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LuK clutch systems and torsional dampers

Key elements for efficient drive trains

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Introduction

Up until a few years ago, engine development showed a strong, consistent trend toward raising the specific engine torque in diesel engines using new injection technologies combined with supercharging. Since the early 1990s, the possible engine torque based on piston displacement has increased by some 300 %. The typical diesel engine at that time had four cylinders and a piston displacement of approximately two liters, with which today's engines can today generate 450 Nm or more [1]. This evolution in diesel engines has, to a large degree, increased the enjoyment and efficiency of driving. So that good results as far as comfort can also be achieved without compromise, the requirements for the torsional vibration damper, which must transmit the high torques on the one hand and effectively keep the high alternating torques away from the drive train on the other, have grown by comparable degrees.

Up to now, when selecting the transmission, the customer mainly had to choose between a manual or an automatic transmission, and in comparatively rare cases, also a CVT or automated shift transmission.

For several years now the pressure has been growing worldwide to reduce fuel consumption and CO_2 output, while maintaining comfort and enjoyment. According to one study [2], for example, the average fuel consumption in Germany will fall from 7.6 liters today at least to 6.1 liters by 2030 (-20 %). With a high degree of hybridization and accelerated technology change, such as in alternative fuels and drives, it could even fall as low as 5.2 liters (-31 %).

Globally, this leads to a tendency towards smaller and lighter vehicles. The drive train requires massive effort in order to raise the overall efficiency.

For the combustion engine, this is done by means of further downsizing, with supercharging now being increasingly used, particularly in gasoline engines. In concrete terms, this means a torque class that has to be covered with the smallest possible engines (Figure 2). 2.0 liter engines are replaced, for example, by 1.5 liter engines with comparable torque. Small engines with up to 1.3 liters piston displacement are showing strong growth, while engines with over 1.8 liters piston displacement are losing share.

In the drive train, automation and electrification are used to enable the combustion engine to be operated with optimal loads and speeds.

Types of transmissions

Despite great strides in transmission technology, the manual transmission continues to have the highest production volume worldwide. The advantages of this transmission technology are relatively low cost, high efficiency and good driving performance. It will remain the world's dominant transmission type for the next several years, and by 2018, with a projected increase of 11 million units, will show the highest growth in absolute numbers.

Compared to a manual transmission, an automatic transmission represented the only option up to now across the board for shifting gears "clutch-free." Up to now, the high comfort level of the automatic transmission was always set against a comparatively high fuel consumption, since the torque converter clutch had to be open at low engine speeds for comfort reasons. But good fuel economy can actually be achieved at low engine speeds. In this regard, damper technology also plays a key role for automatic transmissions, since the performance capability of the damper largely determines the engine speed from which it is possible to drive with no slip and therefore optimal fuel consumption. LuK has already shown what is technically possible today in that area. Using a double damper and centrifugal pendulum-type absorber (CPA), it is possible to increase the degree of isolation by more than 60 % compared with a conventional damper. This creates the conditions required for achieving significant advantages in fuel economy [3].

The desire to combine the advantages of the previous manual transmission with those of the auto-

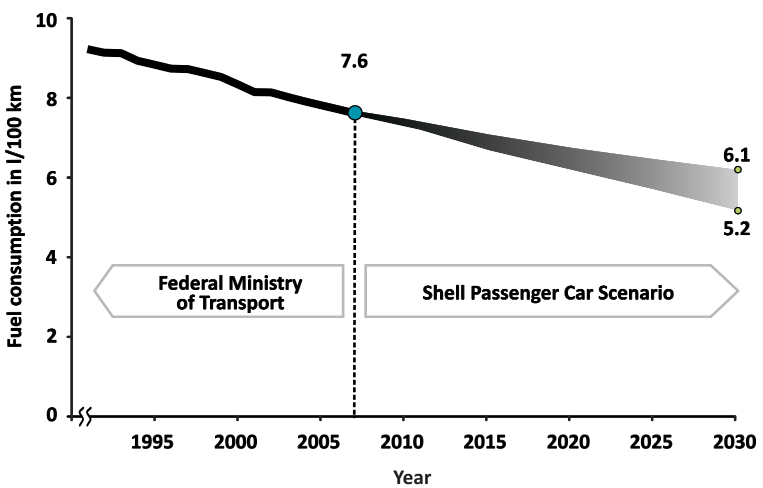

Figure 1 Predicted average passenger car fuel consumption in Germany

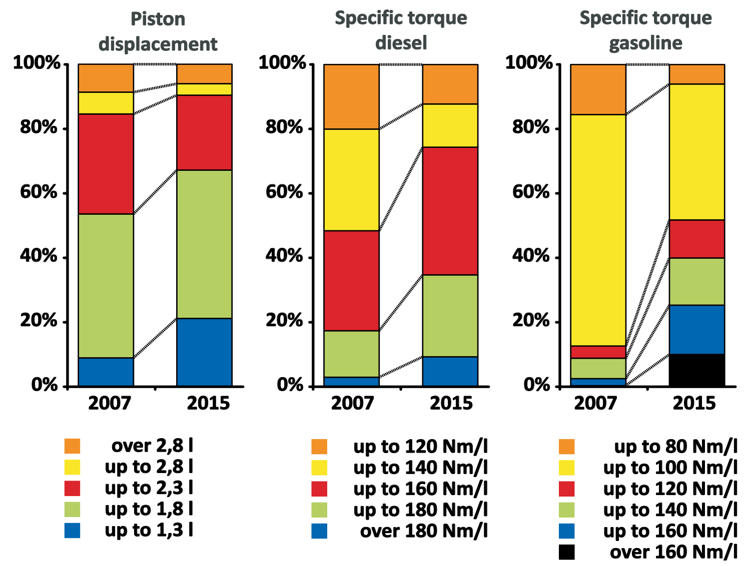

Figure 2 Engine production in Europe by piston displacement and specific torque (Source: CSM)

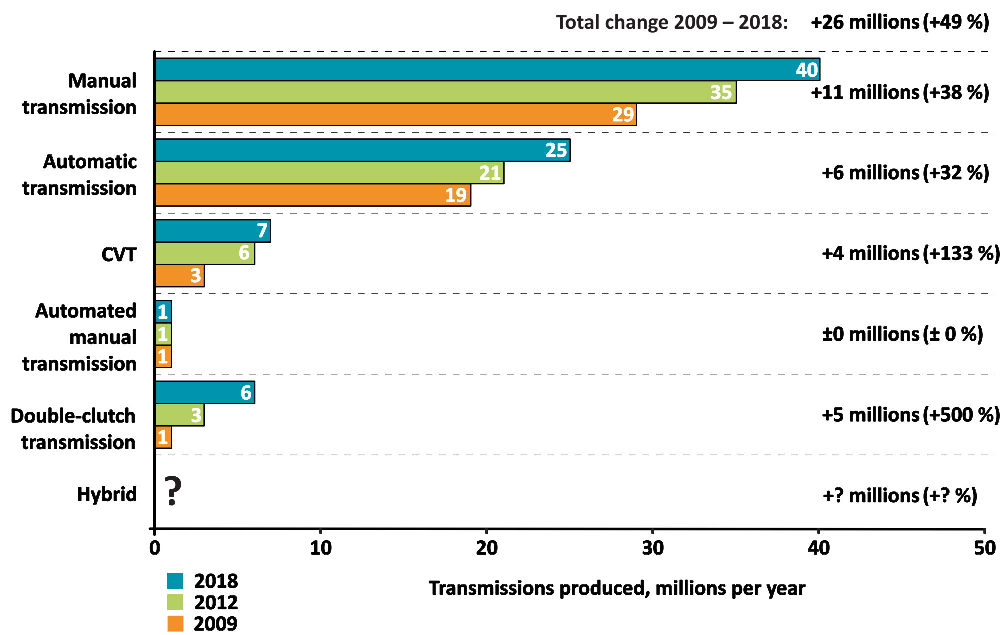

Figure 3 Global production figures by transmission type

matic transmission led to the development of double clutch transmissions. This new transmission concept shows how enjoyment, consumption and comfort can be combined with impressive results. It is here that the highest relative growth will be realized in the next several years.

The next logical step in the ongoing process of automation and electrification is hybridization. Here, too, the goal is to further decrease fuel consumption through energy management without compromising comfort or enjoyment. The strength of its market penetration and the hybrid concepts with which it will develop cannot be fully foreseen at this time. What seems certain, however, is that hybridization will begin to establish itself across the board in the model series of all automakers in the years to come.

The contribution of the transmission to favorable consumption values stems in large part from creating the foundation for operating the combustion engine at a low specific consumption. To do this, the number of gears and the gear ratio spread are both increased. Automation ensures that the correct gear is always engaged. With manual transmissions, gear selection is left to the driver, but even here a visual shift recommendation can provide positive support if the driver feels right in the recommended gear.

Another area where efforts are being made has to do with mechanical efficiency. Lower friction and light construction, however, also bring about a greater sensitivity to torsional vibration, since less mass is moving and vibrations are dampened less. Particularly with double clutch transmissions, the requirements regarding torsional irregularity significantly increase compared to a manual transmission, since a partial transmission is not in the flow of power and is therefore susceptible to rattling noises. It must therefore be taken in consideration overall that, depending on the starting situation, optimizations in this connection come with higher requirements for the torsional vibration damper.

Optimal dampers for comfortable driving with low fuel consumption

Independent of the transmission concept, vehicles, apart from purely electric cars, will still be powered by the combustion engine for the foreseeable future. This means that the fundamental

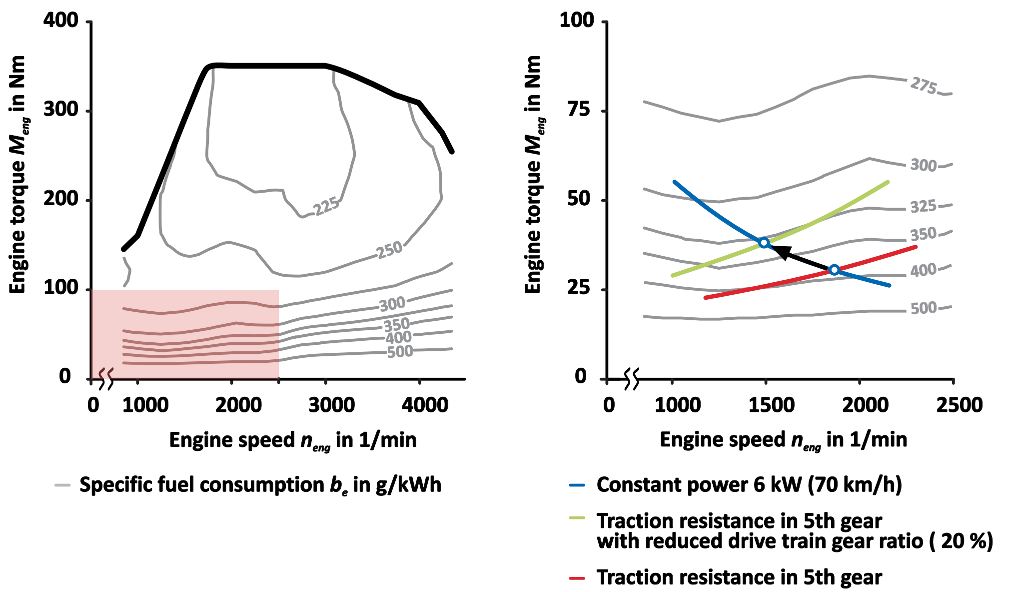

Figure 4 Consumption characteristic map for a 2.0-liter diesel engine – potential consumption reduction due to lowering engine speeds (downspeeding)

requirements at the interface between engine and transmission are the same at first for all transmission types. There must be a starter element, a means of transmitting the average torque, and the alternating torques must be dampened as well. The damper requirements increase with higher torques at low engine speeds and as the number of cylinders is reduced. Or to put it another way: The damper requirements rise with the objective of lowering fuel consumption while keeping driving enjoyment and comfort the same.

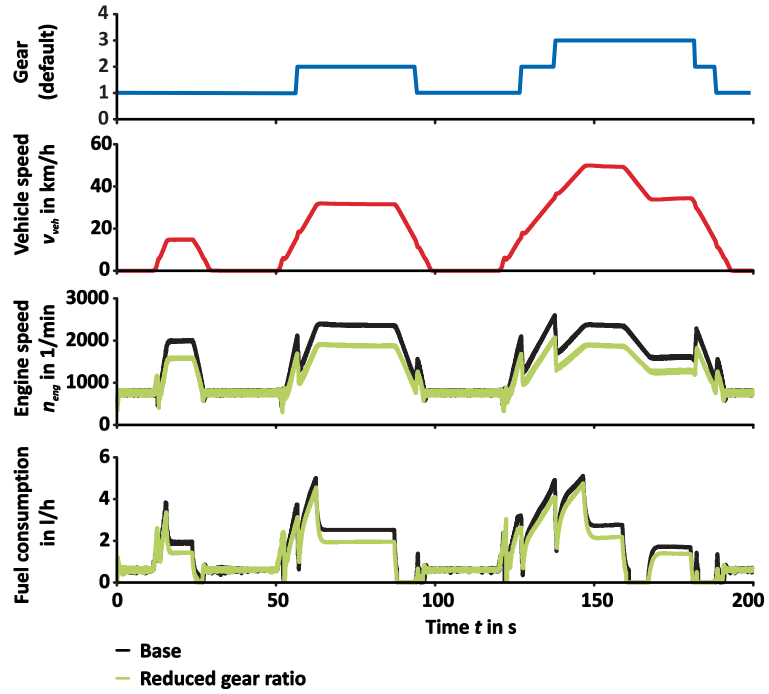

Figure 5 Effects of downspeeding in the NEDC – consumption simulation (city cycle)

Reducing consumption through optimized dampers

A torsional vibration damper in itself does not, of course, directly reduce consumption, but a simple example makes it clear how closely the choice of damper technology is linked with fuel economy. It is based on a current 2-liter diesel engine with about 350 Nm. The vibrations are effectively reduced with an optimally designed dual mass flywheel (DMF). If this vehicle is driven with a given gear ratio at a constant speed of 70 km/h in 5th gear, the specific fuel consumption is 385 g/kWh. This can be converted to a fuel consumption of 3.96 liters per 100 km for this vehicle. If the gear ratio is reduced by 20 %, for example, the engine speed drops by the same factor. This lowers the specific fuel consumption to 330 g/kWh or 3.39 liters per 100 km, which corresponds to a 14 % reduction!

A comparable improvement is achieved when a speed of 70 km/h is driven in 6th gear instead of 5th gear.

Consumption simulations were carried out to determine the achievable advantage of driving at a lower engine speed in the new European driving cycle (NEDC). Figure 5 shows the comparable result for a city cycle. Together with the consumption characteristic map from Figure 4, a consumption advantage of 0.92 liters per 100 km, or 11.4 %, is calculated for the city cycle. Consumption falls from 6.08 to 5.44 liters per 100 km for the entire cycle. This is a savings of 10.5 %.

By lowering the engine speed, the engine torque rises by the same degree and both lead to a decline in driving comfort, since the crankshaft irregularity increases while the degree of isolation of the DMF decreases. With a more effective damper, this worsening can again be compensated for. The CPA developed by LuK offers adequate potential [4, 5] to realize the depicted consumption advantage without impacting comfort.

LuK has long been working on using this principle to reduce vibrations in the passenger car drive train. This technology was explained in connection with a dampened clutch disc as far

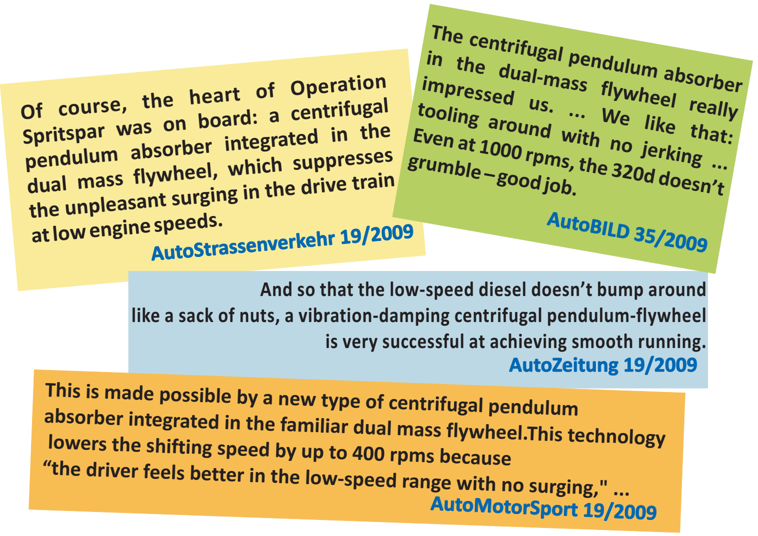

Figure 6 LuK CPA – successful implementation in production

back as Symposium 1990 [6]. In Symposium 2002, the CPA on the secondary side of a DMF was presented [7] and the technology has been successfully in production since 2008.

The potential consumption reduction is confirmed in real driving operation for a DMF with CPA. Together with other measures, fuel consumption could be reduced by 0.7 liters with no reduction in comfort in a production vehicle with manual transmission. A success that would not be possible without an effective damper.

This potential can be transferred without restriction to all other transmission concepts (Figure 7). A better damper also supports driving in the speed range favorable for consumption with double-clutch or automatic transmissions. Better decoupling of vibrations also makes it possible for the torque converter to be bypassed earlier in an automatic transmission. Not only can the engine efficiency be positively affected in this way, but also the efficiency of the transmission. Especially for automatic transmissions, effective dampers are of elementary importance to competitiveness in fuel economy compared to other transmission concepts.

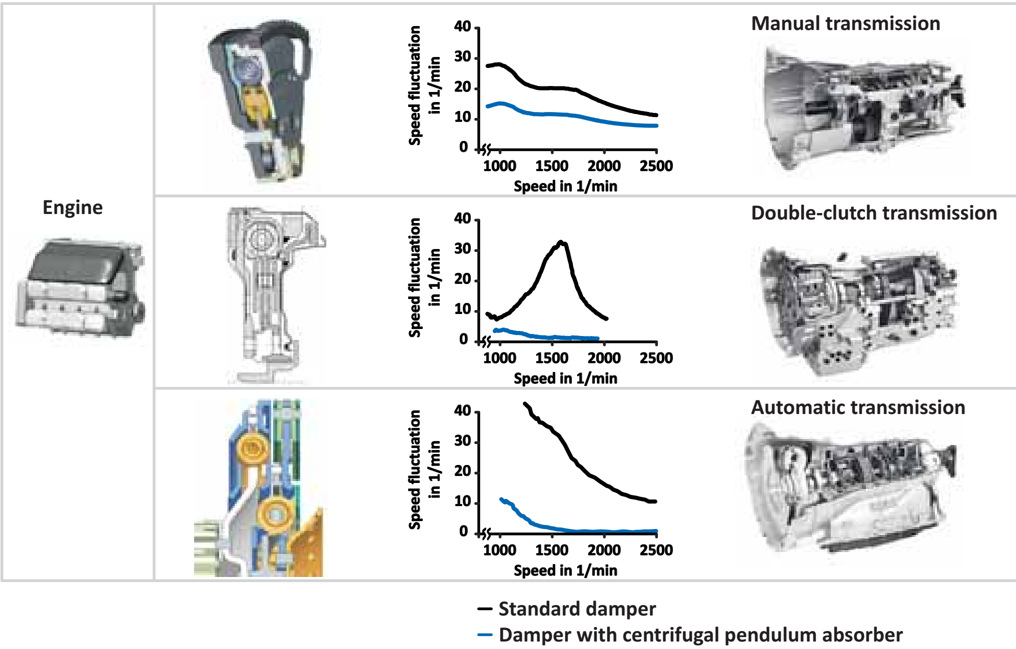

Figure 7 LuK CPA – the standard for torsional vibration isolation in all transmission types

The development and optimization of torsional vibration dampers was and is driven by an effort to achieve drives that are low in noise and vibration. Better dampers can naturally still be used purely to improve comfort as well. The possibilities of more efficient vibration reduction are qualitatively summarized in Figure 8. Depending on the starting position and objective, there is a great deal of flexibility in selecting the extent to which this potential is to be used to improve comfort or reduce consumption. As mentioned, these options are independent of transmission type. Compromises in comfort as a result of economizing on fuel, for example, remain without effect on the consumption values in the NEDC. In real driving operation, they will, however, have a negative effect on fuel economy.

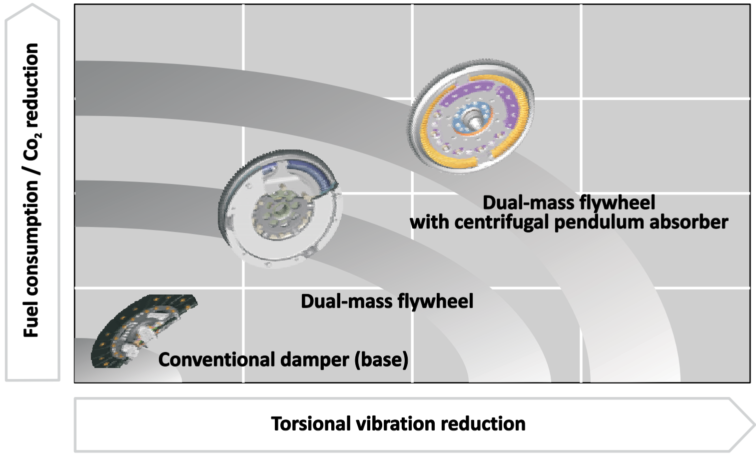

Figure 8 Flexible options in connection with improved damper technology, using the example of the manual transmission

New challenges

Considering the entire system, using the 3-cylinder engine as an example

In larger engines, it has long been the practice to reduce the number of cylinders; today's 6-cylinder engines replace the 8-cylinder units of former days, and 4-cylinder units have replaced 6-cylinder engines. The advantages are obvious: lower masses, fewer moving parts and lower friction lead to less dissipated energy. The advantages of engines with fewer cylinders are first set against louder engine performance, particularly when the engine is to run in the lower speed range with optimal fuel economy.

This is one possible reason why the supercharged and thus high-torque types with 3 or even just 2 cylinders are still comparatively rare. The requirements for noise reduction rise disproportionately. If, for example, a 4-cylinder engine with DMF is replaced by a 3-cylinder type, the torsional irregularity is practically doubled at the transmission input with the same damper technology. The reason for this is the lower ignition frequency, which causes a higher irregularity of the crankshaft and a shift in the drive train resonance closer in the speed range relevant to driving.

In addition to the more critical situation on the transmission side, the requirement for the power take-off is also significantly sharpened. Here, too, the irregularity rises to an extreme degree for the reduced number of cylinders, despite the same engine torque. A single-mass flywheel (SMF) would be advantageous for the power take-off.

On the drive train side, the resonance likewise shifts to higher speeds. This is positive, however, in contrast to a DMF, since the resonance lies within the drivable speed range as it is. Due to the shift to higher speeds, the resonance in an SMF is not as strongly excited, nevertheless the speed fluctuations lie clearly above those of a 4-cylinder engine (Figure 9).

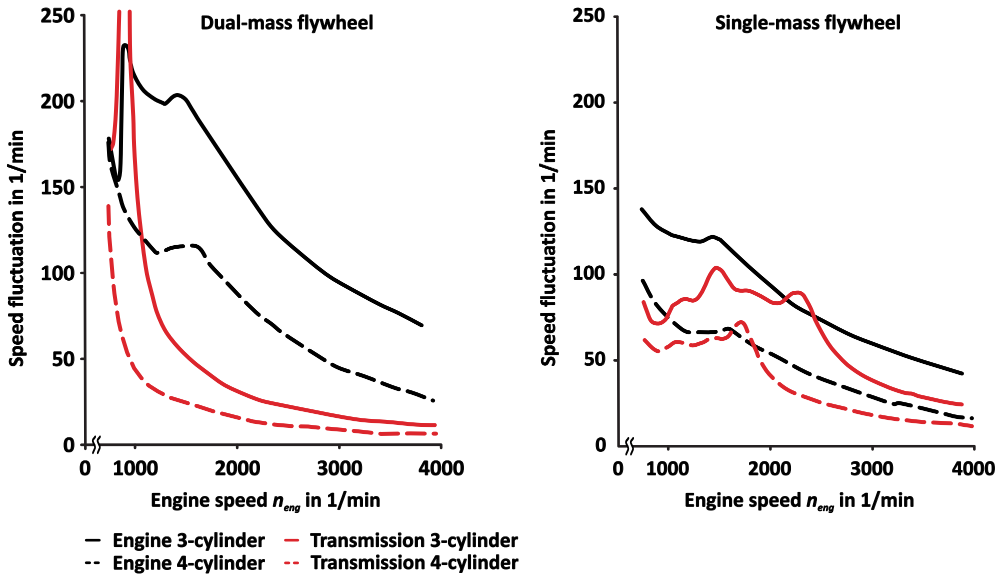

Figure 9 Increasing requirements when reducing the number of cylinders – Example: 3 cylinders instead of 4, with the same maximum engine torque

In order to achieve better results with conventional damper technology, a shift in the drive train resonance would be helpful. The resonance frequency would have to be reduced for a DMF, and raised for an SMF. In concrete terms, this would mean modifying the stiffness of the drive train in order to expand the application area of the damper (Figure 10).

The theoretical potential is considerable. To the extent that the boundary conditions and other requirements permit, the possibility of a drive train modification should be considered as early as possible in the concept phase. With a corresponding reduction in drive train stiffness, a DMF could remain the first choice for supercharged 3-cylinder engines as far as torsional vibrations on the transmission. On the other hand, the potential of an SMF can be significantly increased by raising the drive train spring rate.

In case an adaptation of the drive train is not possible and no satisfactory result can be achieved with conventional damper technology, alternative concepts have to be considered early on. The potential of the LuK-developed CPA technology can be used here as well. Considering the overall situation, a pendulum in combination with either a DMF or SMF can present interesting solutions.

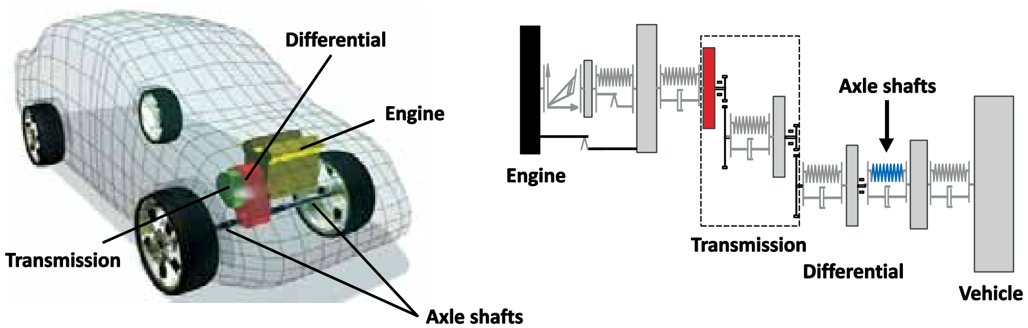

Figure 10 Taking the entire drive train into consideration to reduce torsional vibrations

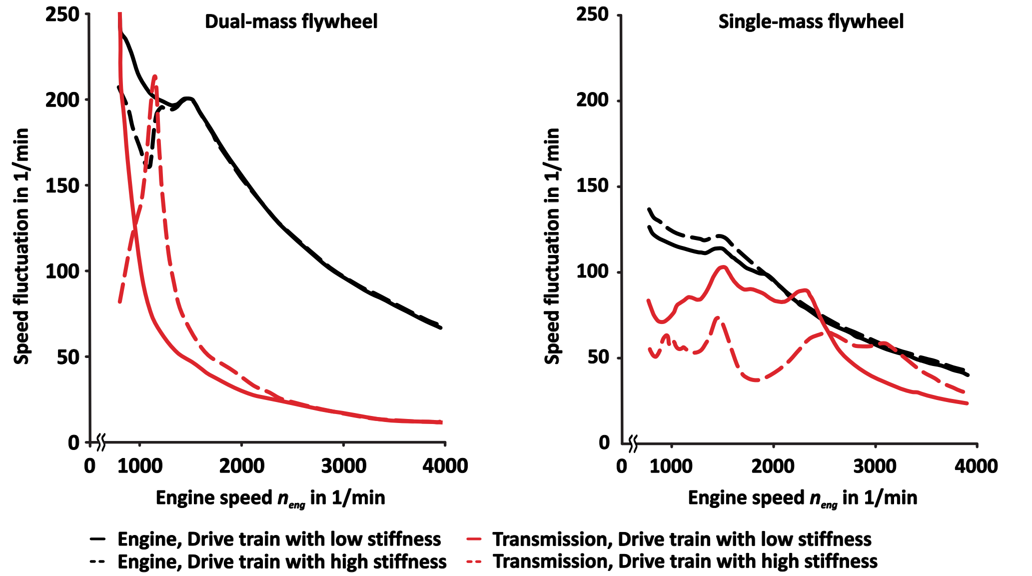

Figure 11 Performance limits of torsional vibration dampers in the entire drive train

In the case of an SMF it has been shown that the doubled primary excitation force is not negligible. The most favorable results are achieved when both the single and double primary excitation forces are canceled out with the CPA.

From a drive train perspective, a DMF with CPA is the best solution. Outstanding isolation values are achieved from an engine speed of 1000 1/min. The advantage of a solution with SMF especially benefits the power take-off,

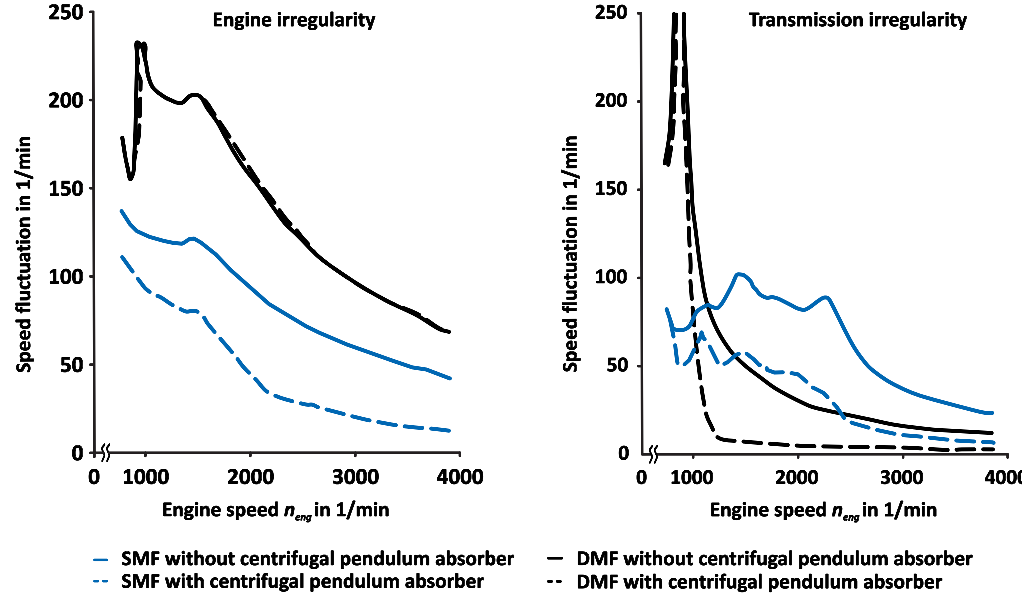

Figure 12 Isolation potential of alternative damper types for 3-cylinder engines

since the CPA directly reduces the irregularity of the engine.

Which type is the best for a concrete application must be evaluated. For the drive train, an optimal result can be achieved with 3-cylinder engines with DMF. LuK has likewise developed a solution for possibly critical vibrations on the power take-off side, which will be explained in the next section.

Solution for the power take-off

Among the options shown above for reducing vibration in supercharged 3-cylinder engines, variants with DMF also offer the highest potential. The best isolation results can theoretically be achieved even from low engine speeds, particularly in combination with a CPA. Greater vibrations on the power take-off side are the disadvantage compared to types with SMF. LuK's solution for this is to bring the vibrations to a lower level. The model is the proven principle of the DMF. This technology, made appropriately smaller, can also be used to enable over-critical operation for the power take-off. Figure 13 shows a sample design for a LuK belt pulley decoupler (BPD) [8]. The BPD is arranged directly on the free end of the crankshaft. The entire belt drive thus benefits from the isolation potential. The BPD is naturally not reserved only for 3-cylinder engines, but can be used in all applications where alternating torques need to be isolated as efficiently as possible from the power take-off.

Figure 14 shows comparative measurements with a conventional generator freewheel on a 4-cylinder diesel engine with 240 Nm. The vibration level on the generator is significantly lower with the BPD. Another advantage is that the dynamic torques between the crankshaft and belt pulley are isolated immediately. The belt must therefore only transfer low alternating torques and the belt pretensioning can be correspondingly low. A lower belt pretensioning in turn means lower friction, which, in the end, can reduce the losses in the belt drive [8]. Thus, in addition to quieting the power take-off, the BPD also allows a further contribution to reducing consumption and CO_2 output.

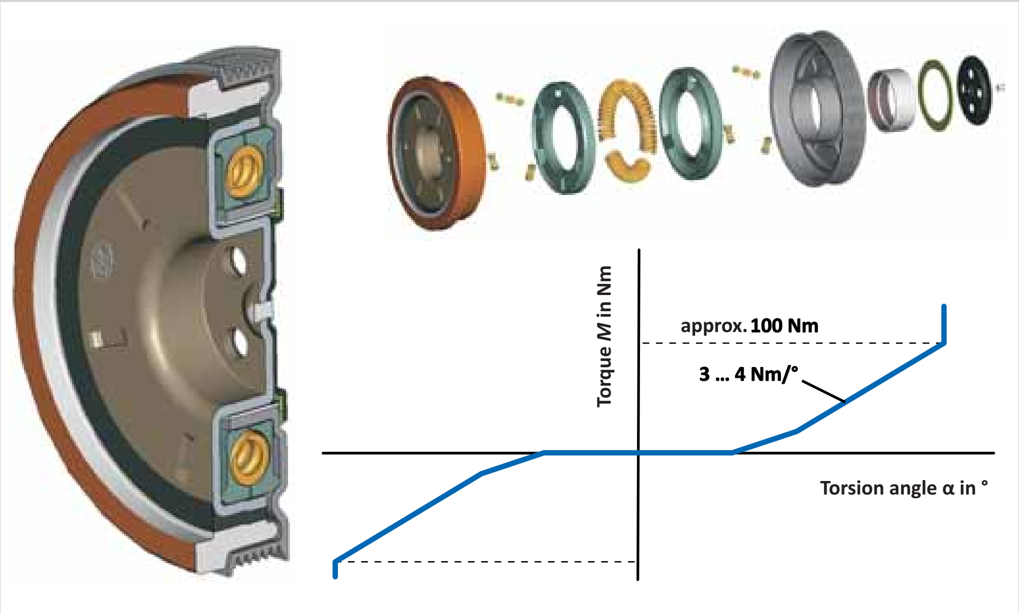

Figure 13 LuK belt pulley decoupler (BPD) – the DMF for the power take-off

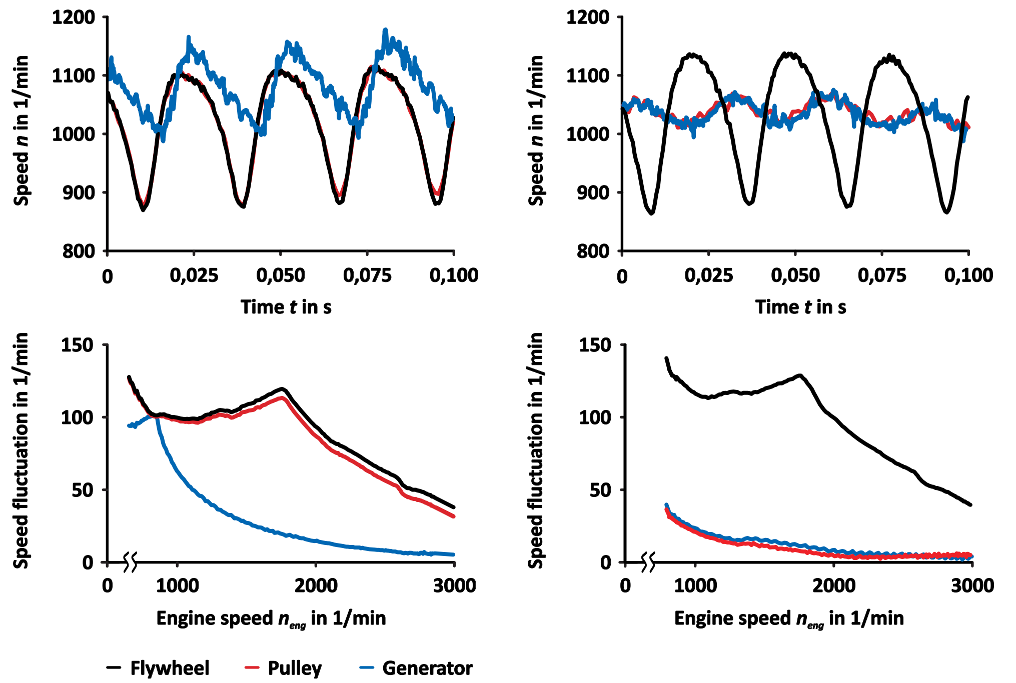

Figure 14 LuK belt pulley decoupler (right) – compared with a conventional generator freewheel (left)

Stop-start systems, leading the way to hybridization

Fuel economy benefits of stop-start systems

Many cars already have it on board today: a stop-start system as a lead-in to hybridization. One forecast [9] concludes that as early as 2012 every second new vehicle will be equipped with such a system. The consumption advantages are considerable: in the NEDC, the stop time totals 240 s, which is 20 % of the entire cycle. This amounts to up to 5 %, or in the pure city cycle, even up to 8 % of the total fuel consumed. Concretely, 4.5 % can be saved in the entire cycle for the vehicle considered above with an idle range of about 0.6 L/h (Figure 5).

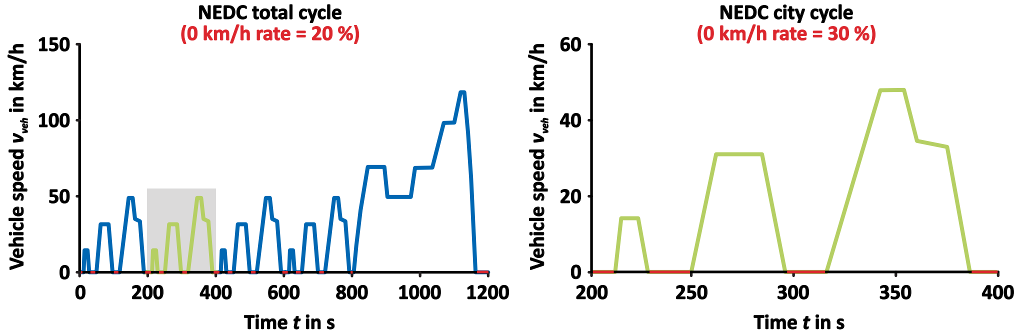

Figure 15 Consumption reduction potential of a stop-start system in NEDC

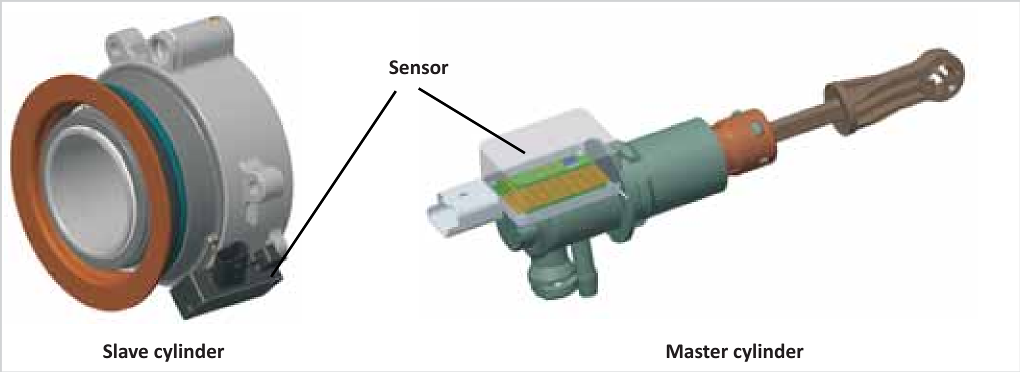

Figure 16 Travel sensors in the release system – not only for stop-start systems

Necessity and option in connection with stop-start systems

The fundamental requirements of a clutch and damper system for applications with stop-start function change only slightly. In the case of a DMF, more stop and start operations must be able to be tolerated and the starter sprocket may have to be made somewhat more wear resistant. As far as comfort, stop-start behavior must certainly be viewed more critically. Since the driver does not, as usual, actively turn the engine on and off, there are no higher requirements to deal with from this standpoint.

The consequences are clearer for release system components, since stop-start systems require information on the clutch position. Position recording in itself is not new in clutch systems; there are many systems that require this information:

- Stop-start systems
- Cruise control
- Start lock
- Clutches for hybrid applications
- Electric parking brake
- Hill-holder system
- Input signal for automated manual and double clutch transmissions

Due to the trend toward increased electrification, strongly driven by stop-start applications in manual transmissions, the number of projects in release cylinders with travel measurement technology is growing to a great degree. At LuK, intensive development is underway to find the best measurement principle from the standpoint of space, performance and cost [10].

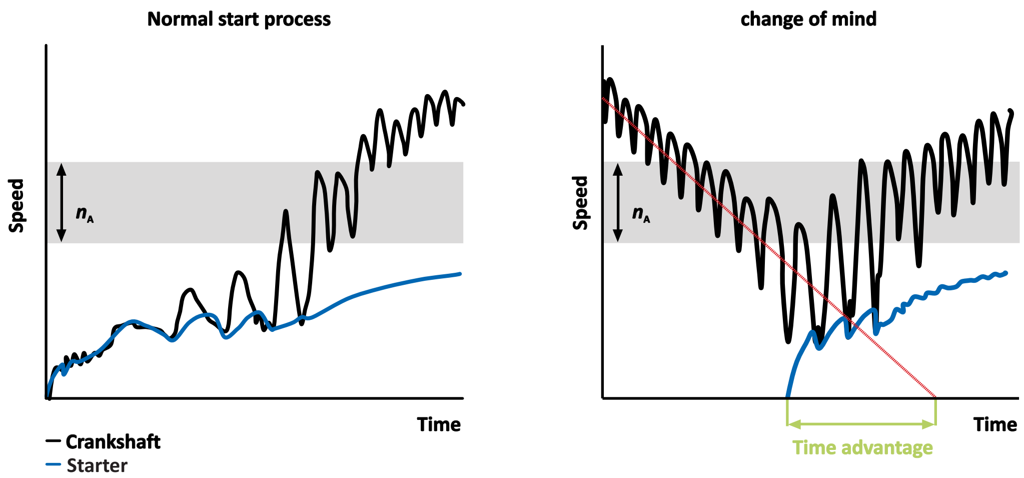

Figure 17 Normal start and restart of a still-running engine (change-of-mind)

Clutch systems and torsional dampers 1

One scenario being discussed in connection with stop-start systems is the system behavior in case of a “change of mind.” In this case, the system has decided, based on the driving situation, to stop the engine, but the driver wants to drive on before the stopping process is complete. A restart of the engine is not possible during the run-out phase. The engine must first be allowed to come to a complete standstill before the starter can be engaged. In this situation there can be a delay of a few tenths of a second, which is subjectively perceived as negative.

In order to eliminate a possible delay with a change-of-mind, there are developments in which the starter pinion continuously meshes with the starter sprocket. The starter thus always remains engaged. In order to make this possible, an additional freewheel is required between the starter sprocket and crankshaft, which couples with the starter at low speeds and decouples when a certain engine speed is exceeded (n_A in Figure 17). This enables the engine to be started immediately and without delay even in the run-out phase. Tests have already shown that such a strategy brings considerable benefits in the subjective evaluation. A restart when the engine is at a complete standstill is shown in Figure 17 on the right. In this concrete example, the time difference is 0.2 seconds better than solutions without a permanently engaged starter.

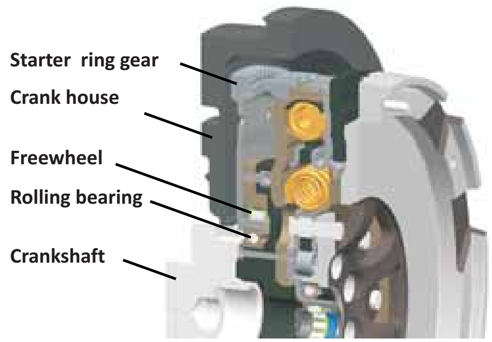

Figure 18 Conventional freewheel arrangement for a stop-start system with PES

LuK solution for a permanently engaged starter (PES)

The challenge for a stop-start system with PES lies in the design of the freewheel. In a design with a conventional freewheel, the starter sprocket is mounted to the output end of the crankshaft with a rolling bearing; at low speeds (starter speed) the starter sprocket is connect-

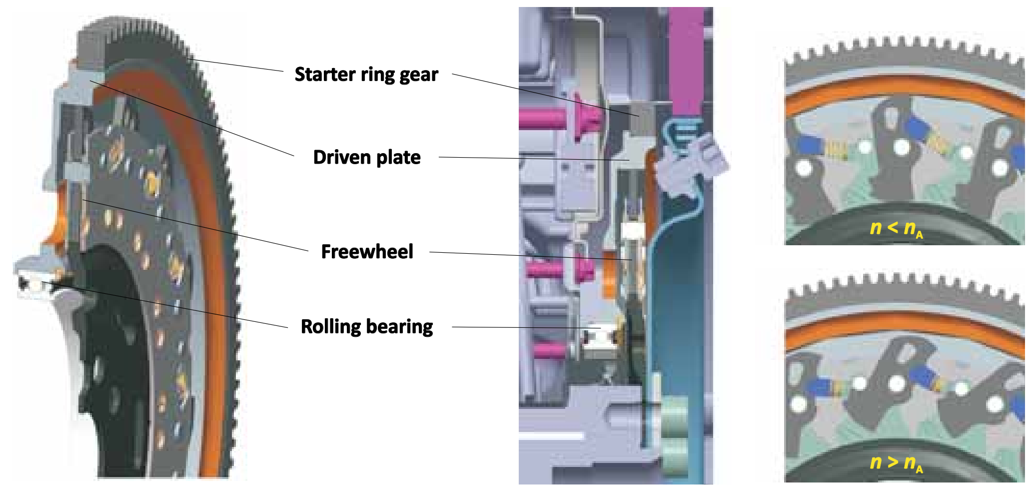

Figure 19 LuK freewheel concept for PES (permanently engaged starter)

ed with the crankshaft by means of the locked freewheel, while at higher speeds, the crankshaft outruns the starter, thus uncoupling it. With such an arrangement, the rolling bearing is under stress during the entire operation, specifically with the engine speed. The demands on the bearing are thus extremely high, as it must be designed for the maximum engine speed and the full engine operating hours. The freewheel is likewise constantly turning with the engine speed. Both components, bearing and freewheel, thus generate a drag torque at all times during engine operation and thus additional dissipated energy.

Simple rolling bearing technology can be used for the LuK solution, since the load turns out to be many times lower than in a conventional freewheel arrangement. The starter sprocket is no longer mounted on the rotating output end of the crankshaft, but on the stationary crankcase (Figure 19). The freewheel is designed as a centrifugal force clutch and bolted to the crankshaft. When the starter speed range is exceeded (n_A in Figure 17), the centrifugal force clutch opens, thus uncoupling the starter sprocket from the crankshaft. In this arrangement, the rolling bearing only has to be designed for the starter speed and the duration of the start process. After the engine start, this arrangement creates no additional drag torque and thus no dissipated energy. The LuK freewheel for a PES is thus highly robust and has no disadvantages for the overall efficiency.

Higher requirements for the clutch system

Optimizations regarding fuel economy and torsional vibration in modern drive trains with combustion engines have almost exclusively to do with driving with a closed clutch. The interface between engine and transmission is definitively characterized by the torsional vibration damper. The circumstances change completely for operating conditions with a slipping or actuated clutch. With ideal friction coefficient performance by the clutch, there would theoretically no longer be any alternating torque transmitted directly from the engine to the transmission at a sufficiently high slip speed. An effect of slip-controlled systems for torsional vibration isolation is used.

Nevertheless, there are known to be a number of comfort and NVH problems for which the clutch system or the entire vehicle has to be designed. In past years, this was also strongly driven by the evolution of diesel engines. The significantly increased engine torques from turbocharging led to higher operating loads in manual transmissions [1], and the comparatively low available engine torques in the lower speed range in some cases led to weak start-up. The latter is mainly a comfort issue, but also makes

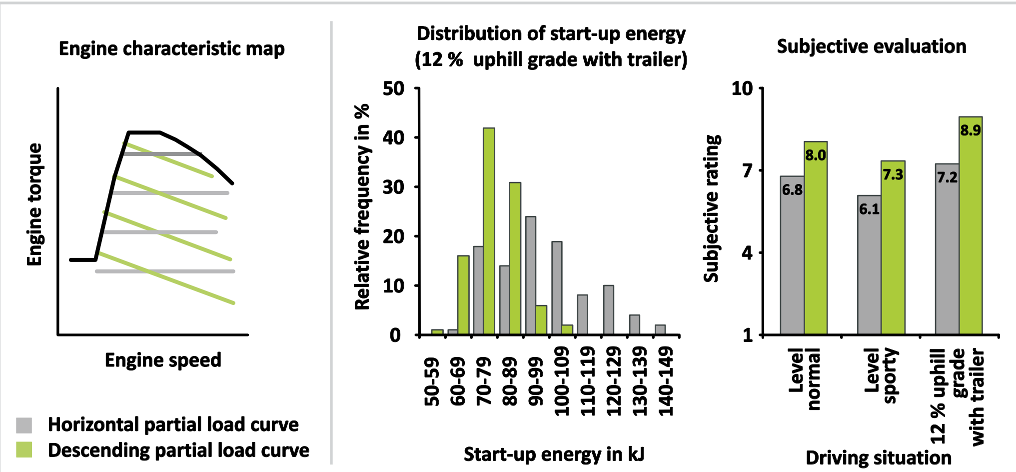

Figure 20 Effect of engine characteristic map on start-up stability – driving test with 10 testers

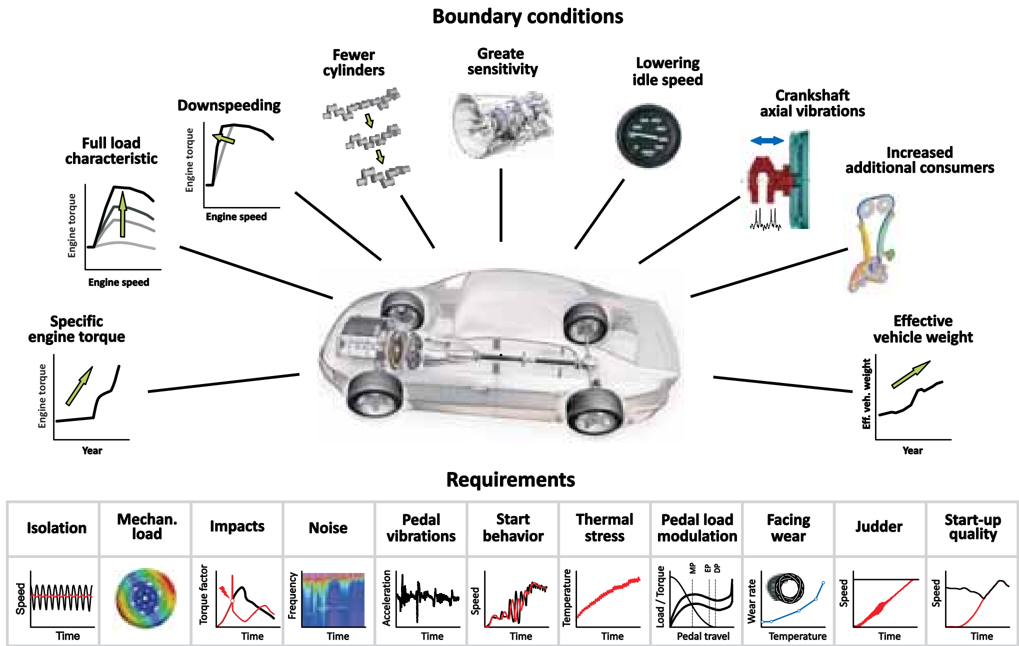

Figure 21 Tightened boundary conditions and requirements for a clutch system

the start-up situation more critical. This can lead to a reduced service life, but also, in particular, to high clutch temperatures when starting up on a hill with a trailer. Here too there are increasingly deficits to deal with in supercharged, small-volume gasoline engines. On the engine side, effective counter-measures can be taken. Special engine characteristic maps, with declining partial load curves and the highest possible dynamic during the start-up phase, stabilize the start-up process. This is equally positive for the start-up energy as for the start-up comfort.

An example is shown in Figure 20. In cooperation with an automobile manufacturer, the engine-side optimization potential was studied with regard to start-up quality for a small-volume, supercharged diesel engine. The modification primarily had to do with the course of the static partial load curves (engine torque plotted against engine speed for constant throttle position). Compared to the base (production design, gray in Figure 20), the start-up energy level has been decreased significantly. Critical start-ups with high energy inputs in particular can be largely avoided by this measure. The difference was also considerable in the subjective evaluation, with ratings improving by 1.5 points on average.

Overall, tightened engine and transmission boundary conditions lead to higher requirements on the clutch system (Figure 21). The engine-side excitement and the sensitivity of the transmission or the entire drive train increase. In particular, a trend can be seen towards greater variety of vibration and noise phenomena in the slip phase. A number of problems can be caused by axial vibrations of the crankshaft. Some important examples of this include:

- Pedal vibrations
- Operation noises
- Chatter (modulation excitation)
- Drive train noises (rattling, clatter, whoop)

These forced or impulse-excited phenomena can be most efficiently solved with a cover-mounted release system (CMR) [10], since the excitation mechanism is compensated for. The CMR has been in production for a hybrid application since 2009 and is in the concept phase for manual transmissions at a few automotive manufacturers to solve various problems.

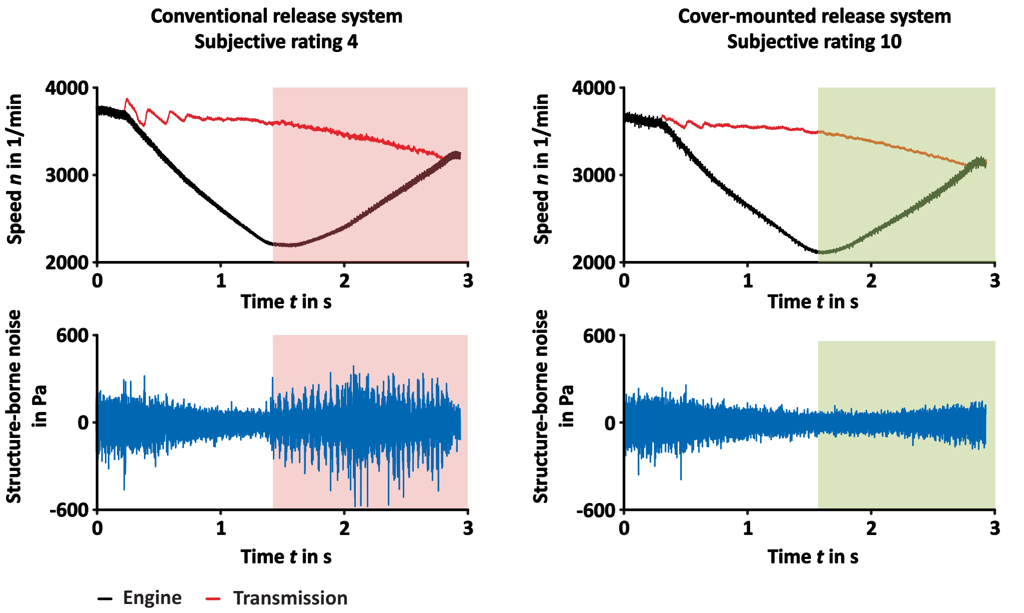

Figure 22 Rattling noise in the slip phase – effectiveness of the cover-mounted release system (CMR)

Figure 22 shows an example of a noise problem (rattling) in the slip phase, which is characterized by structure-borne noise peaks on the transmission occurring every 0.5th engine order. The starting situation with a conventional release system is scored with a subjective rating of 4. With a CMR, it achieves a rating of 10; the peaks in the structure-borne noise signal during the engagement phase are completely eliminated.

Figure 23 shows another example of the effectiveness of the CMR. With a CMR, a rating of 10 can

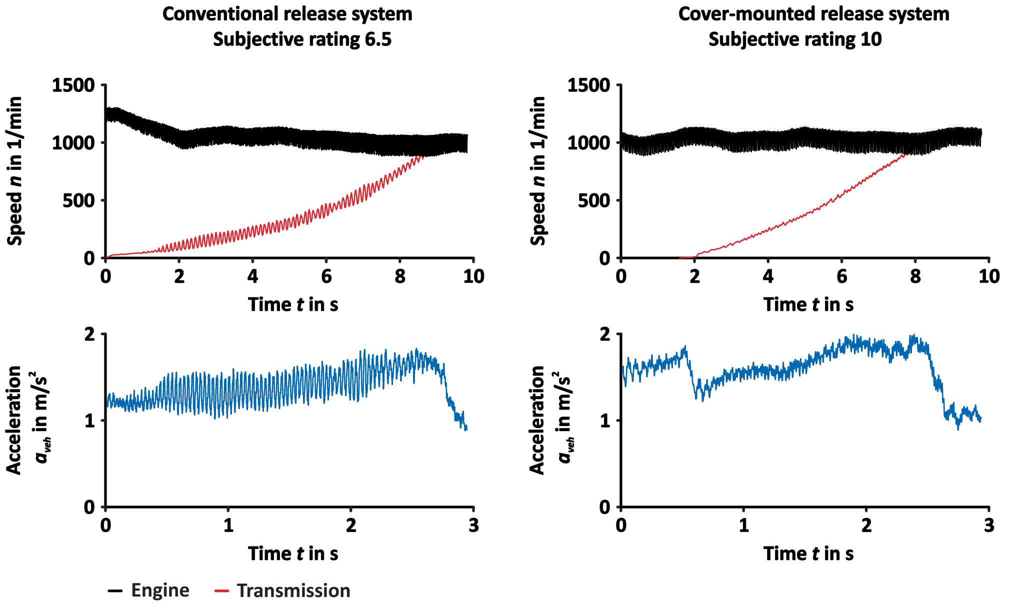

Figure 23 Crankshaft-excited slip – effectiveness of a cover-mounted release system (CMR)

also be achieved in the slip evaluation in this vehicle. The excitation is demonstrably caused by crankshaft vibrations.

The strength of the effect of an excitation on the subjective rating depends definitively on the vibration ability of the system that is excited. The same excitation can thus lead to a good rating in one vehicle and a poor rating in another. For example, different vehicles have significant differences when it comes to slip sensitivity, as the comparison of some 40 vehicles in Figure 24 shows.

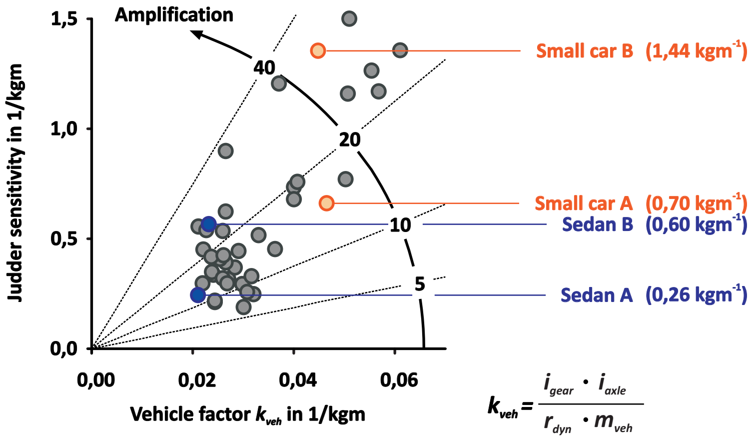

Figure 24 Benchmark slip sensitivity of automobiles in 1st gear

The vehicle factor on the x axis represents the effective vehicle weight or the vehicle size. The slip sensitivity is a vehicle constant. It is the factor between cause (excitation) and effect (vehicle vibration) and applies to a harmonic excitation in the slip frequency, smaller values being desirable.

Sedans A and B are in the same vehicle class and have similar engines. The slip sensitivity of sedan B is more than double that of sedan A. In concrete terms, this means that more than double the vehicle vibrations can be expected with the same slip excitation. The same applies to the example of the two small cars. In general, smaller vehicles are more sensitive than larger ones, since less mass must be accelerated. This is partially compensated for, however, since the engines are smaller and the torque capacities of the clutches are less.

The differences in sensitivity result largely from the interactions of the drive train with the eigenmodes of the engine block (rotation, translation) and the wheel suspension (translation).

Vehicles with high slip sensitivity can be mastered only with difficulty with the current state of the art. Special measures can be necessary to avoid complaints. In addition to component optimization, a cover-mounted release system (Figure 23) or an impact compensation bearing (Figure 26) can help, depending on the type of excitation. Another solution is offered by a slip damper [11], which has the advantage of efficiently reducing or preventing the slip type of excitation.

The possible problems are multi-layered, and are often first identified in vehicle trials, and thus late in the development process. At LuK, intensive measurement and simulation methods are developed to duplicate the various phenomena at the system level as well as the component level. The objectives are the earliest possible detection of potential problems and the development of robust designs and remedies. For example, the "eek noise," as it is called, an instability of eigenmodes of the transmission input shaft, has been simulated virtually. That was the only way stabilizing measures could be determined. In concrete terms, clutch discs were developed with tilt and radial flexibility which significantly reduce the probability of unstable system behavior [11].

In connection with pedal vibrations, the entire system can be analyzed and optimized from flywheel to pedal using well-grounded simulation models [12]. This approach is already being used intensively in the development process to precisely tune hydraulic lines and dampers [10]. Supposedly small details are also being closely modeled and tested. An example of this is the interface between the diaphragm spring finger and the release bearing. Depending on the configuration of the finger design and the friction coefficient in the contact zone, appreciable improvements may also be made at this point, depending on the starting situation (Figure 25). The lowest possible friction coefficient that can be reliably obtained with an additional contact disc on the release bearing is desirable [10].

With tightened boundary conditions, it has become even more important for automaker and supplier to work closely together in order to identify possible problems early on. This is the only way to find the need for action as early as possible so that the best solution, from both a technical and a commercial standpoint, can be developed jointly. Figure 26 shows some known as well as some new examples of problem- and comfort-oriented system solutions.

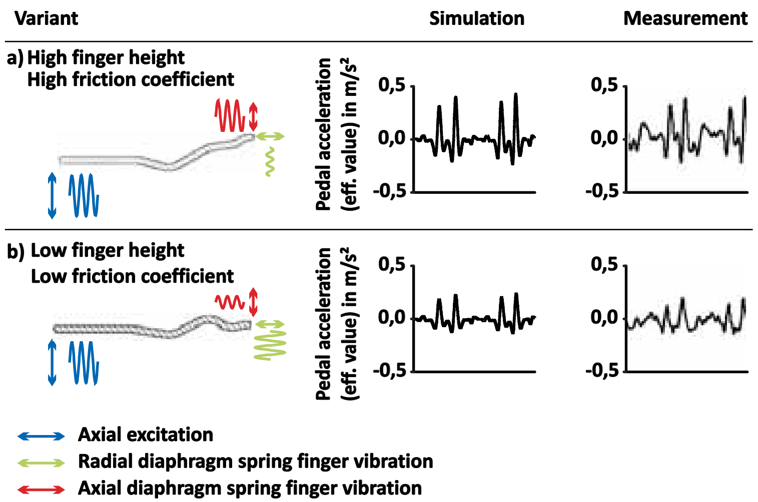

Figure 25 Pedal vibrations – detail optimization at the contact point between diaphragm spring finger and release bearing

Summary

In competition with hybridization and ultimately electrification of the drive train, the combustion engine will continue to claim a leading role for some time to come.

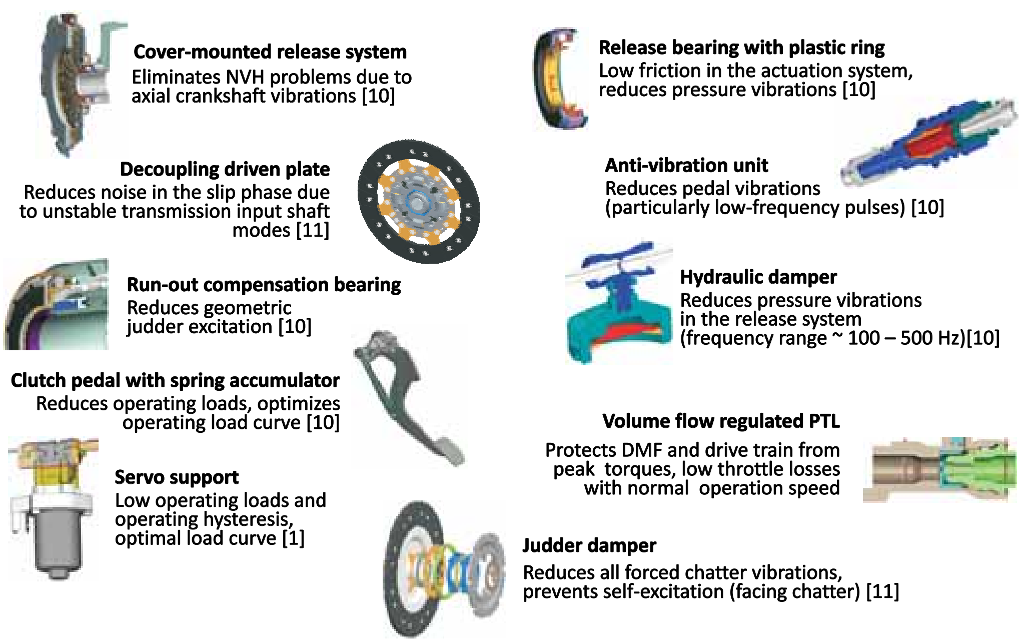

Figure 26 Examples of efficient products to optimize the system behavior in the slip phase

Optimizations on the engine side as well as the selection of a suitable transmission concept to make full use of any potential for reducing fuel consumption will turn the conflict of interest between pleasurable driving or efficiency into the goal of pleasurable driving and efficiency.

The damper and clutch systems will be key elements for such drive trains – they will be given the Herculean task of offering optimal degrees of isolation in the face of increasing irregularity, rising comfort demands and friction-optimized drive trains.

Shift recommendations, stop-start systems, and, depending on the vehicle class, transmission automation will soon be a matter of course and will no longer have to court the car buyer's acceptance. The vast majority of these technical solutions can be found in the intelligent refinement of existing components, such as the DMF, clutch and release system.

Close cooperation between automaker and supplier is required now more than ever, both in concept selection, or even drive train definition, as well as in production development.

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