) were found:

Deflection angle of the shaft in 1/60° (second speed selected) at various points:

<table>
<thead>
<tr>
<th>Point</th>
<th>Gear constant reduction</th>
<th>Gear 1st gear</th>
<th>Gear 2nd. gear</th>
<th>Bearing 1</th>
<th>Bearing 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Shaft</td>
<td>0.01</td>
<td>0.5</td>
<td>1.0</td>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Secondary</td>
<td>2.4</td>
<td>0.6</td>
<td>1.8</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td>0.3</td>
<td>0.6</td>
<td>0.5</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

A simple variation of this model would be, for example, to change the order of gear and bearing on the secondary shaft. This leads to a representation as in Figure 3-2.

Figure 3-2 Secondary shaft is now supported by bearings at each end.
The calculations yield, again, the deflection angles of the gearwheels and at the bearing points:

Deflection angle of the shaft in $1/60^\circ$ (second gear selected) at various points:

<table>
<thead>
<tr>
<th>Point</th>
<th>Gear constant reduction</th>
<th>Gear 1. gear</th>
<th>Gear 2. gear</th>
<th>Bearing 1</th>
<th>Bearing 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Shaft</td>
<td>0.02</td>
<td></td>
<td></td>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Secondary</td>
<td>0.5</td>
<td>0.3</td>
<td>0.6</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Primary</td>
<td>0.9</td>
<td>0.2</td>
<td></td>
<td>0.7</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Thus, by changing the position of the bearing, the deflection angles of the gearwheels and bearings can be significantly reduced leading to improved load capacity and increased service life, or (with reduced shaft cross-section) to a reduction in weight. Such a comparison typically takes only a few minutes but yields very valuable information.

GETRAG, a leading global gearbox manufacturer, currently uses KISSsys in pre-development for new automotive gearboxes and for double-clutch gearboxes. According to GETRAG engineers, the applications and benefits of KISSsys are:

- investigation of gear-set concepts (time consumption for the construction of a new gear train model, 4-6 h)
- comparison of bearing concepts (time for comparison of a number of bearing concepts, depending on the work required to modify the model, 0.5 to 1h per variant)
- layout optimisation (a change in the order of the gearwheels increased the service life of a critical bearing by a factor of 4 while halving the shaft deflection. Eight variants: 4 h)
- sizing of shafts and initial selection of bearings (time consumption for sizing of shafts and bearings when investigating a twin clutch gearbox, approx. 4 h)

According to information from engineers responsible for the development, analysis time for comparing different concepts could be reduced by a factor of five!

### 4 Application in the Pre-Development of automatic gear boxes

Not only parallel shaft gearboxes can be modeled with KISSsys but also epicyclical gears. The modeling of the power flow and calculation of the gear forces, torques and relative shaft speeds in epicyclic systems was one of the main requirements in the development of KISSsys.

In combination with the clutches, the power distribution and the various reductions in the planetary stages can be realized (e.g. in a Ravinaux set). As an example, a complete model of this type of automatic gearbox was created for a major German automotive manufacturer.

For twin clutch gearboxes, clutches can be represented not only as open or closed, but can also be taken into account in the kinematic calculation with slip or pre-determined torque transmission.
5 KISSsys model of a camshaft drive for a diesel engine

The camshaft drive of an engine consists of multiple gears and, in addition to the actual engine control, also drives various auxiliaries. These include hydraulic pumps, compressors, water pumps and generators. The type and number of auxiliaries attached can vary considerably, depending on the purpose of the engine.

Consequently, before a given engine is released for a new application it must be verified that the various parts have been adequately dimensioned. A drive normally consists of 12 to 20 gears with associated shafts and bearings, see Figure 5-1. If the calculations of the various elements are carried out individually, the effort is significant and, because of the complexity of the power flow, prone to errors.

Liebherr Machines in Bulle, Switzerland, has used KISSsys for two years now for the design of gear trains in diesel engines that are used as the prime mover for a wide range of uses. The customer requirements for the use of the energy supplied are varied. With the help of KISSsys, customer-specific configurations can be examined and the critical components can be quickly and reliably checked. The risk of error is reduced significantly and the time consumed by the calculation is minimized. A single check including the full documentation takes less than 15 minutes!

Figure 5-1 shows an example for the camshaft drive with hydraulic pumps and a compressor. The KISSsys model (Figure 5-2, with some additional power splits) manages the power flow from the main engine shaft, through the gear train, to the auxiliary drives and the camshafts. The auxiliaries are an air compressor, an injection pump, a water pump and a hydraulic unit. Via the user interface of the model (an Excel-like spread sheet, see Figure 5-3) the power requirements of the various auxiliaries are defined. Further necessary input information, such as the nominal engine speed or application factors, is also defined directly as appropriate to the particular case. Using function buttons, the calculations can be carried out for the complete system or individual gear pairs can be examined and modified in detail (by opening the KISSsoft gear calculation interface). Another button initiates the generation of an overall report, documenting the system data and the strength calculation according to an ISO standard for all gearwheels. The report language can be selected from English, German, French, Italian or Spanish.
Figure 5-1 Camshaft drive of a Liebherr D9508 diesel engine

Figure 5-2 Representation of the gear train (3D view) and power flow (schematic) in KISSsys
6 Conclusion

The examples discussed prove an increase in efficiency in drive train design and in checking new requirements for existing drive trains. A good number and wide variety of projects have proven the potential of KISSsys. The number of KISSsys users and fields of application is growing constantly, now that the modern software concept of working on a system level (instead of working on a machine element level) is more familiar to calculation engineers.

The time required for a first qualitative and quantitative assessment of a concept is greatly reduced, especially if different variations of the same concepts are to be considered. This will eventually lead to more variants being investigated, which in turn is likely to result in a more balanced final design.