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Torque Converters

Launching over new challenges

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Introduction/ engine trends

It is a good time to be part of torque converter development; assuming that one enjoys a good challenge. The job of the torque converter is to make the engine look good by providing a smooth launch and isolating the transmission and driveline from the engine's vibrations. The torque converter has done so effectively for more than 100 years now but things are getting ever more difficult. Engine development has focused on reducing fuel consumption while increasing torque. This has been accomplished in recent years by downsizing and boosting which makes torsional vibration more severe and launch more difficult. Figure 1 shows the trend in engine torque and the associated increasing requirements for isolation at the transmission.

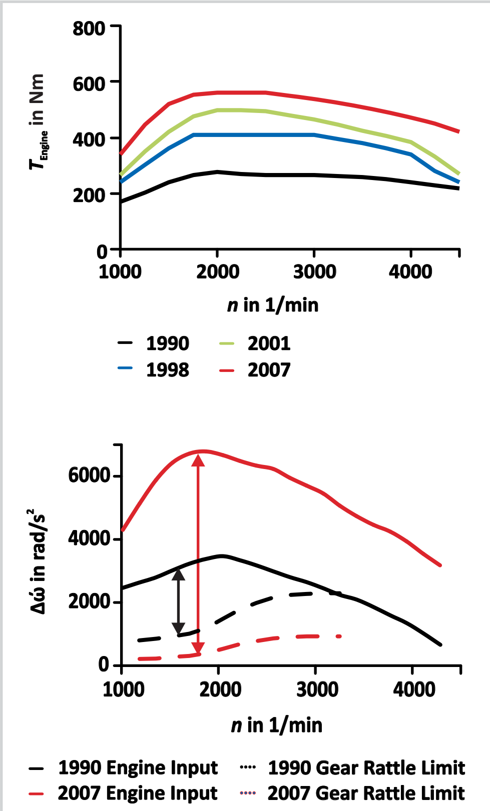

Figure 1 Increase in engine torques and vibration sensitivity

Isolation of torsional irregularity

Centrifugal Pendulum Absorber

Isolation of vibration is conventionally accomplished by using coil spring dampers. The coil springs absorb the energy of the combustion forces and return it during the compression cycle of the engine thus smoothing vibration. The key parameter in coil spring design is energy capacity which depends on the size of the spring. The larger the spring, the more energy it can store. If bell housing space was unlimited, this would be relatively straightforward engineering. However, the

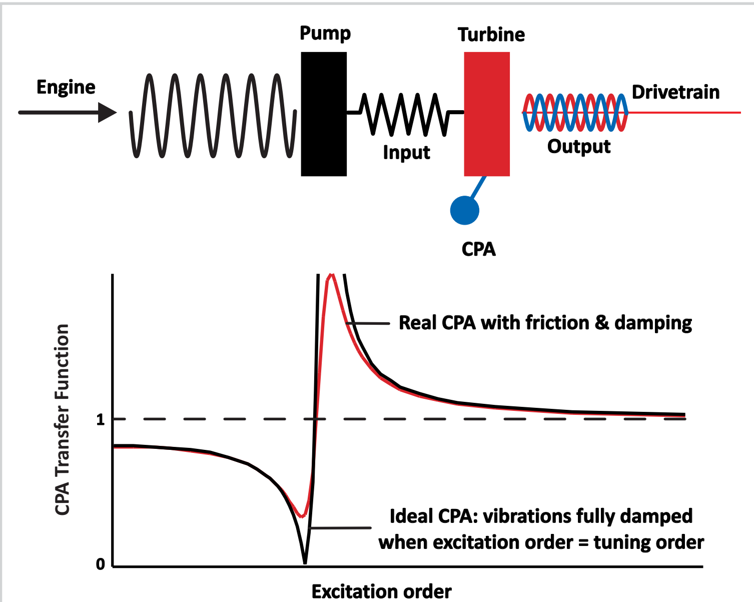

Figure 2 Dynamic absorber system schematic

trend toward smaller, front wheel drive vehicles has seen to it that less space is available than ever before.

A new paradigm is needed to address this challenge: the dynamic absorber. An absorber consists of a small mass or inertia connected to a larger mass through a spring. The natural frequency of the small spring mass absorber is tuned to the natural frequency of the larger mass and cancels the vibration of the larger mass. Figure 2 shows a schematic representation of a dynamic absorber system.

This effect is commonly used to advantage in front end accessory drive pulley dampers which cancel a crankshaft torsional natural frequency. A dynamic absorber is only partially helpful in transmission isolation because it can only cancel one natural frequency. A transmission presents several different natural frequencies based on its degrees of freedom and the multiple gears available. Therefore, a conventional absorber can only address one situation, offering only a partial solution in most cases.

This disadvantage can be remedied by replacing the spring-mass-system of the absorber by a pendulum exposed to centrifugal force. Because centrifugal force varies with speed, the natural frequency of the absorber now varies with speed. It can therefore be tuned to the firing order of the engine instead to one "fixed" frequency, preventing this "variable" frequency from entering the driveline. A schematic representation of this Centrifugal Pendulum Absorber (CPA) and the associated equations are shown in Figure 3.

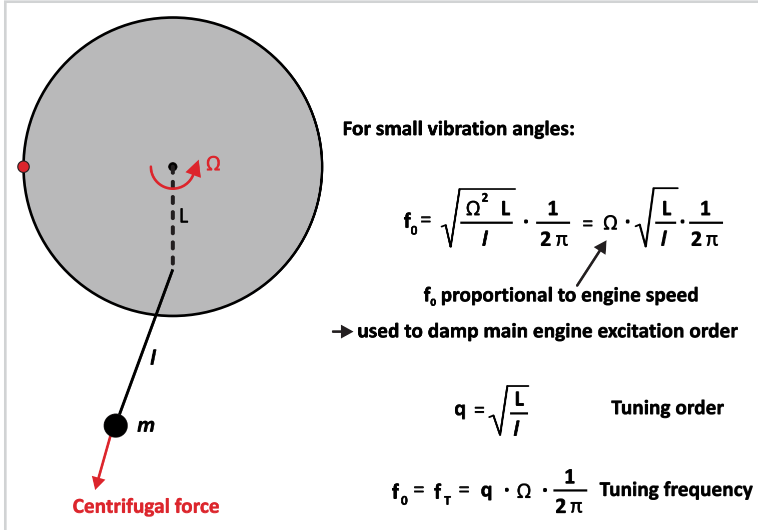

Figure 3 Centrifugal Pendulum Absorber and governing equations

The CPA has been introduced successfully in the Dual Mass Flywheel and is on its way to production in the torque converter as well. A torque converter damper with integrated pendulum is shown in Figure 4 along with a measurement of vibration isolation achieved with the pendulum in comparison to a conventional damper.

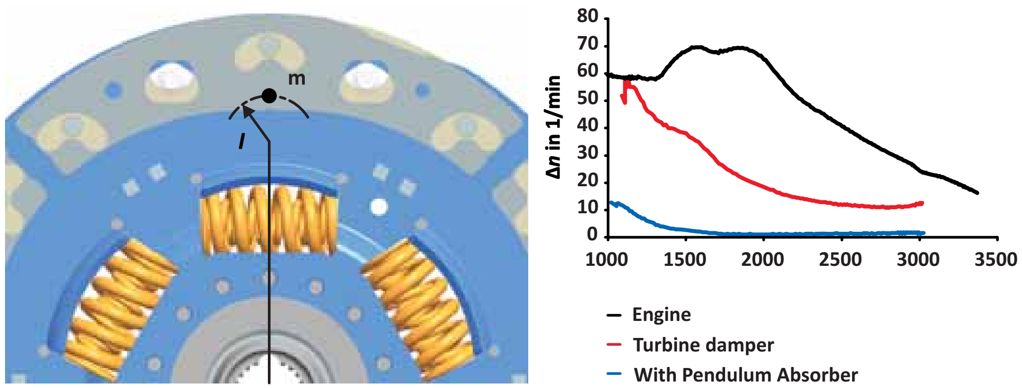

Figure 4 Torque converter damper with integrated Centrifugal Pendulum Absorber

Turbine tilger

The performance of the CPA is superb, however, some applications will benefit from another elegant absorber – the Turbine Tilger. The Turbine Tilger makes use of an inertia that is already present in the driveline to create a dynamic absorber – the turbine inertia. A schematic diagram of the Turbine Tilger is shown in Figure 5. As can be seen the turbine inertia, which would normally be connected with the drive plate directly, is instead connected to the intermediate flange over a set of small coil springs. In closed mode, the turbine is not active since all the torque is passing through the lock-up clutch. Therefore, its inertia can be used to as an absorber. The turbine oscillates on these small springs against the intermediate flange, cancelling the vibration in the system at this point.

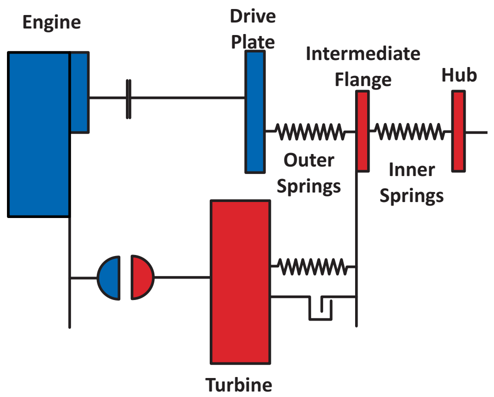

Figure 5 Turbine Tilger schematic

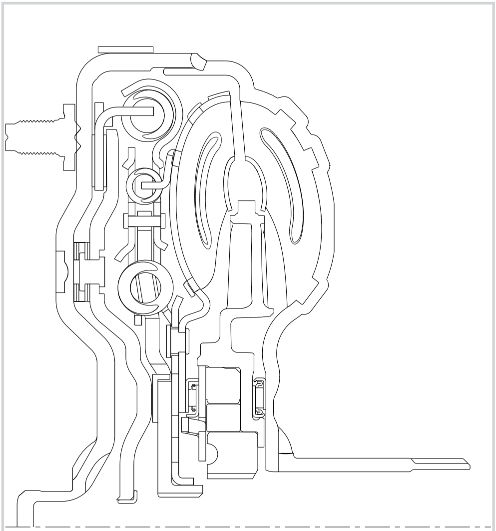

Figure 6 Torque converter with integrated Turbine Tilger

A cross section of a design with a Turbine Tilger can be found in Figure 6. The small set of coil springs between the two larger coil springs is sufficient to create the desired effect. The improvement in NVH can be seen in Figure 7. While this device is a single frequency absorber, one can see that it is effective over a wide engine speed range. This is due to the ratio of the inertias involved which allow a small amount of friction to spread the absorbing effect over a broad frequency range. The turbine tilger is especially useful in highly boosted four cylinder engines but can be used in many different powertrains.

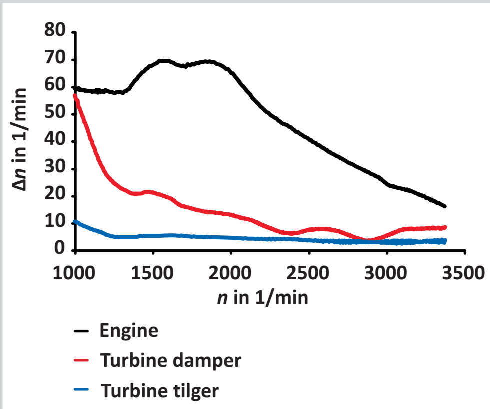

Figure 7 Vibration isolation of Turbine Tilger compared to Turbine Damper

Making space

Fluid circuit optimization

The space available for the torque converter fluid circuit is continuously reducing with the evolution of the transmissions. All new automatic transmissions, whether step gear, CVT or mild-hybrid type, require more space. At the same time, more stringent torque capacity demands on TC clutches and dampers (for early lockup) allow even lower axial space for fluid circuit components.

Some of the concept to improve torque capacity of the torque converter (to address limitations on radial space) and optimizing use of axial space by shearing the torus in either direction were presented in the 2006 LuK Symposium [1]. However, recent trends show that the limitation on radial space is not as severe as limitation on axial space. Therefore, LuK's focus shifted to optimizing performance for axially squashed fluid circuits.

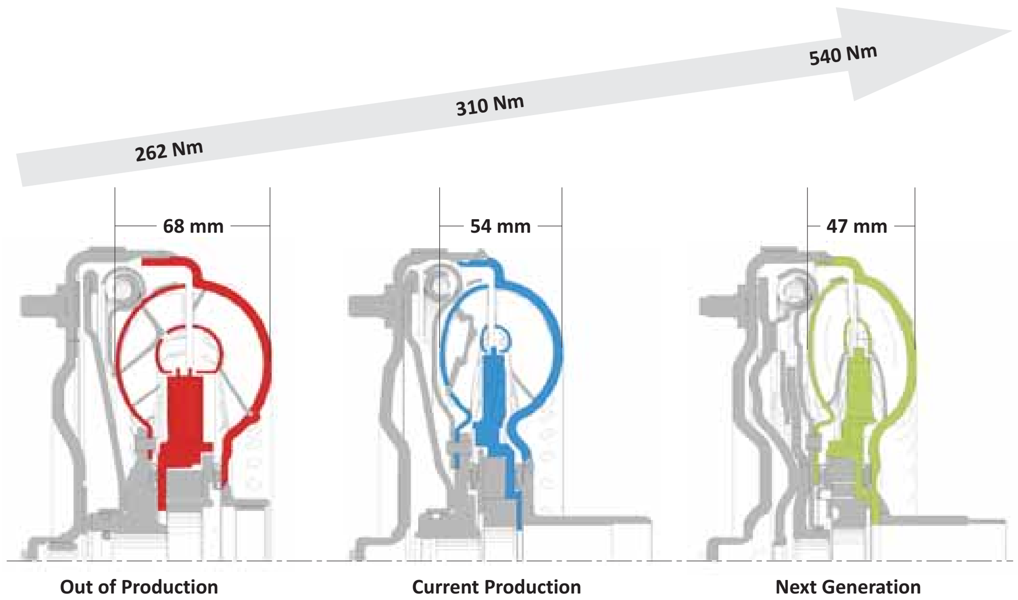

Figure 8 Decreasing torus size with increasing torque

Traditional fluid circuit designs lose performance significantly when components are squeezed axially to fit in the space available. Also, reduced width of the stator blades increases the tendency of the TC to cavitate at lower charge pressures. These issues were addressed while formulating new strategy for TC design.

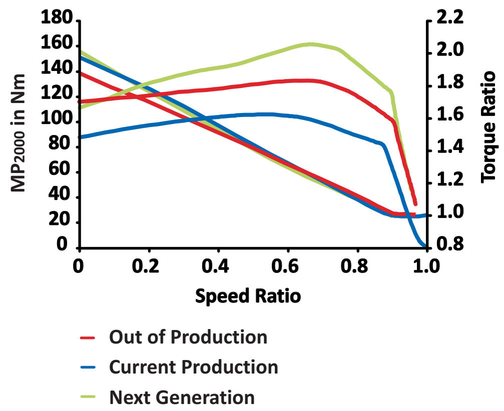

Figure 9 Improved characteristics with reduced torus size

The traditional role of each component (impeller, turbine and stator) to obtain a specific performance curve was reexamined. The reexamination revealed that these roles can be changed/optimized by redesigning shapes of blade passages. The examples in Figures 8 and 9 show that it is possible to reduce axial width of the torque converter with little or no negative impact on the TC performance parameters that determine fuel economy or performance of the vehicle.

The optimization of the leading and the trailing edges of the blades for all three components also significantly reduced the negative impact on stator cavitation that often accompanies size reduction. This allowed further reduction in axial width of the fluid circuit.

The combination of many small changes has led to significant reduction of axial width without sacrificing performance. This makes space for LuK to fit advanced damper designs in the available space and to introduce modularity in the TCC/Damper components.

Modularity

The quest for improved fuel economy has led to significant variation in engine and transmission types, i.e. naturally aspirated, turbo-charged, and

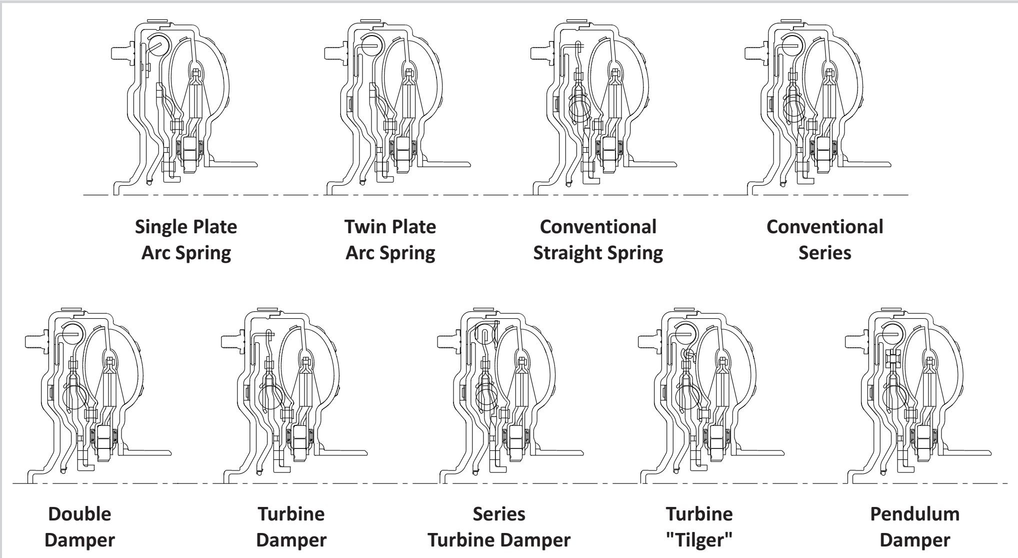

Figure 10 Modular torque converter portfolio

stop-start equipped engine mated with CVT and AT. In order to cover these many powertrain combinations with as little investment in development and tooling as possible, LuK has created a modular solution which allows several versions of a damper and fluid circuit to be used in one housing with minimal changes.

The modular portfolio for Front Wheel Drive vehicles can be seen in Figure 10. The first adjustment which is provided for is the lock-up clutch torque capacity. This is accomplished by allowing either a single plate or twin plate clutch. In the single plate clutch the friction material is bonded to the piston plate directly. To change to a twin plate clutch, one new stamping is used with friction material on both sides and drive tabs for the damper springs formed on the outside diameter.

Damper flexibility is provided by designing connection points for all damper types into the simplest damper. With this protection, straight spring, arc spring, series, double, centrifugal, and turbine absorber dampers can be created from one basic set of hardware. Only the additional parts needed for the new damper type have to be tooled from scratch.

Stamping and processing technology

In order to provide space for these many damper types and to at least partially offset their cost, innovation in processing technology is required. An example of a modular TC with optimized processing technology is shown in Figure 11. The use of stamping technology to create features that would ordinarily be machined can be seen in the area where there would normally be a forged or powdered metal turbine hub. This hub would normally connect the input shaft to the turbine, provide a spline for the damper, and contain seals to both the piston and the input shaft. In the optimized design, these features are produced directly in the stamped components. Therefore, the damper flange has a spline which mates to the input shaft. The piston bore contains a bushing which both centers the piston and seals the hydraulic pressure to the shaft, eliminating one seal. The turbine then connects to the damper directly.

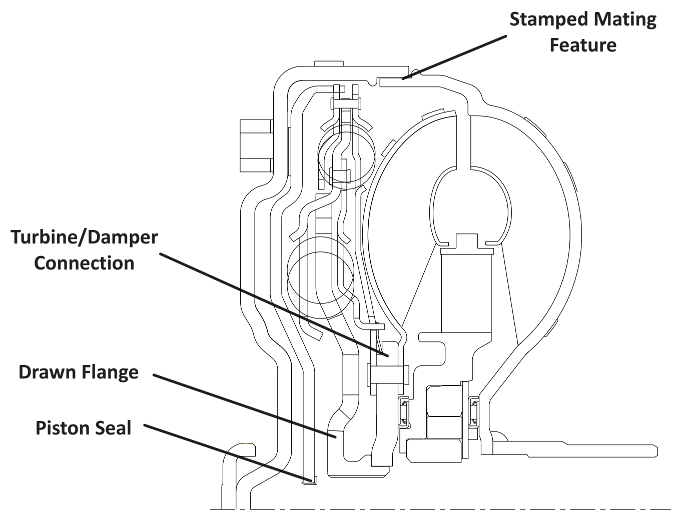

Figure 11 Torque converter cross-section with simplified processing

Another example of stamping technology is shown at the outer seam of the TC shell. The mating dimensions for this seam are normally produced by machining of the stamped shells. In this case, both the diameter and shoulders are created by a coining operation in the press. The shells are delivered to the assembly line ready to weld.

Welding is conventionally done by a MIG process using filler rod. To avoid both, the expense of welding wire and the contamination caused by weld spatter entering the TC, LuK has developed an autogenous weld which uses the base parts themselves as filler material. This eliminates contamination and simplifies processing.

Sheet metal stator and OWC

The innovations in sheet metal forming reviewed so far are considerable, for example replacing powdered metal or forged components with stamped parts. The next challenge is to supersede die cast aluminum and ground steel components with stampings. In this case, the objective is both, to reduce the space required for the stator assembly as well as to reduce its cost. More effective dampers need more than space; they also need off-setting cost savings in order to offer overall value.

The advantages of a sheet metal stator blade have been shown in several different applications over the past several years [1][2] and are summarized in Figure 12. In short, steel has triple the strength of aluminum, which allows for a thinner stator blade. A thinner stator blade offers less resistance to fluid flow, thereby increasing capacity. The greatest challenge is to retain the coupling point, or overall efficiency of the torque converter. Since a sheet metal blade must have a constant thickness, it cannot duplicate an airfoil profile, which is helpful in achieving a high coupling point. The penalty in efficiency for use of a sheet metal stator blade varies from almost nothing to as much as 3% depending on the torus geometry. However, this penalty is less and less meaningful as torque converter lock-up occurs at lower and lower speeds.

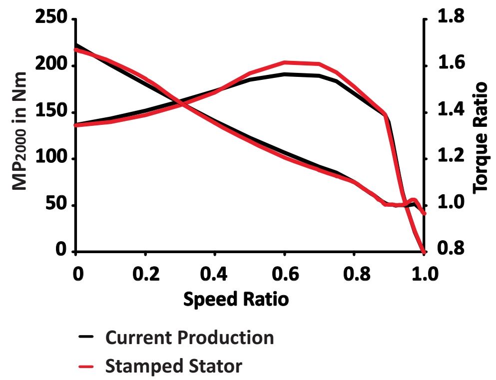

Figure 12 Space savings with sheet metal stator and resulting characteristics

Furthermore, the characteristic obtained with a constant thickness blade, is normally looser at stall and of higher capacity at higher speed ratios. This means that the converter transmits less torque at the beginning of the launch event and more torque later. This characteristic is ideally suited to modern turbo-charged engines, both diesel and gas iIn two ways. First, the idle losses are reduced since idling always means the converter is in stall where the stamped stator characteristic offers a lower capacity. Second, because this lower capacity allows the engine time to spool up the turbo charger during launch. This naturally overcomes turbo lag, a prevalent problem in highly boosted engines, by allowing the engine to increase in speed quickly thereby accelerating the turbo charger. Taking both phenomenons into account, the sheet metal stator offers a favorable characteristic for modern engines.

The question then becomes: “Which is the correct choice for a one way clutch (OWC)?”. In order to reduce space and cost, it is desirable to use a sheet metal OWC. Since such a OWC is necessarily thinner, a lower stress for a given torque is required. This can be accomplished by changing from a line contact, as is usual in roller or sprag OWC's, to a surface contact. A new OWC concept, called the Wedge OWC, which achieves this effect, is shown in Figure 13. This clutch operates by clamping the wedge ring between the hub and the outer race in the locking direction. In the freewheel direction, the wedge ring is drawn out of contact with the outer race as it moves down the ramps of the hub.

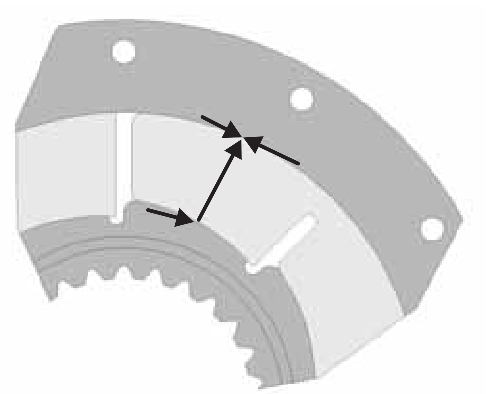

Figure 13 Schematic of Wedge OWC

An assembly using this OWC is shown in Figure 14, compared with a conventional roller OWC. The advantage in thickness is obvious from the figure. This additional axial space can be used to help package larger dampers or to accommodate a shorter bell housing between crank shaft and transmission housing. Since all the components of the Wedge OWC are stamped, multiple machining operations are eliminated, thus providing a cost advantage. The Stamped Stator with Wedge OWC is a further advantage gained from optimal use of stamping technology.

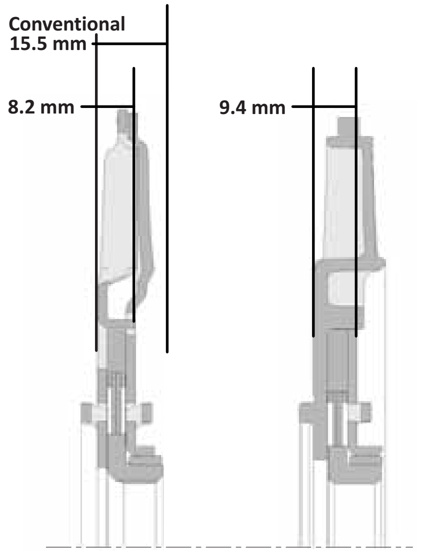

Figure 14 Stator assembly using Wedge OWC

Stop-Start for the AT

As increasingly stringent fuel economy and emissions standards become commonplace in the automotive industry, so does the importance of introducing new technologies or sets of technologies that allow these standards to be satisfied. Equally true is that expectations for vehicle comfort levels and functionality have escalated, perhaps at a rate that exceeds the increased fuel economy and emissions standards.

The concept of improving fuel economy via an engine stop-start strategy is not new. Indeed, vehicles with this functionality were offered for sale in both manual and automatic transmission variants as far back as the early 1980's. However, in spite of the oil crisis as well as the much lower comfort expectations of the time, the sacrifices in comfort for these systems were too great. The consumers cast their votes and these systems were eliminated from the vehicle manufacturers' product offerings. In the past few years, though, stop-start systems have made a resurgence, particularly in vehicles with either a manual or hybrid transmission. Technology now exists to address the subjective challenges that plagued systems of old and market acceptance is on the rise. However the staple transmission of the North American automotive market, the planetary automatic transmission, is thus far without a parallel, problem solving set of technologies. 95 % of the vehicles sold in the US are waiting for an answer to three basic problems:

1. Restart the engine quickly while also protecting for change of mind events
2. Return control of the transmission hydraulics to a normal level of function as quickly as possible
3. Manage the launch event or change of mind event in a manner that is subjectively acceptable to the vehicle operator.

There are various solutions to each of these problems, some of which have already been implemented

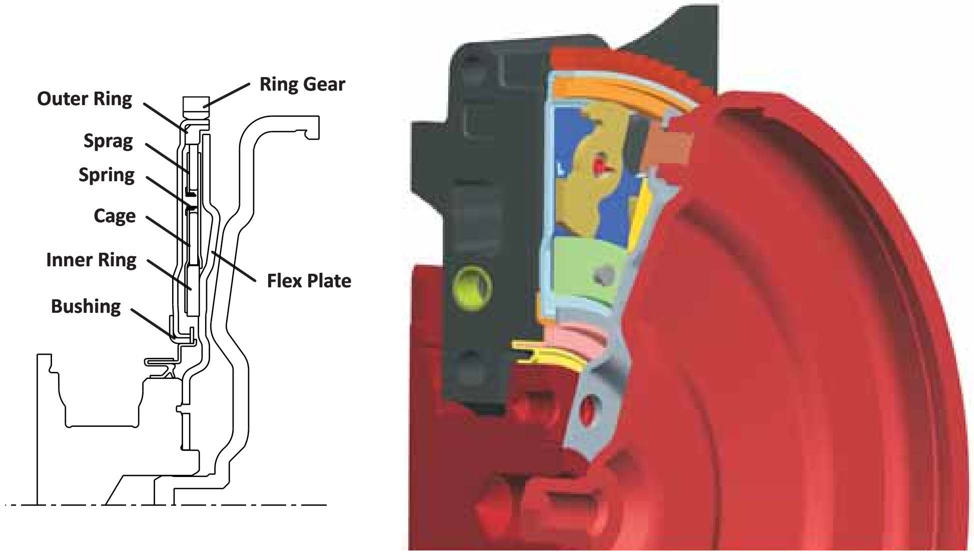

Figure 15 Cross-section of PES

in manual or hybrid transmissions. Particularly the first task, starting the engine quickly and smoothly, generates solutions that can be applied to a vehicle somewhat independently of the transmission type. Today, many vehicle and engine manufacturers are investigating upgraded starter motors or, in the case of direct injected gas engines, motorless direct start – a technique whereby fuel is injected and ignited to restart the engine from a standstill. Though each of these schools of thought offer attractive means to handle engine restart events, both are limited with respect to their ability to be used over all modes of operation and at all extremes of either environmental temperature or engine temperature.

Permanently Engaged Starter

The concept of the Permanently Engaged Starter (PES) offers an interesting way to address the shortcomings of the systems discussed thus far. The addition of a one way clutch between the engine crankshaft and the starter ring gear allows the mesh between the starter ring gear and starter motor pinion to remain constant. Once the engine is started, the one way clutch freewheels allowing the starter motor speed to come to zero. As such, engine restart events can be quick as there is no delay associated with engaging drive to the engine. Change of mind events can also be handled as the starter can be engaged at any time without the need to synchronize ring gear and pinion speeds prior to engagement. Finally, as the basic function of the starter system is not altered, there is no sacrifice in engine starting performance with respect to environmental or engine temperatures.

To date, PES systems have required changes to the rear face of the engine block, the addition of a lubrication port for the wet one way clutch, as well as the addition of bearings and seals. Typically the latter two hardware additions are implemented such that system drag is added while the engine is operating, thereby reducing fuel economy and the net benefit of implementing engine stop-start.

LuK has developed an alternate configuration for the PES. With the LuK configuration, shown in Figures 15 and 16, the need for lubrication ports

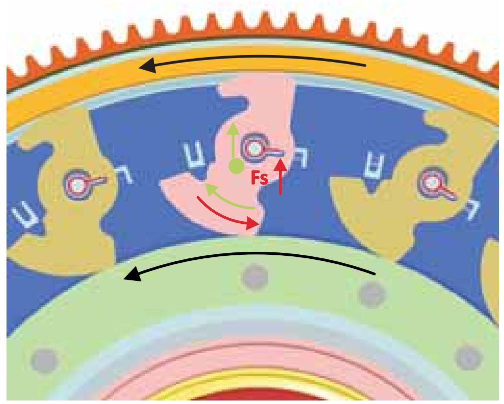

Figure 16 Functional diagram of one-way mechanism for PES

and seals is eliminated via the use of a novel dry sprag one way clutch. Additionally, as the sprags are attached to the crankshaft via a cage element, the behavior of the clutch can be tuned as a function of engine speed. The one way clutch can be designed such that it is fully engaged over a range of engine speed up to a given change of mind threshold, typically 400 1/min, yet fully lifted off at a speed just below engine idle speed. Therefore the system can respond to a need to restart during a change of mind event even if the engine speed has dropped below the speed that would allow the addition of fuel and spark alone to restart the engine. Additionally, once the engine is started and has reached idle speed, there is no drag across the one way clutch. Finally, the system has been configured such that the ring gear support bearing is at zero speed for all conditions but engine restart, thereby eliminating loses since the is no differential speed in relation to the engine block. The resulting solution means that a PES can be implemented with a minimum of changes to the existing engine and transmission combination and have no drag penalty compared to the baseline conventional starter system.

The remaining tasks of returning transmission controls to normal function and managing the launch event are perhaps most easily tackled by borrowing technology from hybrid drivetrains, that being an externally mounted, electrically driven, hydraulic pump. This pump serves to keep the transmission's hydraulic circuits operable even though the main engine driven pump is not being driven by the engine. Additionally, this pump enables transmission shift elements to be controlled or modulated during the restart and launch event, thereby mitigating disturbances to the extent that the event is subjectively acceptable. This solution is a sound approach for hybrid drivetrains where electric vehicle operation is a common mode, hence there is a need for this auxiliary pump for reasons other than just stop-start. For vehicles with stop-start systems alone, however, the on cost of a dedicated pump becomes unattractive.

Another competitive solution specifically for planetary automatic transmissions is the hydraulic accumulator. This device is designed to supply the transmission with a small volume of high pressure fluid during the engine restart event, the effect being that the hydraulics of the transmission should be ready to return to normal operation more quickly. This system requires that the timing of the accumulator discharge is accurate. Additionally, the transmission hydraulics needs to be designed to accommodate this type of device.

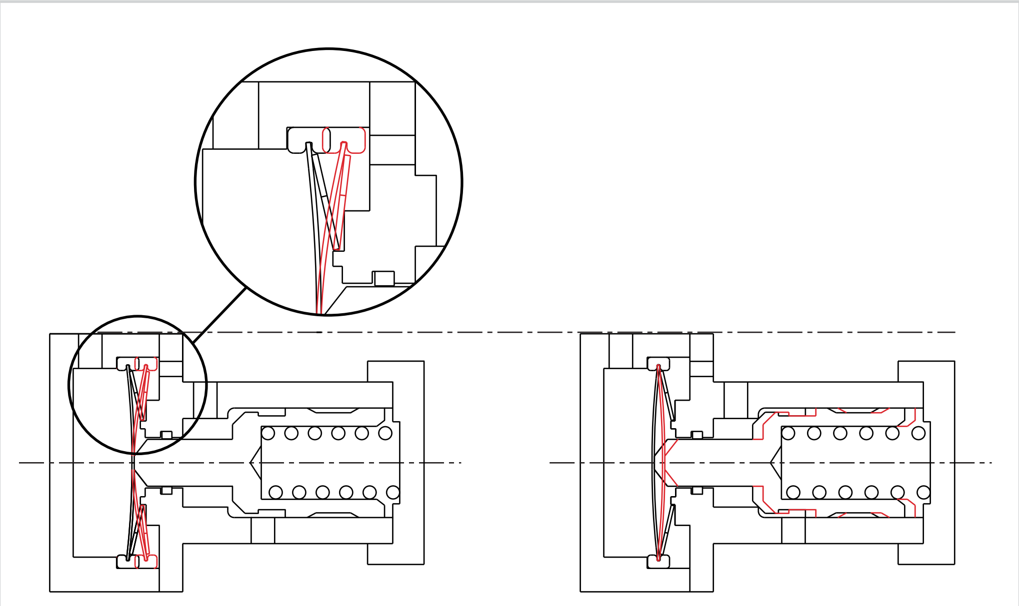

Figure 17 Controlled Latching Check Valve in latched and open mode

Controlled latching check valve

LuK has developed yet another solution to these two problems – the controlled latching check valve, shown in Figure 17. This system consists of two functionally separable elements: the check valve or pressure control valve itself, as well as a device to enable the control valve to be either activated or deactivated. The principle is quite simple and relies upon using the control valve to stage or position the shift elements of interest in a desired position such that the vehicle launch event can be accomplished as quickly as possible while the transmission hydraulics return to operation. The second portion of the system consists of a bistable diaphragm spring and allows that the valve can be enabled prior to an engine shut down event or disabled after the engine has restarted. By sending a brief pressure "spike" slightly higher than normal operating pressure, the bi-stable spring is made to snap over center, allowing the valve to regulate the piston pressure. The next normal actuation of the clutch causes the spring to snap back, returning the transmission to normal operation, as if no valve were present.

This system can be tuned to address the needs of a particular transmission. As an example, if the desire is to hold the shift elements staged at the touch point of the clutch, thereby eliminating the need to learn the clutch piston position and stroke the clutch to the appropriate point, the valve can be tuned to hold a pressure that will overcome the clutch return spring force. Alternately, it may be desirable to hold the clutch at a defined torque or pressure to allow creep torque during the launch event but mitigate effects such as engine flare during restart.

This device is designed to be installed in close proximity to the shift elements required for first gear operation, which in the modern planetary automatic transmission are typically one clutch and one brake. By doing so, the device can be implemented in a transmission with minimal hardware changes and need not contend with leak down effects across seals upstream of the transmission valve body.

The combination of the LuK Permanently Engaged Starter and Controlled Latching Valve offer a set of technologies that brings engine stop-start systems closer to the marketplace with a minimum of investment and the least disturbance to proven transmission systems.

Hybridization options

The sales of hybrid vehicle have grown to represent more than 3 % of all vehicle sales over the past years, and projections suggest that this trend will continue into the future. LuK is no stranger to these applications and is steadily building a strong portfolio of dampers suited to the needs of these rather special drivetrains.

As LuK goes forward with hybrid activities and grows with the challenges of this new market, it is interesting to note that one of LuK's core technologies, the dry clutch, is finding a new home in the drivetrain as part of a P2 Hybrid architecture. The P2 layout offers the flexibility to operate the vehicle via the combustion engine or with the combustion engine boosted by the e-machine. The addition of the aforementioned dry clutch, in this case implemented as an engine disconnect clutch, enables the vehicle to be driven fully electrically as well as to improve regenerative braking efficiency by eliminating engine losses.

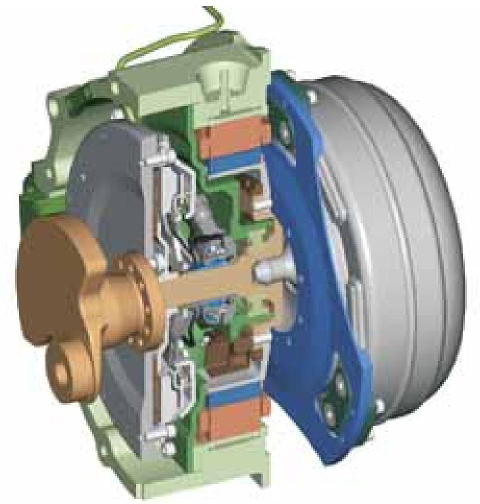

Figure 18 Hybrid module for use with conventional automatic transmission

Perhaps one of the most attractive aspects of the P2 architecture is its ability to offer all relevant modes of hybrid operation without the need for a new transmission design. The engine disconnect clutch, release system, e-machine, and associated shafts and bearing can all be implemented in as independent module. This module, shown in Figure 18, can be bolted into place between the engine

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and existing transmission complete with its launch device, typically a hydrodynamic torque converter. Clearly this approach may not be suitable for a front wheel drive platform where there is insufficient space to incorporate this additional hardware. In the case of many rear wheel drive platforms, however, this approach offers the most value when investment and development costs vs. function are considered.

An alternate manner in which the P2 architecture can be realized is through integration of the engine disconnect clutch and e-machine with the torque converter itself. A layout of this type is shown in Figure 19. Via this effort it is possible to combine advances in modern torque converter design, discussed earlier in this paper, with torus downsizing activities, the latter being made possible as a result of improved damper technology and reduced TC duty cycle, to arrive at a solution that can package in a space similar to the state of the art torque converters of only a few years ago.

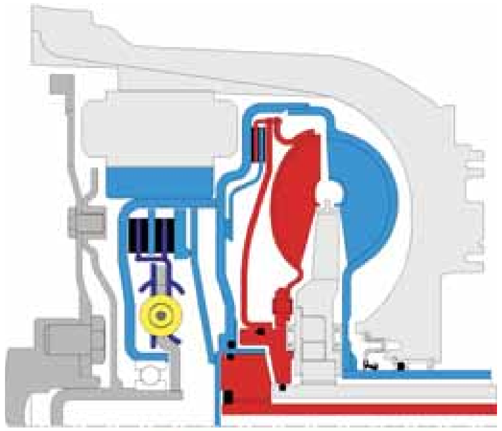

Figure 19 Hybrid module integrated into the torque converter assembly

Conclusion

It is indeed a good time to be part of torque converter development. As can be seen from the many elegant and effective concepts presented here, the challenges of the modern powertrain are being met. The vibrations of boosted engines can be isolated by a library of damper types which can be interchanged in a modular portfolio. The space challenges can be met by downsizing the torus and innovating process technology. Stop-Start and hybridization are technically possible and affordable. The torque converter will have a long future as the old technology continues to fight back.

Literature

[1] McGrath, M.; Hemphill, J.; Bailey, G.; George, P.; Swank, M.; Krause, T.: Torque Converter, 8th LuK Symposium, 2006

[2] Advanced Torque Converter Concepts, CTi North America, May 2007

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