cti magazine

AUTOMOTIVE DRIVETRAINS | INTELLIGENT | ELECTRIFIED

December 2019

INTERVIEW

Oliver Blume, Porsche

“We need Exciting Cars – and just as Important, a Fast Charging Infrastructure”

PUNCH Powerglide

An Innovative Concept for an Optimized DHT in Terms of Efficiency, Cost and Packaging

eKontrol

eDMT for Commercial Vehicle Applications

cti magazine

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Dear reader,

welcome to the thirteenth issue of CTI Magazine. Inside, major suppliers describe the latest developments in transmissions and drives, where two factors – the diversity of electrified drives and digitization – continue to fuel R&D activities.

In addition to DHT and add-on hybrid drives for passenger cars and multispeed BEV transmissions for commercial vehicles, we also explore component-related topics such as pumps, lubricants, controllers and software methods. For developers, the primary aims are to increase efficiency and performance while simultaneously reducing costs and weight.

To complement these specialist articles, we interview top automotive managers and experts including Dr Oliver Blume, CEO Porsche, who describes Porsches electrification strategy and how the digitization changes the automotive industry. Top drive expert Stephan Tarnutzer, AVL, reflects on how electrification affects the work content of OEMs, suppliers and engineering service providers, while automotive specialist Prof Giorgio Rizzoni, Ohio State University, examines the 'drive mix' for commercial vehicles.

Last but not least, you'll find all the news from the recent CTI SYMPOSIUM CHINA (Shanghai) in the form of a follow-up report.

Our special thanks to everyone who helped make this issue of CTI Magazine happen. Enjoy!

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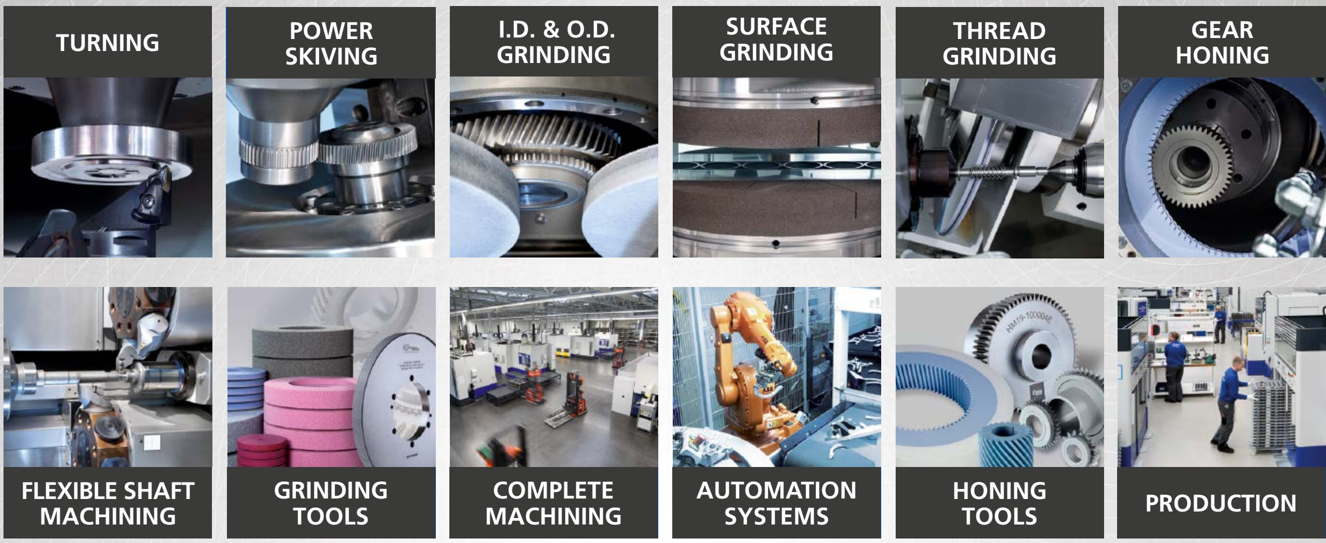
INTEGRATED SINGLE SOURCE PRODUCTION SOLUTIONS



The DVS TECHNOLOGY GROUP is made up of Germany-based companies focusing on turning, gear cutting, grinding and gear honing technologies. Besides engineering and manufacturing machine tools, automation systems as well as grinding and gearhoning tools, DVS operates two production sites where transmission parts are machined in series production exclusively on DVS machines. This adds a high degree of production know-how to the experience of the DVS machine tool and tooling manufacturers.

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Flexible Fleet Hybridization with 'Native Hybrid' DCT Range

Electrification of powertrains is on the rise, in order to meet the environmental targets. This trend typically increases powertrain size, cost and complexity at the production line. A new approach emerges to tackle these challenges: a DCT, which is designed as 48V hybrid, with the conventional (non-hybrid) and high voltage strong hybrid being derivatives. Basing all 3 variants on one design allows adjustment of the fleet electrification mix with minimal effort.

An additional merit of the design is its compactness, as it takes up no more space than a conventional DCT. This was enabled by a new way of realizing the dual clutch principle. By linking a planetary gearset to one of the two clutches, a shiftable pre-reduction in front of transmission gearsets emerges. This allows to substantially reduce the amount of components and leaves space for an integrated e-machine.

Dr Ir. Alex Serrarens, Manager Business Development, Punch Powertrain

Dr Ir. Roëll van Druten, Chief Engineer DCT, Punch Powertrain

MSc.PhD. Dirk Kok, System Engineer, Punch Powertrain

1 Electric Vehicles (EVs) Need

While EVs need evolution time to mature, substantial reduction of CO2 emissions cannot wait [1]. Massive introduction of hybrids (mild, full and plug-in) is required to address this in a balanced way and allow both production and market to absorb the gradual on-cost.

The introduction of a flexible and integrated hybrid DCT platform, both available with 48V or high voltage e-motor is a logical choice for regions, already having a strong legacy in MT/DCT adoption (such as EU, China, India and South America). Cost-effectiveness can be achieved if the hybrid is not designed as a niche product, but as the new standard automatic that is able to be fitted in the OEM's entire front-transverse platform program, regardless of the (continuously adjusting) mix in mild, full or plug-in hybrids.

2 Unique DCT Concept

2.1 Strongly Reduced Amount of Components

This DCT concept introduces a new way of realizing the dual clutch principle. By linking a planetary gearset to one of the two clutches, a shiftable pre-reduction in front of transmission gearsets emerges.

In this set-up, the new DCT called "DT2" (and also its predecessor DT1) makes each gearset in the gearbox available for 2 distinct transmission ratios; one when closing the normal clutch and the second by closing the static clutch (brake) of the planetary gearset. So, the 2 DCT "clutches" can connect to the same gearset by (pre-)synchronizing from one input shaft to the other. This is not seen in other in-market DCTs. Fig. 1

The clutch & topology innovation enables a significant reduction of internal gearwheels, shafts and synchro-sets. It results in a compact, efficient transmission leaving enough room for integration of the e-machine (48V or HV). Fig. 1 illustrates how the new DCT principles are

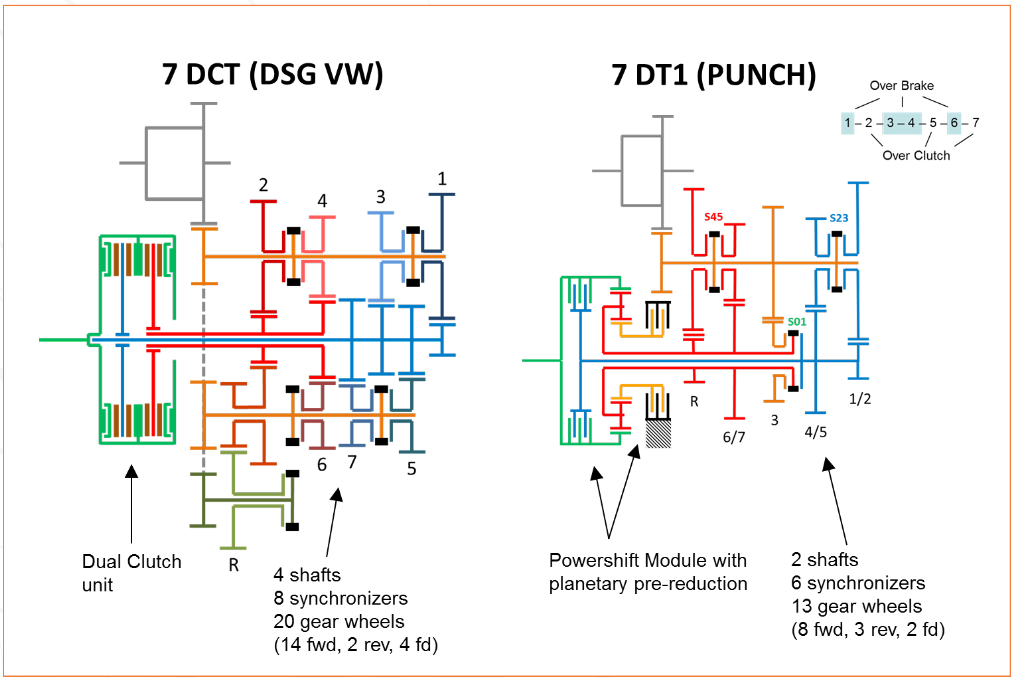

Figure 1 Illustration how to decontent a 7speed DCT using Punch Powertrain's DCT mechanical principles. DT1 is a 200Nm wet clutch 7DCT.

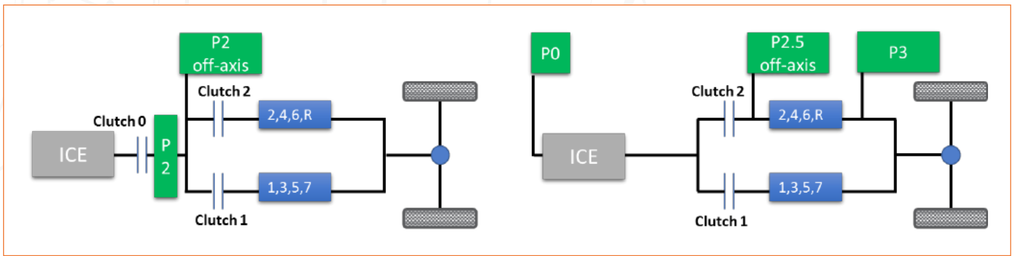

Figure 2 Left: P2 hybridization options, right: other hybridization options

exploited for the 200Nm DT1, using only 13 gearwheels in total vs. 20 gearwheels in a mass produced benchmark 7DCT. Note that the DT1 topology constitutes a 7speed DCT with only 1 layshaft, which is also unique. The (higher torque) successor DT2, also has just 13 gear wheels in total. However, the first DT2 release has (contrary to DT1) a very short 2nd layshaft carrying 2 gearwheels and a final drive pinion.

2.2 Seven Speeds for Optimal Gear Ratio

In theory, these principles imply that (for example) just 4 forward gearsets (8 gear wheels) inside the main gear cluster could enable a 8DCT, albeit with a number of gear dependencies and less flexible ratio design. Instead, we chose to create a unique 7DCT structure with less gear dependencies, leading to increased fuel efficiency and driver comfort.

2.3 Tailored Shifting

These valuable benefits, however, do come with a minor compromise. In case of the DT1 both 3rd and 4th gear are selected by engaging the braked planetary ratio. Therefore, to powershift from 3rd to 4th gear, the clutch is shortly sliding on 5th gear to provide shift time for synchronizer S01 (Fig. 1) towards 4th gear. Through sophisticated controls, this is unnoticeable for shifts at low to medium power. For shifting maximum engine torque some driveability specialists might slightly feel this "supported" 3/4 shift. For the application range of DT1 (120–200Nm) this overall drive quality is more than sufficient. In case of DT2 (230–350Nm) we configured the gear topology in such a way that only the 6/7 shift is slightly different from the other standard DCT shifts. In day-to-day driving this is unnoticed as 6/7 shifts usually occur at low power, when the driver reverts to a cruising mode at high vehicle speed. Nevertheless a full power kick-down shift from 7th to 5th gear is possible without compromise, particularly including electric machine boosting in case of the hybrid variants.

3 First P2 integrated DCT

3.1 Comparison hybrid topologies

Various mainstream options to integrate an electric machine into the DCT were investigated, notably P2, P2.5 and P3 configurations, see Fig. 2.

It is known that a P3 & P4 configuration cannot do without an additional P0 belt starter/generator machine and therefor essentially forms a 2-motor hybrid. On the contrary, P2 and P2.5 are both single motor hybrids and can therefore be analysed and compared in further detail, which is done through Table 1.

Attribute	P2 (all ratios)	P2.5 (half of ratios)
Boost/regeneration	++	+
Electric Driving	++	+
Charging at standstill	++	+
ICE restart at standstill	++	+
ICE restart while E-driving	+ (with P2 motor only) Using both C0 and DCT clutch torque & inertia control	– (with P2.5 motor only) With DCT clutch, only some torque damping possible
Impact EM on gear changing	Independent of EM power, temp or BAT SOC	EM (and bat.) actively assist gear synchro
Shifting during EV (mot+gen)	Powershift possible in all gears	Shifting of EM shaft causes interrupts
Hybrid propulsion during shift	EM can support ICE & DCT at any shift	EM can only support when it not shifts itself
Max EM launch torque	EM launch in 1st gear wheel torque	EM launch in 1st gear requires both DCT clutches to be closed (safety challenge)
EM speed at high veh speed	DCT in 7th → EM in 7th gear	DCT in 7th → EM in 6th (20–30% higher rpm)
NVH/active damping by EM	EM can be active damping device in all gear selections	EM often drives other gear than ICE, NVH complex
Functional Safety	DCT clutch(es) are immediate torque fuse at EM drift	Synchromesh hard to decouple at EM torque drift

Table 1 Comparison P2/P2.5 configuration

At first sight a P2 and P2.5 off-axis integration of the electric machine look quite similar. However, the electric motor in P2.5 is directly coupled to one of the gear clusters inside the transmission and uses only 3 of the 7 forward gear ratios. In this topology shifting the electric machine from one gear to the other cannot be done through the controllable friction clutch(es). Therefor a lot of performance, comfort and even safety is lost when choosing P2.5 instead of P2. Mind that the C0 clutch can be omitted for potential future engines with full cylinder deactivation (P2 becomes P1) and, of course, for the conventional DT2. This results in even more modularity opportunities.

3.2 Market of P2.x Topologies

P2 configurations have been used already extensively in many applications. For example by BMW and Daimler, where a co-centric (on-axis) large diameter electric motor is integrated in the Torque Converter housing of rear wheel ATs. VAG has integrated a P2 high power co-centric machine into a front/transverse 6DCT and applied it to PHEV models (Passat/Golf GTE). P3 configurations are rarely seen, instead P4 configurations are usually chosen, where the rear wheels are separately driven by a high voltage e-axle. T he front wheels are driven by a conventional front transverse powertrain with P0 high voltage starter generator (e.g. Volvo). Finally, P2.5 hybrid DCTs examples from Getrag [2] and CEVT [3] use an off-axis machine connected to one of the existing gears at the even gear input shaft. Such P2.5 arrangement enables the even clutch to also operate as a kind of C0 clutch, however with some drawbacks as discussed in the previous paragraph..

A P2 hybrid DCT with off-axis (48V) integrated machine is not yet seen and DT2 is the first DCT to use such packaging arrangement within this hybrid topology option. The unique mechanical structure of DT2 generates space to integrate a cost effective off-axis electric machine and the on-axis C0 clutch. The C0 clutch can mechanically decouple the engine and have the hybrid transmission propel (or regen) the vehicle on its own. In case of the 48V Mild Hybrid variant the electric machine with inverter is integrated and for the high voltage (P)HEV variant the powerful electric machine occupies the design space, whereas the high voltage inverter is placed on top of the hybrid transmissions.

3.3 Opposite Design Approach: 48V Variant as Standard

The goal was to realize a high speed, off-axis (side-mounted) electric machine integrated into the transmission, without enlarging the traditionally accepted DCT size in any direction. This was made possible by the reduced number of gears, shaft and synchronization components, which generated a compact design basis to accommodate the side-mounted electric machine.

Rather than starting from a conventional DCT and adding an e-machine, an opposite design approach of 'native hybrid' was chosen. This entails that the DT2 is designed as a 48V hybrid Dual Clutch Transmission right at the start of the product creation process, from which the High Voltage and the conventional (non-hybrid) DT2 are derived. This implies that DT2 hybrid is the standard, while the conventional DT2 is the option, sharing the same design base.

DT2 – 'Native hybrid' DCT family for multi-energy platform application			
Orientation:	Front Transversal		
Max. Input Torque:	350 Nm		
Max. / Peak Input Speed:	6.500 / 7.000 rpm		
Ratio Spread:	7,5 with 7 speeds		
Shift Mechanism / Shifter:	Electric Shift Drum / SbW PRND		
Park Lock:	Electrically & Hydraulically Actuated		
Clutches:	Wet Plate Clutch & Brake		
Oil Pump:	2 Electric Pumps (act + lube)		
Installation Length (min. / max.):	327 / 393 mm		
Center Distance:	189 mm		
Oil:	4,5 l		
Hybridization:	P2 with ICE (C0) Clutch		
Variants	**Conventional**	**MHEV**	**P/HEV**
Weight (dry):	77 kg	97 kg	105 kg
Nominal E-Motor Voltage:	–	48 V	320 V
E-Motor Power (mot. / gen.):	–	21 kW / 24 kW	93 kW / 93 kW

Table 2 Product specification sheet of the 3-fold DT2 hybrid DCT platform

DT2 is therefore very suitable as a portfolio solution for OEMs that look for a flexible CO_2 compliancy package in FWD volume segments (B to lower D). Table 2 illustrates the variant specifications of the 3 platform options.

4 Smart, Integrated Design & Inherent Adjustments

The reduced number of gears, shaft and synchronization components generate a compact design basis, particularly to accommodate the side-mounted electric machine, viz. Fig. 3. In terms of synchronizer actuation both DT1 and DT2 use a single shift drum. This is possible thanks to the limited amount of shift forks that are required for the simpler gear structure and sequential shifting being sufficient for this e-motor assisted hybrid transmission. Apart from the direct 7-to-5 power-on downshift (and upshift) to enable swift highway vehicle takeovers, the transmission does not enable direct skip-shifting. Furthermore, the entire envelope of DT2 product requirements introduces a number of new design decisions compared to, for example, DT1.

4.1 Engine-off & Park Lock

During instances with engine-off the transmission needs to be able to operate stand-alone, purely by electric propulsion. Therefore an electric oil pump, instead of mechanically driven oil pump, is required to pressurize the hydraulic system. Furthermore, to comply with international industry practice and safety standards, including ISO26262, the park lock system is designed with two (principally different) redundant actuation means. Furthermore, park lock has a self-engagement mechanism in rare cases where the 12V board net is interrupted or failing.

4.2 Packaging & Assembly

Within the design space that was allowed, viz Fig. 3, the only way to integrate the 48V e-machine was by integrating the stator and rotor into the main transmission housing instead of a bolt-on motor with separate housing, bearing and cooling solution.

To assemble such setup generates some challenges. Often the stator is fixed in its motor housing by a press fit process, where the housing is thermally expanded. Because in DT2, the stator is to be fixed in the transmission housing this cannot be done in a cost-effective way. Therefore a fixation strategy was chosen through the use of a mounting frame between stator and transmission housing. The housing part around the motor then mostly provides a covering and sealing function.

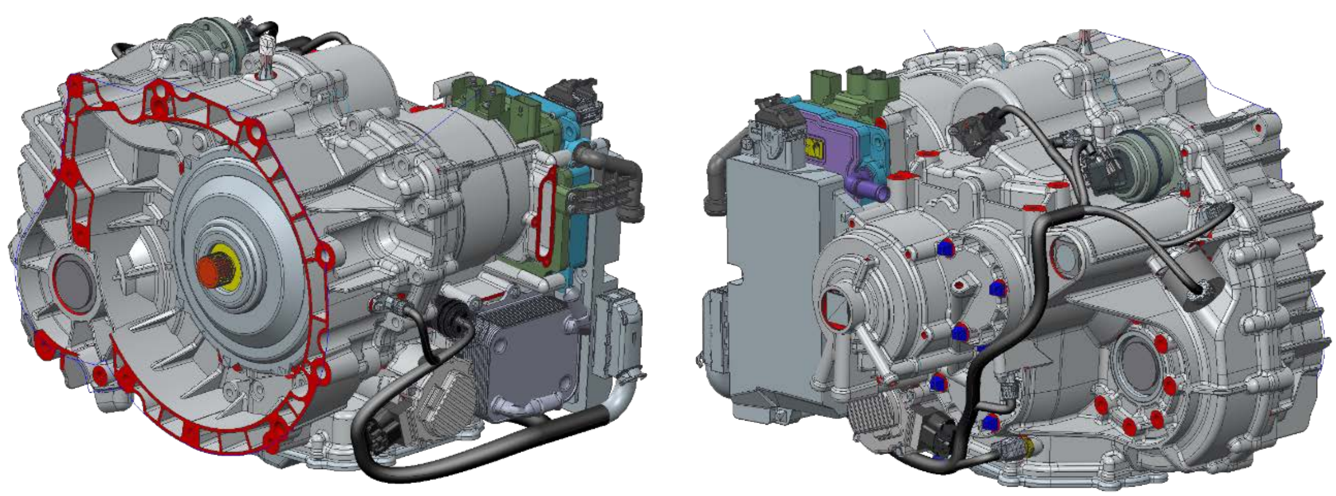

Figure 3 DT2 mild hybrid 350Nm 7DCT. Left: the 48V E-motor/inverter (colored). Right: the high connectivity, ASIL-C TCU is at back of the 48V inverter.

4.3 Tight E-motor Packaging

Because of the packaging constraints, two more steps towards tighter integration of the e-motor were taken. One is that the rotorshaft with output gear is suspended with bearings like the other gearshafts directly inside the transmission housing. Secondly, further integration was achieved by incorporating the cooling of the e-motor windings and rotor as part of the active transmission oil cooling system. The rotorshaft assembly enables a direct spray of filtered cooling oil with unconstrained drainage flow of the oil into the transmission. These aspects result in a smaller motor design and internalized cooling, without the need for bulky piping and sealing.

4.4 Power Dense Inverter

As for mechanical integration of the inverter, it locally has a very dedicated shape to accommodate space for internal (rotating) transmission parts. Also the AC links between the 48V motor and the inverter are kept as short as possible. Furthermore, the 48V inverter electronics design is optimized and tailored to the specific performance requirements that are defined in the range of 3 to 60 sec, in addition to sustained (continuous) performance. The consequence of the limited inverter design space is a small DC link capacitance. A small capacitance means limited filtering capacity and thus challenges to ripple and emc requirements. To neutralize these challenges and also to cool the MOSFETS, we have a battery-shared cold cooling circuit with cooling temperature conditions normally between 20 and 40 degrees. This is well in line with the battery cooling circuit requirements. [4]

5 Conclusion

In this article, we motivated the introduction of a new type of platform native hybrid 7speed DCT, the DT2. The transmission is unique in many ways, most notably an off-axis P2 hybrid topology combined with a new DCT mechanical and functional principle. The result is a compact solution that was designed as 48V hybrid and where the conventional (non-hybrid) and high voltage strong hybrid are derivatives. The 3-fold platform DCT can be flexibly produced in a continuously adaptable mix dependent on the market demand and CO_2 compliancy targets of the OEM applications. The hybrid system will have its first SOP early 2022, followed by several further SOPs.

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Dedicated Hybrid Transmission (DHT) by PUNCH Powerglide

An innovative concept for an optimized DHT in terms of efficiency, cost and packaging.

Philippe Ramet, Engineering Project Manager, PUNCH Powerglide

DHT Concept as Cost Reduction Opportunity

Car manufacturers around the globe have to hybridize their vehicle range to meet increasingly challenging CO_2 and emission standards. We all acknowledge that CO_2, emissions and energy transition will be prevalent for the years to come. This is one of the reasons why a holistic approach is required. Unavoidably, this challenge results is additional development effort and costs for all organizations involved in powertrain development.

Hybrid P0 and P1 versions are attractive solutions from a cost perspective. However, they provide limited potential to achieving future emission standards. Other approaches such as P2, P3 and P4 hybrid solutions have shown that significant vehicle alterations to integrate an electric motor and power electronics onto the front or rear drivetrain is required.

The main drivers for DHT and DHE (Dedicated Hybrid Engine) drivetrains is to facilitate cost reductions for specific sub-systems. The benefits afforded by the electric motor to reduced emissions while maintaining the same vehicle performance, can also support a de-contenting of the combustion engine and transmission. This is one logical step to compensate for the on-cost of these electrified drivetrain solutions. Cost reduction will be instrumental in facilitating DHT's market penetration.

DHT is a radical transformation of the conventional transmission, bringing new philosophies that need a permanent electric power management. DHTs driven by an internal combustion engine and an electric machine, offer multiple running modes where the e-machine is used either as a generator or as a motor.

The Automotive industry is currently looking for efficient hybrid transmission concepts for use with a single electric machine. The aim is to find a cost effective alternative to current parallel and power-split hybrid concepts.

To meet this challenge, PUNCH Powerglide is introducing a novel hybrid concept that delivers electric and mechanical states using less number of gears and dog clutches to maximize efficiency.

Philippe Ramet, Engineering Project Manager, PUNCH Powerglide

Given the high costs of batteries, amongst other items, further improvements in efficiency (reduction of losses) of the DHT is one of the key success factors.

Ambitious Goal for OEMs Needs

Having identified the technical issues, PUNCH Powerglide has developed the following requirements in order to identify a well suitable dedicated hybrid transmission concept.

A key objective is to identify technical solutions to optimize gearbox efficiency, while assuring a similar level of comfort and performance as today's solutions. A weakness of current power-shift transmissions on the market is the use of multiple friction plates for the shifting system. It is generally recognized that dog clutches represents the most efficient solution for this type of connection. However, in today's transmission market, only few have implemented dog clutches and expertise is still limited (ZF 9HP and Renault Locobox).

In order to limit vehicle electrification cost, a de-contenting approach has been considered for the DHT definition. A solution with four mechanical gear states (ICE) and one electric gear state is sufficient to meet the emission targets. Apart from the significant reduction of components, a considerable benefit is realized in the reduction of installation space.

The project target is to use one single high-speed IM (induction machine) where torque, speed and packaging is adapted to suit various hybrid vehicles. The number of gears and ratios are to be flexible to cater for various vehicle requirements such as gradeability and top speed.

Even if the concept must utilize dog clutch, the DHT has to be a power-shift transmission and has to fulfill standard hybrid functions such as regeneration / recuperation, boost mode, and serial mode.

OEM needs		Design targets
Efficient concept	⇨	Replace standard clutch packs with dog clutches and limit gears for losses reduction
System cost optimization	⇨	Minimize components in compact concept, 4 gears base architecture
Flexibility	⇨	Adjustable number of mechanical gears & ratios and scalable EM and Inverter power
Hybrid functions	⇨	Regeneration & Recuperation, Serial mode, Power-shift gearbox

Figure 1 PUNCH Powerglide's Integrated Hybrid Design Targets

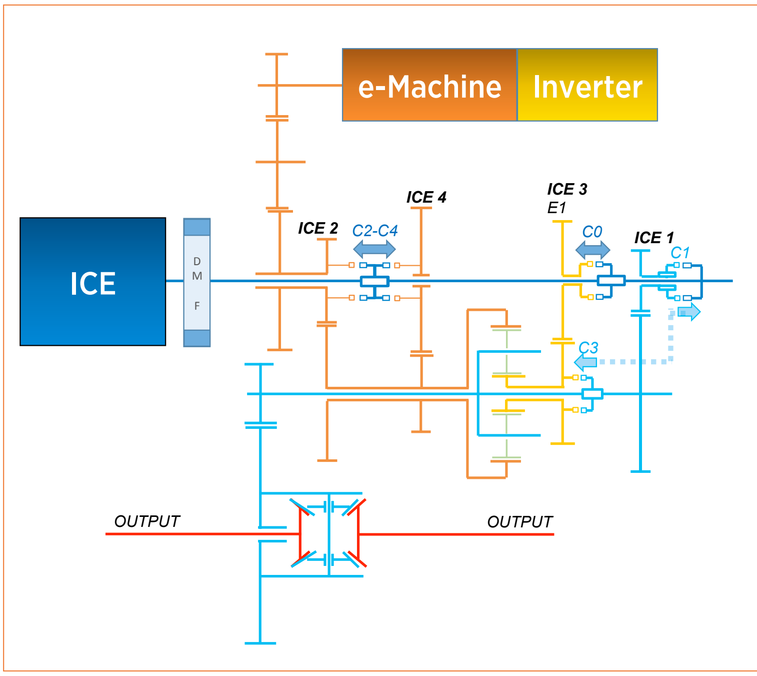


Figure 2 PUNCH Powerglide's DHT Powerflow

PUNCH Powerglide's Concept: a DHT with Dog Clutches

PUNCH Powerglide's research outcome has resulted in a DHT with modular powerflow.

The core element of the powerflow is a single planetary gear set where the carrier is directly connected to the output shaft, the ring gear to the electrical machine, and the sun to the combustion engine through a C0 connection. This is the key element to enable an EVT mode in which the relative speed of the connection elements is controlled.

This powerflow provides 8 different modes comprising: 1 electric gear, 4 mechanical gears (ICE), 1 EVT mode, and 2 serial modes. Only 5 connection elements are needed to provide these states. In hybrid mode, the torque at the wheel is a combination of the combustion engine and electrical machine torques. In this mode, the electric machine is used either as a generator or as a motor, allowing for boost, regeneration (also at standstill) and recuperation functions.

The primary and intermediate shafts contain all the connection elements and gears. The advantage of this configuration is to limit the number of transmission components, i.e. main shafts, bearings and casings. This arrangement is significant in minimizing the transmission length and helps facilitating the transmission integration into what is typically a limited workspace in hybrid variants. Naturally, lowering the component count also results in cost reduction.

Modes	ICE Ratio	EM Ratio	C0	C1	C2	C3
Hybrid drive 1	8,8	5,8	X	X		
Hybrid drive 2	6,1	8,7	X		X	
Hybrid drive 3	4,2	10,8	X			X
Hybrid drive 4	2,9	12,2	X			
Electric mode	0,0	10,8				X
EVT mode	14,1	15,3	X			
Serial mode 2	0,7				X	
Serial mode 4	0,2					

Figure 3: DHT Actuation Table – 8 Modes

Activation of various connection elements enable the various mode and gear states. These are described in the table depicted in figure 3. The ratios shown in this table are only one example and are modifiable through different gear designs, i.e. number of teeth.

In hybrid mode, upshifts and downshifts are performed with the release of one connection element (dog clutch) and the application of another one. However, during this state change, C0 remains engaged putting the transmission into EVT mode. This mode is used to control the speed of the connection elements for shifting into the various states.

EVT Mode for Dog Clutch Engagement

The advantage of dog clutches is the negligible losses when closed, but especially when open. However, their use brings new constraints on transmission concepts. Engagement and disengagement of a dog clutch is possible only if the relative speed of elements as well as the torque are close to zero. The challenge is even more complex considering that synchronization of dog clutches should take place without wheel torque disruption, to maintain an acceptable shift comfort.

Strategy for dog clutch disengagement in hybrid mode:
In hybrid mode, the reduction of torque required for tooth disengagement of the dog clutch is managed by adjusting the torque distribution between the combustion engine and electrical machine. The kinematics of this transmission has engaged dog clutches physically linked to the combustion engine and electrical machine. Therefore, there is always a torque state where the dog clutch transmitted torque becomes null, allowing the disengagement of the element.

Strategy for dog clutch synchronization before engagement:
The synchronization engagement speed of the dog clutch is achieved again via the EVT mode. In this mode (C0 remains applied), the carrier is connected to the wheel while the electrical machine is connected to the ring gear, and the combustion engine to the sun gear. For a simple planetary gearset arrangement, there are infinite possibilities of motor speeds for a given output speed. Based on this relationship the combustion engine and the electrical speed are controlled until dog clutch tooth speeds reach the design threshold for engagement. The benefit of the EVT mode is that constant speed to the wheels is maintained while synchronizing the connection elements.

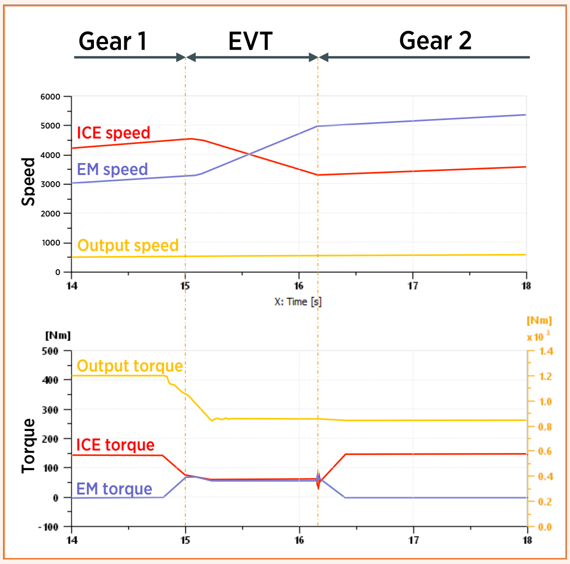


Figure 4 Hybrid mode - Gear 1 to gear 2 change

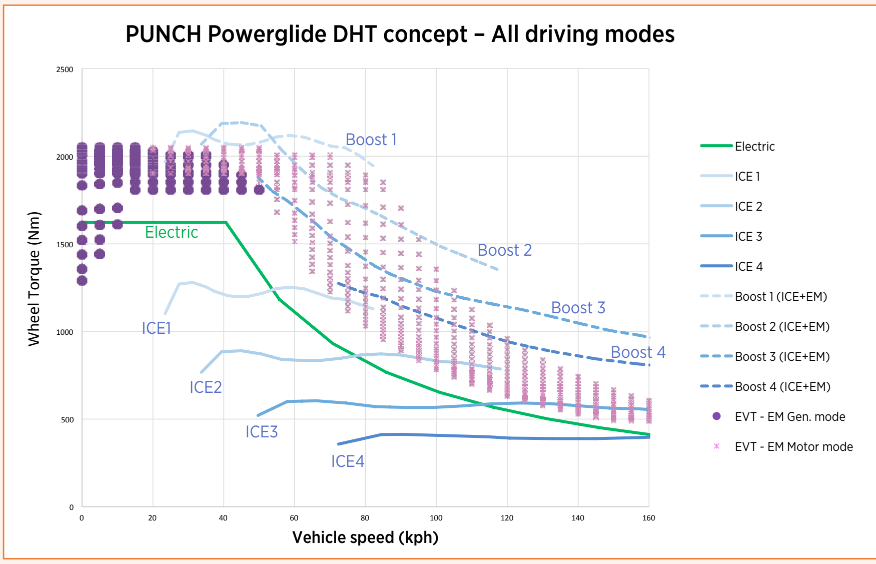


Figure 5 Performance and traction diagram

Results & program risks:

The introduction of an EVT mode supports perfectly the dog clutch implementation. The result is a powershifting transmission (refer to figure 4 for gear 1 to gear 2 change). However, this specific mode requires precise control of speed and torque of both motors to prevent mis-engagement and to limit output torque disturbance affecting shift quality. There are tooth design and the actuation selections that improve this concept's implementation success.

EVT Mode for Vehicle Launch

Another benefit of the EVT mode is during vehicle launch. It consumes electric energy from the High Voltage battery but in such condition, the electric machine is acting as a reaction element, and so, as a generator.

The selection between electrical mode and EVT mode during vehicle launch depends on the battery SOC (State Of Charge). When the battery SOC is insufficient, EVT is selected; otherwise, pure electric driving is preferable.

As the torque ratio in EVT mode is higher than first gear, this mode can act as an additional gear to the transmission. Although this DHT concept has four mechanical gears, it can behave as a five-speed transmission if desired.

Combustion Engine Restart

During transitions from electric to hybrid mode, the combustion engine needs to be restarted. Transmissions using only dog clutches can only start the ICE via the electrical machine when the vehicle is stopped. While driving, this causes loss of vehicle traction and is thus not desirable. Several solutions are adaptable to the concept. These being: add a starter motor, a launch clutch, or a second electric machine (as the Renault Locobox). Replacement of a dog clutch by a friction clutch is also an option but is probably least desirable.

Performance and Flexibility

Fig. 5 shows the traction force in each mode of PUNCH's DHT. Traction torque depends on ICE (Internal Combustion Engine) and EM (Electric Machine) characteristics, and values shown are only one application example. Here, the maximum available traction force is similar for EVT mode, 1st gear with EM boost, or second gear with EM boost.

The base kinematic variant has been developed to propose four mechanical speeds, which allow a good compromise between functionality and system cost. By applying slight changes within the modular design, the proposed concept can be adapted to a 2-speed transmission with EVT mode or even a single speed transmission. These may be advantageous in supporting a lowest transmission family cost due to common parts on the same manufacturing line.

For example, C1 and C4 (refer table in figure 3) could be optional connecting elements which are removed for cost optimization without compromising DHT functionalities.

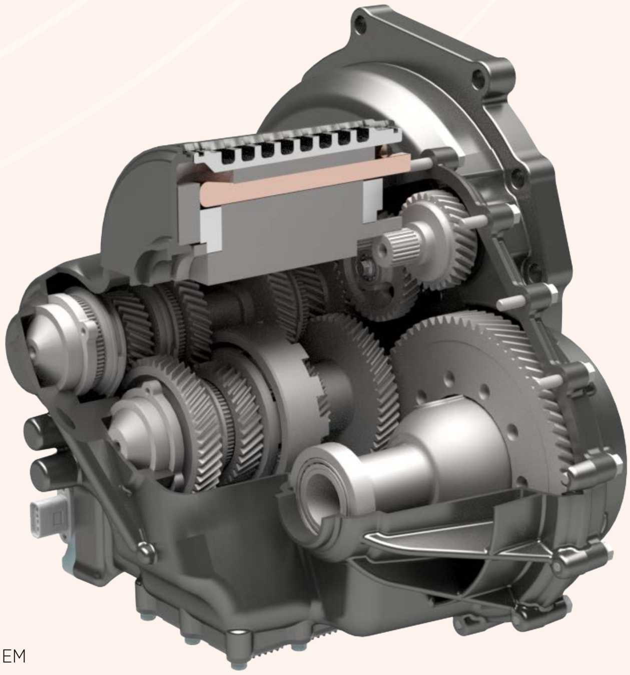


Figure 6 DHT 3D Model with a 50 kW EM

Detailed Design

A 3D model (Figure 6) has been developed for a powertrain configuration of 50 kW [150 Nm peak] for the electric motor and 70 kW / 150 Nm for the ICE.

The transmission is designed for a transversal installation using four axes. The ICE is on the primary shaft while the planetary gear set on the intermediate shaft, the differential on the output shaft and the EM on an offset axis. For integration simplicity, reliability improvement and cost reasons, a common housing is used for the gearbox, the electrical machine and the inverter. As a result, the total length of the transmission does not exceed 350 mm.

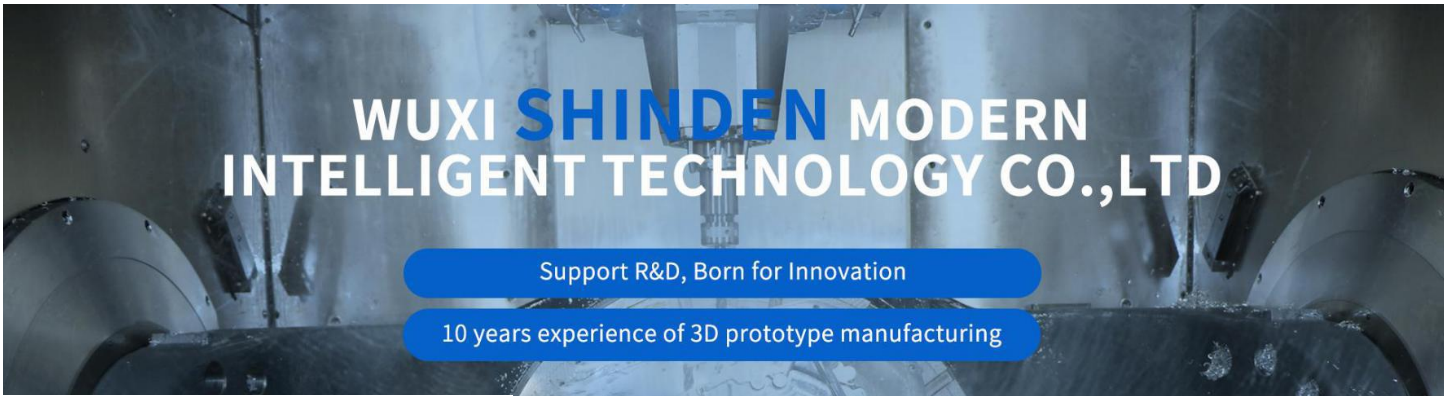
Outlook

In the past years, OEMs have introduced HEV/PHEV vehicles using existing transmissions and adding electrification concepts such as P1, P2 or P3. The market trend is clearly to develop electric drivetrain solution with increased electrification content and power.

Consequently, more affordable solutions with combustion engines are still needed. DHTs that are cleverly de-contented are attractive concepts in delivering efficient, compact solutions at reduced cost. The increasing market share of hybrids will provide the needed volumes for such dedicated drivetrains and thereby help to reduce the overall fleet consumption. It is the logical next step!

Contact

sales@punchpowerglide.com
www.punchpowerglide.com



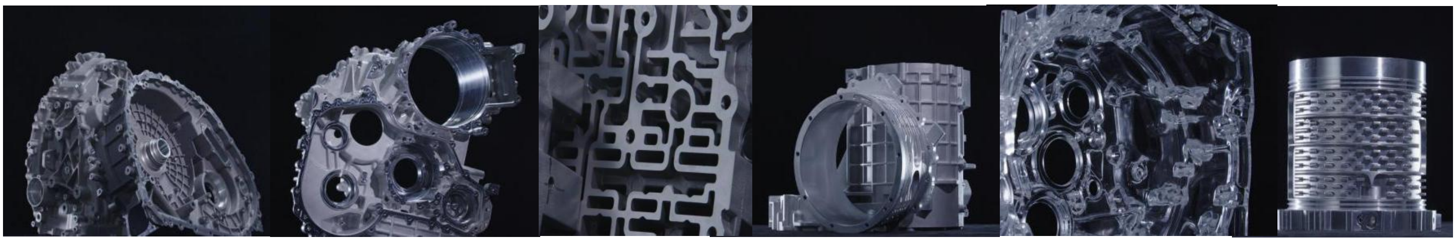
SHINDEN

An Automotive Rapid Prototype Manufacturer in China.

Established in 2010, Wuxi SHINDEN aims to become the first-class rapid prototype manufacturing enterprise in China.

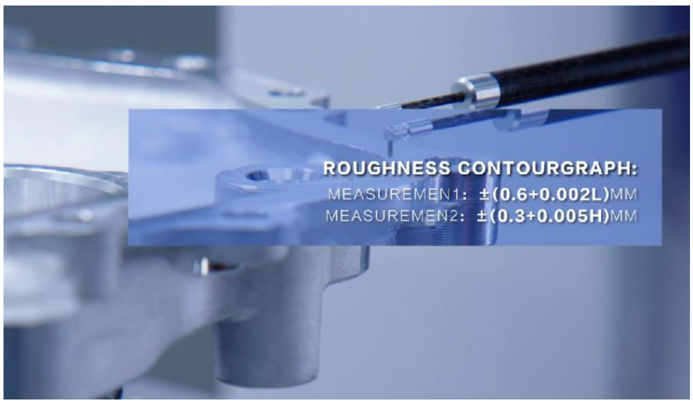
At present, we have high-precision equipment (9 five-axis, 25 three-axis, etc) in the workshop and various types of testing equipment (3 CMM,1 3D Scanner, etc) to ensure the quality. We have more than 120 employees and a cumulative investment of more than 50 million yuan.

Recently years, nearly 100 top 500 enterprises in the world and top domestic enterprises (SAIC, GM, Volvo Group, Schaeffler, ZF, BorgWarner, etc) choose us, cultivating and promoting SHINDEN International Development.



Our products include CNC Milling prototype, 3D transparent parts and sand casting parts in the core industries of automobiles, aviation, and medical devices.

Our purpose is to make more high-end, more precision and more rapid products for our clients by providing one-stop service and year-round high-quality guarantee.



Contact

Domestic:
Aaron.peng@shinden-model.com
Nick.zhang@shinden-model.com
Overseas:
Simon.yuan@shinden-model.com
Beagle.wen@shinden-model.com
Tel: +86 51081815470
Web: www.shinden-model.com

Interview

"We need Exciting Cars – and just as Important, a Fast Charging Infrastructure"

Oliver Blume, Chairman of the Executive Board of Dr. Ing. h.c. F. Porsche AG

Mr Blume, tell us about the importance of research and innovation for Porsche.
We're a sports car manufacturer, so innovation has always been a very high priority for our company. Our research and development costs are high as a result: R&D costs for the last year alone totalled EUR 2.2 billion, roughly equivalent to 8.5 per cent of our annual turnover. We'll have invested around EUR 6 billion in e-mobility alone by 2022.

Is the automotive future electric at Porsche? They say almost every car on the road will be electric by 2030, while the figure for 2025 stands at 25 per cent.
So by 2025, we expect every second Porsche to be electric – either plug-in hybrid models or all-electric sports cars. Our range has included hybrid models since 2010. And we're about to make a major breakthrough with the electric powertrain thanks to the market launch of the Porsche Taycan.

Will we be seeing any Porsche cars still fitted with internal combustion engines and manual transmissions in future, and if so, for how long?
Internal combustion engines are sure to be around for some time to come – in some regions even for a very long time and in large numbers, too. The markets are developing towards e-mobility at different rates. That's why we need to remain flexible: our cars are fitted with one of three different powertrain types; additionally optimised petrol engines, advanced plug-in hybrids and all-electric sports cars. This is the right strategic response to the radical change that will be taking place in our industry over the next ten to 15 years. But that said, the trend couldn't be clearer: we'll be seeing a sharp decline in the market share for petrol engines in the long term. The future is electric.

Oliver Blume, Chairman of the Executive Board, Dr. Ing. h.c. F. Porsche AG

Why this narrow focus on just one technology? Other providers are preferring to keep their options open as far as technology is concerned.

At present, only three technologies offer local CO_2-free powertrains: e-mobility, hydrogen and synthetic fuels. We've opted for the electric powertrain. In terms of the well-to-wheel analysis – that is, the entire mobility chain – an electric car is roughly three times more efficient than an equivalent hydrogen-powered car. And it's six times more efficient than a car that runs on synthetic fuels, even when you include battery production in the calculation, the ratio is still 1:2 when it comes to hydrogen, and that figure stands at 1:3 as regards synthetic fuels. And the benefit will be even greater when we take into account the advances anticipated in battery development. This is a convincing argument – not to mention the outstanding performance specifications delivered by the electric powertrain. That said, though, pursuing one avenue doesn't mean completely neglecting the other: synthetic fuels could help reduce CO_2 emissions in internal combustion engines in future. In the longer term, even hydrogen may offer more potential. But we can't wait that long. We have to act now if we want to do something to help the climate.

What needs to be done to help e-mobility achieve a breakthrough?

For this, we need exciting cars – and just as important, a fast charging infrastructure. There'll be nothing to prevent the ultimate breakthrough for e-mobility when charging the batteries takes about the same time as it takes to refuel a petrol car today. We're already working along the right lines with the Taycan when it comes to charging convenience.

What part do hybrid cars play?

A very important one, particularly during this transitional period. In 2014, Porsche was the first manufacturer to offer models with modern plug-in hybrid powertrains in three different premium segment models simultaneously. A hybrid is the most powerful top model in the Panamera and Cayenne model ranges. Our customers are really pleased about this: at present, 60 per cent of our new Panameras are being supplied with hybrid powertrains – and this percentage is even significantly higher in some markets.

There are around 1200 parts in a conventional engine, while there are only 200 in an electric powertrain. What does the future hold for Porsche suppliers, and what about their jobs?

The supplier industry is just as affected by the upheavals in our industry as we are, in our position as a car manufacturer. Our supplier partners also have to face up to this change and actively shape their future by turning their attention to new fields of technology in respect of e-mobility and digitisation. I don't expect this to lead to massive job cuts. That said, the requirements profiles for new staff will change considerably, and existing staff will have to obtain new qualifications for future activities.

Production is also set to become more climate-neutral. What does this mean in specific terms?

Taycan production at our plant in Zuffenhausen is already carbon-neutral. Production in Leipzig is about to follow suit, too. We've been using photovoltaic systems to generate electricity for body construction since 2013. We converted our mains power supply to green electricity back in 2017. We use waste heat from a nearby biomass power station to heat the paint shop, too. At the same time, we're reducing our energy requirements thanks to a range of efficiency measures. We've already made significant progress. And we'll go on making progress. Our objective is clear: to achieve a "zero impact factory" – production facilities with no ecological footprint. In the long term, we're even aiming to become a "zero-impact company".

Digitisation is moving forward. Is this costing jobs?

At Porsche, the emphasis has always been on people. Digitisation doesn't change this mindset in the slightest. Quite the opposite, actually: Porsche production 4.0 assists our colleagues with their day-to-day work. Our networked, digital production simplifies processes and makes us faster, more flexible and more efficient. In turn, this will lead to sustainable, secure jobs in the long term. Moreover, there's one thing we shouldn't forget: digitisation is not something that's going to happen overnight. It's an evolutionary process that presents us with a massive opportunity if we manage and shape it correctly.

How is this changing the automotive industry?

It goes without saying that digital transformation isn't restricted to production alone. It's affecting all parts of the company – the products, processes and services, as well as interaction with customers. It's changing the entire face of mobility. And for Porsche, that means we have to think beyond the car and become a provider of exclusive sports mobility. That's why we're building an ecosystem around our core business, with digital services and new value creation models that fit our brand. But digitisation is making its way into our sports cars, too. In future, we'll be providing "over the air" updates – functional improvements that can be uploaded digitally via the mobile network without having to visit a garage. Or "functions on demand" – optional features that customers can enable on demand, temporarily or permanently. And we'll be offering autonomous driving modules as options, too.

Where's the fun in autonomous driving?

Drivers will always want to control their Porsches themselves. But that said, there are situations in everyday traffic where autonomous driving would be useful even for Porsche drivers. Consider for a moment all that "stop-and-go" traffic you get during city rush hours. Or being able to get out of your car in front of a restaurant – and then leaving your car to find its own parking space, completely autonomously.

> Our objective is clear: to achieve a "zero impact factory" – production facilities with no ecological footprint.

Oliver Blume, Chairman of the Executive Board, Dr. Ing. h.c. F. Porsche AG

Interview

"It's the Ecosystem that Counts in E-Mobility"

There's more to e-mobility than just drive electrification alone. It's an ecosystem where infrastructure, connectivity, HMI, ADAS, security, etc. all interact as a system. We asked Stephan Tarnutzer, President, AVL Powertrain Engineering Inc., what that means for the work of OEMs, suppliers and engineering service providers.

Stephan Tarnutzer, President, AVL Powertrain Engineering Inc.

Mr Tarnutzer, in your plenary lecture 'The E-mobility Ecosystem as the Differentiator' at the CTI SYMPOSIUM in Novi, you talked about 'multilayered challenges' for the automotive industry. What do you mean by that?

Twenty years ago it was still relatively easy for OEMs to develop, test and build a car, then support it in the market. But when you look at in-car connectivity today, with Apple Carplay, Android Auto and so on, there are so many technologies you can no longer see as individual components. Data is increasingly important: Tesla for example puts out over-air software updates almost every week. They don't just change the look of your display, they also offer functional improvements based on what Tesla learn from Big Data. It's a paradigm shift – from a component viewpoint to an ecosystem that extends well beyond the drive.

How does this paradigm shift change the way OEMs, suppliers and engineering service providers work together?

OEMs are creating new areas that they see as Intellectual Property (IP). In the past, that mostly meant combustion engines. Today it includes driver assistance systems, algorithms for software-based functions, and of course the electrified drive systems. But there's also a tendency among suppliers to increasingly offer systems or subsystems, not individual components. Systems thinking is increasingly shaping cooperation. For development service providers, that's actually good news because they can be the glue that holds the collaboration together.

"I'd say automotive startups, but also companies like Google or Alibaba that bring a whole new way of thinking and a dynamic approach to the table."

Stephan Tarnutzer, President,
AVL Powertrain Engineering Inc.

Who do you see as new partners in the market, and how will they work together with traditional car manufacturers?

I'd say automotive startups, but also companies like Google or Alibaba that bring a whole new way of thinking and a dynamic approach to the table. People already talk of them in the same breath as traditional suppliers and OEMs. The more the focus shifts from the car itself to an e-mobility ecosystem, the more important these companies will likely become.

What are the chances this might shift the balance of power in the industry?

You already see OEMs, and in some cases major suppliers too, building up an ecosystem of partners. They're doing it either because they don't have the in-house capacity, or because they don't understand the technology, so they call in external specialists. This is a change process that's currently in full swing. Of course, suppliers and OEMs recognise the risk of their offer becoming just a commodity, and no longer exclusive. That's something they have to prevent. So the strategy involves growing in-house competence on the one hand, and creating reliable partnerships on the other.

What are the different challenges for e-mobility in international markets?

You can even see differences within the United States. OEMs in California, for example, have a very different take on electric vehicles than OEMs in Detroit. In California they deliver a platform, a system for getting from A to B – a kind of Automotive 2.0, if you like. In Detroit, manufacturers still want to sell customers cars. Overall EVs are less important in the US than in Europe so far, and certainly China where the government is pushing hard. Things are a little more balanced in Europe, where green thinking and an urban mindset are also in the mix. In the US, the government often gives business a free hand. It's mostly the startups in California that get the ball rolling.

What could slow down the success of e-mobility?

It's not just about how good the car is, how good the range is, how fast I can charge. You have to master the whole ecosystem too. As networking and digitization increase, the biggest challenge is probably cyber security. People talk about it a lot, but nobody is actually doing much. Okay, we know how to protect a single vehicle. But the bigger the ecosystem becomes, the more penetration points you have. If problems arise, people immediately question the entire system.

Will repair shops need to upskill too?

Absolutely, and looking forward there are several questions. How do you notify workshops about new technologies, for example? How hard will it be to fix a car? In the past, you might have replaced a controller. In future we're going to see more domain controllers, overarching software that handles everything for the powertrain, ADAS, or networking in a single controller instead of five or six connected controllers. Obviously, a controller is a black box for repair shops. Many mechanics were hired back in the day for their mechanical skills. So now to identify problems, they're going to need a better understanding of the system, the software and electronics.

How does AVL operate in the new e-mobility ecosystem?

It's important for us to control not just individual components, but the system and the dynamics of the various system components. That includes the cloud, the infrastructure and the way all these systems interact. That's a huge paradigm shift for us too. AVL was founded more than 70 years ago, and like some other suppliers and system developers, we originally focused mostly on powertrain. Internal combustion engines aren't going away, but powertrain as a discipline is changing, and we need to constantly grow our learnings from the past 15 years. Twenty-five years ago, cars were basically mechanical objects; today, we see them as iPhones or Androids on wheels.

How do you think driving fun will change in a networked, electrified world of mobility?

I still enjoy driving, but like many people I'd rather take an Uber to the airport so I can work or make phone calls on the way. In future, with autonomous vehicles, that will be the new normal. But again, the US market will probably tick differently than the markets in China or Europe. In general, I think people will tend to see driving as less important. And looking at the technologies that are emerging, whether it's hybrid and electric drives, fuel cell or autonomous driving, I'd say it's more or less just a matter of time before people get used to it.

Interview: Gernot Goppelt

Interview

"We're on the Verge of Electric Solutions for Certain Fleets"

CO2 emissions in the commercial vehicle sector must be reduced: When are battery electric drives suitable, where are alternative fuels an option? We talked to Professor Giorgio Rizzoni of Ohio State University, who, inter alia, researches 'future ground vehicle propulsion systems'.

Professor Giorgio Rizzoni, Ohio State University

Professor Rizzoni, what are commercial vehicle use cases in the US compared to Europe?

I'm going to divide the commercial market a little bit: One side is the bus transit, which is transporting passengers on fixed routes. Then you have a sector that we call the work trucks. They could have a variety of functions, from picking up garbage to being cement mixers etc. Another big category is package delivery. Then you have the long haul trucks for the long routes. Generally, vehicles in the US are classified from class 1 to 8. Class 1 and 2 are light to medium trucks, 3 to 6 medium trucks and 7 to 8 the heavy trucks. One big difference outside the US is that some light-duty trucks and vans would in fact be considered medium vehicles in Europe – trucks start 'smaller' in Europe.

Regarding future transportation, long haulage with BEVs seems to be a contradiction. What prospects do you see for fuel cell drives?

If you are looking at long-haul type transportation, battery electric solutions are probably not practical indeed, because you would have to carry a lot of batteries, and have a considerable charging infrastructure along major freeways. Here in the US, liquefied natural gas, LNG, has been considered and is being developed. That is a realistic prospect. I am personally a little bit less positive about hydrogen, because its storage and distribution is really an issue. And not only that: From a volumetric perspective, hydrogen requires sizable tanks, even if weight is not comparable to batteries. But to have an infrastructure for hydrogen fueling – I see greater challenges than for LNG.

What about synthetic natural gas made from hydrogen and CO_2?

Let's paint the picture: If you were not required to store and move hydrogen, when you might find a way near a refueling place to produce it, it would be fantastic. But would you create dedicated pipelines to special refueling stations? That second part, the infrastructure, is still a question mark in my mind. Renewable hydrogen, produced from wind energy through electrolysis, has been demonstrated quite successfully (including in Germany), with the hydrogen produced being injected in the natural gas pipeline network. But when you use it in vehicles, you are caught up with the same problem of range and volume of storage. Especially for line haul purposes, if you're really going across the country, it's not practical. On the other hand, what has worked in the US, is natural gas for transit and city buses; the penetration is increasing significantly. In the city of Columbus for example, they have two major depots and about 400 buses. Today, the penetration is 75 to 80 percent. But if I'm going to drive from New York to Los Angeles, I don't think that will work.

So what would be the best fuel for long distances?

I think, practically, liquefied natural gas is probably the best thing we can do for long-haul freight in the short term. You can deploy most of today's well-known diesel engine technology and convert the engines to run on gas in a relatively simple way. But along the main corridors we still need a sufficient density of refueling stations. To replace diesel as the fuel for long haul trucks is a tough thing to do. I know, in Germany there is quite a bit of talk about overhead electric power supply. I think that is probably very expensive on long distances. So again, we keep coming back to the same word: 'infrastructure' is the main challenge for all kinds of energy.

Let's assume we wouldn't have gasoline and diesel anymore. What would we do?

Certainly, some aspects of e-mobility are reasonable. Locally, you have zero emissions. In cities like Stuttgart, with this bowl geometry, it would be good to have no particulate emissions anymore. But in fact, the electricity is produced somewhere else, making electricity from a coal plant is not that great, you are just displacing emissions. Of course, the electric power grid is continuously reducing its carbon dependence, but that is a long-term process. Now, if we didn't have petroleum-based fuels, we would have to look for a low carbon fuel alternative. For example, biomass based fuels – plants absorb carbon dioxide from the atmosphere. It will not be net-zero carbon, but with much lower CO_2 emissions. It's petroleum-like and can used like it in engines. There is no simple answer, but low carbon fuels should be a subject of research as electrification is. They are alternatives, it's not the one or the other. We already have the infrastructure for liquid fuels. Let's learn how to make fuels from biomass that have the least impact on the environment.

Do you think e-fuels are feasible?

Electro fuels are a fantastic prospect for the future. The ideal world is one in which we use solar power to produce hydrogen that we marry with CO_2 extracted from a power plant. But you have to be in proximity of the CO_2 source. There are people also working on extracting that from the atmosphere, but we have to be realistic: every day, the world uses 100 million barrels of petroleum – whether you produce substitute natural gas, e-fuels or biofuels scaling up these processes is a huge challenge.

Would it ever be possible to replace these 100 million barrels of oil?

The good news is, that the number of vehicles worldwide has increased dramatically, but the consumption of petroleum hasn't at the same rate, because we make more efficient vehicles. The not so good news is that the desire for mobility has grown with industrialization, and so has the need and desire for transportation. If someone in any emerging region wants to drive a car – can you tell him, no you won't? What is happening now is that the democratization of mobility causes a steady increase in petroleum consumption. The petroleum reserves that we know how to retrieve are approximately 1.7 trillion barrels. If consumption and demand remained constant, we could go on for 50 years. That's clearly not sustainable for the planet, but for an oil company that's forever. There is not much motivation to change strictly based on the economics of energy, without policies driving business decisions.

> "Electro fuels are a fantastic prospect for the future. The ideal world is one in which we use solar power to produce hydrogen that we marry with CO_2 extracted from a power plant."

Professor Giorgio Rizzoni,
Ohio State University

How could alternative fuels be scaled up?

I think the challenge is not how to make them. On pilot scale it has been shown that we know how to do it. But you need to scale up – who makes that investment, for what? Our federal government in the US is not in the position to do that. In my mind as an engineer, a policy system of carbon taxes would have to add a minimum to push things in the right direction. By the way, I interject one comment: In the EU, targets for CO_2 reduction in the industrial and transport sector are two different things. On the transportation side they call electric vehicles zero emission, which is not true. Where we are missing the boat, is that any of the benefits, which you could have from a low carbon fuel, don't count for transportation. In the US, it's a little bit better. When the automakers look at the CAFE credits, alternative fuels do play a role. Okay, corn may not be the best solution – but if someone figures out a way a better way to make ethanol, the credit system is there to motivate.

What do you expect to be the most important changes in commercial vehicle technology in the next ten years?

Despite its disadvantages for some use cases, I think that electrification will really happen, to varying extents. In fact, I expect the penetration to be more significant in the commercial sector, for those duty cycles where it makes sense, like transit buses, work trucks and delivery trucks. When delivery trucks drive less than 100 miles every day, when you exactly know what they do, electrification can be a successful solution, from a business perspective. You could charge these trucks while they are being loaded and unloaded in 20 or 30 minutes, using a three-phase high-voltage system. Transit buses may also provide a viable alternative, if their purchase price is affordable for public services. If you consider cost of ownership over the lifecycle, payback on electric vehicles may be attractive, because electricity is cheaper and maintenance may be substantially reduced. Another example is mail delivery vans: There is much stop and go and they go back to the same place and can charge slowly over night. So where the opportunity is, electrification may happen faster in the commercial vehicle sector than with passenger vehicles. Fleet operators act rationally, and they will do what's best for them. I think we're on the verge of solutions that fit certain fleets.

Interview: Gernot Goppelt

eDMT for Commercial Vehicle Applications

eDMT – electric Dual Motor Transmission

Cao Zheng, Managing Director, eKontrol Drive Technology

Electrification is a growing trend in all vehicle industries worldwide. This trend is especially prominent in the commercial vehicle industry with the rate of electric city buses having reached up to 80% in China. Compared to city buses, the electrification of larger vehicles such as commercial trucks has been significantly lower. This is due to in part being faced with higher power and torque requirements and more complex operating conditions, yet there is great future potential in this industry and new technological advancements provide solutions. In large electric vehicles, very powerful electric motors with corresponding power electronics and multi-speed transmissions are required, and it is essential for the electric commercial vehicle industry to increase the efficiency of the powertrain whilst also considering comfort. Customer surveys have shown that powershift transmissions are preferred, as these have the advantage of providing continuous vehicle propulsion as opposed to automated manual transmissions, where a power interruption occurs during shifting.

eKontrol Drive Co., Ltd., an established manufacturer of electric and hybrid powertrains from Suzhou, China, has developed the eDMT (electric Dual Motor Transmission) to be used in vehicles with a total weight of 31 to 90 tons. The eDMT is a 4-speed electric drive unit for longitudinal installation. It consists of two high-speed electric motors, which are performance-enhanced versions of existing tried and tested units from eKontrol's product portfolio. The system's maximum power from the electric motors is 400 kW and it has a maximum combined input torque of 800 Nm.

Figure 1 shows the exterior view of the "eDMT800" electric drive unit. Both electric machines are flange-mounted to the transmission and guarantee powershift capability. The 4 speed transmission, also known as Module 1, feeds the power to a power-split reduction gearbox, Module 2. Module 1 also has an output for an auxiliary drive (PTO – Power Take Off). Module 2 is used exclusively for very heavy vehicle applications, e.g. at ports or at mines.

Figure 2 shows the interior of the 4-speed transmission. The transmission is based on a layshaft design and has two selector forks with a common shift drum, which is electro-mechanically actuated. Shifting energy will be efficiently consumed only when needed ("power-on-demand actuation"). The shifting elements are designed as dog clutches. During shifting, the synchronisation of the input side gearset inertias is actively carried out via one of the two electric machines respectively. In contrast to an AMT (Automated Manual Transmission), this transmission offers the powershift capability because during the gear change the torque of

Figure 1 Exterior view of the electric machine drive unit

1. Max total power and output Torque
2. 2× 200 Kw, 16 300 Nm
3. Power shifting
4. Robust and high performance with two electric motors
5. Packaging, Compact design
6. High efficiency, low weight, modular design

Figure 2 Interior view of the transmission (Module 1)

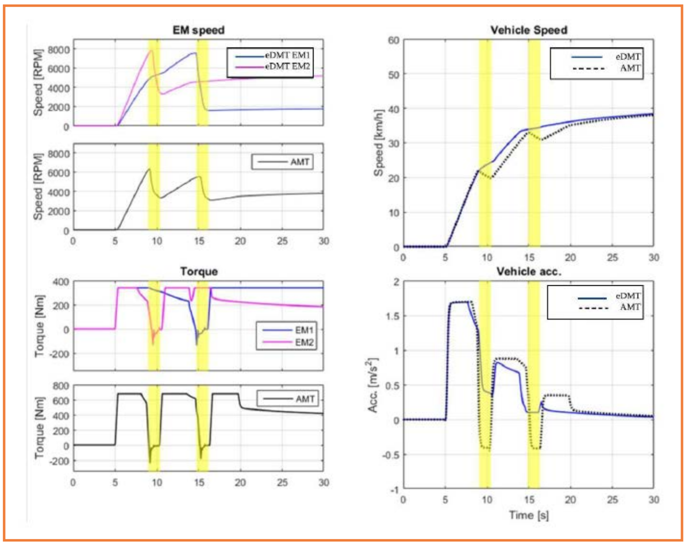


Figure 3 Simulation of eDMT800 Module 1 in comparison to AMT; Acceleration on a 3 % incline

one electric machine will always continue to be available at the output and therefore, it is possible to sequentially shift through all four speeds with no interruption in torque. Figure 3 shows the advantages of the powershift-capable eDMT800 over an AMT, in particular, the significantly better shift quality.

Active wheel set lubrication is implemented for Module 1 for the purpose of robustness and efficiency. A cost-effective mechanical oil pump is driven by one of the two electric machines for this. The injection lubrication, as well as the geometric design of the oil sump, guarantees that there is practically no splashing caused by the rotating gear wheels.

Based on very detailed simulations, the Module 1 transmission housing has been designed as a weight-optimised aluminium construction, whilst a cast steel construction is used in Module 2 for strength and cost reasons. The gear and bearing layout have been optimised to suit the loads and to guarantee maximum reliability and efficiency.

The eDMT from eKontrol offers a unique solution for electrifying large commercial vehicles with complex operating conditions covering city and highway travel speeds or steeply inclined roads. With a suitable and efficient driveline, electrification is not only possible but profitable in more areas of the transportation sector beyond passenger cars and city buses.

Contact
zheng.cao@auto-ekontrol.com

Figure 1

From Three To One

Carmakers always try to gain in size, weight and prize. A possible solution for all of them is not easy but feasible. Whereas traditional actuators are made up from 3 parts (motor-harness-electronics) reduction in size and weight is only possible by combining them together into a single part, the so called smart actuator (SMA).

Manfred Lex, R&D Director, MELECS

Traditional designs to develop motor/controller combinations consist of an ECU with housing and cooling, a cable harness and a motor that has its advantages:

- ECU and motor may be off the shelf and the harness easily adapted to the required arrangement
- an external sensor may be addressed by the cable harness
- cooling of the ECU is easier by scaling
- good scalability of the system in terms of power and functionality

On the other hand, the smart actuator is restricted in size and power dissipation but has advantages in system integration and benefits in cost and less EMC radiated emissions.

Figure 1 on the left side shows a traditional design of an eLSD consisting of a gearbox mounted ECU with a harness and a motor. Position control is read from the 3 BLDC motor commutation sensors or the attached built-in sensor interface via SENT. An additional temperature sensor is connected through the harness to the ECU.

This design already takes advantages from a cost efficient glass reinforced PA66GF30 housing with molded connectors and a stamped aluminum cover for mounting and cooling.

Right side shows a combination of ECU and motor having the same functionality but integrated into a single piece.

A more detailed view of the realized concept is shown in figure 2.

Smart actuators have combined features into the design, which are:

- Where to put all the heat produced from motor and electronics?
- Due to a lot of mechanical constraints the PCB is odd shaped and sealing, vibration resistance, screws also take up space.

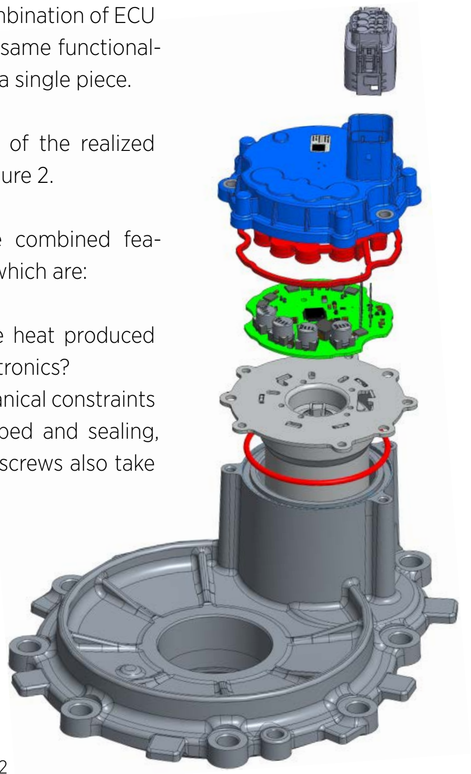


Figure 2

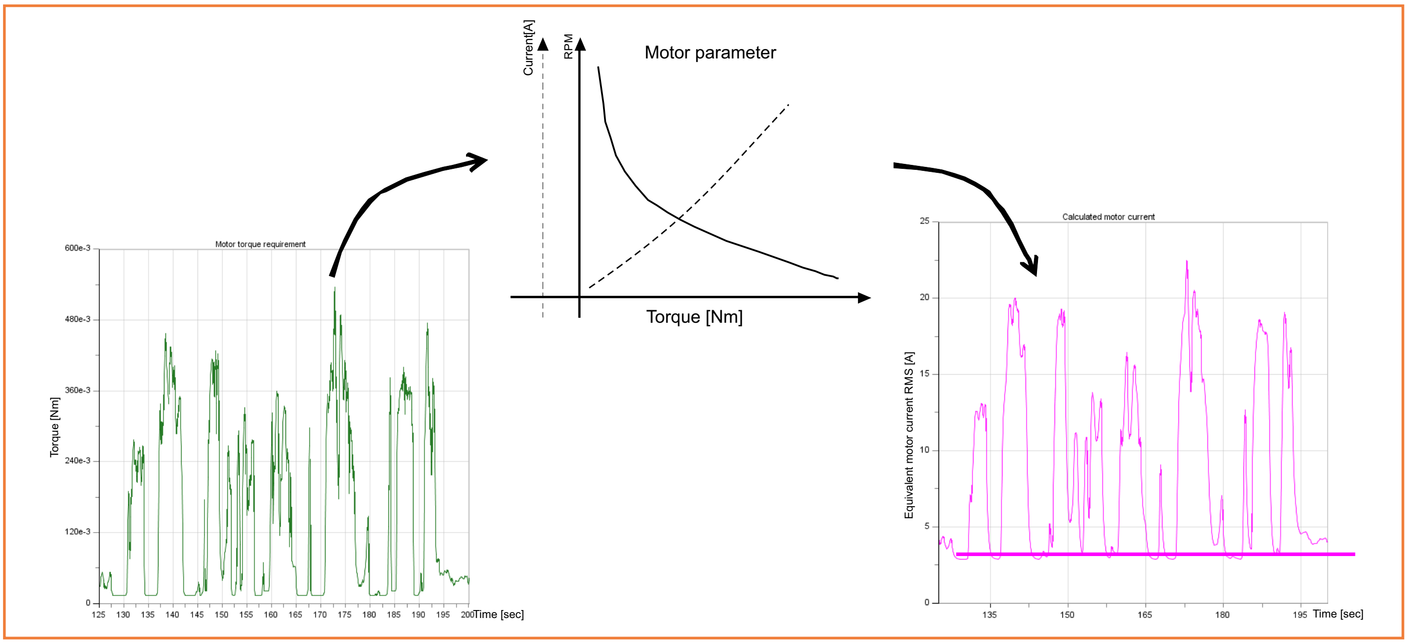


Figure 3

Explosion view shows the parts involved with the gearbox fulfilling the required functionalities cooling, sealing, small size, light weight, no TIM (Thermal Interface Material).

This achievement is only possible with a deep investigation of customer/project needs in case of power load and temperature, at the beginning with a load profile shown in figure 3.

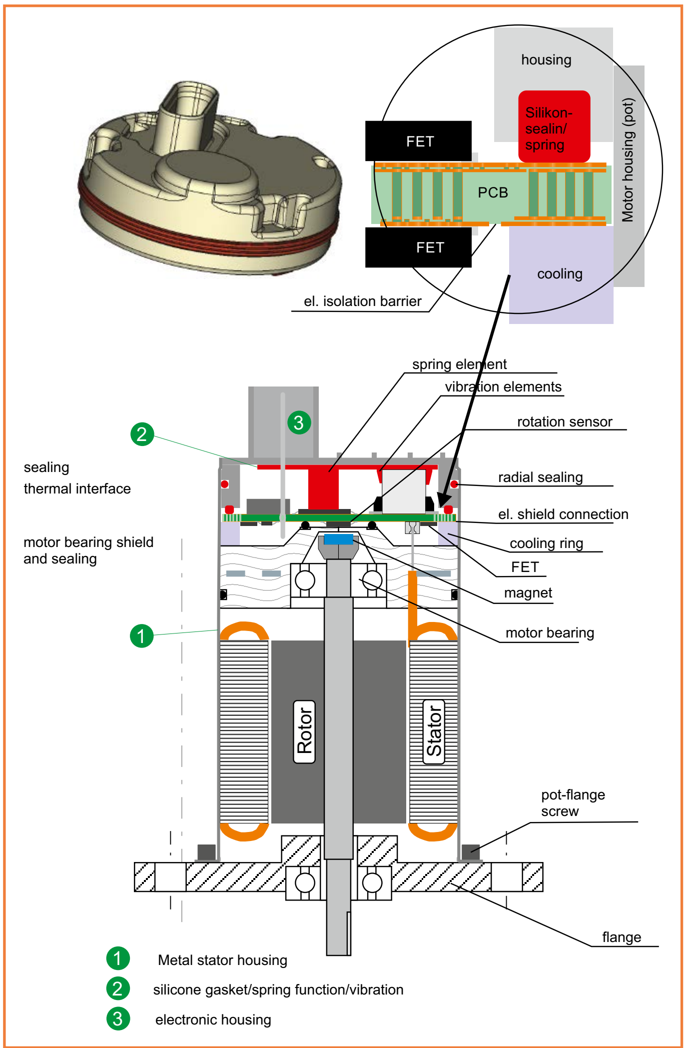


Figure 4

Together with the required location, ambient and cooling concept the temperature rise at worst case is calculated dynamically and placed into the simulation tool, this leads to an average current of 9.5A@Vbatt = 13.5V and a temperature rise of 15 °C which makes the SMA operable from -40°C ... +130 °C. Simulation results in figure 5.

A closer look how the heat is dissipated from PCB inner circuitry to the cooling transfer surface gives picture 4: Hot components are placed on both sides of the PCB and heat is spread with copper blind and buried vias. The 2k plastic housing uses silicon elements to act as springs pressing the PCB surface onto the cooling ring made from aluminum without using TIM. This ring may also be the bearing shield of the motor (figure 2). The thermal simulation shown in figure 5.

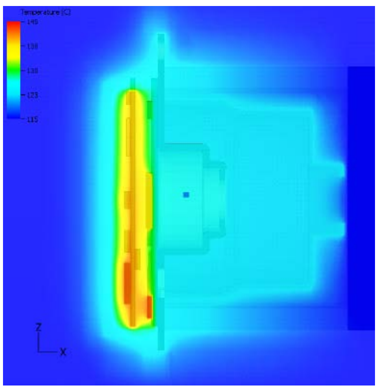


Figure 5

To act as an actuator the rotor has a permanent magnetic pill attached on the shaft end within the motor sealing to allow position information read from the µC via a sensor on the bottom of the PCB. This is one of the main advantages over the standard 3 part concept where the sensor is external to the ECU and needs a separate power supply and interface lines facilitated from the harness.

Worth to mention the advantages for EMC with no necessary dual shielded cables for HALL sensors and motor wires.

To go further down into SMA integration with less power another interesting concept is potting. Again here (pictures 7,8) show an ECU with highly thermally conductive potting material (light blue) where a plastic housing with connector socket and over molded 6 pins is married with the PCBA before potting

The potting is a very good heat dissipater and thermal energy storage medium, because it is adhesive not only to the cooling pads of the components but also to their surface which allows operation under improved cooling conditions and hence increased lifetime especially for ELCAPS. This is important for BEV due to operation not only at engine-on (8,000 h) but for charging too which is typically more than 25,000 hours over lifetime.

Potting is highly resistant against environment and aggressive materials like salt and oil, which allows exposure to the environment.

Complete 52mm actuator with hydraulic pump – motor – attached ECU as a cross-sectioned view is shown in figure 9. No screws are necessary for this 60W design.

Typical usage of such a highly integrated small SMA is for applications like eLSD with position control, park lock on/off, water/hydraulic pumps.

It is also possible to have a stacked PCB arrangement to keep the size small. The power PCB uses thick copper layers for current wear, cooling and on top, the control PCB with a cheaper layerstack supporting Autosar and Flexray (figure 2 green parts).

Keep in mind that small designs do not allow extra parts for external functions like brakes or additional interfaces due to size constraint. Some minor scalability is given by variation of motor length. Usage for higher power loads than 300W is possible but needs fluid cooling.

Conclusion

Even when it is alluring for commodity staff to buy off the shelf parts and just tailoring the harness, the demand to use small, lightweight, robust, high vibration resistant, SMA's is evident. Sourcing only one supplier decreases audits as well as problems which may arise in the lifetime of the product.

The small and handy design makes an SMA very suitable for automotive underbody designs and usage for more than one application in car is very likely.

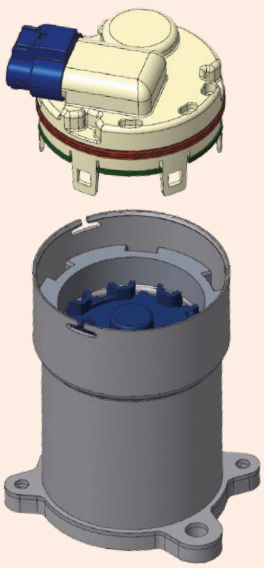


Figure 6

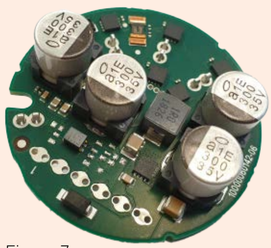


Figure 7

Figure 8

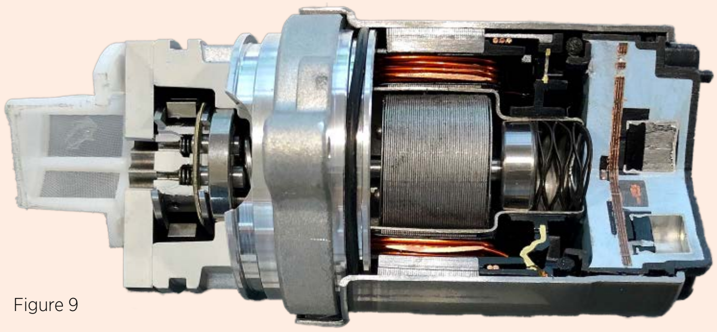
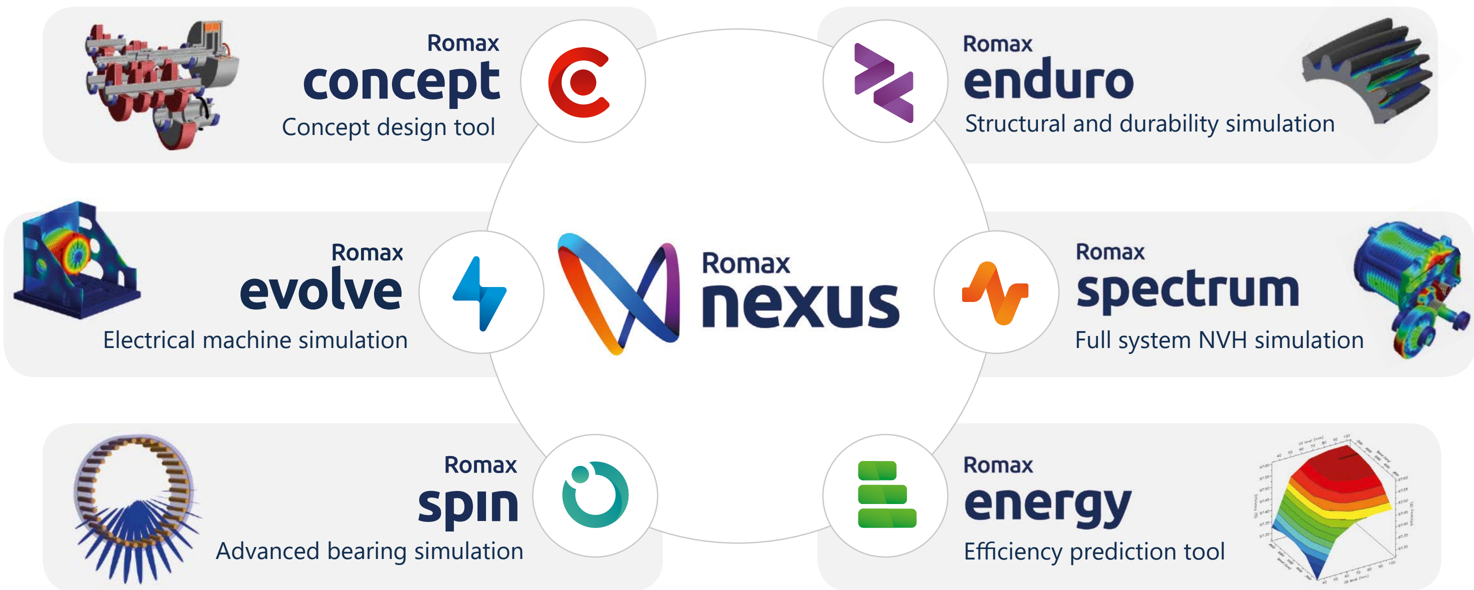


Figure 9

More Information

www.borgwarner.com/newsroom/press-releases/2019/08/22/brushless-dc-motor-brings-amazing-performance-to-borgwarner-s-new-awd-coupling



Application of COR Pump Technology in Positive Displacement Machines

Klemen Petrič, Senior Project Manager | BU Electronic & Drives | e-Pumps, Kolektor Group

Jernej Munih, Design, CFD simulations | BU Electronic & Drives | e-Pumps, Kolektor Group

Introduction

Pumps generally divided into hydrostatic and hydrodynamic. Hydro dynamical pumps operate on a hydrodynamic physical process in which there are pressure and energy changes in the proportional square of the speed of the rotor. Hydrostatic pumps (also known as positive displacement pumps) increase and decrease volume of the pump chamber during operating cycle.

Target properties of hydrostatic pumps are:

- Stable efficiency in wide working area (over different flow or pressure) with low noise emissions,
- high reliability at high mechanical and/or thermal loads,
- small size and weight, low price, easy assembly and servicing,
- possibility of integration with control devices (pressure, flow, temperature sensors),
- possibility of operating over wide viscosity range of liquids and
- low pulsation of pressure and flow.

The trends in the development of the positive displacement pumps are oriented towards achieving higher pressures and rotating speed of products. Less material consumption and simplified production technology solutions are motivations from the design and manufacturing aspect. Hydrostatic pumps are classified into two larger groups - to pumps with a translatory motion of liquid displacement element, and to pumps with a rotating element (shaft).

COR Pump Technology – Made by Injection Molding

To save weight and meet modern fuel efficiency standards, automotive engineers have learned to substitute plastic materials for metal wherever possible. Even beyond weight savings, versatile plastics offer numerous manufacturing efficiencies.

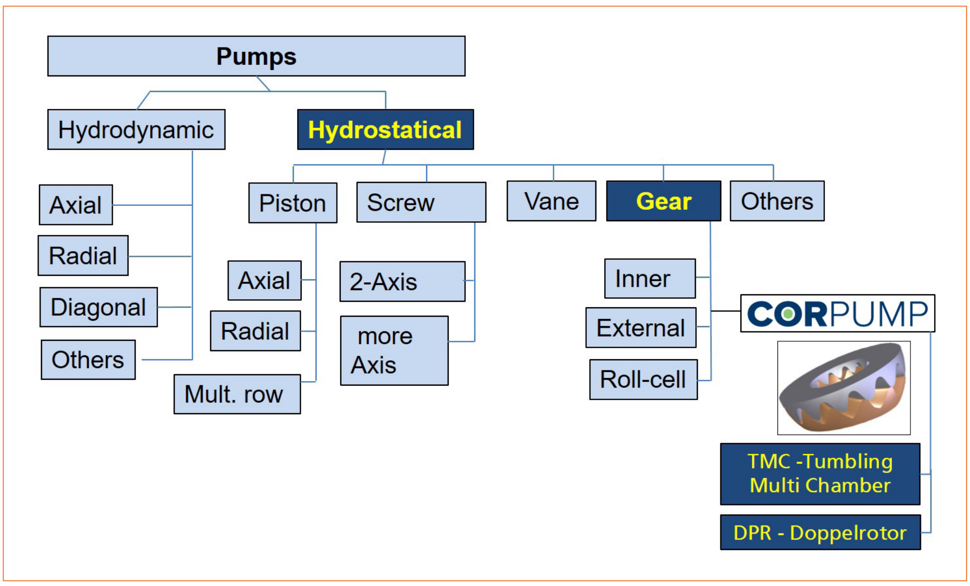


Figure 1 Pump technology classification

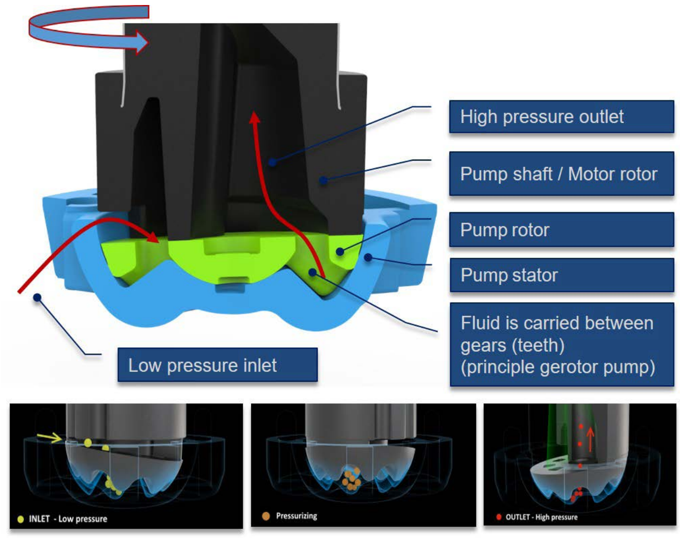


Figure 2 Basic components and engagement of fluid @ COR pump technology

Compared to machining or die-casting, rapid, cost-saving material processing methods such as short cycle-time injection molding allow high-volume production, often with no secondary steps. Nonetheless, many automotive parts are made from metal. The applicative temperature and dimensional demands are often the deciding factors in terms of material chosen.

However, new developments in high dimensionally and thermally stable polymer resins and molding tooling techniques have shifted that balance, expanding the range of applications for which polymer materials may be used. One example of an automotive component now amenable to be made from high dimensionally and thermally stable polymer material is the COR pump technology where most important and demanding components are made with injection molding production process.

The COR pump is a new pump technology in group of positive displacement pumps. Basic pumping idea came from the axial piston pump family. The COR technology consist of 2 pumping principles: DoppelRotor (COR-DRP) and Tumbling multi chamber (COR-TMC). The COR pump system consists of 4 pieces of which 2 are rotating. No valves are needed. Most of the torque is converted into useful work as only one of the two rotating pieces is driven. Due to the design concept, the second one only needs torque to overcome its friction. The fluid is transferred through the center of the pump and transferred with the help of moving cavities and centrifugal force to the outlet on the periphery.

Figure 3 Exploded assembly of Pump Stator/ Rotor with Pump-Motor Shaft

Basically the pump design is based on 3-dimensional trochoid gear shape with function of pulsating chambers for volume displacement. The operating principle is based on the formation of the separate chambers, closed by two gearing topographies. When rotated, the chambers open (grow) and close (shrink) simultaneously and control fluid displacement precisely. Connection of the pulsating chambers with suitable control openings (with matching contours) results in the displacement effect. One of basic outputs of this pump design is pressure separation effect. The enveloping part (pump housing) also serves as a separating element between the pressure side and the suction side.

COR-DRP is analogous to a non-orbital ge-rotor pump, as the fluid between the teeth is displaced by different rotational speeds of the rotors. COR-TMC is analogous to an axial piston pump, as the fluid is displaced by opening and closing of chambers.

The COR pump consists of a pump stator with a 3D inner gear shape with n teeth and a pump rotor with n+1 teeth, which fits on the stator shape under a certain angle. The gear shape (teeth) is arranged axially and the shape of the teeth enables simultaneous engagement, which ensures sealing between individual interdependent gaps.

COR pump advantages over other types of pumps are:

- Economically interested production price (all pumping parts are produced with injection molding of dimensionally stable polymer material with high mechanical & thermal performance),
- Robustness against particle contamination corrosion resistance,
- good hydraulic characteristics,
- small dimensions,
- high working pressure and
- bi-directional (backward) rotation.

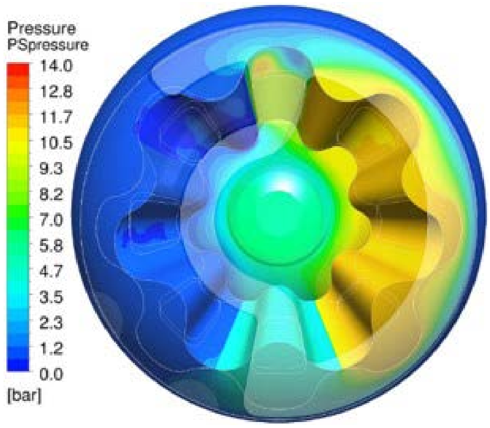


Figure 4 Pressure distribution on pump stator, which was obtaied from CFD analysis

Motion of the pump rotor is determined by the rotation of the rotor of the e-motor and with the position relative to the gear shape of the pump stator. Sliding movement occur on flat surfaces between pump rotor and the rotor of the e-motor.

Pump rotor rotates with 1/8 of the angular speed of the shaft. In addition, pump rotor makes a change angle around the apparent point above the upper plane on the pump rotor. Composed motion causes the inter gap between the stator's gears and the rotor gears. As a consequence, there is a vacuum (under pressure) on one side and overpressure on the opposite side that causes suction and displacement of the pumping medium.

Figure 7, which shows the assembly of pumping parts, where red co-color depicts the pressure area and the blue part depicts the suction side of the pump. In addition to a pair of pumping parts, the pump consists of a motor rotor and a stator of e-motor. Electric motor rotor has 2 journal bearings positioned between the magnet of e-motor.

Performance Parameters of COR Pump

The sources of performance losses in the pump are divide into mechanical-hydraulic and volumetric. Mechanically hydraulic losses are divided into mechanical due to mech. (contact) friction, and into hydraulic due to viscous friction in the gaps, friction due to turbulent liquid flows and friction due to the difference in pressure in the system. Volumetric losses also include compression losses due to internal leakage, and loss due to compressibility of pumping fluid. The purpose of hydraulic pumps is to convert the mechanical energy into hydraulic. Efficiency characteristic is the parameter-defining ratio between input energy and useful energy on the exiting side of the system. The hydraulic power is defined with product of torque value and angular velocity on the shaft which drives the pump rotor: Hydraulical power is define as the product of pressure difference (output-input) and flow of liquid. Overall efficiency is defined with conversion of mechanical work into hidraulical power.

$$Pmeh(t) = M\ x\ \omega \ \ | \ \ P_{hidr} = \Delta p\ x\ Q \ \ | \ \ \eta_{m,h} = \frac{P_{hidraulical}}{P_{mechanical}}$$

In assembly, where electric motor is part of the pump, total efficiency of the system is defined as the ratio between hidraulical power on input and electrical power given from e-motor. Electric power is equal to the product of the DC current and the electrical voltage UDC. Total efficiency of pump is given as a combination of electrical current and voltage, pressure difference and liquid flow. The total efficiency of the pump can also be defined as product of volumetric efficiency, mechanial-hydraulical efficiency and efficiency of e-motor.

$$\eta_{pump} = \frac{P_{hidraulical}}{P_{electrical}} \ \ | \ \ \eta_{pump} = \frac{\Delta p\ x\ Q}{I_{DC}}\ x\ U_{DC} \ \ | \ \ \eta_{pump} = \eta_{vol}\ x\ \eta_{m,h}\ x\ \eta_{EM}$$

The volumetric efficiency is influenced by compression losses and losses due to internal leakages. Leakages within pump unit relate to the size of gaps between pump elements, pressure difference (input vs. output), rotation speed, volumetric displacement and viscosity of fluid. Volumetric efficiency is defined as the ration between real output flow and theoretical volumetric flow defined by pump ideal geometry. In positive displacement pumps, flow of a liquid is linearly correlated to rotation speed.

The internal leakage is one of the biggest sources of pump efficiency losses, through which the geometry is strongly influenced by the manufacturing process. It appears in the 3D shape of pump parts and in air gap in journal bearing of e-motor.

Flow-rate Simulation (CFD), Motivation, Goals & Results

To define best approach for CFD simulation of COR pump an review of the different methodologies used for the simulation of the flow rates generated by ge-rotor, external gear and crescent pumps was elaborated. Studies taking into account the influence on leakages of the interactions between the fluid and the mechanical parts where analyzed. The COR pump system includes a sophisticated software which enables to study the behavior of the fluid in four dimensions and to optimize conditions with regard to a given specification. The software also generates the necessary CAD data for the design of a pump.

Goals achievable with CFD simulations in R&D phase of COR pump:

- flow & flow ripple calculation
- pressure field & pulsation analysis
- volumetric loss calculation
- viscous loss calculation
- torque calculation
- volumetric, mechanical & total efficiencies

CFD simulation steps in COR pump technology consist of:

- Proparation of the geometry
- Mesh generation on pump parts, static & rotating geometry
- Setting of initial & boundary conditions (pressure, speed,..)
- Solving + monitoring the solution
- Results analysis

One important simulation step is mesh independence study where test of different mesh refinements are done to find optimal mesh density. Basic study of CFD simulation on COR pump technology was done on COR200 pump used for different applications in automotive industry (diesel fuel pump, ICE water injection pump, oil lubrication pump). Theoretical flow @ 3000 RPM is designed for 140,6 l/h. Simulated flow result at 0 bar is 140,0 l/h , at 10 bar 135,7 l/h. Simulated from ripple at 0

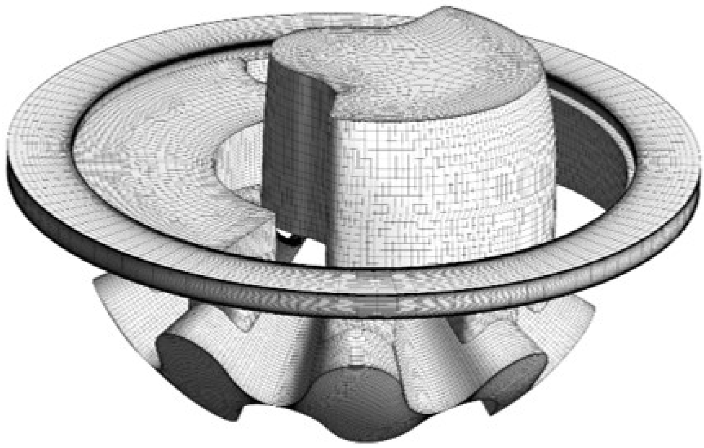
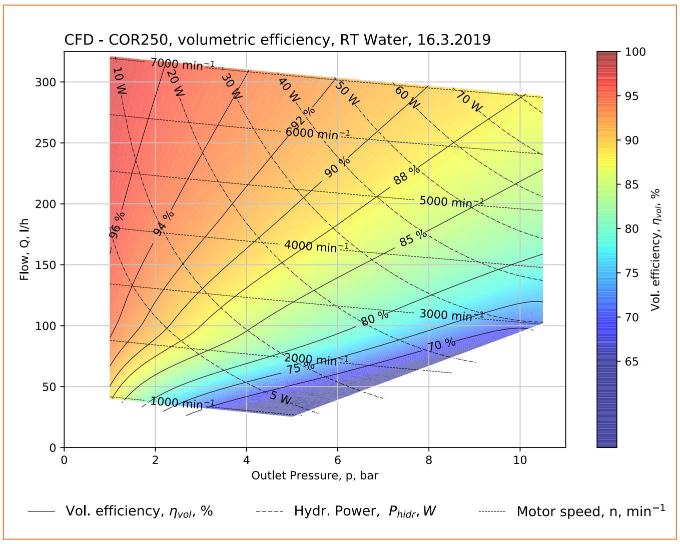


Figure 4 3D Morphing mesh setup for CFD simulation



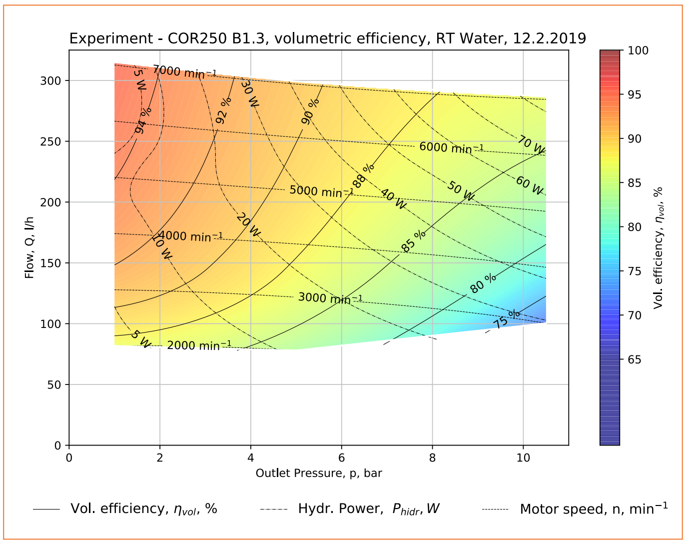


Figure 5 COR200 Pump Volumetric efficiency (water @ room temperature). Comparisson between CDF simulation (left) and experiment (right)

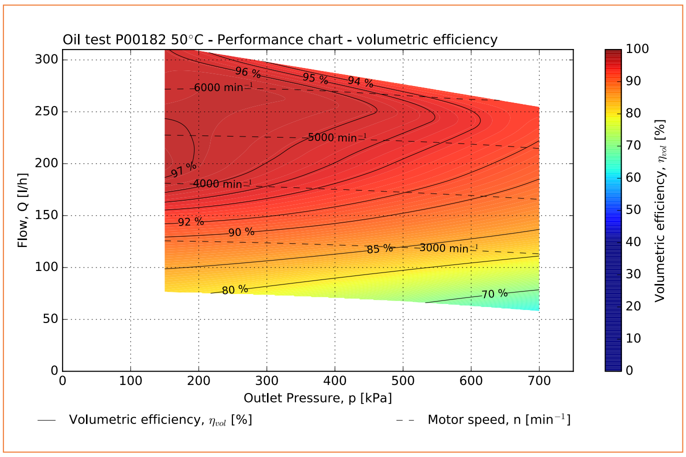
bar is 8 l/h (5,8 %) and at 10 bar 9,2 l/h (7,3 bar). During CFD simulation, also calculation of 5 leakage paths was done with analyzation of separate contributions. Comparison of CDF simulation and experimental result shows lees than 5 % difference.

Experiment & Validation Results COR200

Beside CFD simulations, physical validations and performance testing performed on COR pump technology under different conditions. Pump design with integrated motor. Reference performance testing done on COR200 pump in water liquid at room temperature. Results show stable flow at constant e-motor speed at pressures up to 10 bar. Volumetric efficiency up to 90 % observed at flow around 180 l/h up to 10 bar. Same pump design were tested in oil fluid at temperature range between −20 °C and 80 °C to determine electrical power change (increase / decrease) due to change of viscosity of oil. Characterization of COR200 pump at different pressures and temperatures show stable flow of liquid and different testing conditions (temperature, pressure). Performance testing in transmission oil at 50 °C done on COR200 pump with integrated motor done up to max pressure of 7 bar (flow around 200 l/h) and/or flow up to max 300 l/h at 2 bar of pressure. Maximal power consumption of integrated motor/controller can be up to 230W. Noticed volumetric efficiency over temperature rage −20 °C – 80 °C is > 90 %, with overall system efficiently up to 70%. Pressure drop over pressure range was measured in range < 1 % / bar).

Durability testing done at 60 °C at constant pressure of 3 and 7 bar. Flow drop in range 3 – 8 % was noticed in duration of 10.000 h. 3D optical scanning of surface on pump elements shows wear in range 5 – 20 microns and confirm that pump has self-adaptive behavior during lifetime.

Performance testing at pressures up to 20 bar done with external e-motor in speed range between 1000 and 5500 RPM at temperatures between −10 °C and 80 °C. Results shows > 96 % of volumetric efficiency at temperatures between 0 °C and 30 °C. Drop of volumetric efficiency < 1 % / bar was observed over tested pressure range. Required torque between 0,2 – 0,4 Nm was measured to achieve pressure 5 – 20 bar at −10 °C with aprox 50 % of torque decrease at temperature 80 °C. 60 – 75% of pump total efficiency in pressure zone 5 – 20 bar at temperature of oil 80 °C measured.



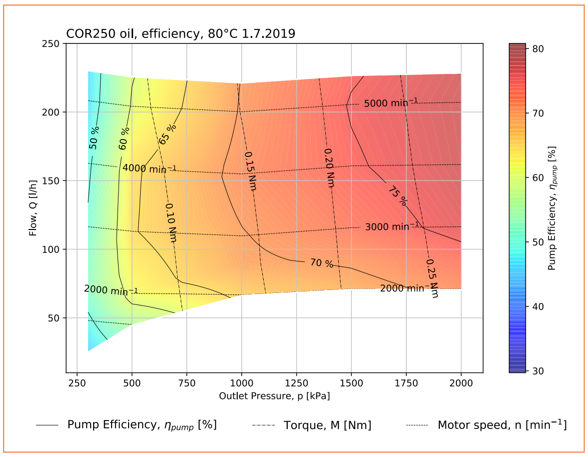


Figure 6 COR200 Pump Voluméntric efficiency (oil @ 50°C) – left, and COR200 Pump total efficiency (oil @ 80°C) – right

Experiment & ValidationResults COR600

Pressure (bar)	Flow (l/h)	Motor Torque (Nm)	Temp. (°C)	Pump efficiency (%)
5	550	0,5		45
15	550	1,1	30	65
25	550	1,75		70
5	500	0,4		46
15	500	1,25	100	52
25	400	1,9		45

COR600 pump prototype designed and produced to test pump performance up to 25 bar and flow up to 1000 l/h. Motor torque measurements at different temperatures of oil (30 °C and 100 °C) for output pressures between 3 and 25 bars and liquid flows between 100 l/h up to 1000 l/h done at motor speed range 1000 – 5000 RPM. Table represent required motor Torque at different output pressures & fluid temperatures at motor speed 3000 RPM and output flow between 400 and 550 l/h

Volumetric efficiency of pump unit at output pressures from 5 to 25 bar measured in range 93 – 97 % at output liquid flow between 200 and 800 l/h at oil temperature 30 °C.

At 100 °C, oil temperature volumetric efficiency dropped for aprox 10 % due to lower liquid viscosity and consequently increased internal leakage in pump unit.

Conclusion – Benefits of the COR Pump Technology

The trochoid gearing is not fundamentally new. In an axial arrangement, however, it leads to complex free-form surfaces, which became manageable only with new computing design (FEA, CFD, …) and production technologies (CNC, Ind 4.0, …)

The COR technology allows the construction of a gear pump with very good overall efficiency for the range of middle pressures.

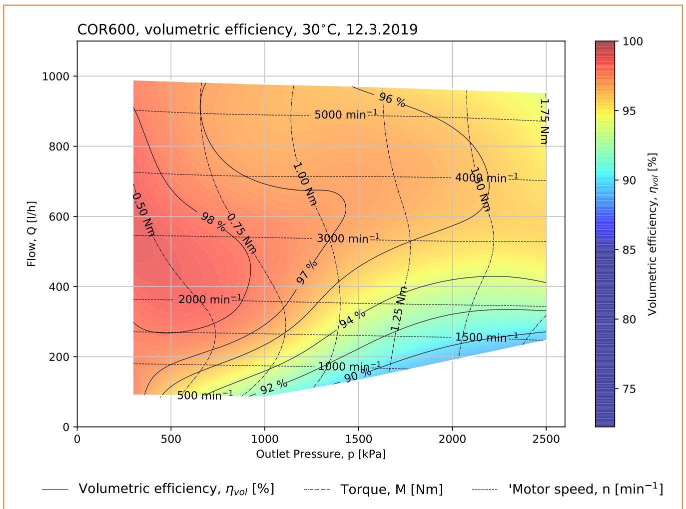


Figure 7 COR600 Pump volumetric Efficiency (oil @ 30 °C)

The feasibility of the COR technology in plastics leads to cost advantage. Due to the design variability of the gearing, the COR technology can be adapted for use in various media (liquids and gases). The trochoid rotating shape allows the simultaneous engagement of all gears, so that self-contained chambers arise.

The main advantages of COR technology are:
- Cost advantages, due to small number of parts and production in plastic injection molding,
- Low wear, due to hydraulic or pneumatic balancing of the rotors,
- Particle resistance, by axial displacement of a rotor,
- Self-priming,
- Pumping fluids and gas (2-phase possible),
- Simplified assembly / disassembly,
- High reliability (small number of components),
- High ratio : liquid displacement / pump size.

COR pumps are suited for – but not limited to – mobile and stationary applications using various drives (mechanical, electrical dry or wet running motors, others) as for example:

Pumps
- Oil Pumps (automotive, industrial, residential)
- Mechanically controlled oil pump (automotive)
- Fuel (diesel and gasoline) pumps (automotive, industrial)
- Circulator pumps for water (automotive, industrial, residential)
- Circulator pumps is solar application for water/glycol (industrial, residential)
- Pressure booster pumps for water
- Carbonator pumps for aqueous suspensions
- Chemical pumps for various liquids
- Transfer pumps for various liquids (portable or stationary)

Compressors
- Small compressors (automotive, industrial, residential)
- Compressor for fuel cells
- Compressor for refrigerant liquids
- Heat pumps

Contact

cor-pump@kolektor.com
klemen.petric@kolektor.com

Marzocchi's Elika Leads a "Silent" Revolution in the Automotive Sector

Marzocchi Pompe has been for the past 50 years a leader supplier of Gear Pumps in the industrial and off-highway mobile applications. Maybe not everybody knows that it is also a key player in the on-highway Automotive Sector.

Danilo Persici, R&D Dept., Marzocchi Pompe

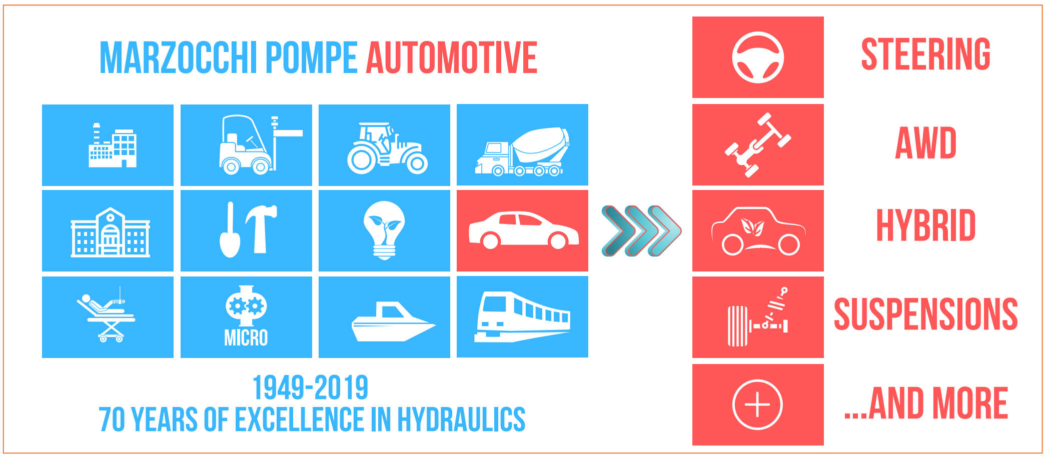


Figure 1
Applications of E05 Pumps family

Gear pumps are volumetric machines widely used in hydraulic system design since a long time mainly because of their unbeatable cost/efficiencies ratio and for their simple construction and compactness.

Marzocchi Pompe is the manufacturer with the broadest range of displacement reaching as low as 0,12 cc/rev and up to 200 cc/rev.

The top characteristics of quality, reliability of the Marzocchi products allowed the Company to gain an interesting share in the Automotive Market, where the most suitable range of displacement goes from 0,12 cc/rev and up to 8 cc/rev which is widely appreciated in all those applications where a mini powerpack is required.

The pumps are designed specifically to be part of the electro-hydraulic system to generate a flow of pressurized oil in a controlled manner to drive the "actuators" required in most of the above-mentioned systems.

Standard application of Marzocchi Pompe products are easily requiring up to 300 bars while the limited operating pressure of the automotive application, generally up to 80–100 bars, has allowed design and process engineers to introduce several design and process optimization with the goal on one side to maintain and even enhance very high performances specifically in terms of efficiencies and noise and reducing overall sizes as well, and on the other side decreasing the manufacturing costs also with the adequate level of automatization of the production and assembly of the units.

Figure 2 Evolution of E05 Pumps family

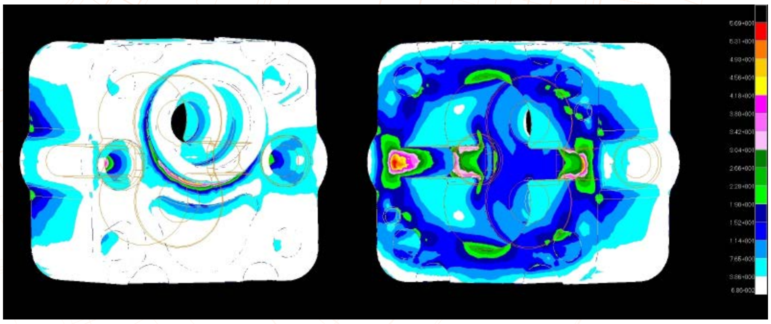


Figure 3 Structural Analysis of E05 body pump

The automotive family of E05 Pumps has been specifically designed to be integrated into assemblies of automatic transmissions, semi-automatic clutches, electro-hydraulic power steering, AWD systems, assistance in hybrid-type of propulsion, suspensions' systems, trucks rear-steering etc. The main parts of the pump, before being physically built, have been subjected to structural verification through FEA simulations, in order to check in advance, the structure of the pump subject to the stresses of work and also to verify the behavior during the most critical stages of the manufacturing process.

Despite their small size, E05 Pumps, depending on the application characteristics, can be internally mono or bi-compensated, the compensation system must always maintain the compensation plates in contact with the gears ensuring in all operating conditions, a drastic reduction of internal leakage, adequate lubrication of the moving parts and excellent volumetric and mechanical efficiency. Synthetic oils used in the automotive industry generally have a low viscosity, as it must maintain adequate fluidity even at low temperatures, down to even −40° C. The low viscosity of the oil has imposed a fine tuning of the compensation system. The compensation system has been designed to reduce the inevitable friction components increasing the mechanical efficiency of the system. High mechanical efficiency has a direct effect to lower consumption and enable a reduction of the size of the other components, such as a reduction in the size of the electric motor required to move the micropump.

A reduction of internal friction also entails a reduction of the heat input in the hydraulic circuit. Reducing the volumetric losses is also possible to reduce the size of other components such as the radiators: lower the internal leakage of the pump means lower heat that should be then taken away through oil cooling.

Because of everything said before, Marzocchi can definitely provide the right answer to the specification that TIER1 or TIER2 engineers are looking for:

- High efficiencies to cope with limited current and voltages requirement
- Low noise in order to reduce NVH (noise, vibration, harshness).
- Limited overall dimensions in order to cope with packaging restraints
- Competitive pricing versus standard pump solutions

A completely new automotive-dedicated Production Plant

Starting from 2016, the automotive pumps had been produced in a new plant completely focused on the Automotive Pumps. In the new factory of more than 9,000 m², located in Zola Predosa, just 5 kilometers from the headquarters of the Marzocchi Pompe, 80 people work. The pumps are produced on semi-automatic assembly and testing lines able to guarantee the high quality and contamination standards that the automotive sector requires. The Plant's ISO IATF 16949 Certificate has been updated until May of 2021.

The best for last – The ELIKA Family of Silent Pumps becomes larger

Thanks to the birth of the ELIKA1P, the range of available displacements of the ELIKA family is once again increasing. This time the development concerns smaller displacements with a standard range from 2.1 up to 8.1 cm³/rev. This family is particularly suitable for automotive solutions, where the producers are increasingly required to produce silent mini hydraulic power units for lifting systems, large hydro guides or rear steering systems for transport vehicles and others. Like all automotive solutions, Marzocchi is widely available to collaborate on customized solutions for shapes and sizes.

Figure 4 Helical Gears of ELIKA1P

Figure 5 New ELIKA ELIK1P

ELIKA itself is a highly efficient, low-noise and low-ripple Gear Pump, designed and manufactured by Marzocchi Pompe. Its realization is a result of a close cooperation with the Engineering Faculty of the University of Bologna and its development brought to many patents and trademarks registered by Marzocchi.

Just recently (09 November) at EIMA 2018 in Bologna its Multiple Version was awarded a Technical Innovation Prize with the following quote by the commission:

> "Elika is a Solution for external gear pumps that allows the same design of gears previously reserved for individual pumps to be used in modular architectures, to reduce vibrations and noise."

ELIKA's Helical Gear Technology is the perfect choice for all low-noise level applications. The ELIKA gears reduce the noise level by an average of 15 dBA compared with a conventional external gear pump.

The specific design of its helical gears ensures the continuity of the motion despite the low number of teeth. The low number of teeth reduces the fundamental frequencies of the pump noise, producing a more pleasant sound. The shape of the ELIKA Profile, patented by Marzocchi Pompe, eliminates the encapsulation phenomenon typical of standard gear pumps by thus eliminating the main source of noise and vibrations. ELIKA tooth profile, without encapsulation, significantly reduces pressure-oscillations and vibrations produced by the pump and transmitted to the other components, reducing the noise of the Hydraulic System.

The particularly low level of noise produced by the ELIKA pump makes it particularly suitable for applications which currently employ much more expensive technologies such as screw pumps, vane pumps, or internal gear pumps. ELIKA, with its characteristics, is the ideal solution regarding a wide range of specifications such as rotation speed, operating pressure and viscosity. The structure of the ELIKA pump minimizes leaks and maximizes volumetric efficiency in all conditions. ELIKA is therefore particularly suited for applications, which use inverters or variable-speed drives to regulate the speed of the actuators.

Contact
marketing@marzocchipompe.com

Electric Vehicle Fluids

With the rise of hybrid and electric vehicles (EVs), the automotive industry is going through one of the most profound shifts in its history. For consumers, the headlines are generally about how automakers are going green, which is undoubtedly positive news. But for OEMs, e-mobility represents some of the biggest engineering and design changes – and challenges – in the industry's history. At Shell, we're working alongside OEMs to help manage those challenges.

Torsten Murr, Shell Transmission Technology Manager

Christopher Dobrowolski, Shell E-Fluids Project Lead

Clarissa Mader-Pistor, Shell Business Development Lead Innovation & Sustainability

For OEMS, E-Mobility Represents some of the Biggest Engineering and Design Changes – and Challenges – in the Industry's History

There's no doubt that e-mobility is here to stay. Questions about the dependability, speed, and distance range of hybrids and EVs have been answered to the satisfaction of a significant, and growing, number of consumers – to the point where demand is steadily shifting in favor of them over internal combustion engine (ICE) vehicles. By 2031, production of electrified vehicles is expected to reach 50 percent of all vehicles made.

Along with consumer demand, of course, is the fact that automakers must meet ever stricter carbon dioxide emission targets and fuel economy mandates imposed by governments. The need is especially important given the projection that global car parc will approximately double by 2045. But automakers have responded not just with hybrids and EVs that are better for the environment. They're delivering on consumers' needs for vehicles that travel farther, drive better, and cost less than their predecessors of just a few years ago.

For now, at least, they won't all be the same kind. Hybrid electric vehicles (HEVs), which continue to improve technologically, increasingly compete for attention with plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs). But despite their differences, to one degree or another they all rely on electric powertrains, which are rapidly becoming more sophisticated and technologically demanding to meet consumers' expectations.

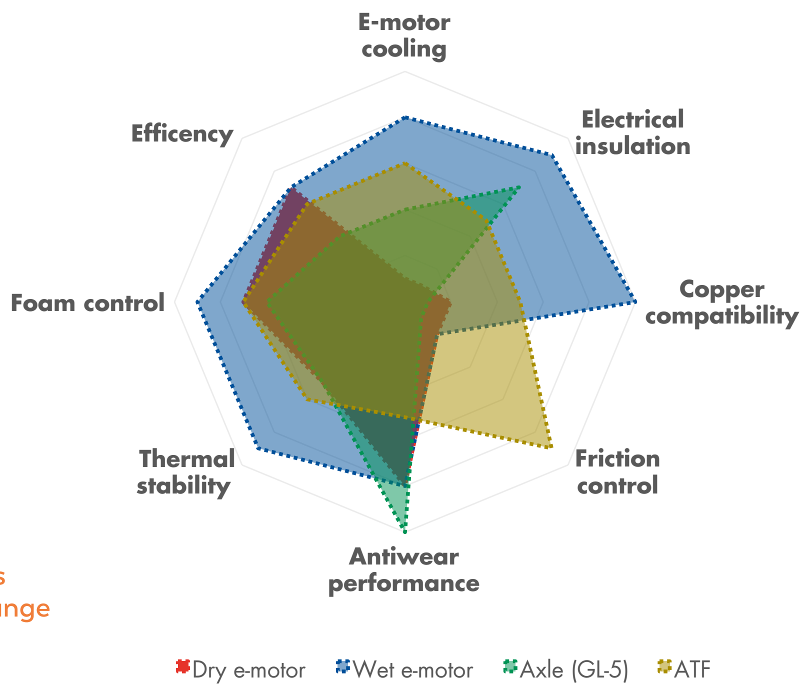
This includes the fluids in them. To most consumers, fluids in hybrids and EVs are all but invisible. But those in the automotive industry know how crucial they are – particularly because, once added to the sealed environments in these vehicles, they need to perform at optimum levels over the vehicle's lifetime. The first fill couldn't be more important.

If anything, the technical requirements placed on fluids in hybrids and EVs are much greater than they are in ICE vehicles. Their core job of preventing wear, reducing friction, and being efficient is still essential, but as e-mobility technology advances, so is the role that fluids play in electrical compatibility and thermal management. Simply put, the fluids developed for ICE vehicles generally fall short of the performance requirements of hybrids and EVs. And the gap will only widen as the powertrains in those vehicles become more sophisticated.

Shell has been working to close the gap. As the leading global lubricants manufacturer for the last 12 years, we have recently developed a line of fluids engineered specifically for the high-tech powertrains of hybrids and EVs. And significantly, these developments have taken place not just from the research in our own laboratories, but also by working in close technical partnership with OEMs and component manufacturers for more than 20 years.

To Consumers, Fluids in Hybrids and EVS are all but Invisible. But those in the Automotive Industry know how Crucial they are.

This is key because in the still-developing e-mobility industry, there is far less brand-to-brand uniformity across hybrid and EV powertrains than there is in conventional vehicles. In fact, electric motor design is unique to each OEM – e.g., the insulation material, winding technology, rotor/stator setup – which makes engineering fluids for hybrids and EVs that much more challenging. But in working with various OEMs, Shell has engineered fluids that effectively and efficiently meet a broad range of performance requirements. We've done this by employing a number of dedicated screening methods, such as copper wire corrosion testing, high-speed foaming testing, and state-of-the-art technology for high-speed driveline test rigs.



Working with OEMS, Shell has Engineered Fluids that Effectively and Efficiently meet a Broad Range of Performance Requirements

These methods and our collaboration with OEMs have resulted in fluids engineered for both the wet e-motors being designed for the newest generation of electric vehicles, as well as the dry e-motors that have dominated e-mobility up to this point.

For wet e-motors, with their integrated design, fluid needs to do two essential jobs at once: lubricate the gearbox and cool the electric motor. And copper compatibility is the all-important factor. On the one hand, these motors need a fluid that works quickly enough for proper gear protection, which requires additives to facilitate that process. But those same additives can corrode copper, a potentially serious problem in e-motor windings – especially when fluid is filled for life.

Shell knows that OEMs and component manufacturers require fluids with the proper chemistry to keep these opposing needs in balance. And with only one fill, there's just one chance to get it right. We've engineered e-fluids that provide friction protection for gearboxes and thermal protection for motors while offering superior copper compatibility and electrical characteristics. In the high-voltage environment of wet e-motors, they provide protection from corrosion – and from the resulting shortcuts that reduce power. All while remaining stable over time.

And while wet e-motors may be the new generation of e-mobility, dry e-motors haven't gone away. E-fluids like the ones Shell has developed are finding increasing applicability in dry e-motors, as OEMs design them to be more compact and more high performance, which results in lower fluid volumes but higher stress on the lubricant.

Christopher Dobrowolski, Shell E-Fluids Technology Expert, says of the latest dry e-motors, "It's the same story as with wet e-motors. OEMs are integrating electrical power components to make the electric drive units more compact, but increasing the overall performance output. This adds significantly higher technical requirements on the lubricant."

One need that both wet e-motors and dry e-motors share is fluids that offer antifoaming qualities. As OEMs design more compact motors to save weight and space, there are higher rotational speeds to contend with. Increasingly, this means that more electric vehicles will need transmissions to manage the high RPMs of the motors. But the high-stress environment of these transmissions can allow air to get into them and cause fluids to foam, which means they lose their ability to protect the components' surfaces. This is another area where Shell's new-generation e-fluids stand up to the technical requirements of e-mobility OEMs.

And as we look to the future of e-mobility, Shell will work with OEMs on new cooling technologies for EV batteries. This need will be particularly important as fast charging technologies improve – a big selling point from a consumer standpoint. But higher charging speeds will likely come at a cost of increased temperatures, as electricity generates heat. Shell knows that the need for thermal management will be vital, and we will continue our history of collaboration with auto industry partners in this area as well.

The automotive industry is undergoing some of the biggest technological changes in its history, bringing e-mobility to a world that is both increasingly on the move and mindful of its environment. As hybrids and EVs continue to deliver a higher level of performance for consumers, we will continue our history of partnership with OEMs to engineer the most advanced, reliable e-fluids in the industry.

SAE 0W-20 Engine Oil Formulations Effects in Taxi Cab Severe Field Service

JoRuetta R. Ellington, Ph.D., Evonik Oil Additives USA, Inc.

Introduction

A series of SAE 0W-20 engine oils were evaluated in a Las Vegas taxi cab fleet to study the durability of two different classes of Viscosity Index Improvers (VII), DRIVON™ Comb Polymer technology and olefin copolymers (OCP). The 100K mile field trial consisted of nine 2017 Ford Taurus vehicles equipped with 2.0L Eco-boost (turbo-charged) engines and six-speed SelectShift® automatic transmissions. Five vehicles were tested using engine oils formulated with DRIVON™ Comb Polymer technology while the remaining four vehicles used engine oils containing OCP viscosity modifiers. The goal of the study was to demonstrate, through an actual field test, that DRIVON™ Comb Polymer technology, known for its superior fuel economy performance, also delivers appropriate protection of the engine hardware from severe driving and the harsh conditions in the Nevada desert. The field trial, designed to evaluate the formulation effects of VII chemistry on cleanliness and wear, would focus on durability. Testing began in March 2017 and lasted over 18 months. Test parameters are summarized in Table 1. To increase severity, oil drain intervals (ODI) were extended past the manufacturer's recommendation for this type of service from 5,000 miles to 8,000 miles. Additionally, periodic tests were conducted to evaluate the oil's performance, including interval sampling at the midpoint and end of each 8,000-mile ODI.

Number of Taxi Cabs	9
Model Year	2017
Displacement	2.0 liters EcoBoost®
Number of Cylinders	4
Oil Viscosity Grade	SAE 0W-20
Oil Sampling	4000 miles
Oil Drain Intervals	8000 miles
Transmission	Automatic

Table 1 Fleet Test Parameters

Test Oils

Although the trend of engine oils moving to lower viscosity grades is well known in the industry, driven by the need for lower CO2 emissions and improved fuel economy, durability remains a concern. While the original equipment manufacturer (OEM) recommended SAE 5W-30 oils for this turbo-charged engine, SAE 0W-20 oils were used in this field trial to evaluate the trend of lighter viscosity grades usage in newer vehicles. Furthermore, moving to a lighter viscosity grade would highlight the strength of DRIVON™ technology and its ability to effectively protect the turbo-charged engine from excessive wear, sludge, and deposits. Two VII chemistries were studied. The low ethylene olefin copolymer VII, LE OCP, represents the market general formulation and the Comb Polymer VII represents the DRIVON™ technology. The data of the tested oils are given in Table 2. The engine oils were designed to be SAE 0W-20 defined by the 100 °C kinematic viscosity. Each oil was blended to the same minimum HTHS 150 °C requirement of 2.6 mPa · s.

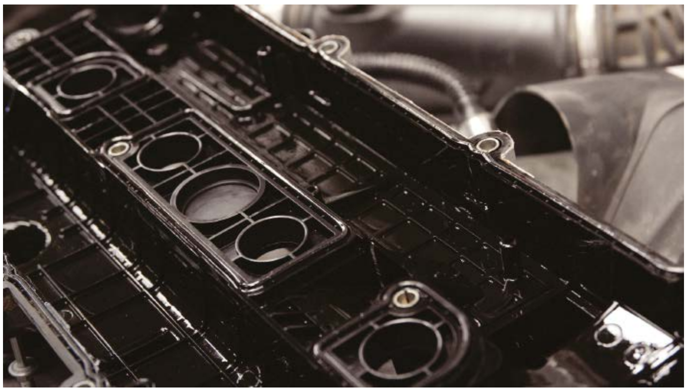
VII	%wt	LE OCP Reference	DRIVON™ Comb
DI Package (GF-5)	%wt	8.9	8.9
VII	%wt	6.0	6.0
Group III base oil mix	%wt	85.1	85.1
		100	100
KV 100°C	mm^2/s	8.4	7.5
KV 40°C	mm^2/s	41.7	33.5
VI		183	205
CCS -35°C	mPa · s	4053	5950
HTHS 150°C	mPa · s	2.6	2.6
Noack	% loss	12.3	11.5

Table 2 Data of tested oils

Intermediate Results

The results highlighted in this paper are from two taxis—one using engine oil formulated with DRIVON™ Comb Polymer and the other using engine oil formulated with OCP. The taxi cabs were placed into service in late March 2017. Intermediate valve and valve cover inspections were performed after 50,000 miles. Using an industry standard method, an independent rater in San Antonio, TX rated the valve deck and valve covers for sludge. The raters are trained to examine these parts and match up the visual color ranking on the sludge depth chart. Parts that are completely free of sludge are assigned a merit value of 10. Parts with increased accumulation of sludge are represented by lower merit values between 1-10. The valve cover sits on top of the valve deck, seals the top of the engine, and prevents oil leaks. During the intermediate 50,000-mile inspection, the valve covers were removed and rated along with the valve deck for sludge. Varnish could not be rated on the valve cover due to the cover's black color, which made it difficult to distinguish varnish.

The 50,000-mile inspections revealed that both SAE 0W-20 oils demonstrated superior cleanliness with no visible sludge or wear on the valve cover or the valve deck even under the harsh conditions of the Nevada desert. Each taxi received a sludge rating of 9.75. Figure 1 showcases photos of the valve cover and valves for the engine that used DRIVON™ Comb Polymer technology.



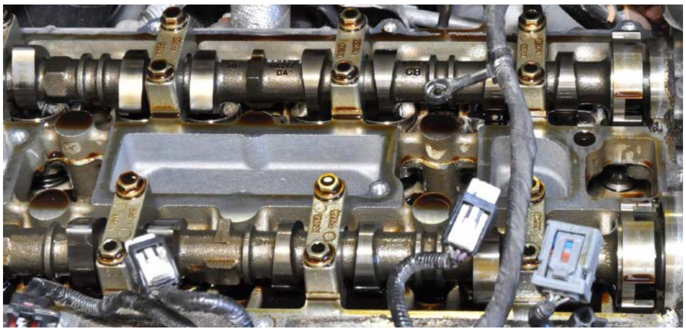
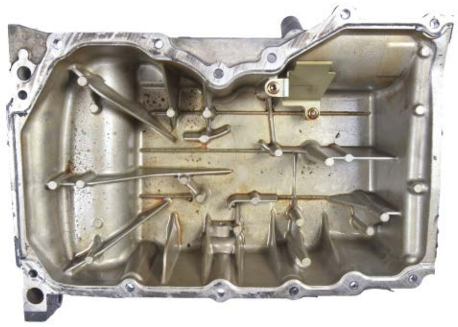


Figure 1 50,000-mile Valve Inspection

Comb VII	
Oil Pan	**Rating**
Sludge	9.74
Varnish	**9.30**

OCP VII	
Oil Pan	**Rating**
Sludge	9.69
Varnish	7.00



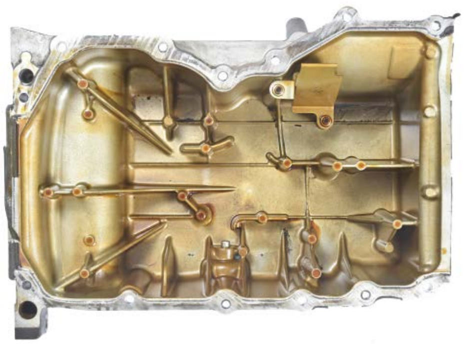


Figure 2 Oil Pan Rating

Final Results

While the DRIVON™ and OCP technologies both performed well at the 50,000-mile inspection, there were some notable differences at the 100,000-mile end of test teardown and ratings.

Oil Pan

The oil pan is the reservoir where the engine oil collects when the engine is not running. Extreme heat can negatively affect motor oils, causing excessive sludge to accumulate in the oil pan. Even worse, sludge can build up and clog the oil screen on the oil pickup tube and lead to serious engine problems. Varnish is an oxidized or carbonaceous adhesive material that covers internal surfaces of the engine. Over time and with high temperatures, these compounds age until they form a consistent, hard, and shiny surface. After the engine teardown, the oil pans were rated for sludge and varnish and the oil's ability to provide increased protection and thermal stability under harsh conditions.

The DRIVON™ Comb Polymer formulation received a sludge rating of 9.74, demonstrating a superior ability to prevent excessive sludge build, ensuring protection for 100,000 miles. The OCP formulation also prevented excessive sludge with a slightly lower sludge rating of 9.69. When comparing the two oil pans for varnish, the DRIVON™ Comb Polymer formulation strongly protected the oil pan against excessive varnish, exhibiting outstanding thermal stability with a rating of 9.3. Conversely, the OCP formulation achieved a lower rating of 7. The visible difference in varnish protection can be seen in Figure 2.

Valve Deck

Like the oil pan, the valve deck is prone to accumulating sludge if the engine oils have poor thermal stability. In this case, both the DRIVON™ Comb Polymer and the reference OCP fluids earned high sludge ratings of 9.75, demonstrating protection despite the harsh operating conditions. The valve deck is also susceptible to varnish due to its exposure to temperature and combustion by-products. The DRIVON™ Comb Polymer technology was more effective in protecting the engine against the formation of varnish with better thermal stability than OCP, with varnish ratings of 8.60 and 6.67 respectively. Figure 3 illustrates the varnish ratings from the two VII chemistries.

Comb VII	
Valve Deck	**Rating**
Sludge	9.75
Varnish	8.60

OCP VII	
Valve Deck	**Rating**
Sludge	9.75
Varnish	6.67

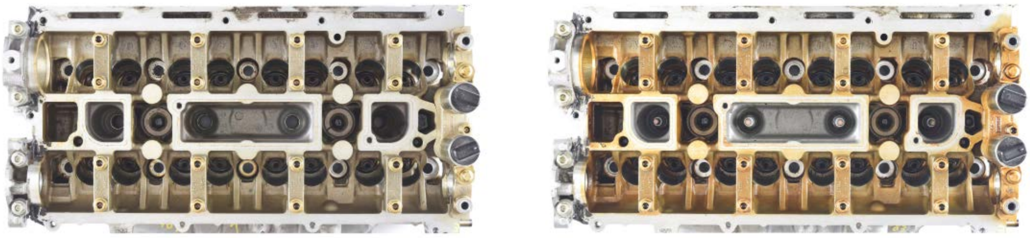


Figure 3 Valve Deck Rating

Pistons

When engine oils are subjected to heat, pressure, and oxygen, carbon deposits can form. In this study, the pistons were rated for how well the oil protected against deposits. Figure 4 illustrates the areas rated on the piston including the piston ring, land, groove, and under crown including the three lands and grooves found on each piston.

Ratings for piston deposits are not measured quantitatively. Rather, they are based on a set methodology employing visual ratings expressed as a merit value between 1–10, with 10 representing a part completely free of deposits. The piston deposit merit ratings for the two different VII chemistries are summarized in Table 3.

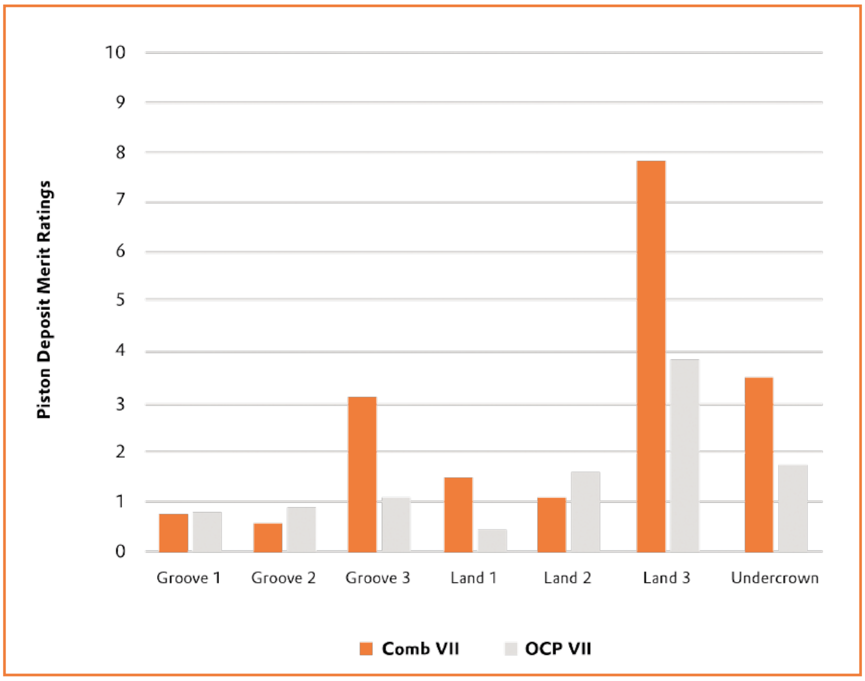


Table 3 Piston Deposit Ratings

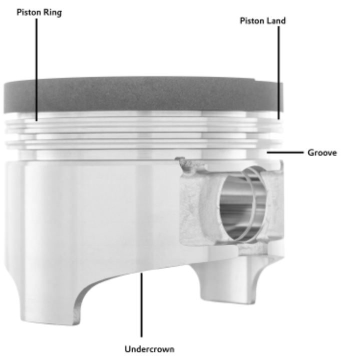


Figure 4 Internal Combustion Engine Piston

Figure 5 Hot Stuck Piston Rings

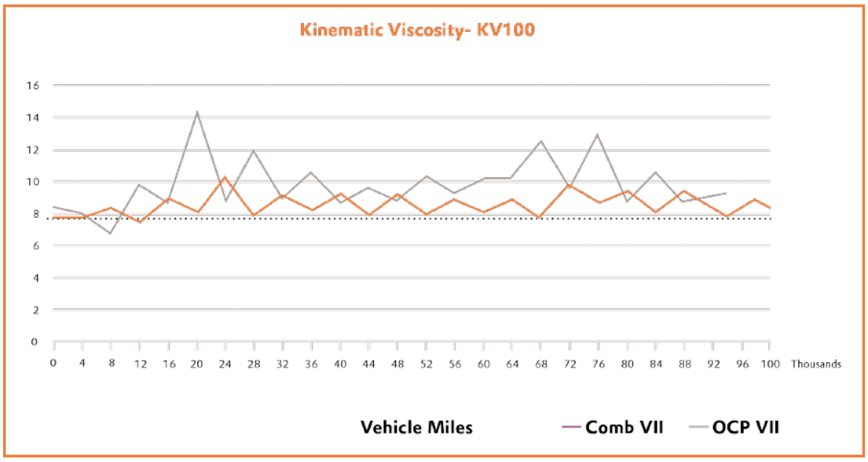


Table 4 Test Oils Kinematic Viscosity at 100°C

The DRIVON™ Comb Polymer formulation performed best on the third land, third groove, and the under crown while the OCP formulation fared best on the second land and under crown. Overall, the DRIVON™ Comb Polymer formulation exhibited better performance in piston deposit control than the OCP formulation on five of the rated areas. While there were no broken ring lands observed with either formulation, the OCP formulation experienced two hot stuck piston rings. The piston rings fit into the horizontal grooves in the pistons. The rings are designed to expand against the cylinder wall creating a seal between the piston and cylinder wall in the combustion chamber. This ensures that the engine maintains a consistent level of compression and prevents combustion gases from entering the oil sump. Therefore, there are two positions where the rings could get stuck, either inside the piston grooves or against the cylinder wall. However, if the rings are stuck against the cylinder wall, the crankshaft will not rotate. In the taxi containing OCP in engine oil, the rings were stuck inside the piston grooves. Pistons 1 and 2 had hot stuck rings in the second ring while pistons 3 and 4 had sluggish rings in the second ring. This caused a reduction in engine power, while blowby combustion gases could enter the oil sump and contaminate the oil. Figure 5 shows the hot stuck rings in pistons 1 and 2. For the vehicle containing DRIVON™ Comb Polymer technology, the oil had good thermal stability and did not experience hot stuck rings in any of the pistons.

Viscosity Retention

While the focus of the field trial was mostly on the hardware, there was also special attention paid to the kinematic viscosity (KV) and the ability of the test oils to remain consistent over the course of the oil drain interval. Kinematic viscosity is very temperature dependent. Typically, the KV of a fluid would decrease with an increase in temperature and behave in the opposite manner with a decrease in temperature. The KV at 100 °C was analyzed at each 4,000-mile oil sampling and 8,000-mile ODI for both VII chemistries to understand the behavior of the viscosities over the course of time through the various seasons and temperature conditions. The DRIVON™ Comb Polymer oil had an initial KV100 °C of 7.8 cSt while the OCP oil began testing with a KV100 of 8.4 cSt. Both oils experienced increases in viscosities over the course of different temperatures in the ODI but the DRIVON™ Comb Polymer oil was more consistent in viscosity fluctuations. Ultimately the goal for formulators is to have an oil with a viscosity performance that mirrors a horizontal line. Table 4 showcases the viscosity fluctuations that occurred in both technologies.

Summary & Conclusion

Lower viscosity lubricants can be used in passenger vehicles equipped with turbochargers to offer superior protection against wear, sludge, and deposits. Consideration was given to the fluid viscosity and the selection of VI and its effects on durability including cleanliness, wear protection, and viscosity retention. Both DRIVON™ Comb Polymers and OCP VIIs were used in severe service to demonstrate superior protection against excessive sludge and wear. Oils containing DRIVON™ Comb Polymer retained viscosity and better consistency in viscosity fluctuations. DRIVON™ Comb Polymer oil also demonstrated outstanding thermal stability in protection against varnish and piston deposits. Additionally, the fluid embedded with DRIVON™ Comb Polymer exhibited strong durability, allowing no stuck or sluggish rings and no harm to the engine. In short, oils run in DRIVON™ Comb Polymer technology performs just as well as – if not better than – OCP over 100,000 miles in severe service conditions.

Innovating Next-Generation Drivelines

How integrated, collaborative software products can streamline the development process and facilitate innovation

Jamie Pears, Head of Product Management, Romax Technology

Our market is rapidly evolving as universal trends towards lower emissions and more efficient drivelines gather pace. Powertrain engineers are constantly facing new challenges, grappling with understanding the effect of new physics on new system architectures running at much higher speeds than conventional drivelines. In order to meet new market demands, multiple solutions are being explored. New layouts are being assessed, as designers try to pack as much power into the smallest space possible, allowing flexibility to improve passenger comfort, handling or battery space. New materials are being investigated for gears and sections of the housing in efforts to reduce weight; by using less metal, designers can typically increase the range and improve the vehicle's general efficiency.

Pressures are mounting on all sides to find optimum solutions. Failure to adhere to government targets will result in heavy fines, whilst unsatisfactory end products will fall short of customers' expectations of higher performance at lower costs, subsequently damaging reputation. Ultimately, all contributions towards improved environmental sustainability have to be commercially feasible; visions have to be attainable.

Additional trends, such as the drive towards autonomous vehicles, shift challenges in a different direction. Whilst they may not require development of novel systems, they will necessitate a renewed focus within the realms of safety and control. Thus, engineers are having to branch out, moving beyond the arena of mechanical expertise into the electrical, and further, into pure electronics and control. What unites these multiple requirements are the needs to harness the best expertise to hand, and to utilise it in a constructive way, to form an integrated and streamlined process. In short, today's engineers need to innovate and collaborate.

Large scale innovation has to happen in all corners of the development process, even if it means radically updating design processes and adopting new ways of working. It is not, however, innovation for its own sake, but rather in order to achieve the best possible solution. Exploring many possible options requires a large scope of investigation, which subsequently has to be weighed up against time and cost. Fully investigating the design space means that engineers cannot rely on expensive physical testing, typically only done at the end of the process. To successfully innovate, testing needs to be done at a time in the process when changes can still be made. In other words, a substantial part of it has to be virtual; it has to be done within the arena of simulation. This digital testing environment allows designers to act, develop and innovate quickly, making crucial decisions without absorbing too much time and cost, enabling a CAE-led design process to be adopted. But with this much reliance on simulation, it is critical that the right products are deployed (Figure 1).

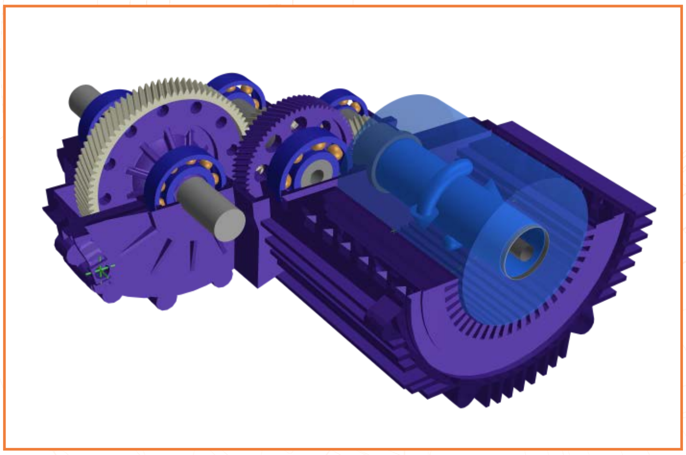


Figure 1 Complete electro-mechanical system modelled using Romax Nexus products.
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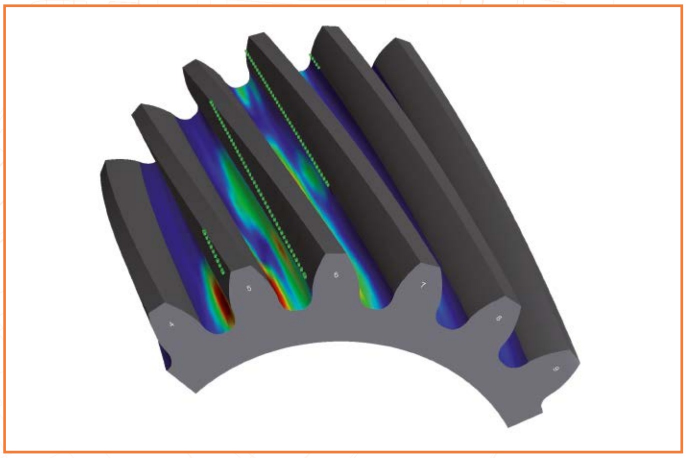

Figure 2 Advanced gear root stress analysis in Romax Enduro
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Encouraging Innovation at the Concept Design Stage

At the concept stage, innovation really comes into its own. Designers need to be able to explore many possible layout options, searching for the right design to meet a given set of targets. To do this, they need to be able to build models quickly, ideally automatically from CAD models, where they already exist, and assess their performance for whichever targets are most critical for them: durability, efficiency, NVH, packaging, weight or cost. They need to make confident engineering decisions and make design recommendations based on overall layout, gear design and bearing selection. They need to do this quickly, to ensure they can explore a wide variety of designs and truly select the best one to pass forward for refinement by other members of their team, keeping themselves ahead of the innovation curve.

As designs are progressed, and engineers have to navigate uncertain territory around an obstacle course of already patented solutions, software products must be validated and trustworthy, as a first priority. They must also encourage innovation in every corner, empowering each member of the development process with specialist tools which enable them to deep dive into their respective areas and pinpoint places where the maximum gains can be made. They must do justice to their expert users, specifically catering for their needs, combining advanced technology with usable analysis speeds and integration to the other tools which they use most regularly, avoiding tedious and "non-value add" activities like rebuilding models and re-entering data – that's time that could be spent innovating.

Refining a Design for Durability, Efficiency and NVH

Once the concept design has been selected, this design needs to be refined, perhaps first for durability. The durability engineer needs to evolve the concept model, adding more detailed definitions, and using CAE to drive the rest of the design process. Analyses should be automatable, using meaningful drive cycles, and providing clear, easy to interpret results which will also enable certification in specific industries. The solution needs to be system-level whilst incorporating advanced component-level capability for gear and bearing design. In designing lightweight and durable systems, the durability engineer needs to minimise prototyping and testing, to minimise overall product and manufacturing costs, trusting in the results that the simulation gives them, and to be confident that it will result in a more durable end product (Figure 2).

Alongside the durability engineer are people looking at the whole system from the point of view of NVH and efficiency. The efficiency expert needs to make sure the correct oil is selected for the system, enabling optimum efficiency and thus meeting tough industry challenges. In order to do this, they need to predict energy losses, CO_2 and fuel consumption using realistic drive cycle data, investigate the efficiency of gears and bearings and then update designs to improve performance, whilst balancing with other criteria and generating efficiency maps. The NVH analyst needs to understand the design's dynamic performance, to allow them to make design decisions confidently based on trustworthy simulation, understanding the impact of variability on noise performance. Access to this sort of analysis right from the start means that they can prevent noise problems before they become problems, even with regard to the new and complex noise challenges associated with EVs.

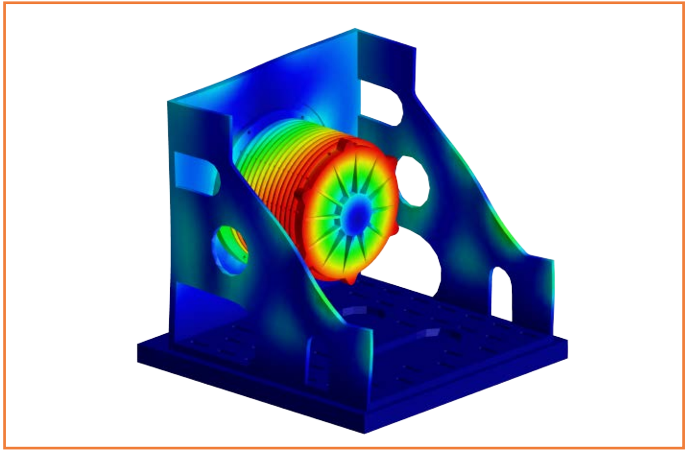

Figure 3 Electrical machine modelled and analysed in Romax Evolve
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Simulating Complex Components within a Full System

These days, incorporation of the electric motor cannot be considered an afterthought, left to the end of the process. The electric machine designer must use dedicated electromagnetic and structural analysis tools to design the best motor for the application. It is crucial to understand its noise performance, so that any potential motor NVH problems are identified. Although previously treated in relative isolation, it is now generally acknowledged that system integration between the motor and the gearbox has to be simulated to make sure that the impact of high operating speeds on the overall noise and vibration performance is understood, and that you can act on critical system interactions. Therefore, when appropriate, the electric machine model needs to be integrated into a full electromechanical driveline system simulation model, to analyse its structural performance in the context of the whole system, and its interactions in terms of system level NVH (Figure 3).

Simultaneously. the bearing designer needs to perform advanced bearing analysis on the full electro-mechanical system to support selection of optimal bearings from up-to-date supplier catalogs. Their main concerns, depending on the application, may be avoiding premature bearing failures or simulating bearing behaviour in a full system, taking into account new challenges associated with electric vehicles such as high speed bearing effects and their impact on dynamic behaviour. They need to work closely with bearing suppliers, but not be reliant on them. To improve crucial collaboration, tools should allow results to be shared between supplier and customer, whilst protecting the sensitive data of each party.

Next Generation Software for Next Generation Drivelines

Although their needs are very different, these people all need to be able to communicate throughout the development process, so they can understand how their changes impact upon other areas. Without sufficient integration, specialists in different areas will diverge, satisfying their own criteria but without any indication on how it will affect other areas of the process and performance targets. All users must be connected, united within an overall platform in which they can integrate their innovations. Everyone's process is different, and so it should be, but to ensure innovation across development, users need to share data and information not only within an organisation but also back and forth across all areas of the supply chain. As such, partnering with the right people at the right time is key, taking advantage of experts and the best available resources and support. The process must be a future-proofed combination of digital testing and advanced simulation, within a CAE environment where tools are focused, flexible and integrated.

This is the philosophy behind Romax's new product launch, the Romax Nexus platform, comprising six products carefully tailored to people working in different areas of the development process: Romax Concept, Romax Enduro, Romax Spectrum, Romax Energy, Romax Spin, and Romax Evolve. They can be used on their own but also work seamlessly together if required, have interfaces to CAD, FEA and a wealth of other gold-standard tools through our many technology partners. The platform allows each area of development to innovate in their own way, to push the boundaries, yet remain tightly integrated with the rest of the process. The product areas have been driven by the needs of our wide and varied customer base, but equally have been carved out of the areas in which we have 30 years of innovation history. The tools use a mixture of cloud and desktop applications to harness power while controlling IP and maintaining security. The result is a flexible platform designed to empower users, to foster innovation and encourage collaboration. It's allowing us to work together more closely than ever before – leveraging expertise across the industry, to face the new challenges it presents; supporting specialists to innovate within their own areas while also linking them more closely together.

More information
Visit us at booth D17, or at https://romaxtech.com/software/

Automation with Next Generation Software Enabling Engineers to Spend More Time on Engineering

Paul Langlois, SMT, UK

The use of software in transmission design, manufacture and troubleshooting processes is nowadays considered essential. Such tools enable virtual design optimisation before any hardware is built, minimising the number of hardware testing loops required to achieve an optimal design. Despite the power of these transmission design and analysis tools significant time is still taken up by the manual tasks of building models, setting up analyses and processing results. Further, companies tend to work with a suite of software throughout the design and development process. This often includes in-house developed tools which contain the companies own IP and cannot be shared outside of the company. Retaining their IP is often a barrier to having these in-house tools more tightly integrated with design and development workflows.

In this article we discuss the next generation of transmission specific software which allows engineers to make efficient use of their time and company IP within workflows without sharing it externally, via scripting.

Transmission Specific Design and Analysis Software – MASTA

Transmission design and analysis software such as MASTA have become critical tools in many engineers' toolbox. A full system approach is essential to capture the interaction between components in complex transmission systems. These tools can be used from concept design, through detailed design, to manufacture as well as to troubleshoot existing transmission problems. Analyses cover a broad range of fidelity from implementation of international standards to higher fidelity component and system level analyses. Considerations including weight, durability, efficiency and NVH can be considered.

Such tools enable virtual testing iterations where the effect of design changes on targets can be analysed with ease and "what if" scenarios investigated quickly and efficiently. Such studies can be

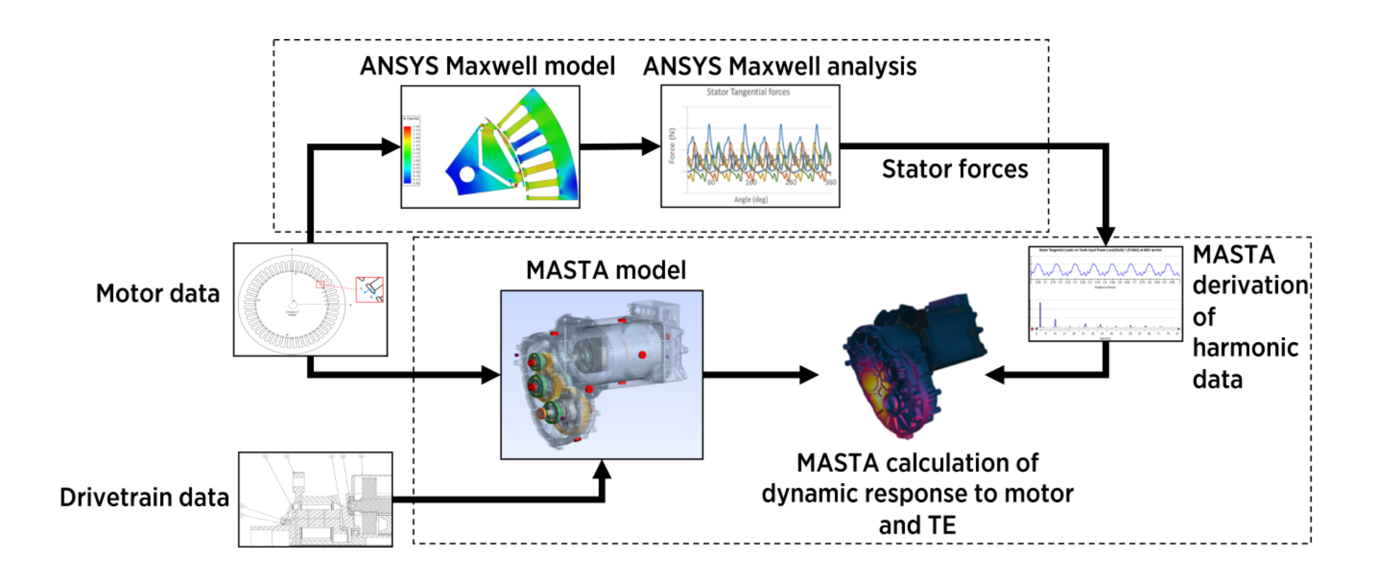


Figure 1 Workflow for NVH response of an EV transmission and motor system to an electric machine and TE at the gear meshes. Images from ANSYS Maxwell reproduced with permission of ANSYS, Inc.

controlled in an outer loop including Design of Experiments and optimisation. Allowing for efficient investigation of the effects of manufacturing and assembly variability.

An example of such a process is given in Figure 1. This shows an NVH workflow for an EV gearbox which calculates the dynamic response to both an electric machine and transmission error at gear meshes in the same model.

Having such software embedded in a company's design and development process, has enabled huge reductions in development times while producing more robust transmissions. Hardware testing iterations are kept to a minimum.

However, there is often still a significant amount of work performed by the engineer which could benefit from being automated. Further, companies can benefit from more tightly integrating such tools with their own IP, analysis methods, workflows, in house tools and knowledge database. This is where scripting comes in.

Scripting – Fundamentals

In MASTA 10, SMT have introduced an extensive set of scripting functionality. Scripting developed out of discussions with a German automotive OEM. They were using MASTA very successfully but had a vision to optimise their use and make it as efficient as possible in two main ways. Firstly, enabling engineers to spend less time on manual tasks of model building, running analyses and extracting results. Secondly, enabling companies to utilise their own IP efficiently in design/development workflows without having to share it externally. Scripting, however, enables much more than this.

Scripting opens up a software program's objects and analyses to enable interaction, integration and customisation. It enables the user to modify and extend the programs behaviour without sharing those extensions with any third party.

MASTA API

MASTA is written in an object-oriented programming methodology. In simple form this consists of; objects, such as a cylindrical gear; properties, such as the number of teeth; methods such as “run analysis”. SMT have created a MASTA Application Programming Interface (API), which gives access to this object, property model. The API contains over 5000 different types of objects and over 18 000 different properties.

The API allows users to write their own code outside of MASTA to interact with MASTA models and analyses. The API can be used from a whole range of languages including MATLAB and Python, as well as any .NET language. The advantages of this are obvious. This flexibility allows users to write in the code languages they are familiar with. Secondly, this enables users to write code using common IDE's, such as Microsoft's Visual Studio, and take advantage of all their debugging, code completion and other development tools. Further it allows easy interaction with in-house tools no matter what language those tools are written in.

The API allows users to, for example, modify properties, create new properties, build models, open models, save models, create and run analyses, extract results and process results. The vast majority of operations possible within the user interface are available via scripting. The use cases for such functionality are limitless and can range from small utility type functions to whole new analysis methods.

One such use case is a customer who has their own in-house code for synthesising planetary system designs. Such a code takes as input the boundaries under which the system is to operate, and outputs a number of different suggested design topologies to consider further. Their next step is to build MASTA models of these options and analyse them in more detail. Scripting allows the customer to write code to automatically create these MASTA models from their outputs. This eliminates the manual work required and eliminates the potential for errors in building those models.

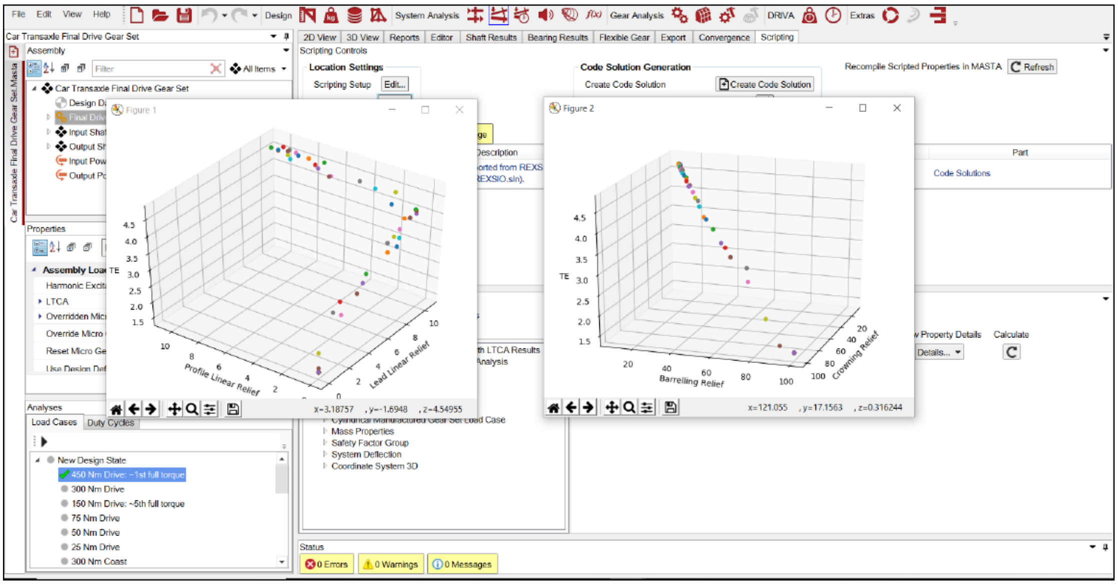


Figure 3 Script using high level Python functions, run from MASTA to optimise micro geometry for minimum TE.

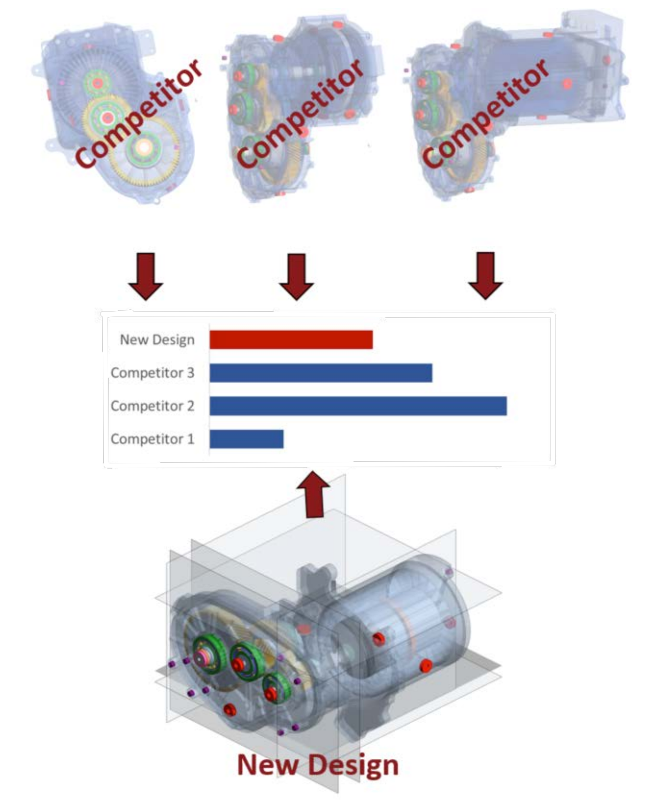


Figure 2 Schematic of a scripted benchmarking tool workflow

A second use case is shown schematically in Figure 2. Companies regularly benchmark their new designs against both competitors and their own previous designs. With a database of analysis models scripting can be used to create a tool which automatically batch runs a new transmission model and compares its performance for metrics such as durability, efficiency and NVH against selected similar transmissions within the database. Such a tool can give a quick overview of how the new transmission performs against its competitors with minimal input from a user.

Running scripts within MASTA

Scripting not only allows the user to interact with software from outside its interface. It also allows more possibilities for extending the software functionality within the user interface. An example of this is shown in Figure 3. This shows the results of a Python script referenced by a button within MASTA. When the button is pressed the script optimises the gear micro geometry to minimise TE. This is a simple example which demonstrates the advantage of being able to use high level Python functions and libraries such as, in this case, SciPy and Matplotlib, within MASTA scripts. The user interface is extended by the script by adding python plots of the results via the Matplotlib library.

Another common use case for scripting is to enable converting of customer data to, or from, MASTA models. For system level models an example of this is shown in Figure 4.

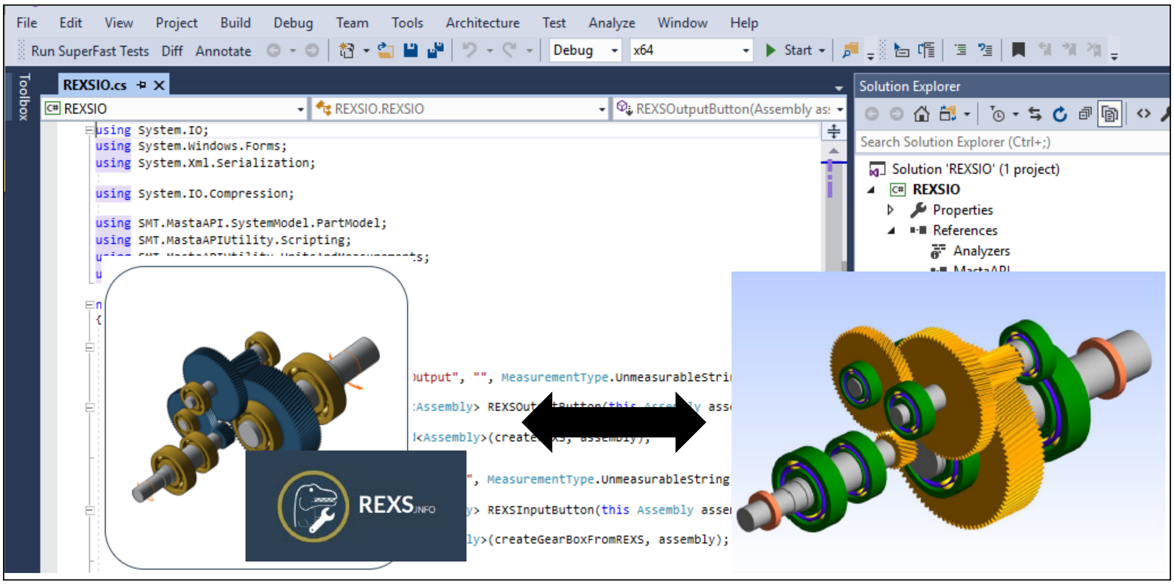


Figure 4 Script used to import a REXS file to automatically generate a MASTA model.

In this example a script has been written to enable import of a REXS XML file to MASTA. REXS (Reusable Engineering Exchange Standard) is a proposed format being developed by the FVA in Germany for the transfer of gearbox model data. It is free, non-proprietary, open source and standardised. Although this example uses the REXS format it illustrates how a user can write a script to convert data in their own proprietary formats to convert data to or from MASTA. SMT have, for example, also written a similar script to convert cylindrical gear data in the VDI/VDE 2610 Gear Data Exchange format.

In a similar way scripting also enables MASTA to be used as a pre-processor for further higher fidelity analysis. As an example of this a global bearing manufacturer uses MASTA for system level calculations to calculate the loads and deflections at the bearings in complex transmission systems. Via scripting they can automate the export of these results at the bearings to their own in-house tools for high fidelity analysis of the bearings. This cannot only be done for bearings. A similar method has been used to extract calculated load distribution data from a loaded tooth contact analysis and use it as boundary conditions for a high fidelity thermal elastohydrodynamic (TEHL) analysis of the tooth contact zone.

Scripts run from within the software can either be obtained from referenced source code libraries or from compiled dynamic link libraries dlls. Source code libraries have the advantage of being modifiable and easily extendable by any user. The advantage of distributing scripts via compiled libraries is that it protects the IP of the code written.

For easy distribution of scripting tools SMT have created an “SMT Store”. The store is accessible via the software. Scripts which have been distributed by SMT can be downloaded from the store. The store also opens up the opportunity for our users to submit and distribute scripts that they write to other users of the software.

Conclusion

There is a need for more automation of many tasks within transmission design and development processes using software. Software does not replace the expert engineer; it can however minimise the time spent by the engineer on manual tasks such as model building, running analyses and results presentation and extraction. This in turn maximises their time spent making important engineering design decisions.

Automation saves time, minimises errors and ultimately saves costs. Scripting and the MASTA API enable this.

Scripting further enables a company to continually improve its design and analysis processes by efficiently and tightly integrating their own technical advancements as they are made and without being required to share their own IP.

Romax eDRIVE: Delivering Propulsion Innovation *Right First Time*

A. Johnston, D. Hind, J. Washington, Romax Technology

What used to be based upon simple monolithic architectures, employing relatively simple mechanical and elementary electronic systems, are quickly evolving into 'Systems-of-Systems', with increasing autonomy, embedded software and complex electronics. To manage this complexity, a systems-approach is required, shortening development lifecycles and better exploiting technology.

Systems Engineering is open, lean, scalable, flexible and agile, furthermore it helps foster improved understanding and ideas to successfully deliver innovative design solutions. A systems-approach aids the delivery of a tightly coupled, highly integrated and optimised product solution. Moreover, Model-Based Systems Engineering (MBSE) techniques are applied to the whole system, including the power electronics, instrumentation and control.

At Romax Technology, MBSE is embedded into our new product introduction process, which is underpinned by established class-leading methods of lifecycle development, emphasised by INCOSE, and fundamentally in accordance with standards including ISO/IEC15288, and Enterprise Architecture frameworks. Our system development lifecycle process is lean through investment in mapping the value streams of various processes, standards and industry good practice: it embodies a requirements-led process inclusive of functional safety and cyber security attributes from the outset.

At Romax, we understand the importance and benefits of Systems Engineering being applied holistically to ensure the right balance of design attributes and decisions are made to meet a given application's unique challenges and requirements. Our design process is data-driven from the outset, bolstered by the heuristic human-touch where necessary, typically, when there are more subjective attributes to manage such as is found with non-functional requirements, although to reduce subjectivity an architectural approach with a predefined set of evaluation metrics is employed to consistently review alternative concepts against one another.

The beauty in embedding the Systems Engineering methodology within our lifecycle is to manage the inherent complexity and natural concurrency in electrification development projects: a staged approach is used overall, inclusive of agile feedback loops to validate requirements and verify the proposed solution.

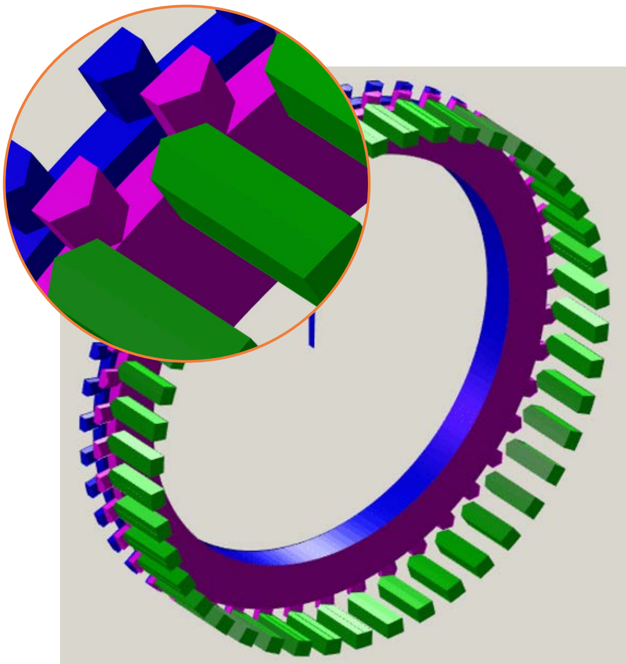
Governing these changes and interfaces enables concurrent engineering to take place with inherently understood levels of risk, while managing quality assurance throughout. To meet extant industry expectations, we have also embedded the traditional AIAG PPAP and APQP methods and outputs within our processes. The end result is an optimised, highly integrated and high-performance solution that exceeds customer expectations. Additionally, the Romax eDRIVE approach may be applied to any aspect of design: whole-system, transmission, electrical machine, instrumentation and control, software, hardware and modelling.

The Essence of Systems Architecting

The initial tasks that propel our design process are requirements elicitation and developing concepts to meet these customer requirements. A fundamental part of our concept development approach is benchmarking, closely followed by architecture definition.

Romax has a suite of inhouse tools to analyse critical attributes and cardinal requirements to rapidly develop physical architecture concepts which align to customer expectations, aiding prompt design down-selection. In addition to this, the electronics aspect of the architecture is also developed, initially based on validating key logical and physical interfaces, while considering associated safety hazards and cyber security threats.

Firstly, a logical architecture is defined, this predominantly states the functions which express the transformations of inputs and outputs as required and generally maps the flow of both information and energy within the system. The functional model is hierarchical, the lower levels



Images from Romax's synchroniser time-stepping simulation used to evaluate the dynamics of electro-mechanical actuation in multi-ratio EV drive units. Copyright: Romax 2019

of which are synthesised with the physical architecture when down-selected. A behavioural model is then developed: a dynamic model of the system behaviour is mapped against its requirements, this is again hierarchical and assembles the functions and subfunctions including their interfaces and transfer functions. In simple terms, this becomes a closed-loop feedback control model. The logical architecture serves to help validate requirements in addition to supporting the functional safety and security lifecycle, as at this stage system hazards are considered and mitigated by design from the outset. The logical architecture serves as an important step to permit ideas without any preconceptions or solutions being immediately put in place.

Physical product development is based on the predefined logical architecture. This includes requirements and functional decomposition, and the allocation of subsystems to physical arrangements which become products: this key architectural design step is determined around key principles such as cohesion and technology choice. The physical architecture, which is again hierarchical, helps control and manage the complexity of the system which may be composed of many hundreds of parts, or more. Evaluation of physical architecture concepts is also data-driven, using key architectural evaluation metrics to ensure a standardised and consistent approach is applied, supported by Romax Nexus, FEA, CFD and more traditional CAD tools.

This is an important step to ensure the system meets important targets: this is achieved through dynamic vehicle modelling including drive cycle analysis, market studies, system topology analysis and trade studies with respect to key attributes (e.g. size, mass, speed, cost, efficiency etc.). The Romax inhouse toolchain, supported by the Nexus ecosystem, enables a rapid down-selection of various electrical machine and transmission/gear topologies, typically, several thousands of possible combinations rapidly evaluated resulting in a single recommended output that best meets all of the target requirements. The definition of the electronics and software architecture will be discussed later.

Placing the Power in Propulsion

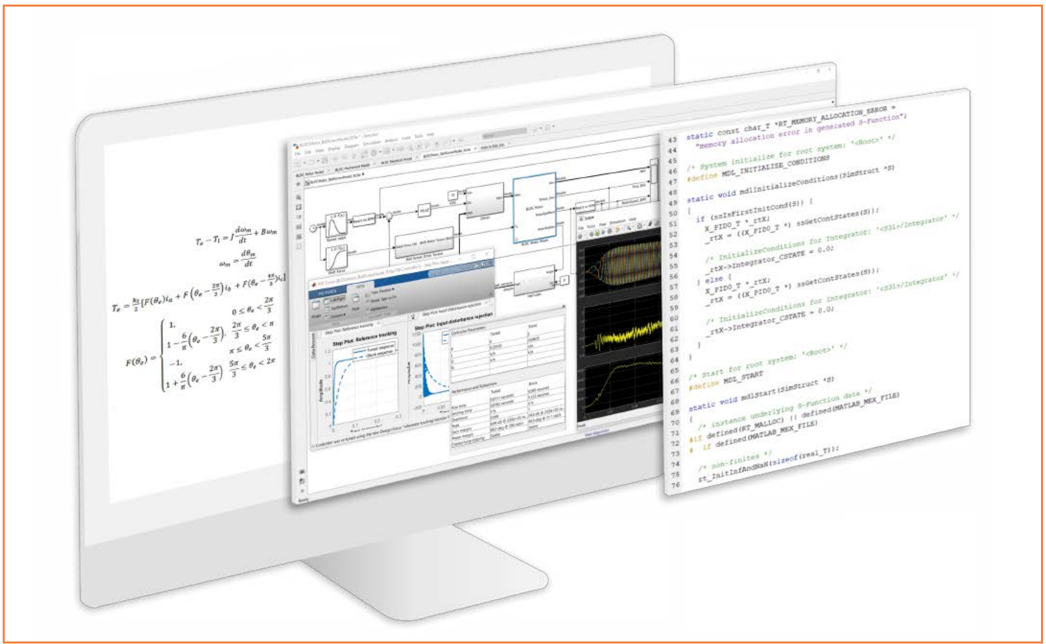
Power electronics is at the core of the Romax eDRIVE system. In simple terms, the power electronics performs the function of converting the supply voltage (e.g. DC voltage from a battery or fuel cell) into a variable voltage, variable frequency waveform to drive the electrical machine. The electrical machine is then responsible for converting this input into a mechanical output, generating torque to drive the vehicle. It is clearly evident that inadequate power electronics and electrical machine design will limit the performance and efficiency of the entire vehicle/platform. Key power electronics performance indicators include: operating efficiency, continuous and peak power capability and lifetime. Increasing the output power capability, while maintaining cooling performance and reducing the number, size, volume and mass of components are all vital factors in the pursuit of increasing the power density of the power electronics, and complete system.

Enabling semiconductor technologies such as Silicon Carbide (SiC) and Gallium Nitride (GaN) allow much higher switching frequencies to be achieved, owing to the reduced switching losses and the electric field strength of the materials. An increase in switching frequency allows the electrical machine to be designed for much higher fundamental frequencies which enables efficient, high speed, compact machine designs than has been previously possible with conventional technology. The devices themselves are also able to operate safely and effectively at higher temperatures, thus reducing the demand on the cooling system, thereby simplifying external system interfaces. With higher switching frequencies also come design challenges: parasitic impedances in the internal inverter circuitry begin to cause signal quality problems. To alleviate unwanted behaviour, careful printed circuit board routing and layout is undertaken coupled to high fidelity model-based simulation. The layout, routing and placement is critical to minimising electromagnetic interference issues.

The key to maximising power density is the integration of the power electronics hardware with other subsystems, predominantly the transmission and electrical machine. Romax have the capability and tools to work on solutions that offer high levels of integration to suit any customer demand, both mechanically and electrically. From an electrical perspective, component selection is also key to ensuring that optimum design solutions are achieved with minimal cost.

Electronics for Electrification

It is perhaps an obvious statement to make that electronics technology is what makes electrification possible. Historically, control systems tend to have been compartmentalised and separated from the system under control, however, as the control aspects of any system have many inherent interfaces to manage, through careful system architecting, design



Model based systems approach to design supports qualifiable embedded code generation Copyright: Romax 2019

solutions can be delivered which closely couple the controller to the systems under control i.e. the transmission, electrical machine and power inverter, whilst maintaining functional safety and cyber security requirements.

Developments in electronics technology is what has made electrification commercially possible in the first instance: high fidelity variable voltage and frequency electrical machine actuation and control was not possible before the development of integrated circuits, gate drives, and moreover, microprocessor control with software. It is through these technologies where the level of complexity increases to a level which calls for modern system design methods and tools.

At Romax we have an MBSE capability which facilitates the modelling of complex plant and controller behaviour, furthermore, we have an electronics hardware and an embedded code generation capability which meets industry regulatory standards such as ISO26262 and IEC61508.

A systems approach inherently helps optimise the control system design implementation, and is the only way to achieve a robust functional safety and security case in line with industry standards, ensuring that it manages and commands the behaviour of the system as expected. Much of what typically applies to control system design applies to the power electronics also, simplistically, the only real differentiation is that power electronics manages high voltages, and the control electronics manages low voltage interfaces.

Once the system boundary, safety and security hazards are understood, control system design can commence. This involves defining the electronics hardware architecture and the software topology, including consideration for several design parameters, such as measurement accuracy, time response and the responsibility of subsystem/function; i.e. the accuracy and reliability of the decisions the control system is expected to make to ensure the correct behaviour of the system. For multispeed transmission control, shift quality is another key design attribute which strongly influences the physical architecture selection, including the transmission gear-shift subsystem.

Romax has an in-depth knowledge of electronics technology, including microcontroller architectures, system-on-chip, FPGA, manufacturing techniques and materials to ensure our delivered product is reliable and predictable in its behaviour down to the deep-submicron transistor level. Furthermore, Romax has a robust model-based application software ('ASW') development lifecycle to reduce systematic design errors. This process is predicated upon the robust V-lifecycle process, including model-in-loop verification, software-in-loop verification, hardware/processor-in-loop verification, and finally hardware/powertrain-in-loop verification and vehicle level validation testing.

These steps are predominantly focussed on ensuring the proposed solution meets its functional and performance requirements, but also serves as an opportunity to refine the control algorithms to meet cardinal requirements such as transmission shift quality targets. In addition, AUTOSAR compatible application software can be developed.

As well as offering integrated design solutions which are compliant to industry standard functional safety expectations, Romax is also able to offer services to both lead and support others in their endeavours to design systems which are safe and secure.

Right First Time Delivery

The Romax product development lifecycle integrates MBSE which is utilised to support the validation of requirements, help inform the customer and other pertinent stakeholders regarding design and development maturity, as well as defining the detailed design solution itself which de-risks the production phase. This MBSE environment is also used to support the preparation of supplier selection (and development if required), including part production. In support of this, at Romax we have a global network of key partners and precision suppliers to support niche/bespoke production requirements, rapid prototyping, and small to medium scale total-quality production.

Our testing lifecycle capitalises on the traditional yet robust V-lifecycle model, exploiting model-based design and analysis to de-risk the design, and conducting hardware tests to verify the product is fit for purpose and correlates to the modelling. Hardware tests include component level open-loop tests, through to integrated subsystem and system open and closed-loop tests, including vehicle level integration testing.

One of Romax's key capabilities in electric propulsion is the ability to manage complex system integration; including both test-rig and vehicle/end-application management. In support of testing, we have developed collaborative relationships with established industry leaders within this sector, enabling the ability to undertake functional, calibration, performance, durability, and environmental withstand testing to meet a vast array of performance requirements.

None of this would be possible without incorporating modern programme management and governance principles to deliver eDRIVE programmes, embodying the flexibility of agile methods when and where appropriate, coupled to the management methodology, engineering approach and culture, at Romax we can deliver total quality *Right First Time.*

More information
https://romaxtech.com/romax-edrive

Impressions from the 8th CTI SYMPOSIUM CHINA 'Automotive Drivetrains, Intelligent and Electrified', 23 – 25 September 2019 – Shanghai, China

"There's no Either-Or"

Things are getting harder in China for electric car manufacturers: lower state subsidies mean more competition in the market. As this year's CTI SYMPOSIUM Shanghai reflected, Chinese OEMs were backing diversity in drivetrain solutions much as Europeans do.

In his introductory speech at the 8th CTI SYMPOSIUM Shanghai, Chairman Prof. Dr Ferit Küçükay said 2018 was a record year for global sales of electric cars. 1.35 million new EVs were registered, of which over 60 percent were 'Made in China'. But now the game was changing for three reasons:

Firstly, OEMs in China must achieve an energy score of 12 (up from ten) starting next year, which requires more electrification. As readers will know, score points are available for PHEVs as well as for BEVs and FCEVs, with extra points for longer range.

Secondly, China was cutting subsidies for EVs. Some had been discontinued by regional governments, and the central government had halved its grants. Only cars with a range of more than 250 km would still be subsidized. According to German newspaper *Handelsblatt*, ranges beyond 400 km will get nothing at all.

Thirdly, internal combustion engines faced an uphill battle. The emissions standard China 6a takes effect in 2020, followed by China 6b in 2021. With 40 percent less NO_X, 40 percent less HC and 35 percent less PM, China 6b will be stricter than Euro 6.

In one sense, customers in China are no different from anywhere else: the bottom line decides what they buy, and subsidies being dropped may change their decisions. Prof. Dr Kücükay said China currently had 460 EV manufacturers. Not all would survive in the new environment, a fact the central government seemed to be well aware of.

Trend towards Layshaft DHTs

The new game rules may be shifting the focus of product development. As plenary speaker Shemin Zhang, Dongfeng, remarked, "Don't let the media mislead you by what some media say." Zhang said internal combustion engines would still be around, mainly as part of a hybrid drive because obviously, ICEs could not meet Chinese fleet requirements by themselves. Dongfeng pursues state-of-the-art ICEs as well as all kinds of electrification.

What are differences between China and Europe or US? The traditional panel discussion on Day One yielded an interesting insight. China's own view is that it already leads for components like electric motors and batteries but has not quite caught up with Europe on ICEs. Even more, Dongfeng is highly active in new ICE concepts that meet both conventional use and hybrid drive requirements. Astonishingly, Zhang predicted that ICE efficiency could be increased to 45 – 50 % by 2030.

As for hybrid architectures, China too is experiencing competition between various concepts such as P2 to P3, power split, and multimode transmissions. Hongzhong Qi, Guangzhou Automobile Group (GAC), described his company's in-house DHT 'G-MC' development, whose concept outperformed parallel and power-split concepts in benchmarking tests. The 1st-generation DHT has three modes: serial, purely electric and parallel, but with just one speed for EM and ICE. The second generation, due in 2021, will use the same basic concept, but with two speeds for the ICE.

Qiushan Wang, AVL, predicted two development strands for hybrid powertrains in China. He foresaw DHTs, which can powersplit with the help of planetary gear sets, but also – like GAC – a trend towards 'Layshaft DHTs' with multiple gears that were more cost-effective than planetary gearsets. In general, 'Multi-speed Layshaft DHTs' combining DHT efficiency with gearset simplicity could be a trend well worth watching.

A Quarter will do

Not that pure EVs were suddenly off the agenda in Shanghai. Ping Yu, founder of Jin-Jin Electric (JJE), presented his company's electric drive portfolio, which covers practically everything from private cars to heavy-duty trucks. He also offered a JJE rule of thumb for the long-standing issue of how many gears EVs really need. Ping Yu said they need one-quarter as many speeds as a run-of-the-mill ICE. Hence, a small EV needs just one speed, high-performance cars or SUVs might need two, and heavy trucks three or four speeds. That compares with four to 16 speeds for an ICE drive.

The Audi e-tron presented in detail by Michael Schöffmann, Audi, needs just one speed, but uses electric motors with different power ratings on the front and rear axles. Interestingly, Audi opted for asynchronous

machines on both axles, as Tesla originally did. Schöffmann said ASMs were affordable, robust, and brought no drag torque into the system. In the follow-up discussion, Zhang, Dongfeng, expressed his view that PSMs would dominate in future, adding that there was still much work be done. Issues included reducing magnet costs, shrinking the motors further, and reducing current flows to reduce demagnetization. Here too, it may be no 'either-or' but a coexistence of solutions according to specific requirements.

No Scale, no Future?

The audience survey in the panel discussion also revealed that most listeners still give ICEs at least another 30 years. And what about fuel cell? Weiyu Shi, SHPT (Shanghai Hydrogen Propulsion Technology), dedicated a whole lecture to this question, saying SHPT had built several vehicles but FCEVs hardly played a role in China. He noted that China currently had just ten commercial hydrogen filling stations, in Shanghai, Beijing and Guangzhou.

For Weiyu Shi, the road to success for fuel cell involves buses, which enjoy public subsidies in China, and heavy-duty trucks. That was because like hydrocarbons, the gravimetric energy density was much better than with payload-devouring batteries. So long term, the total cost of ownership could favour FCEVs. Shi said the biggest cost driver was the stack. SHPT's latest fuel cell, the Prone 390, produced 91.5 kW, was 60 % efficient and cost about € 125 per kWh. To put that in context, that adds up to approx. € 12,000 for the entire fuel cell. Shi said more advances in power density were required, plus economies of scale via higher volumes. As with any technology, the same would apply here: "No scale, no future."

ICEs aren't going away

One lasting impression from this year's CTI SYMPOSIUM Shanghai was that despite media occasional reports to the contrary, China's OEMs are backing a range of possible solutions, as Europeans do. However, the panel discussion made one small difference clear. When Prof. Kücükay asked about the chances in China for 48V, support was more muted than in Europe. Shemin Zhang said 48V had been a hot topic in the past, but the cost-benefit ratio was too unfavourable for this price-sensitive market, so companies might invest in better ICEs instead. But that could change if hybridization was added further downstream, i.e., in P2, P3 or P4 architectures rather than P0. Then 48V could enable savings up to 15 percent.

The audience response to the question: "Which kind of drivetrain will be in your next private car?" captured this year's mood nicely. Over 80 percent voted for a drive that still had an ICE, either alone or as part of an HEV. Almost 20 percent said they were considering a PHEV, just over ten percent an EV and only a few an FCEV. Prof. Tong Zhang, Tongji University, looked ten to fifteen years further down the road: "In the short term, my next car would be an HEV or PHEV. But the one after that could already be an FCEV."

Gernot Goppelt

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