Torque converters –

Comfort and fuel economy in tight corners

Marc McGrath
Jeff Hemphill
George Bailey
Philip George
Mike Swank
Thorsten Krause

Introduction

The torque converter celebrated its 100th birthday in 2005. Invented in 1905 in Stettin, Germany, by Dr. Hermann Föttinger of the Vulcan Ship Yards, the torque converter was originally a steam turbine drive for a ship propeller. It gradually found its way into the mainstream automotive industry over the following 25 years. The book Changing Gears [1] shows a Lysholm-Smith transmission with a torque converter and direct drive feature designed in 1928, which contains the basic functions of today's lock-up torque converters. Torque converters of today look similar, but they have undergone continuous refinement through the years that have paralleled the development of the automobile, and these improvements continue.

Since the early days of the automobile, there have been consistent trends towards better fuel economy, higher horsepower, and lighter, more compact drivetrains. Trends that are more recent are for example cylinder deactivation, diesel engines, and hybrids. There is much speculation surrounding which of these trends will prevail in the future. In the near term, however, it appears that each fills a niche due to varying legislative and environmental pressures in different regions.

The United States Federal Motor Vehicle Act of 1960 mandated federal research to address vehicle emissions, and in 1961 California mandated positive crankcase ventilation. Since that time emissions laws have become more stringent and automakers have continually evaluated concepts aimed at lowering emissions. Today, direct injection diesel engines have provided not only fuel economy benefits, but emission benefits as well. Hybrid vehicles use their engines less hence they are lowering their emissions. Diesels represent about half of the vehicles sold in Europe and they are gaining popularity in North America. In the United States, consumer incentives in the 2005 Energy Bill could boost the popularity of diesels and hybrids. The 2005 Ricardo Diesel Report [2] predicts the U.S. market will exceed 1 million diesel units annually by 2012.

Although the torque converter has existed for a century, there have been tremendous changes in the most recent decade. As a major torque converter supplier, LuK has driven many of these changes. The torque converter developments described in this article are the result of system knowledge, which has enabled LuK to tailor the fluid circuit, TCC, and damper to a particular application.

The Shrinking Bellhousing

For decades, suppliers have lamented the shrinking of the bell housing while the engine's torque continues to rise. A historical study of Front Wheel Drive transmissions shows that their complaints have some basis. Figure 1 records 20 years of space versus torque history.

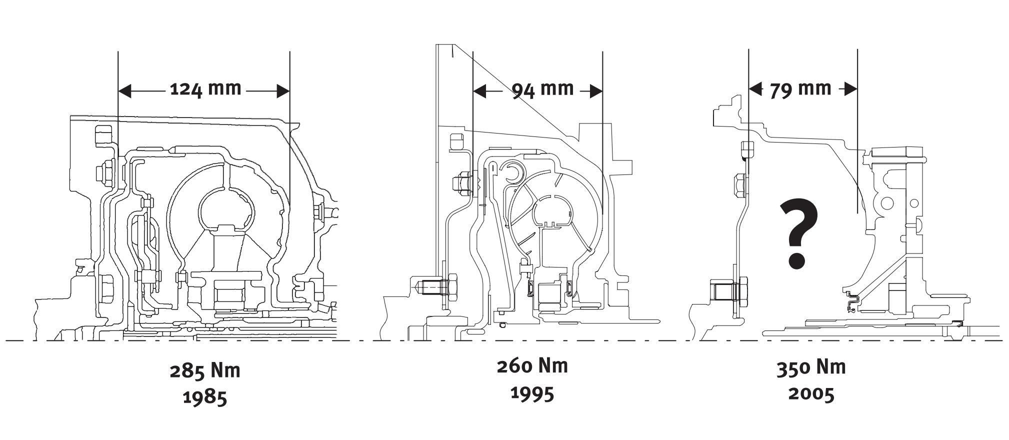

Figure 1 History of axial space and torque

The 1985 installation space allowed 124 mm for the toque converter with a generous clearance around it. In this space it was possible to create a large round torus for good characteristics and fit a generous damper spring for good vibration isolation. The picture in 1995 was similar with respect to torque but dramatic with respect to space. The largest possible converter was 94mm long. This requires some rearranging of the internal parts. In this case the torus was reduced in size and the damper spring was moved radially outward. This is a better use of space and with modern CFD and vibration simulation tools, the vehicle performance was not only maintained but also improved upon with respect to performance and fuel economy.

The 2005 picture shows a healthy torque increase with a further dramatic reduction in axial space. To meet this packaging challenge requires either compromise or innovation. The fluid circuit could be further reduced in size and axially squashed but fundamental physics dictate that fluid flowing in a circle is more efficient. At some point, this squashing will result in fast rising k-factors and loss in converter efficiency, all of which effect fuel economy. Similarly, use of exotic, high-stress coil spring wire and optimization of spring support can extend damper function, but at some point, isolation will be compromised. Poor isolation leads to higher lock-up speeds that also degrade fuel economy.

Many variations on the above themes have been tried successfully and continue to be developed at LuK and elsewhere. But through all these developments, the stator and one-way clutch have remained untouched and are now the axial space bottleneck in the bellhousing. LuK has decided to address this previously “untouchable” need.

The Fluid Circuit

The stator has the simple function of turning the fluid flow, reflecting it back into the pump and thereby creating toque multiplication. The demands on this component have fallen as the industry adopted 4, 5, and 6-speed transmissions. Since axial length must be reduced, a new stator paradigm is needed. The blade length could be cut in half, if the number of blades is doubled. Since, in this configuration, each blade bears only half the torque, the blade thickness

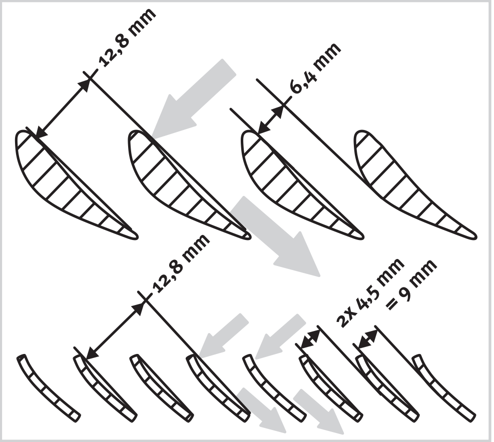

Figure 2 New blade paradigm

can be reduced as well. The comparison of the old and new paradigm is shown in figure 2.

This new profile lends itself to production with sheet metal stamping technology. Steel blades also have higher strength than aluminum or phenolic blades, allowing further reductions in blade thickness. Half of the blades are formed in one blank and the remaining half in another. The plates are then placed around the one-way clutch (OWC) and crimped or riveted together, forming an assembly.

The requirements for good retention and efficiency are still attainable in this configuration. The airfoil profile of the cast blades can be approximated by coining, as is commonly done in impeller and turbine blades. One measured characteristic is shown in figure 3, which demonstrates this capability (MP2000: pump torque at 2000/min pump speed).

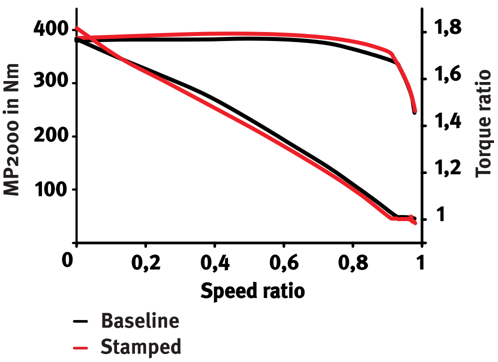

Figure 3 Measured TC characteristic

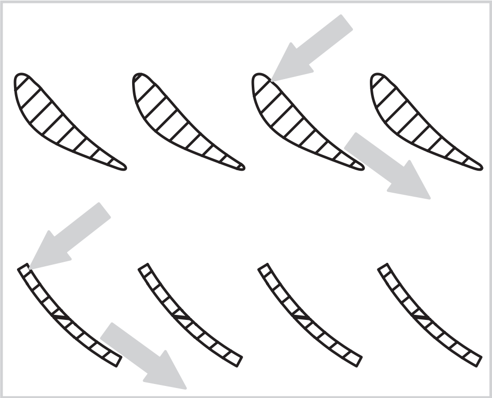

Figure 4 New blade design

While the objective in the current exercise is to reduce axial space, it should be noted that a similar sheet metal design could be used to produce a relatively long blade. This can be effective where a higher torque ratio or more fluid turning is desirable. An example of such a design can be seen in figure 4.

Returning to the axial space challenge, the axial space within the fluid circuit has been reduced and the OWC must be addressed next. Since the sheet metal stator has ample material available at the center, it would be elegant to make use of it. One solution would be to use a roller OWC that is also formed from sheet metal. Such a OWC is shown in figure 5.

This design features an outer race with formed ramps for the rollers. The outer race also acts as a cage for the rollers and supports the roller apply springs. This outer race is supported by the blade plates and reinforcing ring. This arrangement yields high torque capacity and economical construction.

Figure 5 Roller OWC with Sheet Metal Outer Race

A further option is to create a OWC directly from the sheet metal itself. This can be conveniently done with a ratchet clutch design as shown in figure 6.

Figure 6 Ratchet OWC

One of the blade plates is fitted with notches. A ramp plate engages these notches and rests on a hub. The hub is splined to the grounded shaft in the transmission and has further notches around its diameter. The flat edges of the ramps engage these hub notches in the locking direction. The

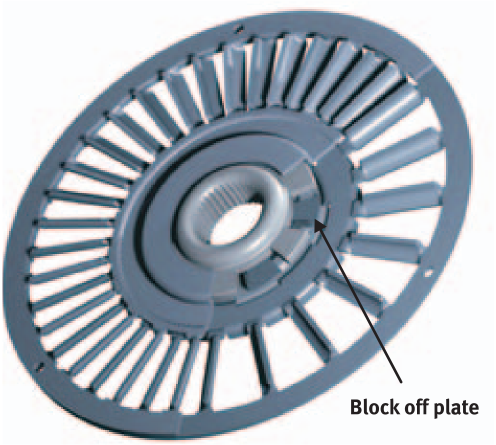

Figure 7 Ratchet OWC with block-off plate

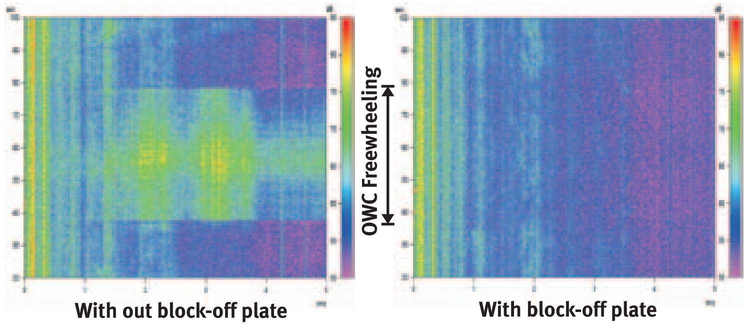

Figure 8 Noise measurement

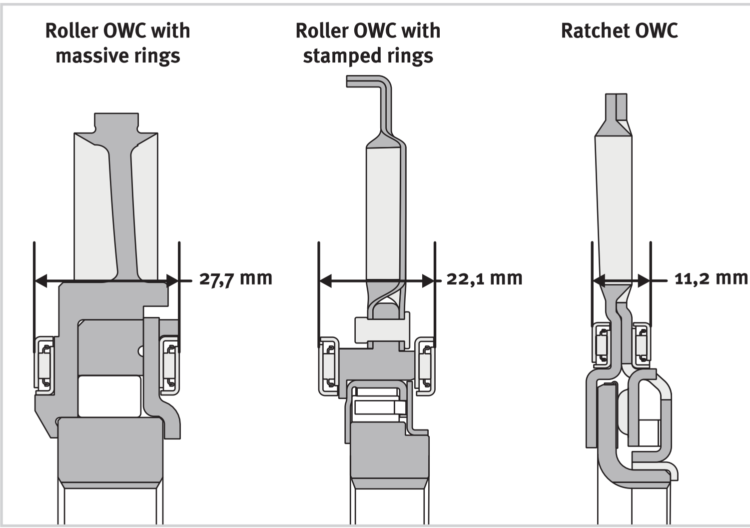

Figure 9 Length comparison

angled edge of the ramp slides over the notches in the freewheel direction. A light spring load pushes the ramp plate against the hub. This is very functional in terms of carrying torque but has the classical problem of any ratcheting clutch: freewheel noise.

This noise is addressed with the addition of a block-off plate, shown in figure 7 (exploded view).

This plate is trapped between the hub and the ramp plate. When freewheeling, the block-off plate rotates relative to the hub due to the friction from the ramp plate. When the block-off plate reaches the stops, it closes off the notches in the hub. The ramp plate then slips on top of the block-off plate or hub notches during freewheeling and so cannot move axially. This eliminates the freewheeling noise as shown in figure 8.

Having resolved noise concerns, an accurate axial length comparison can now be made. Figure 9 documents this comparison.

The space advantage of the sheet metal roller OWC is 5.6 mm. The ratchet OWC measures 11.2 mm or a 60% reduction compared to the conventional cast stator and standard OWC. This space combined with the stator savings results in a Super Slim Stator assembly and fundamentally improves the space situation inside the torque converter.

As figure 10 illustrates, a significant gap is opened in the conventional design and this space can be used in several ways.

Simplification of the piston plate and damper is very effective. By using the space to increase the cone depth of the piston plate, the plate's stiffness is improved and its thickness

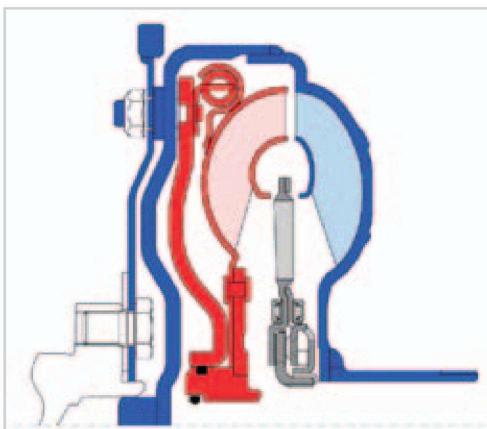

Figure 10 Space saving

can be reduced from 5mm to 3.5mm. The coil spring arrangement is also simplified since the thinner piston plate can be formed more easily to form spring engaging tabs at the outside diameter. This eliminates one part, which opens up space for a larger coil spring. The additional space above the thinner piston plate allows a riveted spring retainer, eliminating the welding operation. This example illustrates the cascading improvements that become possible with fundamentally better use of space.

Another option for use of the new space is the twin-plate lock-up clutch, which doubles torque capacity. Still another potential use is to reduce the overall torque converter thickness. In this example, 5mm of overall transmission length could be saved.

While re-invention of the stator assembly has made significant improvement in the rising torque/shrinking bellhousing challenge, further benefits can be achieved by considering the fluid circuit. Careful analysis of this critical function can result in higher torque densities without sacrificing efficiency. As a first step, numerical optimization strategies are combined with CFD calculations of the torus. The large number of variables in the fluid flow passages such as blade angle, angle distribution, and torus shape and the relationship of these parameters in the impeller, turbine, and stator make this problem ideal for numerical optimization. The optimization strategy includes parametric variations in individual CFD calculations to study the effect of the influence of the parameters on the system. This data is assembled into a response surface and combinations are chosen using gradient methods. CFD calculations for the chosen combinations are run and the response surface is improved based on these results.

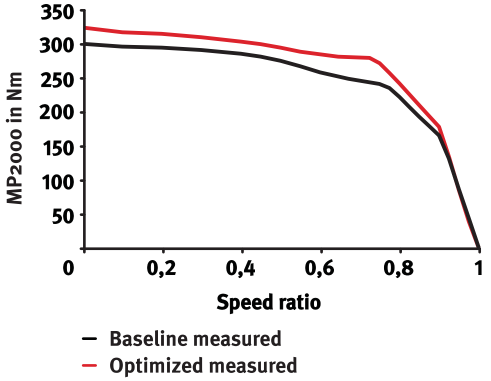

Figure 11 TC characteristic

The optimization routine was given the goals of increasing retention, increasing coupling point and maintaining torque ratio. These changes all result in greater fuel efficiency and lead toward better torque density. A base converter characteristic, which is the industry benchmark for these characteristics, was chosen as a starting place. If the optimization routine was able to improve this characteristic it would have demonstrated real world success. The results are shown in figure 11.

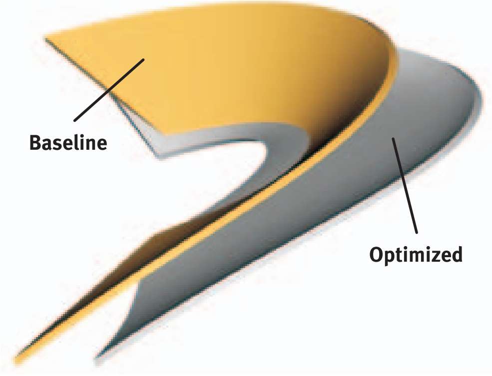

Figure 12 Optimized blade geometry

Clearly, the routine achieved its aims. The resulting blade geometry is shown in figure 12.

This geometry is unconventional and almost bionic in form. It is unlikely to have been discovered without such an optimization strategy.

Another method of improving fluid circuit capacity is to consider the basic physics of a torque con-

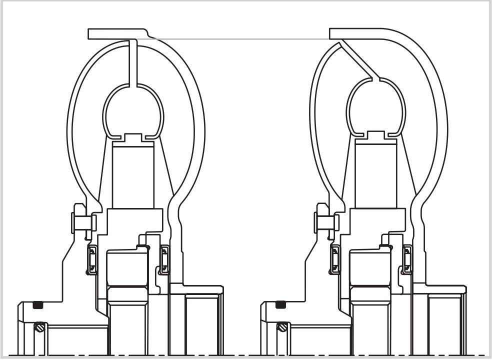

Figure 13 TC with increased radius

verter. In the equation for impeller torque, the torque is proportional to the outer impeller radius to the 5th power. Any improvement in this radius will therefore be helpful in achieving greater torque density. Figure 13 shows one method for improving this radius within a given space.

Here the impeller is extended to maximum radius allowed by the envelope and the turbine shape is modified at the outside edge to accommodate this change. The impeller blades are continued around the fluid circuit to meet the new turbine shape. The measured results with this configuration are shown in figure 14. The greater torque density is achieved.

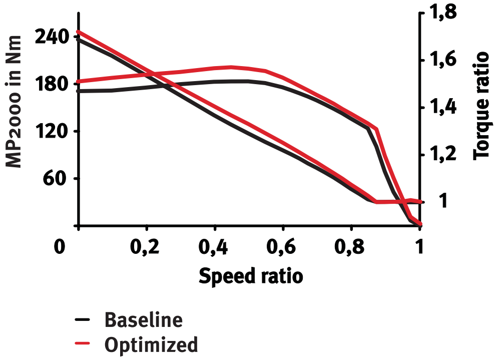

Figure 14 TC characteristic with increased radius

Consideration of the flow through the stator can lead to further torque capacity improvements. Figure 15 shows a diffuser style stator.

The flow area through the stator increases as the fluid moves towards the impeller. This decreases the fluid's axial velocity while leaving the torsional velocity unchanged. The fluid can therefore be turned more easily into the impeller. The resulting characteristic improvement can be seen in figure 16.

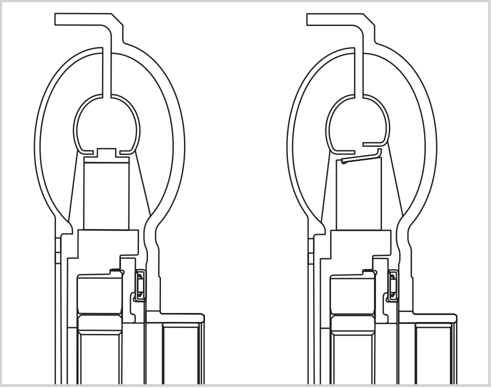

Figure 15 Diffuser style stator

The final space saving strategy for fitting into the space allowed in modern transmissions is torus shearing. This technique is illustrated in figure 17.

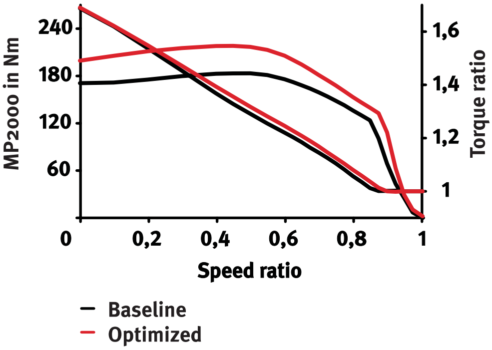

Figure 16 TC characteristic with diffusor stator

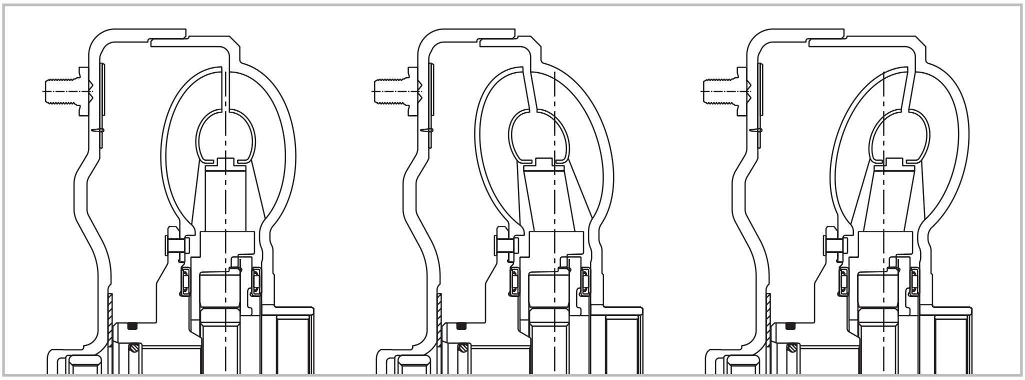

Figure 17 TC with sheared torus

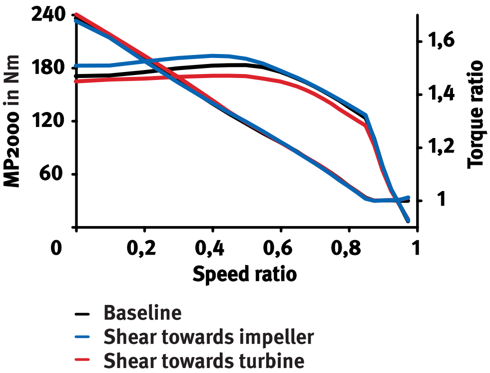

Figure 18 TC charactersitic

Here a semi-squashed torus is sheared along the centerline in order to make space for either an arc spring damper at the outside diameter or a straight spring damper near the inside diameter. The outer tip of the torus is shifted by the desired amount, the inside edge does not move and the points in between are sheared over to a line connecting the inner and outer points. This strategy maintains the torus flow to maximum extent possible and therefore the characteristics are not degraded as shown in figure 18.

The combination of these strategies can be chosen based on the application, enabling LuK to meet the rising demand for torque capacity while dramatically shrinking the required space and improving fuel economy and NVH behavior.

Damper and Clutch Innovation

Overall greater driveline efficiency is being achieved by increasing the ratio spread and increasing the number of gear ratios of planetary automatic transmissions. Increasing the usage of the TCC presents an opportunity for even greater benefit. To accomplish this, the TCC must be capable of a greater number of engagements at higher energies than in the past. Of course, NVH issues from torsional drivetrain vibrations often limit lock-up speeds, so extra attention must also be paid to the damper design.

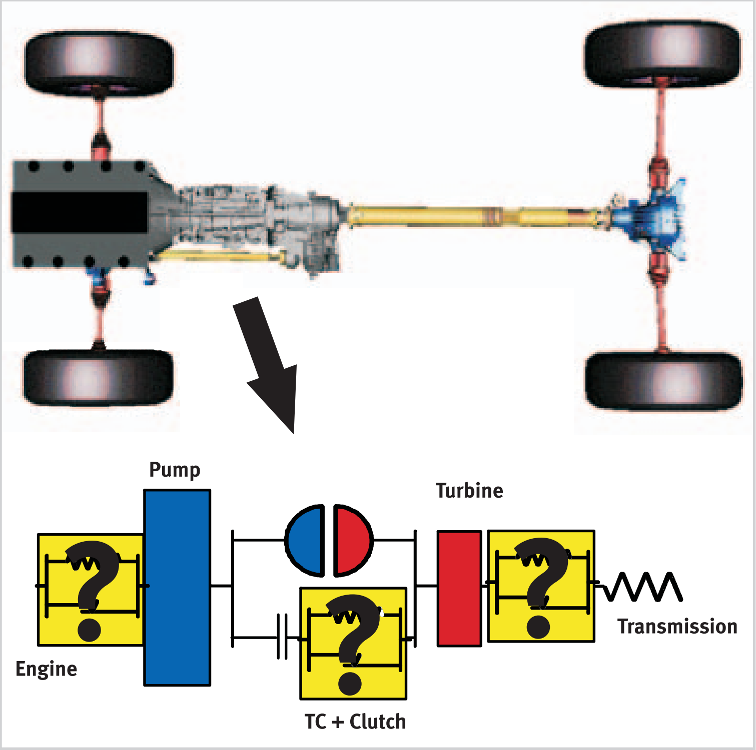

Figure 19 Possible Damper positions for a traditional planetary automatic transmission

LuK has been using a system or holistic approach to driveline damper tuning for over twenty years. This approach has lead to the development of various damper concepts such as the Dual Mass Flywheel (DMF) and the Turbine Damper. This experience and the tools developed over this period of time allow LuK an un-paralleled ability to tailor dampers to meet the challenges of the ever-changing automotive market. The current automotive market is seeing the introduction of many types of transmissions. These include 6 and 7 speed planetary

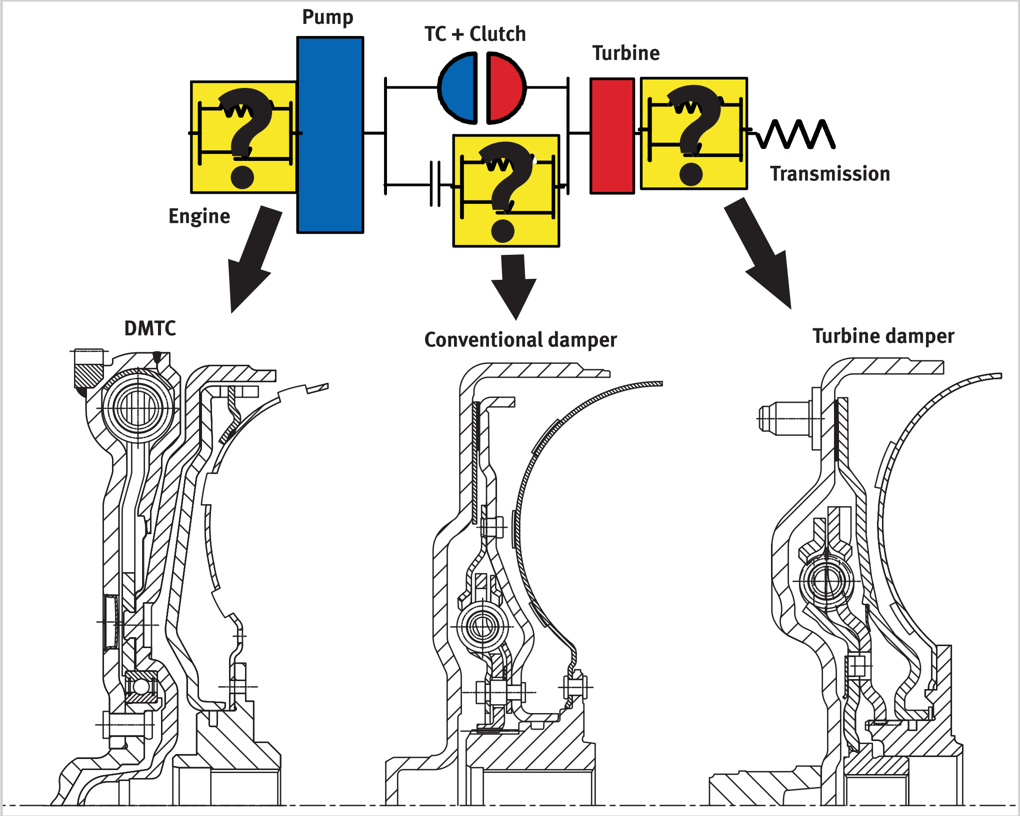

Figure 20 Representative dampers for each position.

automatic transmissions, belt, chain, and toroidal CVT's, parallel and series hybrids with numerous start/stop systems, and double clutch powershift transmissions. Recent engine trends also demand our attention with the ever-increasing popularity of diesel engines and the resurgence of engines with cylinder deactivation capabilities.

Looking at the traditional planetary automatic transmission, it becomes apparent that there are three places to place a damper in the torque flow of the traditional torque converter as shown in figure 19. Figure 20 shows representative dampers for each of these positions.

LuK introduced the Dual-Mass Flywheel (DMF) in 1985, providing superior vibration isolation for manual transmission drivetrains. A great number of dual-mass flywheels have been supplied since then, and approximately one in four cars is equipped with one in Europe. To achieve DMF isolation quality in automatic drivetrains, the Dual Mass Torque Converter (DMTC) was developed. A DMTC is shown on the left with the damper between the engine and the TC pump. A conventional (typical) TCC and damper are shown in the center, with the damper between the pump and the turbine only active when the TCC is engaged. A Turbine Damper is shown on the right, with the damper placed between the turbine and the input shaft. Each arrangement has its own advantages and disadvantages. The DMTC typically provides superior torsional isolation, but just as with a DMF, care must be taken about start-up and shut-off resonances. The conventional TCC is a great all round performer, but has some shortcomings especially in rear wheel drive applications. The Turbine Damper is an excellent solution for many rear wheel drive vehicles. The Turbine Damper, as has been previously shown, eliminates a drivetrain mode common in most rear wheel drive based vehicles, commonly called the Turbine Mode. The elimination of this mode allows more extensive use of the

TCC therefore improving fuel economy while maintaining superior NVH. Since its production introduction in 1996, the Turbine Damper has gained in popularity, see figure 21.

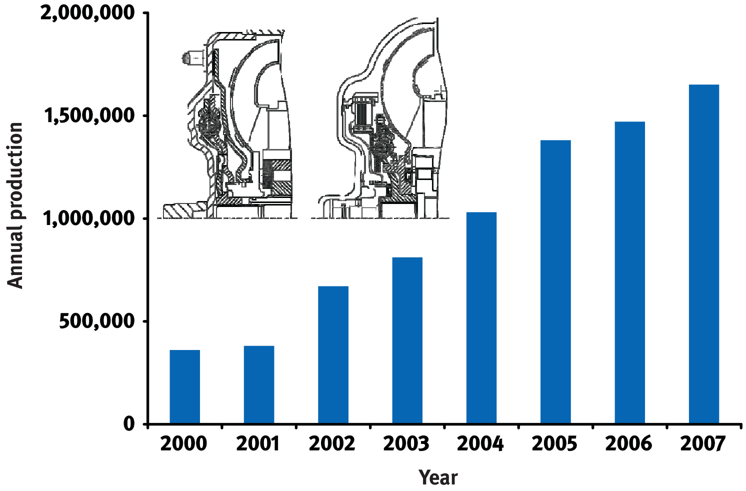

Figure 21 Turbine Damper Worldwide acceptance

The rapidly changing automotive market along with consumer and governmental pressures continue to push the automotive manufactures to find and develop new powertrain concepts. This, in turn, continues to push the envelope in damper design. Many times the damper concepts introduced so far are just not good enough. More advanced and robust solutions are required. Figure 22 shows some possible damper concepts. As direct injection diesel engines evolve and produce higher output, their torque fluctuations continue to increase as well. These engines are used in lightweight drivetrains that possess very low drag and damping. This is done to maximize performance and fuel economy. Such powertrains may require combinations of the above damper concepts. A compact version of the DMTC with a turbine damper is shown on the left. An inertia ring on the secondary side of the damper moves critical modes of vibration out of the operating range. Figure 23 shows the simulated torsional response of a drivetrain with the illustrated advanced damper concepts. The evolving automotive market has forced a previously unreachable isolation target.

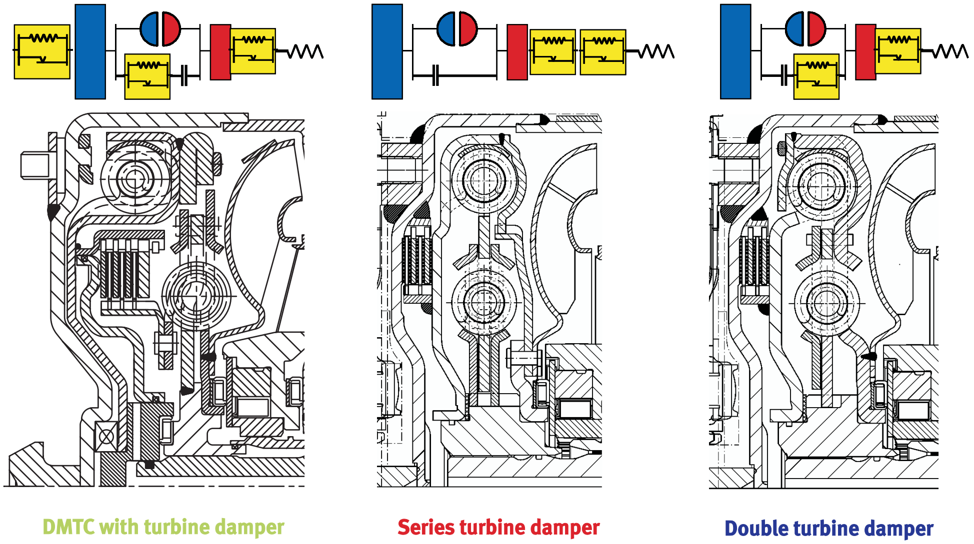

Figure 22 Advanced damper solutions

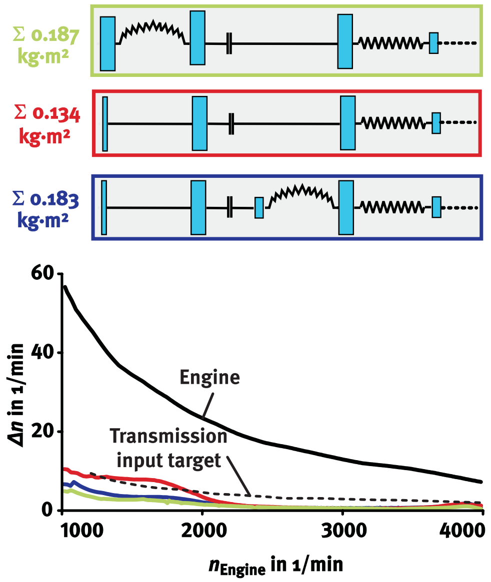

Figure 23 Drivetrain response versus target for advanced damper concepts

These advanced damper concepts allow us to provide damper solutions that do attain these targets.

Hybrid vehicles are entering the market, and there are several hybrid drivetrain layouts. Some contain torque converters, some dry or wet clutches, while others eliminate the launch device completely. All hybrid drivetrains must deal with torsional isolation, and in most cases, a damper is required. A damper for a hybrid system without a launch device is shown in figure 24. This damper is installed between the engine and the transmission. The transmission contains an electric motor used to start the engine after it has been shut off each time the vehicle stops.

The damper must have a sufficiently low spring rate to isolate torsional vibrations throughout the engine operating range. This low spring rate can create a problem when the engine starts. The natural frequency of the engine-damper-electric motor system lies at an engine firing frequency below idle. This resonance must be crossed every time the engine is started or stopped, which can create noise and durability problems. To avoid this issue, a lockout clutch can be provided which is engaged during engine start-up and shut-off. A spring applies this clutch, and pressurized oil disengages this clutch when the engine is running. The engine drives an oil pump through a pump hub similar in design to that of a torque converter.

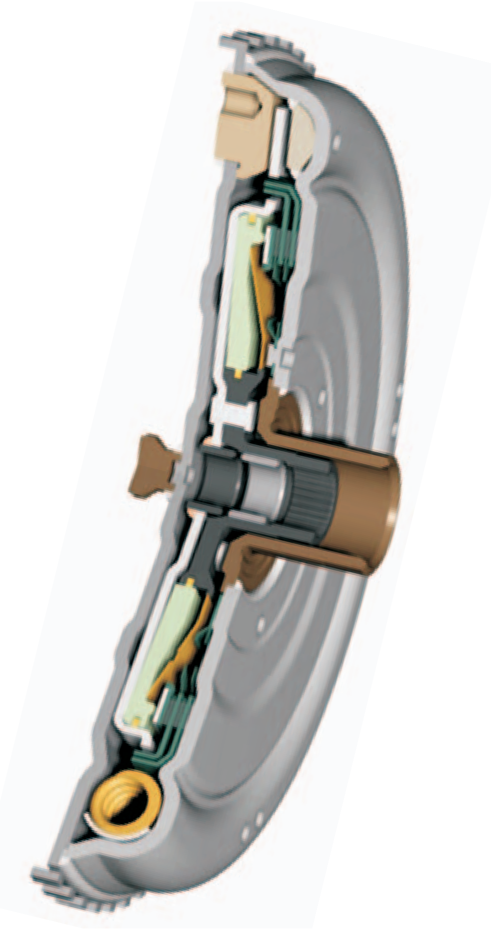

Figure 24 Hybrid damper with lockout feature to eliminate start-stop resonance

The Multi-Function Torque Converter (MFTC)

The MFTC was developed and presented in the LuK Symposium 2002 [3]. Development on this concept has continued, since it addresses challenges presented by both SUVs and diesel engines. The demand for increased fuel economy from SUVs requires lower lock-up speeds and less idle losses. Torque converters used with diesels typically need their TC characteristics tailored to

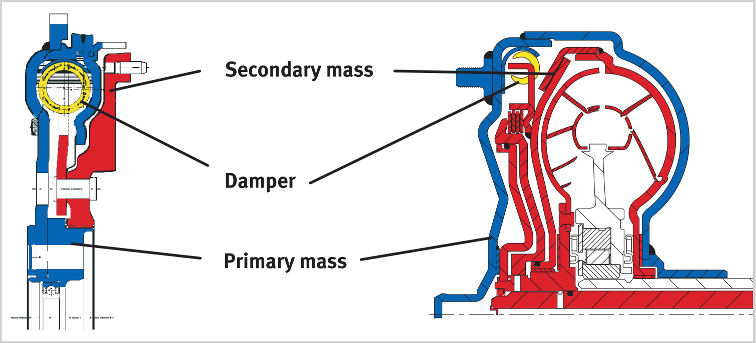

Figure 25 Inertia distribution of a Dual-Mass Flywheel (left) and Multi-Function Torque Converter (right) when the TCC is locked

provides pressure to lock-up the TCC.

When the vehicle is idling in gear, fuel is saved by opening the impeller clutch to disengage the engine from the rest of the drivetrain. This is accomplished by pressurizing the outer pressure channel as shown in figure 27. The engine still turns the transmission oil pump to provide the oil pressure.

carry the higher torque from the diesel engine, and special attention needs to be paid to the TCC damper to deal with the higher torque fluctuations from a diesel. In the MFTC, when the TCC is locked, this concept provides an inertia distribution similar to a dual-mass flywheel as shown in figure 25. It also has a clutch between the engine and the impeller, which can be disconnected at stoplights to save fuel at idle.

A three-pass MFTC designed for a gasoline engine SUV is shown in figure 26. This design uses a multi-plate TCC with a closed piston, a conventional arc spring damper, and an additional impeller clutch. The outer pressure channel between the pump hub and the stator shaft controls the impeller clutch, which provides an idle disconnect function. The inner pressure channel between the stator shaft and input shaft is always kept at high pressure and provides the charge pressure for the torque converter torus. The channel through the center of the input shaft

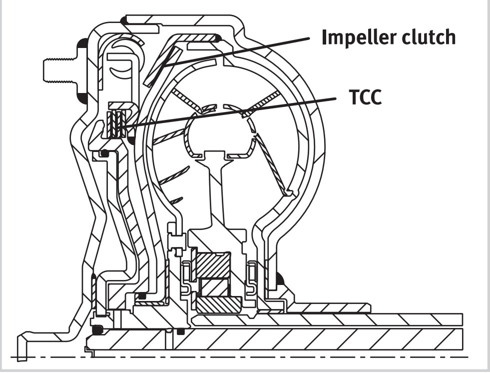

Figure 26 Three-Pass Multi-Function Torque Converter with 273 mm torus

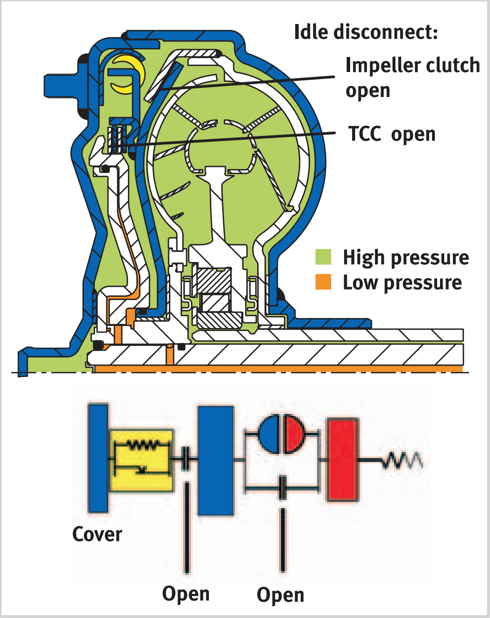

Figure 27 Disengaged impeller and torque converter clutches at idle to save fuel

When the vehicle moves, the pressure in the outer channel can be dropped suddenly to engage the impeller clutch as shown in figure 28. No piston needs to be filled with oil, so this engagement takes place quickly as the impeller is accelerated to idle speed. This is imperceptible to the driver compared to shifting an automatic transmission into gear. When a transmission is shifted into gear, the spinning inertia of the turbine and transmission components must be stopped quickly, causing a torque spike in the drivetrain.

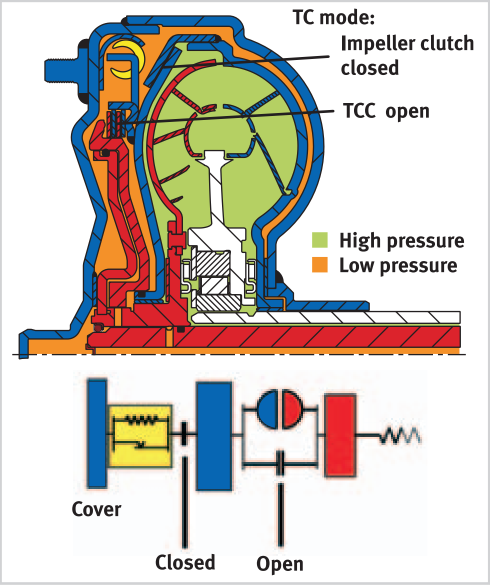

Figure 28 Engaged impeller clutch provides conventional torque converter operation

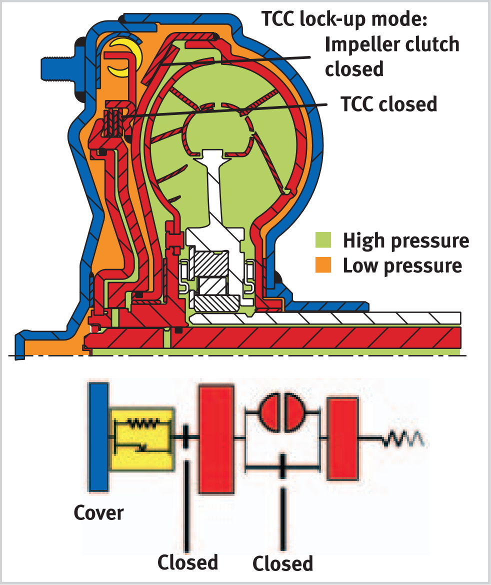

Figure 29 Pressurizing the closed piston engages the torque converter clutch

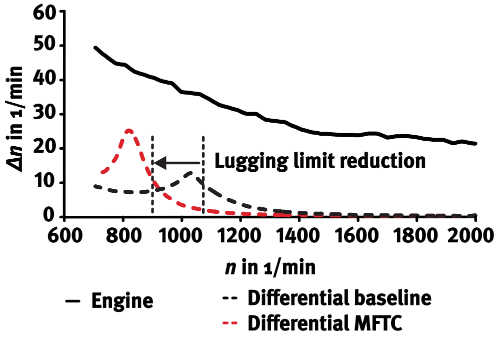

Figure 30 Simulation of torsional vibration isolation improvement with MFTC

In the MFTC, the comparatively small inertia of the impeller is accelerated against the TC fluid circuit, resulting in a smooth torque increase.

When torque converter clutch lock-up is commanded, the channel through the input shaft is pressurized as shown in figure 29. The resulting inertia arrangement is similar to a dual-mass flywheel. An advantage of this three-pass arrangement is that the impeller clutch retains its torque at all times, so that the driver's perception of TCC engagements is not different from a typical lock-up torque converter.

The dual-mass inertia arrangement provides superior vibration isolation. Figure 30 shows a simulation of the torsional vibrations of the differential in a large SUV with the MFTC and the production TCC. The MFTC allows the lugging limit to be lowered by 200 rpm. Measurements taken in the vehicle show this improved isolation in figure 31.

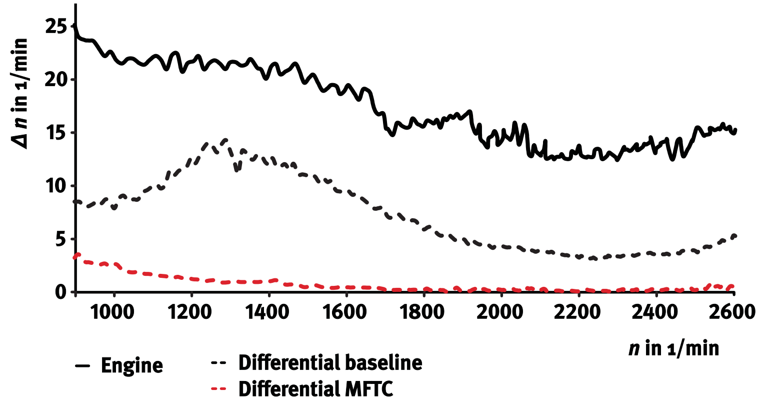

Figure 31 Measurement of torsional vibration isolation improvement with MFTC

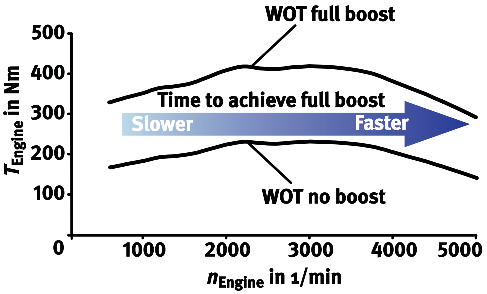

Figure 32 Engine output torque variation due to turbocharger lag

The impeller clutch can be slipped or engaged during launch, providing in effect a variable torque converter characteristic. This can be beneficial in reducing the acceleration lag present in turbocharged diesels. Figure 32 shows the output torque of a turbo diesel engine at wide-open throttle. Each point in the top curve shows the engine output torque recorded at constant engine speeds after the turbocharger has had time to get up to speed. The bottom curve shows the torque output of the engine when the throttle is first opened, and the turbocharger has not had time to get up to speed. The difference arises because it takes time for the exhaust to accelerate the turbocharger to produce boost. When the engine runs at higher speeds, there is more exhaust flow to spin the turbocharger. Therefore, it takes less time for the engine output to increase from the bottom curve to the top curve as engine speed increases.

If the engine was relieved of some of its load at the beginning of the launch it will reach high

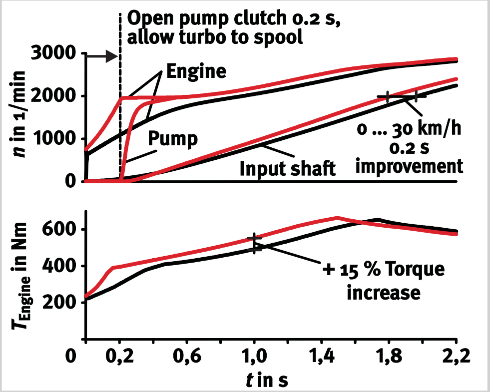

Figure 33 Simulation of improved acceleration from slipping impeller clutch

speeds sooner, which will then accelerate the turbocharger quicker, and the engine will build up potential faster. An example of this situation in a light truck is shown in figure 33. At the beginning of the launch, all of the engine's torque is used to accelerate its own inertia so it gets up to a higher speed quickly. When it begins to produce higher torque the MFTC impeller clutch is closed, which launches the vehicle. The vehicle begins moving 0.2 seconds later using this strategy. However, the rapid increased torque output from the engine more than makes up for this difference and the vehicle reaches 30 km/h 0.2 seconds faster.

Friction Launch and the Mechanical Torque Converter

An extension of the trend towards higher performance dampers and increased TCC usage leads to the natural evolution of the wet clutch as a launch device. Devices of this nature completely eliminate the need for a hydrodynamic torque converter and allow for reductions in mass, inertia, and installation space. As a result, sufficient packaging space for a sophisticated damper system that will allow the clutch to remain locked during all driving conditions results, therefore offering higher system efficiencies than can be achieved with conventional hydrodynamic torque converters.

Two approaches to wet friction launch clutches exist: 1) the device can be part of a clean sheet of paper design and can be integrated into the transmission assembly itself, or 2) the device can be a plug in direct replacement for the torque converter of an existing transmission. The core understanding required to arrive at successful concepts for each of these approaches is fundamentally the same. Therefore, it is the latter of these two approaches that LuK is focusing upon as this design direction leads to the additional benefits of near drop-in compatibility and the elimination of costly transmission design efforts and large production capital investments. However, this design direction brings with it the challenges of creating a system that is compatible with the limitations of an existing transmission

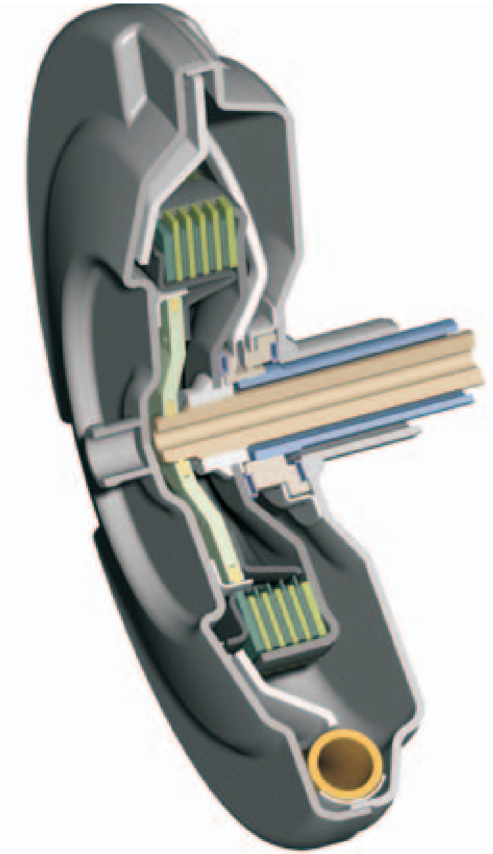

Figure 34 Friction Launch Clutch

design, most notably with respect to providing sufficient cooling oil to the launch clutch itself and, in some cases, offering comparable vehicle launch performance and feel.

Figure 34 depicts the basic launch device concept. The wet launch clutch and damper system are contained within a housing much like that of a conventional torque converter. All interfaces of this system are the same as the base hydrodynamic design that it replaces, meaning there are no required changes to the pilot, lugs, pump hub, and transmission pump drive. Additionally, the stator shaft of the transmission is required for the function of the device so it does not need to be modified or removed.

The system is configured such that torque passes through the housing, into the torsional damper, through the wet launch clutch, and then into the transmission input shaft. This arrangement of springs and inertias results in a very favorable configuration with respect to NVH isolation. In fact, this configuration is not unlike the standard dual mass flywheel concept. The clutch is actuated via a sealed hydraulic piston which is connected to the existing transmission TCC apply channel. There is no need for a charge pressure as with a conventional TC, and the outlet of the clutch housing can be left at atmospheric pressure and allowed to drain back to the transmission sump.

The cooling requirements of a wet launch clutch would typically demand an oil flow rate of 20 to 30 l/min, depending upon the application. Unfortunately, this flow rate is not available in most existing transmissions and would require significant re-design and a larger transmission pump in order to realize this flow rate. However, the cooling system detailed in figures 35 and 36 is a simple approach, which circumvents this problem and enables the clutch to be cooled adequately without changes to the base transmission's hydraulics.

The system consists of two independent cooling circuits, one which is actively linked to the apply pressure of the clutch, the other which is passively connected to the output of the clutch. The first system (Figure 35) consists of a flow control orifice in the sealed clutch apply piston and a fixed scoop pipe. Cold, high-pressure oil is bled off through the flow control orifice at a rate of approximately 5 l/min. This cold oil passes through the clutch, extracting heat along the way. The scoop pipe, which is splined to the stator shaft and thereby fixed rotationally, returns this 5 l/min of now hot oil to the sump. This pipe

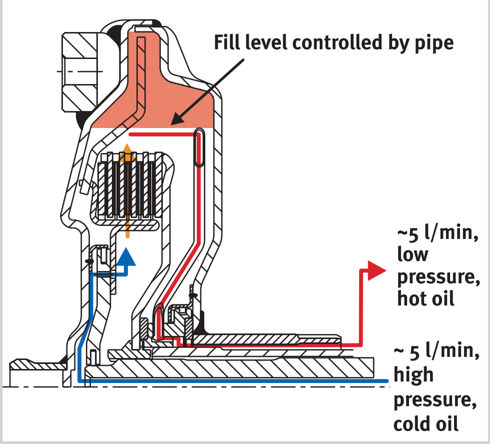

Figure 35 Cooling Circuit 1

also serves to control the fixed volume of oil within the clutch housing, meaning the clutch pack is not submerged.

The second cooling circuit (Figure 36) consists of one additional scoop pipe, this time attached to the output of the clutch/input of the transmission. This pipe serves to recirculate oil through the clutch at a high volume flow rate, thereby providing the additional cooling that the clutch requires during a launch event. This pipe, which delivers up 25 l/min, will only pump when there is slip across the clutch. Once the launch event is complete and the input and output speeds of the clutch are synchronized, the kinetic energy of the fluid relative to the scoop pipe is zero and the system no longer pumps. The combination of these cooling circuits as well as not having a clutch pack that is submerged in fluid, by virtue of the first scoop pipe, means that the system operates with the minimum of drag or pumping losses. Additionally, this system may be tuned so that idle disconnect functionality can be realized.

Systems of this nature are particularly well suited for front wheel drive applications where space is at a premium, but also have application in rear wheel drive platforms. As the launch energy that the clutch must be capable of dissipating is a function of the vehicle mass, overall gear ratio of the transmission, engagement time, and engine performance it is likely that modern 6-speed applications are the target for this system.

However, should an application exist that does not have the required overall launch ratio or that is particularly heavy or underpowered, the combination of the previously discussed concept and a simple planetary gearset offers an attractive alternative when investigating friction launch clutch concepts. Alternately, the concept can transform an existing 4-speed transmission into a 6-speed whilst offering improvements in performance and fuel economy. The gear ratios of the MTC in conjunction with two speeds of the transmission transform the 4 speed baseline transmission into a 6-speed. This approach has the added benefit of enabling a transmission manufacturer to be market ready with 6-speed offerings whilst having none of the financial burden of designing and producing a new transmission.

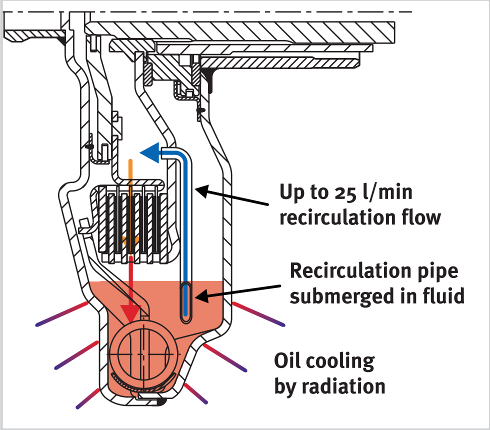

Figure 36 Cooling Circuit 2

LuK has also completed significant design work for a concept like this, which is known as the Mechanical Torque Converter (MTC). This product satisfies all of the design objectives of the friction launch clutch in terms of drop-in compatibility, making use of existing transmission and engine interfaces, as well as utilizing the same cooling concept as previously discussed. The Mechanical Torque Converter consists of one launch clutch actuated via a sealed piston, one sequential clutch that is used for gear ratio changes, a planetary gear set and two torsional isolators for NVH performance that will allow fully locked driving. See figure 37.

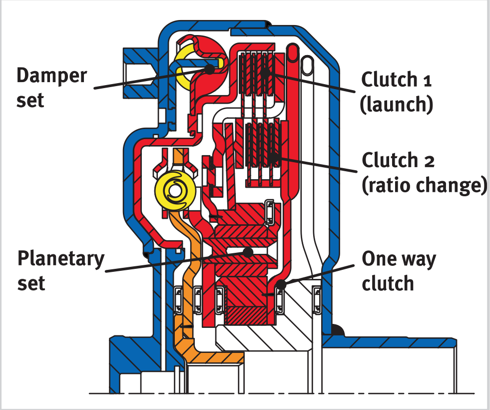

Figure 37 The Mechanical Torque Converter

Simulations for this device show a reduction in 0-60 mph acceleration times of 10% while offering a 7% increase in fuel economy vs. the baseline 4-speed planetary automatic with a hydrodynamic torque converter.

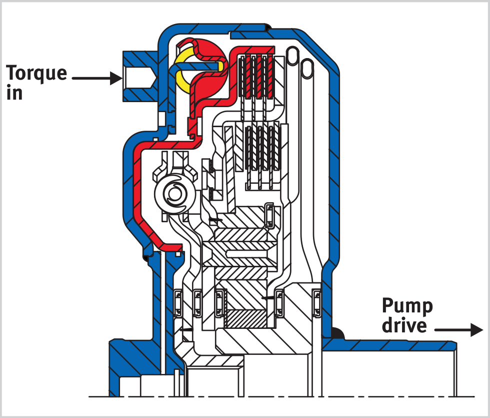

Figure 38 Idle Disconnect Mode

The device operates in three discrete modes. These modes, shown in Figures 38, 39 and 40, are idle disconnect mode, torque multiplication mode and fully locked mode. Idle disconnect mode is achieved by having no apply pressure commanded to the clutches. In this case all clutches are open, no flow is entering the device, and the scoop pipe 1 will partially empty the enclosure and the system will run with a minimum of drag torque. However, the transmission pump is continuously driven via the pump hub, so all functions in the transmission itself will operate normally. See figure 38.

Vehicle launch is managed by commanding pressure to Clutch 1, which will simultaneously initiate the launch event and fill the system with oil via the flow control orifice (figure 39). As such, the clutch will automatically be provided with

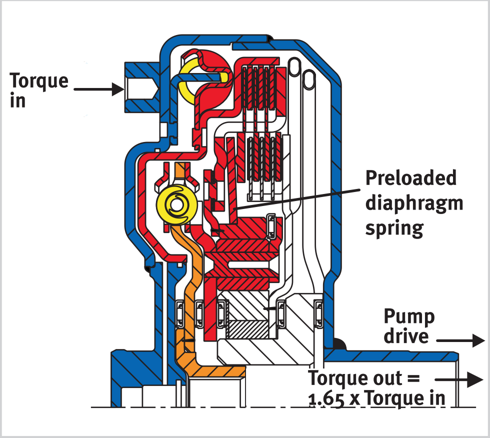

Figure 39 Torque Multiplication Mode

cooling oil via the aforementioned scoop pipe arrangement. The apply force on Clutch 1 is reacted via a preloaded diaphragm spring, which serves to ensure that Clutch 2 will not be actuated. In this mode, torque passes from the cover to the main system damper, and then to the piston plate, which is flexibly connected to the damper to allow the actuation travel of the piston to occur. The output of the launch clutch is the input to the planetary set, in this case the ring gear. The sun gear of the planetary set is grounded via a one way clutch to the stator shaft of the transmission, leaving the planetary carrier as the input to the transmission with a torque ratio of approximately 1.65 times engine torque. An additional damper, situated between the planetary carrier and the transmission input shaft, is required to control an input shaft resonance, which is excited at low engine speeds.

Changes in the gear ratio of the device are realized by further increasing pressure to the piston (figure 40). Once the preload of the diaphragm spring is overcome, Clutch 2 will begin to engage. As such, the planetary set will now be locked and the ratio of the system will change from that of 1.65:1 to 1:1. This transition is managed by simply taking torque off of the one-way clutch with Clutch 2, an event that is easier to

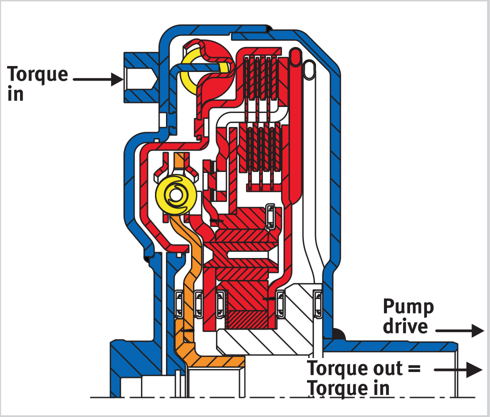

Figure 40 Fully Locked Mode

manage than clutch to clutch shifting. Furthermore, the pressure at which this event takes place can be altered via changes in diaphragm spring preload, resulting in a system that is flexible to the needs of various hydraulic control circuits.

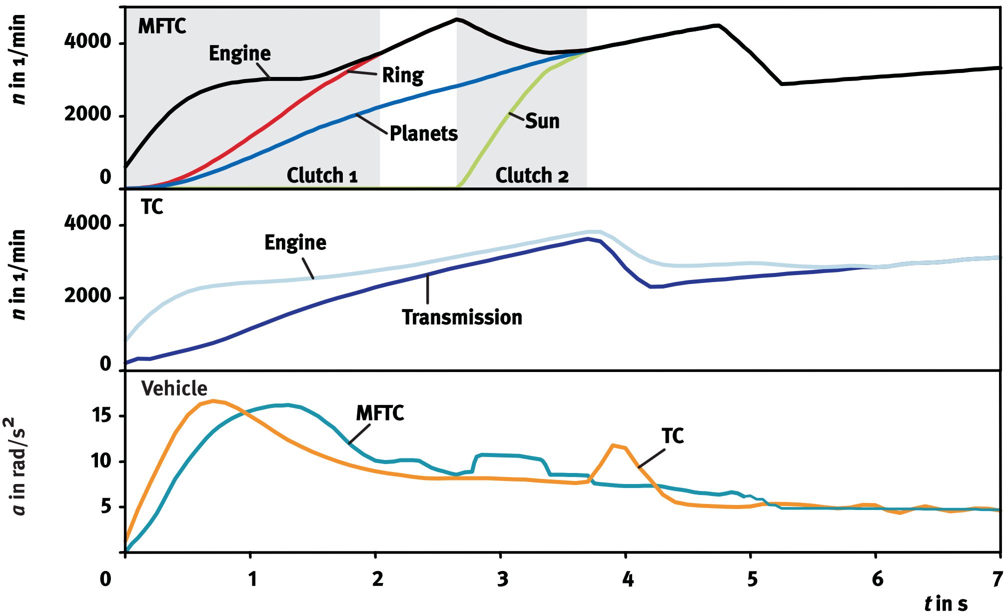

Figure 41 Vehicle Launch Simulations

Finally, the performance of this system was simulated in order to gain an understanding of the expected vehicle launch feel. Figure 41 details the differences in the Mechanical Torque Converter and the baseline hydrodynamic approach. Of particular interest is the bottom plot, which compares the acceleration of the two systems. In large part the behavior of the systems are comparable, indicating that similar levels of launch feel can be achieved with the mechanical device. If desired, a more aggressive clutch calibration can be used to allow the two events to match even more closely.

In summary, LuK is capable of offering a variety of friction launch solutions, each with the benefits of improved fuel economy, reduced mass and inertia, reduced installation requirements and compatibility with exiting transmission systems.

Conclusion

Over one hundred years after its invention, the torque converter continues to evolve along with vehicle drivetrains. Smaller torque converters with optimized fluid circuits will meet the needs of compact transmissions with more speeds. Unique damper arrangements will address the particular requirements of each drivetrain. In addition, concepts such as the MFTC will provide added functionality to improve fuel economy and vehicle quality. These developments naturally lead to similar products such as dampers for hybrid drivetrains. It has been an exciting 10 years since LuK entered the torque converter market. LuK is leading the way with innovative solutions to address the continuous evolution of the automobile.

References

[1] Gott, P.: Changing Gears: The Development of the Automotive Transmission. Warrendale: Society of Automotive Engineers, 1991, pp. 99

[2] Diesel Passenger Car & Light Commercial Vehicle Markets in Western Europe. West Sussex: Ricardo plc, 28 June 2005

[3] McGrath, M.; Müller, B.; Maucher, E.; Marathe, B.; Bailey, G.: Torque Converter Evolution at LuK, 7th LuK Symposium, 2002