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Tractor transmission verification with KISSsys model



daedong



Total Gear Solutions

A tractor transmission is usually very complex with a lot of gear pairs, shafts and bearings in it. Modern transmissions have also several functionalities like shifting without clutch, 4WD/2WD forward/reverse shuttle and PTOs. They must work smoothly and quietly like an automotive transmission, but usually working conditions are much more severe. They must also be reliable in different kind of working conditions and fields of applications. Because of the great variety of gears and speeds selectable, calculations for safety factors and component lifetimes becomes usually very complex, time consuming and challenging to manage.

In this project, a very complex and modern transmission was modelled to be able to calculate the whole tractor transmission with PTO driveline simultaneously. There are almost 300 different power flow variations and also the possibility to check against wheel slip and calculate the whole system with a load spectrum.

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2 The project

2.1 Introduction

In close collaboration between Daedong, KISSsoft AG and STech&H, an analytical model of a tractor transmission was established using KISSsoft and KISSsys software. Based on Daedong requirements and transmission layout data, KISSsoft AG established a suitable analysis process and a detailed transmission model. The know-how generated in the project was then transferred by STech&H to the customer. The analytical model of the complete transmission is beneficial for Daedong in several ways:

- data management is simplified, all engineering analysis data for the whole transmission is contained in one single file
- parametric studies can be performed for the whole transmission in very little time as the KISSsys model includes a scripting language for automatic execution of such tasks
- interaction between designer and analytical engineer is simplified as any change in the analysis parameters is immediately visible in the component geometry as well
- time spent with analysis reports is much reduced as the complete analysis is documented based on the in-built reporting functions of KISSsoft and KISSsys software
- design reliability is improved as any design change or changing load assumption can be verified in short time due to the parametric approach used in KISSsys, allowing for extremely short computation times

- design process is accelerated as the transmission is considered as a system where components interact with each other therefore eliminating the need for time consuming manual exchange of data between CAD system and engineering analysis
- accuracy of the life time prediction is improved as benchmark information can be included in the analytical model of the new transmission
- interaction with customers, suppliers and the management is simplified as analytical results are represented using 3D graphics, charts and results tables

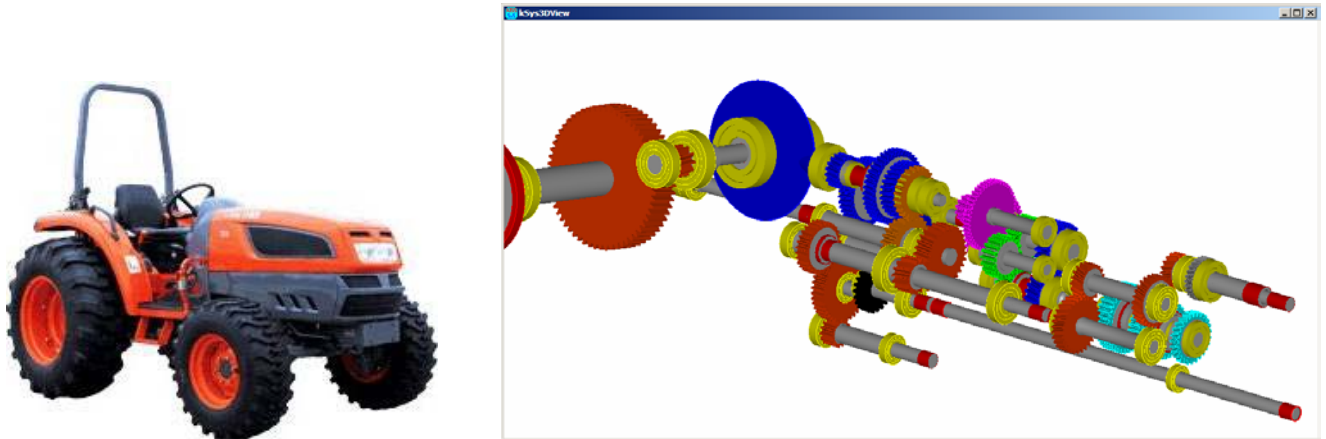


Figure 2.1-1 Daedong tractor, transmission modelled in KISSsys

2.2 Project partners

Daedong Industrial Co., Ltd.

Since its foundation in 1947, Daedong Industrial Company, Korea, has taken the role of leader in the fields of modernization of the agricultural industry and development of agricultural machinery by producing the first cultivating machine. Daedong, not satisfied with the position of the national leader in the agricultural machine industry, is endeavouring to become a global enterprise in the world market with continuous development of technology and overseas marketing. Through their local corporation in the USA and their European parts centres, Daedong and its export brand, KIOTI, can be found all over the world. Daedong R&D Centre is continuously expanding its field of research through the development of environment friendly diesel engines and new products.

STech&H

STech&H is a service firm specialized in gears and gear trains. The company aims to provide its customers with valuable technologies in partnerships with the gear design and service firm KISSsoft which offered full cooperation and represents KISSsoft AG in Korea, Japan and Taiwan and interacts closely and on a regular basis with KISSsoft AG in Switzerland. STech&H has a technical cooperation with the world-renowned gear research institutes Ohio State University GearLab, the gear train analysis firm ANSOL in the U.S., the specialist noise and vibration institutes KIAST and KIMM in Korea, the world-class noise and vibration equipment firm DELTA in Denmark, and the specialist gear and gear train test equipment company Superior Control in the U.S. Many kinds of engineering service are a part of the company's efforts to give its customers more satisfaction in this regard.

KISSsoft AG

Switzerland based KISSsoft AG is a leading provider of engineering analysis software to the power transmission community. With some 1100 licences sold and performing some 60-70 engineering projects a year, KISSsoft AG has earned a solid reputation for high quality gearing and transmission engineering and CAE software. Furthermore, KISSsoft AG assists their customers by providing consultancy in the area of analysis process implementation. Having more than a dozen customers in tractor transmissions and having staff with a background in tractor transmissions, KISSsoft AG is in a

unique position to provide a total solution consisting of engineering services, process consultancy and engineering software.

3 Project scope

3.1 The problem

What do you think as an engineer about the possibility to perform whole tractor transmission calculation within minutes with only a couple of mouse click? Transmission engineers would say: “Yes please!” Add in there also a need to calculate with a given load spectrum and/or compare results with several nominal loads and speeds. This task may sound impossible to handle and will take probably huge amount of time. But that is not true! You may do all of this within relatively short time and you will have more time for other productive things.

3.2 Solution

But how is all of this possible? There are not many programs available in the market to perform such a task. Mostly you can only calculate single components or simple combinations of elements, but not the whole system with using only one calculation file. A model may contain everything between the engine to the wheels and instead of using fixed structure user may customize his model to meet exactly his needs. Own user interfaces and tables can be created to make settings and calculations which are needful. If you feel that this is exactly what you have to do, KISSsys is the correct program for you to use. And what is the best; with the same model you can also make design, change parameters and test easily different configurations and components.

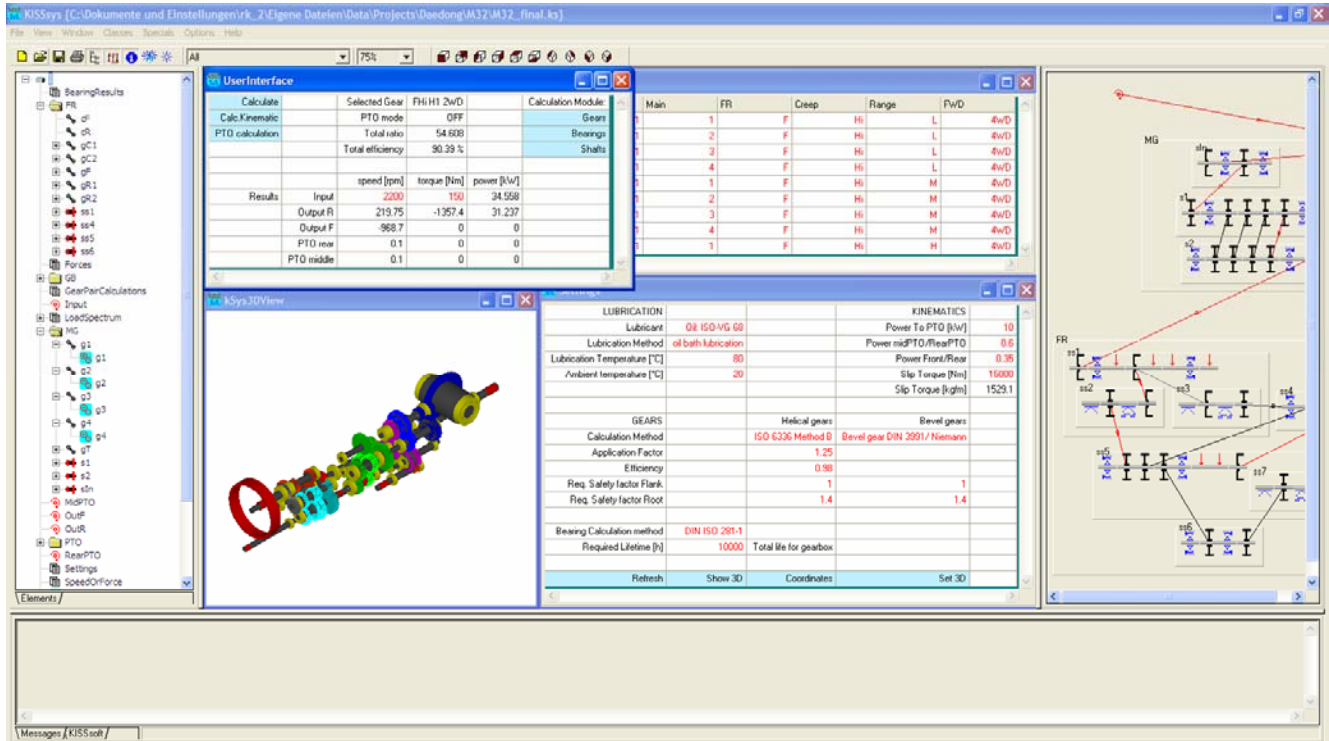


Figure 3.2-1 KISSsys model of the tractor transmission. Left: tree structure. Centre: Tables for user input and results output. Right: schematic.

There is only one lead input from the engine (Diesel), but number of outputs can vary depending on gear and power flow selections. The outputs may be from rear axle, front axle, rear/front/middle PTO, or any combination of those. That gives user a freedom to use any type of power flow distribution in

the same model. The only thing that needs to be defined is how to divide power between the outputs and the program does the rest for you.

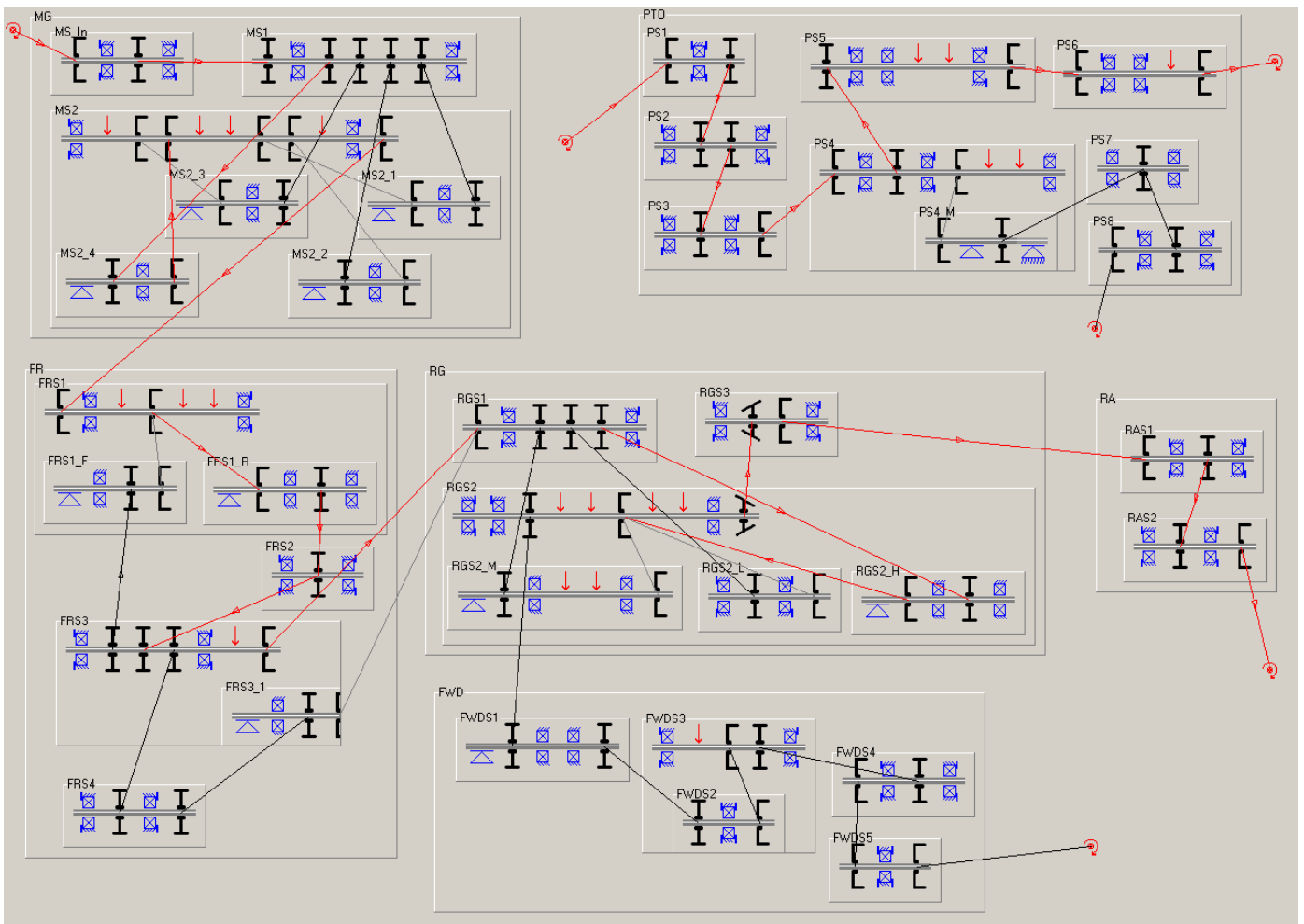


Figure 3.2-2 Kinematics of the transmission

Single nominal load cases as well as different power flows through the drive train can be selected (see Figure 3.2-3) and analyzed in less that a minute. When using a load spectrum, detailed information of each load step results can be exported to Excel and different trends and pictures can be created. Any kind of load spectra can be analyzed, it doesn't matter if the data is collected from the field usage or if it is according to a bench test run. With these load spectra, the user may perform virtual tests and then compare results to the real tests to get feedback and to be able to adjust parameters and required safety factors more precisely. The model can also take into account if the whole power from the diesel engine cannot be transported into the road with the lowest gears (wheels slipping) and calculation can be then performed according to the wheel slip torque instead of the input torque. In that case, according to total efficiency, needed input power is calculated.

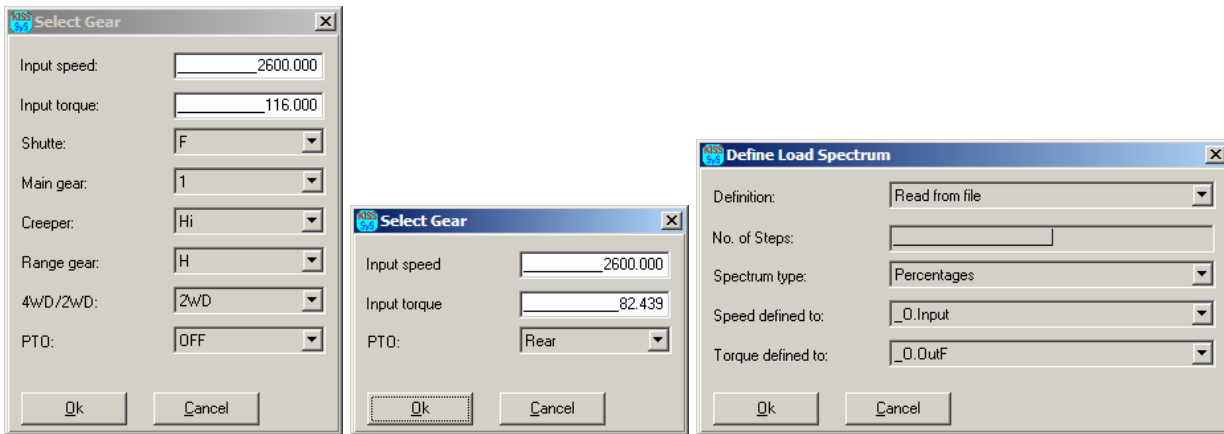


Figure 3.2-3 Load input and settings dialogues. Left: for main transmission. Centre: for PTO. Right: load spectrum import function.

If application has very low gears it may be possible to overload transmission. Thanks to new technology it is possible to make the engine and the transmission to communicate with each other to prevent that to happen. Also with a mechanical engine control, it is necessary to know what may happen to transmission in case of overload. Calculation can therefore also be based on the slip torque instead of the engine input torque. That case weight of vehicle, axle load distribution, friction coefficient, tire size, soil type and some other values may have an effect to what is the maximum torque that can be obtained from the tires to the ground. Then calculation is made with this fixed torque value and needed input torque is then calculated taking also all efficiencies and power losses into account.

4 The calculation model

4.1 Sub-structure modelling

Due to the complexity of the transmission, a sub-structuring modelling technique was applied. The transmission was broken down into several groups, each modelled independently. After that, the groups were joined by connections to form the overall transmissions. Boundary conditions (power input and power output) were then applied to balance the system. Below, the individual groups are shown.

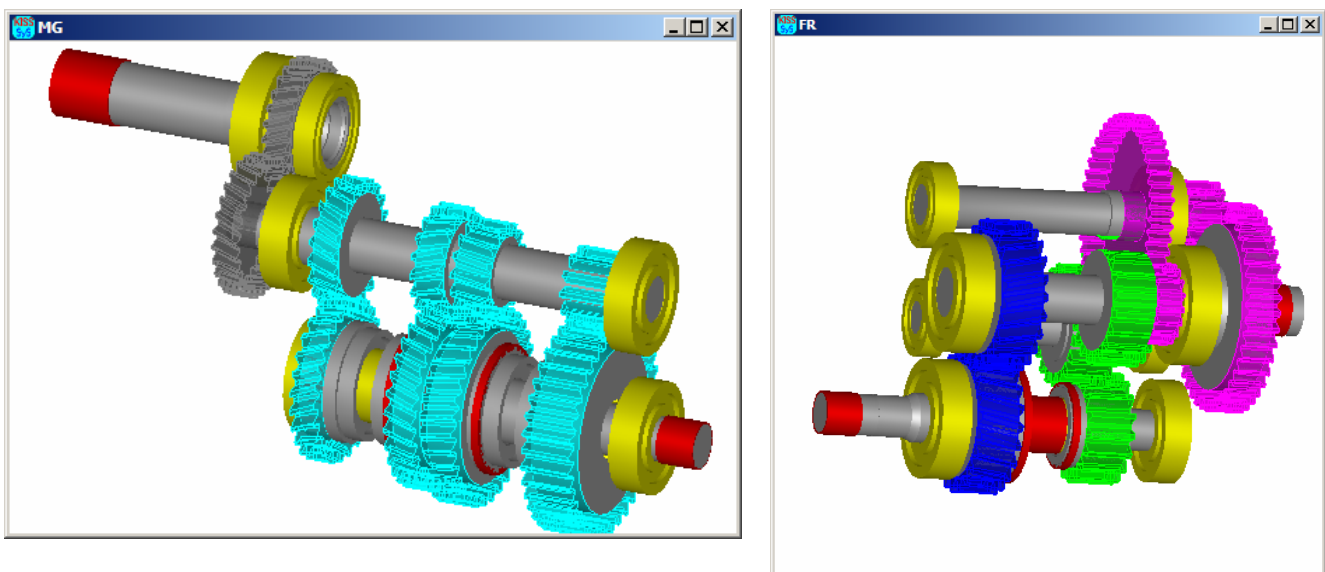


Figure 4.1-1 Left: Main transmission part, speeds one to four. Right: Forward reverse group

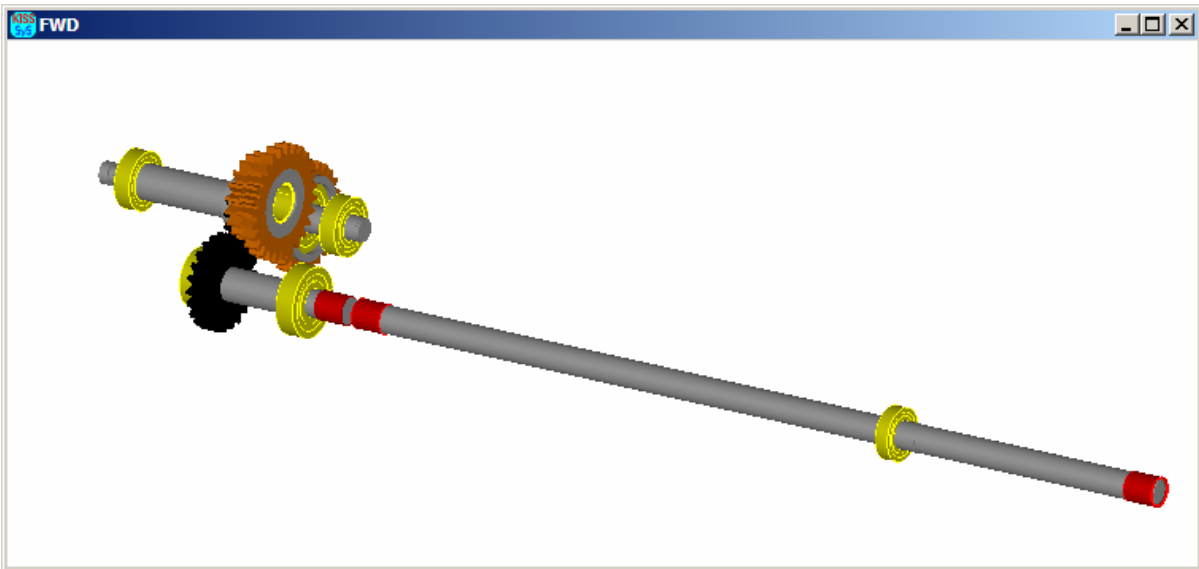


Figure 4.1-2 Front axle drive.

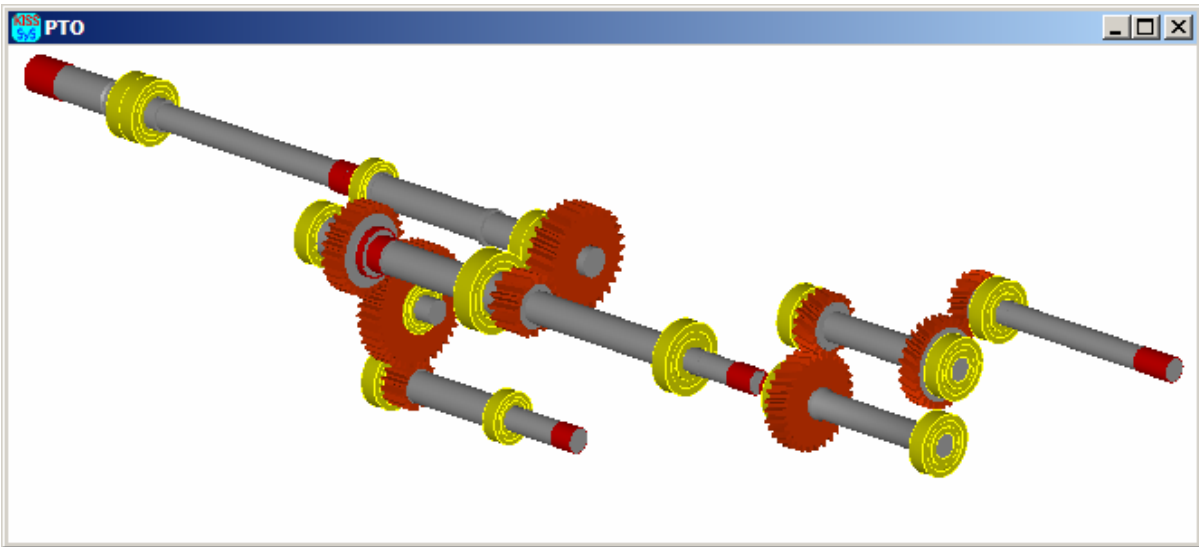


Figure 4.1-3 PTO drivelines, for front, centre and rear PTO

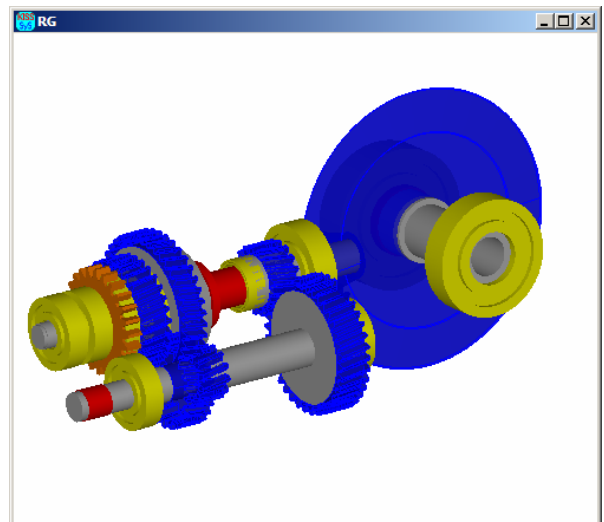
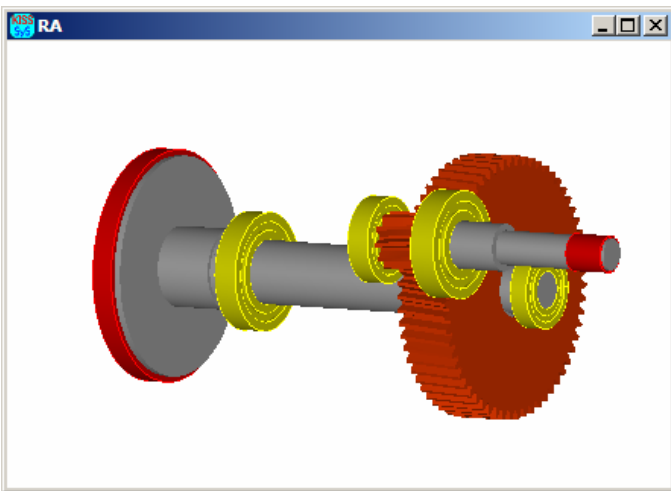


Figure 4.1-4 Left: One side of rear axle assembly. Right: Final drive with rear differential

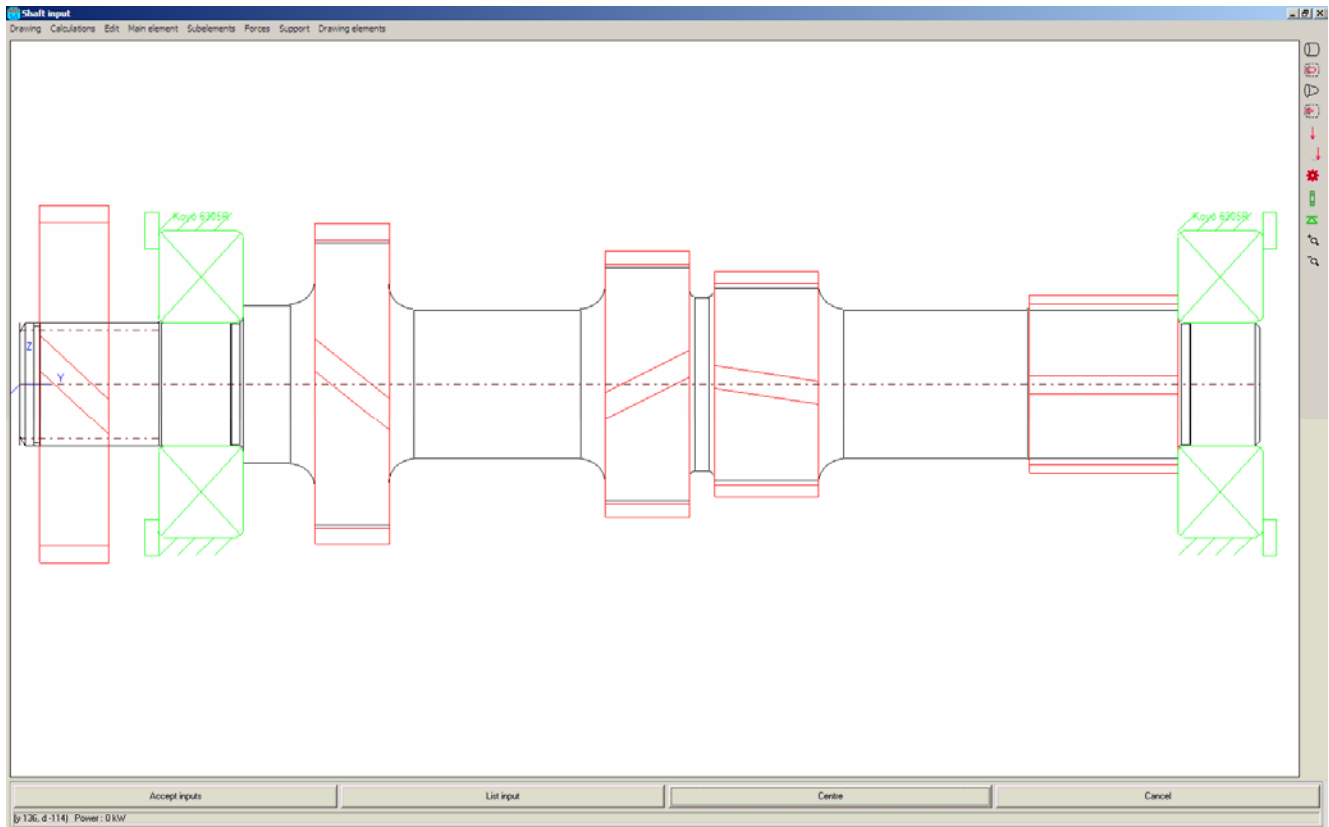


Figure 4.1-5 Modelling of shafts in KISSsoft shaft editor. Arbitrary number of gears can be placed on shafts and up to eight bearings may be modeled.

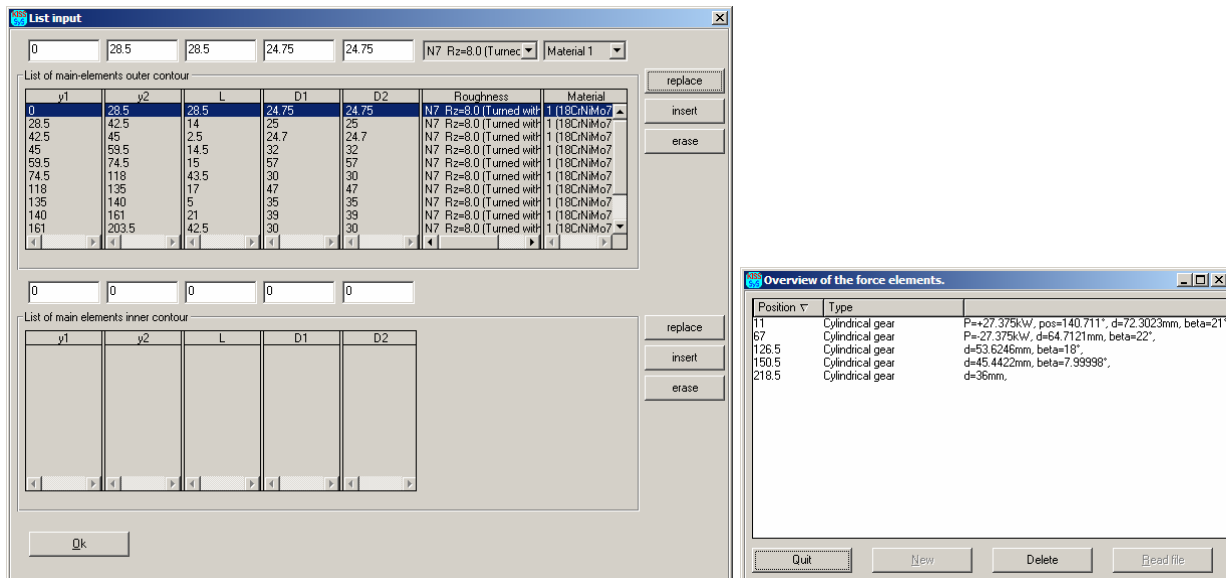


Figure 4.1-6 Left: Shaft geometry editor, Right: shaft force elements editor.

4.2 KISSsys software

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 transmission 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 different criteria.

When designing a transmission, an engineer must carry out an iterative process: Every change of an element of the transmission (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 transmission 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
- Epicyclic gears (planetary, Ravigneaux, Wolfrom, ...)
- Model differential gears (bevel or helical type)
- 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 transmission in the same KISSsys model
- Perform sensitivity analysis automatically
- Automatically generate documentation for a complete transmission analysis
- Use scripting language for automatisisation 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.

4.3 Specialties in the tractor transmission

There are several specialties in tractor transmissions (several gear selections and power flow possibilities, wheel slipping...) which must be taken into account when building up a model and when calculations are performed. These things need some modification for default components and calculations, but it is not a problem to add or modify any of the components easily, because of internal programming language own expressions and functions can be easily created to make model to fit your own needs and to make it do exactly what you want.

4.4 Settings

To apply any global setting for every component separately is not reasonable, that is why there is a "Settings"- table to do that easily. E.g. change of the lubrication temperature can be selected from a drop down list of that table and it is then automatically obtained to all components where it has to be put into. Similarly any other value in the table can be changed and this new input goes directly to all necessary places.

LUBRICATION		KINEMATICS	
Lubricant	Oil: ISO-VG 68	Power To PTO [kW]	10
Lubrication Method	oil bath lubrication	Power midPTD/RearPTD	0.6
Lubrication Temperature [°C]	80	Power Front/Rear	0.35
Ambient temperature [°C]	20	Slip Torque [Nm]	15000
		Slip Torque [kgfm]	1166.6
GEARS		Helical gears	Bevel gears
Calculation Method	ISO 6336 Method B	Bevel gear DIN 3991/ Niemann	
Application Factor	1.25		
Efficiency	0.98		
Req. Safety factor Flank	1		1
Req. Safety factor Root	1.4		1.4
Bearing Calculation method	DIN ISO 281-1		
Required Lifetime [h]	10000	Total life for gearbox	
Refresh	Show 3D	Coordinates	Set 3D

Figure 4.4-1 Setting table for global settings

4.5 Synchronizing gears

There are three different methods to make gear changes. It doesn't matter if gear change is power step type or mechanical, because finally calculation is performed statically and the shifting mechanism itself cannot be simulated.

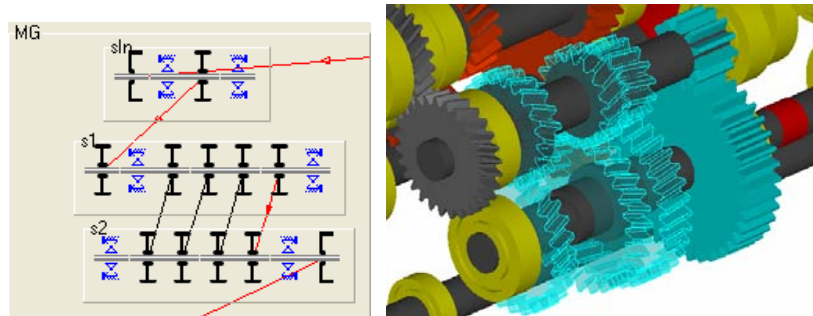


Figure 4.5-1 Gear selections for main gears

If bearings between shafts are not an issue or if there is no bearings to be calculated all gear can be modelled in to shafts and gear connection in each case can be activated or inactivated according to gear selection. Loose and fixed gear can be then defined via KISSsoft mask to determine which gear is reference gear. Speed of reference gear or fixed gear is then defined to be same as the speed of the shaft and the speed of the other gear is calculated according to the ratio.

The loose gears (e.g. power shift or synchro operated) on shafts can be modelled in separate shafts. Forces acting on those gears, when activated, can be obtained to other shaft by iteration. Forces can be "moved" to other place by adding connection between bearing or support and central load. Iteration between shafts gives then correct forces from bearings as well as shaft deflections due to the forces.

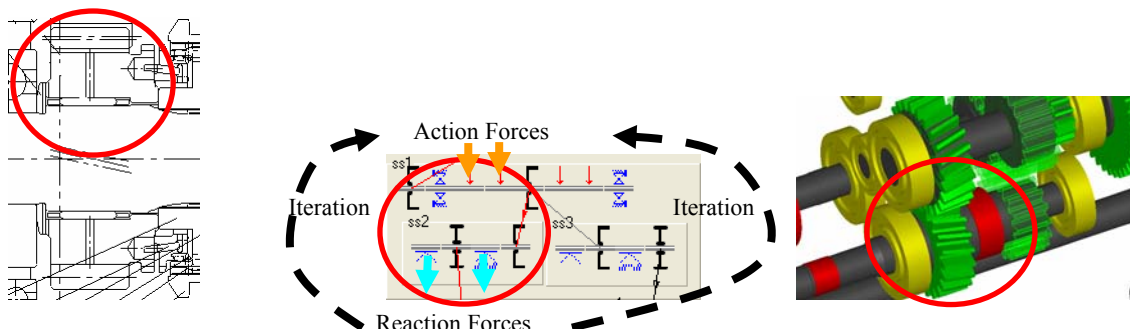


Figure 4.5-2 Moving bearing forces for other shafts

4.6 Bearings between rotating shafts

In that case bearing speeds are not only a speed of inner or outer ring but speed difference between shaft speeds. That can be also easily considered in model and bearing lifetime is then calculated with correct relative speed. For this project “templates” were also modified to make it easier to calculate bearings with correct speed when they are between two shafts and both of them are rotating. Normally outer or inner ring of bearing is considered as fixed in housing in that case it is only needful to determine speed of one shaft. With following dialog it is possible to select two different shafts to determine real bearing speed. Speed is then determined as speed difference between selected shafts. For bearing rating, lubricant properties can be considered and thermal rating can be performed as well. See figures below.

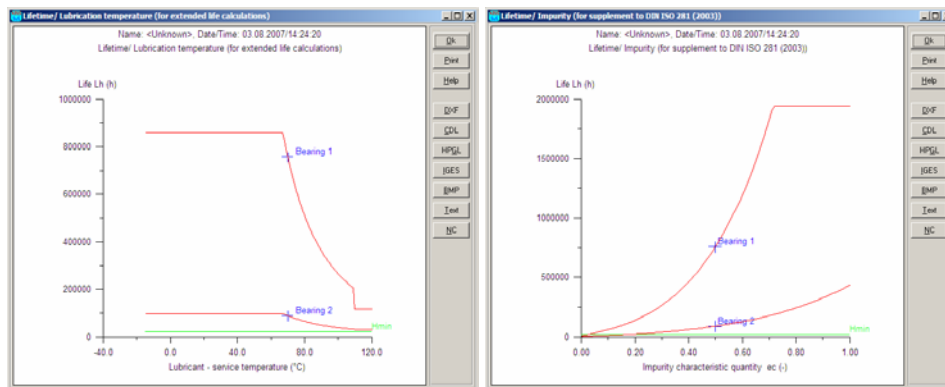


Figure 4.6-1 Bearing life as function of lubricant temperature (left) and oil contamination (right)

	Bearing 1	Bearing 2	Bearing 3	Bearing 4
f0r	2.000000	2.000000	0.000000	0.000000
f1	0.000293	0.000362	0.000000	0.000000
f1r	0.000200	0.000200	0.000000	0.000000
As	4646.416	4646.416	0.000	0.000
P1	1455.800	2216.500	0.000	0.000
Reference speed ntr	16116.581	16116.581		
Permissible speed nt	8262.896	7495.627		

Figure 4.6-2 Thermal rating of bearings, giving permissible speed as a function of bearing friction energy.

Pilot bearings as shown below (schematically) were included in the model were necessary. Shaft stiffness and bearing stiffness may be considered for calculation of resulting bearing forces and shaft deflections in an iterative manner.

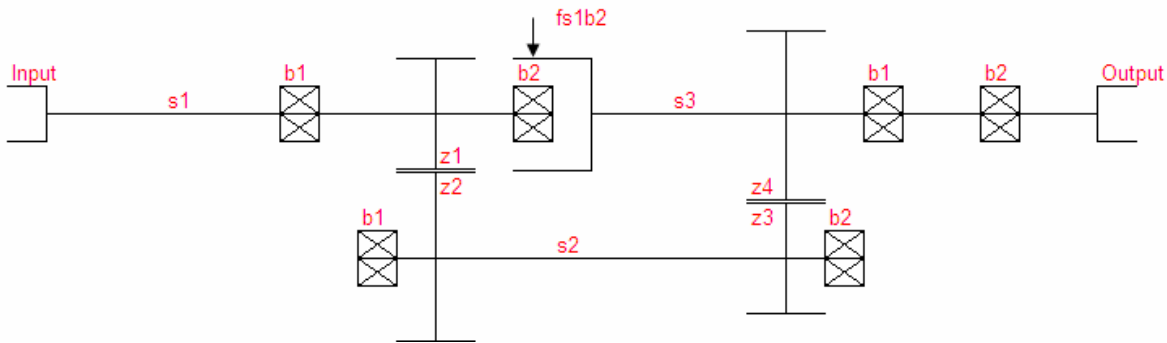


Figure 4.6-3 Schematic of a pilot bearing model in KISSsys.

4.7 Changing power flow and gears

Power flow selection for nominal load calculation can be easily made through only one dialog. All independently selectable gears can be changed. Also “nominal” input speed and torque can be given in same dialog. After these selections the program will calculate whole transmission through and shows results according to selected power flow. See Figure 3.2-3

4.8 Wheel slip

In case if output torque calculated according to input torque is more than defined slip torque program automatically changes input and output definitions and will then calculate according to slip torque when input torque is not anymore given, but determined according to power flow, possible output torque and efficiencies.

KINEMATICS	
Power To PTO [kW]	10
Power midPTO/RearPTO	0.6
Power Front/Rear	0.35
Slip Torque [Nm]	15000

Figure 4.8-1 Defining maximum torque in wheels

4.9 Calculation with the Load Spectrum

It is possible to calculate whole transmission through a spectrum that requires that all gears that can be changed needs to be defined in the table. Calculation with load spectrum is easy with the model once all gears and components are defined for every spectrum step. That means that user may define whole transmission spectrum into one table only and calculation can be then performed to whole transmission with one mouse click. The calculation function will then go through the table line by line and readjust the power flow and saves all results in the variables. The gear selection is changed for every line and in case of some components remain without load it has no effect for total strength calculation because in that case lifetimes or safeties for those components is infinite.

	Frequency	Torque	Speed	Main	FR	Creep	Range	FwD
0	0.01	0.2	1	1	F	Hi	L	4wD
1	0.01	0.25	1	2	F	Hi	L	4wD
2	0.02	0.3	1	3	F	Hi	L	4wD
3	0.11	0.35	1	4	F	Hi	L	4wD
4	0.15	0.4	1	1	F	Hi	M	4wD
5	0.2	0.45	1	2	F	Hi	M	4wD
6	0.15	0.8	1	3	F	Hi	M	4wD
7	0.25	0.8	1	4	F	Hi	M	4wD
8	0.1	0.8	1	1	F	Hi	H	4wD

Figure 4.9-1 User defined load spectrum

Spectrum values can be taken from the field usage or from the test spectrum or from any other course. The calculation is then performed according to this spectrum. Lifetimes and safety factors for the bearings and the gears can be calculated with this spectrum. See chapter 4.11.

4.10 Transmission classification

Grouping things according to functionality, housings or other reasonable interfaces helps to keep model in hand. E.g. possible groups may be shuttle, rear axle, front axle, PTO, main transmission, additional gears.

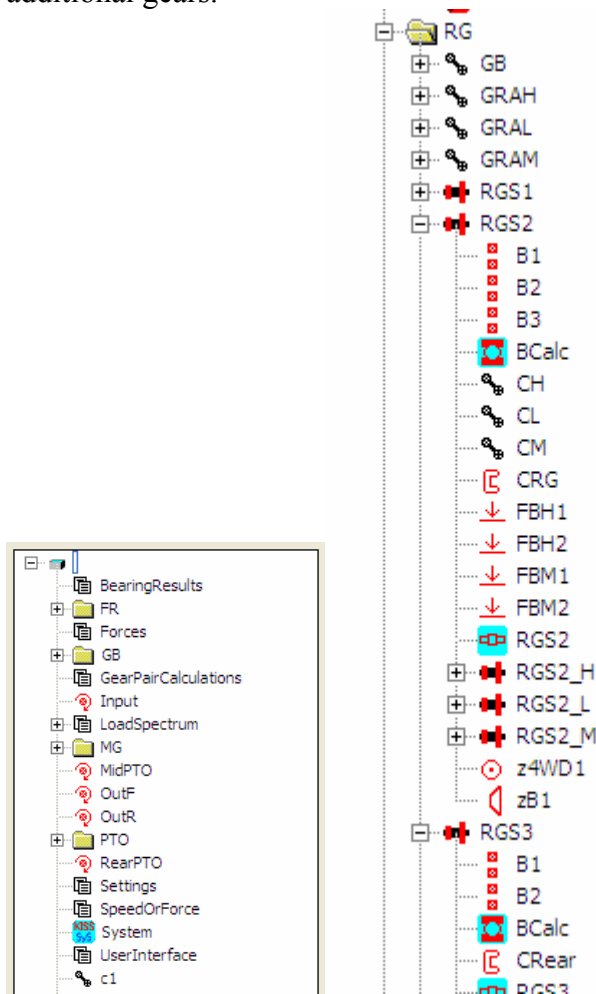


Figure 4.10-1 Model tree for the transmission

Left: The tree structure in KISSsys allows for simple organisation of even the most complex transmissions. In this example, front/rear group was put in one group, the PTO in another, the main gears in the third and rest into group “MG”. Names can be given as appropriate. Additional groups – e.g. for a rear axle – may be added.

Right: Details of shaft RGS2: as can be seen, three bearings (B1-B3) are used on the shaft. Furthermore, gearing forces from superimposed gears (connected to RGS2 shaft by needle bearings) are acting on the shaft. The blue symbols represent KISSsoft calculations associated with the shaft, in this case, it is the calculation RGS2 (for the strength calculation of the shaft itself) and the calculation BCalc for the bearings supporting the shaft.

4.11 Calculation results

After every calculation, a table for calculation results is automatically updated according to the calculations done. User can easily check most important results from the table for the gears and the

bearings. User can also directly see if results are according to “Nominal (single) load” or “Load Spectrum”.

		Results from: Nominal load					
		Lifetime Gears:		Safety factors:		Scuffing safety:	
Gear pair:		Root [h]	Flank [h]	Root [-]	Flank [-]	Integral [-]	Flash [-]
_O.FR.gC1.gC1	Gear1	2.6045e+025	2.6045e+025	9254.4	45.932	10000	10000
	Gear2	7.2007e+025	7.2007e+025	8205.1	49.66		
_O.FR.gC2.gC2	Gear1	7.2007e+025	7.2007e+025	5843.7	33.099	10000	7498.3
	Gear2	2.2156e+026	2.2156e+026	5243.3	37.692		

Figure 4.11-1 Table of results

4.12 Power flow

If you want to see which gears transfer power in different power flow selections, that can be easily made via a dialog where all 3DView settings can be done. User can give a value for threshold or minimum power that can be taken in the account. All gear having bigger load are solid and gear without load are shown in transparent. See figure below.

In case if you want to calculate only with using PTO driveline, when all the power will go through PTO driveline, it is also possible with the model. There is a separate function in “UserInterface” to perform this calculation. New settings for outputs are configured and according to selected power flow for PTO outputs new calculation is performed. This is also one of the strengths of the model. User needs only one model to perform calculations for the whole transmission, the driveline or the PTO driveline only.

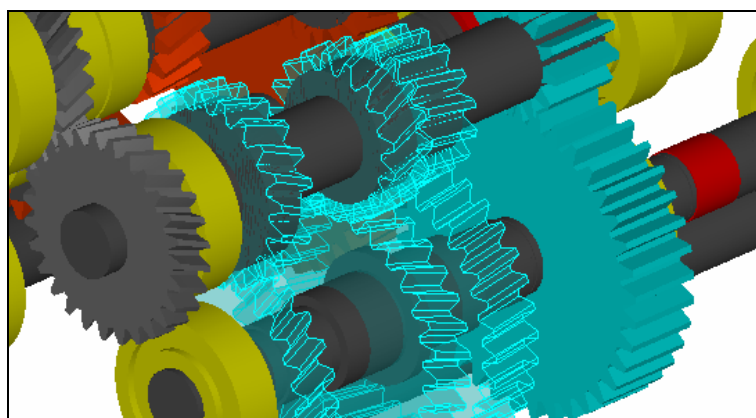


Figure 4.12-1 Power flow. Gears transmitting power are solid, gears transmitting no power are translucent.

4.13 Calculation of meshing frequencies

Based on the number of teeth of the gears and gear speeds, the below Campbell diagram was created. Shown – as a horizontal line is the operational speed. This will inform about the excitation frequencies in the transmission.

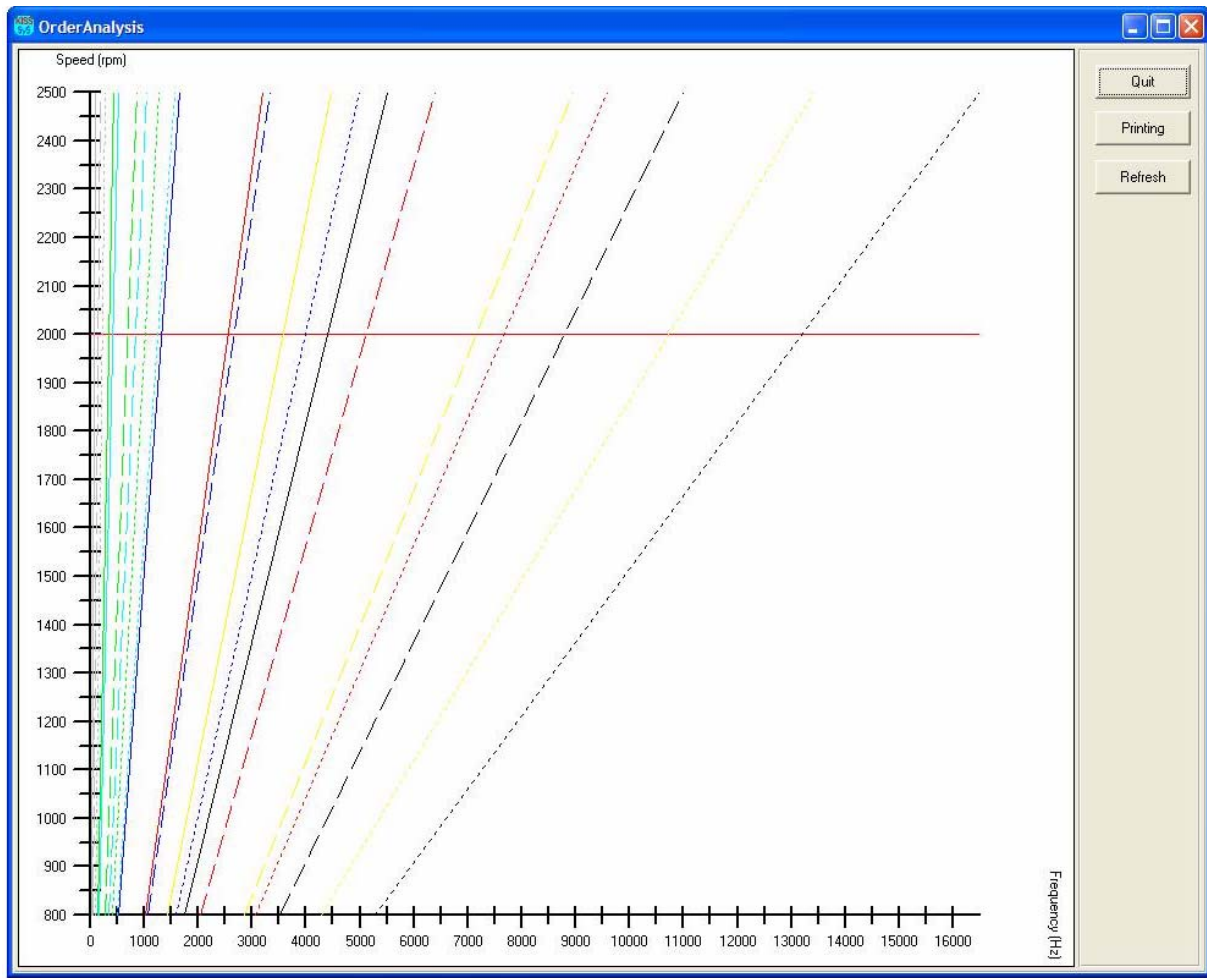


Figure 4.13-1 Meshing frequencies, up to 3rd harmonic shown.

4.14 Export to CAD

Whole transmission model according to KISSsys 3DView can be exported as a step file and can be afterwards opened with any CAD system.

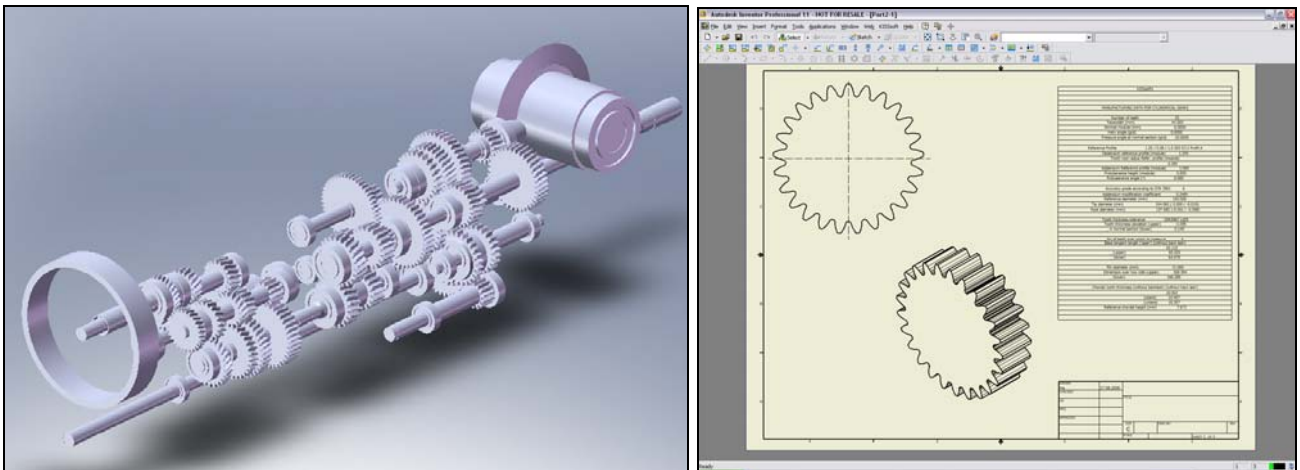


Figure 4.14-1 Exported transmission model opened with SolidWorks. Gear drawing export from KISSsoft.

5 User and customer benefits

Once the model is built, then the user starts to see how powerful it really is. Recalculation of the whole transmission with different power flows and powers will be performed within minutes. To do that by hand or with separate calculations is time consuming and error prone. If we are thinking of doing that all for several load steps, time for building the model and learning to use would be already compensated. This is not only a tool to make basic calculation, because thanks to internal programming language, it is possible to create own functionalities and methods in the model that may have nothing to do with strength calculation e.g. calculate all meshing frequencies. It doesn't matter what type of transmission you want to model and calculate, totally mechanical synchronizer operated, power step - or CVT - type transmission, all are possible. Because the calculation is performed as static manner, only thing you need to know is what are the speed, selected gear, and the input power to perform calculation.

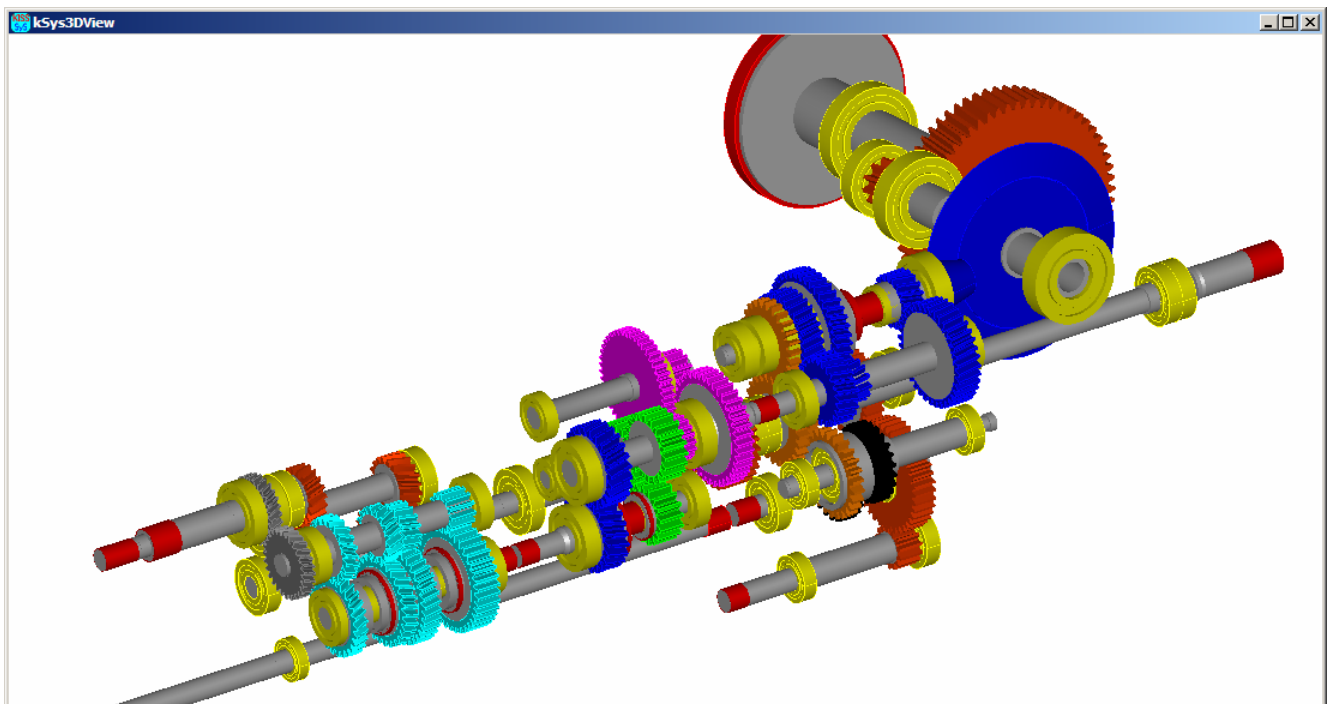


Figure 4.14-1 Handling complex drive trains

Users of this model are very pleased for the program and its capability, because the more complex your transmission is the more you can benefit from the program. This means that if you are in tractor business and because tractor transmissions are one of the most complex transmissions your benefit from the program is guaranteed. Once the model is built the benefit from it can be seen immediately in the very first project. Payback time for your investment is short and engineers will like to work with the model, they can get rid of repetitive, boring tasks.

- Analyze of existing transmission
- Start with totally new transmission design
- Evaluate different layouts by changing component positions
- Check results with different components
- Change power flow via only one dialog
- Change parameters in no time at all and recalculate everything
- Define your own load spectrum and perform calculation with it
- Export whole transmission to CAD system
- Read in ready made KISSsoft files
- Save all necessary information in a one file
- Create easily reports of all calculations
- Check if all components meet the requirements