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Tractor Transmission Design with KISSsys Model

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Abstract

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. Due to the wide variety of gears and speeds that can be chosen, calculations for safety factors and lifetime of components are typically very complicated, time consuming and difficult to manage. It is laborious, unproductive and error-prone to administer the many calculations that occur in a tractor transmission due to its complexity. The use of a calculation model, that simultaneously administrates all the calculations, brings many advantages for the manufacturing process, planning of tests and sales support. A very complex and modern transmission was modeled in this project to be able to simultaneously measure the entire tractor transmission driveline. Tractor with 12x12 driveline shifting system and power flow variations can be calculated the whole system's gears, shafts, bearings with a load spectrum.

Keywords: Tractor gearbox design, KISSsys, KISSsoft, Gear, shaft, bearing

Research Article

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1. Introduction

Specific attention is given to the transmission in the design of a tractor as it constitutes about one third of the total cost of the tractor. The main goal of the development of the transmission is to achieve the optimal traction force as close as possible. The motor must run within an optimal range of revolutions as different driving speeds between 3 and 40 km / h are needed for the different tasks of a tractor. The better this method is done for a wide range of revolutions, the finer the incremental transmission function should be [1]. Because the engine rotates at high speed (a few 1000's of rpm) and the tractor wheels must operate at low speed (a few 10´s of rpm), the traction transmission has the function of reducing the speed of rotation of the engine to that required for the rear wheels. Further, because not all operations require the tractor to travel at the same speed, the transmission also has the function of enabling the speed reduction from engine to wheels to be varied by the operator. This leads to a transmission design with a high number of speeds (up to 64 speeds for a tractor).

A tractor gearbox may have approximately 300 possible kinematic conditions and may have tens of load cases. Also, approximately 50 components and 3000 calculations need to be carried out [2]. In hand calculations, those processes are extremely difficult, and it is not easy to handle iterations to find the best results.

In KISSsys, these many load cases and calculations are handled for single components so that all calculations can be simultaneously controlled. Naturally, a calculation of a tractor gearbox especially with the application of load spectrum, needs time; the calculation time of such a project can amount to an hour [6]. However, the advantage is that it can clearly summarize in tables all lifetimes and safety factors. The results can also be exported to Excel where they could be graphically displayed and evaluated in detail. Any desired load spectrum can be calculated, should they be based upon measurements, synthetically or as test stand spectra values. Under application of these spectra, the user can run virtual tests and compare the calculation results with his/her experience.

Also, calculation of machine elements such as gears, shafts, bearings and shaft-hub connections must, more and more, be carried out faster and in even larger numbers, entirely comprehensible and, at the same time, be better documented. Although the time pressure increases, the susceptibility to errors during the exchange of data between individual calculations, calculation and CAD platforms must not increase during the whole project term. Customer

wishes for changes involving alteration of the constructive implementation of a task are on the order of the day, and multiple calculation steps with reworked assumptions are requested. These increasing demands require a calculation tool which permits, time and again, a quick, sure and still comprehensive sizing of multiple stage drive trains. The graphic, tabular and textual display of the results is of the utmost importance because the designer must have the report writing task simplified and the propositions presented to the customer in a user-friendly way [7]. Through a combination of the KISSsoft machine element design software and the KISSsys system software, the calculation engineer has at his/her disposal a tool that, within the team, solves the stipulated tasks with the required degree of detail in a timely and verifiable way.

The KISSsoft design program was specifically developed for engineers and designers. It simplifies and accelerates the sizing and verification of machine elements under the application of valid standards like ISO, DIN, AGMA, etc... The construction process becomes essentially more efficient, particularly by considering most different design variants. Due to its flexibility, kisssys is a good choice for strength and lifetime analysis of various kinds of drivelines. industrial gearboxes, automotive, construction and agricultural, , power generation and power tool industries etc. are using this tool with their applications. Formula 1 team's sevenforward one-reverse gearbox service life calculation is carried, and gears, shafts and bearings are examined through the kissys model. Large mobile cranes complex gearbox modeled and iterations for different load conditions are calculated. New drive concepts of tractor which has cvt gearbox is modeled and determination of overall efficiency study is performed. Getrag is used kisssys for automatic and manual transmission gearbox for all load conditions. Liebherr calculated camshaft drive design of a diesel engine with kissys [8].

In this paper, a tractor driveline will be analyzed with KISSsys tool. Gears, shafts and bearings model will be built in the tool and recalculated according specific load spectrum. At the end calculated safety factors will be discussed.

2. Project Scope

Türk Traktör driveline system from reverse/forward gear to bevel and pinion gears is modeled in KISSsys tool to recalculate all gears, shafts and bearings with specified load. spectrum. Here below, you may see an example of tractor driveline in Figure 1.

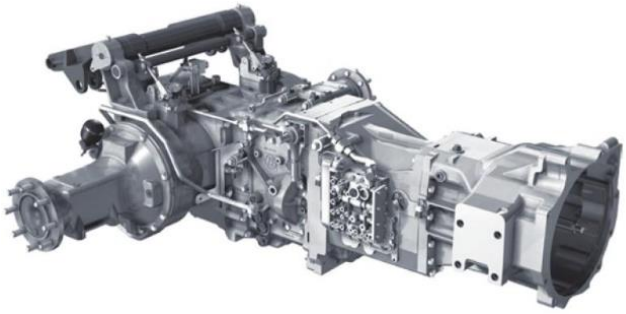

Fig. 1. An example of tractor driveline

For the KISSsys model some basic inputs need to be known such as engine max power, engine speed at max power, engine max torque, engine speed at max torque and tire index for rear, here below in Table 1 summarized all related driveline inputs.

Table 1. Driveline technical specification

Engine Max Power (kW)	Engine Speed @Max Power (rpm)	Engine Max. Torque (Nm)	Engine Speed @Max Torque (rpm)	Tire Index Rear (mm)
55	2300	309	1500	750

2.1 Structure of the Gearbox

There are four speed known as "speed gears", then "range gears" come which 4x3 makes 12 options for the user, then bevel pinion gear is placed in the tractor gearbox. Three of range speeds named as high, medium, low ranges. So, with that 3-speed range options user can drive in any speed option within 0 to 30 kph which is shown as below in Figure 2.

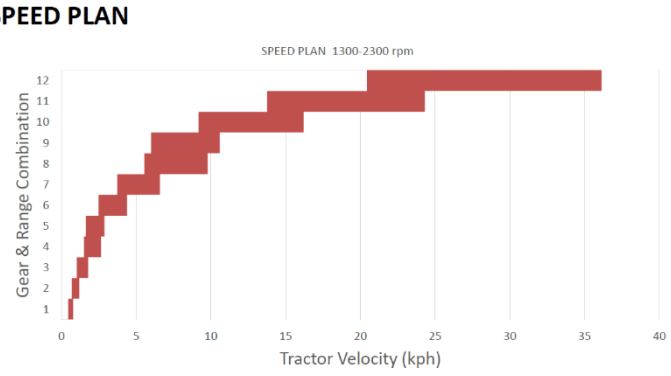

Fig. 2. Tractor gears within 0 to 30 kph tractor velocity

To analyze the system, all the gears must specify in detail such as number of teeth, normal module, normal pressure angle, helix angle at the pitch diameter, hand of helix, center distance, face width, root diameter, tip diameter, addendum shift coefficient, material and gear quality, ratio. Also, all the shafts and bearings are to be well defined such as shaft geometry, material ,bearings and boundary conditions.

2.2. Load spectrum

The tractor driveline should be provided worldwide in the fields of agriculture and construction to different end-users. Therefore, the conditions of application and the loads (e.g. due to soil characteristics) vary considerably from customer to customer [3].

Türk Traktör use a specific cycle to simulate tractor life in the field. KISSsys allows users to type in specific load spectrum input so the model is having specific Türk Traktör 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. The calculation function will then go through the table line by line and read just 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.

Description of the model

KISSsys uses KISSsoft for the lifetime calculations of the various machine elements. KISSsoft is a CAE tool for 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, and DIN) or well recognized and accepted literature [9].

Every change of an element of the transmission influences most other parts (e.g. the bearing loads). Checking these influences by manual calculation is slow and prone to errors. 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. Here below the Figure 3 for related driveline.

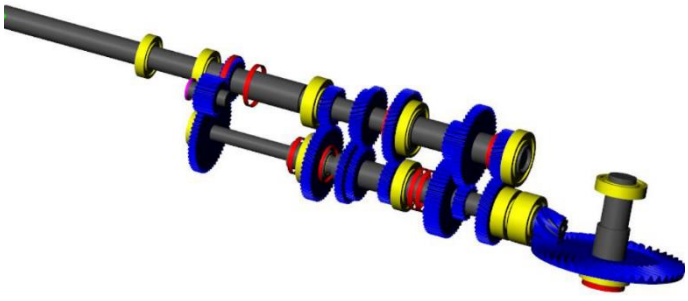

Fig. 3. KISSsys model of driveline

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 [4]. Below shows in Figure 4 related kinematic diagram.

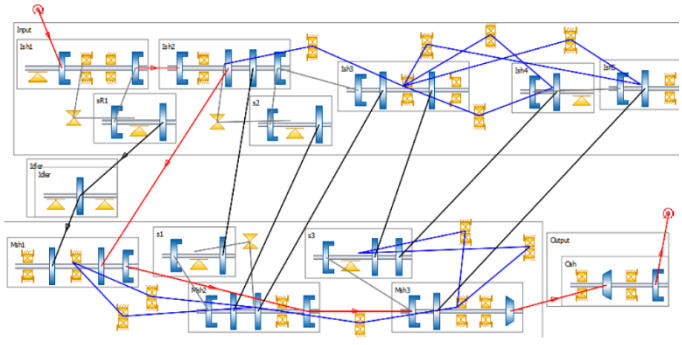

Fig. 4. KISSsys kinematic diagram of driveline

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.

In KISSsys tool, grouping things according to functionality, housings or other reasonable interfaces helps to keep model in hand. The tree structure in KISSsys allows for simple organisation of even the most complex transmissions. Below is the related driveline model tree in KISSsys in Figure 5.

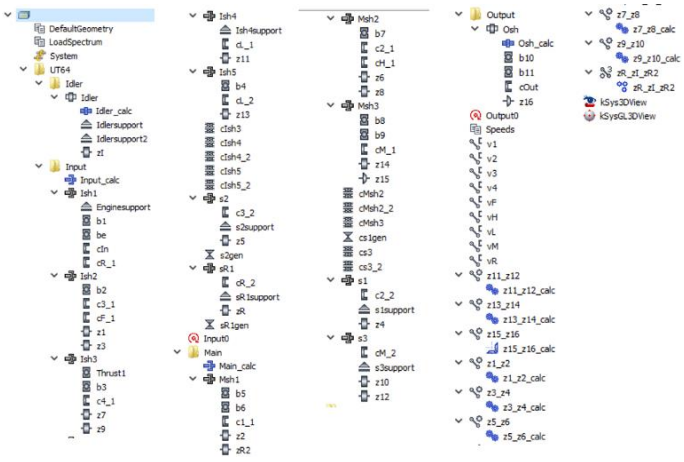

Fig. 5. KISSsys model tree of driveline

(2)

4. Analysis Results

After model is set with all required information such as gears, shafts, bearing geometry material positions. Load conditions will be applied via specific load spectrum for each shifting scenario.

The calculated lifetimes with specified load spectrum for bearings are shown in Table 2. Bearing lifetime needs to be greater than the company limit lifetime in order to satify the tractor service life.

Table 2. Bearing lifetime investigation

Bearing Type	Bearing Name in KISSsys	Total Lifetime (h)
SKF 6210	b1	10000
SKF 6209	be	10000
SKF 6309	b2	126744
Koyo TP4565	Thrust1	4607
SKF 6014	b3	115759
SKF 6212-2Z	b4	68316
SKF 6306	b5	171827
SKF 6211	b6	338841
SKF 6212	b7	69604
SKF 31309 J2/QCL7C	b8	10000
SKF 32309 BRJ2/QCL7C	b9	4267
SKF 32013 X/Q	b10	6553

SKF 30211 J2/Q	b11	844592
INA K35X45X20	cIsh3	42307
INA K45X52X18	cIsh4	10517
INA K45X52X18	cIsh4_2	10395
INA K40X48X20	cIsh5	2314
INA K40X48X20	cIsh5_2	117314
INA K35X42X20	cMsh2	581814
INA K35X42X20	cMsh2_2	175595
INA K25X35X20	cMsh3	997559
INA K40X45X27	cs3	6448
INA K40X45X27	cs3_2	6076

For input shaft according to the related load spectrum strength investigation @max input torque at critical load condition FH4. Minimum fatigue safety @E-E cross section, also minimum static safety is occurred @F-F cross section. Here below it is summarized in Figure 6.

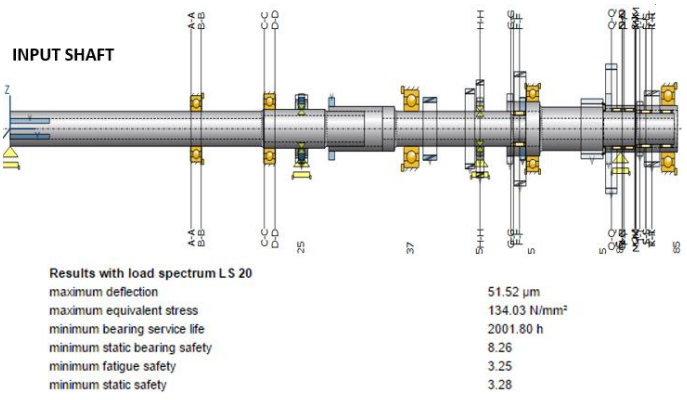

Fig. 6. Input shaft safeties at critical cross section

For main shaft is also investigated at critical load condition which is FL1 gear. Figure 7 show the analysis results as below.

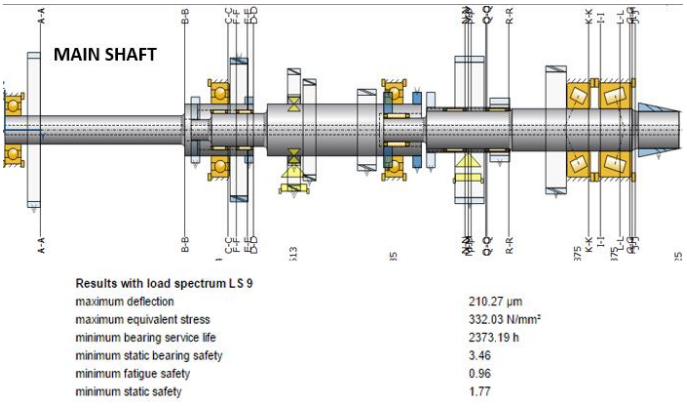

Fig. 7. Main shaft safeties at critical cross section

For output shaft is also investigated at critical load condition which is FL1 gear. Figure 8 show the analysis results as below

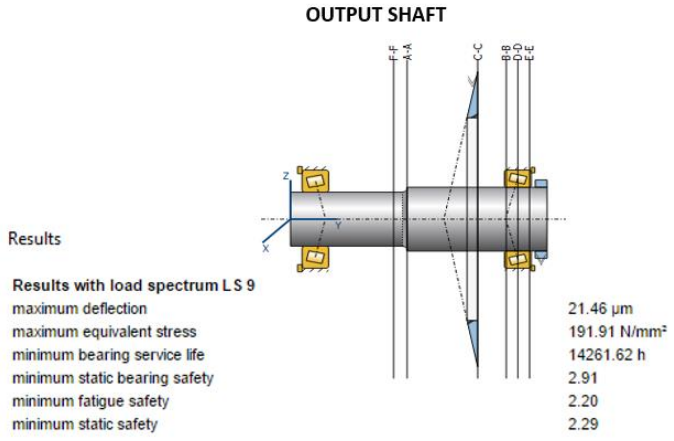

Fig. 8. Output shaft safeties at critical cross section

Lastly, for all the gear pairs here below in Table 3, see Flank safeties-SH, and Root safeties-SF according to load spectrum. Root safety factor bigger than 1,2 and Flank safety are to be bigger than 1.0 may be the acceptance criteria.

Table 3. Calculated gear safeties

Gear	SF Root safety	SH Flank safety
Z_reverse1	3.028	1.691
Z_idler	2.269	1.591
Z_reverse2	2.464	1.743
Z1_shift1	2.336	1.678
Z2_shift1	2.175	1.77
Z3_shift2	2.106	1.664
Z4_shift2	2.018	1.707
Z5_shift3	1.662	1.59
Z6_shift3	2.356	1.57
Z7_shift4	2.353	1.679
Z8_shift4	2.631	1.598
Z9_rangehigh	2.159	1.413
Z10_rangehigh	1.972	1.531
Z11_rangemedium	1.548	1.343
Z12_rangemedium	2.413	1.214
Z13_rangelow	1.668	1.449
Z14_rangelow	1.562	1.494
Z15_bevel pinion	1.295	1.03
Z16_ bevel pinion	0.928	1.162

5. Conclusions

This paper discusses in detail the design and duty cycle analysis of gears and shafts also selection of bearing for 12 forward speeds and 12 reverse speeds gearbox of tractor application. Given gear ratios are tailored specifically for tractor application. Gears are analyzed for safety parameters like root safety, flank safety by using KISSsoft software. According to the analysis results z15 and z16 bevel pinion gear couple seems need more attention for root and flank safety results which are at the limit of the related safeties. Alternative gear face width, gear quality or material can be reconsidered to be at the safe side. Additionally, shaft is analyzed for its minimum fatigue safeties and minimum static safeties. Bearings are analyzed for their total lifetimes. Also, correlation study needs to be done between model and the real component to see the KISSsys model convergence of the real life.

The objective of a current gearbox modeling of a tractor is to achieve the required (in the range of a few hours) lifetime with safe operation. 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 or different load spectra) after having modified e.g. the form of a tooth or using. Furthermore, it is very useful for the user to be able to analyze the gear box for different conditions and model of tractor virtually simultaneously.

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Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Müjdat Ersarı: Conceptualization Formal analysis,Investigation, Methodology, Writing - original draft
Selahattin Sarı: Conceptualization,Supervision,
Ali İlker Tuğru: Visualisation, Writing - review & editing
Hüseyin Erkek: Visualisation, Writing - review & editing

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