Using KISSsys in design and verification of a large crane gearbox

SEW China and KISSsoft AG used KISSsoft and KISSsys software in the development of a large crane gearbox. Exchanging data between Switzerland and China became very simple due to the fact that all relevant gearbox data is contained in one single KISSsys file. Every design change could be implemented rapidly, sent across the globe and re-analyzed. Instead of sending pages and pages of calculation reports, the calculation file itself, containing all updated strength and lifetime data was sent back and forth between SEW China and KISSsoft AG.

Furthermore, the design process was accelerated due to the time difference. In afternoon, the Chinese colleagues would send the KISSsys model containing all necessary design data to Switzerland for verification and modification and by the time they got back to the office the next morning, the results were all available to them in their Email!

Any design changes that became necessary during the manufacturing phase (due to e.g. limited availability of certain tools) were relayed to Switzerland where the modification was implemented in the KISSsys model. All necessary load cases were then re-analyzed immediately and the results sent back to China, informing about the feasibility of the required change within minutes to hours.

The gearbox has proven itself in its first year of operation and a happy customer decided to purchase additional gearboxes from SEW.

KISSsoft AG thanks SEW Eurodrive China for allowing us to publish this application report. See www.sew-eurodrive.com for more information on SEW.
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1 The calculation model

1.1 How did SEW benefit

1) Allowing two parties simultaneously to work on the design, the development time was reduced. This was achieved by using a shared software platform and by maintaining all relevant design data in one single KISSsys file that could be shared easily by email.

2) Data management, storage and exchange was simplified. When dealing with multiple components, a tight schedule and several load cases, managing all design and calculations in one single KISSsys file helps the engineer to reduce his workload. Error prone exchange of data from one calculation to another is eliminated as all calculations are connected with each other in KISSsys. Data exchange is automatic, the engineer is relieved of this boring task.

3) Documentation generation, both for analysis reports and CAD data, was automatised. All analysis reports can be generated automatically from KISSsys for the whole gearbox, relieving the engineers from the tedious task of compiling engineering analysis reports. Furthermore, CAD interfaces allowed the fast generation of production data from KISSsoft.

4) Manufacturing aspects were considered in gearbox sizing phase. KISSsoft integrated gear geometry calculation continuously checks whether gears sized or rated can be machined using a given tool and whether any meshing errors occur for the final, manufactured gear geometry.

1.2 The application
In large cranes, a single gearbox is used for simultaneous control of hoisting and traveling works. The two output shafts of the gearbox can be controlled independently, by means of employing two input shafts (with two independent input speeds) and a differential planetary arrangement. One input shaft basically drives both ring gears whereas the other input shaft drives both sun gears. Superimposing these two speeds, two different speeds on the planet carriers (the output) result.

As ships, be it container ships or bulk carriers, need to be loaded and unloaded in ever shorter time, the requirements on the gearbox with respect to operational availability are stringent. These gearboxes need to operate day in, day out, with high loads, reversing speeds and often minimal maintenance. A safe design is therefore of prime interest.

As one of the world leading supplier of geared motors as well as industrial gearboxes, SEW China supplied a custom made gearbox for such a crane. As the time frame allowed for the design was tight, SEW approached KISSsoft AG for some assistance in preparing an integrated calculation model of the gearbox.

In collaboration between SEW China engineers and KISSsoft AG, the calculation model was then used to optimize the gearing properties, select the bearings, decide on the final shaft dimensions and to check the key strength. In this design process, conditions with respect to the input and output shaft centre distances had to be observed as they were given from the customer.

### 1.3 The KISSsys model

With KISSsys the power flow and the resulting loads on the elements (shafts, bearings, gears) 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 is 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 multiple speed 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 gearbox is available. Each step in the design and optimisation can hence be 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.

![Figure 1.3-2 Input of settings valid for all components in the gearbox.](image)

### 1.4 Data exchange using the KISSsys model

As soon as several parties are involved in the simultaneous design, analysis, and manufacturing of a gearbox, design data exchange becomes crucial. KISSsys allows all relevant design and analysis data to be kept in one small file. This file can easily be exchanged by email. An integrated text utility allows for taking down notes, e.g., informing the receiver of the KISSsys model to be informed about the changes undertaken by his colleague. Furthermore, all CAD drawings of the gears as well as the analysis reports can be generated in little time using the KISSsys model. It was therefore not necessary to keep the same as they could be re-created whenever needed.

### 2 Calculations

#### 2.1 Kinematics

Understanding the kinematics of the gearbox is less than intuitive for the newcomer to differential gears. The basic principle is that the speed of the ring gears and the speed of the sun gears is controlled. This is opposed to the standard case where the ring gear has no speed (speed = 0 RpM). The next difficulty, for the rating of the planetary gear sets is that only the meshing power need be considered for gearing strength.
During the design phase, the kinematic condition had to be checked continuously. The resulting gear ratio had to be maintained within a few percent deviation of the desired gear ratio. Therefore, whenever some gear data was changed, the kinematics of the gearbox was reanalyzed to verify that the resulting ratio was within the requirements. Using the fine sizing options in KISSsoft, the target ratio per gear pair could be specified. In the final design, therefore a deviation in the total ratio less than 0.1% was achieved!

Based on the kinematic definition in KISSsys (see below), all powers, torques and speeds are calculated. This kinematic conditions serve as input into the strength calculations.

In addition to the two input torques and speeds, forces acting on the output side of the gear box were considered.

![Figure 2.1-1 Representation of the gearbox kinematics. Power flowing is indicated by red arrows. The two planetary units are of identical design.](image)

### 2.2 Shafts and bearings

Shafts are crucial in any hoisting application; any shaft failure may result in the load lifted to fall. Shaft strength is therefore checked for a worst case load assumptions and rating the shafts both for fatigue and static strength. The rating was done along DIN743 standard and using the most critical cross sections as defined by the local load and stress concentrations.

![Figure 2.2-1 Shaft model of one of the input shafts as modelled in KISSsoft and then integrated in KISSsys](image)

The bearing calculation was done along ISO281 using static and dynamic load capacity numbers. Resulting radial and axial bearing forces as well as rotational speeds were automatically calculated in the shaft calculation and forwarded as input to the bearing life calculation. The required lifetime was met, as well as the required static strength of the bearing.

The bearing selector was used to find the smallest possible bearing, by scanning the KISSsoft bearing database for suitable bearings in terms of required diameter and lifetime.
Figure 2.2-2 Bearing rating is integrated in shaft analysis, bearing forces acting are automatically calculated from gearing loads acting on the shafts.

Figure 2.2-3 The bearing selector was used to find a suitable bearing of minimal size but sufficient lifetime.

2.3 Keys

A total of four keys were analysed simultaneously. The key calculation takes into account the surface pressure between key, shaft and hub. This again is a function of the effective contact area, torque applied and shaft diameter. The permissible surface pressure is a function of the material strength and the type of loading (shock loads, alternating loads).
2.4 Gearing

Gear sizing was based on given target ratio, power transmitted and size constraint. Gearing quality was defined by SEW as well as material choice. Based on this data, using the KISSsoft gear sizing function, gearing data optimized in terms of mass, strength and manufacturing (use of available tools) was performed. The subsequent gearing rating can be done along DIN3990, ISO6336 or AGMA2001 standards. The KISSsoft gear geometry calculation was used to check the final gear geometry based on simulation of the manufacturing process in order to avoid and meshing error on the final gears.

Figure 2.3-1 Key rating along DIN6892 in KISSsoft

Figure 2.4-1 Left: Possible gearing solutions within a given parameter space. Right: simulation of gear geometry based on hob geometry.
Figure 2.4-2 Left: S-N curve used for rating (bending) along ISO6336, using ML material data. Right: shear stress inside of tooth for determination of required hardness depth.

2.5 Reports

Besides the comprehensive strength calculation report (total of 151 pages per load case), the most critical results (like safety factors and life times for bearings) were summarised in tables as shown below. Furthermore, gear manufacturing data as required on the drawings as well as summary reports were generated.

Manufacture-Tolerances

<table>
<thead>
<tr>
<th>Tolerances for helical gear sets 120 1328-1:1994</th>
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<tr>
<td>Accuracy grade</td>
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<td>Pitch single deviation (µm)</td>
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<tr>
<td>Normal base pitch deviation (µm)</td>
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<tr>
<td>Pitch total deviation (µm)</td>
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<td>Pitch tension deviation (µm)</td>
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<td>(Fpt)</td>
</tr>
<tr>
<td>Profile total deviation (µm)</td>
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<tr>
<td>Profile angular deviation (µm)</td>
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<td>Profile flank deviation (µm)</td>
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<td>Tooth trace angular deviation (µm)</td>
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<tr>
<td>Tolerance for helical gear sets 120 1328-2:1996</td>
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<td>Concentricity dev. (µm)</td>
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<td>Double flank composite transmission error (µm)</td>
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<tr>
<td>Double flank tooth-to-tooth transmission error (µm)</td>
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</tbody>
</table>

Figure 2.5-1 Different output and report formats accessible from both KISSsoft and KISSsys