CTI MAG

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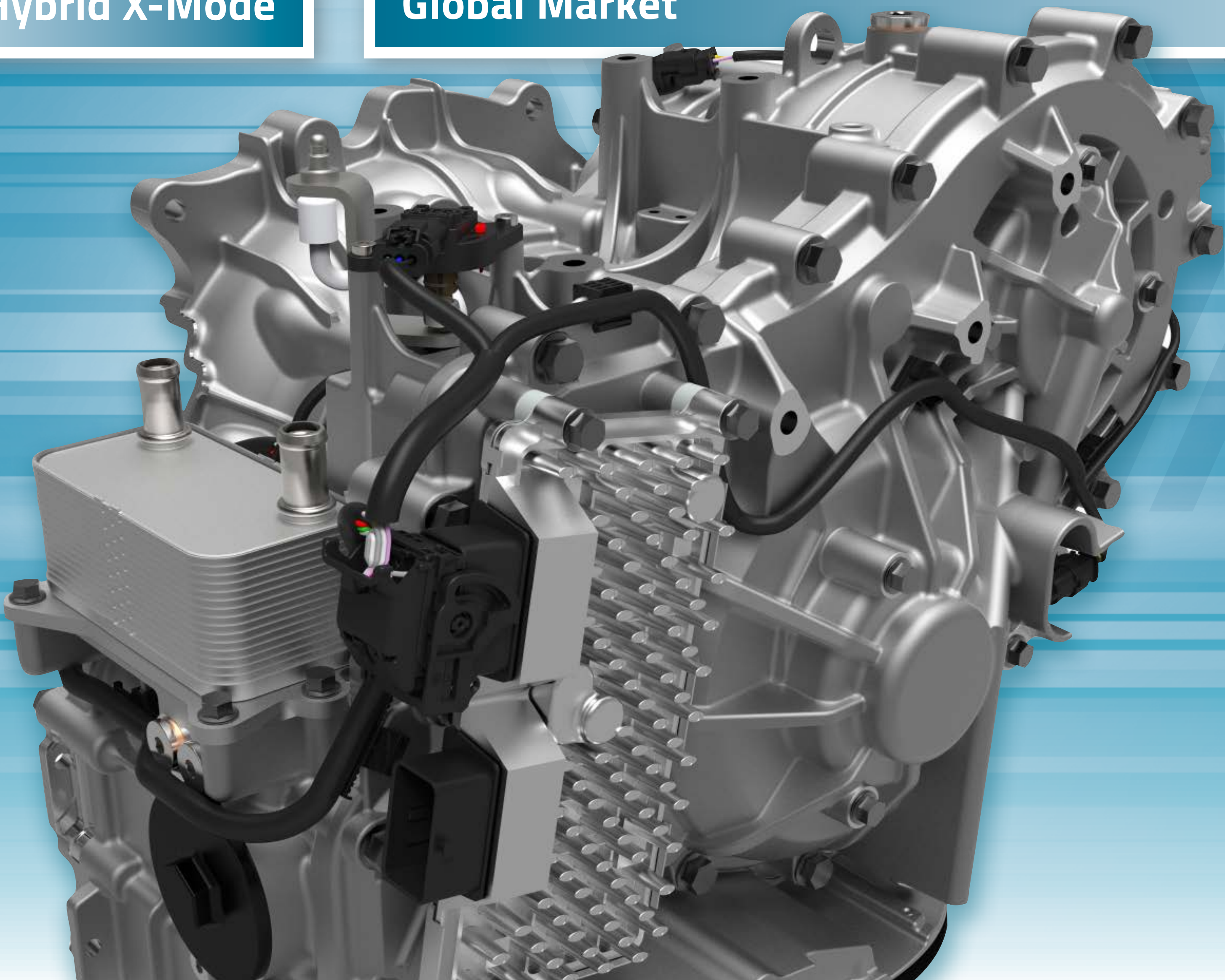
December 2017

Expert Forum: Are Engines and Multispeed Transmissions Still Needed in 2030?

Paradigm Shift in Thinking on Four-wheel Drives

AVL's Future Hybrid X-Mode

CVT Fit for a Global Market

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CTI MAG Contents

Dear reader,

welcome to the ninth issue of CTI Mag.

Once again, there are more innovative and interesting contributions than ever. We start with an IHS market analysis of current developments in passenger car transmissions and drives. Next, we ask experts what role they expect combustion engines, multispeed transmissions and CVTs to play in the year 2030. Find out what they predict on pages 12 - 15.

Elsewhere in this issue, leading manufacturers and suppliers describe their latest electrification concepts and ongoing development efforts in conventional transmissions and individual drive components with regard to efficiency, performance, cost and weight. We also present important insights in the fields of development methods, transmission management and actuatory systems.

To round off the specialist articles, we interviewed two drive experts – Dr. Carsten Bünder (GETRAG Magna Powertrain) and Theodor Gassmann (GKN) – about e-axles and how automated driving will affect transmissions. And on top of that, there's an out-of-the-box interview with 2016 Formula One champion Nico Rosberg too. Last but not least, we share key insights from the CTI Symposium China in the form of a follow-up report.

Our special thanks to everyone who helped make the latest issue of CTI Mag happen. We hope you enjoy it as much as we did!

Your CTI Mag Team

Michael Follmann, Exhibition & Sponsoring Director CTI Transmission Symposia, CTI
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Transmission and Driveline Electrification Adaptation for Passenger Car Fleet CO_2 Reduction in EU28 Market

It will be no easy task for vehicle manufactures to meet passenger car fuel consumption and emission targets for Europe. Improvements to gasoline and diesel powered engines to meet alone will not be sufficient to meet upcoming CO_2 and air quality targets. To satisfy continually tightening legislation in Europe, manufacturers must utilize a variety of vehicle strategies and powertrain hybridisation topology. Car manufacturers and technology suppliers are currently developing and implementing radical technological innovations to address mobility challenges in meet regulatory targets. Crucial to this process is selecting the optimal hybrid architecture that will maximize CO_2 reductions, maintaining essential vehicles attributes, and minimizing cost and modularity.

■ Vijay Subramanian, Associate Director, IHS Markit Automotive – Powertrain and Compliance EMEA Team

Introduction

From a technical perspective, there is a broad range of possible powertrain electrification configurations for car manufacturer and technology suppliers to consider. In addition to the inherent complexity of the numerous configurations, there is a compounding complexity in the planning process involving both the cost and the modularity that comes with increasing the number of vehicle architectures. While we cannot evaluate the merits of all possibilities in such a short article, we examine some of the broader market trends of current and future transmission strategies that are emerging in this transformative period has a significant impact on vehicle range, fuel consumption and cost.

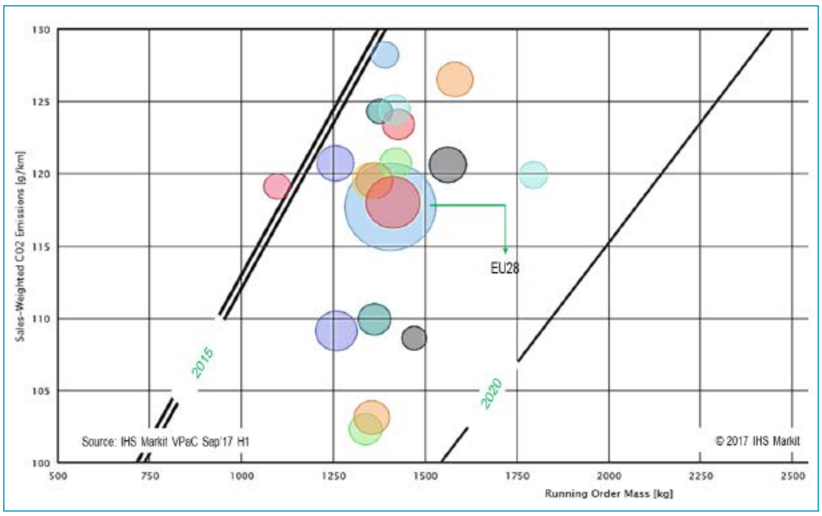


Figure 1 Outlook of 2016 EU28 passenger car fleet CO_2

I. EU28 Market status and forecast on fleet CO_2

The sales weighted fleet average CO_2 of new cars sold in EU28 was well below the stated target and contained only a 1.2 % improvement as compared to 2015 rates. This is the smallest annual improvement achieved by the Europe in recent years. Even though a slight drop in diesel share was reported, as compared to 2015, an increase in vehicle sales has provided a counterbalance result to meet the EU28 fleet average CO_2 target with similar level of electrified vehicle as compared to 2015. Fig.1 below shows the overall average fleet CO_2 performance of Europe with contributions from all major passenger car manufactures.

II. Impact and Outlook of 2021 EU28 Fleet CO_2 Status

Europe implemented two new emissions regulations in September 2017, intended to deliver cleaner vehicles to consumers. These new regulations aim to achieve CO_2 emissions and fuel consumption statements that are more comparable to real world driving conditions. All new passenger cars have to comply with on road NOx and PN emissions which will be capped at 2.1 times the Euro 6 limit and will be further lowered to 1.5 times in January 2020. Additionally, all new car types need to be homologated on "Worldwide-harmonized Light vehicle Test Procedure" (WLTP) for the measurement of CO_2 emissions, fuel consumption and tailpipe pollutant emissions. This legislative framework is expected to deliver air quality benefits for citizens, EU Member States, and local authorities. We anticipate that the decline in diesel share needs to be offset by developing highly efficient gasoline engines combined with a growth in market share from electrified vehicles (Mild, Full and Plug-in). Fig.2. below shows the overall trend of Europe powertrain sales with a seven year forecast of Diesel and Gasoline.

Sales of efficient diesel engine that were contributing to CO_2 reductions in the past have started to decline. With a current share of 49 % in 2016 it is expected that diesel volume will drop to 33 % by 2025. This reduction in diesel sales is large due to air quality requirements and costly emissions after treatment that are required to meet emission targets under WLTP and RDE regulations. The regulations are severe enough that car manufacturers will avoid producing A & B segment vehicles with diesel engines after 2019. This change is based on the significant increase to vehicle price that would be necessary due to costly after treatment emission reduction systems. The contribution from gasoline in Europe's market is growing and expected to be as large as 60 % by 2025. The technology required for further reduce CO_2 and other emissions from their current levels are being developed and demonstrated by car manufacturers and technology suppliers utilizing gasoline engines; this does enable the gasoline growth in EU28 market along with certain level of electrified vehicles offered as gasoline.

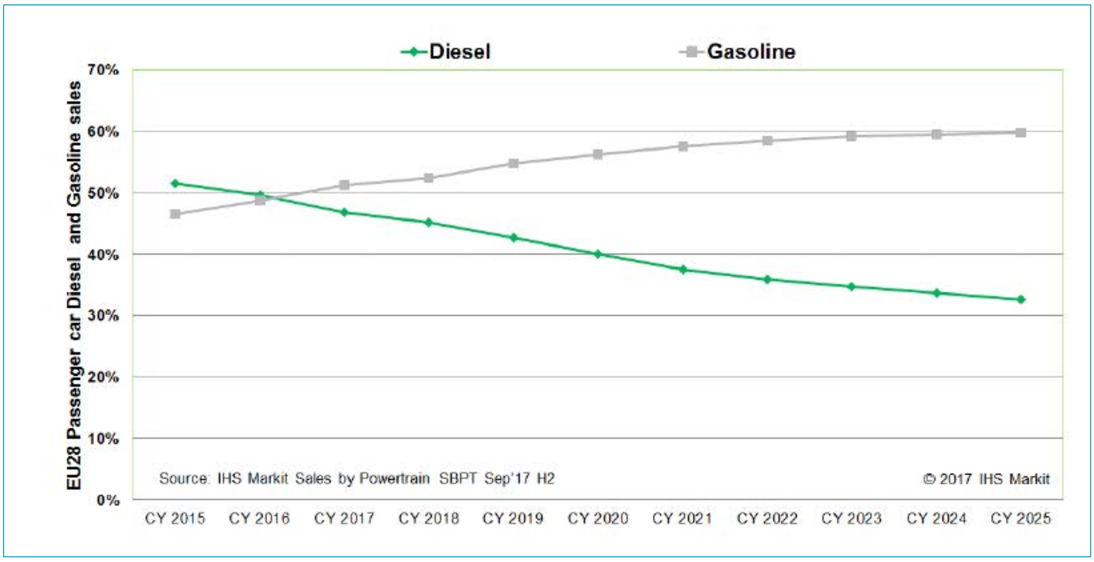


Figure 2 Gasoline and Diesel trend for EU28

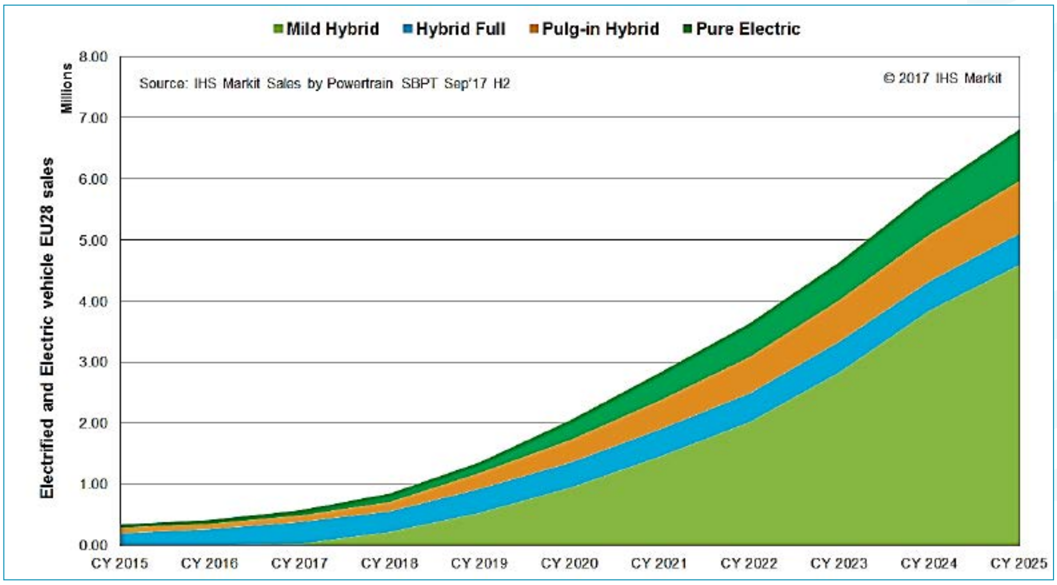


Figure.3 Passenger car electrification sales in EU28 (only Mild, Full, Plug-in and Pure Electric)

III. Electrification Roadmap to Meet Greenhouse Gas and Air Quality Target

The overall contribution from pure electric and plug-in electric vehicles sold currently in EU28 market has remained stagnant compared to 2015 levels. However, they are expected to grow and achieve a combined growth of four % by 2020. Linear growth is expected on pure electric and plug-in electric vehicle after 2021 as the super credit multiplier provision granted for such vehicles are condensed on year-on-year basis and the overall allowance is restricted to 7.5g of fleet CO_2 offset during WLTP transition period in Europe. The forecast illustrated in Figure 3 shows a six % market share for pure electric and another six % growth for plug-in vehicle by 2025 respectively. This level of share is expected based on the alignment noticed from seven governing factors which include: legislation and incentives; battery cost; supply capacity and production of battery cells; fuel price; charging time; charging infrastructure, R&D lifecycles of car manufacturers; and driving range in real world conditions. Mild hybrid electrification is expected to grow to 4.6 million vehicles by 2025; this comes for various level of electrification topology. The electrified passenger car market in Europe consists of the sub-categories of Mild, Full, Plug-in and Pure Electric vehicle. Vehicle electrification, the further tightening of emission standards and a shift in consumer preference towards SUVs will bring a drastic change to powertrain architectures across Europe.

IV. Powertrain System Design on Electrified Vehicle

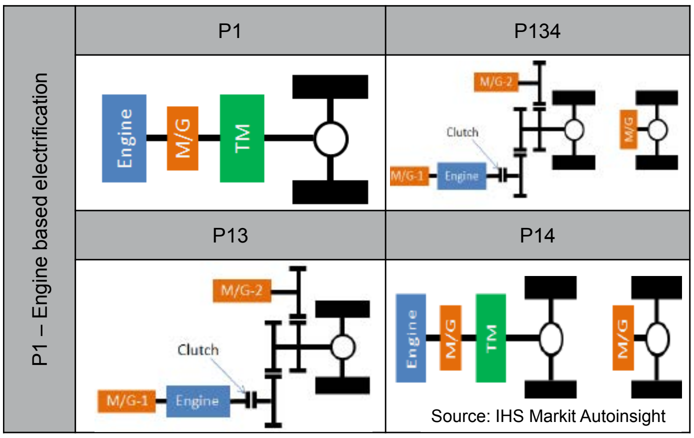
Within electrified powertrains, different degrees of topology will exist within and across the market. We anticipate that there is also an increasing demand to understand the forecast of various technical concepts and differentiating factors that have arisen from hybridization topologies P0 to P4. Benefits from these hybridisation topologies include a number of features, including:

- Pure electric driving
- Assisting the tractive effort of the ICE ("Boosting")
- Energy recuperation during coasting
- Energy recuperation during braking
- Generator mode under driving conditions
- Level of disconnect depending on topology
- Coasting , Sailing and Creep
- Pre-conditioning powertrain to suite route

All reported market share on subsection below are based on the volumes reported in Fig. 3 for Passenger car electrification sales in EU28

a. P1 Architecture in Electrified Vehicle

P1 architecture is a cost effective solution for engine manufactures and technology suppliers, which offers more flexibility with extended configurations like P13, P134, P14 etc. (as shown in the configurations below). Current P1 configurations in full hybrid vehicles are expected to grow significantly with additional market share coming from the introduction of P1 mild hybrid systems beginning in 2019. P13 and P14 configurations are expected to grow during the 2019–2021 timeframe as these architectures are expected to be incorporated into vehicle powertrains that deliver less than 50g/km CO_2 and qualify for super credit on full hybrid plug-in electric vehicles from major car manufactures.



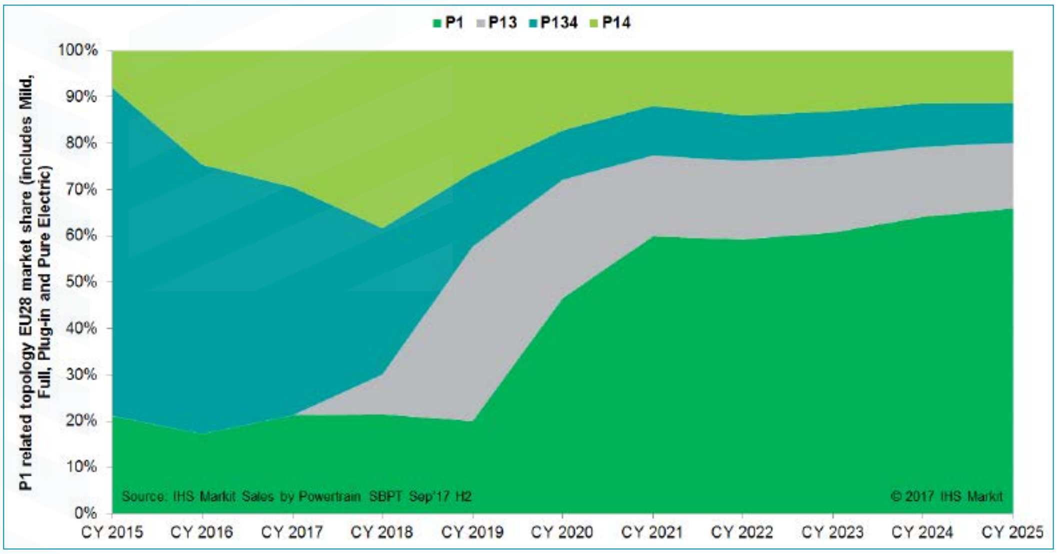


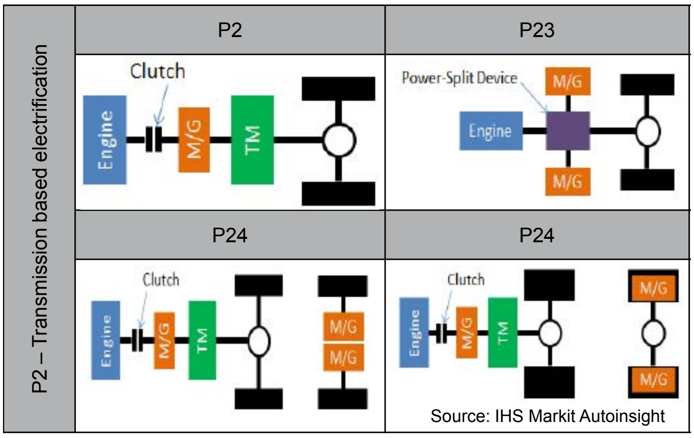
Figure 4 P1 related topology EU28 market share

b. P2 Architecture in Electrified Vehicle

While the overall cost benefit of having a P2 topology favors car manufacturers who currently produce in-house transmissions, it does enable additional fuel economy gains. Conversely, these transmissions are not a low-priced option when being offered from transmission technology suppliers. This topology can enable disconnect from the combustion engine for additional fuel efficiency gain. Power from both the combustion engine and the electric motor is transmitted through the gearbox for decent performance at all competitive vehicle speeds. Tractive effort at low speed does not conflict with vehicle top speed requirement. Overall P2 configuration enables efficiency improvement through appropriate powertrain integration, packaging and calibration.

The current P2 topology available in full hybrid vehicle is expected to grow by 50 % by 2020. Similar to P1 architectures, this contribution is expected to grow with P2 type mild hybrid topology vehicle by 2018 timeframe. Since SUV vehicle growth in Europe is significant, the growth of P23 full hybrid topology is expected to gradually decrease in the European market.

However, P24 is preferred for SUV vehicle with plug-in architecture, hence leads to a significant growth in European market.



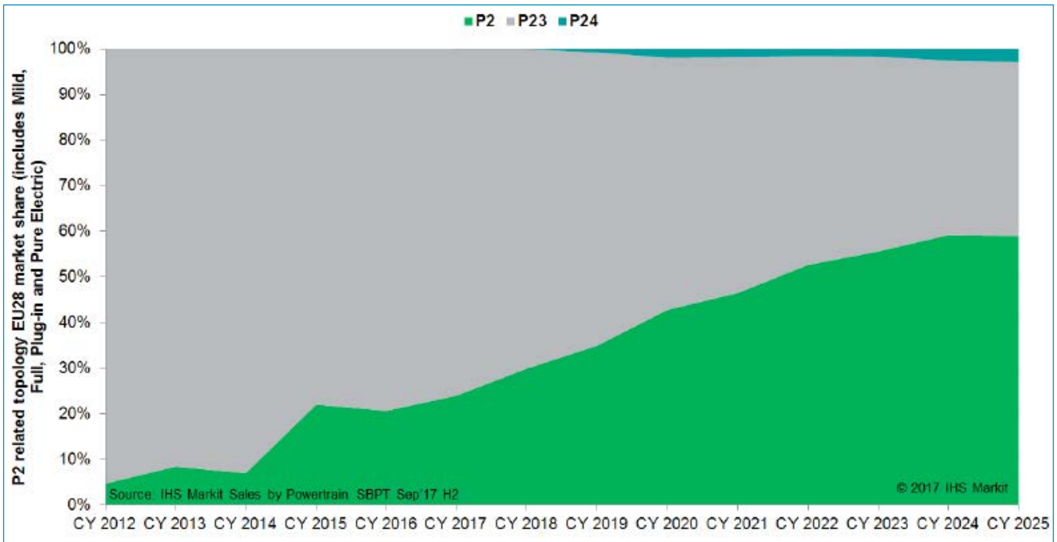


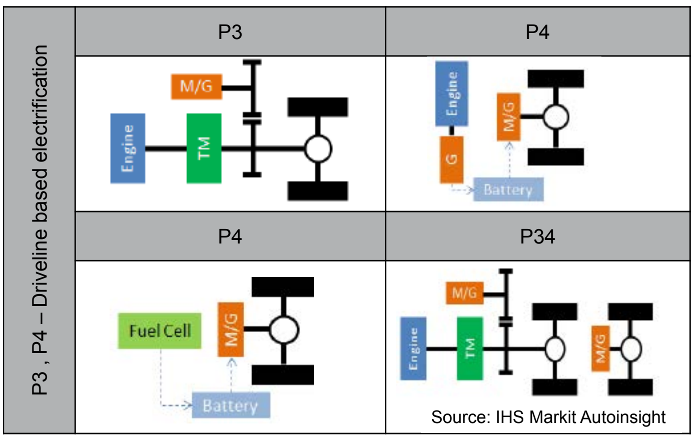
Figure 5
P2 related topology EU28 market share

Figure 6
P3&P4 related topology EU28 market share

c. P3 & P4 Architecture in Electrified Vehicle

P3 vehicle topology is a recent addition to the European market and is commonly a parallel co-axial type full hybrid system. This is an enabler for vehicle performance and fuel economy with the ability to disconnect the combustion engine when being propelled from alternate sources of energy. Power from both the combustion engine and the electric motor is transmitted through the gearbox for good performance at all competitive vehicle speeds.

P4 topology, which is primarily exclusive to pure electric vehicles, is expected to remain flat as the technology seen on P3 topology where a motor fitted to differential with reduction gear does seem beneficial for EV range and vehicle attribute requirements.



Conclusions

Overall, contribution today from pure electric vehicles and plug-in electric vehicles is at similar level to 2015 levels in Europe market. However, we anticipate a combined overall market share of four % by 2020 and sixteen % by 2025 in passenger car segment. As we move towards achieving this type of growth, vehicle manufacturers will use a number of hybridization topologies out of necessity. The various approaches considered each have a different balance of benefits to reducing emissions, increasing fuel economy, incorporating into existing systems, and degrees of cost increases. Legal requirements to reduce vehicle fleet CO_2 emissions and requirements to improve air quality in key markets will accelerate the spread of these electrified powertrain architectures. Future legislation, such as the introduction of WLTP, low emission zones in cities etc., means a long range in electric driving is essential. This, too, comes with a multiplicity of benefits and costs. Regardless of what approaches are utilized, in a sea of shifting customer needs and preferences, there is no single electrification solution that can be treated as a panacea but all options must be carefully weighed and considered.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Will We Still Need Combustion Engines and Multispeed Transmissions in 2030?

Stricter environmental regulations, e-car quotas and calls for banning combustion engines are driving electrification. Local emission-free mobility will prevail in cities, but for long-distance use it's less clear whether fully electric drives can replace combustion engines with multi-gear transmissions and CVTs. We asked transmission and engine experts what role combustion engines and multi-gear transmissions or CVTs will play in 2030.

"We can still expect a long life for multi-speed transmissions"

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

The future of transmissions depends on the propulsion systems. Reading the newspapers, you might almost believe there will only be e-drives after 2030; the German Bundesrat for example is discussing a ban on combustion engines from 2030. The poor air quality in cities due to NO_X is a main driver. Although legislated emission limits for the cycles have been reduced to almost one-tenth in the last 20 years, air pollution remains almost unchanged because real-life emissions have hardly been reduced at all.

Under RDE legislation, real-life emissions are significantly reduced towards the levels defined for the chassis dyno-based test cycles. By 2030, fleets should have been renewed to such an extent that fleet emissions will be far below today's values. So air pollution from car traffic will be reduced dramatically, and from this point of view we can expect the problem of air quality in cities to be solved.

Nevertheless, pure electric drives will gain market share – especially in urban scenarios. Non-driving phases must be used to recharge the batteries – for example, overnight. Long-distance traffic has other requirements. Take a traffic hotspot like the Brenner autobahn, for instance: if all vehicles were purely electric, instead of 20 pumps for liquid fuels you would need 1000 charging stations with a 400 MW peak power rating. That may be feasible, but it doesn't add up.

So it can be concluded that in 2030, more than 70 % of powertrains will have an internal combustion engine. They will be electrified to a high degree. 48V systems with mild hybrid functionality (meaning reduced costs compared to 400V systems, not increased costs compared to 12V systems), or hybrid drives with an increasing share of dedicated hybrid transmissions (DHT) will grow their market share. So multi-speed transmissions probably still have a long life expectancy.

"Electrification overcomes the disadvantages of combustion engines"

Dr. Ryozo Hiraku, Engineering Director,
Powertrain Engineering Division, Nissan

To achieve high level powertrain system efficiency, electrification is mandatory. So a movement to an e-motor drive system would seem to be a natural transition.

However, a battery electric vehicle (BEV) is not a perfect zero-emission solution from a well-to-wheel point of view, even though it achieves locally emission-free mobility. That means that unfortunately the BEV cannot be a technical goal currently. To make a BEV the perfect zero-emission solution, a fully fossil fuel-free energy supply is essential; but we are a very long way from being able to achieve this.

On the other hand, internal combustion engine (ICE) based powertrain systems including transmissions, which emit CO_2 and other pollutants during operation, have been continuously improved year after year. Ongoing evolution to further reduce emissions can also be expected. Especially recently, electrification has been overcoming the disadvantages of ICE with regard to inefficient conditions such as low load operation and rapid transient load changing. So in combination with electrical devices, ICE based powertrain systems still have huge potential for improvement.

In fact, both BEVs and ICE-based powertrains are not perfect solutions today. But both are improving and heading towards the perfect solutions. Therefore, we assume that both BEVs and ICE-based powertrains will be important technologies for sustainable mobility as early as around 2030, and it will not be a question of choosing one of them.

"Bigger changes than anything we have seen in more than a century"

Prof. Dr. Leopold Mikulic, Managing Director,
Mikulic Consulting

The fundamental changes that powertrain technology now faces are bigger than anything we have seen in more than a century of evolution in passenger car technology. Driven by environmental and health requirements, regulators are striving for even stricter air quality standards. As a result, OEMs face more challenging emission standards and test methods in future. On top of this, the automotive industry must comply with drastically reduced CO_2 emission ceilings on a global basis.

As a result, powertrain electrification in passenger cars began with the advent of hybrid technology. In the next few decades, efficient, pure electric powertrains are seen as the game-changer in automotive powertrain technology. It's not just combustion engines that will undergo massive changes, for example rightsizing and high pressure turbocharging, cylinder cut off and variable compression ratios; transmission technology will also have to adapt to help reduce emissions, yet still provide enough agility and response even with fewer speeds.

Electrified powertrains will involve integrating electric motors into stepped automated or dual clutch transmissions, while power split transmissions may cover the high end too. Some markets will appreciate electrified CVT, and AMTs with an integrated electric motor are an affordable solution for volume segments.

The rollout of pure electric vehicle technology will also bring highly integrated electric axles to the markets. These will feature reduction transmission concepts with planetary gears, or other technologies.

"With more refined e-machine integration, conventional and DHTs will converge"

Larry Nitz, Executive Director,
Global Propulsion Systems, GM

We see continued pressure from CO_2 and Real World Driving Emissions as governments regulate and customers desire "connected and clean" solutions. In serving these customers, our propulsion systems will pivot to more efficient solutions. Certainly, there will be a place for combustion engines and multi-gear / CVT transmissions, and by 2030 most will have significant connected and electrified content for regenerative braking, load shifting and EV driving.

Within a connected environment, these propulsion systems will become individually personalized to the mobility mission. They will plot routes with energy budgets to enable ZEV experiences where legislated, efficient and beneficial to society. Transmissions with high efficiency and small ratio steps (including efficient CVTs) will survive, however more ratios are unnecessary.

As electric machine integration becomes more refined, conventional and DHTs will converge at the propulsion system level. As battery energy becomes substantially cheaper (think $50/kWh), more energy will be carried to optimize the drive and deliver greater EV benefits. Coupling electrically heated exhaust after treatment with initial EV driving will enable dynamic engine starting without attendant cold start emissions on Real Driving cycles.

In this integrated and connected future, electrified MTs, ATs and CVTs will co-exist with DHTs and EVs.

"Until the revolution occurs, look for significant growth of 48V and full hybrids"

David Petrovski, Principal Analyst Powertrain Forecasting,
IHS Automotive

There are a lot of variables that come into play when you evaluate technology adoption. It becomes a function of government policy, regulations and incentives, energy prices, new technology cost and benefit, infrastructure, as well as consumer desire, acceptance and affordability – and what the incumbent technologies can do.

The EV hype and headlines are in the forefront as many OEMs and governments are announcing ambitious plans, but one still needs to fully evaluate all the variables of technology adoption and their interplay. The ICE and conventional transmission will definitely still play a significant role in 2030. Until the propulsion revolution occurs, look for significant growth of 48V mild hybrid and full-hybrid options, as suppliers and OEMs stretch the internal combustion-transmission lifetime.

The competition for market share is limited at this point, because as soon as government incentives are dropped on EVs, vehicle registrations are very quick to follow. However, if the variables change or are tilted in a particular direction, technology can quickly follow.

We are definitely in an exciting time, OEMs and suppliers are facing new influences and trends in the form of rising integration of vehicle autonomy, electrification and personal mobility over the coming years. If you bury your head in the sand now and ignore the trends in electrification and autonomy, you might be in for a rude awakening.

"Transmissions for E-Drives are anything but low-tech"

Professor Dr.-Ing. Stefan Pischinger, President & CEO, FEV Group

For the global car and light commercial vehicle market, both ICE-only conventional drives and hybrid drives will still exist in 2030. The demand for drives with greater efficiency, and the use of synthetic fuels with a distinctly better ecological balance than fossil fuels will also continue up to 2030.

The key to achieving global climate objectives lies in a mix of all drive concepts that utilizes the individual benefits of each one. ICE-only drives will still require multispeed transmissions in 2030. In the case of pure electric drives using high-speed electric motors, some vehicles will manage with single speed transmissions.

These transmissions are definitely not low technology. Omitting the internal combustion engine increases NVH requirements considerably. High electric motor speeds, sometimes above 15,000 rpm, lead to high sliding speeds in the transmission and require specific measures – for example to increase scuffing load capacity. At the same time, multispeed transmissions will also be necessary for BEVs.

At FEV, we already know some BEVs cannot meet the requirements for starting performance and maximum electric motor speed with a single speed gearbox. However, a smaller gear ratio spread would suffice. The requirements for a smaller gear ratio spread and power shifting capability also make CVTs interesting. Achievable transmission efficiency levels, and hence ranges on a full battery charge, will play an important role – as, of course, will transmission costs.

"Tailored electrification for specific customer demands"

Carsten Weber, Manager Engine & Powertrain Systems, Research & Advanced Engineering, Ford

Combustion engines are under enormous pressure with regard to emissions. But what often gets neglected is that efficiency and emissions are related to the chemical properties of fossil energy carriers, and are often inversely proportional. Sustainable fuels made with renewable energy are one very promising alternative. Recent developments in the field of power-to-gas and power-to-liquid are predestined for wider use in automotive applications.

In the foreseeable future, the dominant technology will be hybrid technology that makes optimal use of electrification and conventional powertrain elements. The role of transmissions will change. Instead of being the element that adjusts torque and speed between engine and wheel, they will become intelligent performance distributors that manage energy consumption, emissions and driving behaviour. Growing electrification will enable us to simplify engines and increase their peak efficiency. Ideally, they will only operate in their highest efficiency range.

To operate hybrid propulsion systems within the required ranges for vehicle speed and load, you need a high variability transmission. New scenarios such as autonomous driving and regulatory changes are exacerbating these demands. Hence, the number of different hybrid concepts is growing rapidly. We are facing a multidimensional trade-off between functionality, attributes and cost.

Against this background, we will see a growing number of electrified vehicles that are tailored to specific customer demands and legal requirements. Most next-generation propulsion systems will still include internal combustion engines in order to ensure the optimum compromise in terms of cost, range, performance and emissions. ■

AVL's Future Hybrid X-Mode

A modular hybrid transmission family that can be implemented as a conventional AT, 48V or HEV/PHEV system, delivering a new dimension of safeguarding development efforts and industrial assets in vehicle markets with volatile customer preferences

- Ivan Andrasec, Design Engineer Powertrain, AVL List
- Bernd Jeitler, Lead Engineer Product Quality Assurance & Production Engineering, AVL List

An ongoing effort to reduce fleet CO_2 emissions of passenger cars is under way and is shaped by corresponding legislation proposals. Hybrid vehicles offer possible solutions to achieve the ambitious targets. Predictions show that an increase in hybrid vehicles is expected, the volume mix forecasts however are changing very frequently. Such uncertainties also pose challenging questions for future transmissions and related investment decisions. A wide variety of possible concepts already exists and this variety will likely grow bigger. Therefore, there is a high risk of increased research effort in the search for favorable concepts. In addition, the cost of production has to be considered and given resources have to be managed under economic perspectives.

Bearing this in mind, a holistic development approach should be chosen to come up with hybrid transmission concepts or dedicated hybrid transmissions (DHTs) with a focus on those topics.

In this way, AVL's new Future Hybrid X-Mode is a viable solution that reduces certain risks. The experience gained from the design of the Future Hybrid 7 Mode and 8 Mode DHTs as well as customer demands formed the basis for this development. The additional aspect of economic effectiveness and a refined development process helped to come up with this DHT system concept.

Future Hybrid X-Mode Layout

The Future Hybrid X-Mode is a modular transmission family for transverse application up to E-segment vehicles. Its variants have different characteristics depending on the level of electrification (LoE). The concept revolves around a core transmission and interchangeable component modules. By combining different modules with the core components, one can freely generate different types of transmissions in terms of LoE. It is possible to generate two high-voltage HEV/PHEV systems (HV and HV+), a 48 Volt system (48V) or a 6-speed conventional automated transmission (AT). Their main layout and characteristics can be seen in Figure 1 and Table 1 respectively. The variants differ in number of operation modes and features (hence the name Future Hybrid X-Mode).

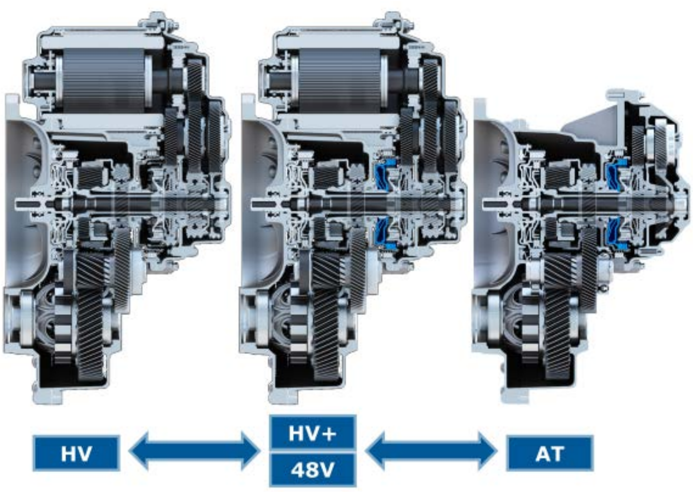

Figure 1 Future Hybrid X-Mode Layouts, left: HV, middle: HV+ and 48V, right: AT

	HV	HV+	48V	AT
PH Modes	4	6+R	6+R	6+R
EV Modes	2	2	2	–
ECVT Modes	1	2	–	–
Clutches/Brakes	4	5	5	5

Table 1 Main characteristics of Future Hybrid X-Mode variants

An example layout was created for a typical C-segment vehicle with a 105 kW gasoline ICE. The DHT version of the X-Mode (HV) consists of one electric machine with a peak power of 100 kW. The core of the transmission is a Ravigneaux planetary gear set with a two-step helical gear manipulating idler for speed reduction coupled to it. The shift elements are two multi-plate clutches and two brakes with hydraulic actuation (see Figure 1, left).

The layout of the HV variant offers the possibility to generate four parallel hybrid modes (PH) that are forward driving and power-shiftable, two pure electric modes (EV), one torque-split mode (ECVT) and one mode for charging at standstill.

The HV+ variant can be derived when adding another clutch to the HV variant. It is marked blue in the central part of Figure 1. This addition increases the number of operation modes by two more PH modes for forward driving and one reverse PH mode – all of them are power-shifted. In addition, the HV+ variant has also one more ECVT mode.

With regard to LoE, this additional clutch enables the transmission to be operated as a 48 Volt system. For the 48V variant it is possible to use an electric machine with up to 25 kW of peak power. Also a conventional 6-speed AT can be realized, if the transmission shall not be electrified (see Table 1 and Figure 1, right).

Features

The Future Hybrid X-Mode is a state-of-the-art transmission family concept. The HV variant is a dedicated hybrid transmission because the EM performs the important task of launch and reversing in EV mode. In this configuration this is the only technical solution for reversing. The traction force at launch can achieve up to wheel slip. The 1st EV mode can reach a maximum vehicle speed of up to 130 km/h and the 2nd EV mode even up to 200 km/h respectively. The traction battery's state of charge is managed by an intelligent operation strategy to provide maximum availability. However, forward launch can also be executed in ECVT mode up to an inclination of 20 % grade if the battery is depleted. The ICE then provides power for vehicle propulsion and simultaneously charges the battery, using the electric machine as a generator.

The electric machine can provide boost and recuperation in every PH mode, it can be used for ICE load point shift and it can crank the ICE using the clutch C2 in EV mode to enable a smooth engine start.

Many of those hybrid features can be applied in the 48 Volt system in a reduced form due to the lower power of the electric machine.

An example layout for a typical C-segment vehicle shows a transmission length of less than 380 mm for the HV, HV+ and 48V variants. The AT variant is a bit smaller due to the absence of the electric machine and its corresponding components. The transmission length would amount to less than 365 mm. The estimated weight of the transmission ranges from under 73 kg for the AT to under 112 kg for the HV+ (without dual mass flywheel and transmission oil). This results in a good fit to typical C-segment vehicle package requirements.

A package comparison between the Future Hybrid X-Mode variants and a technically similar 6-speed dual-clutch transmission (DCT) with a corresponding P2 add-on module (including a separation clutch) for the same vehicle class can be seen in Figure 2. The AT variant and 6-speed DCT share a similar package. An advantage of the Future Hybrid X-Mode regarding transmission length can be seen when the HV and HV+ versions are compared to the 6-speed DCT with a P2 add-on module.

Figure 2 Package comparison between Future Hybrid X-Mode and a DCT

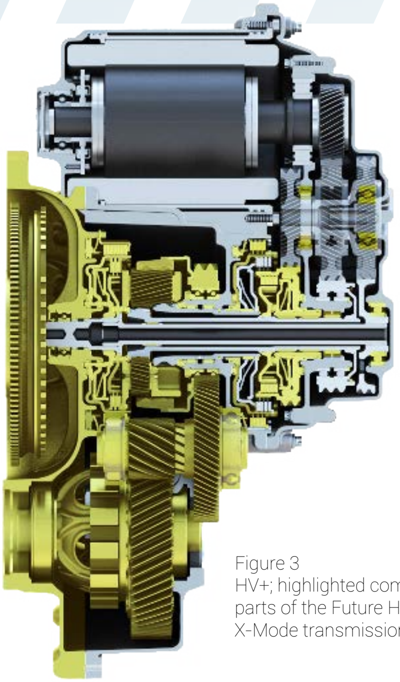

Figure 3
HV+; highlighted common parts of the Future Hybrid X-Mode transmission family

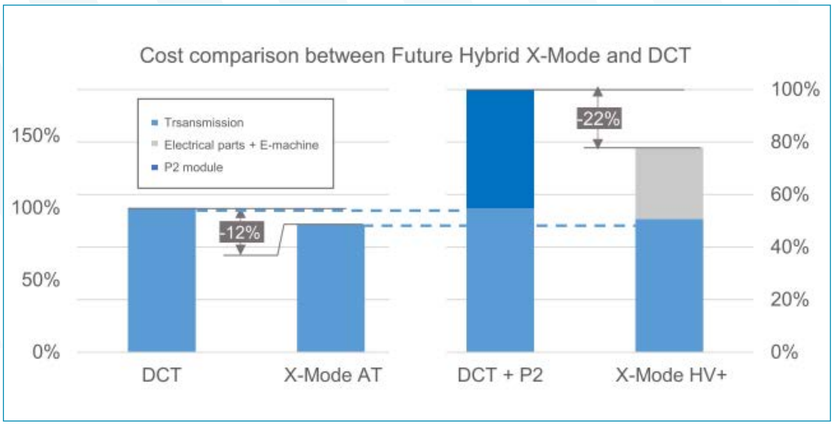

Figure 4 Product Cost comparison between Future Hybrid X-Mode and DCT

Benefits of Modularity

Regarding production, two main benefits have been targeted and achieved:

- high parts commonality between all transmission variants with focus on components with high investments in specific equipment and tooling (see Figure 3)
- assembly of all mentioned transmission variants on a single main assembly line, with variations only in subassembly stations

Depending on the line concept, the latter can be achieved with quick changeover times between variants or even by mixed-model assembly. Prerequisite is a state-of-the-art external and line logistics system. Therefore, the proportion between the transmission variants can be changed freely, without causing significant downtimes. More importantly, reactions to changing market demands can be implemented quickly.

Since the core transmission is included in every transmission variant, the amount of common parts within the Future Hybrid X-Mode transmission family is very high. This leads to the following effects:

1. low investment risk due to a high degree of re-use of production equipment
2. optimized product cost between hybrid and conventional powertrain variants
3. investment only in one main assembly line and subassembly stations

In order to quantify the financial viability of the Future Hybrid X-Mode, AVL defined an exemplary business case with the following key parameters:

- transmission units per year: 400,000
- production duration: 7 years
- automation level: high, with focus on risk avoidance

Variant Split:

- AT: 52 %
- 48V: 26 %
- HV/HV+ 22 %

This scenario was assessed within a target costing calculation. Each manufacturing step was calculated with respective processing times, investments, personnel costs, utilities and overheads and final assembly of the transmissions. The cost for final assembly is low, because the assembly concept enables a total assembly time of approximately 45 minutes, equally shared between manual and machine processing.

The results of this scenario's assessment, illustrating the potential of modularity, were again compared to a technically similar 6-speed DCT with a P2 add-on module under the same boundary conditions.

The costs of the Future Hybrid X-Mode AT are approximately 12 % lower than the product costs of such a DCT (see Figure 4, left).

When considering hybrid functionality, the impact of the modularity is visible in the right part of Figure 4. It illustrates the difference between the Future Hybrid X-Mode HV+ and a 6-speed DCT with a P2 add-on module. In this case, the product cost reduction amounts to approximately 22 %.

Conclusion

Thanks to its modularity, AVL's Future Hybrid X-Mode is a transmission family with a broad range of applications compared to stand-alone solutions. The concept is designed as a minimalistic and compact transmission without compromising functionality. It enhances flexibility in the face of forecasted market development and their challenges. Furthermore, the Future Hybrid X-Mode concept combines decreased investment risk with attractive product costs for the full bandwidth of considered applications.

More information: www.avl.com/-/avl-future-hybrid-technology

The MAGSPLIT® Hybrid Transmission

The Magsplit transmission device splits propulsion power magnetically. In operation, it offers greater efficiency with superior NVH compared to the alternatives. As a power split, the launch quality is smooth and tunably progressive, whether driving purely electrically or with the combustion engine. As electrification proliferates, hybrids must continue to offer a competitive driving experience and, for Chinese customers, this magnetic power split transmission is ideal.

■ Mr. Andrew Chapman, Powertrain Attribute Leader, Changan UK R&D Centre Limited

The Magsplit device

The conventional powersplit has an input from a combustion engine and an e-machine into a mechanical epicyclic gear arrangement. The Magsplit combines the epicyclic and e-machine functions into one device. The device comprises an outer stator and two concentric rotors. The inner rotor has a magnetic field that is, in the current development, generated using permanent magnets and is connected directly to the device output. The secondary rotor, connected to the combustion engine, is positioned in what would be the air gap in a conventional e-machine and has circumferentially alternating materials of high and low permeability. The torque ratio of the device is determined by the ratio of inner and secondary poles.

The transmission arrangement

The transmission arrangement is from then on familiar enough but with the package constraints applied for Changan C/D segment products forcing the second e-machine onto a parallel axis. The transmission length is short at 345 mm with scope to optimise the flywheel and end winding spaces. The secondary rotor acts as a simple single mass flywheel with the magnetic gearing isolating the drivetrain mechanical gears from torsional vibrations.

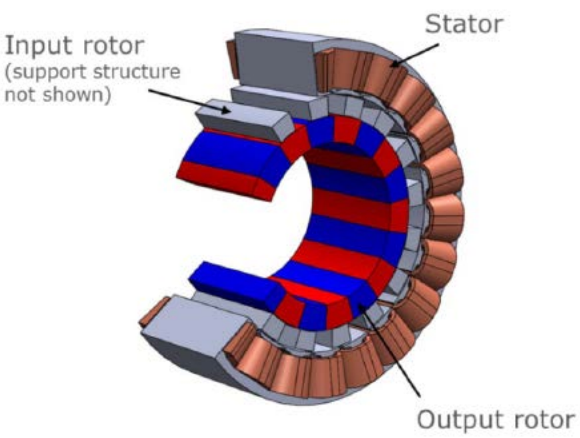

Figure 1 The Magsplit device

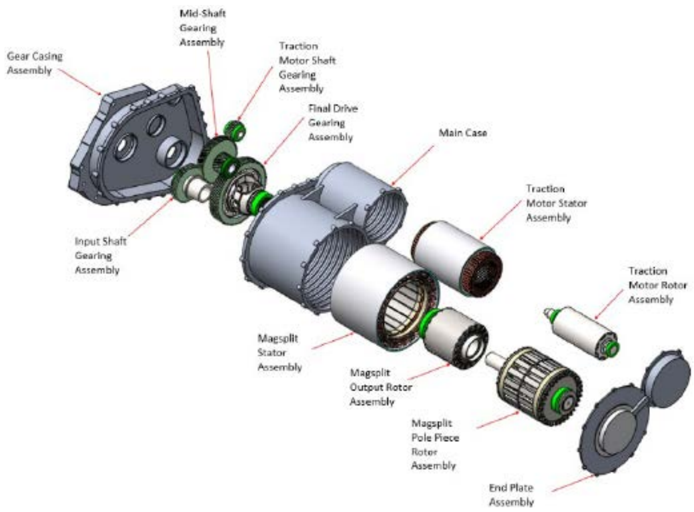

Figure 2 Transmission exploded view

This isolation is possible because the reaction torque for the engine input is provided by the magnetic field of the stator which has zero mechanical inertia. The resultant magnetic field can therefore be placed with precision to counter the torsional oscillations induced by the reciprocating engine. This ability complements engine down speeding and dethrottling techniques which further improve powertrain efficiency.

Changan UK is in collaboration with Magnomatics, Romax Technology, The University of Sheffield and CMCL Innovations, with financial support from Innovate UK, to progress the design and test of the transmission and powertrain system. The integrated powertrain will be manufactured and tested during 2018.

System sizing & vehicle performance

The transmission initial system sizing process starts with the use of the proprietary Magnomatics sizing tool which was utilised to check for performance against Changan requirements. The system supports 0 – 100 km/h acceleration times of <8 seconds when coupled to a combustion engine with a 200Nm torque capability and meets standard gradeability demands.

The Romax developed methodology for rapid concept transmission design and evaluation in conventional, hybrid, and electric vehicles was utilised to inform the early design. In addition to simulating five different drivetrain layouts, sensitivity studies were carried out to evaluate the effect on fuel consumption of changes to magnetic and mechanical ratios, control strategy, and component efficiencies. Romax uses a statistical approach to drive cycle simulation which directly considers speed-acceleration operating points in place of a speed vs time profile, and a single calculation over the operation space in place of a separate calculation for each timestep. A high-level control strategy allowed different energy flow paths to be assessed, optimising the powertrain operation to give the best overall system efficiency and

Figure 3 Relative fuel consumption vs transmission arrangement

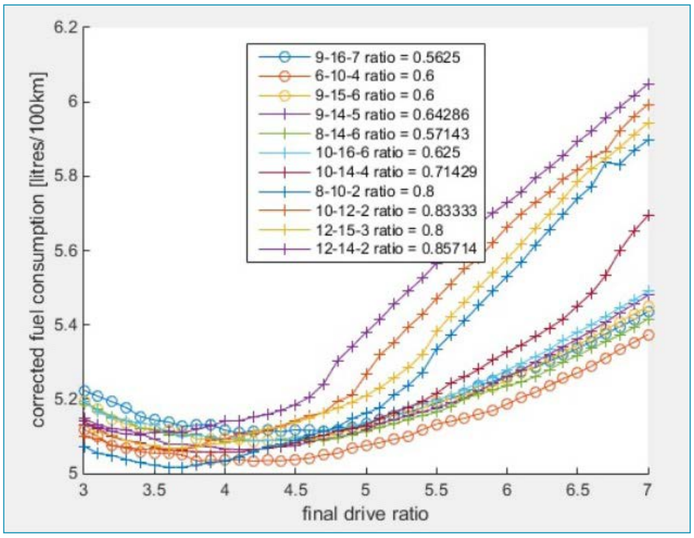

Figure 4 Romax fuel consumption vs ratio analysis

lowest fuel consumption. Although the simulation takes mere seconds to perform, the results have been validated to real world test data with a typical accuracy of ~2 %, which is sufficient for architecture and sizing selection.

The parallel axis, single speed solution is in fact the worst case for fuel consumption of the arrangements reviewed but this solution meets packaging & performance and is within the complexity scope of the project.

The gear ratio assessment showed (Fig 4) that the Magsplit might also be improved compared to the concept design option of 9-16-7 (9 pole pairs on the output rotor, 16 pole pieces on the input rotor, 7 pole pairs on the stator field) but design momentum is maintained by keeping to this choice. Charge sustain fuel economy, when simulated driving the NEDC, is predicted to be ~4.5 l/100 km in a Changan Eado PHEV vehicle whilst accounting for a balanced battery charge state and all warm up factors.

The engine initially used for the physical test cases is the Blue Core 1.0T GDI Otto cycle engine released for the Alsvin V7 in 2016. The energy required to propel the car over the NEDC is 12.4 kWh/100 km at an inertia test weight of 1700 kg and a road load power of 8 kW at 80 km/h. Estimated in this way we can say that the propulsion efficiency is 31 % when operating in charge sustain mode.

Virtual assessment of NVH

To virtually assess the NVH properties of the system, CMCL and Romax are combining their capabilities to generate a computationally efficient oscillatory engine torque signal input for Romax's in-house transmission dynamic analysis tools. CMCL's Stochastic Reactor Model (SRM) Engine Suite and Model Development Suite (MoDS) software toolkits were used to develop a model to predict engine instantaneous torque.

The SRM Engine Suite is an advanced toolkit used to simulate fuels, combustion and emissions in internal combustion engines. Input parameters include engine geometry, operating conditions e.g. EGR, fuel characteristics and features to account for characteristic k-ε turbulent mixing time profiles, injection mass rate profiles. The SRM Engine Suite uses a Probability Density Function (PDF) transport equation based approach. This method allows for rapid model evaluation whilst accounting for detailed chemistry and inhomogeneities in the φ-T space (chemical equivalence ratio; temperature) in the cylinder. The PDF transport equation is solved using a Monte Carlo particle method with an operator splitting algorithm.

MoDS is a highly flexible software package designed to aid in- model development through its suite of advanced numerical and statistical tools. MoDS can accept models in a variety of forms through a user-friendly interface. MoDS was used to calibrate the SRM Engine Suite model of the 1.0 TGDI engine using a select dataset including measured cylinder pressures. The model was formulated based on engine geometry and operating conditions provided by Changan. A Wiebe model (Eq 1) was used to parameterise the flame propagation.

$$x_b = \left\{1 - \exp\left(-a\left(\frac{\theta-\theta_0}{\Delta\theta}\right)^{m+1}\right)\right\} \qquad (1)$$

where:
θ is the crank angle
θ_0 is the start of combustion
Δθ is the combustion duration
a & m are model parameters

The parameters, and from (Eq. 1) are provided by the SRM Engine Suite and have been calibrated such that the model represents the experimental pressure profiles.

The instantaneous torque versus crank angle is calculated by the SRM Engine Suite and includes the frictional and in-cylinder pressure components. The output from the SRM Engine Suite gives the instantaneous torque from both a single cylinder and all the cylinders combined. Figure 5 shows a comparison between the pressure-based torque calculated from the experimental pressure profile and the torque profile output from the calibrated SRM Engine Suite simulator.

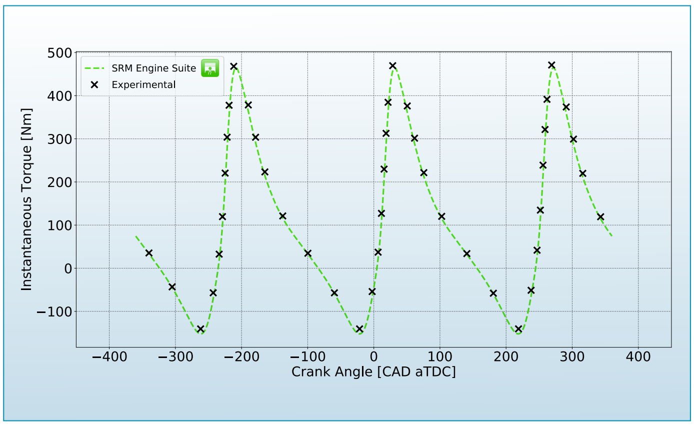

Figure 5 Example torque plots, at 3600 rpm, 97 Nm.

Magsplit control principles

The principal propulsion control of the powersplit is to provide the driver demanded torque into the final drive at an engine speed and load that minimises powertrain system losses.

To illustrate the control principle whilst ignoring losses for simplicity, we first relate propulsion power to a torque demand and speed into the final drive:

$$P = T_{fdi}\,\omega_{fdi} = T_e\,\omega_e - P_b \qquad (2)$$

where engine torque T_e is controlled via command to the engine controller and engine speed ω_e is imposed by control of the Magsplit stator magnetic field. Battery power P_b may also be utilised.

The traction motor torque T_{tm} may be determined using either an engine or Magsplit torque basis as follows:

$$T_{tm} = T_{fdi} - \frac{p_m}{n_p}\,T_e \qquad (3a)$$

$$T_{tm} = T_{fdi} - \frac{p_m}{p_s}\,T_{ms} \qquad (3b)$$

where:
T_{ms} is the Magsplit stator torque demand
p_m is the number of pole pairs of the Magsplit inner PM rotor
p_s is the number of pole pairs of the Magsplit stator
n_p is the number of pole pieces in the secondary rotor

Whilst either method produces the same mean torque into the differential, they will lead to different magnitudes of oscillating engine torque isolation. Use of Eq. (3a), results in ripple-free traction motor torque but a final drive torque with some ripple magnitude. Utilising the Magsplit torque demand (Eq. (3b)), the final drive torque is virtually ripple free, whilst there is torque ripple evident in the traction machine torque. Attempts to control the engine speed by increasing speed controller bandwidth in either case leads to the magnitude of torque ripple increasing. What is also interesting is the electrical system ripple is very much reduced compared to an antagonistic damping method employed using a conventional e-machine with a rotor mechanically connected to the combustion engine. It is possible to illustrate torsional isolation before the fully integrated Romax dynamic modelling or physical testing takes place. Figure 6 below shows two engine operating conditions with the anticipated engine speed oscillation input into the Magsplit device (accounting for engine and secondary rotor inertia), with the resultant isolated output torque below.

Summary and outlook

Use of the clutchless, stepless Magsplit device in a hybrid transmission enables excellent drive quality and engine torsional vibration isolation. The former manifests as repeatable, smooth launch and low speed gradeability and stepless acceleration. The excellent isolation of the engine torque oscillations enables further engine efficiency improvements including stop-start on the move, down-speeding, downsizing and cylinder deactivation. The innovative damping transmission provides the excellent drive quality and NVH vital to meeting the demands of Chinese customers and enables the path to meet future fleet fuel consumption requirements. ■

www.changanuk.com
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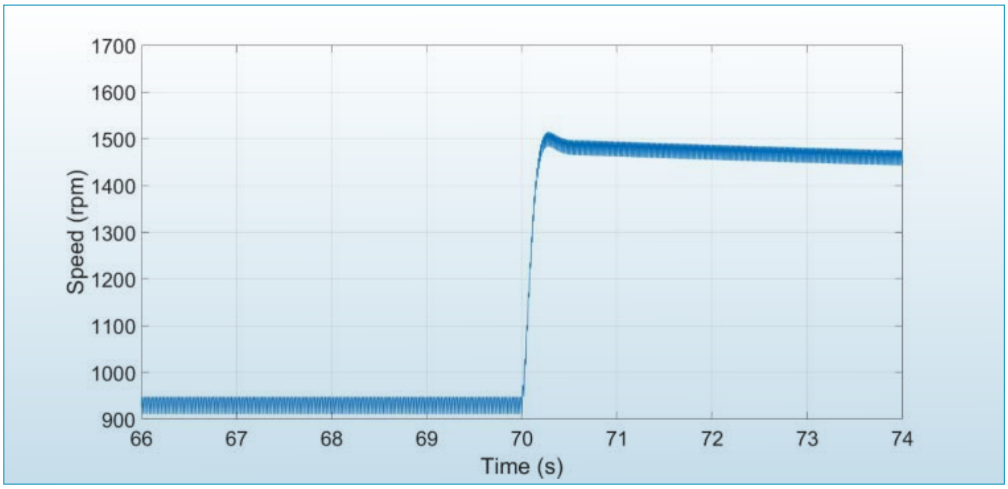


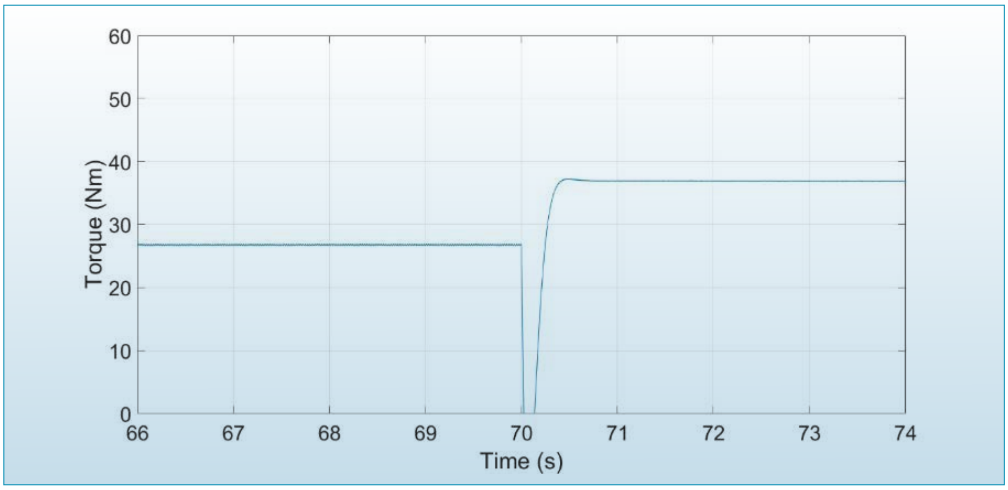
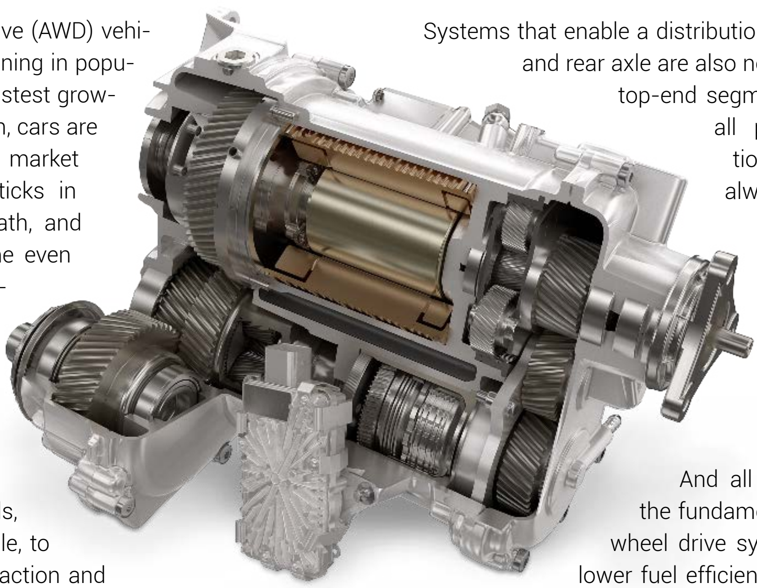


Figure 6a Engine torque input to Magsplit and 6b The resultant isolated Magsplit output torque

Paradigm Shift in Thinking on Four-wheel Drives

Vehicles with four-wheel drives have lower fuel efficiency than models with two-wheel drives? Magna Powertrain shakes up this dogmatic way of thinking with an electric transfer case. It greatly increases fuel efficiency and lowers emissions, increasing driving dynamics of vehicles in the top-end segment.

■ Walter Sackl, Director Product Management, Global – Driveline Systems, Magna Powertrain



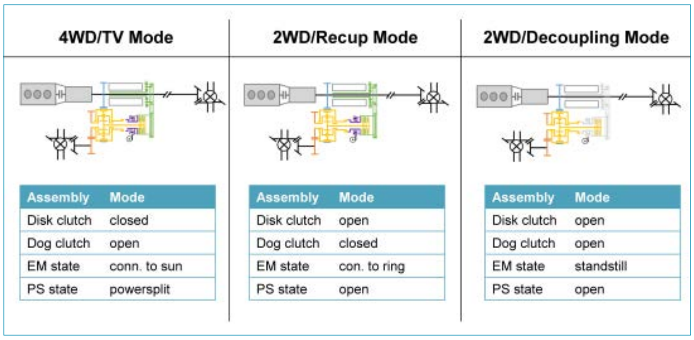
The significance of all-wheel drive (AWD) vehicles is growing, as SUVs are gaining in popularity, which is also one of the fastest growing vehicle segments. In addition, cars are becoming more powerful, and market researchers expect to see upticks in torque, acceleration, braking path, and many other parameters – some even substantial leaps – by the mid-2020s. This changes the requirements for AWDs. Once, traction on snow and ice had been the focus of improvements; now safety and driving dynamics are increasingly overtaking those past needs, enabling sports cars, for example, to benefit from greater traversal traction and faster cornering properties.

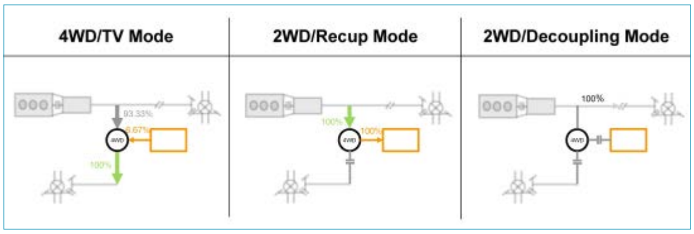
However, the AWD trend has one downside: Providing power to four wheels means more weight, more friction, lower fuel efficiency, and higher emissions. The first generation of powertrain systems for AWD vehicles consumed 14 percent more fuel in comparison to two-wheel drive models. Now advances in technology have trimmed this figure down to five percent. Manufacturers are now using disconnect systems, which interrupt the transmission of power to one axle when all-wheel drive is not necessary, like when coasting in the city or highway driving. The Flex4 by Magna Powertrain is one example of a solution for actively disconnecting from the secondary axle.

Systems that enable a distribution of the torque between the front and rear axle are also now the standard in vehicles in the top-end segment. However, they do not cover all possibilities in torque distribution. For example, the rear axle is always engaged and the front axle only ever receives approximately 60 percent or less of the entire available torque, often quite less, in particular with faster acceleration. This fact is unsatisfactory when faced with increasing torques.

And all of these systems do not solve the fundamental problem: Compared to two-wheel drive systems, there is still the issue of lower fuel efficiency, and there are limitations to a free distribution of the torque between the front and rear axle. Magna Powertrain is developing a novel concept that will finally decouple the driving dynamics–fuel efficiency incongruity. The concept improves the fuel efficiency of a four-wheel drive (4WD) vehicle, surpassing that of a two-wheel drive. The electric transfer case is the remarkable innovation that makes it possible.

Magna Powertrain's Product Development Center in Lannach, Austria, is developing the transfer case and expects the concept to reach maturity by 2019. It is suitable for vehicle classes with higher performance needs and longitudinally mounted engine and rear-wheel drive. It is located in the P3 position, attached right onto the gearbox output





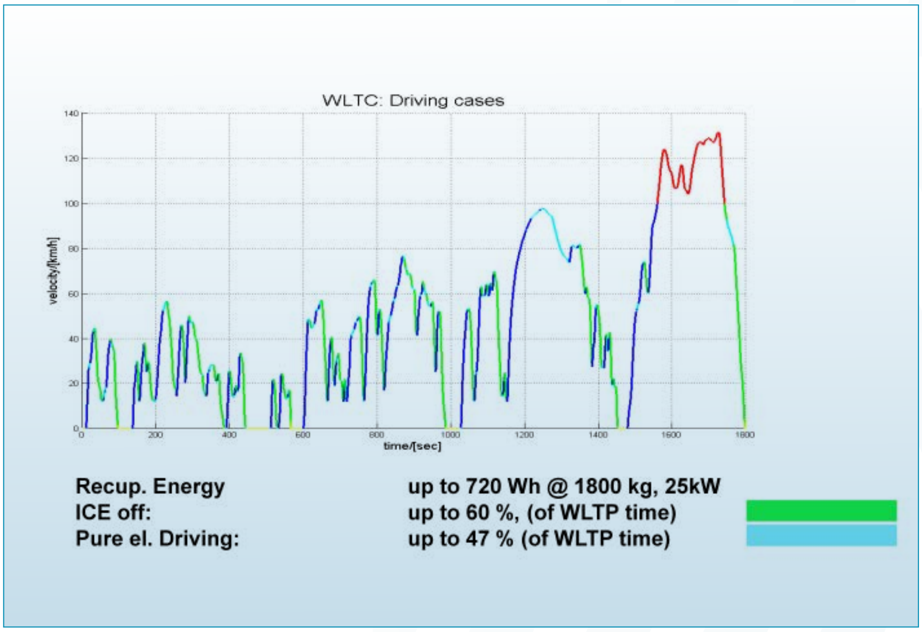
itself. The electric transfer case consists of the following components, in addition to two reduction gears (planetary gear and chain drive):

- High Power Density Electric Motor: It has a capacity of 25 kilowatts and provides power to a small-diameter hollow shaft and is compact enough that the system fits into the available space of top-end vehicles without additional adaptations. This electric "engine" is unique thanks to a compact design with 48-volt supply voltage. The electric machine supports the powertrain via
- Powersplit: It is a planetary gear, which sums the total torque of the electric machine and the internal combustion engine. The torque is distributed to the axles fully mechanically, while the sun gear is connected to the front axle and the hollow shaft to the rear axle. The powersplit functions in a manner similar to a differential. The electric machine varies the rotational speed differential and regulates torque distribution. A greater torque will be transferred to the front axle when the speed of the electric machine is higher compared to the rpms in the internal combustion engine, and less when the speed is lower. No drive is transferred to the front axle if the electric machine is disconnected. The electric transfer case enables three driving modes that can be engaged using the mode-shift system, an arrangement of multi-plate clutch parts, dog clutch, and actuation via ball ramp:
- Four-wheel drive with torque vectoring: The electric machine is connected to the sun gear in this mode. The electric machine is supported by the energy from the battery, and together they attain the maximum performance level of the drive. The torque is automatically distributed to the axles depending on the driving situation, for example, when a wheel starts to slip.
- Two-wheel drive with recuperation: This mode disconnects the electric machine as a drive – it is connected to the hollow shaft of the planetary gear – and no torque is transferred to the front axle. Instead, the electric machine generates energy that is recuperated in the battery when the vehicle brakes, for example.
- Two-wheel drive with decoupling: The electric machine is switched off as the drive and generator in this mode, and the powersplit's planetary gear rotates freely. The output is performed by the rear axle only. This mode covers all driving situations where drive using all four wheels is not necessary due to the low requirements for driving dynamics and traction and no energy recuperation takes place.

The electric transfer case offers a number of advantages, such as perfect traction even when oversteering and true torque vectoring that covers the entire range from 0 to 100 percent on both axles. Distribution of the torque is free of wear and tear because the electric machine performs this function. Tests show that the time needed for stabilization in the electric transfer case is much faster when cornering quickly than the distributor gears of today's leading manufacturers like Actimax from Magna Powertrain. In addition, the electric transfer case enables the vehicle to provide 48-volt electric drive performance in a P3 mild hybrid topology. It offers comfort functions such as fully electric driving in congested traffic situations or when parking.

This situation raises the question 'Why not rely on a fully electric rear axle like Magna Powertrain also offers?' The reason is related to the performance limits of such systems. The capacity of a purely electric-driven rear axle is limited to approximately 80 kilowatts. It would not offer a true freely distributed performance–torque between the axles when combined with a powerful internal combustion engine with several hundred kilowatts. The advantage offered by a fully mechanical AWD that can distribute high performance levels to both axles would disappear. On the other hand, the electric transfer case can offer both this advantage and the possibility of specifically providing additional torque to each of the axles while increasing driving dynamics and safety. And it offers all advantages regarding the improved fuel efficiency of a hybrid drive. If a comparable increase in driving dynamics were created by using a fully electric solution, it would involve higher costs due to the increased weight.

However, there is one item regarding of the electric transfer case that must be mentioned: The battery cannot be charged when the vehicle is not moving because the electric machine is coupled with the output of the gearbox and not with the internal combustion engine. It would require an electric starter generator connected to the internal combus-



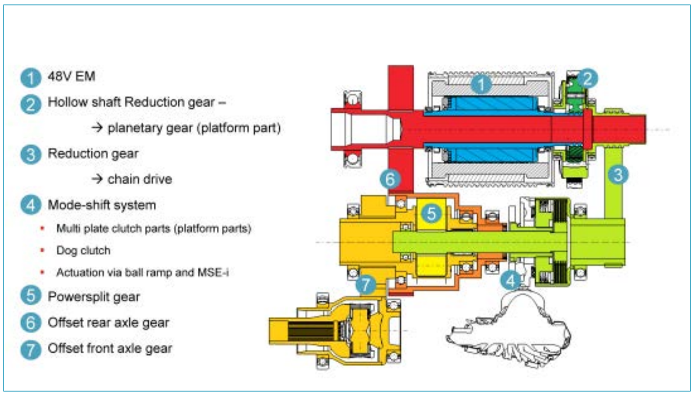
tion engine via a belt. The electric machine from the new concept can only generate energy when the vehicle is moving. However, this concept and the high savings potential it entails are based on the fact that the internal combustion engine is less used. Simulations have shown that it is possible to manage without the internal combustion engine up to 60 percent of driving time in the WLTP cycle if the vehicle slows down and the energy is recuperated or if it is powered by electricity only. In the latter case, it is possible for up to 47 percent of the time.

The etelligentDrive eTC 48V 4WD System, which is the full name of the electric transfer case, is the first four-wheel drive concept that does not only consume less fuel, but that also saves it and emits less CO_2. Developers at Magna Powertrain predict to see savings of around ten percent in comparison to a conventional two-wheel drive.

Tests have also shown that the ‘sweet spot’ in this configuration is a 25-kilowatt electric machine. An engine with less capacity would not make a noticeable contribution to increasing the driving dynamics of an AWD, and if the engine were larger, it would push costs up.

The supply voltage basically sets the standard itself with this capacity, for which an onboard power supply with 48 volts is ideal. The standard 12-volt onboard electrical system cannot supply this power, and it could only recuperate small quantities of energy for the battery. On the other hand, a high-voltage electric system is not worthwhile, because it costs considerably more in terms of safety requirements and weighs more. On the way to pure electric powertrain solutions, 48-volt systems will play a more important role as a transition technology due to the expanded possibilities of implementation in hybrid vehicles and the addition of numerous comfort functions that offer more performance. 48-volt systems will go into series production in many vehicle models starting in 2021. And according to market researchers, 60 to 70 percent of all new cars sold in Europe will feature this power supply from 2025, while the 12-volt power supply will continue to be used for performance of up to three kilowatts. In addition to pure electric powertrain solutions in the high-voltage segment, a large number of new vehicles will be equipped with two onboard electrical systems in both voltage levels starting in the mid-2020s, whereas both systems will be connected by a bidirectional voltage converter to enable the flow of energy in both directions. On the one side there is a considerable gain in efficiency and on the other there is a minimal extra cost, even in terms of weight, which will result in higher fuel efficiency and fewer emissions.

The electric transfer case is currently in development, but the concept should be mature enough by the beginning of 2019. This system targets the top-end segment with its properties of better driving dynamics in AWD vehicles with powerful internal combustion engines. The higher fuel efficiency and fewer CO_2 emissions will provide a vital sales argument that will garner the sustainability of this vehicle class. At Magna Powertrain, we supply the power to the wheels for all powertrain configurations. ■



Interview

"A Quantum Leap in e-drive Performance"

At the 2017 Frankfurt Motor Show, GKN Driveline presented eTwinsterX – an eAxle system with a seamless shift two-speed transmission, and the Twinster module instead of a differential. What's the thinking behind the new concept, and how will eAxle markets and technology develop? We spoke with Theodor Gassmann, Manager Advanced Engineering at GKN Driveline.

Theodor Gassmann, Vice President Advanced Engineering, GKN Driveline

Mr. Gassmann, what are the benefits, specific characteristics and typical applications for eTwinsterX?

Essentially it's a combination of a new seamless shift two-speed transmission, and the Twinster module with two clutches instead of a differential. So we have Torque Vectoring, Limited Slip Differential, Disconnect and Torque Limiter, plus two gears that shift seamlessly. The most compelling application for eTwinsterX would definitely be hybridized SUVs in the premium segment, where it offers significantly higher e-motor performance and axle torque. First-generation eAxles called for around 1500 to 2000 Nm of torque; the eTwinsterX motor supplies 120 kW, has 3500 Nm drive-away torque in first gear, and works at speeds of up to 250 kph in second gear.

Why are the performance parameters higher in the next SUV generation?

Up to now, eAxle applications in plug-in hybrids faced a dilemma. Due to the low battery capacity, and hence limited motor performance, system configurations were always a trade-off between start-up performance and electric top speed. To achieve acceptable acceleration in all-electric mode, the e-drive is only available at road speeds up to 120 to 130 kph and has to be switched off above that. In the second generation, that changes. Firstly, new developments in battery technology mean we can install more electric power. Secondly, we're seeing a shift towards smaller ICEs and more powerful e-motors in split axle hybrid drives too. That means you can drive further, and also faster, in all-electric mode.

"The eTwinsterX is essentially a combination of of a new seamless shift two-speed transmission, and the Twinster module with two clutches instead of a differential. So we have Torque Vectoring, Limited Slip Differential, Disconnect and Torque Limiter, plus two gears that shift seamlessly."

How are two gears useful?

When you optimize a hybrid drive rigorously for CO_2 and downsize the ICE too, you need to be able to use the e-motor in all scenarios, be it launch, off-road, uphill or highway. So you either need very high-torque e-motors, or two gears. Most e-motors with permanent magnets have a 'sweet spot' at mid-range rpm and higher loads where they're over 95 % efficient. Above or below that, their efficiency drops off markedly and can dip below 50 % in the immediate start-up range. When you pull away uphill, for example, or just want to hold your vehicle's position, the motor basically just generates heat at first; that improves quickly once it starts to turn. Also, eddy current losses rise significantly at very high rpm, again reducing efficiency. With a two-speed transmission and a good shift strategy, we've found we gain at least 10 % in terms of system efficiency.

How did you construct the seamless shift?

In essence it's basically a simplified wet clutch DCT. We learned a lot about what synch shift transmissions can do on the BMW i8. You can synch and change gear really well with the e-motor, and on a hybrid drive you hardly notice the short interrupt. It does bother you in all-electric mode though, particularly under higher loads. And if you're going to be driving further and faster in electric mode in future, whether in a plug-in hybrid or an EV, you're not going to want torque interrupt any more. That's not to say you don't feel a thing when you shift under load, because when you shift you're taking more energy out of the drive than the e-motor can fully compensate for, especially under full load. But the increased shift comfort gives you lots of flexibility to shift at will, and hence use torque and efficiency to the max at all times.

How does that affect clutch load?

Obviously, the power loss factors and challenges are different than with a normal multispeed unit. e-Axle drives are very rigid; the e-motor is highly inert. There's no dual mass flywheel, no converter, no long longitudinal shaft … so the clutch needs to be very robust and easy to control. The e-motor has to assist during shifts, and harmonize with the clutch. It can be done, but it requires a sophisticated control strategy. In terms of e-drive availability and performance, though, it's a quantum leap.

How does eTwinsterX torque vectoring differ from classical solutions?

One way to achieve conventional torque vectoring is with additional, controlled override transmissions. Typical examples would be the Audi Sport Differential or the BMW QMVH. The GKN Twinster system in the Ford Focus RS needs no complex override transmissions, and not even a differential in the classical sense. It provides wheel-specific torque distribution via controlled clutches. That works really well in conventional all-wheel-drive vehicles, but an autonomous e-motor on the rear axle lets you do totally new things too. Firstly, you can influence the wheels' cornering grip by modulating the torque on the rear axle. Secondly, you can build a delta of up to 2000 Nm between the wheels, using the two Twinster clutches. Together with the lever arm,

> “With one e-motor and the Twinster system you can use maximum torque vectoring particularly well at full power”

that creates an enormous yaw moment around the vehicle’s vertical axis that basically lets you turn the vehicle in the direction you want. To send torque to the other side, you just open one clutch slightly and close the other a bit more.

You could also use two e-motors and control them separately. What do you think of that?

That’s an interesting solution, using two e-motors off the shelf and doubling performance that way. But in terms of how they work, Twin Motor and Twinster are totally different concepts. To get maximum torque vectoring with Twin Motor, you need to run both e-motors in opposite directions. But then the sum torque is zero, and you don’t move. And at full speed, when both e-motors are supplying maximum torque, torque vectoring is no longer possible. By contrast, with one e-motor and the Twinster system you can use maximum torque vectoring particularly well at full power. Also, a system with one e-motor and clutches is cheaper to build because you don’t need multiple transmissions, disconnects etcetera. That said, I can see applications for two e-motors too – for example city EVs with a 48V system and two 25 kW e-motors. A single 50 kW motor with 48V is not viable.

Do you think torque vectoring with 48V is promising for larger applications?

I’d say it’s more of a dead end. Torque vectoring tends to be a desirable feature and selling point more on the high performance, high voltage vehicles. 48V mild hybridization definitely makes sense up to and including the D-segment, as a way of reducing consumption. But that’s about CO_2 and acceptable costs, and perhaps electric crawling and parking too, not performance. Technology-wise you can, of course, emulate a sports differential with 48V too. But from a market viewpoint I wouldn’t say it fits.

Let’s go back to the eTwinsterX again, which you presented as a coaxial solution. When do offset solutions make sense?

There’s a lot to be said for offset. Coaxial is more the exception you only use when installation situations demand it. In offset drives, the output shaft runs offset from the e-motor shaft, not straight through. That simplifies the interface between transmission and e-motor, and you can vary the installation height by moving the motor and transmission. But we deliberately chose a modular concept for the eTwinsterX. You can use the two-speed transmission and Twinster module for offset solutions too, and you can leave one module out depending on the application. You get the same underlying benefits – such as two-speed seamless shifting and torque vectoring – in both coaxial and offset applications, including in EVs, and also in combination with a second e-drive in electric All Wheel Drive vehicles.

Interview: Gernot Goppelt

A Beltless CVT Technology that really Works

Dana's VariGlide® planetary variator is a CVT innovation with unique benefits and fewer drawbacks

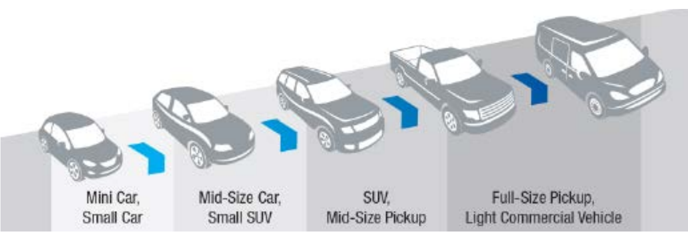
■ Patrick Sexton, Director of Engineering, Light Vehicle Driveline Technologies, Dana Incorporated

With Dana's VariGlide® beltless variator, the promise of a versatile, modular continuously variable transmission (CVT) has been realized. Offering higher durability and fuel savings than competitive belt technologies, VariGlide technology delivers a CVT without the traditional CVT compromises.

Although evolutionary advancements in belt-based CVTs have taken place over the past decade, now a significant breakthrough in CVT technology is setting new standards in fuel economy, performance, controllability, and noise, vibration, and harshness (NVH). The scalable design coupled with the simple, passive mechanical clamping system makes VariGlide technology a significant departure from tradition.

Plus, the VariGlide variator is the only CVT technology capable of packaging within existing rear-wheel drive (RWD) package envelopes.

With the potential for greater fuel savings than competitive belt technologies, Dana's VariGlide beltless variator represents a logical CVT technology choice for original-equipment manufacturers (OEMs) seeking 2025 fuel economy target solutions for applications including small front-wheel drive (FWD) passenger cars, RWD pickups, and all-wheel drive (AWD) sport-utility vehicles (SUVs).

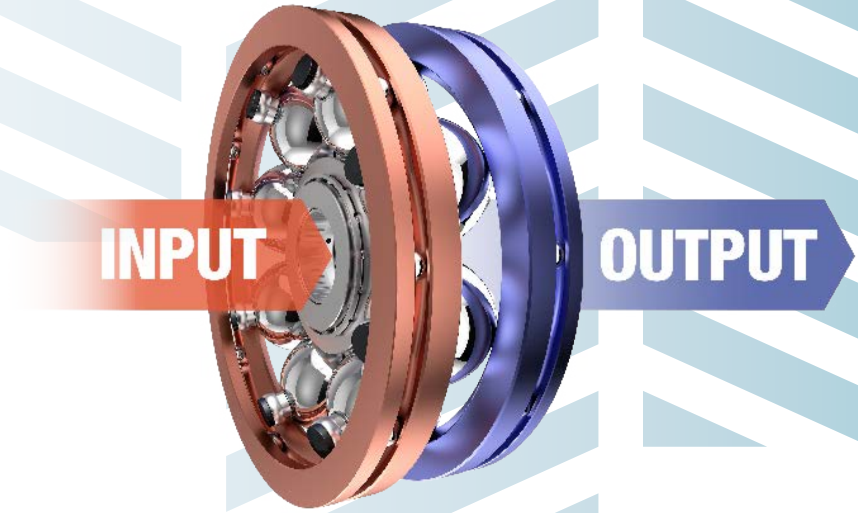


Unlike conventional CVTs, the VariGlide® variator is compatible with rear-wheel drive vehicle architectures.

The VariGlide variator is easy to control and insensitive to slip induced damage. The high-pressure pump typically associated with high parasitic losses and complex control strategies required for belt CVTs has been eliminated.

The VariGlide variator operates as a traction drive. When the fluid at the contact patch experiences high pressures (>1GPa), it behaves like an elastic solid, enabling torque transfer. Speed ratio is controlled by modulating the relative contact diameters between input and output rings. The system uses skew shifting to minimize shift energy requirements and maximize stability. Ratio control is achieved using a low-energy electrical or hydraulic actuator.

With regard to hybrid and electric vehicles (EV), VariGlide technology has the potential to right size the motor and power electronics, optimizing overall system efficiency and energy recuperation, while boosting performance and maximizing operating speed range. The simplicity and precision of the VariGlide-equipped hybrid power path offers enhanced electric motor operating efficiencies, energy economy improvements, and the potential to use a smaller internal combustion engine. For pure electric systems, the VariGlide variator eliminates the need for a mode shift relative to traditional 2-speed systems.



At the global technology center in Cedar Park, Texas, U.S., Dana has nearly 40 engineers and technicians working exclusively on VariGlide® technology development and supporting customer applications.

To develop the variator for volume production, Dana built a dedicated, 45,000-square-foot technology center in Cedar Park, Texas, U.S., where customer prototypes are designed and tested. This advanced facility houses design, analysis, simulation, controls, and manufacturing teams dedicated exclusively to refining VariGlide technology for production applications.

The on-site test equipment accommodates applications up to 400 hp, featuring low-inertia motors equipped with engine-firing pulse simulation and tilt and roll capabilities. A cold chamber, AWD chassis dynamometer, and metallurgy and metrology labs are available on-site and used to support the product validation process.

Being uniquely compatible with RWD configurations is another attribute of VariGlide technology. To showcase the variator's performance in the RWD segment, Dana is developing the next-generation test vehicle equipped with a 4-mode VariGlide transmission architecture designed to demonstrate drivability and fuel economy. The unique characteristics of the selected powerpath enable torque transfer during the mode shift to enhance drivability and acceleration.

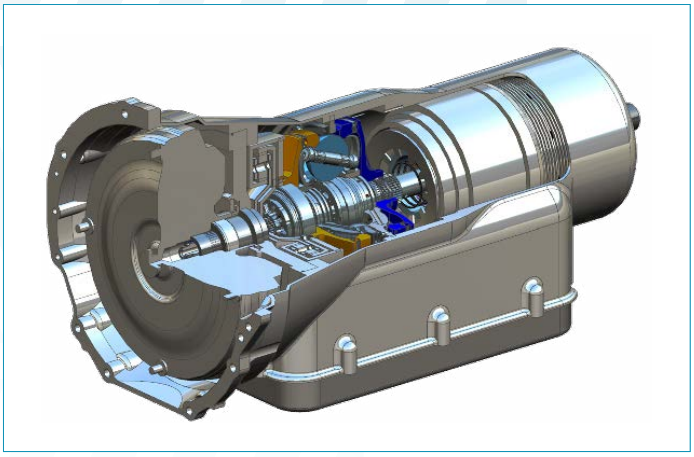
Dana has made substantial investments in developing solutions for light-duty primary transmission, EV, and hybrid applications. VariGlide technology leverages almost 1000 U.S. and international patents and patent applications.

The scalability of the VariGlide variator design extends beyond primary transmissions as the technology can be used in high-power off-highway applications, including forklift trucks, telehandlers, wheel loaders, skid steer loaders, and compact utility tractors.

VariGlide technology has the potential to significantly improve fuel economy without compromising drivability when compared with automatic and current production belt-based CVTs. With more than 300 powerpath permutations available, OEMs have the ability to fully customize and optimize transmission solutions depending on application, market, and drivability requirements. This provides packaging, weight, and cost benefits.

The VariGlide technology architecture is unique and simple. Resembling a planetary gear configuration, the variator is designed as a bolt-

Similar to bearing technology, the VariGlide® variator offers superior NVH characteristics through its smooth and seamless operation.



The current, third-generation VariGlide® variator is production-ready. It represents significant improvements in performance, weight, and cost relative to previous designs.

in module to minimize integration complexity and maximize assembly robustness. The life of the unit is very predictable and extremely robust for a variety of duty cycles and environments, including towing. More than 70,000 hours of durability testing have been accumulated to date.

The only control requirement for the variator is speed ratio selection. Unlike competitive technologies, ratio control is highly stable and requires minimal supervision. Full ratio sweep from underdrive to overdrive can be accomplished in as little as 0.2 seconds. This provides calibration engineers the unique flexibility to develop a variety of shift characteristics ranging from smooth acceleration and cruising to aggressive sport modes for spirited driving.

VariGlide technology enables higher launch torques, maximum energy recuperation, and downsizing of motors and power electronics. Its completely smooth operation makes it a perfect fit for both hybrid and EV applications where perceptible mode shifts are not acceptable.

The popularity of CVT technology is growing in the United States and Europe, and today approximately 40 % of all new car buyers in Japan choose CVTs.

"We are very pleased with the VariGlide variator's performance to date and are focusing our efforts now in scaling for a variety of customer applications," said Patrick Sexton, director of engineering, Dana Incorporated. "We're working with a number of global customers. With our deep understanding of CVT technologies, Dana has built a solid reputation for itself in this area. The goal is to have VariGlide technology in production by 2021."

With the significant market shift toward electrification in recent years, the VariGlide variator is gaining attention from major OEMs and Tier 1 suppliers in multiple applications in addition to primary transmissions.

With more than 70,000 hours of durability testing accumulated on the core technology, the VariGlide® variator presents OEMs with a durable, fuel-efficient, beltless CVT technology.

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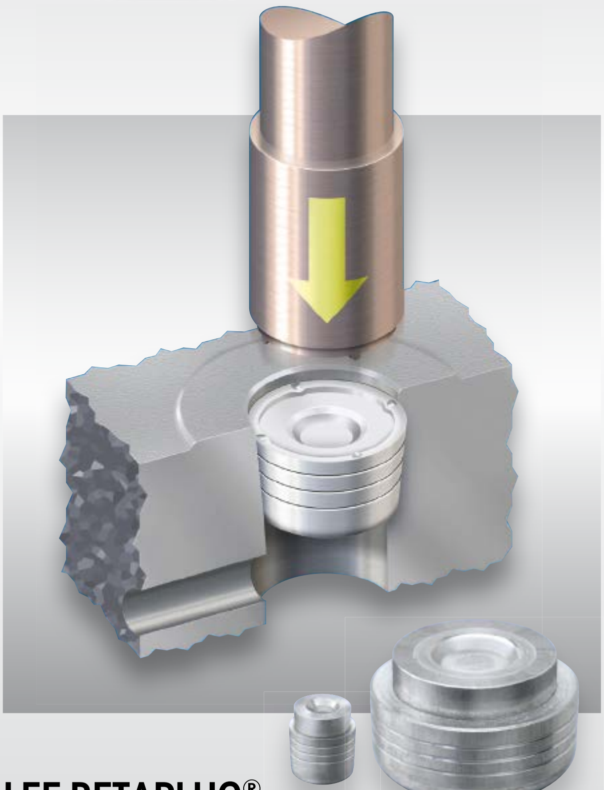

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Continuously Variable Transmission fit for a Global Market

The CVT represents the 2nd largest volume product in the global automatic transmission market. The rising popularity of cross-over SUVs in many of the main markets requires comfortable, highly efficient and hybrid-ready transmission solutions. Punch Powertrain's new torque converter CVT family is fit for that demand.

- Dr.ir. Alex Serrarens, Manager Business Development, Punch Powertrain Nederland B.V.
- Ir. Koen Laurijssen, Manager System Engineering – CVT Development, Punch Powertrain N.V.
- Darren Foster (B.E.), Product Architect VT5, Punch Powertrain Nederland B.V.

Context

Increasing vehicle efficiency and emission reduction has to be contributed for by all members of the modern powertrain. Ultra-high combustion efficiency, various levels of hybridization and a very efficient and functional transmission are mandatory to comply to worldwide emission regulations, particularly CO_2. Such measures should not degrade or should even improve the comfort, convenience and performance of the vehicle to justify the higher cost that is usually involved with clean(er) powertrains, particularly those with increasing levels of electrification. A counter-intuitive trend within the strive for efficiency is the high rise of the very popular cross-over and SUV segments. Particularly in regions where fleet-average fuel consumption and real world emissions come in place, such vehicles even put more pressure on the powertrain requirements. Finally, an additional trend impacting the future powertrains is Advanced Driver Assist Systems and ultimately Automated Driving. In the combination of things, the powertrain should be efficient, safe as well as silent and very smooth.

Given these high level requirements as well as our expertise and background in CVT development and production, Punch Powertrain has designed a totally new and future-ready CVT family of which the first product enters into production in China before the end of 2017. This new CVT—named VT5—realizes a higher efficiency, ratio coverage and comfort level than its predecessor (VT3) and many of its competitors. The first production application vehicle is a cross-over SUV with 250Nm 1.5L TGDI gasoline engine.

Growth of Automatic Transmission Market

Where 20 years ago, only 2 types of transmissions: MT and AT mainly dominated the automotive industry, today the automatic transmission experiences fierce competition from DCT and CVT, particularly in China. In the US, the traditional automatic is increasingly replaced by CVT. Collectively, DCT and CVT outpace the traditional automatic transmission by 2023. The youngest type disrupting the drivetrain but also the car market as a whole are battery-chargeable vehicles, that is EV and PHEV. Punch Powertrain is active in all growing segments, see Figure 1. The manual transmission more or less sustains its absolute

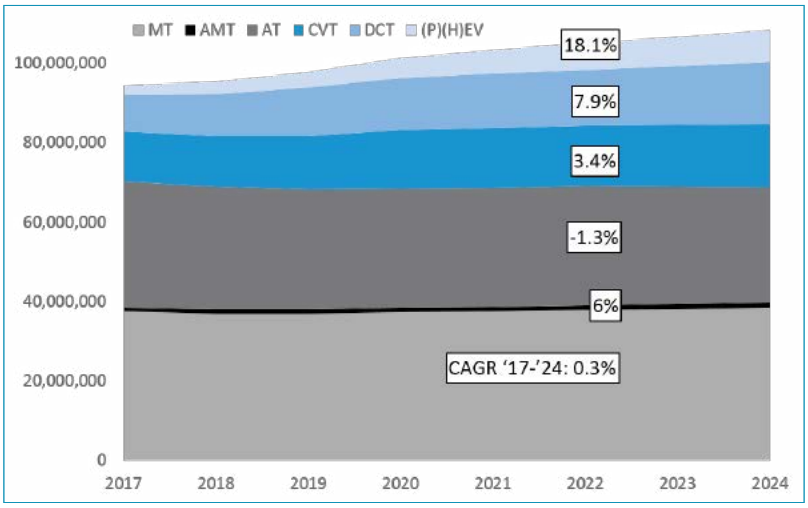

Figure 1 Transmission market outlook up to 2024 (IHS-April 2017), the portfolio CVT+DCT+(P)(H)EV respectively surpasses the AT and the MT market volumes in 2019 and 2023.

Figure 2
VT5 Torque Converter CVT

production volume, however in an ever-increasing world market volume, it has to give away market share to CVT, DCT and battery vehicles.

The main reasons for AT losing ground in the world wide automatics market is that it is harder to meet the differentiating requirements in the various regions. For highest efficiency, and sporty step shifting usually a DCT is the best choice. When fuel efficiency resembling the MT is required in combination with easy (and fast) application as well as smooth, comfortable driving, CVT is the best choice. The traditional AT cannot meet up with this new mix of requirements, so more OEMs are choosing either or even both of these new risers within their portfolio.

Another aspect relating to the rise of CVT and DCT has to do with hybridization. It appears easier for offset type of transmission (like CVT and DCT) to integrate electric machines than for other transmission types. This urges OEMs to choice for portfolio transmission solutions where conventional, 48V and high voltage (HV) hybrids can be modularly produced with the same base transmission design. As an independent CVT supplier, Punch Powertrain develops such new modular CVT family in various torque classes where the new VT5 CVT (Figure 2) is the first in this future proof portfolio.

VT5 Continuously Variable Transmission

CVT expands its position in the world market so the next question for product development is what technical, func-

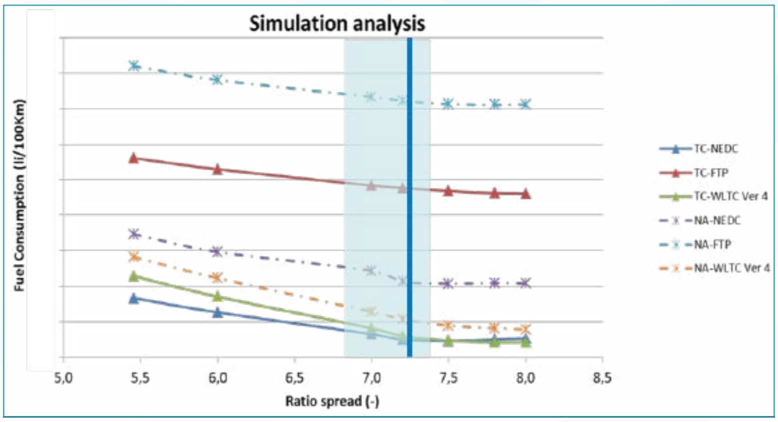

Figure 3 FE sensitity wrt. ratio spread on NEDC, FTP and WLTC cycles for NA and Turbo Charged Engines

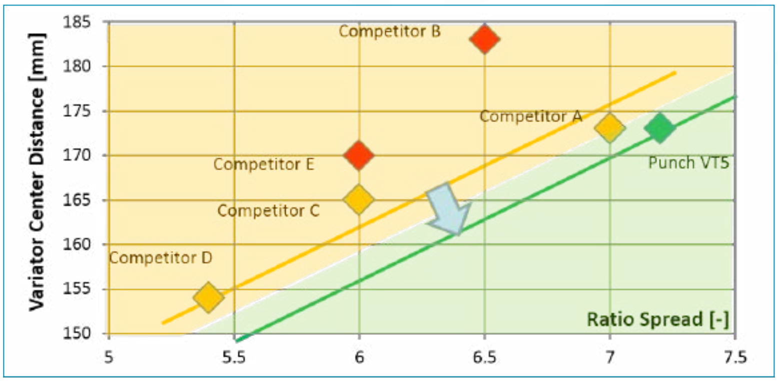

Figure 4 benchmarking of the variator center distance wrt. ratio spread.

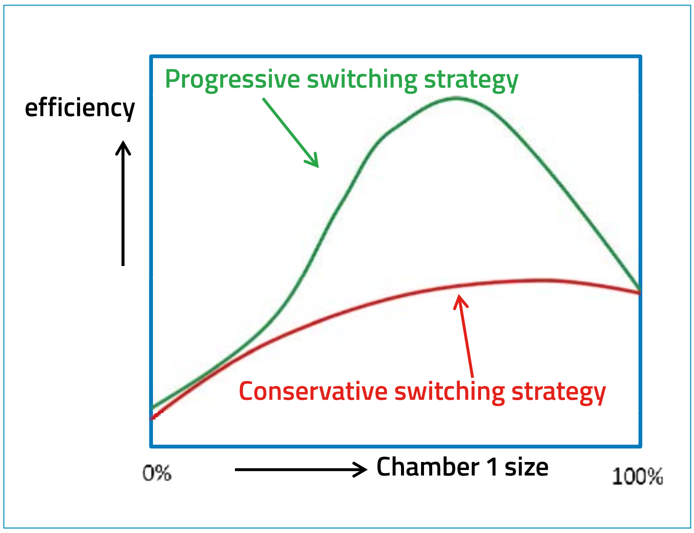

Figure 5 overall pump efficiency dependent on size of base pump

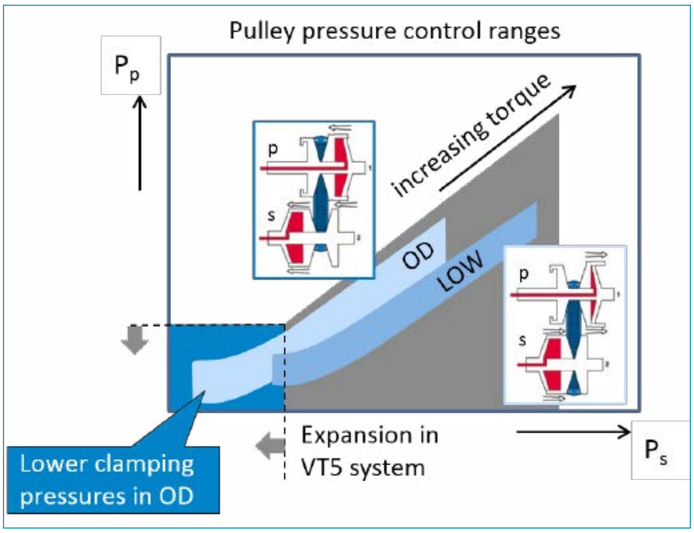

Figure 6 reducing primary pressure level in chamber and the pump switching strategy overdrive

tional and cost requirements need to be met to have a proper fit into the market.

There is a globally increasing trend in the use of downsized up-torqued turbo charged DI gasoline engines as well as an increasing adoption of heavier and more demanding (cross-over) SUVs. For these vehicles it is generally harder to meet CO_2 regulations even though these are weight-based. There is an increasing share of 1.5L turbo engines with torques up to and higher than 250Nm in Asia. Even though their best efficiency regions are usually relatively flat, there is still sufficient benefit in increasing the ratio coverage up to some optimum. According to a detailed sensitivity analysis including a loss model of the CVT, this optimum ratio coverage lies at about 7.2, see Figure 3. If such ratio coverage is to be realized using a single range variator design, it might have a negative impact on the packaging. Ratio coverage particularly impacts the variator pulleys' center distance and with that the entire package of the CVT. By close cooperation with the 28mm pushbelt supplier and smart design of the pulley-set (particularly its stiffness) VT5 achieved a best-in-class match between center distance and ratio coverage, see Figure 4.

State-of-the-art hydraulic and mechanical efficiency

The VT5 achieves an overall higher transmission efficiency than its predecessor VT3 due to several improvements in mechanical efficiency and pushbelt traction of particularly the variator. At the hydraulics side, the improvements arise from the use of an actively controllable, chain driven dual mode vane pump, independent pulley pressure control and reduced churning losses at the final drive.

Torque loss reduction is particularly important for ratios from medium to overdrive, as the CVT tends to be in this ratio range for longer periods with higher loads particularly during rural and highway driving. In such driving missions, the relative energy consumption and thus effectiveness of loss reduction is the highest. Punch Powertrain therefore focuses on exploring efficiency improvements for the overdrive ratio.

The reduction of torque losses is realized in various parts of the transmission and relates to both the mechanical and hydraulical domain and their interrelations. In the pure mechanical domain a substantial reduction in bearing losses was realized due to a reduced radial sag

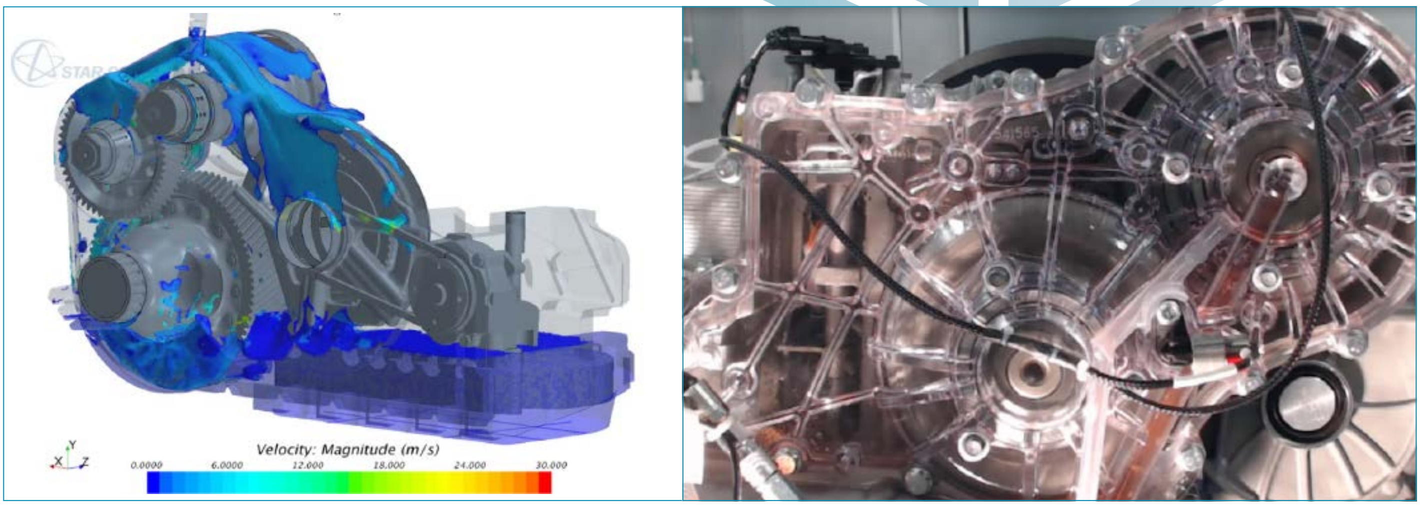

Figure 7 advanced development tools for minimization of hydraulic churning losses

of the secondary pulley shaft by rethinking the system design of the downstream 2stage final drive assembly. Furthermore, the use of the latest high efficient 28 mm pushbelt also contributes to a higher mechanical efficiency and traction of the variator.

Other torque loss reductions are realized in the hydraulic domain however these also induce reductions in mechanical losses. Together with our pump-supplier a new dual lobe vane pump was designed with two output ports where the second can be selectively de-activated using a valve. The pump has good volumetric efficiency in either of the modes, however is further improved in partial load by de-activating the second (boost) port. In this mode only the first port is used, effectively reducing the pump size and torque losses at those instances. In concert with the switching control strategy, Punch Powertrain has further optimized this concept by searching for the optimal split between single port pump size (chamber 1 size) with respect to the full pump size with both ports active, see Figure 5.

The second hydraulic improvement relates to independent control of the primary and secondary pulley pressures. This enables the secondary pressure being controlled lower than primary at overdrive ratio. When dependent pressure control would be chosen, the secondary pulley pressure determines the minimal primary pressure also if this would lead to overclamping. This would occur for ratios from (slightly above medium) to overdrive. On the contrary, by adopting independent pulley pressurizing, much lower clamping control pressures are feasible in VT5. This, together with further minimization of leaking losses, achieves both a reduction in pumping losses as well as mechanical (traction) losses in the variator. As said, the new 28 mm pushbelt also realizes a better traction coefficient between pushbelt and pulleys, in effect this enables lower overall pressures and thus both mechanical and hydraulical losses.

The third hydraulic loss reduction relates to churning losses in the final drive assembly. Using sophisticated simulation and testing techniques, see Figure 7, Punch Powertrain was able to minimize the amount of sump oil and route the lubrication flow off-going from the final drive assembly as to reduce the churning losses in a quite substantial way.

In total there are many contributions to torque loss reduction, they are indicated in Figure 8 in comparison with the predecessor product, both in overdrive situation and an average input torque level. As is clear from the graph, 21 % less torque losses were achieved, where most of that is contributed by reduction of variator losses (less clamping) and the final drive churning losses.

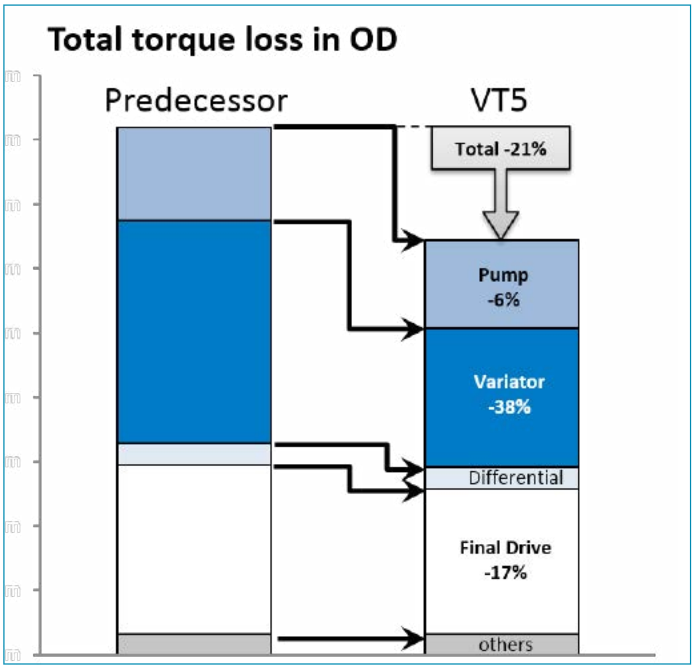

Figure 8 overview of total torque loss reduction in Overdrive ratio

First Application

The first application of the VT5 torque converter CVT will be a cross-over SUV with 1.5L turbo charged petrol engine. The transmission SOP will commence by the end of year 2017. The vehicle and transmission are produced in China for the first customer. Subsequently, the VT5 applications and production will be ramped up for next customers inside and outside China.

The vehicle application has a (12V) start/stop system and the optimized, low-leakage transmission hydraulic system enables this feature without driveline response delay. The transmission TCU software enables some special control features; to name a few, that is altitude compensation, sportmode, step-shift mode, adaptive cruise control support, hill assist support and engine warm-up support.

Conclusion & Outlook

This report discussed the development topics of a new mid torque converter CVT having a first application in a cross-over SUV with 250 Nm turbo gasoline engine. This vehicle segment is very popular in most markets and particularly also in China. These vehicles typically have a higher weight and require relatively stricter fuel saving means than smaller sized passenger cars. Furthermore, the required driving comfort for this application range is high while the cost and price of the cars should attract the main stream public.

The VT5 continuously variable transmission has a torque converter to meet launching and hill start performance. Furthermore, it has greatly improved its mechanical and hydraulic efficiency with respect to the predecessor as well as a class leading single range ratio coverage of 7.2. It can accommodate start/stop functionality and has superior driving features. Amongst others those are stepped shifting for linear drive feel, and a dedicated high altitude control mode to support the ICE's lower torque and breathing capabilities.

The transmission is entering into a first series production by the end of 2017 for a Chinese OEM. Furthermore, variants that accommodate 48V BSG, a fast, advanced start/stop systems and shift-by-wire will be introduced subsequently. With that, the first VT5 sibling of the new modular CVT product family is fit for global passenger car and emission requirements. ■

Figure 9
First application vehicle
Vehicle type: C-SUV
Region: China
Curb/Gross Weight: 1500/1865 kg
ICE max torque: 250Nm
ICE type: 4cyl, 1.5L TGDI
SOP: Q4-2017

Rapid Electric Shift; Reducing the Cost of Integrated Electric Drive Systems

The automotive industry is driving a great deal of exploration into powertrain configurations for electric vehicles, however, the availability of electric passenger vehicles is dominated by designs that use single speed gearboxes. The performance of the traction motor across the vehicle speed range can be improved using a multispeed gearbox; motor torque requirements can be reduced, speeds increased and efficiency performance optimised[1].

- Dr Nick Rivara, Senior Controls Engineer, Electrified Powertrain, Drive System Design
- Simon Shepherd, Head of Electrified Powertrain, Drive System Design

Batteries remain the dominant cost in hybrid or electric powertrains and so opportunities for cost reduction in the remainder of the powertrain need to be utilised to improve affordability of a total system. Genuine advances in optimisation can be realised if a true system design level approach is taken. This article looks at how this type of systems thinking could bring transmission benefits to electric vehicles by designing the motor and transmission to compliment the requirements of each.

Transmission Challenges

The potential negatives associated with the inclusion of a multi-speed transmission with an electric motor are increased weight, complexity, packaging volume and losses through drag and actuation power.

Parallel shaft dog-shift transmissions are the simplest, cheapest and most efficient multispeed options. Electric traction motors can potentially achieve the shaft speed synchronisation function, negating the requirements for conventional synchronisers with associated drag. However, the interruption of traction torque during a shift is inherent in a non-powershift multispeed design.

The challenge is making the shift acceptable to an electric vehicle driver who is accustomed to the seamless nature of single speed system. Minimising the torque interruption duration by rapid shifting, utilising the traction motor to synchronise the shaft speeds, is a possibility: electrically actuated systems, if designed to undertake highly dynamic motion control, can provide response times in orders of magnitude faster than conventional hydraulically actuated systems.

DSD has built up significant project experience in modelling and developing systems utilising highly dynamic electric actuation and combining this experience with our expertise in transmission design have set out to investigate if a dog-shift multispeed transmission could work for an electric vehicle by applying a system design approach.

The Transmission

A simple two speed design employed in the study. Shifting is achieved through a dog clutch on the input shaft connected to the electric motor. Shaft speed synchronisation is undertaken by the motor, avoiding the drag associated with open synchroniser clutch packs and conventional clutches. The output shaft drives torque to the wheel through a conventional differential.

The concept aims to achieve a shift time which is as short as possible. The stipulation for an unnoticeable transmission shift lies in the period of torque interruption being reduced below the limits of human perception for audible noise or perceived jerk (rate of change of vehicle acceleration).

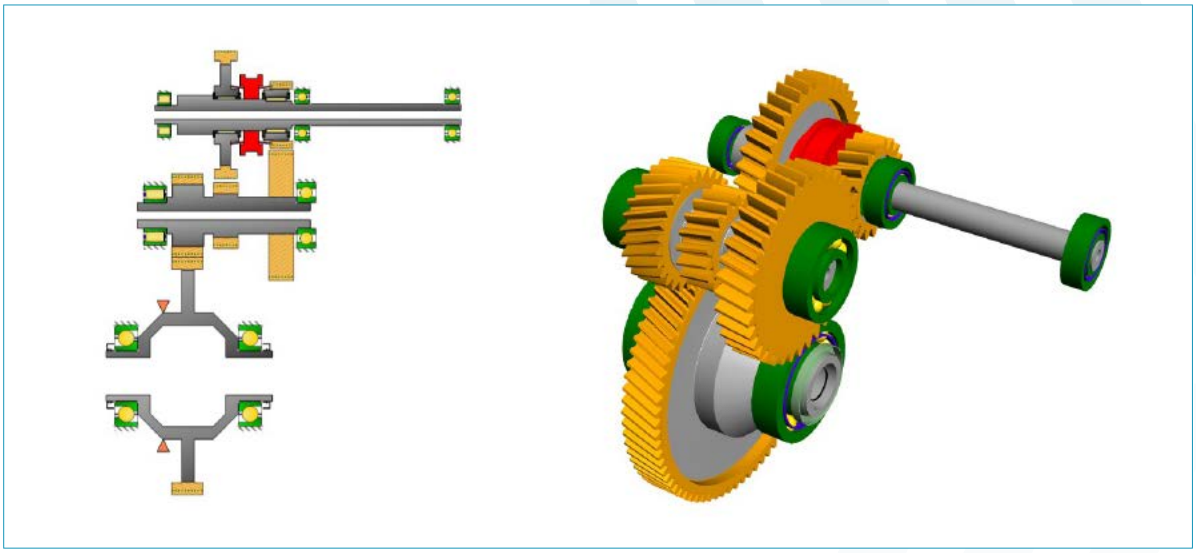

Figure 1 Example Two Speed Transmission with Dog Clutch Engagement

This is an impossible task in a conventional torque-interrupt shift sequence. As the shift duration is reduced, the torque gradients increase, and the theoretical jerk exceeds a level deemed acceptable by conventional thinking. The challenge for a rapid electric shift concept is to make the interrupt at a frequency well above the natural frequency of the driveline and further providing damping of any resulting oscillations with the electrical machine. Stiffness, damping and inertia of the driveline components can also be modified to support the system response.

Initial evaluation of the concept is to be undertaken by dynamic modelling of the transmission and electric motor. The shift sequence is composed of:

- Motor torque reduction
- Dog clutch moves to neutral
- Shaft Speed synchronisation using motor torque
- Engagement of next dog clutch.
- Restore torque to driver demand.

As the dog clutch is moved to neutral, shaft speed synchronisation can occur. This involves the electric motor exerting torque to incur rapid speed changes. The motor encoder or resolver provides high-resolution feedback for the torque control of the electric motor which must ensure appropriate torque at speed synchronisation to prevent unnecessary oscillations or shift shock through the driveline as the oncoming gear is engaged.

Most of the shift period is taken up by the shaft speed synchronisation phase. The dynamic response of the motor in this phase is highly dependent on the inertia of the rotor and any meshed rotating elements on the motor side of the dog clutch.

The illustration above shows ideal speed synchronisation. With the introduction of real system latencies, motor speed can tend to over or undershoot the target shaft speed. This can significantly extend the speed synchronisation time. There are opportunities to reduce this period by implementing alternative optimal motion control strategies.

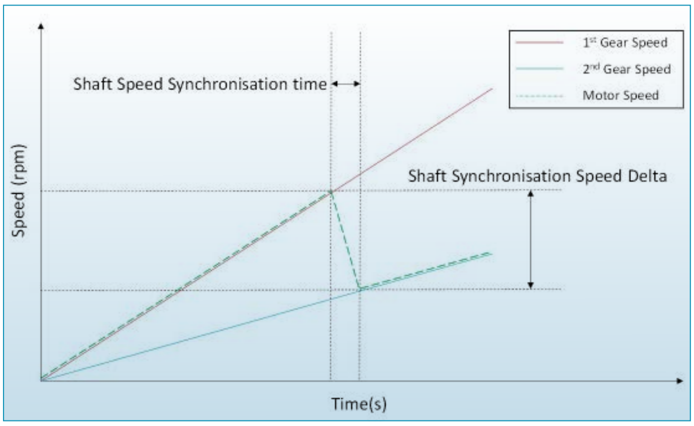

Figure 2 Idealised Shaft Speed Synchronisation

The rotational speed profile of the motor can be planned and executed in such a manner as to optimise the synchronisation event. Planning the speed profile of the synchronisation can help both minimise the energy expended by the motor and reduce phase delays of the control through the inclusion of feedforward control terms. Feedback control relies on speed error to accelerate and decelerate the rotor to track desired targets but introduces control phase delays. Implementing model based control around a dynamic model of the system minimises control loop phase lag in the system and can achieve optimal motion tracking to a defined target. Drive System Design have significant practical experience in motor motion control and aim to combine this experience into torsional simulation system models to investigate the viability of this concept.

Gear Ratio Selection

Selection of optimal gear ratios for a multispeed transmission is critical to achieving the desired performance criteria. In addition to both higher acceleration and/or vehicle speed, ratios that allow the electric motor to operate predominantly in the most efficient envelope of the motor torque-speed curve can directly influence the range of the vehicle on a single charge. Using a simulation tool developed by Drive System Design, the in-gear residency plots of drive cycle simulations overlaid on motor efficiency maps can be analysed to understand the most influential system operating points on vehicle range and highlight potential to improve system efficiency.

Electric Motor Design

This study aims to evaluate the time period for shaft speed synchronisation with various motor configurations. Drive System Design have analysed a current state of the art design (single speed) and extracted performance data against which an alternative motor design (multi-speed version) will be compared.

The torque capability of an electric motor is closely correlated to its physical size and a good guiding metric of the magnetic loading of a machine is the air gap shear stress. In an electric motor with rotor diameter D, stack length L, the shear stress σ produces torque T [2][3],

$$T = \sigma . Area . \frac{D}{2} = \sigma . \pi D L \frac{D}{2} = \frac{\pi}{2} D^2 L \sigma = 2 V_r \sigma \quad (1)$$

(1)

where V_r is the rotor volume of the motor.

This relationship is used to investigate the potential advantages of different motor geometries whilst maintaining the same magnetic loading of the existing state of the art motor.

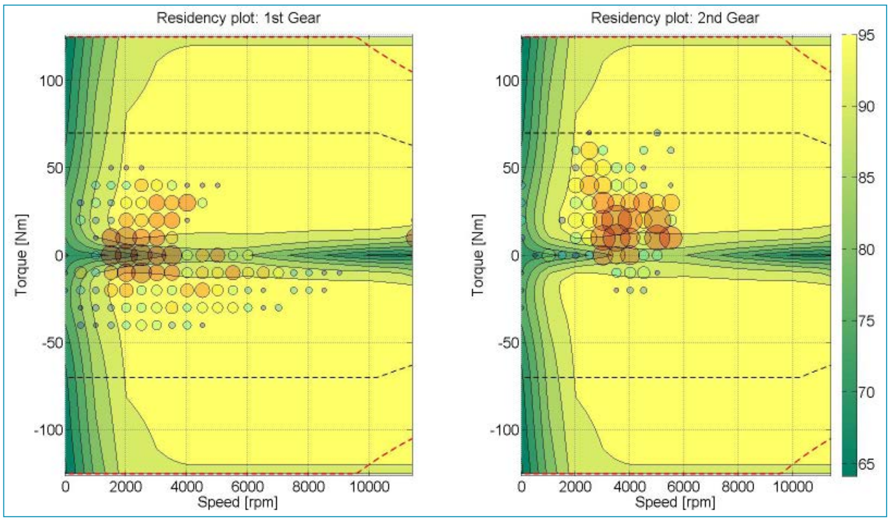

Figure 3
Example of a Motor Residency Plot for 1st and 2nd Gear over a Typical Drive Cycle.

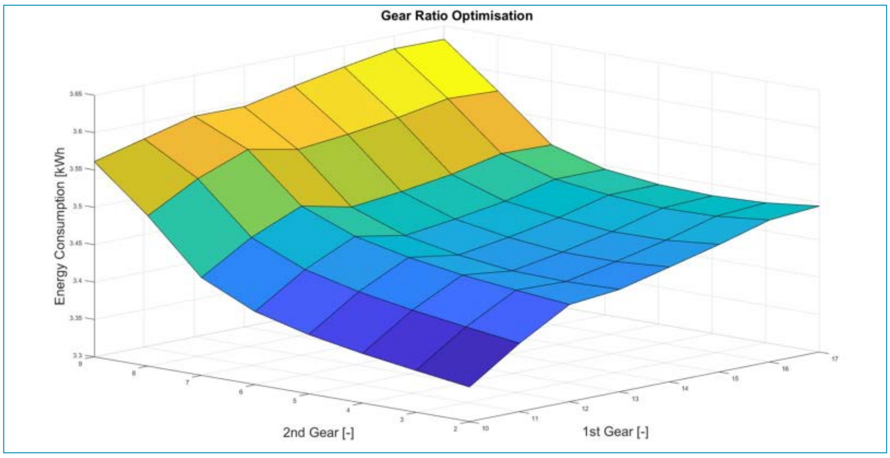

Figure 4
Example of a Gear Ratio Optimisation Sweep

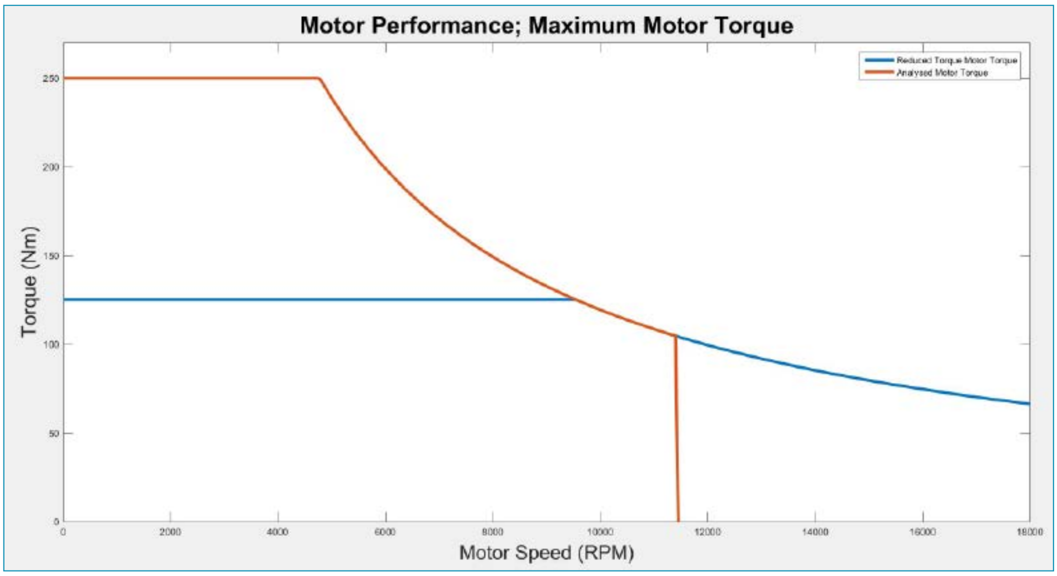

Figure 5 Analysed Electric Motor Torque Speed Curve Reduced Torque Motor

The study first evaluates motor size reduction through reduced torque requirement of a multispeed transmission before an alternative motor package is examined, whereby the motor maintains the original air gap shear stress capability, but is dimensioned for lower inertia to improve the dynamic response of the motor in the synchronisation phase.

Analysed motor parameters from the state of the art permanent magnet motor have been used as a baseline for the further novel motor design:

- Maximum Motor Power: 125 kW
- Maximum rotor speed: 11000 rpm
- Maximum motor torque: 250 Nm

At a system level, incorporating a multispeed transmission can allow the electric motor to operate at lower torque and achieve the same vehicle performance. A production electric vehicle incorporating the state of the art motor studied by Drive System Design shows a single speed reduction ratio from motor to wheel as 9.7. Torque at the wheels during periods of maximum traction motor torque would be 2425 Nm.

Selection of gear ratios for the study assuming a final drive ratio of 3.48:

Gear	Chosen gear ratio	Final Ratio at Wheels
1st	6	20.9
2nd	2.8	9.7

Back calculating the wheel torque in 1st gear gives a motor torque output of 116 Nm, which is under half of the original torque capacity.

Using torque inertia equations and taking motor parameters into account, the time for speed synchronisation is 183 ms for the standard motor.

From equation (1), the torque output of the motor is proportional to the stack length: one simple way to reduce the torque capacity in line with the high first gear ratio is to halve the motor stack length. This will approximately halve the content of rare-earth magnetic material, electrical steel and slightly less than halve the copper content (allowing for fixed end-windings).

Whilst this form factor will reduce inertia, there is little improvement in dynamic response. The potential self-synchronising capability of the motor has not been changed. But if it is assumed the motor has an equivalent maximum power rating (double power density) when compared to the standard motor, the shaft synchronisation time falls to around 145ms.

Selecting an upshift motor speed of 8000 rpm defines the speed synchronisation differential of 4266 rpm before the 2nd gear dog clutch elements can engage. Simulated speed synchronisation times must consider the torque available to the motor at the stated shift speed according to the torque-speed curve.

Dynamic motor design

From equation (1), by increasing the stack length and reducing rotor diameter, rotor surface area can be maintained and hence the air gap shear stress is also maintained. A reduced rotor inertia is realised that enables a significantly faster dynamic response.

For the next study, the rotor diameter is reduced by half but stack length is doubled. Using inertia acceleration equations, observing the motor parameters, the same shift point of 8000 rpm produces the motor speed synchronisation times:

Motor Selection	Delta Speed (rpm)	Time (ms)
Original motor	4267	183 ms
Reduced radius, extended length	4267	73 ms

Although 73 ms is still above the target shift time, this simple model demonstrates the potential that motor design choices can have for electric synchronisation and the viability of the rapid shift concept.

Motor Design Challenges and Opportunities

Reducing the peak torque requirements of the motor enables significant downsizing. However, the motor still needs to deliver the rated system power in a smaller volume. This increases thermal loading and calls for more effective cooling methods to avoid reducing the continuous power rating of the system. The heat-flux achievable through stator water jackets is a limiting factor in this cooling approach. Use of transmission oil for cooling supports active direct cooling and is often found in higher power density motors. A shared cooling fluid and lubricant approach gives designers more scope to deepen integration of the machine with the transmission.

The long, slender rotor design can prove difficult to get even temperature distributions along the length. Cooling gaps in the stator are one potential solution, reducing the non-active copper content of the machine but potentially enabling other solutions that are under investigation.

Initial simulations have shown that by changing the motor form factor, target shift times of less than 75 ms are potentially achievable. The disturbance this rapid event places into the driveline is a subject of further investigation using Drive System Design's dynamic torsional models. The opportunity presented to this research area is to make the duration of interruption short enough to be well above the natural frequency of the driveline and within the ability of the motor to damp out any potential oscillations induced by the event.

Conclusions

- A systems approach to electric vehicle driveline development is the optimum approach – transmission design should optimise the motor performance and the motor design must optimise the transmission.
- A multispeed transmission paired with an electric motor has the potential to reduce motor size and cost but also improve overall efficiency thus reducing battery pack size or increasing range.
- Dog-shifting transmissions are the simplest, most efficient and low cost multispeed solution but torque interrupted shifts prevent their uptake. Highly dynamic shifting has the potential to mitigate this disadvantage.
- A form factor for the motor that is elongated and with reduced rotor diameter reduces inertia and reduces shaft speed synchronisation time.
- The response of the driveline to rapid shifts requires further investigation through detailed torsional modelling.
- In considering motor designs of a higher power density, cooling methods to prevent limitations of the continuous power rating must be developed.
- Drive System Design are taking up the challenge with a goal to minimise shift times, analyse shift quality through full vehicle simulations and investigate adequate motor cooling methods experimentally. ■

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Interview

"Efficiency is the main Goal at every Level of Automation"

The growing automation of vehicles, right up to 'autonomous' automobiles, enables more safety and lower consumption and emissions. What role do transmissions play, and how will they change? We asked Dr. Carsten Bünder, Director Global Product Management at GETRAG, Magna Powertrain.

Dr. Carsten Bünder, Director Global Product Management, GETRAG Magna Powertrain

Mr Bünder, how will automated driving change traffic?

Automated vehicles drive sensibly by nature. They have a plan, and they communicate and cooperate via Car2X. It's almost inevitable that vehicles with higher levels of automation will adopt a guiding role among the automobile population – almost like holding a swarm together. That effect will kick in at relatively low numbers of automated vehicles, we could see it fairly soon on highways. The harmonica effects we know today will be smoothed out, we don't even need Level 5 automation for that. So in that sense both safety, and consumption and emissions, benefit clearly from automated driving.

What role does powertrain electrification play in this?

Automated driving and electrification are not necessarily interdependent. They are parallel developments, but they make almost perfect partners. You can use the opportunities of hybrid drives even more effectively, for instance – for example by tailoring your charging management to your route. When your car knows it's heading for a city, it will enter the low-emission zone with a fully charged battery. And when you drive home in the evening, the charging system will run the battery flat knowing that your car will be plugged in all night. All that works much more comfortably and predictably with automated driving. Plus, it opens up new ways for the electric motor to support the ICE, for example during stop-and-go, crawling etcetera. That enables simplified hybrid drives like DHTs. Autonomous driving and Car2X interact here, theoretically from just Level 3 partial automation on.

Automated driving means people will expect more comfort too. What does that mean for transmissions?

That's true, the driver basically becomes a passenger and is much more aware of the car. NVH requirements will rise sharply because as a passenger, you notice all the influences from the drive train. Again, a hybrid's e-motor can help here by partially absorbing or softening NVH influences from the engine or transmission. NVH performance on all-electric drives is very good per se, but for larger speed spreads they too need load-shift enabled transmissions that can span large ratio steps comfortably. Looking ahead though, I see all-electric drives mainly in inner cities.

Wouldn't stepless transmissions be better there?

As I said, Car2X communication, further automation and the support from the e-motor improve comfort significantly for step transmissions too. But we shouldn't lose sight of the real purpose of automated driving. No matter what automation level people use –conventional, partial or full – the focus is always on lower consumption and minimal emissions. And in terms of physics, multiple-step transmissions like a DCT do have a clear advantage. Then if we can add support from the e-motor, we're pretty close to the optimal combination of efficiency and comfort.

How will automated driving affect the number of gears?

In the mid-term I think it's realistic for the number of gears to decrease. Again, that's a point where electrification, automation and Car2X complement each other: the e-motor, with its greater rpm spread, adopts a more dominant role and eases the load on the ICE. Automation and networked communication calm the drive train down even more. We'll still need transmissions, but they will tend to have fewer gears. The

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

The six levels of Automated Driving

'Automated' and 'autonomous' driving are often used synonymously. However, in its 2015 report 'Automated and Autonomous Driving – Regulation under Uncertainty', the International Transport Forum at the OECD makes this distinction: "… it's not clear at present to what extent future autonomous vehicles will be connected, or truly autonomous (relying minimally on external data inputs)". The general consensus today is that Car2X and cloud computing-based services will play a major role in further automation. Automated vehicles may be fully autonomous in certain driving scenarios, but are likely to be highly communicative in most traffic situations.

(Source: SAE)

"Vehicles with higher levels of automation will adopt a guiding role among the automobile population – almost like holding a swarm together"

DHTs that people have been talking about for a while basically reflect this development.

You talked about the calming influence of automated driving – how does that impact on transmission configurations?

I think as automation levels grow, a new automobile DNA will emerge, defined mostly by comfort and smoothness. That reduces loads, and above all peak loads – what we call the special cases – in the drive. Automated vehicles would never accelerate hard unnecessarily; they always drive economically. And you won't normally see change-of-mind shifting either because they don't suddenly change their mind. So we can simplify transmission components like the clutch, the actuator system, gearset and bearings etcetera. Load monitoring, meaning monitoring and evaluating loads in real-time operation, opens up more opportunities. You don't need to build in mechanical headroom for loads that in reality either never occur, or only rarely in the case of partial automation.

How will automated driving affect the work of engineers?

That's obviously something we factor into our human resource strategy. But I don't think traditional developers and their skills will become less important because even with hybrid drives, transmissions still play a role – and ultimately with advanced electric drives too. What's important is that system interactivity, including cross-vehicle interactivity, is going to be really big. So we need to anchor that way of thinking too, and it will affect every single person. The e-motor developers, for instance, will need to know the whole system just as well as their

colleagues who work on the mechanical components. That's actually a fascinating role. The day may come when we no longer need specific fields of expertise in depth, but that's still a long way off.

Speaking of a long way off, will we still be at the wheel ourselves long term?

I think steering wheels will be around for a long time yet. They don't always have to be right there in front of you. They could retract into the dashboard, for example. I think steering wheels still make sense for special case manoeuvres, just like in a plane. But they'll definitely lose their importance as the main interface between driver and automobile. Coming back to today, it would be wrong to equate automated driving exclusively with robot taxis. There are lots of stepping-stones along the way that make sense, and that will change transmissions and their development without making them obsolete.

Interview: Gernot Goppelt

Systematic Development Process for customized, high efficient Transmission Actuation Solutions

Dipl.-Ing. André Uhle, Team Manager, Transmission Hydraulics & Actuation Technologies, Powertrain Systems Development

Motivation

Automated transmissions use a wide range of different systems for actuating clutches, synchronizers and other shift elements. Beside the classic hydraulic systems, diverse electromechanical and decentralized electrohydraulic systems have come onto the market in the last ten years. One reason for this new diversity lies in the greater number of functions performed by modern actuation systems. Through transmission hybridization, the classic functions of gear and clutch actuation, lubrication and clutch cooling are being joined by additional cooling and shifting functions for integrated electric traction motors and disconnecting clutches. A further reason is found in the tougher legal demands being made on efficiency, which are hard to meet with classic hydraulic transmission control systems. So for example, an electromechanic shift system can save up to 3g CO_2 per km compared to a high efficient hydraulic control system. The broad diversity within the group of electromechanical actuation systems as well as the tighter requirements profile is making it more complicated to select a suitable transmission actuation system. A large number of influencing factors must be taken into consideration. The type and number of gear-shifting elements, the available package, the required shifting time, the different amounts of energy consumption and the system costs are just a few of these influencing variables.

Systematic Advance Engineering Process

The systematic advance engineering process developed at IAV addresses the complexity of optimizing and evaluating electromechanical actuation systems as early as possible in the development process. Involving a minimum of time and following a targeted approach, it provides the engineer with a tool for generating application-oriented solutions for diverse actuation tasks in the vehicle environment. The simulation process starts with a requirements phase in which the actuation system's target application and input variables are defined. In addition to the maximum values for shifting force, shift travel and the required shifting time, key input parameters also include the force-travel characteristics of the shifting elements being actuated. The core element of the simulation process is the systematic generation of electromechanical shift actuation concepts. This begins by determining the main influencing parameters of such a system and varying them within physically meaningful limits. These parameters have a significant influence on the attainable shifting time, on energy consumption, the package needed and the costs of the considered actuation systems. In order to obtain information on energy consumption and shifting time, the next step involves a transient 1D shift simulation of all parameter variants across the actuation process. In this context, the electric motors and mechanical components contained in the actuation concept are pre-dimensioned and reproduced in the simulation model by using their specific characteristic curves, mass inertias and efficiency levels. This makes it possible to generate a simplified package model for all configuration variants of the actuation concept examined in the search space, permitting initial package studies as well as providing information on their suitability. The subsequent utility value analysis filters and evaluates the layout variants in terms of defined criteria and also permits parameter studies and sensitivity analysis. This makes it possible to reach a final concept decision either iteratively by manually limiting the solution set, or fully automatically using the utility value analysis.

As the spectrum of electromechanical actuation system principles is extremely broad and these systems can be designed in very different ways in terms of technical design, it is worthwhile and necessary to systematically describe the sub-functions and the potential concepts for realizing them using the principle of the morphological box. By

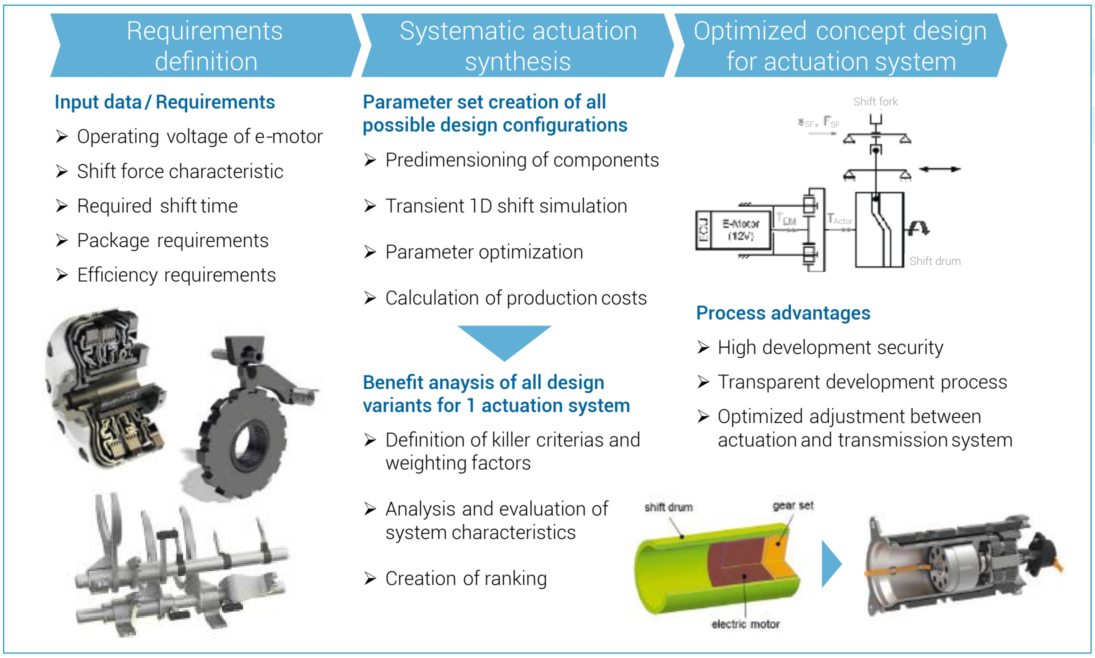

Figure 1
Systematic Advance Engineering Process for Optimization of Transmission Actuation Systems

breaking down the overall function into individual sub-functions (e.g. energy provision, torque conversion, motion conversion), describing them mathematically and combining them to produce a complete actuation system, it is also possible to generate new shifting systems synthetically on the basis of familiar function principles.

Example: Electromechanical Gear Actuation in a Hybridized Dual-Clutch Transmission

In this section, the advance engineering process is explained in detail on the basis of the layout of an electromechanical shift drum actuation system designed for gear actuation of the hybridized 8-speed

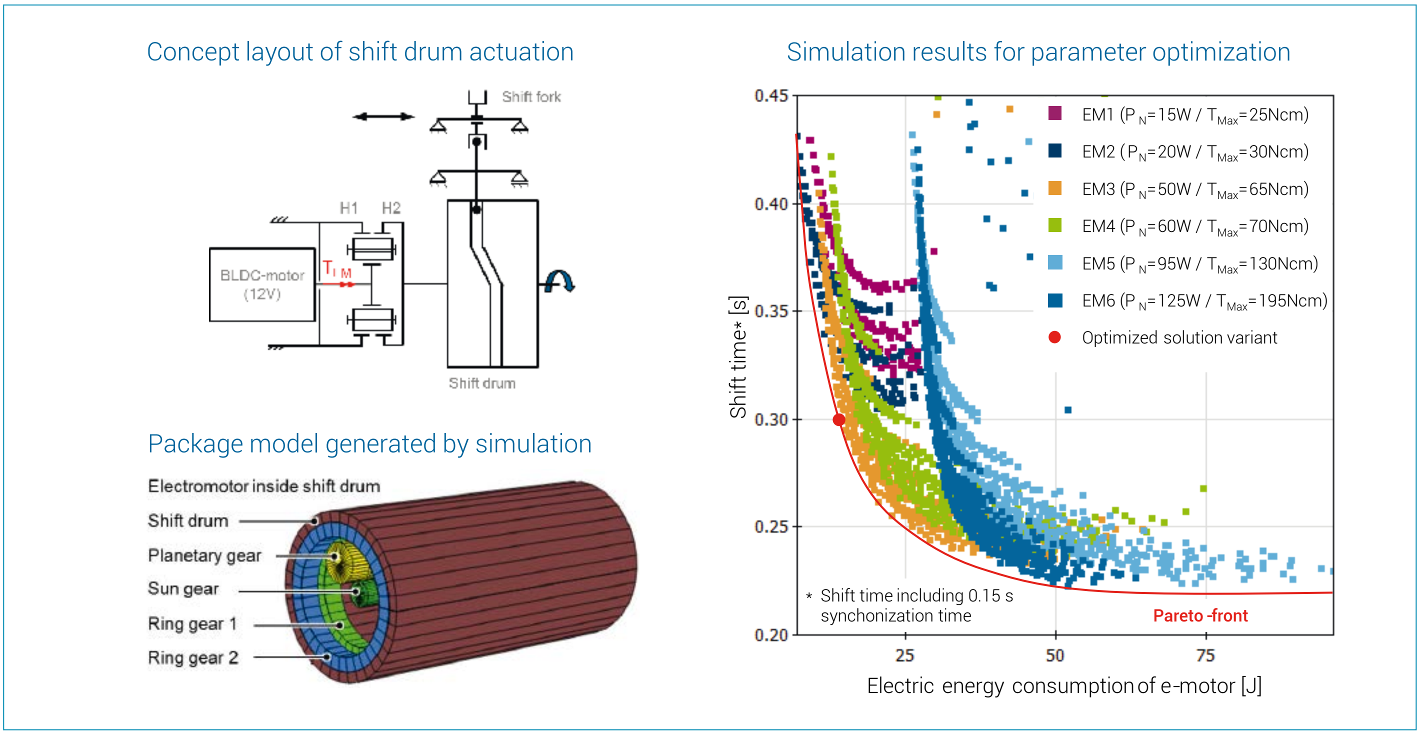

Figure 2 Structure diagram (left) and selected results for parameter optimization of shift drum actuation system

dual-clutch transmission developed by IAV. This transmission is designed for maximum input torque of 450 Nm and has eight forward gears and one reverse gear as well as a wet dual clutch and a disconnecting clutch. Given relatively compact package, it is possible to integrate an electric drive motor in P2 design. This is mainly because of the transmission's coil structure and the associated reduction in the number of wheel planes to four. The actuation system needs to engage five shift forks, each with a maximum shift force of 600 N and a shift travel of 7.5 mm. The left-hand part of Figure 2 "Structure diagram (left) and selected results for parameter optimization of shift drum actuation system" shows a schematic diagram illustrating the setup of the shift drum with integrated electromechanical actuation system. For clarity's sake, the structure diagram only shows one shift path with associated shift fork.

During the transient 1D simulation, the gear shift process is broken down into a defined number of time steps, with the physical system's characteristics being computed for each step. Using characteristic maps for the electric motor, it is possible at any time to ascertain the motor's energy consumption from the prevailing operating state. The aim of the advance engineering process is to optimize the performance of electromechanical actuation systems in relation to the particular application case and customer focus. This is essentially a matter of the main system parameters. The energy consumption, shifting time and production costs of the shown shift drum actuation system are largely determined by the size and power output of the electric motor used, the transmission ratio of the planetary gear set, the pitch angle of the shift paths as well as the diameter of the shift drum. Varying just these four parameters within the specified physical limits leads to a variant diversity of approximately 10,000 parameter sets. Other actuation systems quickly reach ten and more parameters, increasing the number of parameter sets to examine at an exponential rate. As each parameter set represents a layout variant of the electromechanical actuation system and, in the further course, undergoes the above-described 1D shift simulation, it is necessary to use computer clusters in order to keep computing times within a reasonable limit. The results of parameter optimization, shown in Figure 2 "Structure diagram (left) and selected results for parameter optimization of shift drum actuation system" (right), illustrates the trade-off between energy consumption and shifting time. The Pareto front shows the line of optimal solution variants in respect of these two criteria. Each dot inside the 2D plot represents one design variant of the actuation system. A utility value analysis makes it possible to perform the selection process for the optimal actuation system layout automatically, transparently and in line with specific customer needs. As can be seen in the 2D plot, a nominal e-motor power of 50 W is the best compromise between shifting time and energy consumption. The preferred concept is further distinguished by the fact that the electric motor as well as the necessary transmission ratio can be integrated into the shift drum. The fully parametric package model illustrated in Figure 2 „Structure diagram (left) and selected results for parameter optimization of shift drum actuation system" (bottom left) is generated automatically in the simulation program and is based on an analytical preliminary layout of the mechanical components shown.

In order to compare several electromechanical actuation systems and examine them for the specific application, the above-described process is carried out for a large number of technically viable shift systems. Besides shifting time, energy consumption and package, the technical criteria applied also include indirect characteristic values, such as the mass moment of inertia of the components to be accelerated and the mean efficiency of the electric motor, across the gear shift process. The results of technical evaluation also undergo economic assessment. Costing is based on the preliminary design of the mechanical components and purchased parts, with each production part being linked to a bulk cost unit rate and taking into consideration a specific production process and material. Purchased parts, such as electric motors, bearings and spindles, are also taken into account.

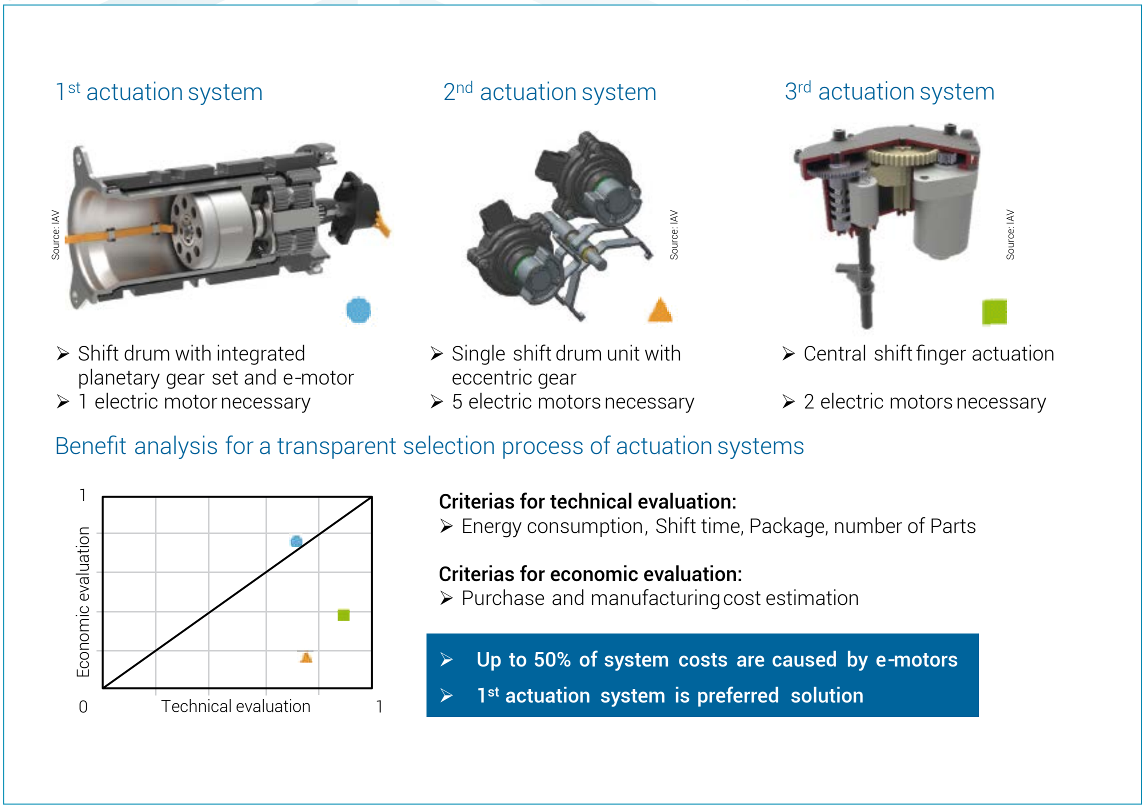

Figure 3 Results of utility value analysis for gearshift system comparison of 8H-DCT450

The aim of this approach is not to predict absolute costs for manufacturing an actuation system but to permit a relative comparison of the systems under analysis. In the final utility value analysis, a technical and an economic utility value is formed for each system under consideration.

The results of this evaluation are shown in Figure 3 "Results of utility value analysis for gearshift system comparison of 8H-DCT450". Based on the results of the simulation process, three design concepts for gear shift actuation has been developed by IAV. These three different electromechanical actuation systems were compared for actuation of the five shift forks of IAV's hybridized 8-speed dual-clutch transmission (8H-DCT450).

As a result, the single actuator (2^{nd}) is rated less favorably than the centralized actuators (1^{st}, 3^{rd}). This means that from a technical point of view, the two preferred variants are the central shift drum already presented as well as a central shift-finger actuation system that uses two electric motors and additional mechanical components to produce a selecting and shifting movement. Essentially, the difference in evaluating cost for these two concepts lies in the number of electric motors that need to be used as these, together with the associated power electronics, account for up to 50 % of the total system costs. The production of gear wheels, shafts and spindles only plays a minor part in evaluating the economics.

Concluding, it can be summarized that in economic terms central actuation is the most cost-efficient gear shift system. In the application example under review, the central shift drum with integrated actuation system represents the preferred solution because its disadvantages do not take effect on account of the given transmission structure.

Fatigue – the common Enemy for Powertrain Components

Tougher load collectives do not have to result in costly solutions at the system level. By utilizing the fatigue resistance of clean steels, the mechanical design world now has a step-change solution to help deliver increased power density, range and efficiency.

- Erik Claesson, Director, Head of Industry Solutions Development (ISD), Ovako AB
- Lily Kamjou, Senior Specialist, Powertrain, ISD, Ovako AB
- Elias Löthman, Application Engineer, Powertrain, ISD, Ovako AB

Introduction

The evolution of power density in terms of the torque delivered through the powertrain shows an exponential increase when we review historical figures for both light and heavy duty vehicles, figure 1.

The demand for more torque in combination with new road load collectives for vehicles is creating completely new fatigue conditions, especially for rotating parts. This is independent of whether it is an ICE (internal combustion engine), HEV (hybrid electric vehicle) or EV (electric vehicle).

This puts new demand on the steel properties of rotating parts with different levels of High Cycle Fatigue (HCF) for light and heavy ICE vehicles. Electrified vehicles will enter Ultra High Cycle Fatigue (UHCF) conditions due to higher rpm, fewer gear steps and the demand for longer service life. In many cases, the best replacement for conventional steels are clean steels with carefully controlled inclusion sizes and in some cases, additional isotropic properties.

Clean steel opens up completely new cost-efficient design possibilities as well as being a competitive alternative. Keeping the same design generation and only upgrading the material in critical components is one solution. It is also an alternative for solving emergency cases where components fail before the calculated service life.

Range and Infrastructure

ICE, HEV and EV share the same target; to achieve the best possible range on energy input. Light weight is one of several variables to consider when increasing the range of any vehicle. Power density is a better way to embrace the task. By using steel with increased fatigue resistance in combination with clever design and manufacturing, the overall system efficiency can be challenged.

For EVs especially, the trend towards higher rpm means that the smallest possible E-motors can be used. This puts increased demands on UHCF where inevitably steel cleanliness will play a vital role.

Changing ownership models for passenger cars and infrastructure solutions to provide a balance in the usage of ICE, HEV and EV will be a delicate task.

Stakeholders providing infrastructure solutions will gain from increased fatigue resistance in the materials used to provide increased range from the EV powertrain systems.

Fatigue – Why Clean Steel matters beyond present design standards

To define fatigue performance levels beyond those currently available in standards such as ISO 6336-5, Ovako has introduced the clean steel denominations BQ-Steel and IQ-Steel. BQ-Steel represents the fatigue performance level corresponding to clean bearing steels. The performance level of IQ-Steel exhibits isotropic properties, i.e. equally strong in all directions. The denominations BQ-Steel and IQ-Steel represent different fatigue performance levels independent of alloying composition.

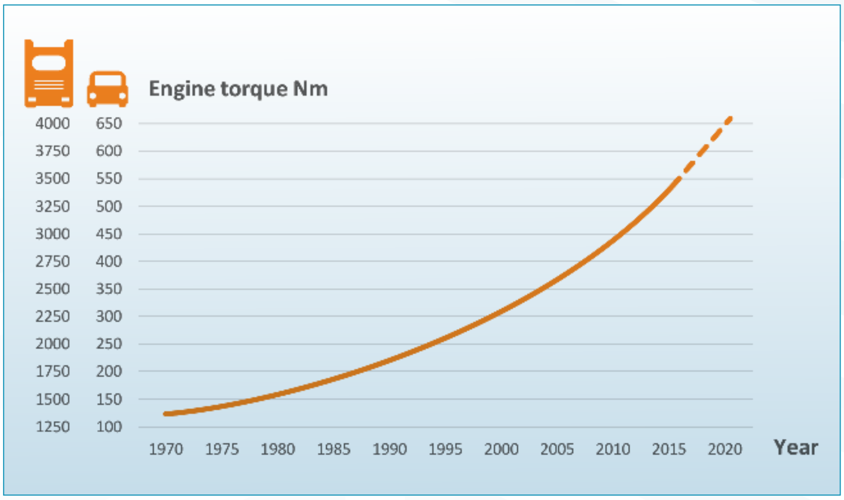

Figure 1
Typical engine torque increase over time

To increase power density in a design, the following fatigue performance strategy is proposed.

1. Change to cleaner steel of the same grade for increased fatigue performance, i.e. reduced maximum inclusion sizes in the steel.
2. Change steel grade and cleanliness level if in addition to improved fatigue performance there is a need for increased hardenability, core hardness and/or reduced internal oxidation.

To provide designers with new tools, Ovako has introduced 'at-least-values' for bending and contact fatigue and placed them into the present ISO standard graphs. Figure 2 shows the BQ and IQ performance compared to the current fatigue limits given by the ISO 6336-5 standard. A step change in fatigue performance provide completely new design possibilities to handle increased torque and tougher road load collectives.

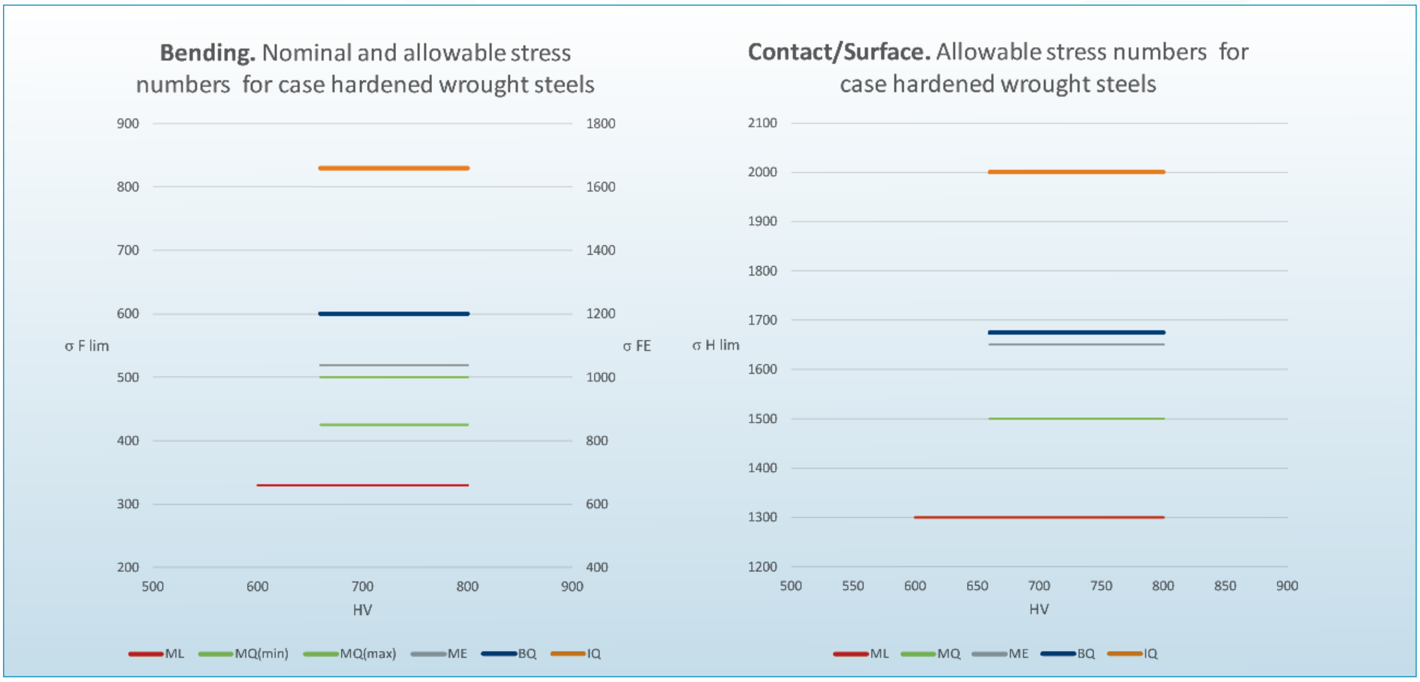

Figure 2 Bending fatigue and Contact fatigue. Performance according to ISO 6336-5 with BQ-Steel and IQ-Steel added.

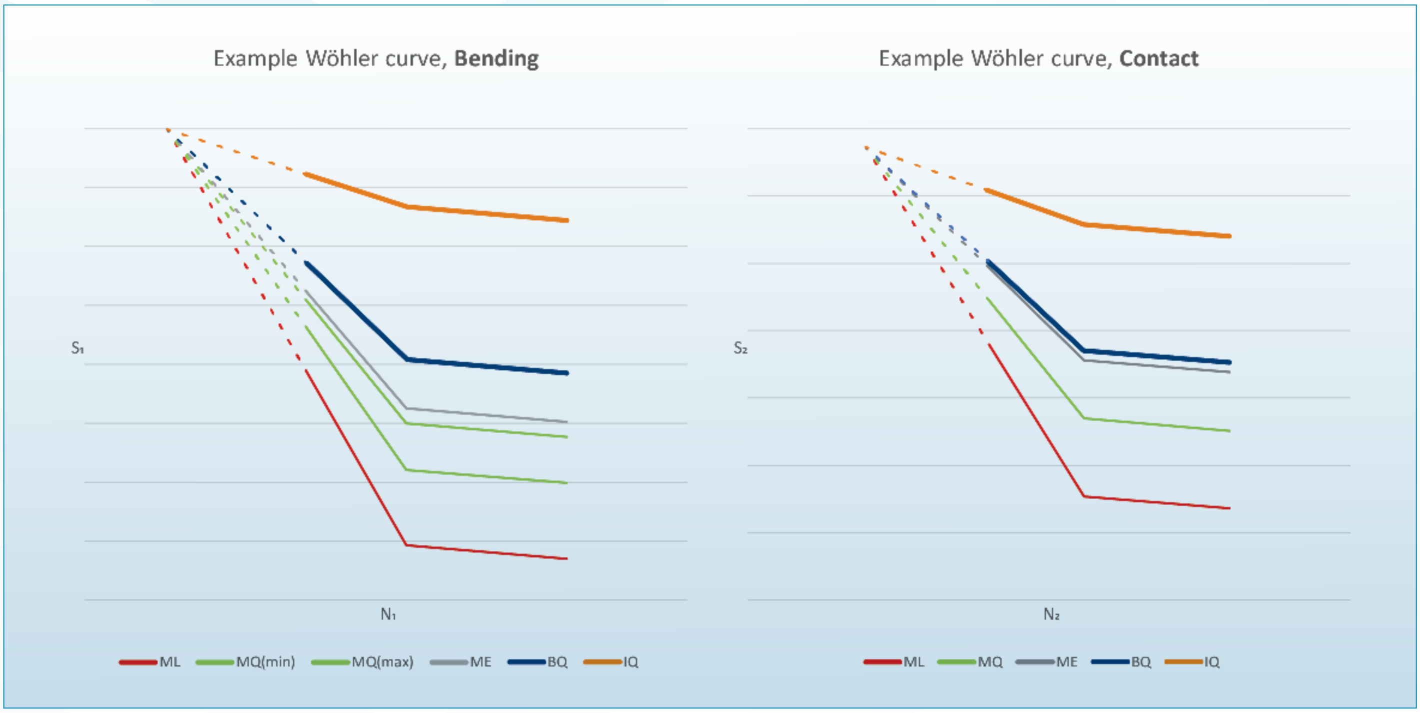

Figure 3 Principal Wöhler curves for Bending and Contact fatigue

Introducing these levels in to Wöhler curves allows designers to use the added steel properties, figure 3. Today's standards limit both component and system performance. Most designers use the ML and MQ levels as the basis for their designs since higher levels are not available in present standards.

How to apply clean steel in current transmission systems

A good example for discussion regarding the application of clean steel fatigue properties, is an FDU (Final Drive Unit), figure 4. In FDU's the hypoid gear set is a key component regarding both cost and performance. Durability issues are often related to bending fatigue, but contact fatigue is also a critical property.

Some drivers for material upgrade and/or change of design are:

1. Increased torque from engine
2. Tougher load collectives
3. Smaller footprint to make space for surrounding systems
4. Increased range.

A common first step is to simply upgrade the performance of the pinion material. This has proved to be a very cost-effective alternative, as the same mechanical design generation can be used longer.

When looking at the FDU from this perspective, it is possible to make a simple total cost comparison. Note that this is a discussion using relative figures, though experience has shown it to be reasonable as well as scalable from light to heavy vehicles. It is also steel grade independent. MQ, BQ and IQ only represent different defined fatigue performance levels for steels typically used in transmission components. In table 1, the cost for a pinion ready for assembly in conventional MQ steel is set to an index value of 100. The steel price is set for a rolled bar including scrap and alloying surcharges, as delivered to a forging shop.

Additional expenses are added to cover normal handling at tiers between steel supply and system owner.

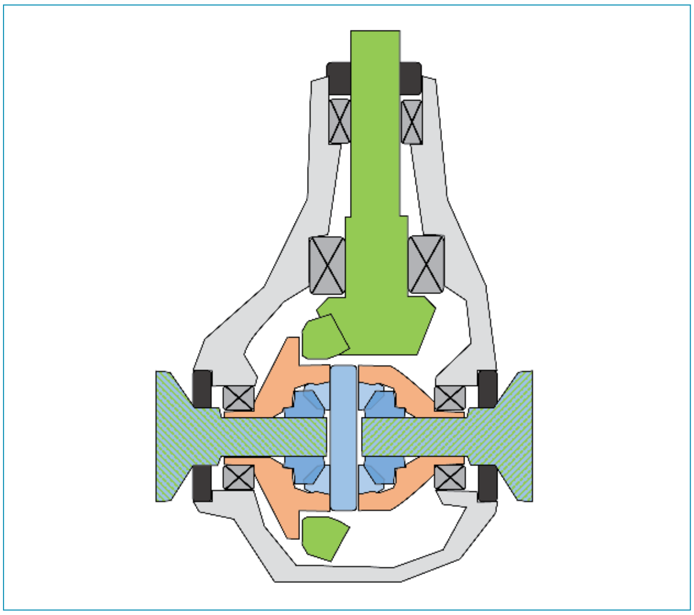

Figure 4 Typical FDU design.

Item	Conventional Steel, MQ Max	BQ-Steel	IQ-Steel
Steel (Incl S&A)	8	11	15
Pinion	100	104	108
FDU	700	705	709
FDU Cost Increase	0 %	0,7 %	1,3 %
Increase of Allowable Bending Stress (Flim)	0	20 %	64 %

Table 1 Cost and performance changes when upgrading to clean steel

The contact fatigue levels provided by IQ-Steels have in some cases proven to support elimination or reduction of downstream operations such as shot peening. This means that the effect on FDU total cost can result in a positive contribution. Looking at a larger perspective including aftermarket issues, the continued use of the same design will create further benefits. Having increased the torque capacity with the initial step as described for the pinion, a similar approach can be followed by working with the connecting ring gear, off-set and ultimately downsizing of the complete differential.

HEV – Considerations

When looking at HEV powertrains there might be some changes in the order of priorities due to the complexity in mix between system space, range, weight and torque increases. Issues, such as handling regenerative braking loads on the conventional driveline can create needs and opportunities to utilize the high fatigue strength of clean steels as a design advantage. The good news is that standard verification methods for clean steel fatigue performance is rotating bending, where push and pull forces simulate both accelerating and breaking actions.

EV – Considerations

Range is everything in the struggle to get the most cost efficient EV solution. It is also a great concern for supporting infrastructure solutions. So how does clean steel support these needs?

The answer is connected to the very high number of load cycles in rotating parts as the rpm is dramatically increased compared to ICE systems. As long as the NVH issues can be handled, a high fatigue resistance is the key to efficient EV systems. There are no load peaks due to ignition and therefore no need to add this in the safety factor for design. BQ-Steel and IQ-Steel do not only represent higher fatigue strength in absolute figures, they also have a reduced scatter compared to commonly used steel. They can constantly be put to the limit in this environment with consistent torque output.

The material will exit the areas of HCF and enter UHCF. An example of an UHCF Wöhler curve is shown in figure 5. It is clear that the higher starting points for BQ-Steel and IQ-Steel will contribute positively to EV powertrain design. Pushing towards a light EV-vehicle service life up to 400 000 km will move the material even further in to the UHCF area.

Table 2 displays how gears and other moving parts will be affected by the increased rpm and reduced number of gear steps. It is evident that no matter how far you go in the EV design, the UHCF area will be entered. The fatigue resistance will be one of the main keys for optimized design.

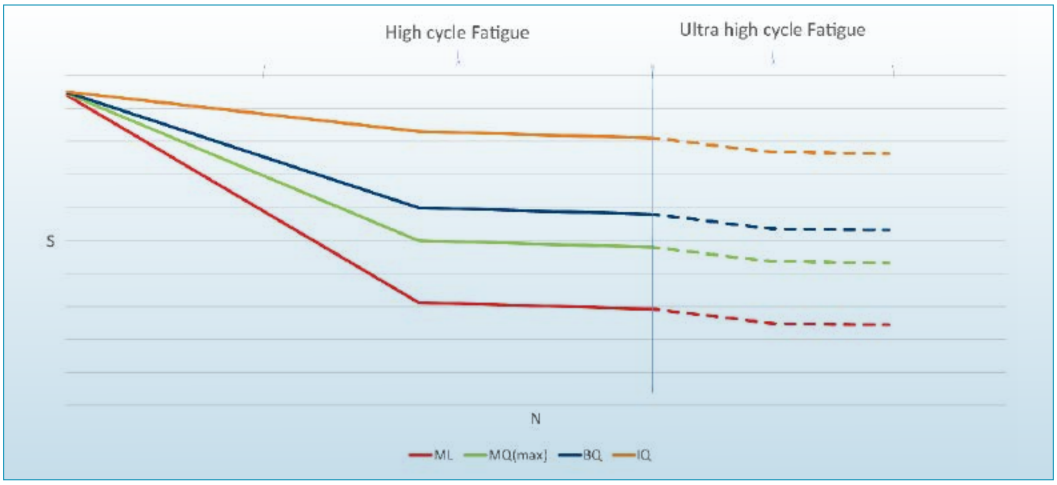

Figure 5
High & Ultra High Cycle Fatigue

System	Desired motor speed (rpm)	Average usage time per gear	Total runtime (h)	Loadcycles (N)
ICE with 6 Speed Gearbox	2000	17 % (4–5th)	5000	1,00E+08
Electric motor with direct drive	15 000	100 %	5000	4,50E+09

Table 2 Examples for positioning of fatigue load cases for gears in ICE and EVs with different rpm and number of gear steps.

The most common layout for EV power transmission is either a layshaft or planetary gear system, figure 6. The gear connected to the rotor shaft is rotating at high rpm and the sun gear in a planetary gear system has usually 3 times the number of gear meshing compared to a layshaft system. The balance between surface fatigue and root bending fatigue have to be treated differently in a planetary system compared to a layshaft system.

Clean steel improves both surface and root bending fatigue, which is why it is possible to increase the power density in both types of system concepts. Moreover the challenge when facing distortion issues can be addressed by the combination of clean steel and alloying strategy.

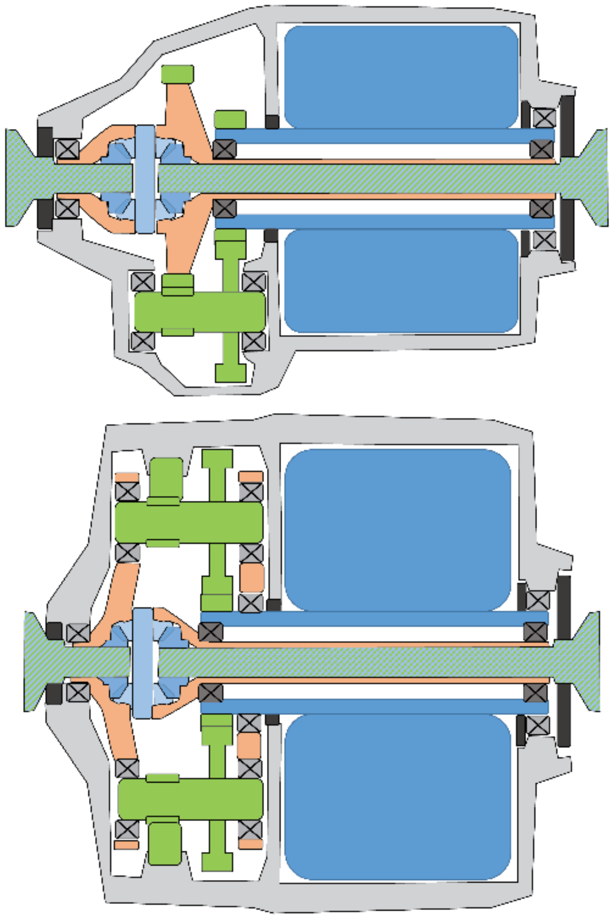

Figure 6 Layshaft concept (top) and planetary gear concept based on BELIX®.

How to shorten lead time to implementation

So, what's new? From a material point of view nothing is really new as these types of materials have been working in similar environments for many decades. Specifications and methods for performance verification are common practice. From a component manufacturing perspective, the same principles apply as for demanding bearing applications and highly stressed fuel injection systems, where clean steels are serving the majority of systems. There is no need to change present machining equipment; tooling and inserts might need to be optimized, but again, this is common practice for many high volume applications and there are generally big possibilities for cost efficient optimizations.

As the fatigue values of BQ-Steel and IQ-Steel have been added to the current design values, designers can now implement these values directly into their calculations.

Summary and Conclusions

Clean steel offers major possibilities for powertrain designers who needs to face the challenges of increased efficiency, range and ultimately, increased power density. Fatigue is one of the main challenges in powertrain design. Switching to clean steel will offer a significant enhancement in fatigue performance. This can enable individual components and systems to be downsized while maintaining equivalent performance or extend the lifetime of an existing design. Clean steel will play a big part in the creation of new space- and weight-saving designs for ICE, HEV and EVs. When looking at the total system, new design and manufacturing possibilities provided by clean steel can result in higher performance at equal or lower cost. ■

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What ECU Concept is the right one for your Project?

■ Ing. Philipp Neumann MSc, MELECS EWS GmbH

What options are possible?

When you design an ECU, the most important thing is to never lose the clear vision of what the customer requires and what options apply to those requirements. Will a standard ECU be enough, or do you need to go all the way and opt for a smart ECU system with an integrated motor?

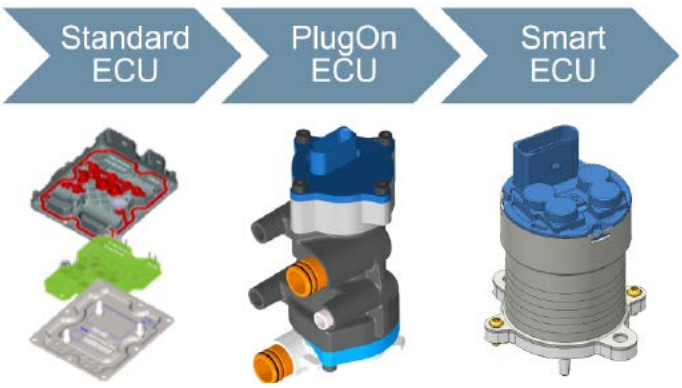

Figure 1 ECU options

Step 1 – Standard ECU

Choosing a standard ECU concept is the most common way of building control units in a car. This concept has many advantages but also some serious disadvantages. On the pro-side, the development of the ECU is very fast and the motor is connected with a cable, which means that the motor does not heat up the ECU. There is also no need to define an internal interface between ECU and motor, which speeds up development time and minimizes the costs. Normally this ECU consists of five major parts that need to be designed:

1) Housing

The housing can be made of different materials. During development, it is important to keep an eye on what the purpose of the ECU will be, and where it will be installed in the car. Some questions must be asked: what is the ambient temperature range, what is the water tightness level and does the ECU need to survive stone chips. Usually, the answers to these questions are -40° to 140 °C ambient temperature with IP6K9K and yes, stone chips will occur on the ECU in combination with high g vibration. Two options are available to meet the stone chip requirements: The first one is to design casualty fins that stop the stones and may break away when an impact occurs. The second and preferred option is choosing a high-quality material that can survive the stone chip test, for example PA66GF30.

Figure 2 Housing with special features

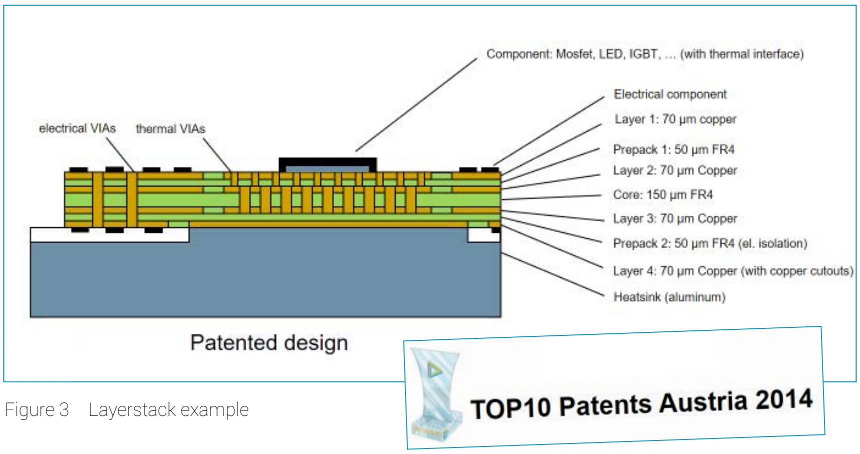

Figure 3 Layerstack example

2) Sealing / Vibration Damping / Thermal Springs

With the IP6K9K requirement, the ECU needs to withstand a high-pressure cleaner, which requires a good sealing concept. Normally you also have a vibration requirement on the ECU that comes from the combustion engine and/or the gearbox(es), which is up to 30 g. Without additional vibration damping features, the PCBA will not win the battle against vibration. To solve those two points, the fastest way is to put an O-ring inside the ECU for sealing and to pot the vibration sensitive parts to fixate them. This is ok if a small number of ECUs are required, but at higher production lots, you need a more stable and higher-quality process as well as a cheaper and faster assembly of the two features. A good, proven option is to include these features inside the housing and create a 2K molded part. The shell of the housing is made of PA66GF30 and the sealing, thermal springs and vibration damping features consist of a second softer material. A good start is to use red liquid silicon rubber (LSR) that is molded inside the PA66GF30 housing in a second shot. This creates a high production quality, removes the manual assembly process of an O-ring and eliminates the potting process. To thermally connect the PCBA to the back cover, you can either apply thermal glue between PCBA and cover or include some springs in the LSR that press the PCBA to the cover with a defined force. This eliminates the need for a thermal glue, because force is the best heat conductor between two materials. The trick here is that you also need electrical isolation which could be easily integrated, with no cost added, into the PCBA by using a layer of prepreg FR4. That would result in a layerstack and a concept as shown in Figure 3 for a four-layer PCBA, but this could be scaled to any layer count.

3) Vent

Since the ECU is completely sealed, another problem occurs. During thermal cycles, there will be temperature differences between the outside and the inside of the ECU. This will result in suction and condensation, which could damage the PCBA. To prevent this it is common to include a vent inside the housing. This vent is made of polytetrafluoroethylene (ePTFE) material, which is ultrasonically welded to the inside of the ECU. This vent allows vapor to escape from the ECU and pressure constantly remains alike inside and outside the ECU while leaving it completely IP6K9K watertight.

4) Cover

The cover of the ECU has two main functions; both sealing and acting as a heatsink. The cover is screwed to the housing and thus pressed against the LSR sealing to prevent water from entering the ECU. As a heatsink, the cover absorbs the heat of the components of the PCBA which are connected as in Figure 3 and routes that heat into the environment through radiation and convection. The advantage of an aluminum cover is that it can buffer short heat peaks and release them over time into the environment.

5) PCBA with pins

The PCBA is the main part of the ECU, all other parts only exist to protect the PCBA from the environment. When designing the ECU it is important to understand that the PCBA is the main part of the complete ECU. Everything must be built around the PCBA. The key point for the PCBA is selecting the components and the layerstack. PCBAs need to be tailored exactly to the customer's needs to have a chance to compete in the automotive market. Concerning the pins, the most cost-effective solution is to press them into the PCBA. This is a fast and reliable process which allows to create a sandwich structure when putting the PCBA inside the housing.

Step 2 – PlugOn ECU

If the installation space or the EMC requirement and the switching frequency of the motor are not compatible with a cable setup, then you need to go for a PlugOn ECU. This is exactly the same concept as the standard ECU described above, but mounted directly to the back of the motor. Disadvantages of this setup are that you now need to clearly define the motor interface and have the power dissipation of the motor heating up the ECU.

Step 3 – Smart ECU

A smart ECU is the highest integration level you could choose. This ECU is completely tailored to the requirements of the customer and is even more complex than the PlugOn variant. The main advantage is lower part costs, but this comes with higher development costs. Smart ECUs are usually potted or overmolded and therefore have no screw connections and such enable a faster assembly process. This also results in a higher production quality. Another key fact is that smart actuators require very small installation space. In a round package of approx. Ø 50 mm, it is possible to pack a full B6 BLDC motor bridge (~35 A peak) with reverse polarity protection, CAN or FlexRay communication with wakeup, a rotary sensor, a voltage supervisor with watchdog and even Autosar and a high security module (HSM). So, if the possibly rather long development time doesn't deter you and your budget allows it, the smart actuator concept is always the way to go for the new standard which Melecs sets. ■

Contact:
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Figure 4 Smart actuator [Ø 66 x 70 mm]

Dynamic Torque sensing for Future Power Train Control

More stringent world-wide government regulations addressing the reduction of poor air quality across many cities and noise pollution whilst increasing road safety are driving the Automotive Industry manufacturers to focus R&D efforts on more efficient and accurate overall powertrain control.

■ Johannes Gießibl, Senior Magnetoelastic Project Manager, Methode Electronics International GmbH

According to the Advanced Combustion and Emission Control Technical Team (ACEC), which is one of 12 U.S. DRIVE technical teams whose mission is to accelerate the development of pre-competitive and innovative technologies to enable a full range of efficient and clean advanced light-duty vehicles, as well as related energy infrastructure, Engine efficiency improvement can be achieved by the application of technologies to a system (engine or after treatment) to reduce the fuel consumption, improve the torque, or improve reduction of a pollutant.

Efficiency improvement is measured at a specific test condition or multiple test conditions. For an engine, efficiency is measured at specific speed and torque. This is reported using measures such as brake thermal efficiency or brake specific fuel consumption. Firstly, the efficiency of the component is improved and studied at specific test conditions. Secondly, the improved component is integrated into a specific vehicle, optimized for the vehicle application and the system is then tested on a drive cycle. Many vehicle specific assumptions including vehicle size, aerodynamics, transmission, tires, drive schedule and control system are required for a fuel economy test.[1] A poor integration or technology mismatch for the vehicle application may lead to little or no fuel economy improvement, despite the improved component and unless new proven technologies for measuring real-time torque are introduced, the need for complex control algorithms, test evaluations, and subsequent qualification that are currently required for monitoring the efficiency of electronically controlled vehicle transmission will remain a time consuming reality for Vehicle Manufacturers and professionals in the field.

New combustion concepts such as LTC (Low Temperature Combustion), PPC (Partially Premixed Combustion) or HCCI (Homogeneous Charge Compression Ignition) are determining a demand for dynamic feedback control. A real-time torque sensor allows combustion balancing within each operational mode, assists in managing mode shifts between different combustion sequences, and for each combustion cycle, provides feedback of combustion efficiency at both steady state and transient operation. By monitoring the torque characteristic before and after refueling fuel quality differences can be identified and used to avoid potential warranty claims.

Diagnostic functions associated with automotive engines involve near periodic processes due to the nature of multi-cylinder engines. The

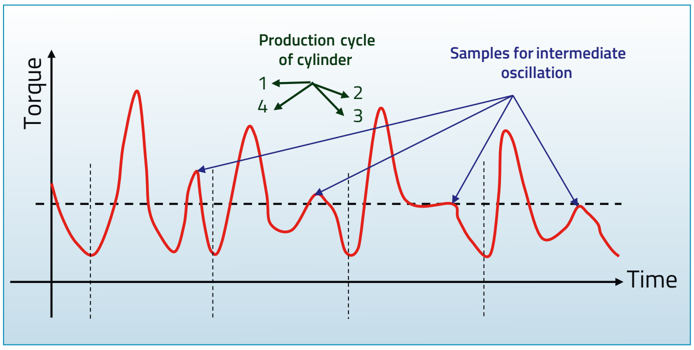


Figure 1 Engine Control

1 2013; US DRIVE – Driving Research and Innovation for Vehicle Efficiency and Energy Sustainability : Advanced Combustion and Emission Control Technical Team Roadmap ; p. 8
https://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/acec_roadmap_june2013.pdf

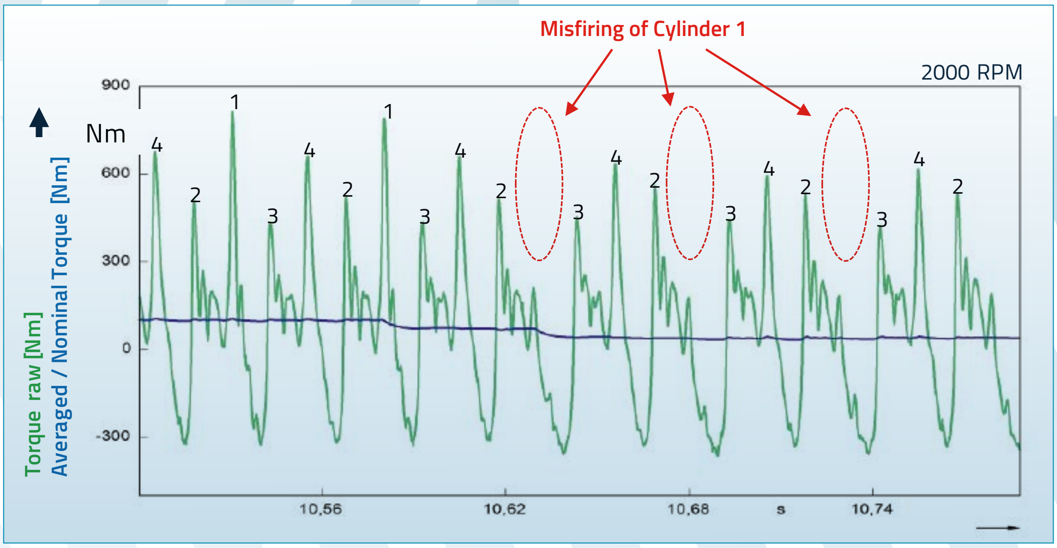


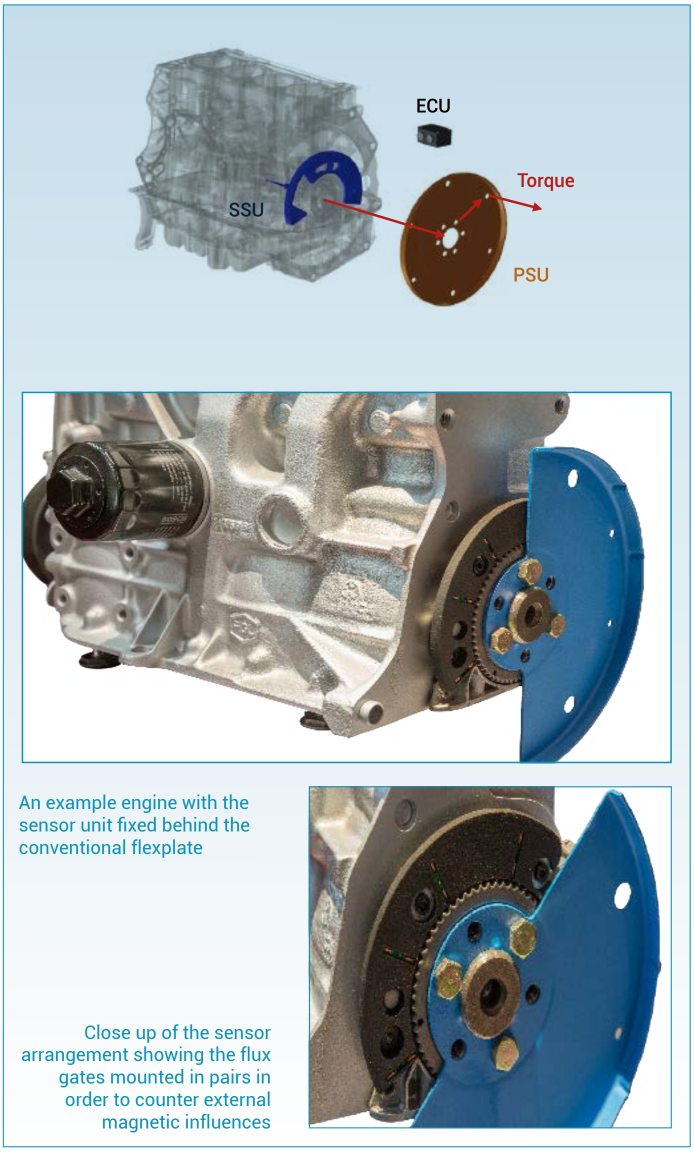
Figure 2 Misfire signal by switching cylinder 1 ignition off

real-time torque sensor exploits the inherent periodicity of the combustion to obtain a mean torque produced by each cylinder during each stroke (Figure 1). Not only is the overall torque measured but for the first time subtle changes in the torque created by each cylinder is directly measureable. This is quite a useful property for torque balancing DI engines with an aim to eliminate vibration and decrease the level of emissions caused by disturbances such as variability in injector efficiency, inertia, and the geometry between cylinders. It is also useful for detecting cylinders that produce variable torque outputs or exhibit signs of misfire (Figure 2) or knock, suggesting that the real-time torque sensor can be a good indicator of engine abnormalities.

Methode's industry proven dynamic real-time torque sensor has been in series production in OEM applications since 2008, while an innovative patented technology with a sensor mounted in a transmission configuration is currently conducting in-vehicle trials and has up till now surpassed 480,000 miles of use without failure or change to its performance. This technology has immeasurable proven potentials:

- Reduces gear change times down to a minimum through the reduction of signal bandwidth, resulting to gear changes twice as fast as current hydraulic auto transmissions;
- Monitors the shift quality between different drive modes controlling the shift performance, due to its accurate measurement properties of the total output of the system;
- Supports a wider spread of gear ratios facilitating engine downsizing and cylinder reduction, and
- The possibility of adding more gears means that the engine RPM can be optimized to the load, thereby saving fuel.

Methode's magnetoelastic torque sensor works by magnetically encoding a region of a flexplate, transmission shaft or dual mass flywheel. A secondary sensor unit is employed featuring a series of fluxgate sensors. Torque creates a specific change to the magnetic coding which, in turn, is detected by the fluxgate sensors. Magnetic influences based on the earth magnetic field (EMF) or other interfering fields are compensated by using pairs of fluxgates in common mode rejection. As an engine applies a load to the transmission it creates a



An example engine with the sensor unit fixed behind the conventional flexplate

Close up of the sensor arrangement showing the flux gates mounted in pairs in order to counter external magnetic influences

Figure 3 Flexplate Sensor Arrangement

Figure 4 Torque and Force Sensing Options

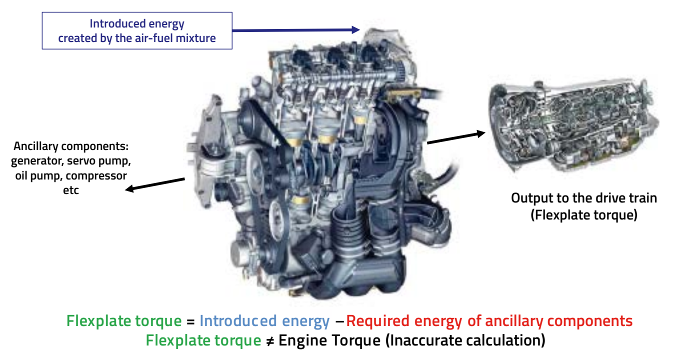


Figure 5 Torque distribution on a combustion engine

unique torque signal that is propagated through for example the flex-plate. The resultant measurement is conditioned and transferred to the ECU as a linear signal representative of the applied torque.

Over the past few years research and development has been applied to the provision of suitable torque sensors for OEM applications. One of the main issues has been the difficulty of measuring torque on a rotating or moving application and making an electrical connection to the sensor. Non-contact solutions have been designed but these have necessitated either modifications or attachments to the crankshaft (or alternatively to a drive/flex-plate, clutch, fly wheel or gearbox) that present their own problems in terms of durability and influences on the torque signal.

The major benefits of Methode's flexplate based transmission torque sensor arrangement is that it requires no alteration to the existing mechanical set-up or routine calibration unlike traditional strain gauge based torque sensors and does not feature any components that degrade over life, ensuring that torque measurement remains accurate over the service life of the engine.

In future applications, the possible uses for this sensor feedback include:

- Adaption of the clutch kiss-point – The kiss-point adaption function uses the torque signal to recognize exactly where the clutch is located when it starts transferring torque. When the kiss-point is requested, the function moves the clutch nearby a previously stored kiss-point and continues closing it slowly until it starts transferring torque again and stores the new kiss point value found.
- Adaption of relationship between clutch torque and position of the clutch actuator – The torque vs. position adaption is based on the torque capacity from the torque sensor and the position from the position sensor when the clutch is slipping. The measurements are used to slightly modify the characteristic torque-position curve. The adapted curve is then used as a pre-control for the position regulation by interpolating the target position out of the target torque.
- Adaption of a safe open point
- Torque control during slip-start of combustion out of pure electric driving – During a slip-start of the combustion engine out of electric driving, the torque signal from the sensor is used to determine how much additional torque must be delivered by the electric motor to start the combustion engine while keeping the output torque constant. The usage of the sensor replaces the torque model of the engine, which is normally very poor at low speed, and enables a softer start of the combustion engine.[2]
- Torque control during shifts with electric torque support and closed loop engine control.

Torque sensing can be applied in other areas of the power train to meet different needs. A torque sensor can be placed on the input oo the transmission where the real power delivered to the transmission can be monitored for optimal drive mode selection and improved gas performance through different outside environmental conditions. Torque sensors applied to the output of the transmission, inside the transfer case, as a part of the yoke or at the half shafts by the wheels can be used as a part of the customer feel and control of power to the wheels.

There have been significant improvements to the torque sensing system since sensing torque in a shaft was best described as being a laboratory operation, and among various torque sensing methods, a magnetoelastic torque sensor appears to be the most promising for automotive production application (Figure 6).

2 http://www.fev.com/fileadmin/user_upload/Media/TechnicalPublications/Transmission/_IV_01_First_Driving_Test_Results_of_FEV_s_7H-AMT_Hybrid_Transmission.pdf

Methode Electronics can offer a diverse portfolio of Magnetoelastic sensors beyond the limits of conventional technologies for sensing torque, force, linear position, angle, speed and direction with guaranteed:

Robustness
- withstanding harsh environmental conditions
- Operation in high temperature up to 210 °C
- Submersible in caustic fluids

Durability
- Competent testing for 480,000 miles equivalent
- Key-Life Testing completed on production level

Easy Integration
- Compact design
- Low space requirements
- Inside-shaft design option

Reliability
- No accuracy loss during lifetime
- No wear over lifetime

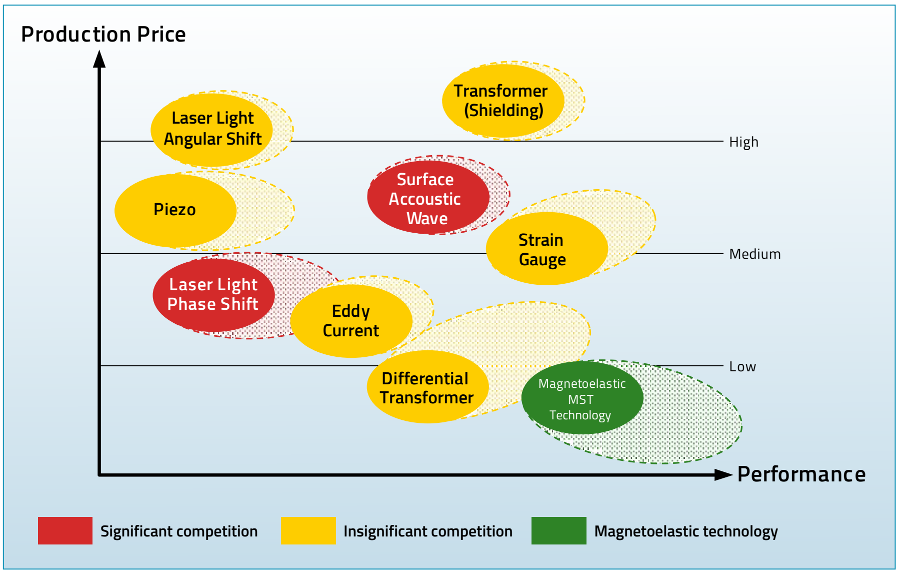


Figure 6 Cost Performance Comparison

If you have any further question or interest in the technology please see us at booth #H04.
www.methode.com

Hydraulic Accumulator in Transmission Controls

Dual clutch transmissions offering disruption-free traction are in the portfolio of all well-known auto manufacturers. The hydraulic accumulator is the ideal solution to ensure that hydraulic actuations are as efficient as possible even at peak demand. Independent investigations have shown that the hydraulic accumulator makes it possible to gear components, such as the hydraulic pump for actuators, to reduced fuel consumption. This saves energy and reduces CO_2 emissions. The hydraulic accumulator needs only about a sixth of energy of a conventional constant pump. Thus, the CO_2 emission is reduced by up to 4 g/km.

■ Thorsten Hillesheim, Technical Director, Freudenberg Sealing Technologies

The market share held by automatic transmissions, dual clutch transmissions (DSG) and hydraulic control systems for start-stop applications is growing each year. The variety of technical solutions for hydraulic actuation is also growing. They range from hydraulic accumulators, to constant and adjustable pumps, all the way to one- and two-stage electrically driven pumps. The following analysis shows how efficiently the piston or membrane versions of hydraulic accumulators perform compared to a torque-dependent, pressure-regulated system with a combustion-engine-driven constant pump. The investigation is based on various driving cycles, defined load values, pressure and volume flow requirements and the efficiencies of individual components. The test series used a compact vehicle with a direct-injection, turbocharged 4-cylinder gasoline engine with 1.4 liters of displacement, 250 Nm of torque, and 110 kW. The transmission is a 7-speed, dry clutch DSG with electro-hydraulic control, including an accumulator charging system.

Hydraulic accumulator for covering peak needs

A hydraulic accumulator consists of a gas segment and a liquid segment, which are separated by a gas-tight (piston or membrane) medium divider. The gas side is filled with nitrogen, and the liquid area is connected to the hydraulic circuit. With an increase in pressure, the hydraulic accumulator takes in the pressure fluid and the gas mixture is compressed. This mostly takes place in the stages between shifting. If the pressure declines, the compressed gas expands out again and forces the stored fluid into the transmission's circuit and thus to the actuators.

A hydraulic accumulator is the ideal solution to cover the peak demand that arises as the gear selector is activated, for example. In this way, both the oil pump and the drive electric motor can be designed for average fuel consumption – they are smaller and thus significantly more efficient. Hydraulic accumulators thus make a significant contribution to improved fuel economy and help reduce CO_2 emissions. One of the best-known examples of the successful use of hydraulic accumulators is the VW DQ200 DCT transmission introduced with very low energy consumption in 2007. The main supplier of this hydraulic accumulator is Freudenberg Sealing Technologies in Remagen.

Minimization of hydraulic losses

The minimization of hydraulic losses plays a crucial role in the use of hydraulic accumulators. To make a comparison of overall efficiency with the combustion-engine solution, the losses due to the interconnected components were determined. This includes the oil pump with electric drive, battery, generator and belt drive. The basic driving cycles in the investigation are the European NEDC and the American FTP75. They differ mainly in acceleration, the driving experience, and trips with air-conditioning. But in the test, these parameters only af-

fect the amount of deviation from the defined cycle fuel consumption – and not the efficiency investigated in the test. Picture 1 shows a summary of energy efficiency at a glance. Here, it becomes visible that the hydraulic accumulator needs only about a sixth of energy of a conventional constant pump.

To assess the efficiency of the hydraulic accumulator itself, the frequency and the cycle profile were determined. If you compare the charging process in the two driving cycles, the frequencies are about 0.05 Hz for both the NEDC and the FTP75 – the accumulator is charged every 20 seconds on average. If you analyze the measured profile, the expected sawtooth behavior does not merely occur during charging and discharging. It also occurs when no gear changes are taking place. This means that a stable pressure level has not developed at this stage. This arises in large part due to leakage at the pressure control and directional valves. Since two to three pressure control valves, depending on the structure, are continuously active in each sub-gearbox, the loss can reach a magnitude that exceeds the usable accumulator discharge volume; even though special low-leakage valves are involved, with leakage levels between about 15 and 50 ml/min. That means a large portion of the control oil stored with the substantial application of energy is unused. One solution could be a new configuration with fewer valves. The result is a storage efficiency of 0.92 for a hydraulic accumulator, based on the described cycle profile at a frequency of 0.05 Hz and the defined pressure and volume levels.

Stable working point for higher efficiency

To ensure and efficient, trouble-free actuation of the transmission, the volume flow to fill the actuators must be appropriately designed. This is closely related to pump output. A load volume flow of 0.7 l/min and a pressure between 43 and 60 bar were provided in the investigation of the 7-speed transmission with electro-hydraulic control and an accumulator charging system.

The calculation of the energy used in both versions of the oil pumps assumes average efficiency in the respective pressure and rotational speed ranges (picture 2). For the electrical accumulator charging pump, a nominal working point at an average pressure of 51.5 bar and electronic load control at 2,200 rpm is taken as the basis. In the case of a mechanical combustion-engine-driven pump, it is an average rotational speed of 1,372 rpm at a load-dependent pressure range between 10 and 20 bar. If you compare the overall efficiency levels determined in this way, you find that the accumulator charging pump and the combustion-engine-driven pump are respectively at 0.60 and 0.75. But higher value for the mechanical solution only relates to standardized driving cycles.

Picture 1:
Energy efficiency considerations at a glance – fuel consumption advantage in the cycles

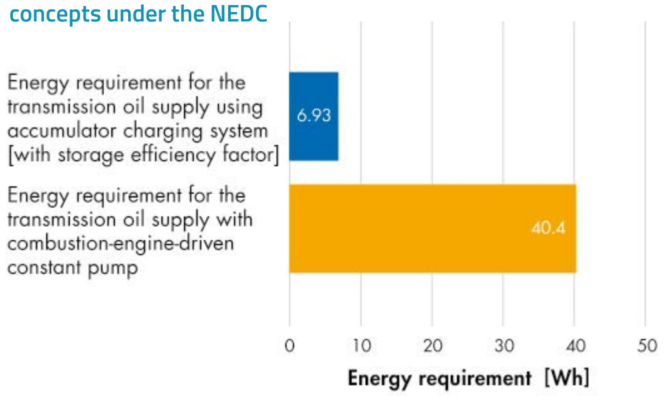
NEDC*		FTP 75*	
Energy input from crankshaft		**Energy input from crankshaft**	
Acc. charging system	Mech. constant pump	Acc. charging system	Mech. constant pump
6.93 Wh	40.4 Wh	7.3 Wh	53.4 Wh
Energy consumption [l/100 km] with regard to standard consumption value of 5/km		**Energy consumption [l/100 km] with regard to standard consumption value of 5/km**	
Acc. charging system	Mech. constant pump	Acc. charging system	Mech. constant pump
0.035 l/100 km	0.202 l/100 km	0.029 l/100 km	0.211 l/100 km
CO_2 reduction [g/km] with accumulator charging system at standard consumption value of 5 l/km**		**CO_2 reduction [g/km] with accumulator charging system at standard consumption value of 5 l/km****	
Gasoline	Diesel	Gasoline	Diesel
3.96 g/km	4.43 g/km	4.32 g/km	4.83 g/km

➡ The accumulator charging system requires only about 1/6 the energy of the constant pump

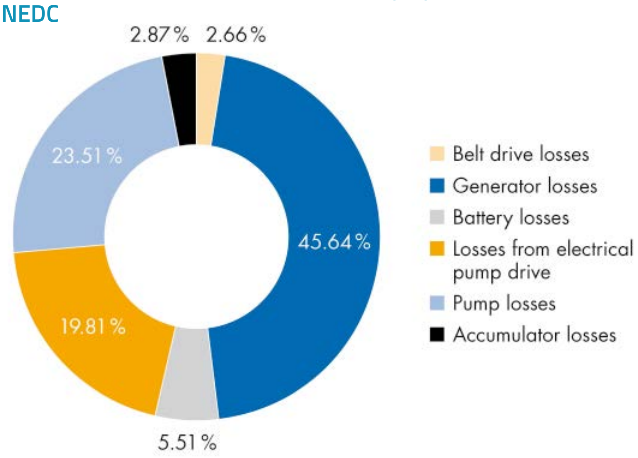
* Values relate to transmission oil supply
** The values shown here assume the operation of the combustion engine at the same load and the same specific fuel consumption in both systems

Outside these ranges, the energy characteristics of the combustion-engine-driven solution deteriorate sharply. Due to the stiff coupling, the fluctuating rotational speed and the continual pressure adjustments allow no specific adjustment of efficiency. The relatively large pump is another negative factor since the layout leads to a high surplus output even at low cycle speeds during near-idling operation. Outside the driving cycle, a major savings potential would only be offered by a two-stage variable displacement pump with a rotational-speed-dependent reduction of the displacement volume. By comparison, the energy attributes of an accumulator charging system change very little in normal driving under everyday conditions. Here the working point (rotational speed and the pressure of the accumulator charging pump) remains unchanged; only the frequency of actuation fluctuates.

Picture 2:
Energy requirements comparision of transmission oil supply concepts under the NEDC



Picture 3:
Loss distribution for accumulator charging system under the NEDC



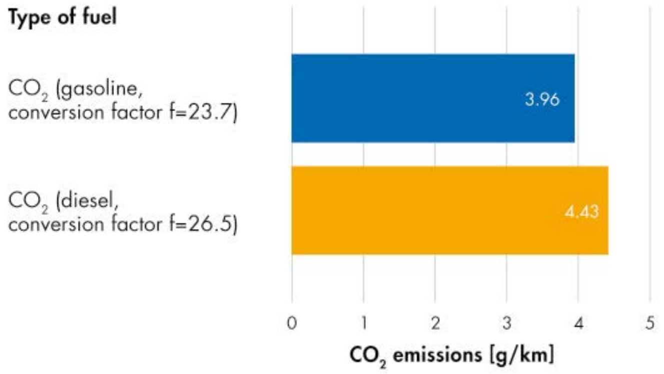
➡ The main sources of losses are the generator, pump and electric motor (89 % share)
➡ Only slight loss due to auxiliary components-belt drive and accumulator

Low CO_2 emissions

The investigation showed that the accumulator charging systems for the oil supply to clutch and gear selector actuators offer significant energy advantages. The reason is the lower installed capacity within the driving cycle. The main sources of losses are generators, pumps and the electric pump drive. Their total share comes to nearly 90 %. The remainder is assigned to the battery, at 5.5 %, along with the accumulator and belt drive, at 2.8 % and 2.6 % respectively (picture 3). A high share of losses of 19,8 % attributed to the electric pump drive could still be improved in the future with better recuperation systems.

Taken as a whole, the accumulator charging system needs about 14 to 17 % less energy than conventional systems with a constant mechanical pump at the combustion engine. In CO_2 emission comparisons, the technology comes in 4 to 5 g/km lower at a cycle fuel consumption level of 5 l/100 km (picture 4 and 5). That shows the considerable efficiency of the hydraulic accumulator for energy storage in automatic and dual clutch transmissions.

Picture 4:
Accumulator charging system compared to mechanical constand pump CO_2 emission difference [g/km] under the NEDC, based on NEDC fuel consumption value of 5 l/100 km
(Gasoline vehicle 118.5 g/km or diesel vehicle 132.5 g/km)

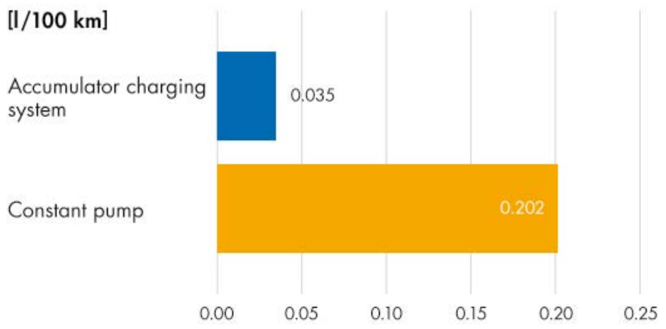


Modular systems for individualized solutions

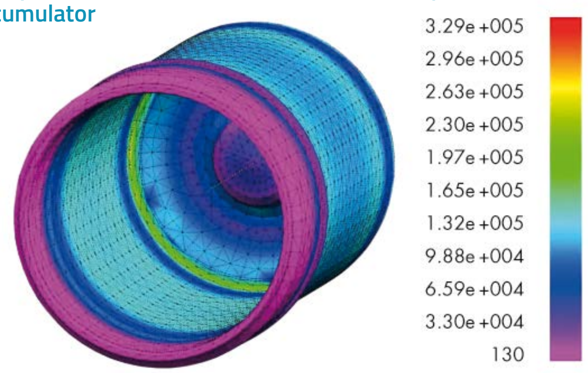
Much has happened since introduction of the VW DQ200 DCT transmission with dry clutch discs. Today, nearly all well-known automakers offer a dual clutch transmission. Freudenberg Sealing Technologies has modularized its design and production principle in such a way that it can respond flexibly to the different requirements of automobile and transmission manufacturers with regard to storage volume and pressure ranges. Moreover, the hydraulic accumulator's diameter and length proportions can be precisely adapted to the respective installation space.

The company's latest developments in the production of hydraulic accumulators include the use of aluminum and plastic. These lightweight materials, used for the first time for pistons and housings, greatly reduce overall weight and contribute to the reduction of fuel consumption and CO_2 emissions. The weight savings compared to conventional solutions are as high as 40 %. The new lightweight hydraulic accumulators are also constructed from fewer individual parts. The best possible design is determined using FEM analysis (picture 6). The manufacturing technology for series production has been optimized to provide the maximum impermeability to gases across all conditions and to make the hydraulic accumulator completely maintenance-free over the vehicle's lifespan. ■

Picture 5:
Energy consumption difference [l/100 km] for transmission oil supply with regard to NEDC standard 5 l/km



Picture 6:
FEM presentation of stress distribution in a hydraulic accumulator



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As the leading specialist in sealing applications and their markets, Freudenberg Sealing Technologies is a supplier as well as a development and service partner serving customers in a wide variety of sectors including the automotive industry, civil aviation, mechanical engineering, shipbuilding, the food and pharmaceuticals industries, and agricultural and construction machinery. In 2016, Freudenberg Sealing Technologies generated sales of more than €2.3 billion and employed approximately 15,000 people. More information at www.fst.com

The company is part to the global Freudenberg Group which, with its Business Areas Seals and Vibration Control Technology, Nonwovens and Filtration, Household Products as well as Specialties and Others. In 2016, the Group generated sales of more than €8.6 billion in and employed approximately 48,000 associates in around 60 countries. More information is available at www.freudenberg.com.

Further CO_2 savings thanks to Electric Transmission Oil Pumps

Conventional, mechanically driven oil pumps must provide the power required under maximum load at each speed in the transmission. In general, under real operating conditions these pumps waste not only valuable energy, but also material and space. Electric oil pumps, on the other hand, provide the power which is actually required at the load points. Further efficiency gains in the transmission are thus possible.

- Dr. Erkan Arslan, Management Concept Engineering Powertrain, Bühler Motor GmbH
- Herwig Moser, Director Product Segment Powertrain, Bühler Motor GmbH

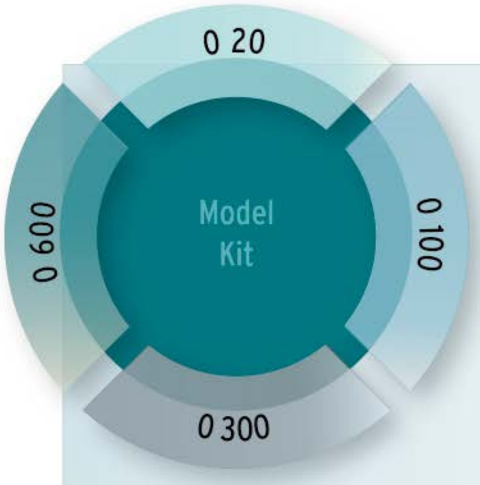
Cooling and lubrication must also be ensured in extreme situations, e.g. in trailer operation, on mountain roads and at low speeds. The design of the mechanical pump has to be correspondingly generous. The bottom line is that, for most driving conditions, a mechanical pump consumes an enormous amount of energy and takes up too much space. The dependency of being operated by the combustion engine leads to hydraulic flow and pressure results, which are characterized by much higher hydraulic power than needed. As a result, the outcomes have to be reduced by control systems like mechanical blinds, valves or other components. These additional components require additional energy to operate in a synchronized way with the mechanical oil pump. In total, the energy consumption of the complete mechanical oil pump with required sub-components is higher than is required for the real need.

The way out of such problems is offered by electric gear oil pumps. They can be controlled in a precise manner so that only the actual power required at any given moment is provided. As supplementary oil pumps, they allow to absorb peak loads. The mechanical main oil pump can thus be designed to be space-, material- and energy-saving. Or an electric oil pump can replace the mechanically driven oil pump completely. In both cases, a significant increase in system efficiency is achieved.

Furthermore, electrical transmission oil pumps can be integrated into the system relatively independently of the location, be it in the gearbox or outside the gearbox. This gives the developers additional freedom.

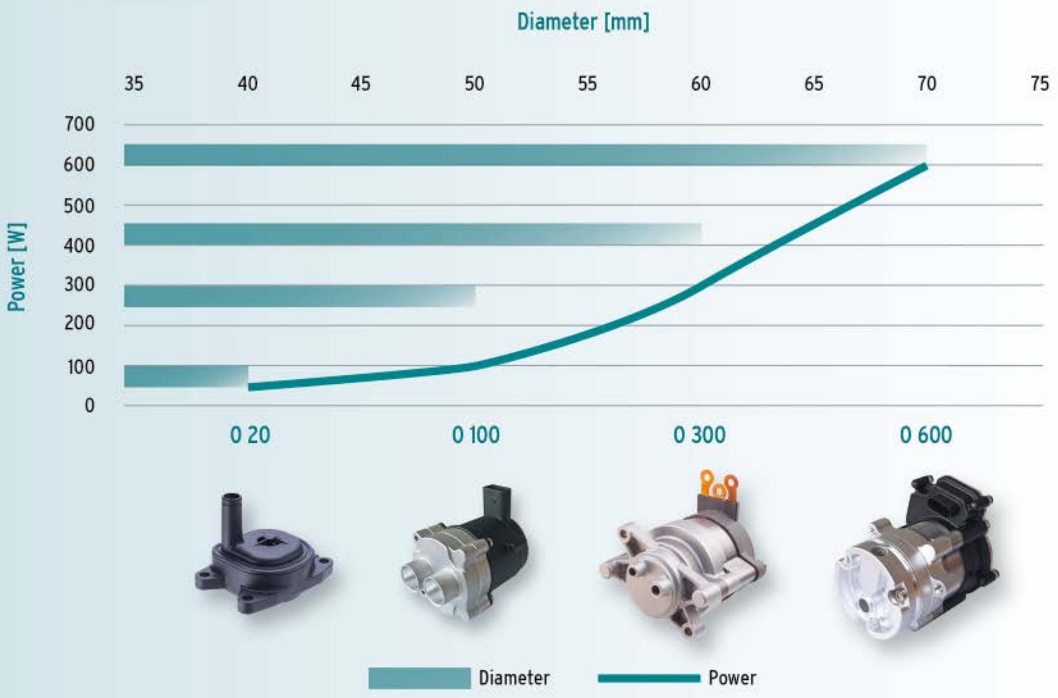
In addition, electric pumps can be easily connected to the customer-specific electronic control systems, and thus optimally adapted to the requirements of the particular transmission solution.

Typical applications in which electrical pumps are normally used in the transmission are start/stop systems, solutions for boosting, coasting and hybrid drives.



	Electronics	BLDC Motor	Pump
η	~ 95 %	~ 90 %	~ 60 %
Weight	~ 500 g to 1500 g		

Bühler Motor GmbH electrical auxiliary oil pump family



However, as described above, they can also include further functions, from coverage of peak demands to the complete replacement of the mechanically driven main transmission oil pump.

Since the application fields are widely varied, there is no "one size fits all" solution. In order to get to the SOP with best value and cost-effective as well as fast solutions, Bühler Motor has developed a solution platform on the basis of which all current and future requirements can be met. Four models form the cornerstones of this oil pump family, named bFlow O.

The bFlow O20 is for low-pressure applications in the power range of 10 to 60 watts. It is particularly suitable for ensuring specific and demand-based lubrication, such as supplying a dry sump lubrication.

With an output of 80 to 150 watts, the bFlow O100 can provide a pressure of up to 15 bar and covers, for example, the requirements of both start/stop functions and mild hybrid applications.

The bFlow O300 is available in versions from 160 to 400 watts and provides a pressure of up to 25 bar. This makes it the first choice for full hybrid use. In addition, it is able to provide further functions.

The bFlow O600 finally provides between 400 and up to700 watts and can provide pressure in the range of up to 40 bar. The typical use of the bFlow O600 is for full hybrid or electric vehicles. Here it can also completely replace the mechanical oil pump.

The bFlow products are designed to achieve the mentioned power classes with a nominal source supply of only 12V. This underlines again the high technical standard of the gained results.

Electric transmission oil pumps do not only support energy saving technologies, such as start/stop systems, hybrid drive solutions or electro-mobility, but also allow additional efficiency gains in the transmission itself.

Bearing up against the Fight with Friction

As ever stringent targets for improved energy efficiency and reduced tailpipe emissions become more demanding to meet, automotive OEMs are waging a fierce battle against powertrain losses of all types. Sylvain Bussit, Product Line and Business Development Manager for Powertrain at SKF explains how innovative bearing design and specification in the transmission area can help.

■ Aktiebolaget SKF (publ)

The drive for better energy efficiency continues to be a core focus of innovation for automotive vehicle manufacturers. However, this focus cannot be viewed in isolated – the demands of the automotive industry dictate that energy efficiency must be delicately balanced with ease of assembly, long service life and good noise and vibration characteristics.

In looking to meet these demands, leading automotive manufactures have spotted an opportunity to leverage the investment in innovation that is being applied by their suppliers. For them, a focus on innovation is a question of competitiveness and survival but for the automotive OEM it is a chance to find novel solutions in a number of application areas.

Taking conventional manual transmissions as an example, switching to an alternative bearing technology can have significant benefits. SKF worked with one major OEM to replace a conventional shaft bearing configuration using twin taper roller bearings with a new approach that used a deep groove ball bearing at the locating end of the shaft and matched with a cylindrical roller bearing at the other end. That change alone reduced CO_2 emissions in the application by 1 g per km. what's more, the sensitivity of the transmission to the effects of thermal expansion was also reduced and assembly was made much simpler.

To further assist the transmission manufacturing process, a range of retainer units and carriers have been developed that are supplied with bearings pre-installed. Using this approach means the gearbox housing requires less machining, and assembly is quick and easy, with just a few screws. Bearing carriers also automatically add the right preload to the bearing, which significantly reduces the potential for noise and vibration.

Automotive component suppliers such as SKF are applying their expertise in materials technology and heat treating to develop solutions with a higher load capacity. Size is also a focus, as smaller bearings for example create less friction as well as taking up less space in the vehicle. Higher quality materials and advanced surface treatments for example, allow smaller sized bearings to be used. In fact, with the latest technologies applied automotive bearings can often be downsized by 15 to 20 %.

With the widespread use of dual clutch transmission designs in the industry, clutch bearing design has quickly become another key area of innovation. Conventional clutch bearings rely on seals to protect the lubricant inside the bearing from the fluid in the clutch. However, seals inevitably have a friction penalty. One innovative design is able to use the clutch fluid as a lubricant, allowing it to work without seals. In one customer application, this design change reduced CO_2 emissions by 0.5 g per km.

The rapid rise in Hybrid and EV transmissions has also created unique challenges for both automotive OEMS and suppliers. Electric powertrains often use very high-speed traction motors fitted with epicyclic reduction gears. That places significant demands on bearings for example, which have to survive speeds of 18,000 to 20,000 rpm, and fit into extremely tight space constraints. High performance needle roller bearings are compact in design and can fulfil the specific requirements for this market.

But it's not just physical loads that challenge EV bearings. High frequency electric drives can generate stray currents that, if not properly managed, can destroy bearing surfaces, leading to premature failure. Bearing with insulating properties, using special coatings or hybrid designs with ceramic rolling elements, can prevent this issue.

Collaborating closely with suppliers and tapping in to their extensive engineering expertise can allow automotive OEMs to take advantage of the latest emerging technologies and innovative designs. Leading suppliers even offer the ability to simulate complex drivetrain configurations and evaluate new designs both in the computer and on the testbed. With powertrain technology evolving at a rapid pace and presenting many new challenges along the way, automotive OEMs need trusted partners to help them on that journey. ■

SKF is a leading global supplier of bearings, seals, mechatronics, lubrication systems, and services which include technical support, maintenance and reliability services, engineering consulting and training. SKF is represented in more than 130 countries and has around 17,000 distributor locations worldwide. Annual sales in 2016 were SEK 72 787 million and the number of employees was 44 868. www.skf.com

HOERBIGER SlimLINE creates Space for Hybrid Drives

Worldwide demand for advanced hybrid technologies for vehicles is growing unabated. These technologies offer a combination of high range, low fuel consumption, and minimal emissions. At the same time, modern combustion engine-based drivetrains leave little room for the integration of additional necessary components. The innovative design of the HOERBIGER SlimLINE synchronizer saves installation space as well as weight and opens up valuable design freedom for hybrid vehicles. Transmission manufacturers can utilize the extra space for an additional electric motor, for example.

■ Dipl. Ing. Ottmar Back, Head of Product Line Synchronizers, HOERBIGER Antriebstechnik Holding GmbH

Legislators around the globe are passing tougher limits on traffic-related emissions and greenhouse gases. The USA require manufacturers to cut average CO_2 emissions of their passenger cars to 121 grams per kilometer by 2010, China is pondering a figure of 117 g/km, and Japan has set an average value of 105 g/km. The European Union has adopted one of the strictest policies, seeking to reduce emissions from presently 120 g/km to 95 g/km by 2021. Diesel or gasoline engines will be hard-pressed to reach these levels solely through optimizations within the engine, and they have no chance to satisfy China's requirements for so-called new energy vehicles.

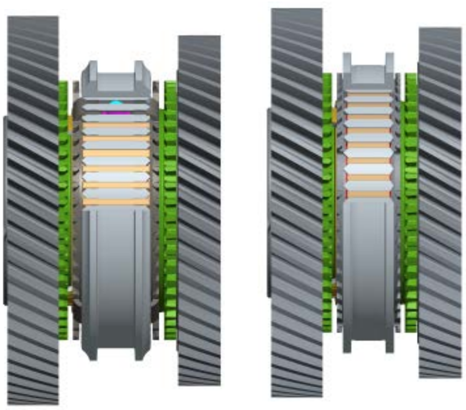


Figure 1
HOERBIGER ClassicLINE (left) compared to the more slender HOERBIGER SlimLINE (right)

Diesel and gasoline engines are in need of additional solutions to meet more stringent efficiency demands. Worldwide, demand for hybrid technologies continues to grow. They play an important role in reducing emissions, without requiring compromises from drivers in terms of range, cost, charging time or infrastructure. Hybrid drives will constitute important bridge technologies in the coming years until all-electric vehicles have become widely established. The efforts of automakers continue to center around the economical implementation of lightweight designs and enhanced performance.

With the SlimLINE, HOERBIGER developed an innovative synchronizer that saves installation space and weight, thereby gaining room for additionally required components in hybrid vehicles.

Reduced installation space and decreased weight

Incorporating the benefits of hybrid drives into vehicles is a complex task for developers. They must find a way to integrate an electric motor in the tight space between the combustion engine and the transmission system. Thanks to the HOERBIGER SlimLINE, this task will become easier: Each installed synchronizer saves as much as seven millimeters in length, i.e. axially, where every millimeter counts. As a result, transmissions can have an overall shorter design in the future. This applies equally to dual-clutch transmissions, automated systems and traditional manual shift transmissions. Moreover, the HOERBIGER SlimLINE offers significant weight advantages.

Innovative shortened design opens up design freedom

HOERBIGER completely redeveloped the existing sleeve/hub system and its pre-synchronization elements. Special spring washers, which are integrated into the hub underneath the outer teeth, are considered revolutionary. They replace the previously necessary detents. While the functional principle remains unchanged, the technical implementation is different: In a first step, the marginally modified sleeve acts on the overlapping spring washer element, causing the element – instead of the formerly used detents – to be pressed against the synchronizer ring or blocker ring. Once this pre-synchronization stage is complete, further force build-up causes the spring to contract radially inwardly. This allows the sleeve to glide across the synchronizer ring as usual.

Thanks to the innovative design, recesses for the detents on the hub are no longer necessary. Without these "gaps" the hub can be built significantly narrower and with thinner wall thicknesses.

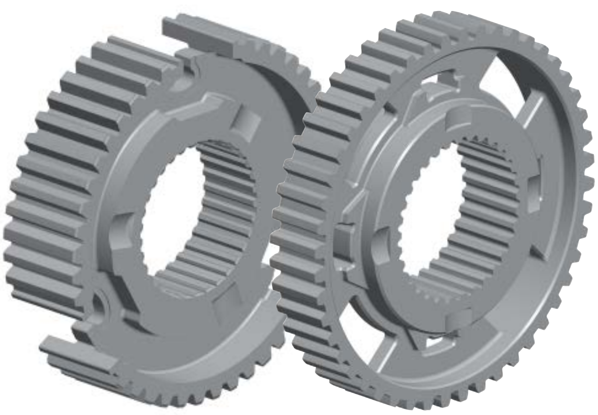


Figure 2
Design of the hubs by comparison: HOERBIGER ClassicLINE (left) and HOERBIGER SlimLINE (right)

The high levels of performance, torque capacity, shift quality and cold-start capability are fully preserved. The special design of the spring additionally allows the pre-synchronization forces to be scaled more individually and broadly than before. For example, by varying the geometry and metal thickness, they can be tailored more precisely to all manufacturer- and model-specific needs.

The continuous, closed tooth ring offers an additional advantage in terms of strength: Viewed axially, the blocker ring no longer has to be positioned entirely next to the hub ridge. As a result of special design solutions for what are referred to as the "indexing and coupling elements," the ring can be displaced through newly created apertures further into the ridge. The installation space that is saved is as much as seven millimeters, while the shift travel from neutral into the respective gear is shortened by 0.5 millimeters.

For transmission manufacturers not focused on space gain, HOERBIGER can design the SlimLINE with increased capacity, so that it transmits more torque than before, at identical dimensions and weight.

The cost savings potential also increases with the new system. Use of the HOERBIGER SlimLINE allows comparatively expensive steel hubs to be replaced with more cost-effective variants made of power metal (PM hubs) if needed.

The new design for "engaging" gears offers more advantages by ensuring active relief of the synchronizer rings. After blocking release, this design ideally supports active lifting and helps the sleeve reach and maintain the neutral position. When "in idle" the synchronizer moves with minimal drag torque. One important aspect is that the SlimLINE, despite its innovative configuration, can be easily integrated into existing transmissions since the interfaces to the gear wheel, transmission shaft and selector fork remained the same over existing synchronizers.

Space gain for electric motors

In total, the HOERBIGER SlimLINE is as much as 20 % smaller and lighter than the HOERBIGER ClassicLINE. When used in dual-clutch systems, savings of another three millimeters for a total of one centimeter is possible. This means that an element can measure only 28 millimeters in width instead of 38 millimeters, a decrease of approximately 25 % – regardless of whether single-cone or multi-cone models are used. To achieve this space gain, HOERBIGER combined the SlimLINE system with the ClassicLINE DCT-Type synchronizer.

Extrapolated, an inline transmission equipped with four of these combinations can be built as much as four centimeters shorter, and a transmission with front-transverse installation typically featuring two synchronizer layers will be reduced by half that. Ideally, it will be possible to almost entirely compensate for the added space requirement of an electric motor for hybrid drives by using HOERBIGER SlimLINE synchronizers. At the same time, the compact transmissions will weigh less, which will positively impact fuel consumption of vehicles both with and without hybrid system.

Regardless of what specific applications the HOERBIGER SlimLINE will be used in going forward, the new design is prepared for everyday demands. The system demonstrated its durability in a pulsation test over ten million cycles. Even after a full validation program, the spring washers still applied the same high pre-synchronization forces as they did at the start.

Rising international demand for electric cars

HOERBIGER SlimLINE synchronizers simplify the path toward plug-in hybrids, the most efficient among electrically assisted vehicles. Average daily distances can be covered with electric power and no local emissions. "Refueling" happens at the power outlet. If the charge is not sufficient, the combustion engine is activated in the form of a full-blown drive system or a range extender. In addition to all-electric cars, plug-in hybrids therefore also fall under the electric vehicle category – and even China's strict administration considers them new energy vehicles. This is extremely important since, starting as early as 2019, new energy vehicles must account for ten % of all vehicles built there (starting in 2020: 12 %).

The opportunities for the SlimLINE synchronizer in the market are enormous from this as well as other points of view. The number of registered new energy vehicles in China alone, for example, doubled between 2015 and 2016 to a total of approximately 650,000 vehicles. Electric cars are becoming more popular in urban areas in the USA (increase of 39.5 %), Japan (increase of approximately 20 %) and certain European countries. Considering absolute manufacturing figures for electric vehicles, China presently ranks ahead of Japan and Germany. In contrast, Norway is leading in terms of the number of electric cars per inhabitant, ahead of the Netherlands and Sweden. This market data underscores the high level of international demand for new developments that, similarly to the SlimLINE synchronizer, advance alternative, low-emission drive systems. ■

> "Obviously I still think a 12-cylinder AMG or Ferrari is brilliant. It gives you goose bumps. But there's a place for everything, and autonomous driving and electric cars are just as fascinating."

Success opens Doors

An editorial interview with reigning F1 World Champion Nico Rosberg

Mr Rosberg, you became Formula One world champion at the age of 31. How does it feel to be so successful that young?

Nico Rosberg: I only know it this way so I can't compare. But it was fantastic, and really emotional. I did it! It cost a lot of energy, but it was awesome. Sharing that success with everyone was great – my family, the team, friends. The title has an amazing effect on your life afterwards. This success opens doors, and it's really valuable for my future.

You surprised a lot of people when you hung up your helmet after winning the title. Was that a gradual decision or more spur-of-the-moment?

Nico Rosberg: It was gradual. Towards the end of the season I was so far ahead in the championship that the decision was in my hands. Suddenly, winning the title was realistic ... and then I got the idea of stopping after the season. I've worked really hard all my life to fulfil my childhood dream, my mission. Driving races to become world champion has always been my source of inspiration. And then I thought: if I win, that would perfect. The best way to end my active career, and the best launch pad for my new life. The day was going to come anyway because you can't do this sport forever. So I made the decision, and then I acted on it. It wasn't easy. It obviously changes your life completely, and there's also an element of uncertainty. But I followed my heart.

It must be quite a shift from a hectic, gruelling job as racing driver to being a family man. Did you take time out first, or did you start looking for new challenges and goals right away?

Nico Rosberg: First I spent a month travelling the world and celebrating! That was more strenuous than the whole season. But then I took time off completely with the family, which I really enjoyed. It was so liberating to be in charge of my own time at last.

But I'm still competitive by nature, I still seek fresh challenges and pursue new passions. One field I find really fascinating is the world of start-ups. I've always been interested in that, particularly in the mobility sector, where disruption is turning things upside down. I think the development that's happening won't just change life – it will improve it too. And there are lots of opportunities to get involved. I'm an investor for example, I had an inspiring trip to Silicon Valley, and I keep up to speed with what's going on. And naturally I'll still be part of motorsport. For instance in Suzuka, I was a TV expert for the first time. Hopefully, I helped make things even more exciting for viewers with interesting background information and details from my own experience.

How closely do you still follow Formula One?

Nico Rosberg: Very! It still gives me great pleasure, and this season is really exciting.

The auto industry is undergoing rapid transformation, and one of the buzzwords is autonomous driving. As a former racing driver, what do you think of that? Can you imagine sitting in a car without steering it?

Nico Rosberg: Sure. I'm really enthusiastic about the whole development. Obviously I still think a 12-cylinder AMG or Ferrari is brilliant – it gives you goose bumps. But there's a place for everything, and autonomous driving and electric cars are just as fascinating. EV development has the potential to ease the burden on our planet sustainably; if we generate more electricity from solar and wind in future, e-mobility will be more ecological long term. Not having to go to a filling station is also cool because for me, that's a waste of time. With an EV I can just plug it in and do other stuff, then drive away. In Monaco I get around in an electric Car to Go, a Renault Twizy. You see them everywhere here. I just book one in the app ... and off I go. The first time I rolled up in one, my father nearly disowned me. But then he just laughed and now he thinks it's great. The world is changing fast.

Do combustion engines still have a future? What about hydrogen drives?

Nico Rosberg: I'd say electric drives are definitely well ahead. It's not necessarily even the best technology, but the electric hype is currently so big, there are huge investments, all the research is focussing on this technology and rolling out the infrastructure. So for that reason alone it will come out on top really quickly. Hydrogen might even be the better technology, but I wouldn't give it much chance going forward because there's hardly any support. There will be fewer and fewer combustion engines as time goes by. But in my opinion, what we need is not a drastic switch, but a relaxed transition that gives the auto industry time to adapt. And above all, consumers shouldn't suffer. Obviously, I personally hope combustion engines will still have their place. I'd love to get in the V12 and enjoy that now and again. I'm not sure how we can arrange that yet.

What's your private car?

Nico Rosberg: A Mercedes GLC diesel, but the smallest engine they do. When I'm out with the family I don't need power on the road, and I prefer not having to fill up so often. So it's a real family car! But my biggest passion is a classic car, a Pagoda. I use that for romantic trips with my wife.

Formula E has been around for three years now. Is that a threat for Formula One?

Nico Rosberg: They don't compete, they serve different categories. Formula One will always be the incredible entertainment sport. I see Formula E more as a tech contest for manufacturers, a chance to test their series. Obviously it will grow because it feeds the topical hype.

Have you ever sat in a Formula E racing car? What's the main difference for drivers?

Nico Rosberg:I haven't been in an e-racing car yet, but I do know EVs. The main difference is the noise, and electric cars have more torque, which means more power. Engine sound doesn't matter to me when I'm driving privately.

How do you think people will get from A to B in 15 years' time?

Nico Rosberg: Easy. I pick up my smart phone and open the app. Depending on my needs, I select a luxury or a compact car. Then up comes a car with no steering wheel, probably with other passengers inside who I don't know. The car takes everyone where they're going by the smartest, most efficient route, and might pick up new passengers on the way. It's an easy, totally relaxed way to get from A to B. Ideally, the app would be able to handle my whole journey – everything from car to plane and train. That would be 360° mobility: you say where you are and where you want to go, and everything gets organized.

Any plans for the future that you can share with us?

Nico Rosberg: At the moment I'm very involved in managing a driver who's launching his Formula One comeback. His name is Robert Kubica. That's really exciting because together with Lewis Hamilton, he's the quickest driver I ever raced. Unfortunately he had an accident and had to take a break. But now it's great to be involved in bringing him back.

Did you ever dream of driving for Ferrari too before you became world champion?

Nico Rosberg: Mercedes and Ferrari are the legendary teams in Formula One. So I was even more proud to become the first German ever to win the World Championship in a German car. I'm a huge motorsport fan, and the Silver Arrows are legends. I went to the museum in Stuttgart recently where they took my world championship car. And there's my car, right next to Juan Manuel Fangio's, one of the greatest legends in our sport! That makes me so proud. Ferrari would have been great too. I have an Italian streak: I speak the language, and I have lots of Italian friends I grew up with. So it would have been fun … but ok, maybe next time around. ■

Impressions from the CTI Symposium China, 25 – 27 September 2017

Electrification has Many Facets

The quotas are coming. As of 2019, automotive manufacturers must have a minimum share of electrified vehicles in their Chinese portfolios. But conventional drives and transmissions will still have a chance too – the technical concepts of Chinese OEMs and suppliers are just as diverse as in other markets.

As the 6th CTI Symposium Shanghai (25–27 September 2017) showed, the question of whether combustion engines still have a future also applies in China. “Despite the euphoria surrounding electric drives, the Chinese have not forgotten combustion engines” said symposium chair Professor Ferit Küçükay in retrospect. This year’s symposium raised the bar once again, with 67 lectures offering 620 participants all the facts on new developments in transmission and drive technology. Unlike Europe and North America, China has seen strong, steady growth in vehicle registrations in recent years, though the curve has flattened of late. The good feeling is that most of the growth is in pure EVs, but Chinese suppliers are also growing their competence in conventional and hybrid drive technology.

Green light for electrification

The Chinese government is driving electrification. From 2019, a quota system will require carmakers who build or import more than 30,000 vehicles a year to have a minimum share of electrified drive vehicles in their fleets. The figures are 10 percent in 2019 and 12 percent the following year, based on a points system that assesses electrification levels, see explanation box. OEMs who miss their quotas must either pay a fine, or buy ‘credits’ from other manufacturers. As a quick glance at 2016 sales figures shows, the legislation poses a challenge for European manufacturers. According to Eurostat, Europe exported nearly 1700 electric automobiles to China in 2016; in the same year, VW alone sold almost 4 million automobiles in China, and BMW a further half a million. So some OEMs will need to ramp up their activities in the EV and PHEV sectors significantly.

The second driver for electrification is restrictive regional legislation that aims to make big city traffic local emissions-free. In Shanghai, for example, licence plates for a new conventionally powered automobile cost almost ten thousand Euros and take a long time to obtain. Electric cars get their licence plates free, right away. So if you want to own and drive a car in a big city, there’s no getting round full or partial electrification – and the relative cost savings go some way towards offsetting the extra outlay for an EV or PHEV.

Diversity of drives and transmissions

But that’s only in major cities. Elsewhere, the Chinese do what everyone does: they opt for less expensive solutions with a conventional or affordable hybrid drive – or an SUV if they can afford it. This means OEMs must tailor electrification levels accordingly and offer everything from 48V through PHEV to pure electric. The diversity of the approaches was reflected in this year’s plenary lectures, as well as in the podium discussion.

This year’s CTI Symposium in China had 620 participants, who could choose from 67 speeches and meet with 50 exhibitors.

Speaking in the plenum, Rongbo Zhang, Geely, pointed out that unlike the rest of the world, China has more EVs than hybrid vehicles. He predicted two million NEVs for 2020 (one million of them pure electric), but said Geely is pursuing a diverse strategy in order to meet China’s fleet consumption requirements. Under CSFC Stage IV, passenger car fleet consumption for 2020 is set at 5.0 litres, which corresponds to

China's EV quota from 2019

Shortly after the Shanghai Symposium the Chinese government published a final set of rules for new emissions vehicles (NEV). Auto makers that produce or import more than 30,000 vehicles per year, will have to obtain an energy score of at least 10 in 2019 and 12 in 2020. The score is calculated by a points system that factors in the type of electrification as well as the electric driving range.

Vehicle	Electric driving range (km)				
type	≥ 50	80 – 149	150 – 249	250 – 349	≥ 350
PHEV	2				
BEV		2	3	4	5
FCEV				4	5

BEV = battery electric vehicle
PHEV = plug-in hybrid electric vehicle
FCEV = fuel cell electric vehicle

If for example 2 percent of the automakers fleet are long-range EVs (≥ 350 km), the volume is multiplied with 5 points, making an energy score of 10. On the other hand, 2 points for PHEVs would require a 5 percent production volume to meet the score. In other words, if an automaker produces or imports one million cars, 20,000 long-range EVs or 50,000 PHEVs would be sufficient accordingly to avoid fines or buying credits from other car makers.

While the disproportional promotion of long-range EVs may be debatable, PHEVs appear to be a realistic alternative to short-range EVs, and FCEVs explicitly stay on the agenda. However, a possible trend to e-fuels for longer-range applications is not represented in the model so far.

117 g/km of CO_2. As part of its 'Blue Geely Action', the company strategy includes methanol and natural gas as well as EVs, PHEVs and mild hybrids.

On a global scale, Dr. Harald Massmann, ZF, expects that in 2026, 70 percent of the cars on the road will still be conventionally propelled; 24 percent will have hybrid drives, and 6 percent will be pure electric. He believes the number of ICE drives will keep growing until then. Citing the example of ZF's 8-speed automatic transmission, the speaker reminded listeners that even 48V mild hybrids save 9.5 percent on fuel, while full hybrids save 11.8 percent.

Dr. Yun Jan, Dongfeng, used market forecasts to show that drive diversity – from add-on hybrids and DHTs to pure electric drives – will still be with us in ten years' time. To master this diversity, Dongfeng plans to build its future hybrid and electric drives around a modular set of eDrive components. The 'building block' system includes scalable electric motors, common ECUs and reduction gear units, all of them suitable for both electric drives and serial or parallel hybrids.

According to Haruhisa Nakano, Jatco, traffic speeds fluctuate more in China than in Europe, including in suburbs. He draws two conclusions from this: firstly, CVT lets developers program gear ratios precisely for Chinese scenarios; secondly, CVTs still retain the inherent flexibility that keeps ICEs in the 'sweet spot' in these driving situations, particularly in 'eco' mode and at low speeds. Nakano says this flexibility in setting ratios also helps in conjunction with 48V hybrids, since ICE-powered operation still dominates there too and CVTs help make drives compact and cost-effective.

E-Fuels – extending horizons

In China too, experts are pondering just how clean electric automobiles are overall, apart from the need for local emissions-free driving in cities. The status quo is something of a dilemma. One horn is the call for local emissions-free mobility; the other is the fact that roughly 65 percent of China's EV power comes from coal, much more than in other regions. Against that backdrop, the commonly used term NEV (New Energy Vehicle) does not really tell the whole story.

On the same topic, Michael Schöffmann, Audi, presented figures that were both interesting and wide-ranging. Taking the local energy mix into account, Schöffmann's figures put the converted CO_2 emissions of pure electric automobiles in China at 167 g/km. That compares with 122 g/km in the USA, 91 g/km in Germany, and 12 g/km in France due to nuclear energy. However, he also made it clear there is no lack of commitment for renewables in China. In 2016 China was already producing 545 gigawatts of regenerative energy, compared to 215 GW in the USA and 106 GW in Germany. But Schöffmann believes regenerative electricity can also be used to make carbon-neutral E-Fuels – an efficient energy source with a relatively high energy density.

Another fuel fan was Pu Jin, Techrules, who presented the company's unusual 'Turbine-Recharging Electric Vehicle' or TREV. Mr Jin argues that while electric motors make ideal drives, the batteries are too heavy, making range extender concepts the better solution. In the TREV, however, what powers the electric generator is not a combustion engine but a fuel-driven, high-speed turbine weighing a hefty 40 kg less. The technology was showcased in an out-and-out sports supercar at the Geneva Motor Show 2017, but Pu Jin sees realistic applications in trucks, passenger cars, two-wheelers and more besides.

China is pushing in-house development

With so much interest in electrified drives, it's easy to forget that China has also built up considerable potential in the conventional solutions segment. One example is the new 7-speed DCT from Great Wall, presented by Lipeng Zheng. Mr Zheng said Great Wall's choice of a DCT

was logical given the company's existing experience with manual shift transmissions, and added two further factors: high efficiency, and the convenient package for front-wheel drives. He noted that the two-stage actuator concept (with a mechanical and a variable electric pump) and the ability to divert part of the oil flow for lubrication are state-of-the-art technical solutions. The new 7-speed DCT came out in March 2017 and was developed entirely in-house, despite the long list of global suppliers.

In the podium discussion, Professor Küçükay asked participants to what extent Chinese OEMs and suppliers are now independent of international support. Lipeng Zheng saw good progress at Great Wall in terms of mechanical quality, and also in software. Rongbo Zhang said the goal for Geely was to become a global Top Ten player. In his view, that means working with the best suppliers regardless of their origin, and paying close attention to customer requirements in different parts of the world. Harald Massmann believes that particularly in Simultaneous Engineering, China is still 'in the starting blocks'. Michael Schöffmann questioned whether it would make sense at all for China to try and develop solutions independently of international partners. "It's an international business and we use third-party components and services at Audi too. It's important to be open."

Between perfection and quick time-to-market

The relatively young category of DHT was also discussed in Shanghai – and with it, another possible dilemma for the automotive industry. As you may recall, Robert Fischer, AVL, put the concept's break-even point at 100,000 units when DHTs were first presented in 2015. Conversely, that implies that modular add-on solutions would probably take preference for shorter production runs.

China now has several DHT manufacturers, including Geely, which is launching a series-production powersplit DHT in 2018. Otherwise, Rongbo Zhang takes a pragmatic view and says transmissions should be selected according to the application. Lipeng Zheng, Great Wall, says DHTs are a good solution, but their success will also depend on future government decisions. For Mr Zheng, costs and time-to-market are key criteria in a fast-growing market. Hence, 'quick' solutions such as P2 or P4 hybrids have the edge when it comes to reducing emissions relatively quickly and cost effectively.

Zheng added another interesting aspect by noting that DHTs require equally dedicated in-car infrastructures. Put bluntly, that means DHTs only become interesting when regulatory pressures are so high that manufacturers are willing to develop a seamless, all-in system that is less scalable than an add-on solution.

What do we take away from Shanghai 2017? In China as elsewhere, the solutions pursued by manufacturers and suppliers are far more diverse than they might sometimes appear. But as Professor Ferit Küçükay points out, "That does not obscure the fact that China is taking big strides towards e-mobility. Bigger than any other country in the world."

Gernot Goppelt

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