HiPerMax®
LuK tooth chain for transmissions

Reliable Power Flow in the Drive Train

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Introduction

A modern drive train cannot be imagined without the use of chains. There are wide ranges of possible applications, starting with the engine timing chain, the transmission chain or the transfer chain for the four-wheel drive train (figure 1). Increasing power densities and requirements with regard to space and weight are forcing the use of chains for various applications. Increasing engine performance levels are also causing an increase in the proportion of four-wheel drive vehicles in the market so that the power can be put on the road safely.

The question arises, as to whether the progress achieved in the development of the CVT-chain, can be transferred to the development of a four-wheel drive chain and whether, at the same time, it is possible to exceed the characteristics of the products already in the market.

Figure 2 shows various possible utilisations of the toothed chain. Its use in the transfer case of four-wheel drive vehicles, the toothed transmission chain, and the application in hybrid drive trains, to overcome the axle distance between the electric drive or gearbox and the drive axle, should be mentioned.

The customer's most important technical demands are achieving the required chain strength combined with a low degree of chain elongation. At the same time, good acoustic characteristics should be realised. The advantages of a narrower width of the chain have a positive effect on the space required for the gearbox in the vehicle.

From the CVT Chain to the Toothed Chain

The use of rocker joints is a common feature of the CVT- and the LuK toothed chain. Rocker joints are particularly suitable when high degrees of efficiency combined with high strength of the chain are required. The rocker joints and the contact area between the rocker pin and the link have been subject to constant further developments within the scope of CVT development with the

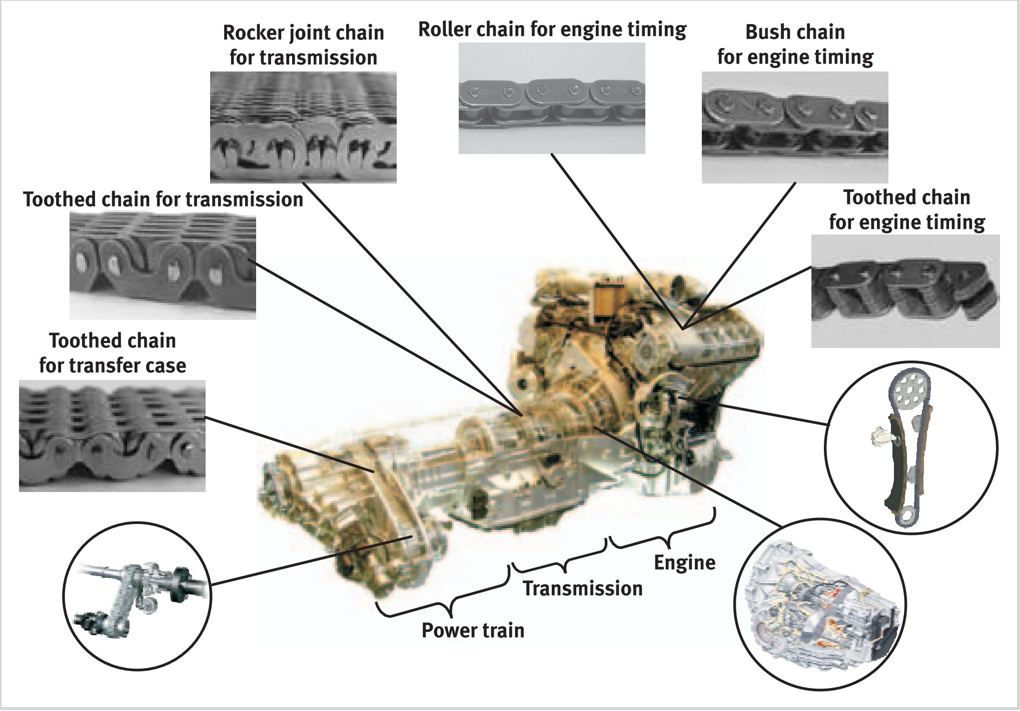


Figure 1 Areas of applications of chains in the vehicle

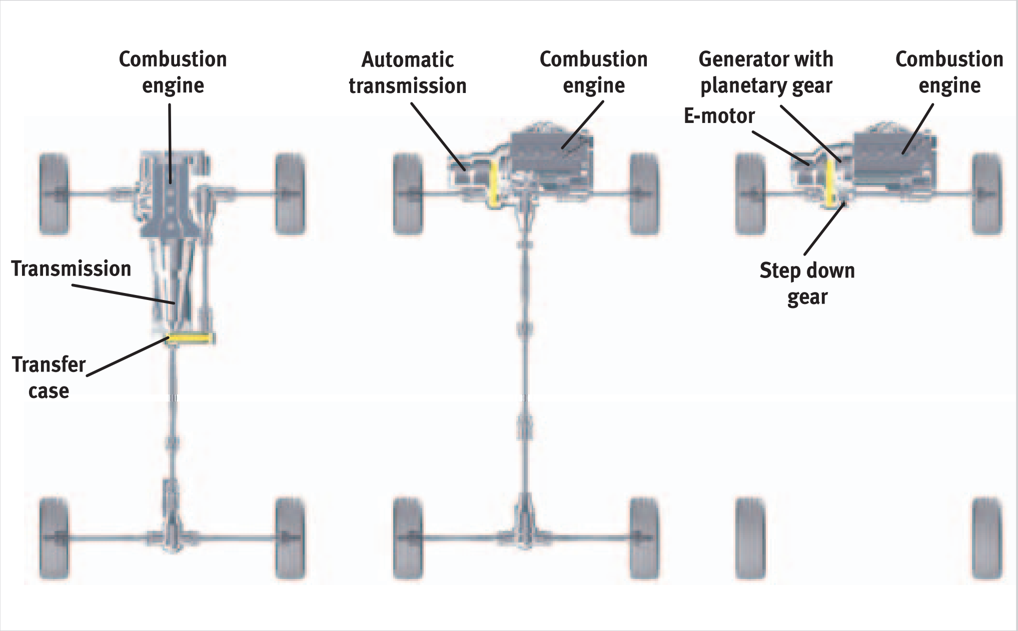


Figure 2 Areas of applications of toothed chains

aim of achieving a further improvement in strength and kinematics. It has been possible to transfer the results to the toothed chain in significant areas. The fundamental principles of the CVT chain acoustics could be used for acoustic optimisation of the toothed chain.

By using two different types of links (figure 3), it is possible to achieve a "randomisation" of the chain pattern, achieving an improvement in acoustic characteristics. One particular feature of the chain is the use of links with greater thickness than the links commonly used nowadays. The thicker links have a higher clean cut proportion. This is associated with a reduction in the amount of setting in operation and therefore a reduction in the elongation of the chain in operation.

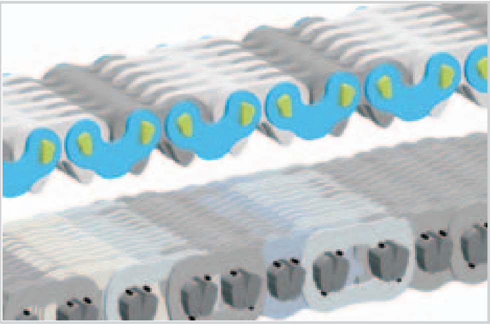


Figure 3 Comparative illustration of the LuK toothed chain (above) and the LuK CVT chain (below)

A comparison of the LuK toothed chain with competitive products show: The LuK toothed chains are, because of the clearly reduced elongation of the chain in operation with an equivalent service life, more narrow and need thus less space required for the gearbox. A further positive side effect is the reduction in the number of components and therefore an easier assembly of the chain.

Description of the Components

The toothed chain consists of the components illustrated in figure 4:

- B-Link
- S-Link
- Covering Link
- short rocker pin
- long rocker pin

The two different types of toothed links, the B-link and S-link, differ in the contour of the

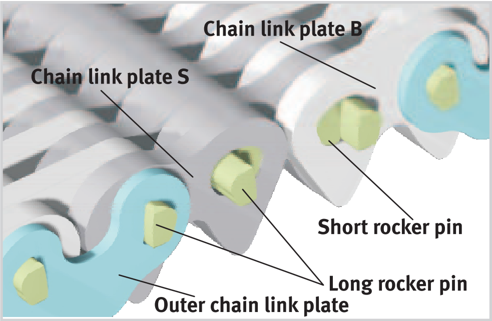


Figure 4 Description of toothed chain components

tooth's face. To keep those two types of links apart in a simple way during assembly, the links have either a straight or a curved back so that the automated systems can distinguish them. The covering link prevents the chain moving off the sprocket. Each joint is equipped with a long rocker pin, which is pressed into the covering link and additionally riveted as well as a short rocker pin, which is covered by the covering link and is fixed axially.

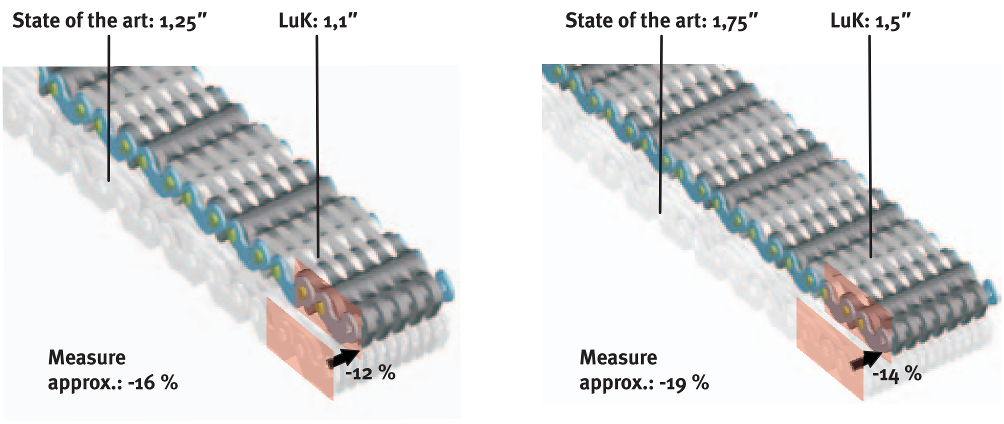
The greatest advantage of the LuK chain shown here is a clear width- and weight saving on the chain. Of course, this space and weight advantage also has a direct positive effect on the space required for the gearbox, the weight of the gearbox and the total costs of the gearbox.

Figure 5 shows two typical applications for transfer case chains. The illustration on the left shows a chain which was originally 1,25" wide. A proven saving in width of 12 % is possible for this application and therewith connected a weight saving of 16 %. In the case of the 1,75" wide chain shown on the right, it is even possible to achieve a width saving of 14 % and a weight saving of 19 %.

Test Results

Initial tests confirm the mathematical forecasts. Figure 6 illustrates the running times of toothed chains of competitive products and the running times of LuK toothed chains, which were achieved under identical conditions on the same test bench.

The test illustrated was carried out in two load stages. At first, the chain is loaded at a constant speed and temperature at 950 Nm until the required running time of 480 min has been achieved. Then the torque is raised to 1400 Nm and the chain is loaded again at the same constant speed until it tears. The upper three bars show the running times of 1,25" toothed chains achieved by a competitive product. The fourth bar from the top shows the running time achieved with a LuK toothed chain with the same



Thickness of links:	1,55 mm	2,3 mm	Thickness of links:	1,55 mm	2,3 mm
Link:	9 + 10 link plates	5 + 6 link plates	Link:	13 + 14 link plates	7 + 8 link plates
Number of links:	86	86	Number of links:	84	84

Figure 5 Examples of typical transfer case chains

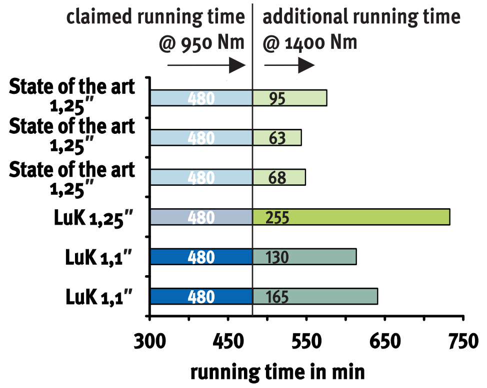


Figure 6 Initial results of strength tests

width of 1,25". This running time is significantly better than the competitive time. This shows that the LuK toothed chain is capable to transfer more torque with the same chain width or to reduce the chain width whilst maintaining the same torque. The lowest two bars show the running times achieved with the narrower 1,1" LuK chain as a comparison, which still represent a distinct advantage relating to strength.

Figure 7 shows the results of a further important test. In this, the elastic elongation of the different chains is shown as a comparison. This elastic elongation has a direct effect on the torque at which the chain jumps which is very important for the design of the transfer chain. The torque at which the chain jumps should be as high as possible, therefore the elastic elongation of the chain should be as low as possible. By optimising the contact shape of the rocker component and the link, as well as the thicker link and the larger and cleaner contact surfaces combined with a better perpendicularity, it was possible to reduce the elastic elongation of the LuK toothed chain and thus increase the jump torque significantly. The jump torque of the narrow LuK transfer chain increases by 25 % and the jump torque with a chain of the same width increases by 42 %.

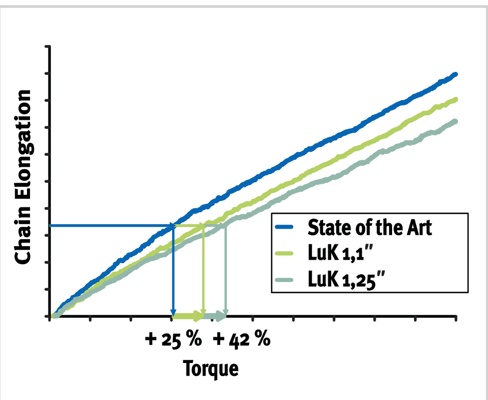


Figure 7 Initial results, comparison of elastic elongation

Optimisation of Acoustics

Optimisation of the acoustic characteristics will be one important focus in the development of the toothed chain. To design the acoustic characteristics of the chain so that they are noticeable as little as possible, a large number of different link geometries have been investigated regarding their feed characteristics.

Figure 8 shows the feed characteristics of a tooth face on the sprocket as an example. First of all the inner face of this link, shown here in green strikes the sprocket at the angle α. During this process, this deflects the outer face of the link in front, which then meets the sprocket with a flatter feed angle β. The criteria for assessment are the combined feed angle (α and β), shown here, the speed at which it arrives and the deflection of the link during the feeding process. The interaction of different types of links needed for ran-

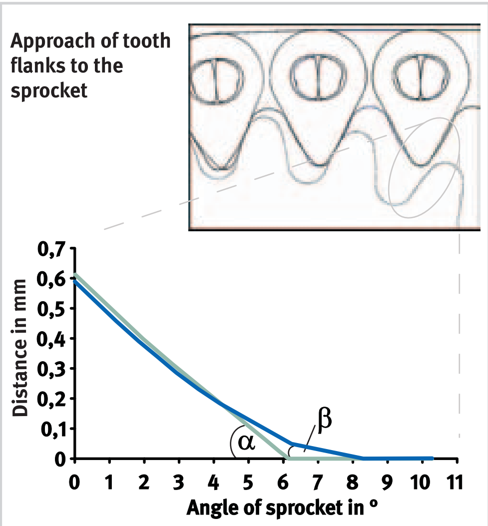


Figure 8 Example of a simulation of feed kinematics

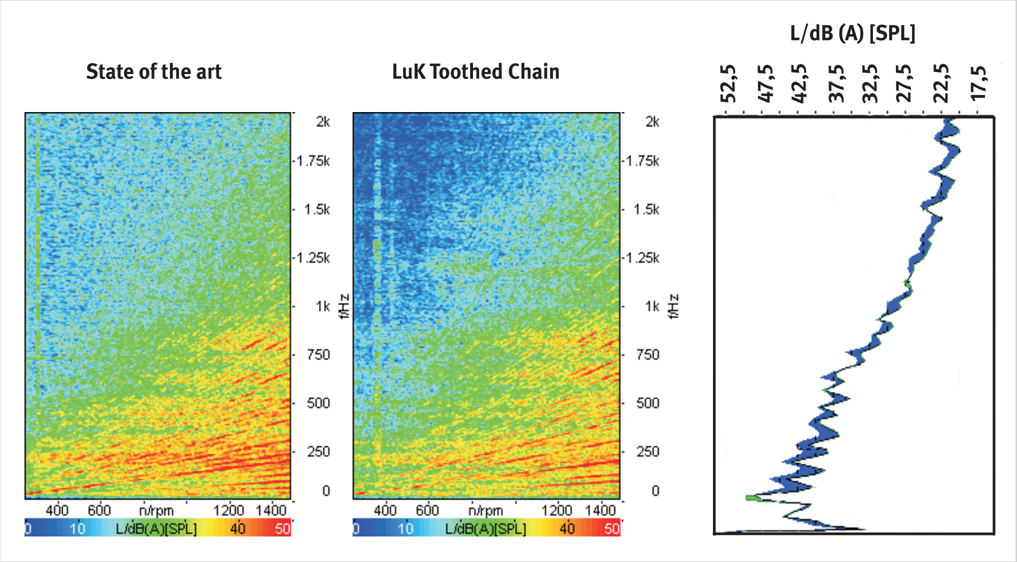


Figure 9 Evaluation of measurements of noise pressure level in vehicle interiors

domisation has also been investigated. The acoustic advantages calculated in theory are proven by vehicle measurements.

Figure 9 shows the results of vehicle interior measurements of noise pressure level during a critical operating point of a transfer case. The vehicle is accelerated with part load in second gear. The measurements shown here were carried out with an identical vehicle and an identical transfer case, only the chains were changed. By comparing the measurements, a clear level reduction of approx. 2 ... 3 dB for the LuK chain at the various frequencies is proven.

Simulation

The modelled 2D system consists of a toothed chain, one driving and one driven sprocket. The toothed chain consists of a multiplicity of individual chain links which are connected via rocker pins so that they can articulate. During this, the individual contours of the sprockets, links (tooth shape and bore shape), and rocker pins are freely definable. It is possible to build up randomised chain patterns.

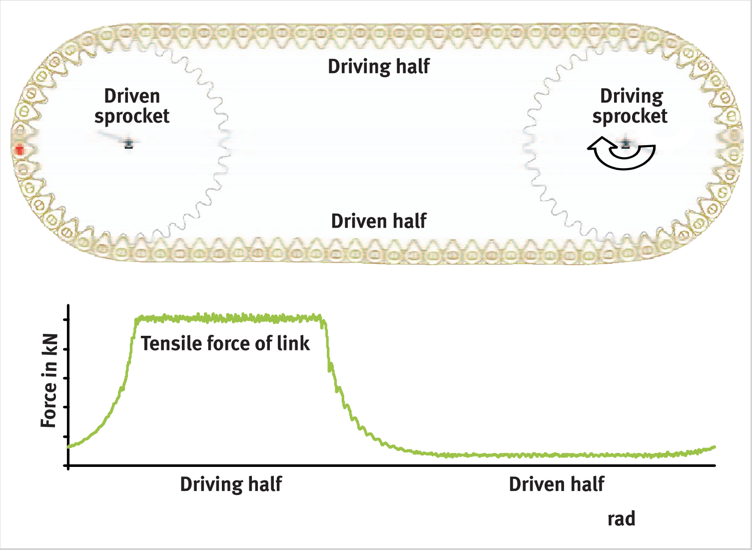


Figure 10 Simulation results, link tensile force during a chain circulation

Using this simulation tool, it is possible, for example, to analyse the dimensions tensile force, contact force (sprocket to toothed link), link system to rocker pin system, (rocker pin to rocker pin), efficiency, approaching speed, feed pulse sequences, and vibration amplitudes.

Different geometrical designs can be analysed at an early stage in the development work thus enabling forecasts of the system characteristics to be produced.

The tensile force of the link is shown during a chain circulation in figure 10. The link tensile force shown corresponds to all the links fitted in parallel in this element for one operating point, taken as an example. The link tensile force rises almost exponentially to a certain level in the driven sprocket. In the strand under tension, it remains constantly at this level and drops exponentially again as soon as the link observed enters the driving sprocket, the force remains at a constant low level in the return strand.

Figure 11 shows the relevant contact forces, marked with blue dots, for this operating point between the sprocket and the chain links. The tensile forces and the contact forces are shown on the same scale. The maximum values for the contact forces are at about 40 % of the maximum link forces for the geometry analysed here. The maximum contact forces occur when emerging from the driven sprocket into the strand under tension and when entering the driving sprocket from the strand under tension. The results show that the simulation represents the ratio of the toothed chain well.

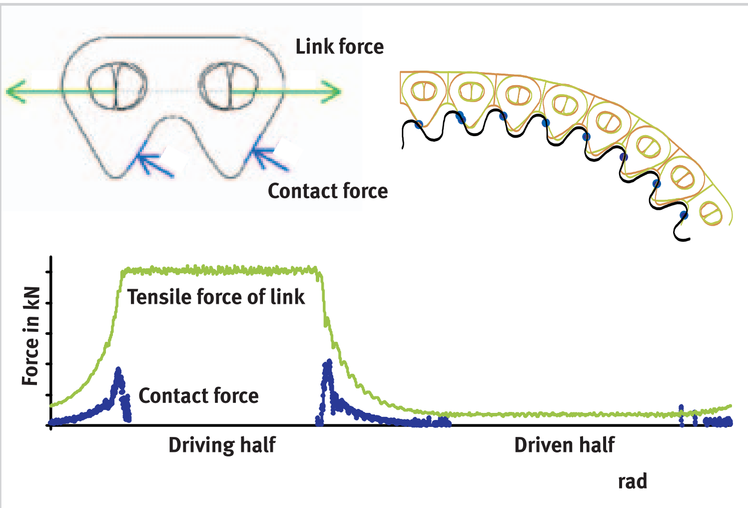


Figure 11 Simulation results for the relevant contact forces

Summary

The knowledge gained with the CVT-chain has culminated into the development of the HiPerMax® LuK toothed chain, so that it differs positively from the competition on significant points. The optimised contours of the rocker components and the links in conjunction with the 2,3 mm wide links should particularly be emphasised. This makes it possible either to transfer higher torques with the same chain width or by using a narrower chain with the same torque and use the advantages of lesser space and weight. The reduced elongation in use enables higher peak torques to be transferred before the chain jumps a tooth. In addition, the disturbing acoustics of the gearbox can be significantly improved with the HiPerMax® LuK toothed chain.