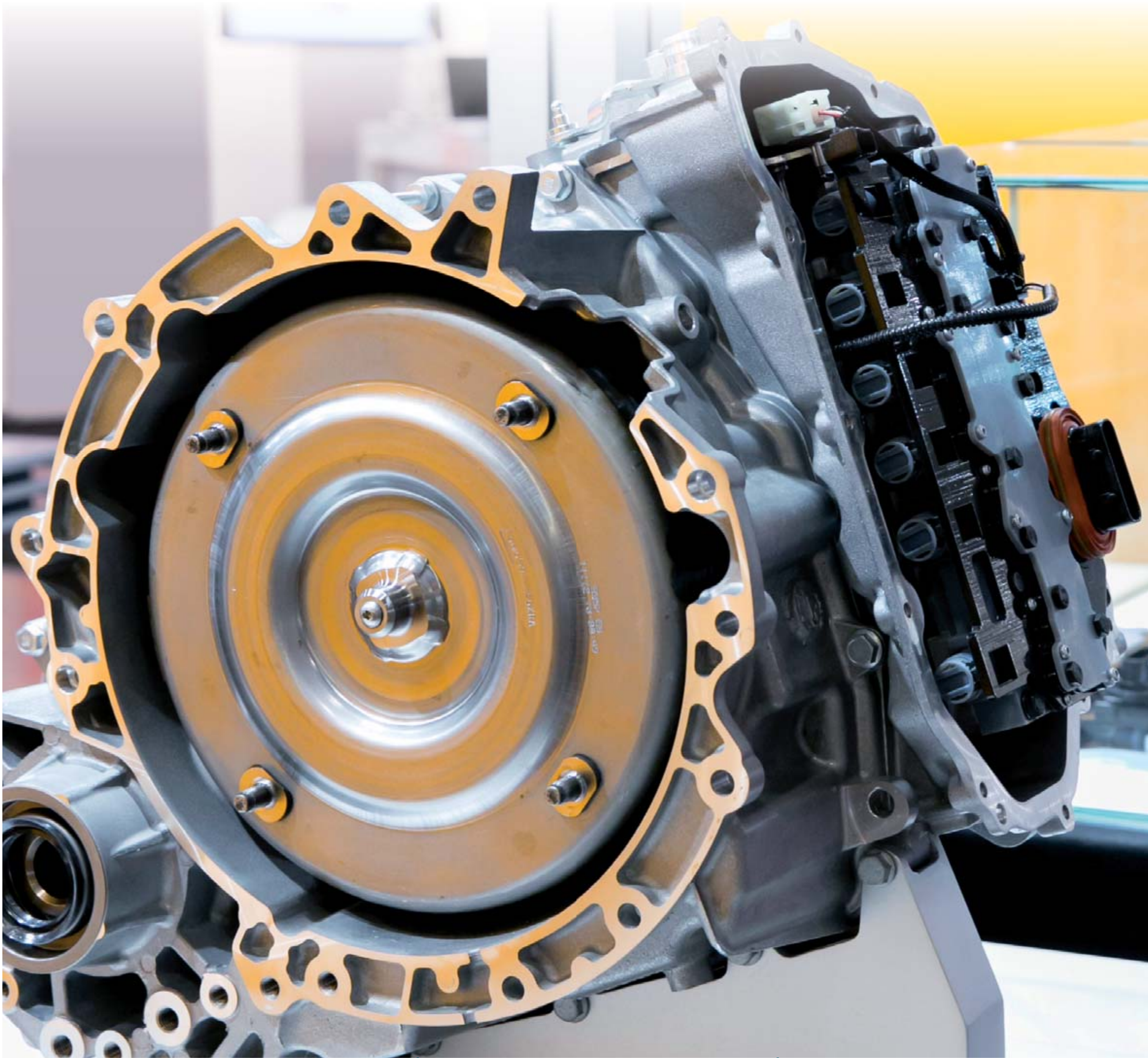
CTI MAG

The Automotive TM, HEV & EV Drives magazine by CTI

May 2015



Expert Forum: How Many Speeds Will Be Right?

A Universal Hybrid Transmission

for HEVs, PHEVs and E-REVs

Interview with Prof. Helmut List

Chairman and CEO at AVL List GmbH

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CTI MAG Contents

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Dear reader,

In this fourth issue of CTI Mag, we continue to provide you with the latest information in the field of transmission and powertrains, given by proven industry experts. We have even extended our content with an experts forum and an interview, both covering current topics in powertrain development.

In recent years, we have been discussing the question of how many gears transmissions need. Will increasing electrification lead to different answers? In our first expert forum, seven experts share their interesting – and sometimes surprising – thoughts.

In our interview, we asked Prof. List, Chairman and CEO of AVL List GmbH, about the future of powertrain and transmission development. He provides interesting insights into the work of engineers who deal with both engines and transmissions – and their interaction. Summing up, Prof. List says: „Every transmission developer needs to understand the entire powertrain system."

We hope you enjoy our new, extended magazine!

Best wishes,

Your
CTI Mag Team

PS: The fifth issue of CTI Mag appears in December 2015.
The submission deadline for articles and adverts is 5 October 2015.
To get all the details, just send a brief email to michael.follmann@car-training-institute.com

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Expert Forum

How Many Speeds Will Be Right?

In 2025, the variety of powertrain architectures is likely to be considerably larger. Conventional powertrains based on combustion engines will be complemented by various hybrid drive solutions. The demands on transmission concepts, ratios and number of gears are becoming increasingly multifaceted. How will this affect the number of gears in both conventional and hybrid transmissions?

■ CTI

Michael Schöffmann,
Head of Transmission Development,
Audi

"Transmissions with a higher electrification level will need fewer gears"

Today´s powertrains use six to nine gears; some manufacturers and OEMs have even announced their intention of raising that to ten. Yet significant benefit is connected to ratio spread, not just increasing the number of gears. A wide gear spread, combined with well-designed gear layout, enables downspeeding potential and reduced CO_2 emissions in the EPA cycle – and even more importantly, for the driver.

A wide spread up to 9 from first to last gear can be achieved satisfactorily with seven to nine gears. In most cases, increasing the number of gears implies more internal transmission parts, or requires the multiple use of gears. The pros and cons of more gears must be weighed up carefully for mainstream transmissions, since more gears could even reduce total efficiency.

With powertrain electrification on the increase, there is no need for more gears because an electric motor can provide significant torque even at very low speeds. As a result, the spread of electrified transmissions can be reduced, since the lower gears can have a higher ratio than in a non-electrified powertrain. This means long term, new transmission concepts with fewer gears, but higher electrification levels, can be expected.

Dr. Uwe Keller,
Project Leader Hybrid Powertrains
Mercedes-Benz Passenger Cars, Daimler

"In conventional hybrid drives, fewer gears are unikely"

We are currently in a transitional phase leading from driving with combustion engines to electric driving. How long this will last depends on various circumstances, mainly on advances in battery and fuel cell technology.

By 2025, one can expect a wide range of different transmission and hybrid drive designs. Plug-in hybrids in particular will grow in importance, due to many advantages and modular designs. In general, an efficient hybrid system within the powertrain is essential for effectiveness during electric driving and recuperation. However, transmissions with a wide gear spread are required for hybrid driving, to keep the ICE within the optimal torque map.

One can therefore conclude that for hybrid drives with electric power up to 100 kW, transmission designs offering very good internal efficiency and adequate gear spread are the ideal solution. It is therefore unlikely that we will see fewer gears in conventional hybrid drives.

Dr. Harald Naunheimer,
Executive Vice President Corporate R&D,
ZF Friedrichshafen

"The further we go towards electric vehicles, the fewer speeds we will need"

The range of transmission concepts for passenger cars – manual, automated, dual clutch, stepped automatic and CVT – that we see today, will remain principally the same in the next ten years. We do, however, expect a significant increase in hybrid drives and consequently in hybrid transmissions as well, such as the 8-speed automatic transmission for plug-in hybrid vehicles recently presented by ZF. The powertrain will be partly electric in the near future, with the functions shared between a combustion engine and an electric motor. The combustion engine only operates in its most efficient ranges, whereas the electric motor can serve all other operating states very well.

Thus, automatic transmissions with eight, nine, or even ten speeds become oversized for the electrified driveline. The number of gears will definitely decrease here. It's not about removing a couple of gears from the transmission, but above all, about adding value with a new, smarter drive system. However: the further we go towards electric vehicles, the fewer speeds we will need.

Didier Lexa,
Chief Technology Officer,
Getrag

"More and varied powertrain architectures require a scalable number of gears"

The gear set of dual-clutch transmissions can be affordably scaled, depending on requirements such as fuel consumption, drivability and product cost. In the A- to B-segment, DCTs with 6 gears will be the most common solution. In the C- to D-segment, 7 gears will be used for medium torques and up to 9 gears in high-torque applications. Especially in front-transversal applications, 3rd generation DCTs like the 7DCT300 are gaining in importance. This transmission family will be supplemented with hybrid variants that can be scaled from 48V mild hybrids to high-performance plug-in hybrid drives. Sharing the basic DCT architecture, this kind of hybridization will be appropriate for small-to-medium volumes by around 2020.

With rising market penetration of hybrid drives due to future CO_2 legislation and an improved charging infrastructure, development and unit costs will go down, paving the way for alternative architectures. There is huge fuel-saving potential for shifting the system power towards more powerful electric motors, thus enabling electric driving over longer distances. The more powerful motor can cover all dynamic driving conditions, while a smaller engine is used for stationary conditions and for maximum vehicle speed. In configurations of this kind, the transmission needs only 2 to 4 gears for the engine, depending on the specific application and driving strategy. One to 3 gears are needed for connecting a high-speed e-machine. For all these architectures, layshaft transmissions offer a good combination of efficiency, commonality and scalability.

Terry Nakatsuka,
CEO
Jatco

"The most flexible solution for hybrid vehicles is the best solution for our customers"

It is predicted that even in 2025, transmissions for HEVs and cars with conventional ICE will co-exist. Therefore, it is necessary to manufacture both types of transmissions efficiently. Both types should be the same size, so they can be adopted on the same vehicle models. Ideally, HEVs should have the same number of gears and ratio coverage as conventional powertrains, in order to deliver good performance even with a low battery state of charge. For these reasons, we use the same concept for both hybrid and conventional drives: both versions have the same number of AT gears or CVT ratio coverage. Today, we use a 7 speed AT for RWD HEV; in 2025, 8 or 9 speeds may be adequate in the future. We use a CVT for FWD HEV that shares 70 percent of its parts with a conventional CVT. This high commonality enables them to be assembled on the same production line, allowing flexible adjustment of the production volumes of HEV and conventional powertrains. This has made it possible to control cost increases. Effective use of the high ratio flexibility of CVTs ensures optimal operating conditions for the motor/generator, which contributes to improved vehicle fuel economy. Recently, a new stepped CVT shift control was added for a more direct feel when accelerating hard. We will continue to evolve our conventional CVTs and utilize the evolved CVT for HEV, to contribute to outstanding vehicle performance and high cost efficiency.

Prof.-Dr. Stefan Pischinger,
CEO ,
FEV

"The combination of electric motors and combustion engines offers the potential for fewer speeds"

All current types of manual and automatic transmissions will continue. Future development efforts will focus on further increasing their efficiency, as part of reducing vehicle CO_2 emissions. The complexity of transmissions will grow as they are adapted to various levels of hybridization, including plug-in hybrid powertrains. This presents a significant challenge to the engineers who are simultaneously facing shorter time-to-market expectations.

The market share of automatic transmissions is expected to increase; all types – from standard planetary designs and DCT to CVT transmissions – will play a role, depending on specific market requirements. Automatic transmissions are also key enablers for new technologies and advanced applications such as autonomous driving.

To leverage the full potential of downspeeding at vehicle level, a higher transmission ratio spread is required. Small ratio steps help achieve good drivability, where for the majority of vehicles 7 or 8 speeds will still be sufficient. A higher number can be beneficial in terms of NVH characteristics at high speeds, or for crawler gears.

The electric motor and the combustion engine supplement each other nicely, and offer the potential for fewer speeds when used in combination. Vehicle packaging requirements and individual business case considerations will determine whether hybrid-specific numbers of speeds will be introduced.

Dr. Robert Fischer,
Executive Vice President, Engineering and Technology Powertrain Systems, AVL List

"Dedicated hybrid transmissions will probably have fewer gears"

Transmission developments are challenged by the increasing demands on fuel economy, respectively emissions reduction and drivability, especially shift comfort and responsiveness. Hybridization, or more precisely electrification, is one measure to achieve fuel economy targets. In conventional powertrains, the overall ratio spread – and, along with it, the number of gears – has been increasing. Yet the additional complexity in calibration, as well as weight and efficiency objectives, will stall this trend, especially as future engines will provide a much broader region of low specific fuel consumption compared to the current ones.

Beyond further improvement of today´s transmissions with respect to efficiency and comfort, dedicated transmissions for electrification will become increasingly important. Transmissions are the natural place to integrate the second propulsion source. As hybrid propulsion is key to achieving emission and fuel economy targets, dedicated transmissions designs are favorable with respect to total cost of ownership and functionality, probably with fewer gears. Volume scenarios will push dedicated hybrid transmissions to ensure cost and technology advantages compared to add-on solutions.

On-Demand Actuation for a New DCT Generation with Wet Clutches

Dual-clutch transmissions combine high energy density, low-friction gearsets and low parasitic losses with a flexible ratio layout. Another key element for efficiency is the power needed for actuation. By means of a new on-demand actuation based on pump actuators, reduced the actuation power to a level previously reserved for dry clutch solutions.

- Reiner Castan | Manager Actuation Systems | GETRAG, Untergruppenbach, Germany
- Alexander Strube | Director Core DCT Technology | GETRAG, Cologne, Germany

Motivation

For a new generation of dual-clutch transmissions, a requirement was to combine the advantages of wet clutches with an on-demand actuation with low power consumption. The specification included a torque capacity potential of around 500 Nm, functions like stop/start and sailing as well as a low-cost option for a hybrid version of the transmission. Other development goals included a precise pressure control under all operating conditions, and low-cost assembly with low cleanliness requirements. These considerations resulted in the new pump actuator design, enabling an extremely efficient on-demand electrohydraulic actuation.

In order to expand the product portfolio, Getrag developed a highly efficient actuation concept for wet clutches. These have a higher torque capacity, are thus smaller and have a lower inertia. The pump actuator concept combines the advantages of wet clutches with an on-demand clutch actuation. The motors proven in the 6DCT250 are reused slightly modified in the new dual-clutch transmissions 7DCT300 and 6DCT150/6DCT200. While still being used for actuating the shift drums, they now also drive the pumps for clutch actuation and cooling.

Development History

The first generation of GETRAG dual-clutch transmissions featured a leakage-optimised valve hydraulics actuation for shifting, clutch actuation and clutch cooling. As usual, the combustion engine drives the pump. In contrast to competing solutions, the predominant use of directly actuated valves made for considerably low power consumption. The next step forward was the consistent on-demand actuation implemented in the 6DCT250, with both shift drums and dual clutch being actuated electromechanically. By means of this on-demand actuation, the power consumption was reduced to <40 W (NEDC).

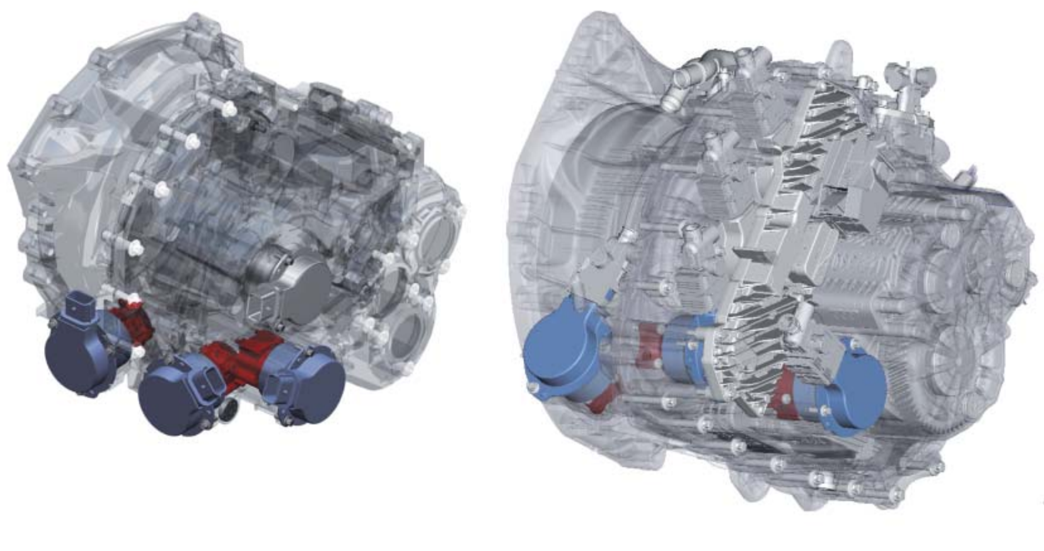

Figure 1: Flexible arrangement of pump actuators in 6DCT150 (left) and 7DCT300 (right)

Pump Actuator Design

Other than in a valve hydraulic design, positioning the pump actuators within the package is not restricted, Figure 1. There is no need for an axial-parallel positioning that a mechanically driven pump requires. In the new 7DCT300, two motors drive the shift drums, two are needed to drive the Gerotor pumps for clutch actuation, and one motor drives the pump for clutch cooling.

The hydraulic plan for the pump actuator design, Figure 2, is rather simple in comparison with a valve hydraulic system. On its way from the oil sump, the oil passes a suction filter for both clutch pumps. A pressure sensor behind the pumps provides the data for controlling the oil pressure of both pumps. The oil for the clutch cooling passes another dedicated filter and the volume flow is led directly to the rotary feedthrough of the dual-clutch.

As mentioned above, the same motor technology is used for the 6DCT250, 7DCT300 and 6DCT150/200. Due to the price volatility for rare earths, brushless ferrite motors are applied in the new DCT generation as common parts. The Gerotor pumps, primarily made from sintered parts, are standard designs as well, Figure 3. Their geometry, however, is different: the clutch cooling pump is designed for a large volume flow, the clutch actuation pump for high clutch pressure.

Compared to a transmission based on valve hydraulics, the pump actuator design gives consistent and precise pressure control through the whole temperature range, down to low temperatures. The pump speed can be varied dynamically. Thus, the pump actuators make for rapid pressure modulation for clutch actuation, allowing the pressure control to be calibrated for different vehicle applications with little effort.

Applications

The pump actuator design enables a flexible and inexpensive application, which is currently being developed for, but not limited to, 500 Nm. Thanks to the high degree of common parts, dual-clutch transmissions in the low torque segment can be offered as well. The new 7DCT300 will be the first series application, being launched with the new Renault Espace this year. Smaller variants are to follow at a later date..

On any scale, pump actuators enable hybrid DCTs with only minor changes. For example, the pump actuator design is implemented in the 7HDT300, currently being developed as a hybrid version of the 7DCT300. The 7HDT300 features an integrated e-machine, which can be oil-cooled at little additional expense.

Summary

The pump actuator design combines the best characteristics of proven DCT technology designs. On one hand, wet clutches offer specific advantages such as high torque capacity, thermal robustness and low inertia. On the other hand, the hydraulic design with pump actuators is much simpler than with valve hydraulics. The components can be freely arranged, and their common use within the transmission architecture enables considerable cost benefits. The pressure control precision is on a consistent level throughout the entire temperature range and the oil pressure can be controlled dynamically and consistently. Finally, the hydraulic layout can be modified for hybrid transmissions with little effort.

Thanks to the very efficient on-demand actuation, the power consumption was significantly reduced, the exact value varying depending on torque application and driving cycle. The 7DCT300 actuation needs a mere 31 W in NEDC and 33 W in WLTC. This substantially contributes to fully carrying into effect the efficiency of dual clutch transmissions.

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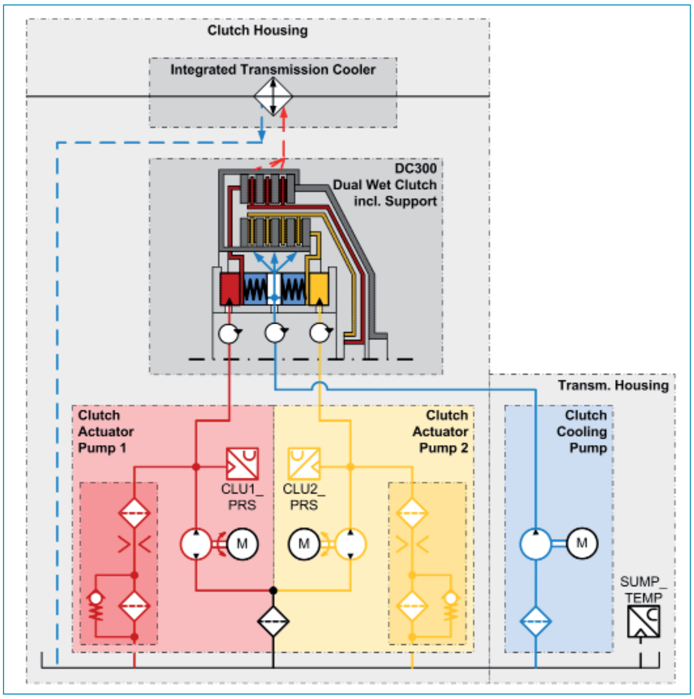


Figure 2: Hydraulic plan for clutch actuation and cooling

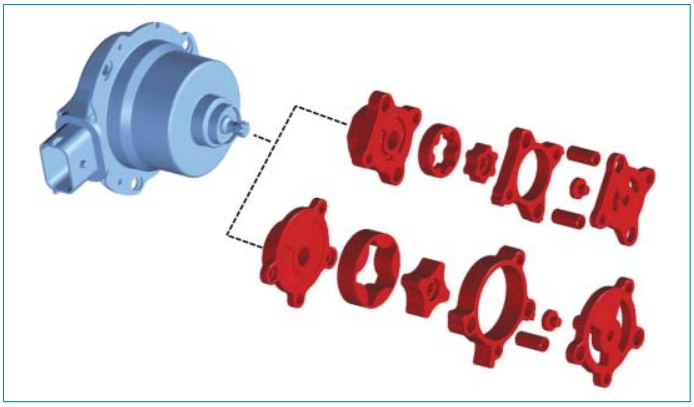


Figure 3: Clutch actuator pump (top) and clutch cooling pump (bottom)

Advances in Rattle and Whine Simulation

Gear rattle and whine are two main aspects of NVH in transmission. There have been much efforts dealing with simulation of these phenomenon. One can explain the physics behind of rattle and whine easily, however, building up a physical simulation model is not as easy, and the parameters involved are relatively high.

by Mario Brunner, Mehdi Mehrgou, Hemant Bansal, AVL List GmbH, Graz, Austria

Physical aspects of the rattle and whine models

Any structure borne noise problem has three important elements, namely source, transfer path to the structure and radiating surface. In most cases, both rattle and whine NVH problems can be traced back to gear teeth forces, these excitations propagates through the structure. Therefore in order to simulate these phenomena firstly, the sources, i.e. transmission error in loaded gears for whine and impact forces on free gears for rattle should be modelled accurately. Secondly, the transfer paths to structure and its radiation from structure surface to air provides further scope for NVH optimization

Here the physical aspects of NVH model and then a brief discussion on overall powertrain NVH optimization have been presented.

All the parts involved in the transmission have either direct or indirect impacts on NVH. Detailed models of gears are needed for computation of elastic meshing forces in the loaded gears as well as free gears. Furthermore a dynamic model requires flexible shafts as well as housing. The housing stiffness influences how the shafts deform and brings further effects such as misalignment into simulation models. Keeping in mind that gear teeth modifications are only few microns and gear backlash is also in order of few hundreds of micron, the deflections both for the housing and shafts cannot be neglected.

Often what is not included in physical models is the interaction of deflection between different support bearings; for example the forces applied on the input shaft bearings on housing will also cause deflection at the counter shaft bearings. These deflections have significant impacts on whine and rattle since they affect the gear contact and backlash. The ball bearings, which are used in almost all gearboxes, are a significant contributor to NVH with nonlinear radial, bending and axial stiffness, which often involve an initial clearance. The clearances lead to axial and radial movement of shafts which then indirectly influence the rattle and whine. These clearances have a very significance impact on transfer of the excitation to housing surface, which was observed in both simulation and measurements. It is important to include the nonlinearity of the bearings in dynamic models to assess NVH. Deep Groove ball bearings are an example which can lead to high axial and radial displacement in shafts in the order of few hundred microns.

Temperature and oil type are other important influential factors. Their impact on the system is rather significant and multifold. The higher temperature affects the clearances in ball bearings which as mentioned above highly influences the NVH. It also effects the damping in the ball bearings. Another aspect of oil and temperature is the drag torque. The drag torque comprises of friction for example in needle bearings (to support free gears), friction in synchronizers, churning losses, etc., it reduces due to lower viscosity and thus directly affects the rattle. Temperature of oil at the contact area of non-loaded gears significantly influences the rattle. The significance of the contact stiffness and damping of free gears is so considerable, that a wrong estimation and modeling technique of their values in simulation model can lead to a completely wrong rattle evaluation.

Including all these physical factors, is necessary to reach a good correlation between the measurement and simulation model. A correlation (measurement vs. simulation) of accelerations of points on the surface of such a model was made. Results of a rattle test rig is shown in fig. 1, the similar comparison for a whine test rig has been shown in fig. 2.

Rattle and whine evaluation:

Such a simulation makes teeth forces accessible for evaluation. A sample impact forces at teeth for rattle are shown in fig. 3. The changes in color indicates switching the flanks. By having the gear teeth forces of individual free gears the participations of each gear can be determined. The level and frequency content of these forces can be

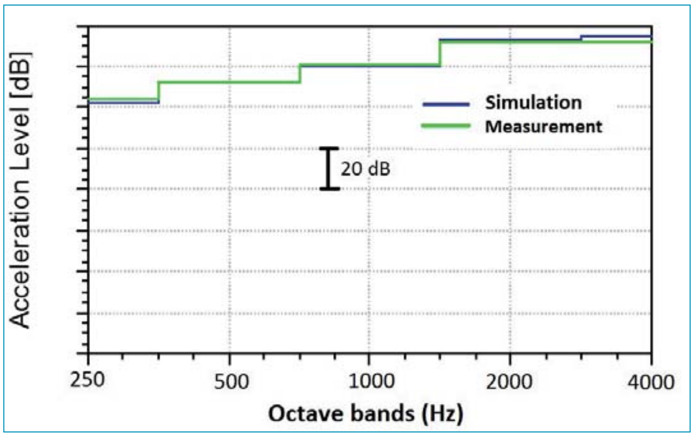


Figure 1: Comparison of accelerations in Octave bands for measurement vs. simulation over a sample point on the structure in a rattle test rig

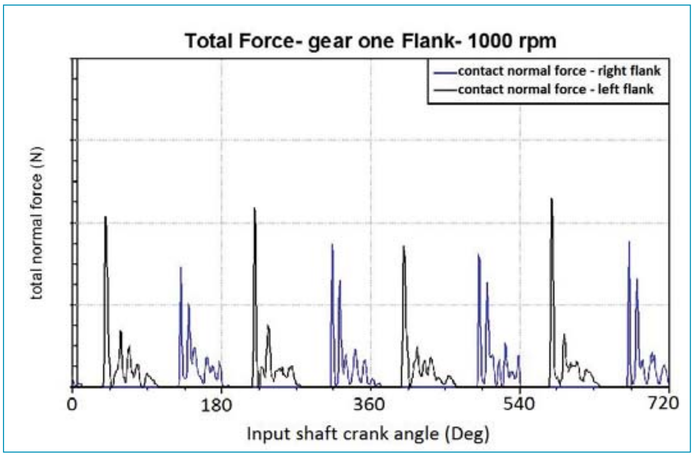


Figure 3: Impact forces in a free gear

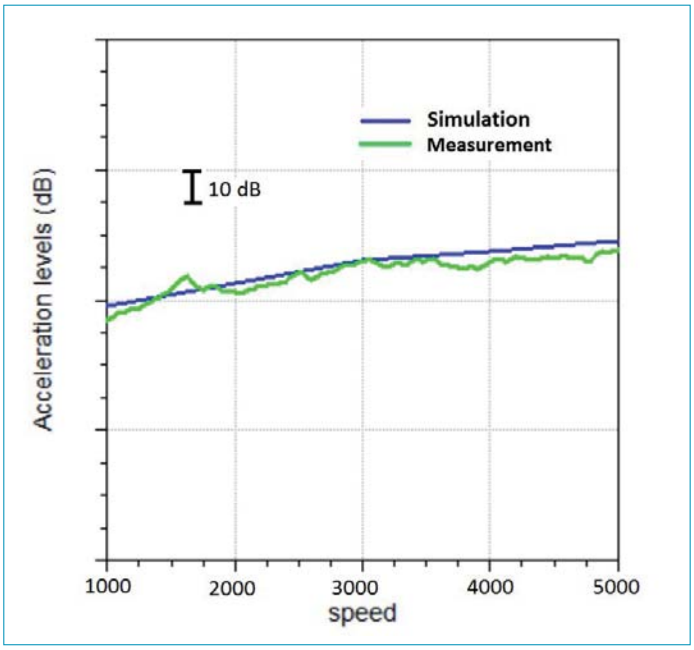


Figure 2: Comparison of accelerations for single order for measurement vs. simulation over a sample point on the structure in a whine test rig

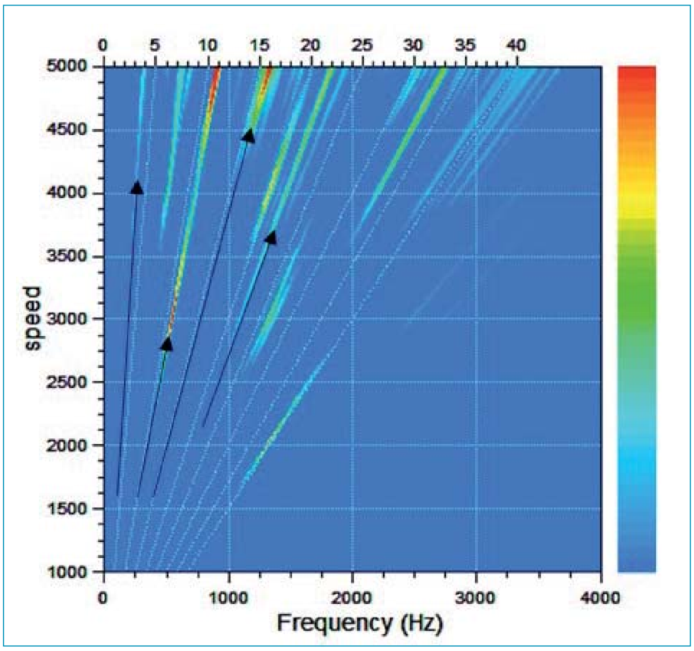
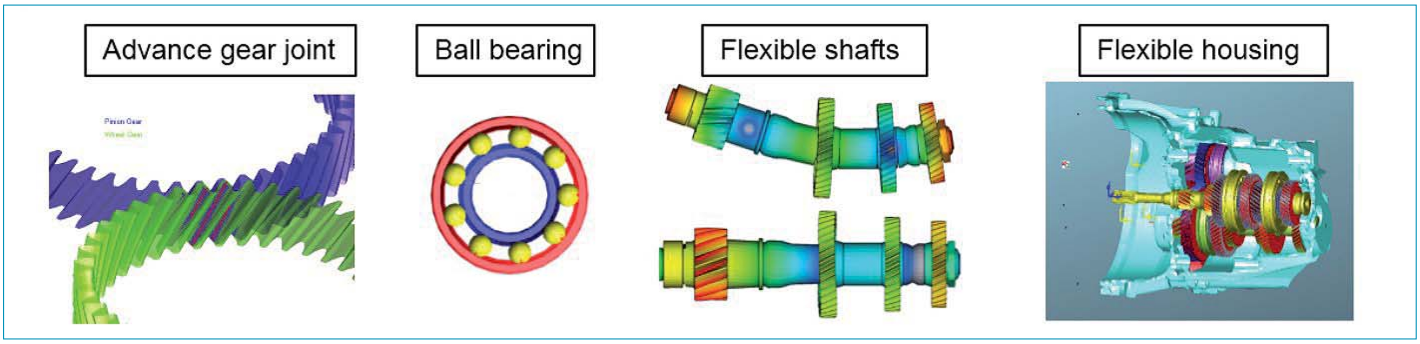


Figure 4: Accelerations on the surfaces indicating the gear meshing frequencies



used to define the criteria. However the transfer path and the radiating surfaces are also contributing to the perceived noise and cannot be excluded.

The outcome of the simulation for whine evaluation, are the transmission error and the gear flank forces, and ultimately the surface velocities on housing. A sample of surface accelerations can be seen in fig. 4 which clearly shows the gear meshing frequencies.

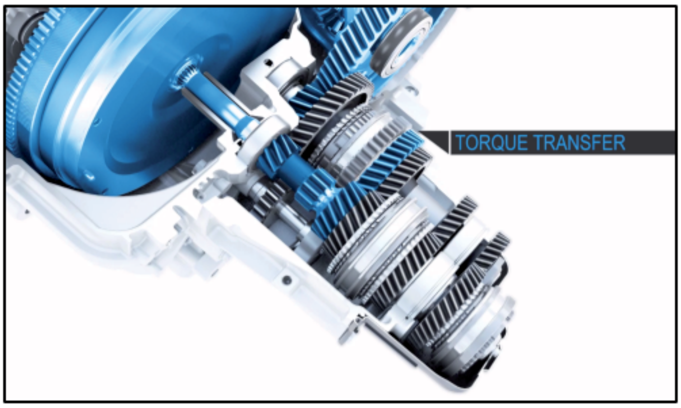
Different counter measures can then be used in sensitivity analysis to optimize the parameters, such as size of the shafts, bearings type, clearances, micro geometry, etc. to optimize the NVH characteristics.

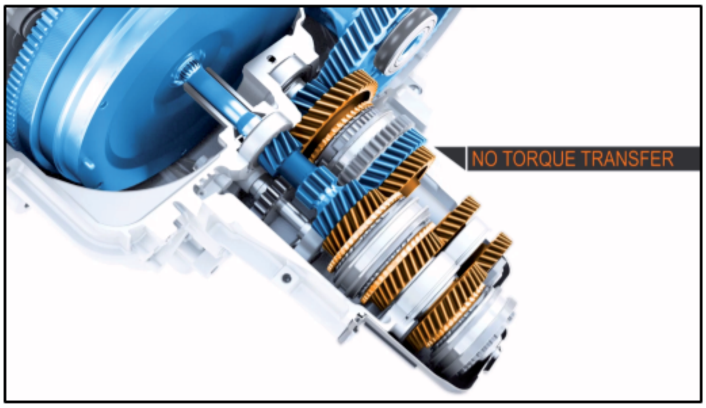
NVH optimization of the structure

One other measure toward NVH optimization is to target the radiating surfaces rather than the source. Optimizing the structure can lead to lower radiation efficiency and lower surface velocities, which can then lead to less perceivable audible sound. Therefore noise could be easily masked with other noise sources such as engine.

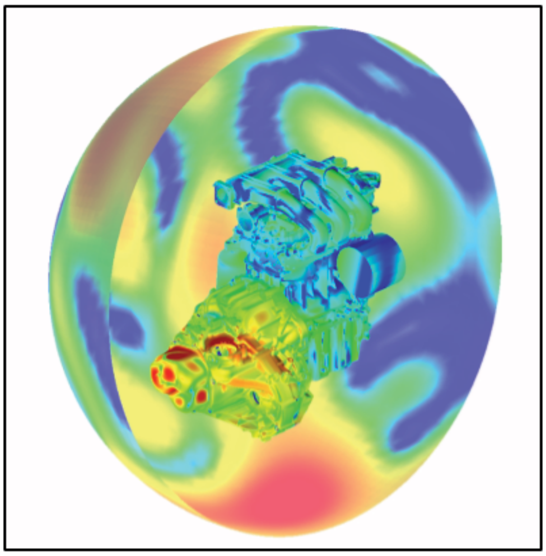
Discussion

Significance of transmission NVH is increasing with strict NVH targets. Defining the criteria for rattle and whine in early stage of the design can help solve these issues, but the CAE model is very demanding and simulation is not free of challenges. With reliable CAE models, optimizations are however achievable.





Loaded gears
Whine analysis



Free gear, for Rattle
analysis

PUNCH Powerglide's Vision of Hybrid Mobility

A Universal Hybrid Transmission for HEVs, PHEVs and E-REVs

Today, the Automotive industry is looking for hybrid transmission concepts with a lower number of gears and a single electric machine, in order to find a simple alternative to current parallel and power-split hybrid concepts.
PUNCH Powerglide is now introducing an enhanced hybrid concept that delivers three purely electric gears and five ICE gears.

■ Dipl.-Ing. Matthieu Rihn, Innovation and Intellectual Property Manager, Punch Powerglide Strasbourg S.A.S.

Hybrid market trends

The current hybrid vehicle market is divided into two main categories: the parallel hybrids (especially the P2 configuration) and the series or power-split hybrids.

The P2 hybrid consists of an adaptation of an automatic gearbox – usually 6 to 8-speed, adding a single EM (electric machine) on its input. This allows an existing product to be used for the hybridization of some vehicles, without requiring any specific system development. Nevertheless, the transmission might contain more material and gears than actually needed for an electrically driven vehicle. This solution is particularly suited to low-volume hybrid vehicle segments.

The series or power-split hybrid systems are much simpler from a mechanical standpoint. However, they consist of at least two electric machines and are therefore much less advantageous in terms of cost, weight and packaging.

This explains the recent trend towards original solutions for hybrid powertrains which usually require one single electric machine, two gear ratios dedicated to the electric driving and three to four gear ratios dedicated to the ICE (internal combustion engine) driving.

Despite all research efforts, the proposed configurations still have a large amount of mechanical material. The number of spur gear pairs or decks of planetary gearsets is sometimes greater than the number of speeds available for the ICE. The same applies to the number of clutches. As a reminder, automatic transmissions of the last generation are able to provide eight forward ICE ratios with not more than six clutches or four plans of gearsets. This lack of optimization results in additional cost, weight and drag loss. The packaging would also be impacted and such concepts would not be able to be fitted to existing vehicle platforms.

Furthermore, when the minimal battery SOC (state of charge) is reached, most of the proposed solutions will offer very limited performance with the use of the ICE only. For instance, some systems will provide only vehicle take-off on the electrical power. In concrete terms, this means that, in conditions of repetitive starts and stops as in a traffic jam, the battery will be continuously depleted to its minimal SOC. The only solution to insure the next take-off will be to reload very rapidly the battery by means of the ICE driving the electric machine as a generator, after each stop. Such a vehicle behavior may be very uncomfortable for the vehicle driver.

In short, whatever the battery load strategy, in real life driving, the vehicle driver will always face situations where the battery is not able to supply any more energy and where the ICE will be the only source of power. Systems with no more than three ICE gears, with low total spread and without any device allowing the vehicle take-off on ICE, will definitely not be able to provide any satisfactory solution regarding vehicle dynamics.

Finally, most of the proposed concepts are the answer to a specific category of hybrid (HEV, PHEV or E-REV) or to a given class of vehicle

(A-class, B-class...). This goes against all industrial logic since the target is to provide global and communized products that are flexible enough to meet the greatest range of vehicle market requirements.

Ambitious goals for OEMs needs

Having identified the technical issues, PUNCH Powerglide has defined the following requirements in order to carry out a new hybrid transmission concept research.

The system should provide at least 2 EM gear ratios for the use of a high-speed IM (induction machine) and a minimum of four ICE gear ratios with a total spread greater than or equal to 5. It should also allow the vehicle to start on ICE only, without launch performance loss vs. electric mode. All these functions should be achieved with a maximum of 5 coupling devices, including ICE starting element or disconnect system, and with a very compact planetary gear system. The concept should use one single EM whereas torque, speed and packaging should be compliant with induction motor, whose power and torque envelope would be adapted on demand to any kind of hybrid vehicle.

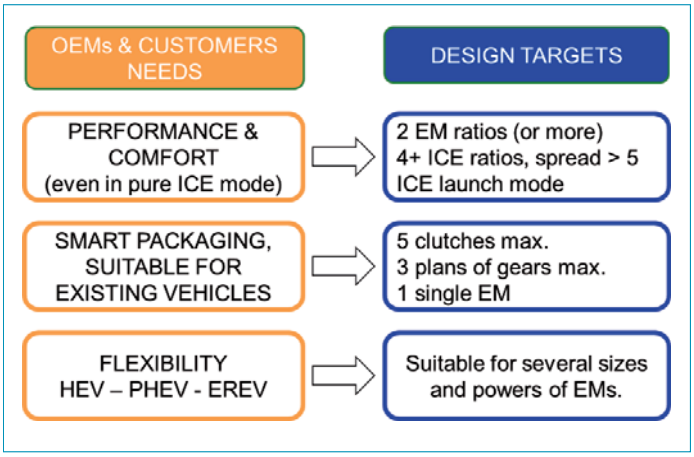


Figure 1: PUNCH Powerglide Integrated Hybrid design targets

PUNCH Powerglide concept: an 8-mode integrated hybrid

PUNCH Powerglide research process has resulted in two variants of a single powerflow.

The core element of the powerflow is a single Ravigneaux gearset, ie. two decks of planetary gearsets sharing a common planet pinion carrier, with a set of long pinions acting as a kinematic link between the two decks. It comprises two sun gears (S1, S2) and two internal gears (R1, R2); thus providing the advantage to offer many connection possibilities while being extremely compact.

The first variant of this powerflow was presented at the 2014 Berlin CTI Symposium. It provides 8 different modes including electric gears, ICE gears and EVT modes, while having only four clutches. However, ICE gears and electrical gears cannot be combined in a consistent way, leading to too low or too high EM speeds in the ICE ratios. This results into lower efficiency of EM boost and battery regeneration, and limitation of the maximal vehicle speed in the last gear.

These drawbacks have been addressed in the second powerflow variant depicted in figure 2. It includes five coupling devices that may be either multi-plate clutches or dog clutches. Three of them are brakes (C1, C23, C5) and two of them are dynamic clutches (C124, C345).

The ICE is linked to an input shaft that can be connected to the Ravigneaux gearset through the dynamic clutches (C124, C345) that act as disconnect clutches in case of pure electric driving.

The EM is permanently connected to the first internal gear (R1). An intermediate set of spur gears may be located between the EM and the internal gear R1. Thus, the EM can be arranged on an offset axis and its speed and torque ranges can be modulated through the adjustment of the intermediate gear ratio.

In comparison with the standard P2 configuration, the advantage of this concept is that the usual additional disconnect clutch is avoided, while keeping an acceptable number of electrical gears.

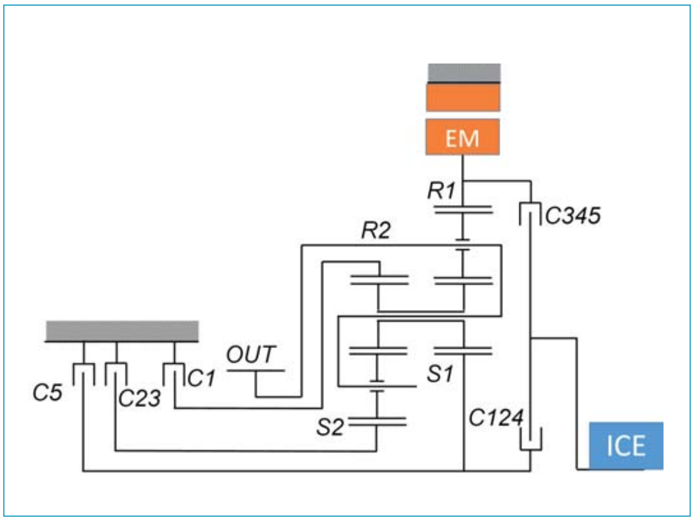


Figure 2: PUNCH Powerglide Integrated Hybrid Powerflow

Mode	Torque ratio	Spread	C124	C345	C23	C5	C1
E1-Rev	1,907						X
E2	1,290	1,478			X		
E3	0,701	1,840				X	
ICE1	4,031		X				X
ICE2	1,969	2,047	X		X		
ICE3	1,290	1,526		X	X		
ICE4	1,000	1,290	X	X			
ICE5	0,701	1,427		X		X	
	Total ICE spread	**5,75**					

Figure 3: 8-modes clutch actuation table

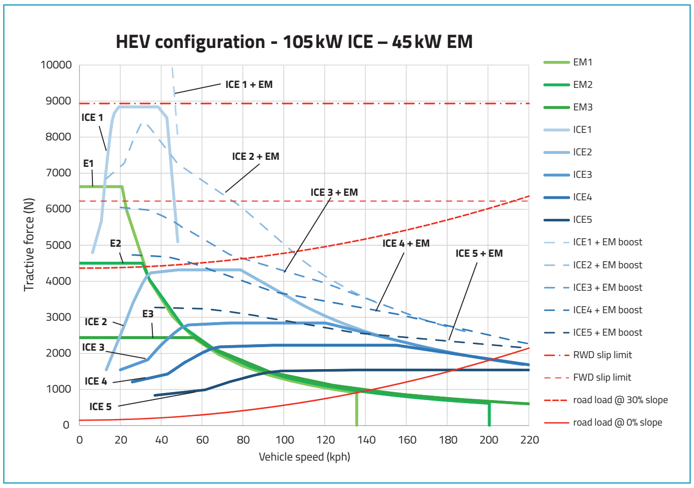


Figure 4: Performance and traction diagram

8 modes are available, including three EM gears and 5 ICE gears. They are activated by applying the clutches according to the clutching table depicted in figure 3. Ratio values are given for example and can be adjusted by changing the tooth counts.

In both electric and conventional driving conditions, any single upshift or downshift is performed "clutch-to-clutch", ie. without any torque interruption. To prevent the need for an ICE launch device at the transmission input, clutch C1 is used as a vehicle launch device in ICE1 gear.

Shift and hybrid strategies

Different shift and hybrid strategies are possible, depending on the battery SOC.

If the battery load is over the minimal SOC, the vehicle can be launched in E1. Then, the transmission shifts into E2, and into E3 as the vehicle speed increases. From any of the electric gears, it can also shift into an ICE-ratio that shares the same brake. For example, from the electric mode E1, the transmission is able to shift directly to ICE gear R1, as both E1 and ICE1 use the C1 clutch. Only the dynamic clutch C124 needs to be applied to connect the ICE. Similarly, from E2, the transmission is able to shift into ICE2 and ICE3, keeping C23 applied and applying C124 or C345. E3 and ICE5 also show the same kind of compatibility.

All these shifts can be performed without any torque interruption as they only require a single clutch transition.

If the battery load is below its minimal SOC, the launch occurs in ICE1, using the clutch C1 as a starting clutch for launching the vehicle under the action of the ICE. Successive upshifts to ICE gears ICE2, ICE3, ICE4 and ICE5 can be performed without any torque interruption.

Depending on the embedded electric power – i.e. the EM power and the battery storage capacity – some different strategies of electric driving may be used. With a HEV (full hybrid) configuration, ie. without any possibility of external reloading of the battery, the pure electric driving via E1, E2 and E3 will be used to launch the vehicle and for low speed conditions only. Boosting and regeneration will be possible when ICE gears are used for conventional driving.

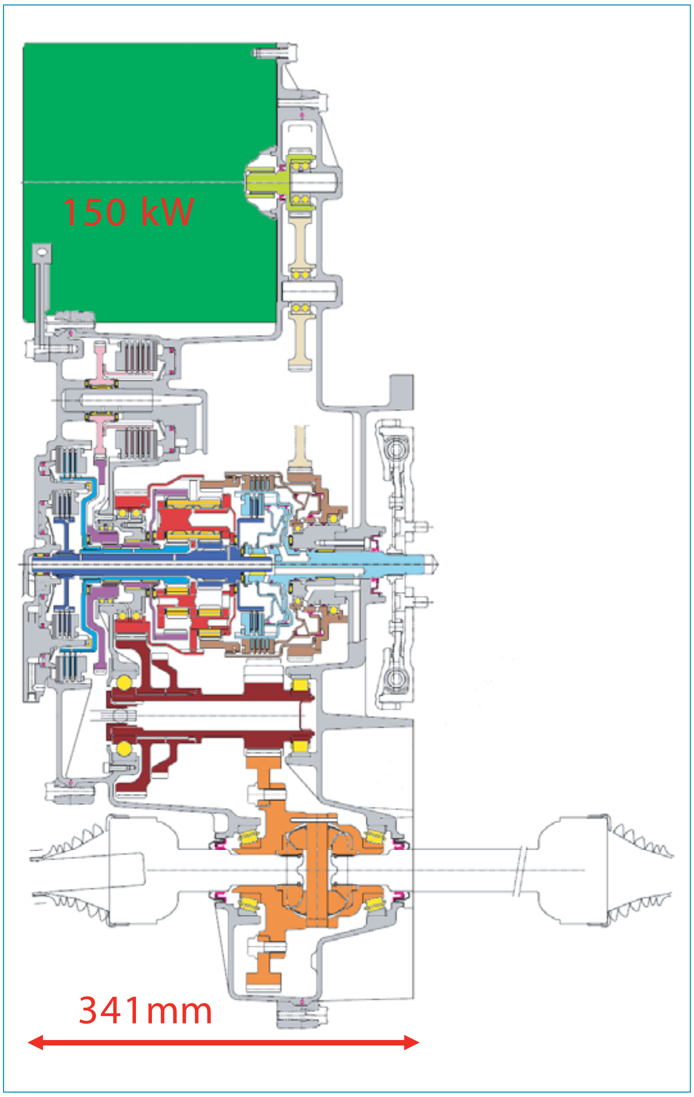


Figure 5: Cross-section with a 150 kW EM

A PHEV configuration, with higher embedded electric power, will allow pure electric driving in cities. All speed conditions under 60 km/h will be performed by pure electric driving in E1, E2 and E3, making of the PHEV a zero emission vehicle in urban areas, as long as the battery remains above its minimal SOC. The ICE gears will be dedicated to extra-urban travels. The AER (all electric range) in city will depend on the battery storage capacity.

An E-REV configuration, with electric power higher than ICE power, will allow pure electric driving most of the time. The ICE gears will be used to boost the EM power and to sustain battery charge in extra-urban travels. This is made possible by the good match between the ICE and EM gears.

Such a transmission architecture also allows the ICE to be started with the EM: when the vehicle is at standstill and ICE stopped, C345 is

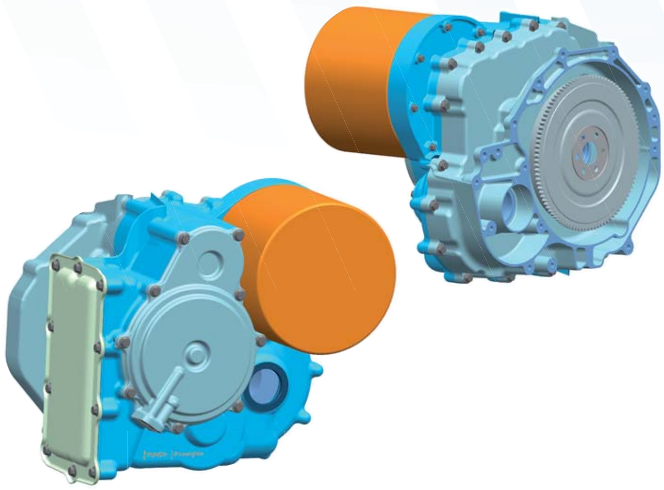


Figure 6: 3D model with a 150 kW EM

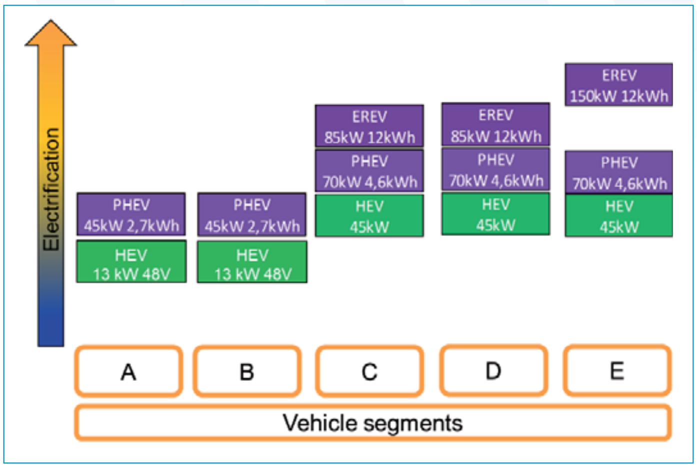


Figure 7: Flexible deployment strategy

applied, establishing a connection between the ICE and the EM. If all other clutches are released, the EM can then drive and start the ICE, without any impact on the transmission output. When the vehicle is driven in electric mode, the ICE can also be started by controlling the application of one of the dynamic clutches.

These functions avoid the need for the conventional 12V starter (and possibly for the alternator).

Performance and flexibility

Fig. 4 shows the traction force that can be reached in each mode for the Full Hybrid example. The maximal affordable traction force is provided by the ICE1 and is far beyond the wheel slip limit for a front wheel drive vehicle, even reaching a rear wheel drive slip speed limit. The maximal electrical traction force is provided in E1 and exceeds the front wheel drive slip speed limit.

Detailed design study

A cross section study has been carried out for respective envelopes of 150 kW for the EM and 150 kW / 300 Nm for the ICE.

Clutches are fitted with spacer springs between the plates to reduce the drag loss.

The EM is put on an offset axis and, with the fact that no launch or disconnect is needed, the total length obtained does not exceed 341 mm.

Smaller and less powerful EMs may be adapted to the same transmission. With such a flexible strategy, PUNCH Powerglide integrated hybrid system will be able to cover all the car segments and all the levels of hybridization, from the mild hybrid to the EREV and for powers from 13 kW (48V systems) to 150 kW.

Outlook

First reactions, e.g. at the CTI Berlin Symposium, were encouraging. PUNCH Powerglide is therefore going further on this research project and is ready to share its findings with future partners. The next step will be a partnering for a joint development.

If taken further, the next hybrid car generation could be based on a single automatic transmission offering highest comfort to the customer and an economic, scalable solution for the OEM for its entire fleet of hybrid vehicles.

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Market and prospects for transmission semiconductors

Recent Transmission Designs Turn into good Business for Semi-conductor Suppliers

In this article, IHS looks at the semiconductor content of passenger car transmission system control units and sensors and discusses the impact of recent designs like the dual clutch and continuous variable transmissions on semiconductors and sensors. IC and sensor suppliers report that these systems are helping to drive their business forward.

- Dr. Richard Dixon, Principal Analyst MEMS & Sensors, IHS
- Ahad Buksh, Analyst Automotive Semiconductors, IHS

Automatic transmissions, particularly new designs, drive semiconductor content

While automatic transmissions have represented the mainstay of the transmission semiconductor market for many years, relatively recent designs like the dual clutch transmissions (DCT) and continuous variable transmission (CVT) are expanding the deployment of electronic components, namely sensors and semiconductor ICs.

Market overview

Clearly, the electronics value of automatic transmissions varies with tier 1 design philosophy, market preferences of the region, prevailing emissions standards, and so forth. That said, a typical transmission control unit (TCU) comprises several $10s of semiconductor IC content, even without consideration of the sensor value.

Taking these factors into account, IHS forecasts that the market for sensors and transmission-related semiconductor ICs will exceed $ 1.75 billion in 2021, up from $1.55 billion in 2014 (see figure 1) – a CAGR of 2.1 %. Beneath this growth are several smaller but high growth systems like DCT and CVT, and established applications that do not grow semiconductor revenue and even shrink, like standard automatics. Note that shipment growth is around 3 % over the same period. The difference in growth rates reflects the commoditization of components in the forecast period.

Picking the right application: DCT

Market maturity of standard automatic transmissions combined with commoditization of staple components like analog ICs and discrete devices in TCUs are the order of the day. These components essentially do not change.

Most new growth, then, stems from the demands on micro-controllers (MCUs), especially as a result of increased sensor content that is a feature of DCTs and CVTs. The share of semiconductor content in these various systems is shown in the figure 2.

DCT drives electronics content

Control units used in DCTs are the most intelligent in the market – the TCU handles a high number of (sensor) inputs compared to other transmission designs, and DCTs are the fastest growing in terms of transmission design.

This explains the rapid growth in semiconductor demand for DCTs, a value of $ 374 million by 2021, up from just $200 million last year – a CAGR of 9 %.

A DCT would typically have between 8–12 actuators depending on the design type. Some of these are used by solenoid, motor, pressure switches, hydraulic filler elements, valves for hydraulics of transmis-

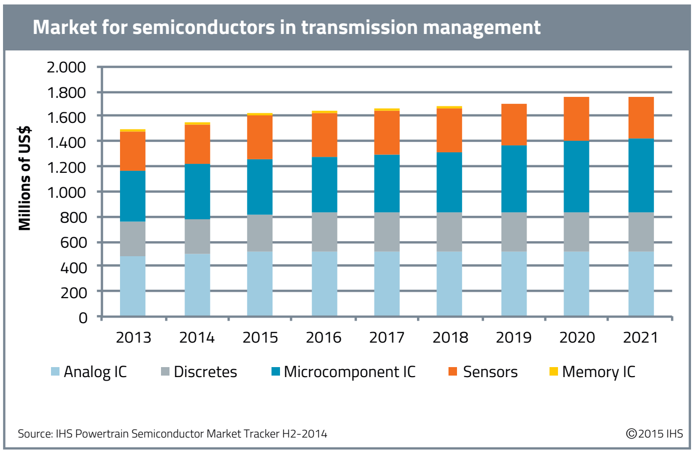


Figure 1: Market for semiconductors in transmission systems (IHS)

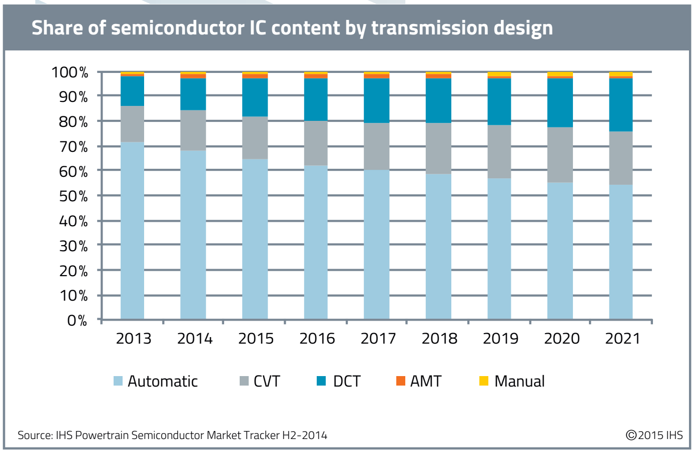


Figure 2: The share of semiconductor IC content increases in CVT and DCT designs

sion and valves for gear changing. Actuators have to be controlled electronically, which is where low- and high-side driver ICs and MOSFETs are required. In addition, a half-bridge driver IC drives the current for the hydraulic pump.

Continuous variable transmissions show modest growth

The semiconductor market for CVT will hit $378 million in 2021—equating to a more modest 5.4 % annual growth. China, South Asia and eventually North America markets will drive these transmissions.

The TCU of a CVT controls the belt clamping force that joins the two pulleys, by estimating optimal rotation speed rpm and selecting the most suitable transmission gear ratio, a ratio that relates to acceleration demand from driver. Power supply ICs are needed to make sure the system works optimally.

Standard automatics stagnate

An automatic transmission features sensor inputs, processing to receive and process the data, and actuators to perform resulting actions. These processes are handled in a TCU that pairs with an engine control unit (ECU). The TCU has the following...

- A 32-bit MCU for processing
- Analog ICs and discrete semiconductors
- Memory ICs

The content of this TCU changes very little. The main variation is the size and value of the MCU, which is in turn dependent on the number of sensor inputs.

For this reason, the market for semiconductor ICs and sensors in standard automatic transmissions is expected to decline in the coming years, ending at $ 952 million in 2021. This is largely due to a replacement by the newer, popular DCT and CVT systems.

Changes in MCU landscape

MCUs are mostly always 32-bit. Currently, and depending on customer safety requirements, the TCU inputs are controlled by a sole 32-bit single-core MCU and one 16-bit MCU.

But with the increase in functional safety demands and ASIL compliancy, future MCUs will feature more expensive 32-bit multiple-core MCUs. The MCU embedded memory will also expand as a result of a higher number of forward speeds, clutches and actuators.

Most of the transmission-related MCUs have 1–2 MB of embedded memory, but IHS anticipates that this value will grow to 4 MB in the next 5 years.

Aside from MCUs, low-side driver ICs control the speed signals, and high-power MOSFETs and the associated high- and low-side driver ICs switch the solenoids. LIN and CAN transceivers communicate with ECU and other applications.

As to who makes these ICs, Renesas is the largest supplier of MCUs and logic ICs worldwide. Freescale is another major supplier, along with Infineon, which is also a key producer of power ICs. STMicroelectronics is the lead supplier of analog ICs. Memory ICs are offered by the likes of Micron and Spansion.

Role of sensors in transmission

Sensor suppliers often cite transmission as a major evolution area. Multiple sensor inputs are needed in a standard automatic...

- Speed sensors on both input and output shafts (though input speed can be supplied by crankshaft, e.g. in some BMW designs).
- One or more temperature sensors
- Pressure sensor (usually 0 or 1)
- "Kick-down" sensor under the accelerator pedal to allow changes of more than one gear ratio on acceleration.

- Gear selection (PRNDL) and/or operation mode control for sport, eco-mode, etc. that necessitate switches. These so-called transmission range switches (TRS) contain a number of position sensors – usually Hall ICs – to determine the user selection.

Note that manual transmissions typically have no sensors. The exception is neutral gear positon needed in a car with a stop-start system.

In contrast, a DCT features many more sensors than a standard automatic shifter. VW's 7-speed Direct Shift Gearbox (DSG) has up to 12 sensors inside, not including the TRS switch. The DSG comprises 2 pressure sensors to monitor the wet and dry clutches, in addition to clutch oil pressure, temperature sensors for the control module and transmission fluid.

A sensor is used to identify the position of each of 4 forks with permanent magnets. Speed sensors are used on the two drive shafts of the dual clutch: on the driveshaft (or input shaft) 1 for 1st, 3rd and reverse gears, and another on driveshaft 2.

The DCT gear selector switch (transmission range sensor) has additional individual Hall ICs to indicate position of the gear dictated by the user. A metal plate with magnet attached to the end of the gear shifter moves past a row of 7 Hall ICs, but note that the design of individual TRS switches at transmission manufacturers varies widely.

Hall sensors are not the only available technology for position, as potentiometers and other inductive type technologies (e.g. Permanent magnetic Linear Contactless Displacement Sensors, patented by TE Connectivity) are in use. However, Hall represents the dominant measurement principle in use for the tough environment of a transmission.

Suppliers of Hall sensors for these applications include Allegro Microsystems, Infineon and ams for speed sensors, Melexis and Micronas for position, TDK for temperature ICs, and Sensata, Bosch and Denso for pressure sensors typically operating in the range of 20 – 70 bar.

Conclusion

While automatic transmissions are a staple of electronic demand, semiconductor and sensor suppliers look to the newer designs to propel faster growth (5 – 9 % annually for the next 6 – 7 years) to fuel their next wave of sales in transmission electronics.

Notes: Data in this article come from the following IHS datasets and reports:

Powertrain semiconductor market tracker H2 2014
Magnetic sensor market tracker H2 2014
Automotive MEMS market tracker H2 2014

Introducing: The Revolutionary ARC Actuator

Kongsberg Automotive Actuator Boosts 'By Wire' Solutions in Auto Transmissions

Kongsberg Automotive has just launched its Actuator Rotary Compact (ARC) actuator that opens up 'By Wire' solutions for OEMs and transmission manufacturers. There is a lot of discussion and focus on By Wire solutions in new powertrains. 'Shift By Wire' (SBW) has increased its market share significantly over the last years and is likely to continue along the same upward trajectory ahead. History shows annual growth rates above 15 % and expectations are that this will continue for the foreseeable future.

■ Staffan Spethz, Global Marketing Manager, Kongsberg Automotive

No new gearbox required

One of the challenges facing By Wire technology is that a new gearbox is typically required, driving development costs prohibitively high. However, by installing the ARC actuator this huge cost is avoided outright as there is no need for a new gearbox to enable the SBW system.

Redefining performance standards

Moreover, the ARC Actuator sets a completely new standard on the market when it comes to performance:

- Best in class packaging
- Low weight (420g)
- Higher forces (18 Nm)

The ARC actuator is designed to meet market requirements in performance, quality, safety and availability. Furthermore, it features a modular design enabling customer to choose unique mounting features, customer specific output shaft interface, and type of the connector, among others. The safety and availability aspects always need to be

Figure 1: Kongsberg ARC Actuator

Figure 2: Kongsberg Generic Shift By Wire CMG2

considered, which is why we have invested and dedicated considerable development time and resources to this important area.

ARC is a robust solution that helps OEMs as well as Tier1 gearbox manufacturers to implement a robust and safe shift by wire solution for the future. In addition, Kongsberg Automotive also offers a generic SBW solution for the shifter in the car, providing a "one stop shop" for shift by wire systems.

Kongsberg has delivered shifter by wire shifters to leading OEM's since 2007 with an excellent reputation and to the highest quality standards. To meet the ISO 26262 is a challenge for the whole industry; however Kongsberg Automotive has everything in place and meets all the requirements for a shift by wire system.

New opportunities to enhance the driving experience

Kongsberg Automotive's mission is to enhance the driving experience and our ARC technology serves this mission well. Indeed, our technology in shift by wire opens up for wider selections of HMI designs as shifters do not need to be in between the front seats, but can be moved up to the dashboard or wherever customers may want to place it (albeit within safety constraints). Alternative shifter designs as push buttons, rotary, joystick are simply not possible without by wire solutions. Also, for the longer term with autonomous driving, auto parking and active safety system require this type of by wire system behind.

High-Performance Polymers Assume Broader Role in Challenging Powertrain Applications

by Brian Baleno and Brian Stern, Solvay Specialty Polymers LLC, USA

Today's powertrain is designed for high efficiency and must comply with tougher corporate average fuel economy (CAFÉ) regulations and stricter CO_2 emission standards while also providing the consumer with a "fun-to-drive" experience at high levels of comfort and safety, albeit at a lower cost.

This high level of powertrain performance is dictated by new technology and innovative design enhancements. Lower displacement, turbocharged engines operate at higher RPMs and weight reduction requirements permit less mass and less design space. Yet further cost reductions, mass reductions, and space reductions are required to provide room for active transmissions that incorporate hybrid and electric drives.

High-performance plastics – known for their mechanical and thermal properties – are a proven entity in transmission applications because of their unique ability to reduce weight and cut system costs through parts consolidation and the elimination of secondary operations such as machining, welding, or painting. Metal-to-plastics conversion also provides additional benefits including chemical resistance, thermal insulation, electrical properties, and better sealing. Other advantages include improved aesthetics; lower noise, vibration, and harshness (NVH); design freedom (3-D shapes); and improved functionality.

Figure 1: Semi-aromatic polyamides such as PPA are improving the efficiency of the drivetrain by means of electrification for transmission applications such as solenoid components.

For powertrain, a core group of high-performance polymers are meeting the challenges of reducing CO_2 emissions while also delivering key performance and cost benefits. Solvay Specialty Polymers, one of the world's leading suppliers of high-performance plastics, offers a broad portfolio of materials that includes semi-aromatic polyamides like Amodel® polyphthalamide (PPA) and Ixef® polyarylamide (PARA); aromatic polyketones such as KetaSpire® polyetheretherketone (PEEK) and AvaSpire® polyaryletherketone (PAEK); polyamide-imide (Torlon® PAI); polyphenylene sulfide (Ryton® PPS); and fluoroelastomers like Tecnoflon® FKM.

Semi-Aromatic Polyamides in Electrification

The electrification of the drivetrain reduces parasitic pump loss and also decreases frictional loss by optimally matching the engine RPMs with the optimal gear speed. Semi-aromatic polyamides such as PPA are improving the efficiency of the drivetrain by means of electrification. Amodel® PPA is used in electronic transmission applications such as bobbins, solenoids, electronic control unit housings, and sensors. Solvay recently introduced its new Amodel® AE portfolio, specifically designed for automotive electronic applications. The Amodel AE product family was developed to eliminate corrosion issues in high-temperature, high-humidity environments.

In addition to electrification, drivetrain designers are focused on the weight reduction of components such as transmission spacers, shift levers, gear selectors, fork reverse gears, gearbox protectors, and slave clutch and master cylinders. A variety of Amodel® PPA grades can be used depending on the operating conditions of the given components. Amodel® A-8950 HS is preferred for replacement of many

Figure 2: Engineering plastics have also made strong inroads in seal rings for clutch components for automatic transmissions. (Courtesy of Saint-Gobain Performance Plastics L +S GmbH)

Figure 3: Transmission parts such as thrust bearings are increasingly being made of high-performance plastics such as PAI and PEEK instead of metal for light weight, design flexibility, improved wear resistance, and space savings.

semi-structural metal casting parts. This 50 % glass-reinforced grade provides high-heat deflection, excellent creep resistance, and high tensile properties including a tensile modulus of 19 000 MPa, tensile stress at break of 275 MPa, and tensile strain at break of 2.1 %.

Plastic Seal Rings and Thrust Bearings Take Off

High-performance thermoplastics have also made strong inroads into seal rings for clutch components for automatic transmissions. As transmission designers increased the number of gears for automatic transmissions (AT), pressure and velocity requirements of AT and dual-clutch transmissions (DCT) also increased, generating higher temperatures due to frictional heat. The operating environment requires materials with a high glass transition temperature (Tg) such as Torlon® PAI and KetaSpire® PEEK, which can operate at elevated temperatures and withstand a high PV environment. These materials also optimize seal ring design which results in operational improvements including a reduced leak path via the joint. Today, Torlon® PAI is used in more than 90 % of the seal rings for dual-clutch transmissions.

Meanwhile, thrust bearings made of high-performance polymers can bring several benefits to the powertrain engineer. These challenges include reduced design space, reduction in NVH, thermal insulation, reduced coefficient of friction (COF), and improved wear resistance.

High-performance thermoplastics can help reduce energy loss by managing and reducing the COF. The Stribeck curve is commonly used by tribologists to predict the relationship between the COF and ηN/P where η is the dynamic viscosity, N is the speed (rpm), and P is the pressure. Often, three regions of the curve are predicted and demonstrated. At low ηN/P, a boundary layer lubrication is predicted which leads to a high COF (high energy loss). This regime is similar to results under dry conditions where high COF exists, along with high temperatures and high wear. At high ηN/P, hydrodynamic lubrication is predicted which leads to very low COF. The transition between the two regimes is called the mixed film lubrication region.

Figure 2 shows a modified Stribeck curve for axial thrust bearings made from PAI and PEEK. The three regions for the Stribeck curve are shown. As demonstrated here, using these materials under appropriate conditions can yield an extremely low COF, approaching the COF of needle bearings. High-performance polymers such as PEEK and PAI are often preferred over standard materials to support boundary layer conditions where temperatures of the polymer/counter surface interface can often exceed 150 °C.

Thermoplastic thrust bearings can be also designed to significantly reduce design space, resulting in an average 2-mm space savings per needle bearing, providing the opportunity to reduce the size of the aluminum casing, thereby resulting in a significant weight reduction which leads to a further CO_2 decrease.

Thermoplastic thrust bearings can be injection molded into complex shapes, thereby eliminating costly secondary operations such as machining. This provides a very high degree of design flexibility and freedom. Features such as axial locking can be incorporated at a minimal additional cost. Finite element analysis (FEA) can be used in the design phase to analyze various features. When properly designed, thermoplastic thrust bearings typically result in a significant cost savings over metal bearings.

High-performance plastics have also replaced metal in check ball applications. PAI is an effective metal replacement option that delivers outstanding compressive properties, improved compliance/sealing, lighter weight for quicker response, reduced noise, and no scarring of the counter surface.

Breakthrough Powertrain Component for GM

An innovative thrust bearing product was co-developed by Solvay and Freudenberg-NOK Sealing Technologies for a General Motors powertrain application. The innovative High-Load, High-Shear Geared Axial Polymer Thrust Washer (HLHS GAP Thrust Washer) was designed and manufactured for General Motors' 2014 Hydra-Matic 8L90 8-speed transmission.

Solvay's Torlon® 4275 PAI, a wear-resistant grade, was selected because of its exceptional capabilities including outstanding friction and wear performance at elevated pressures and velocities. Torlon® PAI has the highest strength and stiffness of any thermoplastic up to 275 °C. It has outstanding resistance to wear, creep, and chemicals – including strong acids and most organics – and is ideally suited for severe service environments.

The thrust washer is attached to the sun gear of an automotive transmission and pushes with the sun gear against the needle bearing. PAI

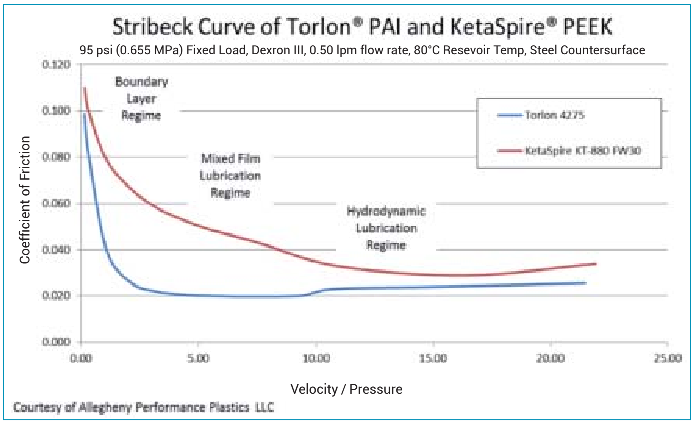


Figure 4: A modified Stribeck curve for axial thrust bearings shows that under the right conditions, very low COFs are achieved.

Figure 5: Torlon® 4275 PAI, an unreinforced, wear-resistant grade, was selected for an innovative thrust bearing product for a General Motors powertrain application.

was able to withstand the load applied by the planetary gear set, allowing the needle bearing to operate with high efficiency.

The original thrust washer design composed of sintered metal was found to be heavy and costly. Switching to aluminum appeared to solve OEM concerns; however, the aluminum components began to fail critical durability testing. Compressive creep of the aluminum was associated with the high stress on the part while the fretting was associated with cyclic shear and torque.

The HLHS GAP Thrust Washer program provides both a template and benchmark for future component program success and opens opportunities for continued metal replacement in powertrain applications.

PPS Targets Connectors and Pistons

Solvay's Ryton® PPS, which was recently acquired from Chevron Phillips Chemical Co., is another key material option that delivers performance advantages in a range of transmission applications. In electrical connectors, PPS has excellent chemical resistance to a range of transmission fluids. It also provides low moisture absorption along with low creep and reduced coefficient of linear thermal expansion (CLTE) in high-temperature environments.

Figure 6: Shaft seals made of fluoroelastomers provide low swell properties, excellent heat stability, and strong compression set resistance.

For transmission accumulator pistons, Ryton® R-7-120 is an excellent metal replacement option due to its dimensional stability, low creep, strong cyclic fatigue resistance, and low CLTE over a wide temperature range. The material is recognized for its part-to-part consistency in molding.

Fluoroelastomers Provide Sealing Solution

Powertrain component manufacturers have adopted a zero-leak policy in pursuit of strict quality and customer satisfaction goals. The physical size and weight of the transmission has become smaller while the typical number of gear speeds has increased from the previous norm of 4 or 5 to now 8, and up to 10(+), resulting in increased operating temperatures. In addition to the evolving mechanical design of the transmission, the hydraulic fluids themselves have also undergone their own evolution. New generation fluids are progressing toward 100 % synthetic base stocks containing advanced additive packages designed to ensure greater stability and longevity in an ever-widening service temperature range.

Compared to traditional hydrocarbon or silicone-based elastomers, Tecnoflon® FKM fluoroelastomers are uniquely designed to meet the sealing challenges of current and new generation powertrain components. Their low swell properties, excellent heat stability, and superb compression set resistance provide the ability to maintain excellent long-life sealing over the entire operating temperature range. For example, Tecnoflon® VPL materials demonstrate high temperature and fluid resistance properties comparable to 70 % fluorine FKM, but with a glass transition temperature as low as –45 °C, thereby surpassing the performance of all other low-temperature fluoroelastomers available on the market today.

Overall, the unique capabilities of high-performance polymers make them a preferred material of choice for many powertrain applications including bearings, alternator components, pumps, and compressors. With a diverse property profile, they continue to answer the challenge by helping automakers and tier suppliers meet weight reduction and low-friction requirements while complying with tough CAFE regulations and stricter emission standards. For more information, visit www.solvayspecialtypolymers.com.

Increase loads on gear material up to or above 100 %

Advanced Engineering Steel – the new Lightweight Alternative

How choosing the right material properties opens up for increased power density, freedom of design and reaching future CO_2 legislations

- Lily Kamjou, Senior Specialist Powertrain, Industry Solutions Development, Ovako
- Erik Claesson, Director, Industry Solutions Development, Ovako
- Patrik Ölund, Director, Group R&D, Ovako

The wheel bearings on a high speed express train or the rotor of a giant wind turbine must withstand massive and complex loads. The diesel fuel injector in a modern engine must continue to perform reliably for billions of cycles under increasingly high pressures, driven by the quest for fuel economy. Popular, eco-friendly, start-stop technology for cleaner city air, puts enormous stresses on injection systems, with maximum pressures reached every time the engine starts. Critical applications such as gears and axles in transmissions are increasingly expected to be lighter, stronger and capable of handling more power, while loads are becoming more and more complex. These are some of the challenges materials are facing today.

As well as demanding a steel with excellent mechanical and fatigue strength in all loading directions, weight is an increasingly important factor in these critical applications. And with fatigue accounting for around 90 % of all mechanical service failures, the potential benefits of steel that can handle these increasingly complex demands in an economical way, are considerable.

Figure 1: Complex gear loading yielding a contact stress on the flank and bending stress in the root.

Today, a fragmented supply chain has cemented a structure where focus is on price and existing material standards, mainly through lack of communication with end-users. Potentially missing out on the possibilities that choosing a fit for purpose material can offer. This is probably one reason why high volume steel components are still made according to old material specifications. There is a real possibility to make use of the best technology available through multilateral discussions with selected non-competing stakeholders along the supply chain.With an increasing need for space under hood to make room for other space competing systems in order to help reach CO_2-legislations; lightweight materials such as advanced engineering steel, open up interesting opportunities.

Looking at aspects such as fuel economy, total cost of manufacturing and energy consumption in combination; it is easy to see that a more holistic approach can be clearly beneficial for all stakeholders along the supply chain.

Current and future demands

Improvements in steel cleanliness result in big design opportunities. That is good news for any designer who has relied on old standards, when in fact modern steel practices have opened up for a new level of performance. Thanks to the properties of BQ-Steel (Bearing Quality Steel) and IQ-Steel (Isotropic Quality Steel), which now close the gap to remelted steels, it is now possible to downsize your gears, bearings and other steel parts to meet new requirements. For instance, a gearbox can be made lighter, with higher power density, by using cleaner steel.

With current and future generations of transmissions evolving towards higher loads as well as weight reduction; the material needs to support the step changes taking place, instead of being a limiting factor. Better performing materials that can handle the higher stresses, means loads on gear material can be increased from 30 % up to or above 100% depending on starting point, thus providing new design opportunities. And with an innovative steel design, costly and undesirable processing steps such as shotpeening, could even be eliminated.

Not only is there a need to meet new regulatory requirements, but steel parts need to keep on going virtually forever. When selecting the right steel quality for high-load applications, it is not always easy to know all the functional properties as well as the cost and quality implications. It is important that suitable test and inspection methods are used to ensure that the material fulfills the desired

requirements. More precise methods, compared to the commonly used international standards should be applied. In fact, such methods are already implemented for steel in highly stressed diesel injection components.

From experience it is known that defects such as non-metallic inclusions will initiate fatigue failures. Ovako has focused very much on

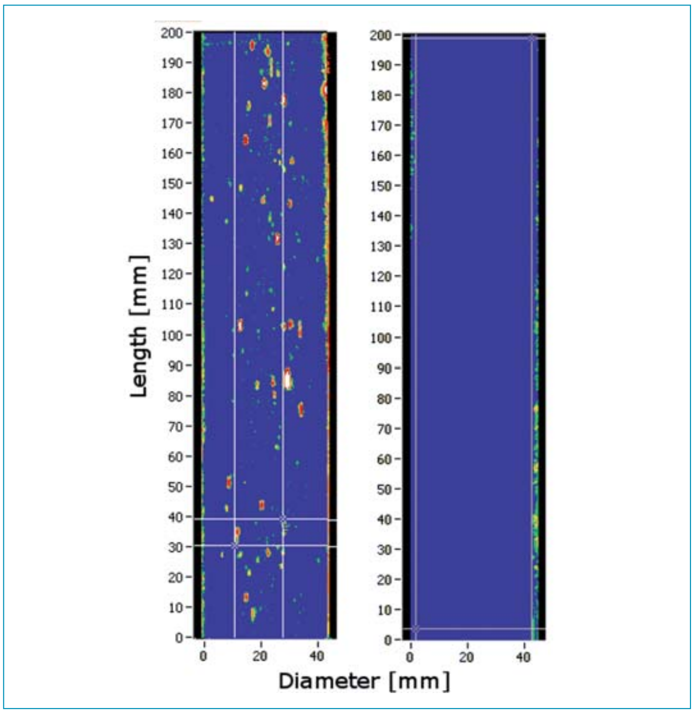


Figure 2: Comparison conventional steel (left) vs BQ-Steel (right) – fit for purpose demands/specifications (10 Mhz UST image)

fatigue research and now have an impressive database with fatigue data. We know and can show that the steel quality has a huge impact on the fatigue life of a component. Consequently a clean steel contains smaller sized defects compared to a conventional steel.

BQ-Steels are a range of high cleanliness steels with reduced defect size. The effect of reduced inclusion sizes in BQ-Steel makes it possible to obtain weight reduction on existing generations of end-user systems. Moderate design changes can also be made while securing

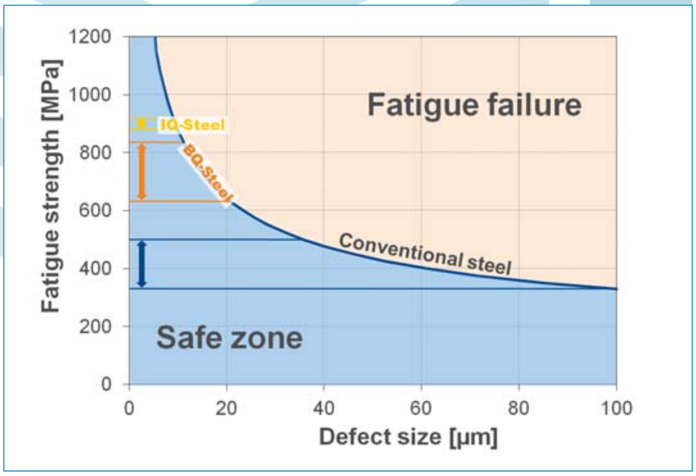


Figure 3: Relation between defect size and fatigue strength

high and consistent quality level for the end-user products. BQ-Steel is normally the first step when upgrading from conventional steel.

IQ-Steels are a range of isotropic, clean steels, designed to have small and isolated inclusions. The small and even sized inclusions creates the isotropic properties that can withstand heavy loads in all directions and therefore makes it tailor-made for complex load cases.

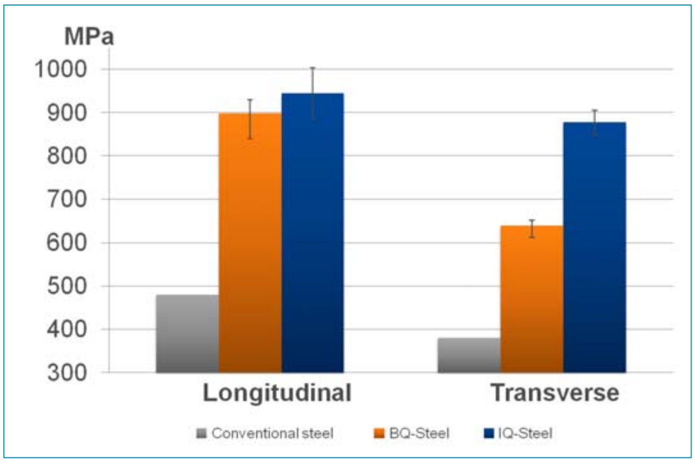


Figure 4: Rotating Bending Fatigue of conventional steel compared to BQ-Steel and IQ-Steel in both longitudinal and transversal direction.

So why a need for BQ- or IQ-Steel? With the increasing demands in the automotive industry for weight reduction, fuel efficiency and reducing carbon footprint; using advanced engineering steels makes it viable. Up until now, conventional steels widely used, have lived up to expectations. However, with more stringent emissions standards, demands on material are increasing. Materials are expected to perform better, resulting in a need for increasing the fatigue strength. Increasing torque on current generations without design changes can be done by selecting suitable materials.

Taking an overall approach and looking at the whole value chain and production steps, what can using the right steel do? As an example, Ovako has developed a case hardening steel grade specifically for gear applications, which combines high cleanliness with improved surface properties. Compared to commonly used conventional carburizing steels, where surface enhancing processes such as shot peening are often required to achieve favorable surface conditions, this material performs just as well without costly and time consuming extra production steps. Initial contact and bending fatigue testing indicates that the un-peened material exhibits the desired properties without further improvement.

Machining of clean steel

Quantitative trials support the feasibility of machining ultra clean steel. The key is optimization; finding the right set up for this type of material. It has been shown through testing done in collaboration with manufacturers of powertrain components and tooling, that producing gears according to current processes (such as turning and milling) can be achieved with cost neutrality or in some cases even at reduced cost. By simply changing inserts to a more modern technology; ultra clean steels machine just as well, if not better, as conventional steels. One important factor is the consistent quality of the material; that the variation delivery to delivery, is very low. Correspondingly, ensuring a more advantageous microstructure than the uneven but standard ferritic perlitic structure, together with smaller inclusions that don't interfere in an adverse way, leads to a stable machining process.

In summary

Upgrading the steel quality for gears can create real value.

- Increased loads through fatigue improvements in the order of 30 % up to or above 100 %
- Torque increase in existing system design
- Creating new design opportunities for further increase in power density
- Making space for other systems in the vehicle, for example increased hybridization
- Eliminating or considerably reducing costly production steps such as shot peening
- Reducing total cost of manufacturing in machining processes through using steels with low scatter combined with more efficient tooling solutions

All this is supported by a more efficient collaboration in the value chain that will contribute to shorter lead times in getting to "Go" or "No Go" in critical issues.

More information please visit
www.ovako.com/rightsteel

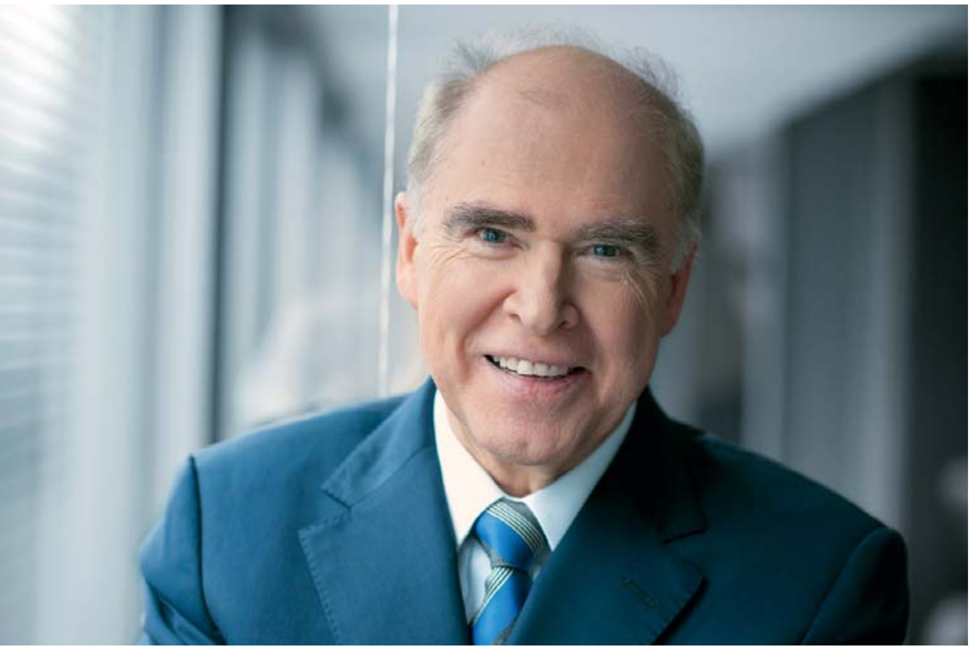
Interview

"Every Transmission Developer Needs to Understand the Entire Powertrain System."

In recent years, the industry has realized that treating engines and transmissions separately is not the way forward – especially with hybridization leading to new powertrains and higher functional complexity. At the CTI Symposium in Berlin, 8–11 December 2014, we discussed the future of drivetrain and transmission development with Professor Helmut List, Chairman and CEO AVL List GmbH.

Professor List, AVL is globally active in powertrain development. What engine technology will transmissions be dealing with in future?

There are big regional differences. In Europe, advanced technology will enable a broader sweet spot for combustion engines, widening their optimal BSFC zone and reducing fuel consumption significantly. How far this development goes depends not just on functional aspects, but also on what the market will accept. For example ten years ago, who would have believed BMW would have a successful 3-cylinder engine strategy, or that four cylinders could replace six cylinders in premium automobiles? Also, varying market conditions mean you have to find a high degree of modularity for all elements. That goes for engines as well as for transmissions.



How do regional requirements differ?

It starts with driving habits. For example, the Japanese like the way the stepless CVT behaves, while the Germans like ia more direct, connected feel. CVTs are very well established in Japan. And you have to remember they are relatively affordable for some countries, especially when you factor in the installed manufacturing facilities.

These are good reasons, when you need to select a car for countries with lower purchasing power. And once a specific technology like CVT gets established, it might even be used in electrified drives, which actually may not need the flexibility of stepless shifts. But the driving cycle results for a transmission's efficiency depend on the general legal framework too.

Those frameworks are changing. What effect will WLTP have, for instance?

A big one, because it will clearly extend the operating scope of combustion engines – including a move to higher load regions. That will balance out some of the advantages you get with automatic transmissions under NEDC. Also, under WLTP transmissions will definitely need to improve their internal efficiency. While this pressure is growing, the potential for using lots of gears or stepless transmissions to compensate for efficiency is shrinking.

So could some transmission concepts be out of the race?

I don't have a crystal ball, but I think not. There are other aspects involved that have nothing to do with efficiency. Manual transmissions are actually very efficient, but they are at a disadvantage because they don't support some aspects of semiautonomous driving. By contrast, hybrid drives give you more choice. With a wide range of combinations of combustion engines and electric motors to draw on, you can design better and better solutions for specific applications. We'll be living with this diversity, from which we can create and design, for a good while yet.

48V hybrids could help hybridization to break through, but could that be at the expense of diesel engines?

I don't think so. Granted, you can reduce $C0_2$ emissions from a spark-ignited engine by 10 to 15 percent – but recuperation helps diesels too. And one difference isn't going away: diesels have a higher thermodynamic efficiency. In countries where diesels are still not widespread, for example in America or China, mild hybridization might slow diesels down a little. But personally I'm optimistic that even there, diesels will grow in importance provided the fuel is available. The fact that you can improve pre-cat emissions a little with an electric motor could prove helpful in transient phases too, by cutting costs for exhaust after-treatment. On the other hand we see that, spark-ignited engines are shaking off the disadvantages that hybridization originally compensated for.

Advanced engine technology like variable compression doesn't come cheap…

These technologies are expensive, but so far the industry has always shown that technology gets cheaper once production volume is high enough. The exception is batteries, which are still nowhere near that. But usually, mechanical or electromechanical components become less expensive as time passes. At AVL we believe hybridization will help both spark-ignited and diesel engines. Both will benefit.

Plug-in hybrids are the next big functional step. Long term, could they even be an alternative to all-electric drives?

It's certainly possible. Especially because in the long term, combustion engines and electric motors will complement each other well in terms of their basic characteristics. Batteries can be much smaller in a plug-in hybrid than in an all-electric drive. And under Euro 6, emissions are already so low, they actually hardly impact on cities at all. We don't really need hybrids to be clean in cities; we need them for maximum efficiency. Our Future Hybrid proposal is a compact, highly integrated solution that follows a highly integrated system concept. We plan to present the next development stage in 2015.

In his plenary speech in Berlin, Prof. Helmut List spoke about "the transmission as a key for the modern powertrain".

What would you recommend to today's transmission developers to help them stay on track?

In almost any technology sector, it's now important to see your product in the context of an overall system instead of just focusing on the specific product. So actually, everyone involved should have a rough idea of how the overall drivetrain works, and be able to depict it in a simulation. From there, you can derive what requirements a transmission needs to meet for a specific portfolio or application. That's particularly important when you think of the impact of things like vehicle networking, which have a growing influence on powertrains.

Professor List, thank you for your insights and outlook.

Interview: Gernot Goppelt, CTI correspondent

Review of the 13th International CTI Symposium Automotive Transmissions, HEV and EV Drives, 8–11 December 2014, Berlin, Germany

The Transmission Becomes the Manager of the Powertrain

The German automotive industry would launch about 30 new cars with electrified powertrains in 2014 and 2015, said Prof. Ferit Küçükay at the start of the 13th CTI Symposium in Berlin. Electrification has increased the competition among the powertrain concepts, but also the possibilities to combine engine, motor and transmission concepts. The powertrain would therefore remain a very interesting field for engineers. Berlin showed: integrated and holistic development approaches become more and more important, but openness to new approaches is also required. The end of the combustion engine is not yet a settled matter, but it will be more often combined with an electric motor, even integrated into active transmissions.

■ Gernot Goppelt, CTI correspondent

The transmission as the "heart" of the powertrain was a phrase – in this or similar form – often used at the conference. Maybe this also explains the increasing interest in the CTI symposium: the number of participants increased by more than 20 percent to about 1,350 participants. The conference took place at the Estrel-Hotel in the southeast of Berlin for the first time. Although the eight sections per day were very well attended, the new venue provided enough space for the participants and 120 exhibitors. The participants came from 28 countries to discuss the future development of the transmission technology.

Evolutionary electrification of today's vehicle concepts

Bernhard Mattes, Chairman of the Ford-Werke GmbH Management Board, started the plenary section on Day 1. He described the conflicting requirements a large-scale OEM had to meet when developing vehicles today. That included the demand for more vehicle safety and reduced emissions, which were subject to different international regulations. The demand for locally emission-free mobility will also grow, as Paris Mayor Anne Hidalgo has called for. She wants to ban cars from the French capital, except for very low-emission cars. Ford counts on modular powertrain concepts, but will keep the overall vehicle concept. An example: the Ford Focus with combustion engine and with electric motor both roll off the same assembly line in Saarlouis. The company's current product range covers conventional petrol and diesel engines, a power-split hybrid and a plug-in hybrid vehicle as well as an electric powertrain. Ford furthermore counts on the use of conventional overall vehicle concepts in order to make electrification available to as many motorists as possible.

The transmission as the heart of the modern powertrain

Prof. Helmut List, President and CEO of AVL List GmbH, greeted the audience with a bon mot: the CTI Transmission Symposium was a true "wonderland for transmissions and powertrains". Transmissions had become tremendously important for AVL since both engine and transmission had to be taken into account when developing a powertrain today. The transmission was therefore the "heart of the powertrain". AVL's integrated development approach addresses the entire process chain from simulation to real world testing. From the integrated development of the powertrain, Helmut List expected a cost reduction of up to ten percent. In view of the various engine/transmission combinations, he advocated a flexible "portfolio management". He said it was hardly possible to use more than six gears of a manual transmission, which required a "broad" sweet spot of the engine. On the other hand, it could be narrower if an automatic transmission, for example, had nine gears. But that required a modular engine concept where the complexity of the basic engine could be varied.

Overall, AVL still sees chances for fewer gears. Mr List said that an "enlargement" of the sweet spot through engine measures could help, but also hybridisation, where the motor helps to avoid ineffective operating ranges of the combustion engine.

The "commander" of energy management

Terry Nakatsuka, CEO of Jatco LTD., also emphasised the prominent role of the transmission: in Jatco's vision, the transmission was the "commander" and the "gate" of the drive torque, which could also sense the demands and report them to the drive system. In the future, the transmission could even become an energy supplier, e.g. through a combination of a CVT and a flywheel accumulator, which suited each other well. Another advantage of the CVT was that it was suitable for scenarios of semi-autonomous driving, e.g. driving in a queue of traffic or adaptive distance control. According to Nakatsuka, the continuous adjustment of the gear ratio was particularly advantageous there. He expects that the CVT will also be successful in Europe in the future, where the acoustic decoupling of speed and drive has not been as well received as e.g. in Japan. Therefore, the latest Nissan Qashqai offers a D step function, which simulates gear steps when driving swiftly. This is meant to give European customers the impression of enhanced driving dynamics. With a calm driving style, however, it is not used in order to give better fuel economy.

There are many ways to the zero-emission vehicle

Prof. Dr.-Ing. Jens Hadler, Managing Director of Automobil-Prüftechnik Landau GmbH, also works at the Department of Sustainable Mobility, Otto von Guericke University Magdeburg. He surprised the audience by stating that one hour of solar energy was enough to provide power for the entire planet for a year. The second surprising fact was that today's fossil fuels were the result of mere chance: originally, they had rather been used for illumination than for mobility purposes. That could also be seen as a chance for regenerative fuels, which can be specifically "designed". Whether electromobility or regenerative fuels: it was most important that the energy source could be used for a "zero-impact emission powertrain". Fuels would still have the advantage that they could be easily stored and transported and therefore were independent of weather conditions. For the near future, Jens Hadler expected smaller vehicles, smaller combustion engines and increasing electrification. He said that seven to ten was the best number of gears for conventional transmissions and that engine technologies for fewer gears "are a thing of the future". Similar to Prof. List, he thinks that a higher level of integration of engine and transmission control as well as a modular transmission range is required in order to meet the international market demands and comply with the powertrain scaling.

More gears are not more efficient, but can enhance the comfort

The best number of gears is still being discussed. Prof. Dr.-Ing. Stefan Pischinger, Head of the Institute for Combustion Engines / RWTH Aachen University and CEO of FEV GmbH, illustrated the various aspects of the topic. He stated that five to seven gears would be sufficient with regard to fuel efficiency. Ten gears might therefore only make sense for high-performance vehicles to enable downspeeding at high speeds. The viewpoint would change though when focussing on comfort: Gear transitions should not be perceived as disturbing and the starting performance could benefit from short first gears. As an example, Prof. Pischinger showed that a dual-clutch transmission plus turbocharged downsized engine has disadvantages compared to a transmission with torque converter in terms of launch performance. In order to compensate lack of torque multiplication, an additional low gear was recommended for a dual-clutch transmission. However, Stefan Pischinger did not want to put the case of an inflation of gears, since it "remains to be seen whether creeper gears are really necessary". He supports a DCT gear set concept where the transmission halves are no longer functionally separated. That allowed for, for example, a 10-speed transmission without having to increase the number of gears considerably compared to a 7-speed transmission. For future hybrid drives, he agreed with Prof. List and suggested fewer gears. He also expects integrated drive train concepts, where the electric motor was integrated into the transmission.

Panel discussion and TED survey

The traditional panel discussion on the first day of the symposium was again combined with a TED survey. For the first time, there was the possibility to pose questions to the discussion participants via a web interface. There was a unanimous response to the question of how many vehicles would still have combustion engines by 2025: about 90 to 95 percent, with a significantly increased proportion of hybrid engines. Another question was how many gears are recommended for purely electric engines. The large majority (40 percent) believed two gears are necessary, while 29 percent favoured three gears. Terry Nakatsuka believes that CVTs make sense in electric vehicles as well, and 11 percent of the audience shared his opinion. The same question related to full hybrids: 31 percent chose five or six gears, and 31 percent preferred six or seven gears. Prof. Pischinger explained this estimation: hybrid engines need fewer gears, but existing technology would be built upon in the evolution of a powertrain. The discussion was similarly pragmatic on the subject of fuels: as Jens Hadler had already expressed in his plenary address, Rolf Najork stated he was open to new kinds of fuel and mentioned Audi's e-gas project as an example. This technology uses electrolysis to create hydrogen and then uses the hydrogen in a further reaction with CO_2 to produce methane. Najork stated that the superiority of a storable liquid fuel was a huge point. Also: "zero impact is a key concept, regardless of how it is achieved."

The modern powertrain looks ahead

In the first speech of the second day, Dr Rüdiger Steiner, Senior Manager of Research and Advanced Engineering at Daimler AG, spoke less about transmission technologies and more about their role in the overall technological context. Using an electric motor producing just 15 kW, it was possible to recuperate 90 to 95 percent of the kinetic brake energy. In the long term, CO_2 emissions of 70 g/km should be the aim. Achieving that would require better aerodynamics, lightweight construction and a powertrain which manages a good 20-percent-higher level of efficiency. Considering the 95 g/km target, 48-volt mild hybrids seemed essential. Besides electrification, Daimler also sees considerable potential savings through modern driver assistance systems and even autonomous vehicles. Steiner mentioned the example of a predictive driving strategy such as that already in series production with the Actros. Knowledge of the route profile is used to apply kinetic energy from downhill stretches for the following uphill climb. This requires navigation data with topographic information and a drive control system which can apply this information to find the appropriate gear-changing strategy. The Mercedes S500 plug-in hybrid goes a step further by using topographic information for the charging strategy. Other possibilities include applying road sign detection to the charging strategy and a destination-based charging concept. For example, the charging state of the traction battery can be adapted to a zero-emission zone at the destination. Dr Steiner argued for an "anticipative powertrain" and thus delivered another reason for implementing comprehensive development strategies.

Versatile hybrid kits for flexible electrification

Uwe Wagner, Senior VP of Automotive R&D at Schaeffler Technologies GmbH & Co. KG, started by comparing different drive concepts from conventional to fully electric with regard to their well-to-wheel figures. From today's point of view, no significant differences can be observed across the lifespan. However, with electricity produced by regenerative means the situation is different. Wagner expects CO_2 reductions of up to 60 percent by 2030 for battery-powered electric vehicles. While there currently are not any significant amounts of electric cars on the road today, he forecasts a pure-electric proportion of 9 percent and 35 percent for hybrids. 56 percent would therefore still be powered by a purely combustion engine. Considering the currently very wide spectrum of drive concepts, Schaeffler is already taking a broad approach – from micro and mild hybrid with belt-drive electric engines (P0 hybrid) through to parallel hybrids with disengageable combustion engines (P2 hybrid). Schaeffler prefers the P2 arrangement due to the high degrees of freedom in scaling. Uwe Wagner also considers five to six gears as sufficient, as long as only the efficiency is considered. With purely electrical drive systems such as through-the-road hybrids (P4 arrangement) he prefers two gears, which result in an efficiency improvement of 6.5 percent. Uwe Wagner finished by describing a prototype Ford Fiesta with wheel hub motors. The two motors, each producing a continuous 33 kW, enable real torque vectoring, but result in 45 kg more weight per wheel. When questioned, Uwe Wagner did not consider that the high unsprung masses would result in significant negative effects, agreeing with Ford's Chairman of the Board Bernhard Mattes.

China: The steep climb remains challenging

It is only a few years since the media was talking about China being in the fast lane with their plans for electric vehicles. However, it seems that the first step will be to catch up on the technological lead in the established markets of Europe, Japan and the USA. Dr Klaus Badenhausen, Vice President and Head of Chery Technical Center Shanghai at Chery Automobile Co. Ltd., described huge growth over the past 20 years in which China had become the largest car market in the world, but while in Germany every second person has a car (statistically), only every 200th person has a car in China. This highlights the potential (and also the challenges) should China continue to grow as it has done so far. According to Badenhausen, Chinese producers have had paid dearly for their early model policies: some had brought too many model variations to market before first establishing a brand identity. Global manufacturers have this edge on them and currently hold 70 percent of the Chinese market. The Chinese also need to work on training their engineers, as they do not have the decades of experience which the global manufacturers have. Also, the technological demands faced by Chinese manufacturers are now much higher than those faced by the Japanese and later the Koreans when they originally came to market. At Chery, Klaus Badenhausen wants to close the gap with processes on an international standard. The opportunity to develop these from scratch is a "fantastic job". A robust, modular platform concept with various car bodies is of key importance. In the longer term, Chinese manufacturers will, he believes, take on a stronger position on the market, which does not necessarily have to be at the expense of European manufacturers: "there is room for everyone on the Chinese market".

WLTC sees an increase in consumption

Dr Robert Plank, Chairman of the Board at TÜV Nord Mobilität GmbH & Co. KG, brought the two days of plenary sections to a close. He shed some light on the complex emissions legislation and driving cycles for the coming years. The comparison between NEDC and the WLTC is of particular importance to transmission developers: due to the significantly lower number of standstill phases, start/stop systems are of lesser importance in the WLTC, for example. In the case of manual gearshifts, the developers are confronted by the fact that the shifting time points are not generally prescribed as in the NEDC, but are each individually calculated depending on various vehicle parameters for each test vehicle. Consumption levels will be higher on average, leading to the question of how this can be harmonised with the stated consumption figures and fleet consumption targets. One possibility would be to calculate the results back to the NEDC and introduce an additional new limit value. According to Robert Plank, a "mixed approach" is currently preferred, with which a conversion calculation is foreseen for a transitional period. Dr Plank also stressed the importance of a worldwide harmonisation of consumption figures as suggested for the "worldwide" conceptualised WLTC. At the end of the day, global standards would also help automobile manufacturers to reduce costs. However, it does not currently look as though the USA or China want to introduce the WLTC.

The anticipative hybrid drive becomes reality

The CTI Young Drive Experts Award was presented for the sixth time at the CTI Symposium. Dr Sebastian Idler took first place with his dissertation "Scuffing load capacity of continuously variable transmissions". The method he developed makes it possible to achieve an improved pressing strategy dependent on the surface temperature. Second prize went to Dr Felix Töpler for his dissertation on the topic of "Anticipative energy management for plug-in hybrid vehicles". With this method, Töpler was able to reduce consumption by a good 5 percent in a close-to-customer cycle. The topic was closely relevant to the conference, as the increasing system integration came up again and again as part of the advancing automation and electrification.

In retrospect, the perpetual discussions about the best number of gears were prominent. On one hand, there was general agreement that ten gears are not necessary from a consumption point of view and that highly integrated hybrid drive systems can live just as well with five gears. Even a combination of fewer steps together with series or power-split operation could be imagined. Nevertheless a certain willingness was apparent to consider more gears (at least for reasons of comfort) as long as new gear set concepts would permit this within a reasonable package. However, the required shifting strategy should not contradict the increase in comfort. Another insight was that marketable powertrain concepts require a manageable drive system assembly kit which enables various drive scenarios and would also be affordable for motorists. The "zero-impact emission powertrain" term, which was frequently heard, holds its own message: the concept of liquid fuels should not be written off prematurely. Scalable hybrid drive systems can thus serve to fulfil the CO_2 legislation just as locally emission-free mobility.

Further information and pictures:
www.transmission-symposium.com