The Torque Converter as a System

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Introduction

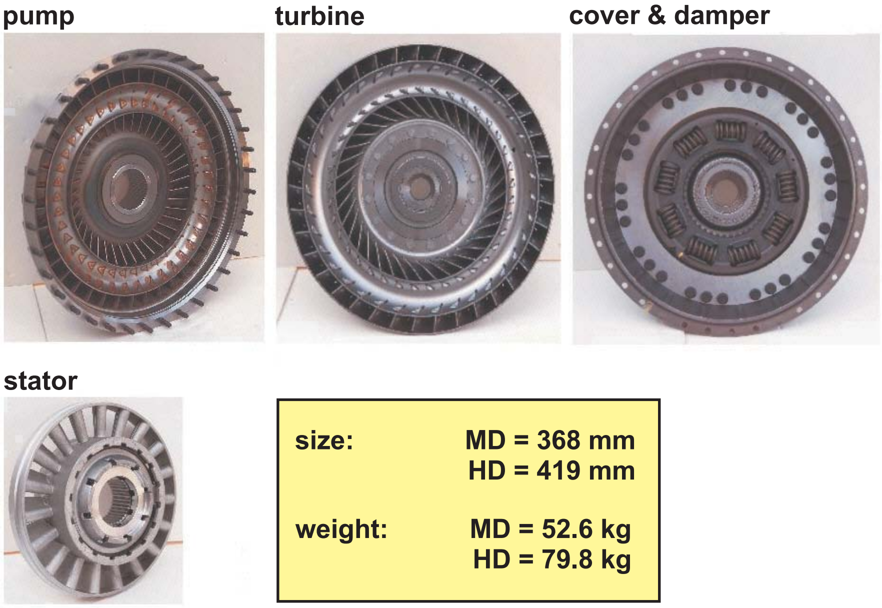
Since its introduction in the 1940s, the torque converter has been utilized as a proven coupling element between the engine and automatic transmission. Its advantages result from the principle of hydrodynamic power transfer from engine to transmission. The available torque amplification (torque ratio) improves acceleration and performance. The ever-present and, in principle, necessary slip isolates the drivetrain from the engine torsional vibrations, prevents Tip-in reactions and provides comfortable transmission shifts. Lock-up clutches with dampers are used to bypass the torque converter and minimize the losses due to slip in the torque converter.

In contrast to automatic transmissions which have had their functionality continuously improved, torque converter design and concept have not been changed significantly throughout the preceding decades. Even the introduction of lock-up clutches in the 1970s hardly changed the principles of torque converter concept, layout and design. This is surprising because of the well-known potential provided by the torque converter system. With a well-tuned lock-up control strategy and appropriate hardware components, tremendous improvements in performance and significant fuel savings can be realized.

In the last Symposium in 1994, LuK presented an innovative torque converter system called the LuK-TorCon-System. This system still uses the advantages of the torque converter but minimizes the disadvantages by introducing a high-performance lock-up clutch and an aggressive lock-up control strategy. Depending on the application, the LuK-TorCon-System provides significant improvements in performance and fuel economy. Furthermore, the system enables us to gain the same performance characteristics using a conventional 4-step automatic transmission instead of a more expensive 5-step automatic transmission. However, the demand for further improvements in performance and fuel economy dictates additional optimization steps. In this context, the selection and tuning of the lock-up control strategy is as important as the design and tuning of the three hardware components: hydrodynamic circuit, lock-up clutch and damper. In fact, only with this holistic approach is it possible to attain the entire advantages provided by the torque converter system.

In spite of these circumstances, over the last few years, LuK has developed torque converter systems, which provide superior characteristics compared to conventional systems. With reduced envelope, lower weight and equal costs, the LuK torque converter systems deliver more functionality, greater flexibility and enables to reduce fuel economy and emissions and increase vehicle performance.

LuK has increased the torque converter development capacity and capabilities in Bühl, and in Wooster, USA, where we have established a second Torque Converter Development Center. At LuK, Inc., USA, we started producing both medium and heavy duty torque converters for Allison’s World Transmission Series in 1997. Figure 1 shows the MD Torque Converter, that also utilizes the advantages of a lock-up clutch.



size: MD = 368 mm
HD = 419 mm

weight: MD = 52.6 kg
HD = 79.8 kg

Figure 1: Components of the MD torque converter series

History and Global Development of Automatic Transmissions and their Influence on Modern Torque Converter Concepts

The American car manufacturer, Oldsmobile, presented already the first fully automatic transmission for passenger vehicles in 1940 (see figure 2).

Figure 2: The beginning of automatic transmissions

At this time, the main focus was on increasing the driver's comfort. Any disadvantages in performance and fuel economy were not yet important. The state-of-the-art transmission was a 2-speed-transmission with a total gear ratio of 1.8 (as shown in figure 3). To compensate for the relatively small total gear ratio, torque converters with a torque ratio of 3 or even 4.5 were used, providing high comfort but resulting in a system with poor fuel economy. Overall, the complexity and functionality of the torque converter used in the 40s and 50s were much higher than those used today. Torque converter models with adjustable stator blades, two or more turbines and stators, and integrated transmission functions were used but lock-up clutches had not yet been introduced.

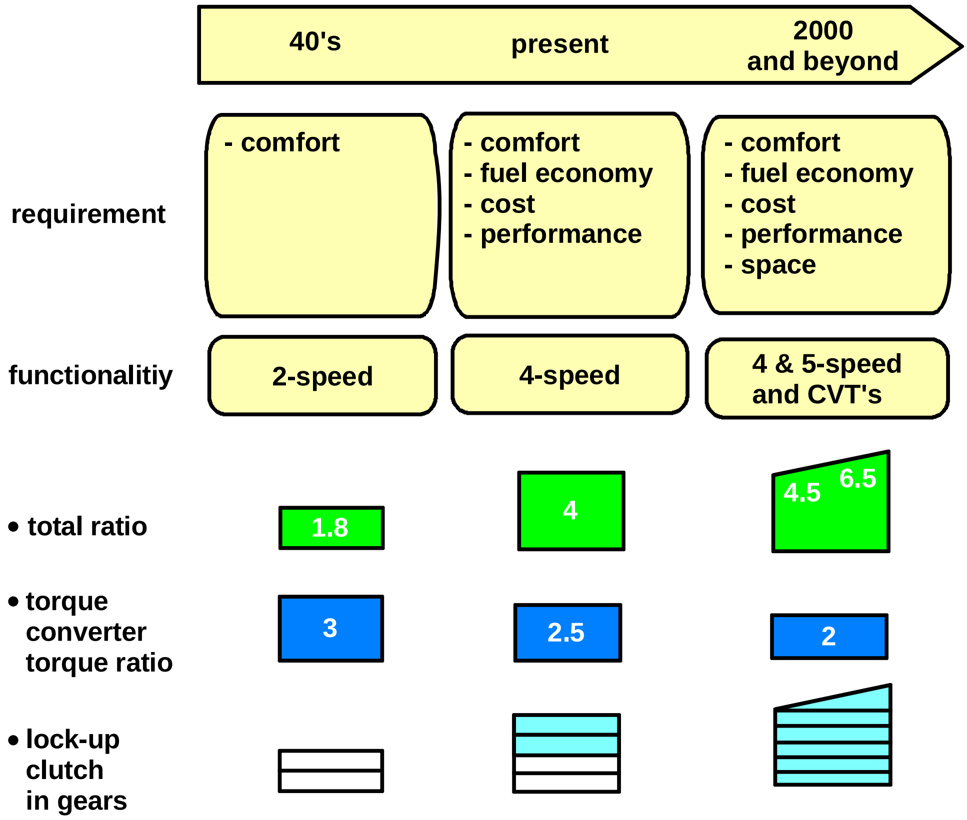


Figure 3: Global development of automatic transmissions

Stiffer torque converters had to be introduced in order to reduce losses. The large torque ratio was no longer possible and had to be compensated for by increasing the total gear ratio with more mechanical gears. In the 1970s, the 3-speed-automatic transmission (total ratio of approximately 2.5) was the most common model. Due to the oil crisis, lock-up clutches were introduced to eliminate torque converter slip losses, at least only in top gear and at high vehicle speeds. The requirements for cooling capability of the lock-up clutch and vibration isolation of the damper were accordingly insignificant.

The 4-speed automatic transmission is the state-of-the-art in the 1990s and provides a total gear ratio between 4 and 4.5. Today, 75% of these transmissions are electronically controlled, and in 2000, almost 100% will have this feature. Compared to the 1970s, the lock-up clutch operates in wider ranges. To reduce fuel consumption, the torque converter is normally locked in third and fourth gear, at engine speeds between 1100 rpm and 1700 rpm. The lock-up clutch operates partially with continuous slip, and is, in many cases, modulated, for example during gearshifts or after tip-ins.

Having reviewed the history and global development of automatic transmissions, we predict the following:

- The functionality (numbers of gears and total gear ratio) of automatic transmission will continue to increase.
- The duty cycle of the open torque converter will decrease further.
- The duty cycle of the lock-up clutch will increase further, either with slip or completely closed.

In addition to these global development trends, it is most likely that fuel costs will increase further and environmental awareness will enlarge. Both developments will require strenuous efforts to reduce fuel consumption. Likewise, the cost of torque converters will have to decline in the future. Space for the torque converter, especially in CVT- and front wheel drive applications, will be less than is currently available.

Figure 4 shows a summary of the global development trends and the resulting design targets for future torque converter systems.

global trends

- **increased functionality of automatic transmissions**
- **decreased duty cycle of torque converter**
- **increased duty cycle of lock-up clutch**

design targets

- **further improved fuel economy**
- **further improved performance/ acceleration**
- **less space and weight**
- **less cost**
- **good driveability and comfort**

Figure 4: Global development trends and design targets for future torque converter systems

The Control Strategy of the Lock-Up Clutch: The Linkage for Target Achievement

Concept, characteristics and design of the three system components of a torque converter - the lock-up clutch, the damper and the hydraulic circuit (torus) - are the result of the required control strategy for the lock-up clutch. The control strategy is the central link of the hardware elements; it determines the requirements for different operation ranges and, thus, the design of the individual components (figure 5).

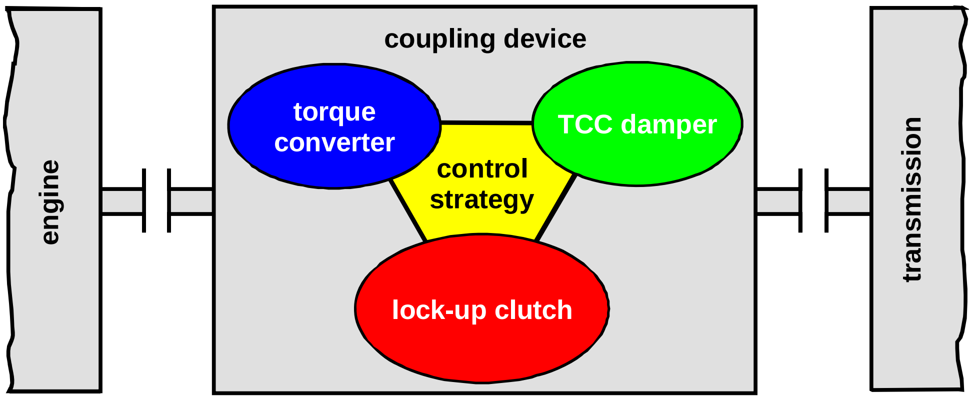


Figure 5: Total system of torque converter, lock-up clutch, damper and lock-up strategy

The appropriate lock-up control strategy is defined individually for each vehicle application by considering the vehicle functionality and the targets for fuel economy, performance, driveability and driver comfort. The total system characteristics determine the lock-up strategy and, hence, the requirements for the component designs.

One of the appropriate characteristics for the best lockup strategy is the total gear ratio of the transmission. Based on the state-of-the-art technology and the consideration of the future development of the automatic transmissions and CVT's, the control strategies can be grouped according to figure 6.

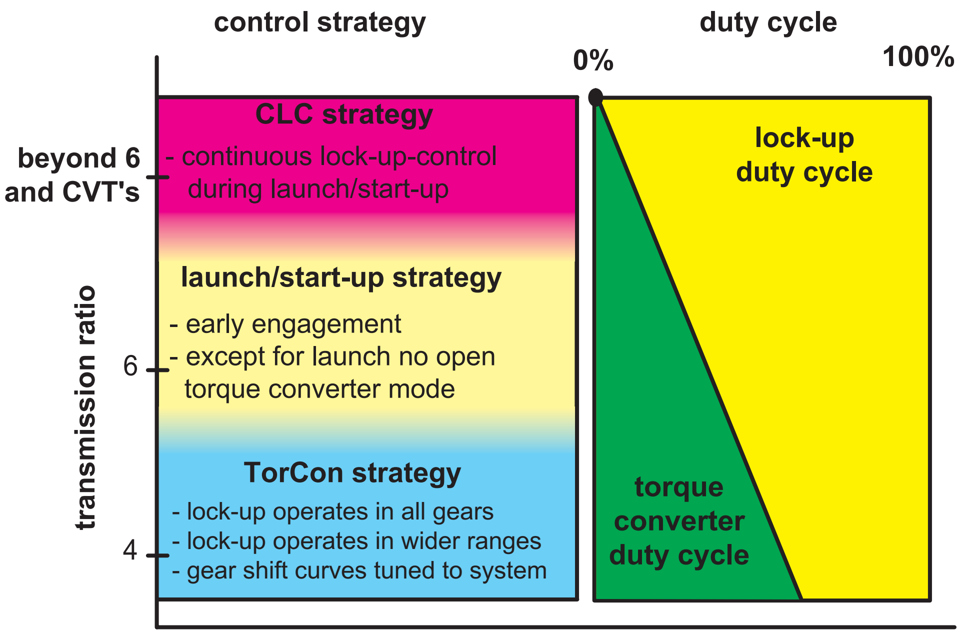


Figure 6: Lock-up control strategies

The LuK-TorCon-Strategy is appropriate for transmissions with a total ratio of 4 to 4.5. To reduce fuel consumption and to improve performance, the lock-up clutch operates

- in all gears and
- over large speed ranges (down to 900 rpm)

In order to ensure sufficient noise reduction in this low rpm-range, at high loading condition, or to avoid engine lugging, a large amount of slip is necessary during lock-up. With the use of a high performance damper, the noise level can be reduced further or the amount of slip can be lowered. The loss due to the high amount of slip can generate excessive heat and temperature build-up at the friction surface of the lock-up clutch. The high temperature causes ATF-oil and friction material degradation. The result is falling friction coefficient with increasing slip speed, which leads to shudder and possible transmission failure. As a counter measure, the lock-up clutch must have a high cooling capacity. The LuK high performance lock-up clutches provide this design feature.

Because the Torque Converter is still partially open with the TorCon Strategy, the appropriate torque converter characteristic must still be selected in order to optimize the system. Loose torque converters with a high stall torque ratio and a high stall speed create less idle losses and provide better acceleration when compared with stiff torque converters. The engine warm-up time is also reduced and, thus, the emission level is lower. However, with a loose torque converter there are excessive losses generated in some operation ranges. As a counter measure, the lock-up of a loose torque converter must take place very soon. This was anticipated in the LuK-TorCon-System and the hardware is designed to permit this.

Figure 7 shows a comparison between a loose and a stiff torque converter when equipped with a conventional lock-up strategy and with the TorCon Strategy individually.

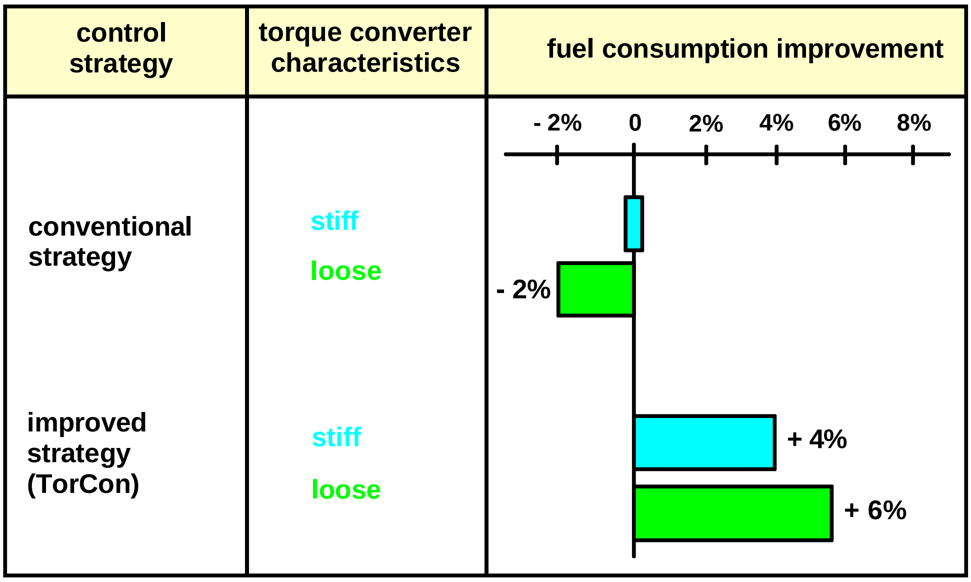


Figure 7: Influence of the torque converter characteristic and the control strategy on fuel consumption (simulation). Example for a 4-step transmission.

With respect to fuel economy, one can say:

- When using a conventional lock-up control strategy, the stiff torque converter is more advantageous than the loose one.
- When using the TorCon Strategy, the loose one is better.
- The influence of the control strategy on fuel economy is higher than the influence of the torque converter characteristic.
- When combining a loose torque converter with the TorCon Strategy, it is in some applications possible to achieve an improvement in fuel economy by 5 to 10% over the combination of a stiff torque converter with a conventional lock-up control strategy.

Similar conclusions can be made, if evaluating the vehicle performance.

With increasing transmission total gear ratio (>5), the selection of the torque converter characteristic (loose/stiff, stall torque ratio and peak efficiency, etc.) becomes less relevant for

- vehicle performance and
- fuel economy.

The reason for this is that there is always an operating condition with a closed torque converter for transmission types with large total ratios and number of transmission speeds that is better with respect to fuel economy or tractive force than an open torque converter. Opening the torque converter makes neither technical sense, nor is required for comfort. The torque converter serves mainly as a start-up element for a comfortable launch.

With this in mind, the conceptual layout of the torque converter has to focus more on the required installation envelope and cost optimization rather than on the traditional criteria, like peak efficiency, stall torque ratio and loose/stiff characteristic. With respect to the torque converter characteristic the function K-factor versus speed ratio and the position of the coupling point are getting most important.

LuK has developed a super squashed torque converter, which is axially 45% smaller when compared with conventional round torque converter designs. This was done without any performance tradeoff by employing the appropriate combination of the lockup clutch and control strategy. Figure 8 compares fuel economy and acceleration between the conventional round torus with the LuK super squashed torus in a CVT- application as an example.

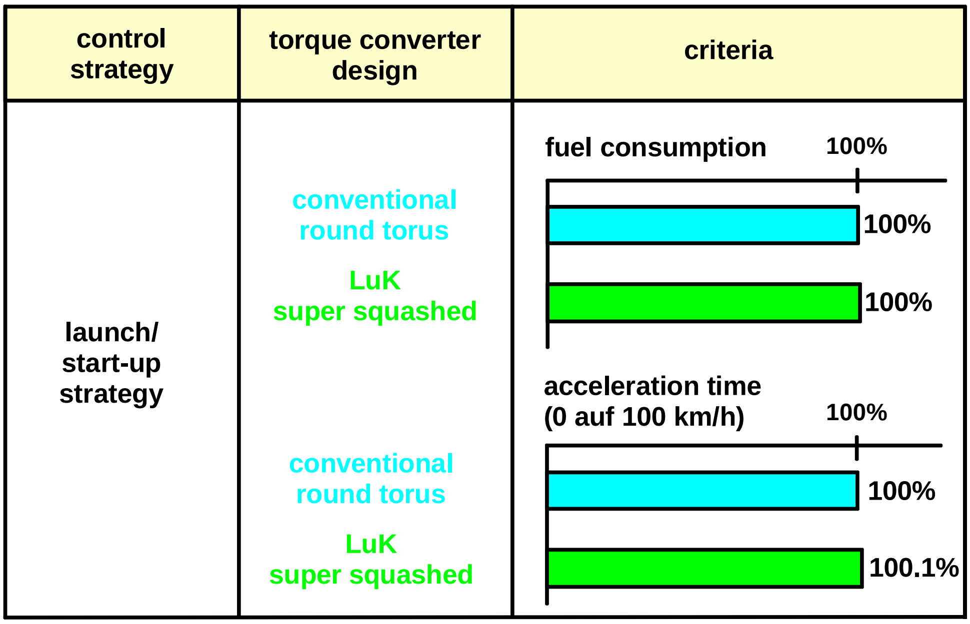


Figure 8: Influence of torque converter design concept on performance and fuel economy. Example for a CVT application.

For CVT-applications, it is even possible to think of a control strategy, which operates continuously without defined shifting points of the lock-up clutch. With a CLC (Continuos lock-up control) strategy, the clutch is activated by releasing the brake when the vehicle is not moving. The clutch is partially applied with a minimum torque capacity of about 10 Nm. The clutch apply increases continuously from vehicle launch until the transmission ratio changes (figure 6). An open torque converter mode during driving is not planned. The advantage of such a system is clearly the improved comfort (no shifting of the lock-up during driving). This strategy requires a larger cooling capacity and a modified cooling system to compensate for the losses in the clutch. This project is now in the initial development stage at LuK.

Based on the presented control strategies, the simulation results of the fuel economy and performance and the development trends, one can summarize quantitatively the development targets for the torque converter system as illustrated in figure 9.

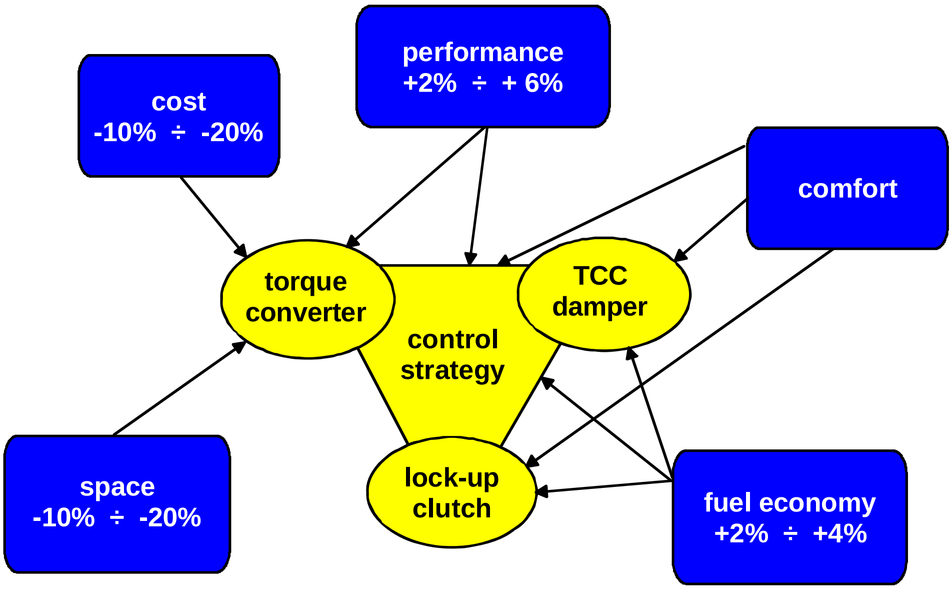
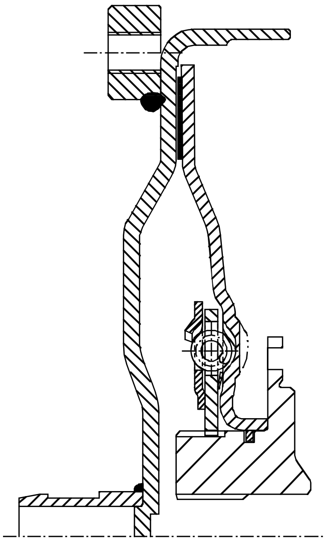


Figure 9: Design targets for the total system consisting of: Torque converter, lock-up clutch, damper and control strategy

Hardware Components

The High Performance Lock-Up Clutch

The common basis of the previously mentioned lock-up strategies is the increased requirement on the clutch functionality. In addition to the clutch torque capacity, both the cooling capability and the clutch controllability need to be taken into consideration.



design targets:

- **sufficient clutch capacity**
- **sufficient cooling capability**
- **good controllability**
  - smooth engagements
  - neutral behavior in drive and coast
  - constant and short response time
  - torque increase with increased slip speed (positive friction coefficient gradient)

Figure 10: Requirements of the high performance lock-up clutch

Torque Capacity

The permissible facing unit pressure of the facing material predominantly determines torque capacity of the lock-up clutch. The differential pressure across the piston plate and the active surface area determines the facing unit pressure. The active surface area is dependent on the mechanical and thermal deformation and the manufacturing tolerances of both the piston plate and the cover. Therefore, the nominal facing area is less important. A more detailed description of this mechanism has been given from LuK already in the 4th LuK Symposium 1994 [1] and in other publications, like [2], showing the substantial experience which already exists at LuK. Depending on the specific application and the operating conditions LuK can offer various lock-up concepts; flat single plates (Figure 10), conical lock-up concepts (Figure 26), twin-plate lock-up concepts (Figure 25) as well as multi-plate lock-up concepts.

Controllability

The lock-up engagement can be divided into three phases:

- Shift phase from open torque converter mode to lock-up mode
- Contact phase (piston plate touches cover)
- Torque build-up phase

It should be possible to engage the clutch with a minimum amount of volume flow. This can be accomplished with a low resistance to applying the piston plate and with a small gap between piston plate and cover, so that a small volume flow already creates sufficient, differential pressure to overcome the apply resistance and closes the gap. A large volume flow would cause a sudden torque build-up during the engagement, since the kinetic energy of the volume flow would be converted to pressure energy. The hydraulic resistance between piston plate and cover and piston plate and turbine hub is also important. It is favorable to keep it at a minimum. With the help of numerical analysis it was possible to optimize the shape of the cover, piston plate and turbine hub for the described purpose.

For the contact phase it is important that the grooves don't cause a self-energizing effect. Experimental development lead to an optimized groove design, which will cause a neutral engagement in drive as well as in coast. In order to achieve good torque controllability a fine tuned torque capacity and a positive friction coefficient gradient versus slip speed are necessary.

Cooling Capacity

Sufficient cooling capacity of the lock-up clutch is very important. The power losses that are generated at the friction surface can cause high peak temperatures, which can destroy the oil additives and, in interaction with the mechanical shear load, split the molecule chains. This causes a negative friction gradient, which can lead to shudder and finally can cause failure of the transmission.

The thermal loading of the high performance lock-up clutch is mainly dependent on the lock-up strategy. The strategy will determine the maximum power loss and the magnitude of the total energy, to be absorbed at the friction surface. The following is valid:

- The lower the rpm at which the lock-up engages (lugging limits), the higher is the needed slip to avoid noise and, therefore, the higher the power losses.
- The lower the gear, the more critical are tip-in reactions. In Figure 11a typical tip-in event is plotted. Immediately after the tip-in the lock-up clutch is slipping, which is meant to eliminate the usual and annoying surging vibration. The plotted event appears to be comfortable. However, this leads to high power losses.

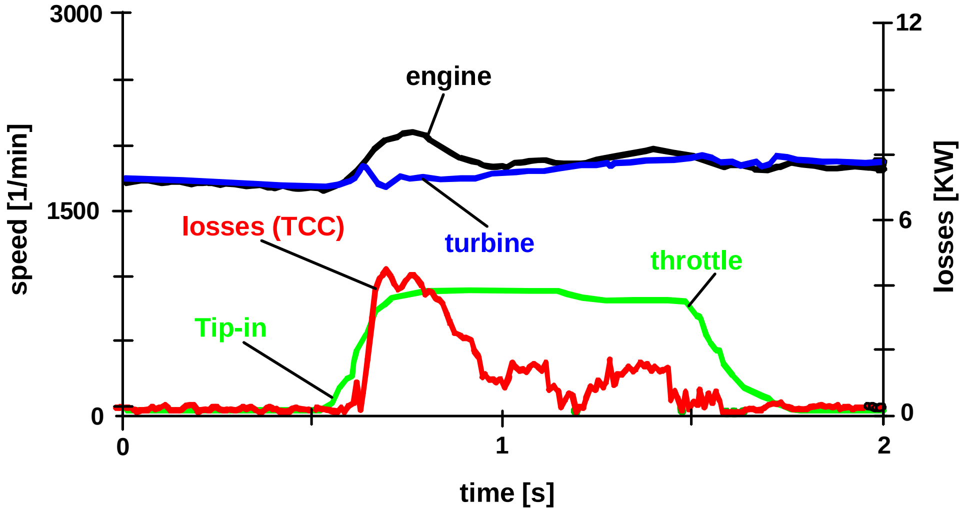


Figure 11: Thermal loading of the lock-up clutch during tip-in

The lower the gear and the lower the lugging limits, the more comfortable, and with this longer, the engagement of the clutch needs to be. The longer the engagement, the higher is the total energy absorbed. Figure 12 shows a comfortable engagement. The maximum power losses are 7 kW during this non-noticeable engagement.

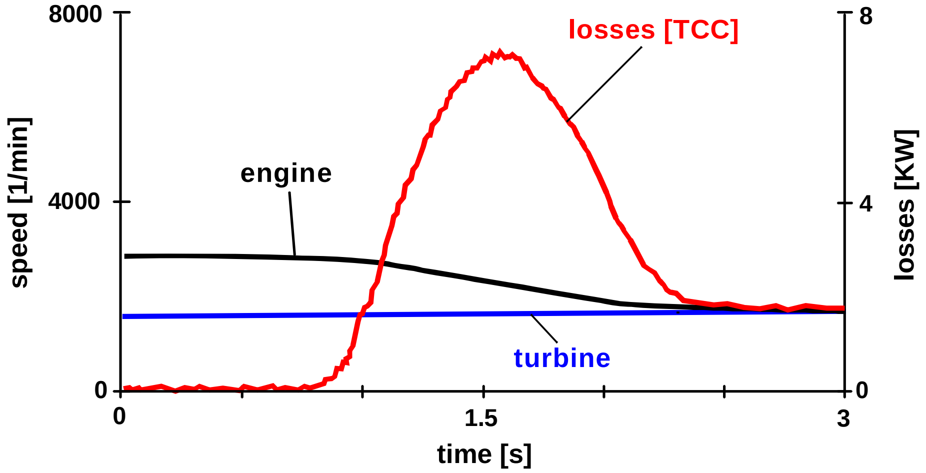


Figure 12: Thermal loading of the lock-up clutch during a “non-noticeable“ engagement

What are the differences between LuK's high performance lock-up clutches and conventional lock-up clutches, and why is the allowable power loss higher? The answer is:

- Well tuned parts.
- Usage of conical shaped piston plates with high stiffness in the friction surface area (Figure 25) or a twin-plate design (Figure 24) for even higher power losses.
- Optimized geometry of the cooling groove in the friction material.

To optimize and fine-tune the components the following interactions are important:

1. The development of the temperature on the friction surface is dependent on the local specific power loss (the product of the local facing unit pressure on the friction surface and the slip) and the development of the power loss function over time (see figure 13). Especially for engagements, the criterion for optimization is the specific power loss on the friction surface and not the local facing unit pressure.
2. When the facing unit pressure on the friction surface is calculated, not only the elastic deformation of cover and piston plate due to apply pressure should be taken into consideration. The thermal deformation also must be considered. This alone can raise the facing unit pressure by 20%.
3. Converters with 2 pass systems should have the friction material on the piston plate, while 3 pass systems should have the friction material on the cover.
4. The development of the interface temperatures during lock-up engagements is very different when compared to continuous slip conditions.

In order to analyze the temperature development LuK uses a special software package which incorporates the mechanical and thermal deformation of the piston plate, the material properties of the friction material and the heat transfer coefficient between steel/oil and steel/air which locally can be very different.

The results from a computer simulation performed with this software package are compared with measured data of a rotating test part in figure 13. The figure shows the temperature rise on the friction surface during an engagement. The maximum surface temperature is reached towards the end of the engagement in the middle of the friction surface even though neither the facing unit pressure nor the specific power loss is at maximum at this location and time.

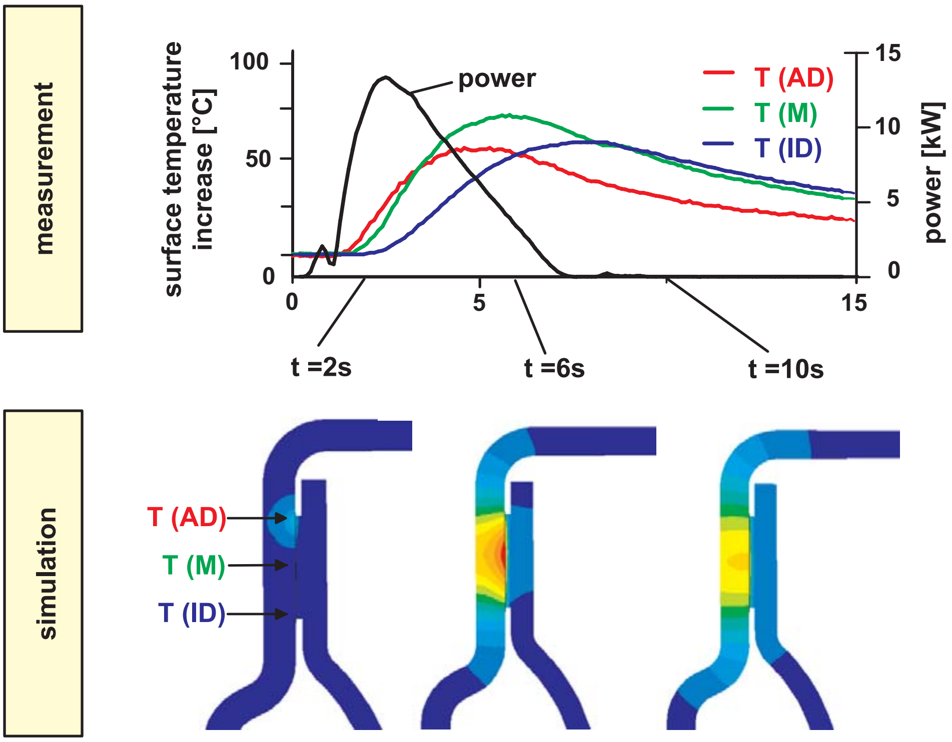


Figure 13: Temperature development at the friction surface during an engagement

Due to these results new development directions and design guidelines could be established, which differ significantly from those that only consider facing unit pressure distributions.

The second important design part of the LuK high performance lock-up clutch is the cooling groove pattern, which shape allows an ideal optimization of volume flow and hydraulic resistance. This shape provides an increased heat transfer coefficient by a factor of 4 when compared to conventional grooves. In addition the LuK groove design exhibits a neutral behavior with respect to friction coefficient and the torque build-up during drive and coast condition. Figure 14 shows the allowable specific power loss of facings with LuK groove designs. It becomes apparent that in continuous slip applications the allowable power loss can be increased by 120%. During shorter slip events the increase in allowable power loss is less.

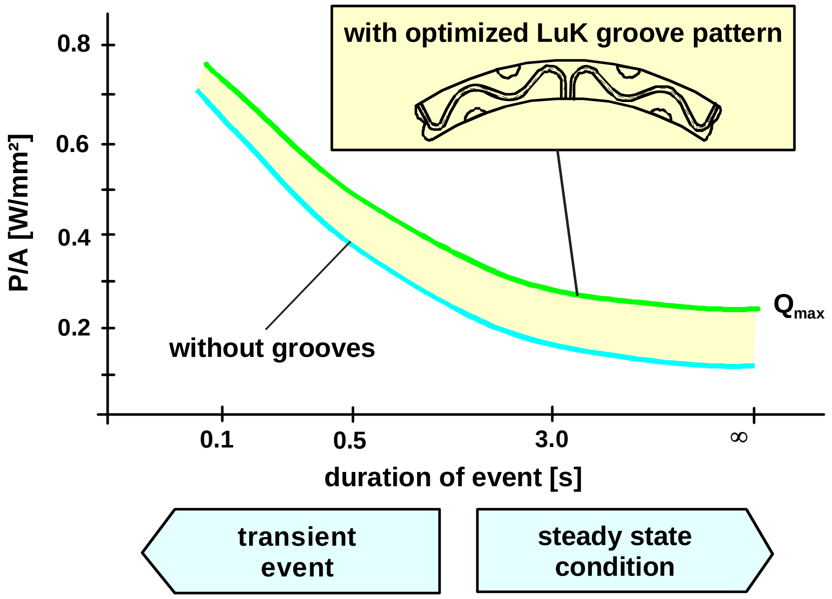


Figure 14: Permissible specific power loss at the friction surface

Figure 15 shows the absolute permissible values of the power losses, if the specific power losses from figure 14 are transformed to a real part. It should be noted, that the pictured lock-up concepts exhibit a strong design-dependent influence with respect to their cooling capacity. The different deformations of the parts and different realistic manufacturing tolerances of each design concept can explain this. The lock-up concept with the conical design of the piston plate exhibits the largest specific cooling capacity.

With the described lock-up concepts the initially mentioned control strategy problems can be solved. The risk of oil degradation does not occur.

Similar care must be taken when selecting the proper facing material for the lock-up clutch. The following criteria are very important:

- Increasing friction coefficient over increasing slip speed
- Good bonding and grooving capabilities
- High mechanical capacity
- Low wear rate
- High thermal capacity
- High level of friction coefficient

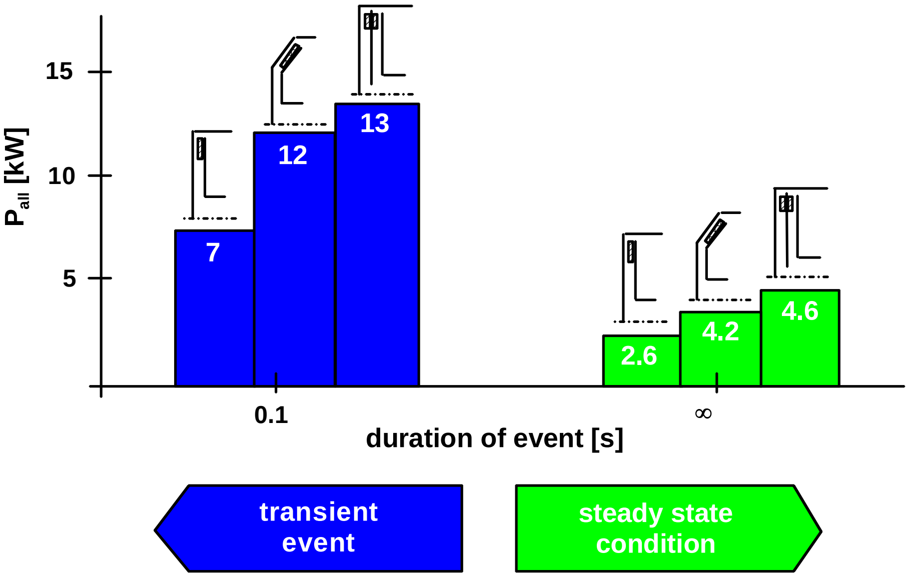


Figure 15: Permissible absolute power losses of high performance lock-up clutches with optimized groove pattern and maximum volume flow

The Damper

LuK produces approximately 3 million torque converter clutches per year, world wide, of various configurations. LuK has a Two-Mode Damper in production since 1996. This innovative damper concept offers many advantages for certain engines and drivetrains.

If a four-inertia model is used to describe the vibration modes of a drivetrain (engine, turbine, transmission and vehicle, like described in figure 15), the third mode is the transmission inertia swinging relative to the vehicle and turbine inertia. The largest vibration angle occurs in the transmission input shaft. The vibration angle in the damper is small in comparison. This mode can cause unacceptable noise, like in this case the boom noise, if the natural frequency of this vibration mode lies in the critical engine speed for the vehicle from 900 rpm to 2000 rpm. A reduction of the damper rate offers no improvement because of the small vibration angle. A long travel damper is therefore no solution for this problem.

A reduction of the transmission input shaft stiffness has a positive effect on this vibration problem, but is usually not possible because of the reduced input shaft strength.

LuK has developed a damper to solve this problem. The turbine is rotationally fixed to the torque converter clutch piston plate and the damper is in series with the transmission input shaft (figure 16).

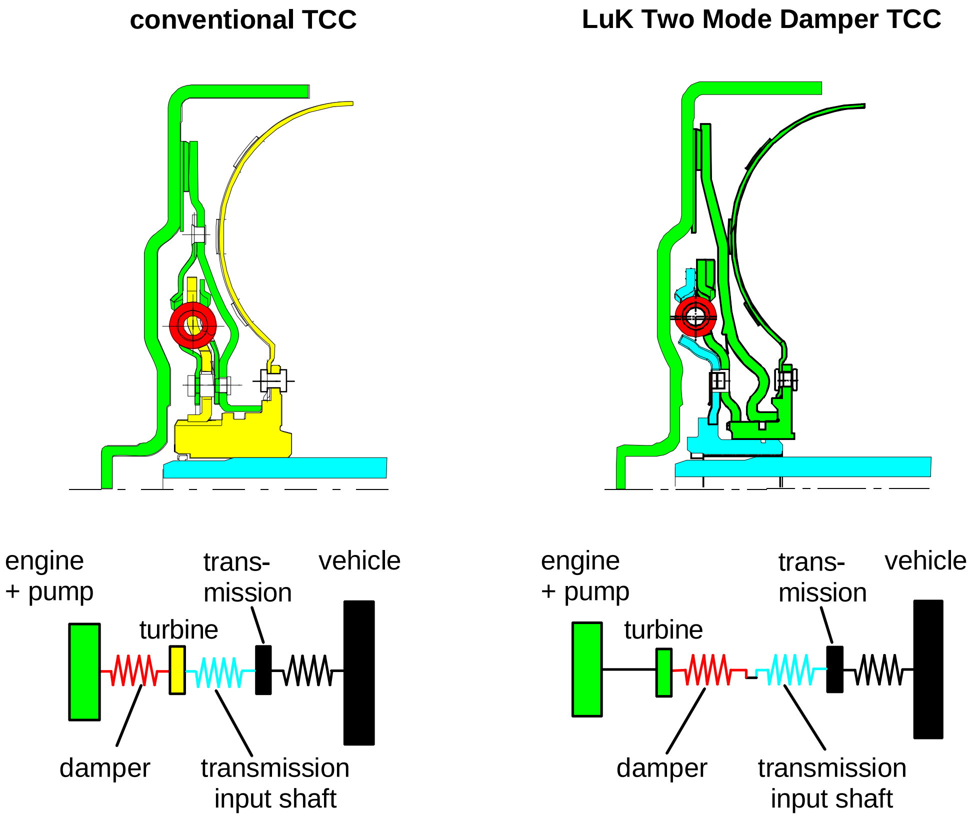


Figure 16: Principle of the LuK Two-Mode Damper compared to a conventional lock-up damper concept

The LuK Two-Mode Damper functions as follows:

- The damper and the transmission input shaft are attached in series which results in a very soft rotational stiffness of the total system (this was the original goal).
- The turbine is rotationally attached to the torque converter housing when the clutch is applied. This adds turbine inertia to the converter housing and engine inertia, thereby reducing the vibrations transmitted from the engine to the drivetrain.
- Combining the engine, torque converter and turbine inertia eliminates one degree o f freedom from the drivetrain.

The third vibration mode can always cause noise problems if the natural frequency of this vibration mode lies in the critical engine speed for the vehicle from 900 rpm to 2000 rpm. Simulations with typical drivetrains show that this can be critical in front wheel drive vehicles with 8- and 10-cylinder engines and rear wheel drive vehicles with 6- and 8-cylinder engines. Front wheel drive vehicles with 8- and 10-cylinder engines are unusual. Rear wheel drive vehicles with 6- and 8-cylinder engines are almost the rule. The Two-Mode Damper offers clear advantages for these vehicles.

By eliminating the otherwise critical third natural frequency, the torque converter clutch can be closed at lower engine speeds without any loss of comfort. The fuel consumption of vehicle types considered (figure 17) could be reduced up to 6%, using a LuK Two-Mode Damper.

The drivetrain natural frequencies for various rear wheel drive vehicles are represented in figure 17. These vehicles are all equipped with the same torque converter and the same automatic transmission. Every point in the diagram indicates a drivetrain resonance point and thus a potential vibration or noise problem. The resonance frequencies that occur with a conventional damper are compared with those that occur with the Two-Mode Damper. One notices that only one resonance frequency occurs with the Two-Mode Damper in the critical area, and this resonance is uncritical with low damper friction. Also important is the conventional damper with 15 Nm/° has a much lower damper rate than the Two-Mode Damper with 45 Nm/°. This means that a smaller spring volume can be used with the Two-Mode Damper.

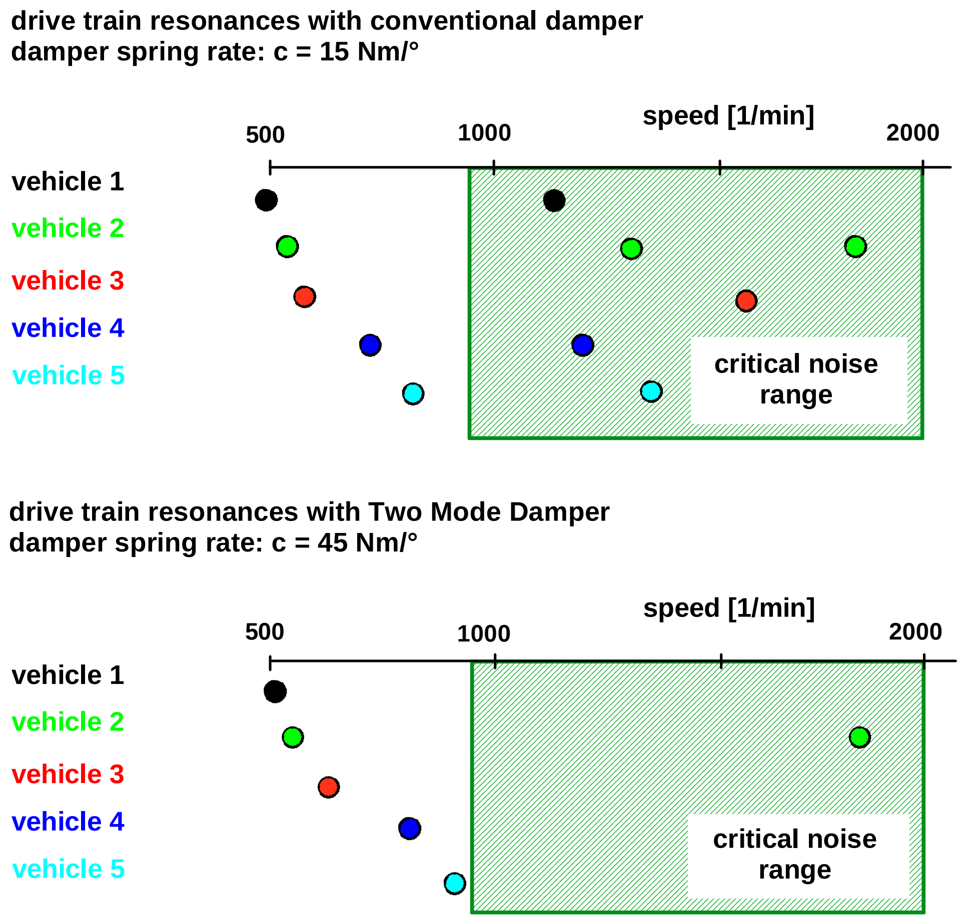
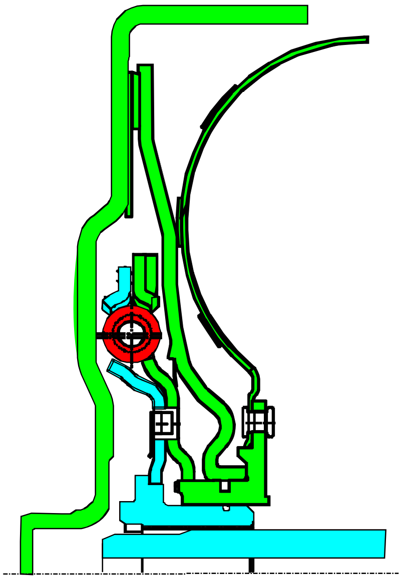


Figure 17: Drivetrain resonance with a conventional damper and the LuK Two-Mode Damper

Another important point is that the torque flow is through the Two-Mode Damper also when operating the converter in open mode. This gives additional vibration isolation in the open mode and provides an advantage for some unique vehicle types, for example, in vehicles with direct fuel injected engines or with cylinder shut-off which can have boom problems in the open mode.

The LuK Two-Mode is also appropriate for CVT transmissions because of the inertia distribution in those applications.

The advantages of the Two-Mode Damper are summarized in figure 18.



advantages

- **better fuel economy due to reduced lugging limits**
- **improved NVH**
- **also active in open torque converter mode**

Figure 18: Advantages of the Two-Mode Damper

The Squashed Torque Converter Torus

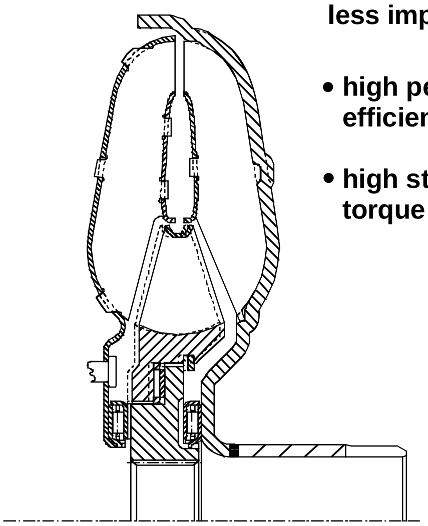
As mentioned in the beginning of this report, the torque converter for the future should be smaller, lighter and less expensive (figure 9).

A geometrical downsizing of the hydrodynamic torque converter torus without simultaneously changing the blading offers little flexibility with regard to the torque converter characteristic. Moreover, such converters cavitate or have an unacceptable K-Factor over speed ratio characteristic curve.

Consequently, the best procedure is optimizing the pump, turbine and stator blade to the new geometrical ratios of an extreme squashed torque converter. Besides the avoidance of cavitation the attention has to be directed to the K-Factor characteristic versus slip speed.

- The ability of the torque converter to transmit a certain torque at a given speed level (torque capacity = 1/K) has to be sufficient in order not to increase the torque converter size (diameter).
- The reduction of idle losses requires a high K-Factor at stall. However the clutch engagement is more comfortable and can take place earlier if the coupling capacity (1/K at coupling point) is as high as possible. This also helps to reduce the thermal load of the lock up clutch during an engagement. Together, both criteria require the ratio of torque capacity at stall and coupling point to be high (flat K-Factor curve)

This development goal is supported by the fact, that the fuel consumption or performance (see page 128) no longer dictates the design of the innovative torque converter along with the lock-up control strategy. Important criteria for the classic torque converter design, such as peak efficiency or high torque ratio, are therefore of lesser importance. The development can be much more focused. Figure 19 summarizes requirements for the future torque converter.



design targets

less important

- **high peak efficiency**
- **high stall torque ratio**

more important

- **extremely squashed torus**
- **no cavitation**
- **sufficient low k-factor**
- **high coupling point**
- **flat k-factor-curve**
- **sufficient heat capacity**

Figure 19: Requirement for the innovative torque converter

LuK has developed a torque converter whose torus is up to 45% axially smaller compared to a conventional round torus.

The torque capacity over speed ratio is a similar curve gained with a conventional, round torus. Without the use of suitable tools, such as powerful software to numerically calculate fluid flow in the circuit and the blade geometry, as well as Rapid Prototyping for fast and cost effective development of geometrically complex prototypes, this development would not have been possible.

The flow phenomena in the torque converter are critical especially at stall condition and at lower speed ratios. The energy builds up in the pump, as well as the energy dissipation in the turbine and also the redirection of the fluid in the stator (change of impulse) are maximum at this operating point. Simply stated the load acting on each fluid particle is the highest at this operating point. This principle is valid for each torque converter type. These relationships get worse tremendously if the fluid flow is unnecessary accelerated in quantity or direction caused by the inertia of the fluid particles. Unless geometrical improvements are made, those problems will occur in a squashed torque converter.

Figure 20 shows the fluid flow field inside the torque converter of an initial and of an optimized design. The initial torque converter design has a tear drop shape for the meridian cross section. This tear drop shape keeps the cross sectional flow area constant in order to avoid undesired accelerations or decelerations of the fluid. In spite of this, the velocity field shows a large separation area starting at the leading edge of the turbine and along the entire inner shell (core ring). This separation area considerably narrows the fluid flow channel and leads to a restriction of the circulating volume flow and therefore, reduces the torque capacity. Furthermore, there is an exchange zone where the energy from the 'healthy' flow is transferred to the circulating flow in the separation area. This distinct loss region can be clearly shown with the help of the turbulence energy (figure 20). This energy is almost fully dissipated in the separation area. In the optimized torus design, adjusting the design of the core and the blades reduced the separation area and the resulting energy losses. This change contributes considerably to the advantageous torque capacity characteristic.

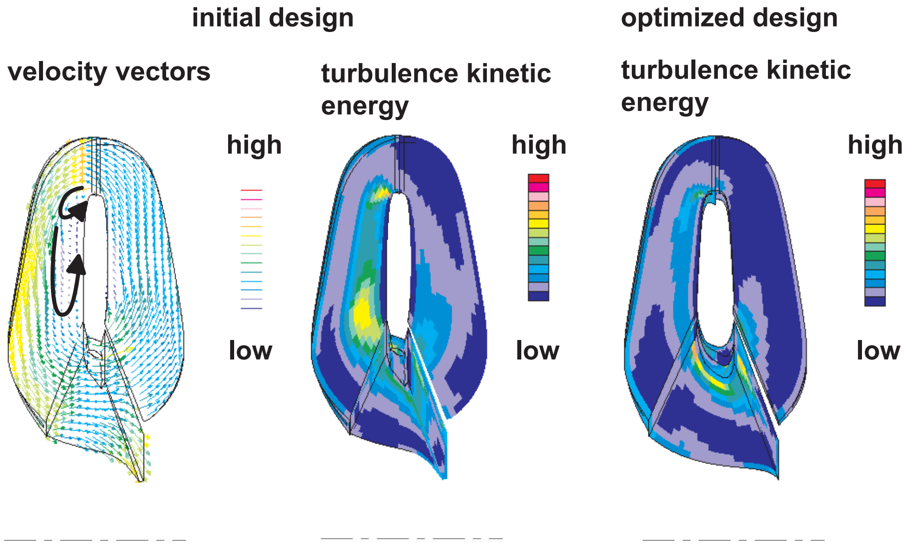


Figure 20: Optimized turbine; flow condition at stall

The critical and most difficult challenge in designing extremely squashed torque converters is avoiding fluid cavitation. Cavitation can be explained as the build-up and subsequent collapsing of vapor bubbles in the fluid flow.

If the absolute static pressure in the flow drops under the vapor pressure, vapor pockets grow and are dragged along in the flow. These cavities contract the cross sectional flow area and throttle the circulating volume flow. The torque capacity and the efficiency drop drastically. In areas of higher static pressure these vapor pockets implode. This collapsing of vapor pockets happens very fast, so the fluid particles impact on the channel surface with a very high velocity (jet-impact), which can result in mechanical destruction of the channel surfaces.

In torque converters, the region of lowest pressure is the suction side of the pump, consequently, the area between the pump and the stator. The profile losses in the stator have to be reduced to keep the static pressure at the stator outlet as high as possible. Figure 21 shows the fluid flow conditions in the stator passage for the initial design. One can identify a distinct separation region at the suction side of the stator blade in the cylindrical cross section. The flow field behind the trailing edge indicates strong turbulence. Both conditions lead to a drastic pressure drop in the stator passage and in the region behind the trailing edge of the stator blade (figure 21 and figure 22). Because of cavitation at the pump suction side, the initial design could not be run at high speed and at speed ratios less than 0.5.

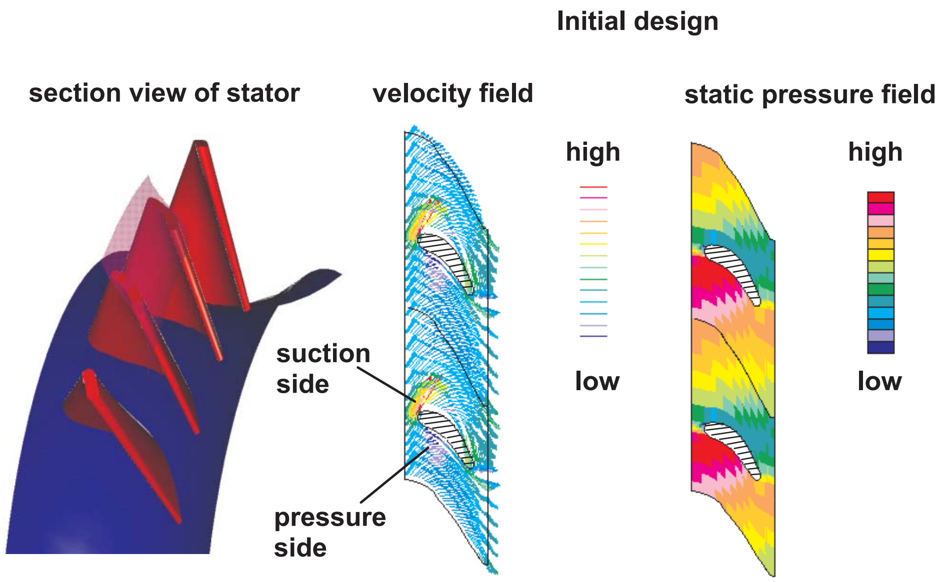


Figure 21: Flow field and static pressure field of a non-optimized stator blade; flow condition at stall

Figure 22 shows the velocity distribution and the static pressure field of the optimized stator design. The separation region at the suction side of the stator blade is much smaller than in the initial design. The flow field behind the stator is almost turbulence free. Both conditions result in a reduction of the pressure drop in the stator and an increase of the relative pressure in the pump inlet region.

As a measure for the quality of the energy transfer the total pressure field of the initial and optimized design are compared in figure 23. The comparison of the loss factors of both profiles indicates more than a 60% reduction of the profile losses in the optimized stator.

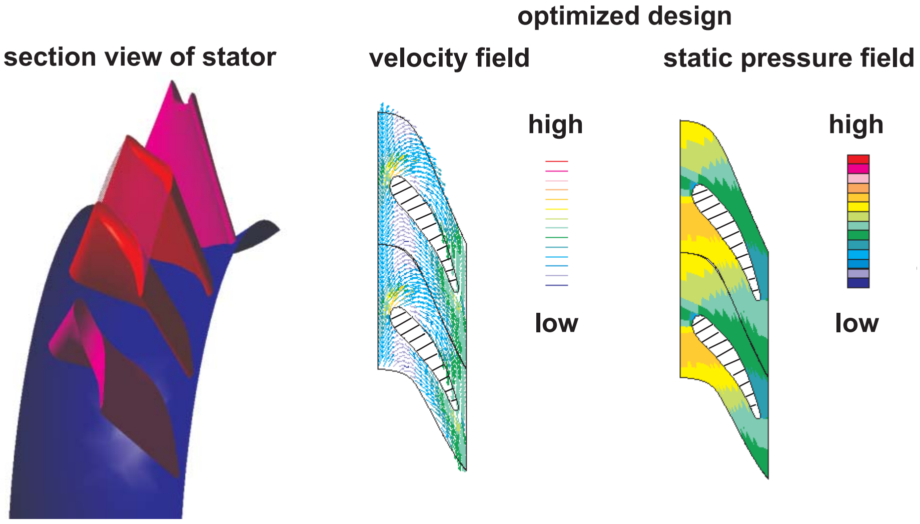
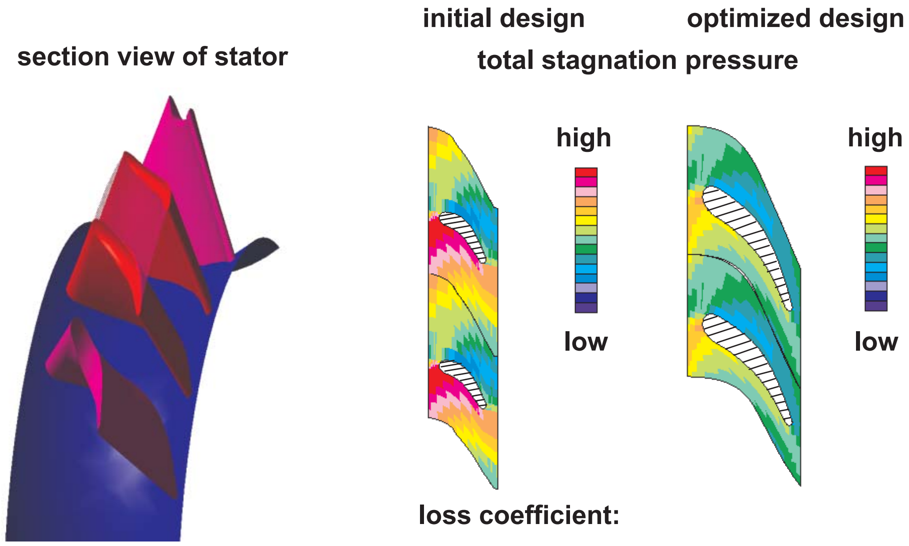


Figure 22: Flow field and static pressure field of an optimized stator blade; flow condition at stall



loss coefficient:

ξ = **1.47** ξ **= 0.623**

Figure 23: Comparison of profile losses; initial and optimized stator design; flow condition at stall

The optimized design of the extremely squashed torque converter shows no indication of cavitation. The quality of energy transfer in this case can be compared to a conventional, round torus torque converter (figure 24). Disadvantages regarding functionality of the squashed torque converter in combination with lock-up control strategy are not expected.

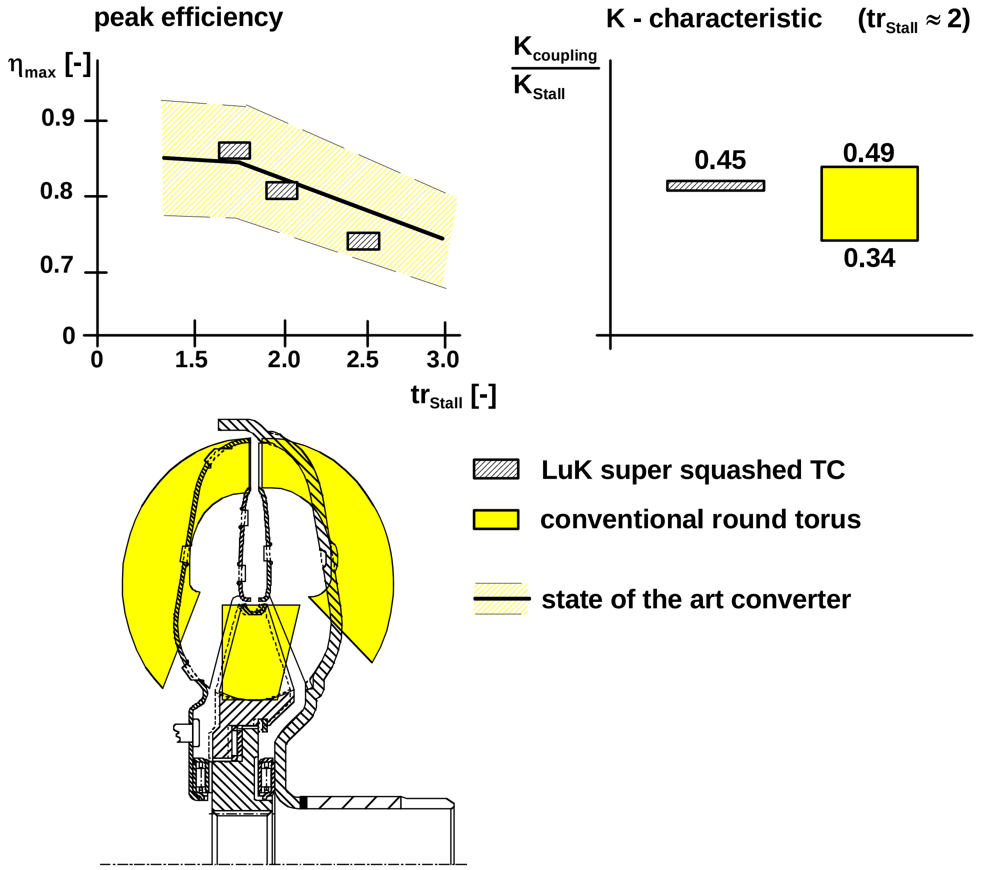
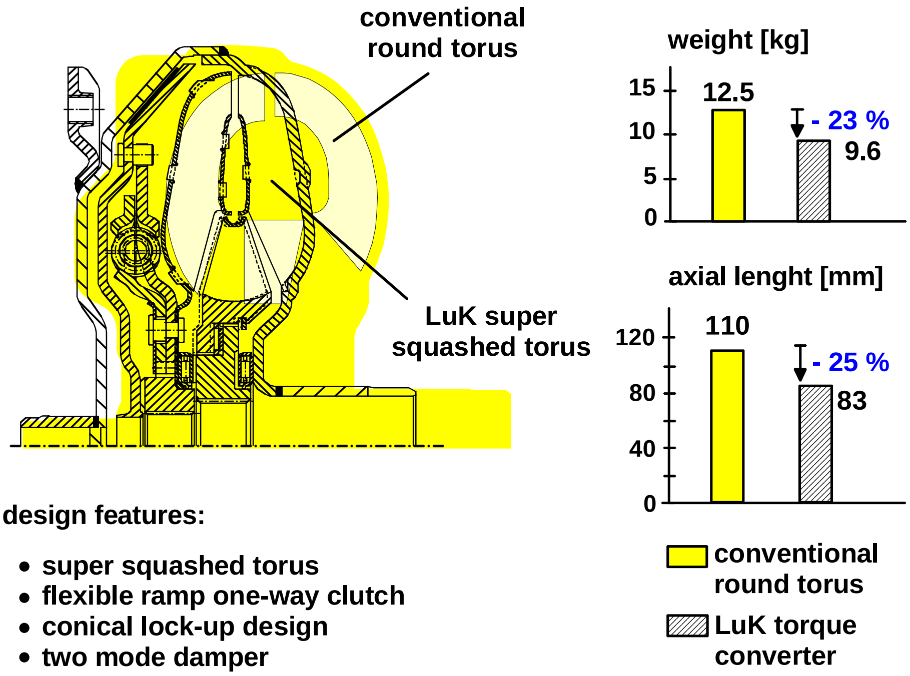


Figure 24: Comparison of quality of energy transfer, conventional round torque converter and LuK super squashed torque converter

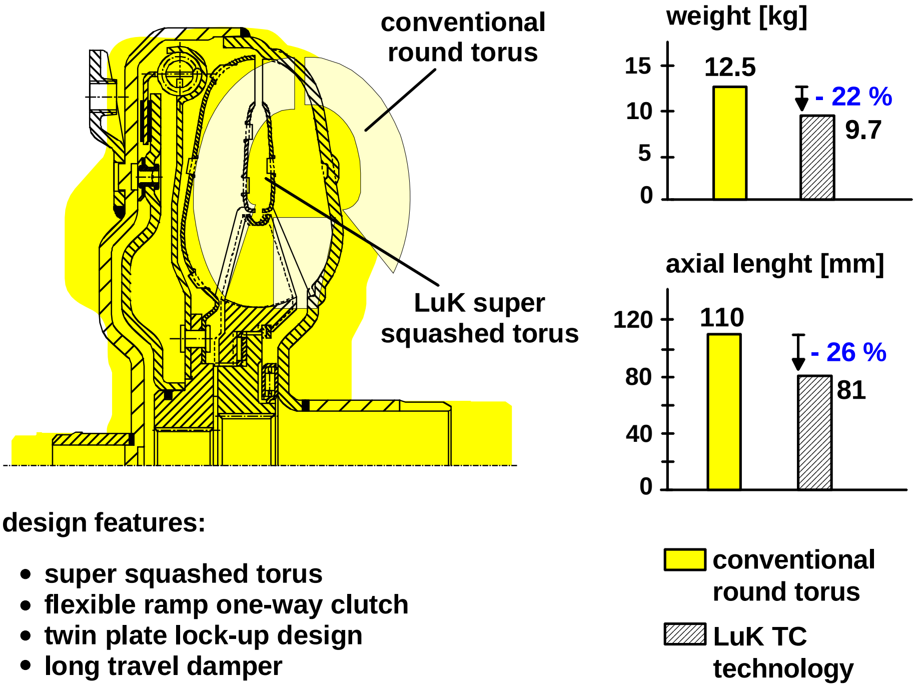
The weight and envelope advantage of the extremely squashed torque converter is between 20 and 26% when compared to the conventional round torque converter. This advantage depends on the configuration and selection of the torque converter clutch concept (figure 25 and 26). The space gained can be used for the transmission design, or the vehicle drive train can be shortened.



design features:

- **super squashed torus**
- **flexible ramp one-way clutch**
- **conical lock-up design**
- **two mode damper**

Figure 25: Comparison of required installation envelope for 260 mm size: Conventional, round torus and LuK super squashed torus with Two-Mode Damper and conical lock-up clutch.



design features:

- **super squashed torus**
- **flexible ramp one-way clutch**
- **twin plate lock-up design**
- **long travel damper**

Figure 26: Comparison of required installation envelope for 260 mm size: Conventional, round torus and LuK super squashed torus with long travel damper and twin plate lock-up clutch.

LuK has developed many torque converter design features in order to reduce manufacturing costs:

- Low material use due to extreme squashed torus
- Use of axial one way clutch
- Phenolic stator with integrated features
- Stamped or pierced slots for blade fixturing
- Reduced number of blades
- Use of innovative manufacturing processes
- Use of powder metal hubs
- Reduction of machining operations

Summary

Modern drive train development, the desire to increase performance and driver's comfort, the demand to improve fuel economy and decrease emissions, and the continuously declining space require a new approach to torque converter concept, layout and design.

The torque converter, with its three elements (lock-up clutch, damper and hydrodynamic circuit) has to be viewed as a part of the total system (figure 27). In this context, the control strategy for the lock-up clutch takes on an important role as the link between these elements. Only with a carefully tuned control strategy which takes into account the demands of each vehicle, and only with hardware components which meet the new requirements, can the entire potential of the torque converter system be fully used.

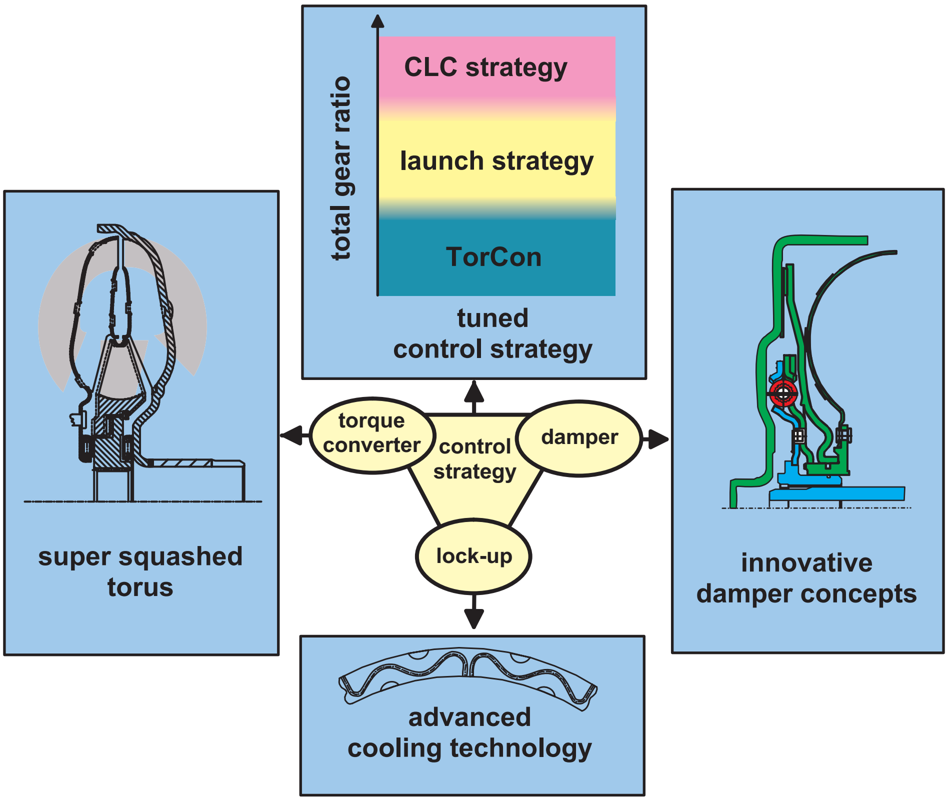


Figure 27: The Torque converter as a system – Summary

Using the full potential will allow for fuel economy savings and increase in performance of up to 10 %, depending on the application. The torque converter concepts developed by LuK make this possible. In addition to decreasing material costs, they provide tremendous savings in weight and space.

Literature

[1] R. Fischer, D. Otto, " Wandlerüberbrückungssysteme," 4th International LuK Symposium 1994 (in German), pp. 133.

[2] R. Fischer, "Das TorCon-System – Ein neues Wandlerüberbrückungs-Konzept als Beitrag zur Ökonomie und Fahrfreude," (in German) VDI Report No. 1175 pp. 301.

[3] D. Piper, " Automatic Transmissions – An American Perspective," VDI Report No. 1175, pp. 25.