

Optimising a transmission for use with higher hp engine

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Tractor Case Study 2015

1. Optimising a transmission for use with higher hp engine



Figure 1.1-1: TAFE is second largest tractor manufacturer by volume in India.

1.1 Objective of the project

Fitting a stronger motor to a tractor raises the question of torque capability of the transmission and how it can be optimised in a given design space to cope with the increased torque. Furthermore, vibration levels must be lowered or maintained and aspects of manufacturing like tool commonisation are to be considered. The transmission shown below is an existing design originally used with a 45hp motor. Key features of the transmission are:

Configuration	Transmission: Forward / reverse, low / high range, four speeds Axle: Bevel gear set and planetary final drive
Power rating	Using clubbed load spectrum covering all ten speeds
Technology	Modified, shaved high addendum helical gears. Gleason type ground spiral bevel gear. Spur gear planetary set in axle.



Figure 1.1-2: Transmission with rear axle and motor mount ready for final assembly.

1.2 TAFE TMTL

TAFE Motors and Tractors Limited (TMTL), a wholly owned subsidiary of TAFE – Tractors and Farm Equipment Limited, consists of three manufacturing divisions, the Tractors Division, the Engines Division and the Transmissions Division. The tractor manufacturing division caters to the dynamic market demands and needs of the modern farmers, with a comprehensive range of tractors and implements. The top-of-the-line Research and Development facility is capable of designing and developing new tractor models with its in-house prototype development and tooling/manufacturing competencies, setting high standards in the industry. The third largest tractor manufacturer in the world and the second largest in India by volumes, TAFE is India's largest exporter of tractors, powering farms in over 75 countries including developed countries in Europe and the Americas. Offering a selection of tractors of superior technology that help their customers reap maximum productivity, be it on the field or in industrial applications, their impressive product line includes tractors under three iconic brands - Massey Ferguson, TAFE and Eicher.

1.3 EES KISSsoft GmbH

EES is a Switzerland based consultant to the gear industry and distributor of KISSsoft software in Asia including India. It is an independent entity run by Mr. Hanspeter Dinner focusing on Engineering, Education and Software (hence the name EES). It was founded some seven years ago and has since worked on about 70 different projects related to gearing, bearings or complete gearboxes. Industries served include wind, mill drives (cement and others), aviation, off highway vehicles and actuators including plastic gears. The areas of expertise include gear geometry, gear modifications, gear strength as well as bearing analysis. Tools used are KISSsoft gear software along with FEM combined with manual textbook calculations. Furthermore, KISSsoft offers test witnessing and assessment as well as certification assistance. Visit www.EES-KISSsoft.ch for further information.



Figure 1.3-1: Test driving the tractor in India.

2. Scope of works and technological advances

2.1 Gear micro geometry

In the rear axle, a planet gear is used as a final reduction stage. TMTL wanted to minimise the vibrations in this stage and improve the power density without changes on the carrier design. EES proposed a change in number of teeth allowing for a higher contact ratio and higher strength while maintaining the ratio and the centre distance. Appropriate helix angle modification on the sun and crowning on the planets were applied. The required helix angle modification was minimised by balancing the sun shaft torsion stiffness and the carrier stiffness so that the deformations would compensate each other as far as possible.

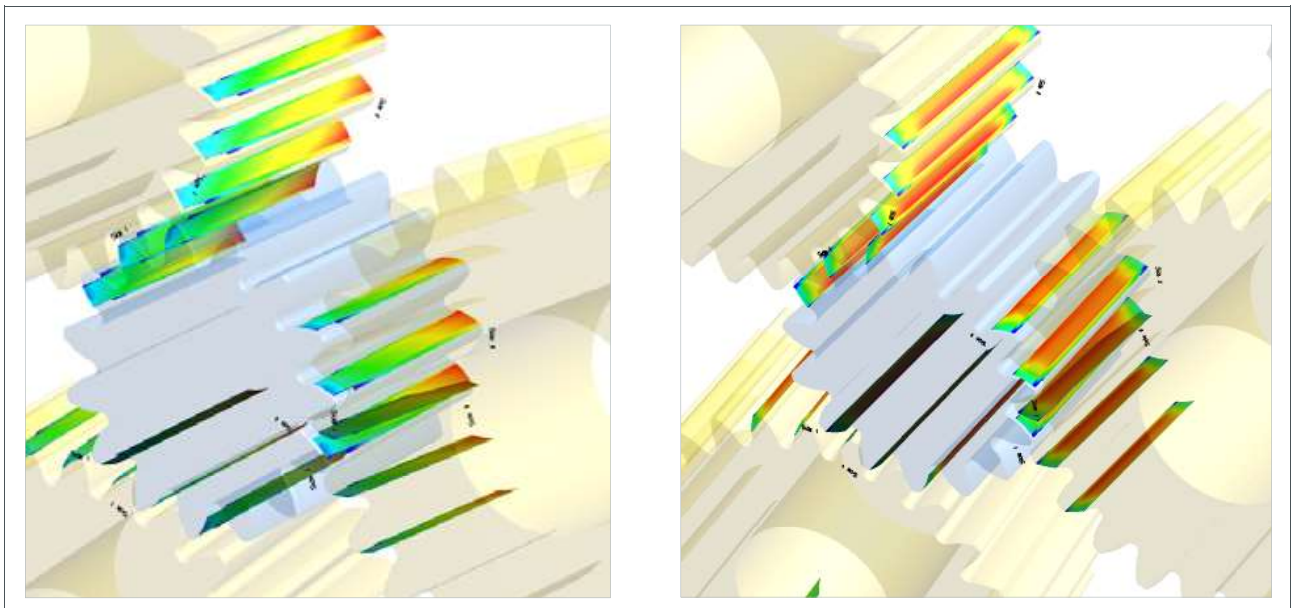


Figure 2.1-1: TAFE is second largest tractor manufacturer by volume in India Load distribution in planetary gear set. Left: before optimization. Right: after optimization.

2.2 Bearing optimisation

Some of the bearings displayed highly uneven stress distributions along the roller length, due to the bending or tilting of the underlying shaft. In particular the planetary bearings showed elevated stress levels due to the increased motor torque and an alternative bearing design was proposed.

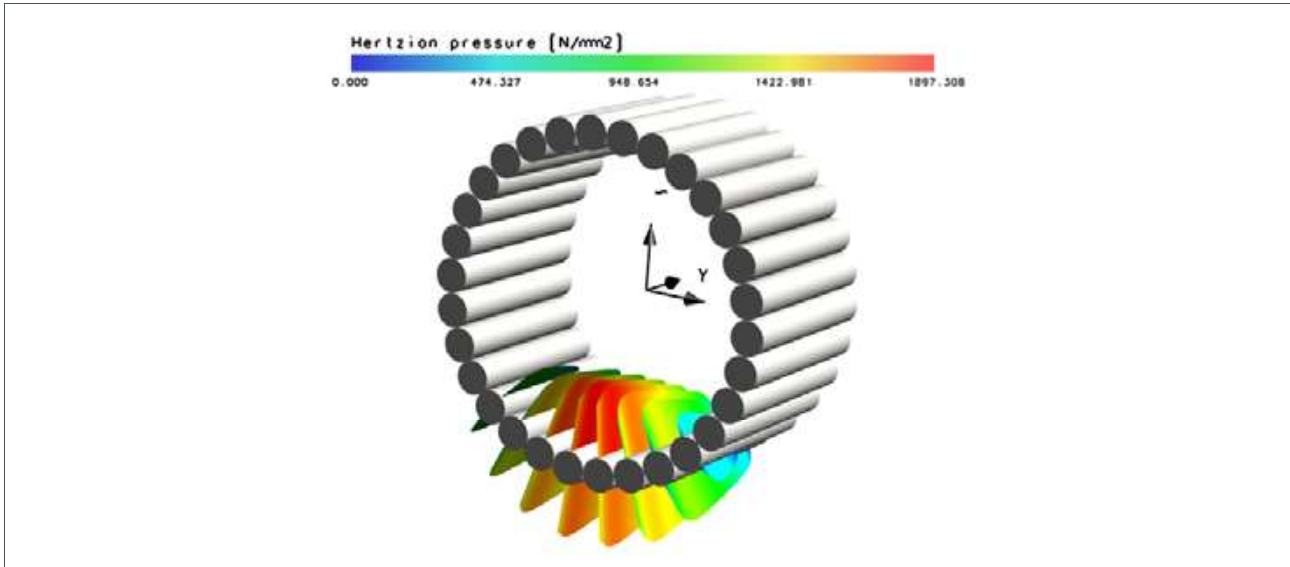


Figure 2.2-1: Uneven stress distribution resulting in peak stresses in planet needle bearing due to bending of planet pin.

As a proposal to the bearing manufacturer, EES designed an alternative needle bearing with higher capacity based on ISO 281. The design was also checked and found to give considerably lower contact stresses to the inner race along ISO TS 16281.

Tractor Transmission 557									
TMTL									
15-005									
15-005-PM-0001-0									
Current needle bearing design for planetary needle				Modified needle bearing design for planetary needle					
Dataset	15-005-Planetary-Needle-Bearing			Dataset	15-005-Planetary-Needle-Bearing-Modified				
File	15-115-Planetary-Needle-Bearing.kds			File	15-115-Planetary-Needle-Bearing-Modified.kds				
Folder	C:\HD\20-Projekte\15-005-TMTL\20-Planet-Needle-Design			Folder	C:\HD\20-Projekte\15-005-TMTL\20-Planet-Needle-Design				
Inner dia	d	mm	30.1	Inner dia	d	mm	33.46		
Outer dia	D	mm	37.1	Outer dia	D	mm	40.46		
Width	B	mm	19.8	Width	B	mm	21.5		
Basic rating	C	kN	46.774	As per supplier	Basic rating	C	kN		
Static rating	C0	kN	46.774	As per supplier	Static rating	C0	kN		
Number of r/z			30	Number of r/z			33		
Roller dia	Dw	mm	3.5	Roller dia	Dw	mm	3.5		
PCD	DPW	mm	33.6	PCD	DPW	mm	36.96		
Eff. Length	LWE	mm	19.8	Eff. Length	LWE	mm	21.5		
bm factor	bm		1	For needle cages, ISO281	bm factor	bm	1	For needle cages, ISO281	
Aspect ratio	Dwe/Dpw		0.10416667	Aspect ratio	Dwe/Dpw		0.09469697		
fc factor	fc		84.2	fc factor	fc		84.2		
Load rating	CR	kN	42	as per ISO281	Load rating	CR	kN	48	as per ISO281
Resulting planet pin dia	mm		30.1	Planet pin dia as it is	Resulting planet pin dia	mm	33.46	Planet pin dia needs char	
Load rating, supplier	kN		47	Load rating, supplier	kN		53.56	Scaled value	

Figure 2.2-2: Redesign of planet needle bearings to achieve higher capacity in almost same design space

2.3 Materials, manufacturing and surface treatment

To streamline manufacturing, the design of some of the helical was changed so that fewer hobs are required for manufacturing. Also, the hob shape was optimised to increase root strength. Requirements on drawings were made more specific in terms of manufacturing processes, allowing TAFE to more tightly control the manufacturing outsourced to suppliers. A more detailed gear and tool data table for use on manufacturing drawings was defined. Furthermore, more stringent material definitions including requirements on steel cleanliness levels, grain size, area reduction ratio and others were defined to comply with ISO 6336-5 type MQ material grade.

The effect of shot peening to induce compressive residual stresses was investigated, however, may be applied at a later stage only.

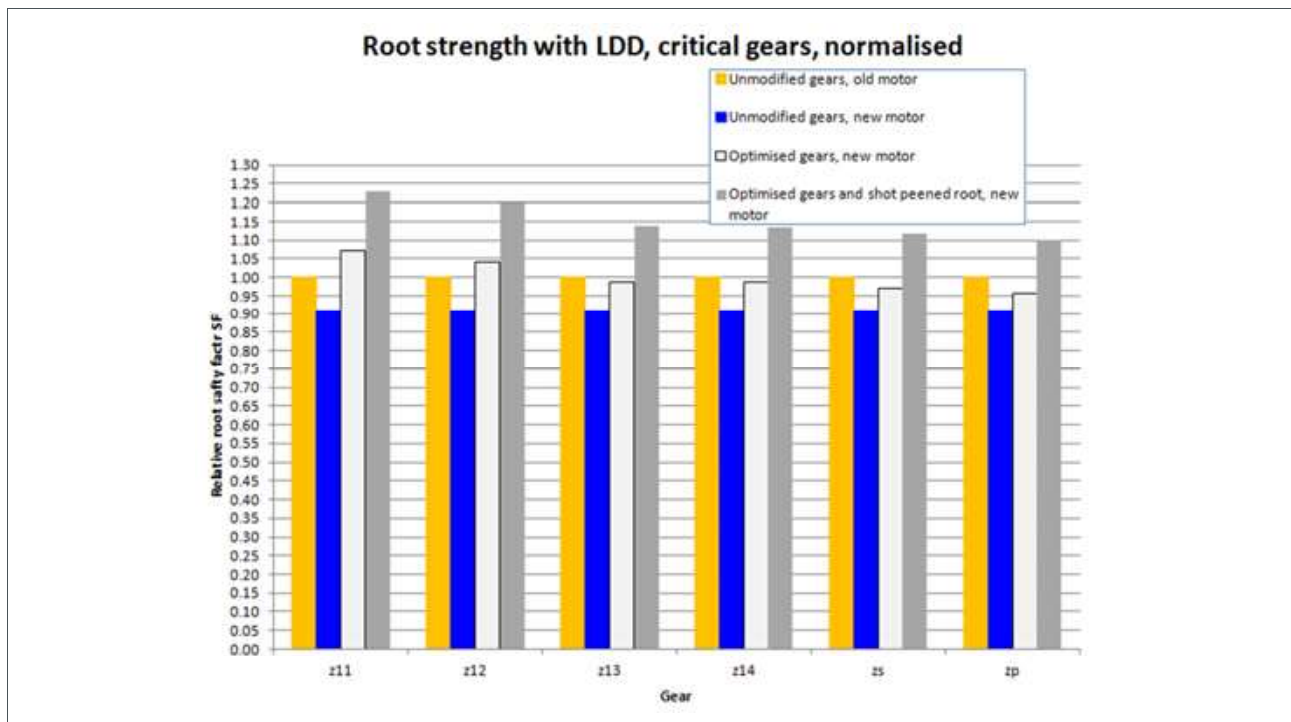


Figure 2.3-1: Strength changes / improvements of most highly stressed gears due to motor change and due to design improvements.

2.4 Load data analysis

Raw load data was provided in the form of extensive load duration distributions (LDD). The number of load bins was very high, requiring clubbing of the bins. In particular load bins with lower torque levels were clubbed while the bins with higher torque levels were used as provided. This ensures that all critical torque levels are investigated in detail and it also ensures that the overall damage values – which are governed mostly by the bins with high load – remain accurate.

2.5 KISSsys and KISSsoft modelling

All strength calculations with the load spectrum were executed using a complete transmission model (including rear axle and two speed PTO). Partial damages were calculated for each bin in the load spectrum separately to identify critical bins, allowing for optimisation of the gears and bearings for the corresponding load levels. Training on KISSsys usage was part of the know how transfer of the project.

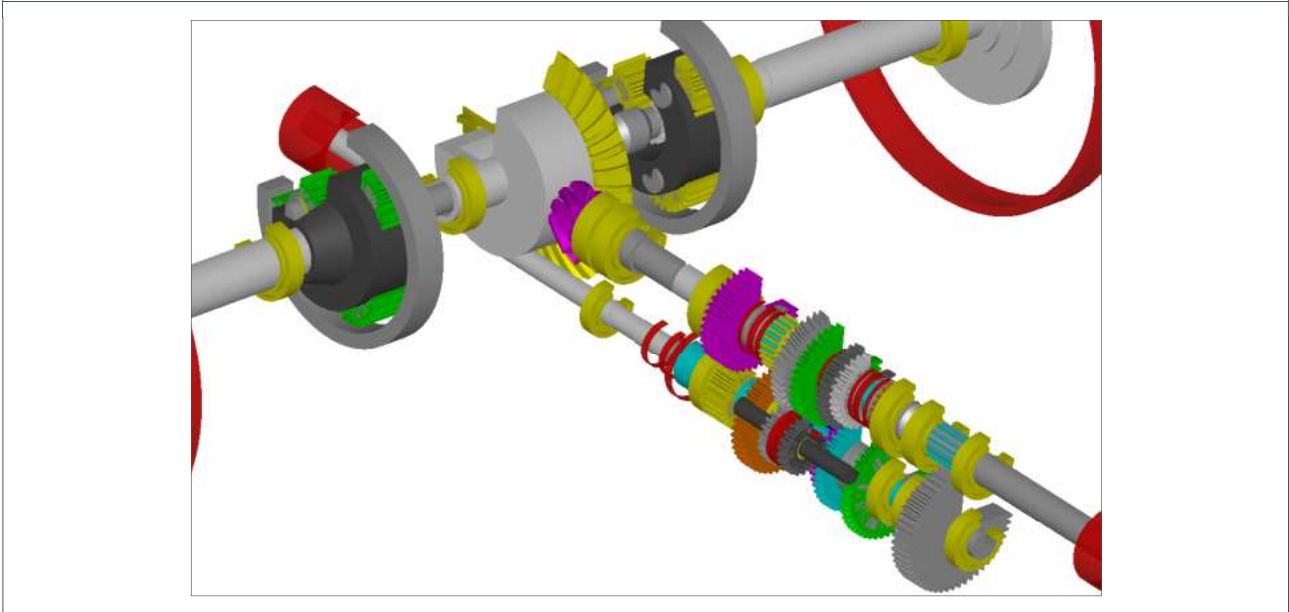
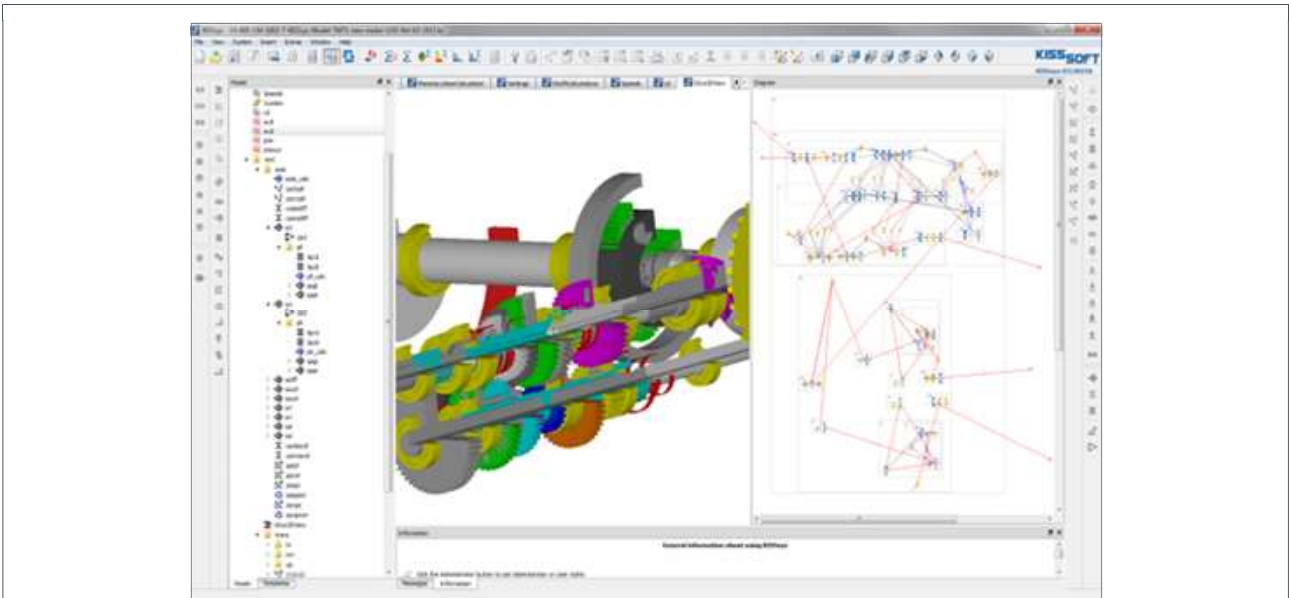


Figure 2.5-1: Upper: Full KISSsys model with power flow schematic.
 Lower: 3D view of model with transmission and rear axle as well as PTO.

Complex coaxial shaft models were established in KISSsoft to accurately consider not only the bearing operating clearance but also the shaft bending when checking bearing stress concentrations. Some of the bearings required modifications (e.g. changes in clearance or higher capacity). Furthermore, shaft deformation has a considerable effect on the tooth contact patterns. Those were optimized by applying suitable crowning values to ensure a good load distribution over a wide range of torque levels and corresponding shaft bending.

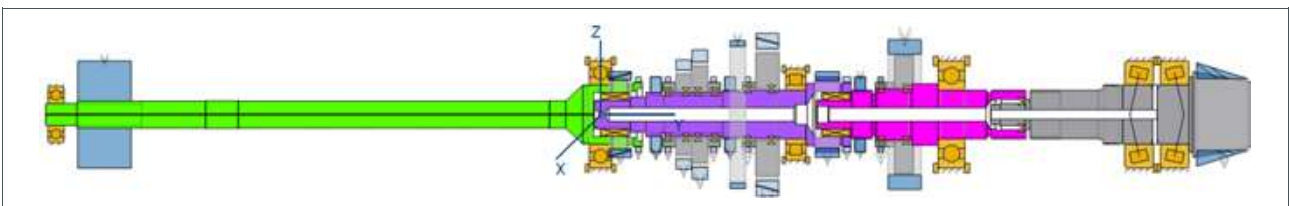


Figure 2.5-2: Typical shaft system where shafts are connected by pilot bearings. Modeling in KISSsoft shaft editor.

3. Conclusion

The project was as challenging as any tractor transmission project, covering aspects of load data synthesis, gear manufacturing, bevel gear technology, planetary gear tooth contact analysis and software training. Key to the success was an efficient communication.

“We managed to fit a new motor with considerably higher torque to the existing transmission with changing only gear geometry, some technology parameters and controlling some machining parameters more closely from design side. Also, some bearings required changed or we designed them ourselves. Thanks to EES we are now also changing our drawing templates and are monitoring tool data more closely as we have seen how important this is on the gear design. We were most happy with the speedy response and technical insights shared and hope to do further projects with Mr. Hanspeter in the future”.

M. D. Shelar, Chief Engineer Transmission R&D, Eicher Tractors

“Working on tractor transmissions is always fun and challenging, there is no other vehicle having that many gears in such a small space. Also, looking at cylindrical, planetary and bevel gear at the same time reminds us of how important the manufacturing aspects are, they are always different for these three types of gears. I trust I was able to calculate awareness of the influence of manufacturing on design and vice versa. Working with TMTL team was refreshing and I enjoyed the interaction much, especially the test drive!”

H. Dinner, EES KISSsoft GmbH

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