There are success stories that inspire people worldwide. For example, the dual clutch transmission technology from GETRAG. The interest in combining “more comfort – more efficiency – more driving pleasure” is literally boundless. Renowned automobile manufacturers from around the world already rely on GETRAG’s leading drivetrain solutions, which are suitable for all types of cars. You too can gain inspiration from the innovative spirit and global power of the worldwide system supplier for transmissions: www.getrag.com
6   A Modular Hybrid Concept for Global Applications
    Getrag

8   High Voltage Power Connector for Automotive Hybrid
    and Electric Drive Components
    ZF Friedrichshafen

10  Affordable Hybrid Drive for Delivery Truck and City Bus
    Vicura

14  Efficiency Optimized Shift Strategy for Commercial Vehicles
    TU Braunschweig, Institute of Automotive Engineering (IAE)

17  Can a ‘One-Size-Fits-All’ Strategy Work, in the Global Transmission Market?
    IHS Automotive

22  VICTREX® PEEK Polymers: Performing Beyond the Limits of Metal
    Victrex

26  PPS – Powertrain Production Systems: Innovative Solutions
    M&R Automation

30  A North American First
    Feintool System Parts

32  Hardware-in-the-loop Test Environment for 2-step Continuously Variable Transmission Control Unit
    HYUNDAI AUTRON

36  Modern Transmission Control Software
    FEV

39  Rome Wasn’t Built in a Day
    Car Training Institute (CTI)
Dear readers,

We were pleased by the readers’ positive reactions to the content and the design of the first issue of the CTI MAG. This second issue is following the same road of covering a wide range of topics about automotive drives and transmissions in an interesting way. The content is intended for the global drive community of the automotive sector.

The ongoing interest of many authors in this publication platform confirms the viability of the strategy to publish the CTI MAG twice a year in print and online. The third issue will be released in December 2014 at the same time as the CTI Symposium in Berlin/Germany is taking place (8th to 11th December).

We welcome your article submissions as well as suggestions on the CTI MAG to michael.follmann@car-training-institute.com.

Thank you to all those who contributed to the current issue!

Best regards

Michael Follmann, Sales Director, CTI – Car Training Institute
Prof. Dr Ferit Küçükay, Managing Director of the Institute of Automotive Engineering, Technische Universität Braunschweig
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Regional requirements have a strong impact on the way an efficient hybrid drivetrain needs to be designed. In a globalized market, car makers rely on scalable hybrid concepts that can be localized with minimum effort.

by Uli Christian Blessing, Senior Manager Programs and Business, Getrag Untergruppenbach, Germany

Engine developers are still successfully improving the efficiency of internal combustion engines. Nevertheless, many experts expect a rising demand for hybrid drives so as to comply with future CO2 legislation. But more than for conventional drivetrains, the specific local requirements in a globalized market are extremely diverse. Due to their global product strategies, leading OEMs may need hybrid concepts suited for many different application scenarios, while at the same time keeping the variant diversity as low as possible. Efficiency will not just be a matter of consumption or performance; it will be a matter of modular and flexible worldwide production as well.

Experience so far has shown that hardly any car buyer will pay an extra price for CO2 savings unless there is a personal benefit. The purchasing decision is basically affected by the product price, the cost of ownership and driving characteristics. Thus, a wide market penetration of hybrid drives requires fairly priced and efficient concepts with further benefits like improved comfort and dynamics.

When considering the CO2 regulations in North America, Europe or several regions in Asia, there seems to be a stronger need for hybrids in western regions. But it is not that simple. In North America, larger cars and trucks make higher demands on CO2 reduction, especially since there is no major market for diesel engines so far. On the other hand, there are very complex driving conditions, like continuous long distance driving as well as stop-and-go in major cities and a large variety of topographic conditions. In the US market, a mild hybrid can be an option as well as full and plug-in hybrids. In China for example, the requirements are even more demanding: On the one hand, there is a strong interest to avoid any emissions in mega-cities, possibly increasing the need for plug-in hybrids with a considerable pure electrical range. On the other hand, OEMs may be confronted with a weak infrastructure for high-voltage service for full and plug-in hybrid drives outside the cities.

Shaping a flexible Hybrid Drive
Given these countering requirements, a hybrid drive concept for global applications will have to be extremely flexible, while being affordable at the same time. Ideally, a mild hybrid with a 15 kW e-machine is feasible as well as a plug-in hybrid with 100 kW enabling electric driving in the cities and on highways. Despite this large variety, the drivetrain package needs to be basically unchanged. It should be possible to install it without having to modify the installation space and interfaces. The need for small size and low costs consequently requires very compact high-speed e-machines.

But which kind of hybrid drive can be scaled from a mild to plug-in hybrid and every shape in-between? Currently the market is clearly dominated by power-split hybrids. This proven technology, though highly efficient in certain dynamic conditions, is restricted to full and plug-in hybrid drives. A mild hybrid does not make sense, as the power-split principle requires an e-machine strong enough to partner the internal combustion engine (ICE). In this respect, parallel hybrids are much more flexible because either e-machine or ICE can be scaled to any need.

In today’s parallel hybrid drives, the e-machine is usually nested in-between ICE and gearbox. In this configuration, it runs with the same speed as the crank shaft consequently. Thus, efficient high-speed e-machines cannot be used, and the ability to scale their power is restricted. Alternatively, the motor can be connected via a belt solution, allowing for lower cost and a smaller housing. Belt-based hybrid drives are restricted to mild hybrids, though. The air-cooled e-machine can have a peak power of 12 to 14 kW, but the continuous power does not exceed around 2 to 3 kW. That having been said, in any parallel hybrid drive, the engine and motor must be operated at proportional speed. Thus, two aggregates with very different efficiency ranges are mated to neither advantage.
Torque-Split — the Key to Efficiency
The dual-clutch technology allows the combination of some of the advantages that power-split and parallel hybrids have, adding a high freedom of scaling of the e-machine. With its HybridDrive concept, Getrag focusses on a flexible and modular hybrid drive kit, extending the functionality of its dual-clutch transmissions at affordable expense. The “torque-split” hybrid drive features a compact high-speed e-machine, being integrated into the housing in axially-parallel arrangement to the gear shaft with the even gears. This arrangement allows the transfer of the input torque of the ICE and the e-machine via different paths, while using different gears. Other than in a pure parallel hybrid, ICE and e-machine can thus be operated in their best efficiency areas.

Typically, these areas will be very different, even when a high-speed e-machine is used. With the wide choice of available gears, any combination of ICE and e-machine is possible, while preserving most efficient operation in terms of consumption and usable torque. The torque-split option is exclusive to dual clutch transmissions. Whether CVT or planetary gear transmission, both technologies do not allow an independent distribution of two torque paths with variable speeds. Nor do they allow a variation of electrification to the amount the torque-split DCT does: Except voltage and battery, the torque-split hybrid can be scaled for mild, full or plug-in hybrids without affecting the package. The e-machine power output can be more than 100 kW without having to modify the transmission housing. Scaling the e-machine can be done “on-site” by modifying two parameters: the number of windings and the length of the assembly. The latter can be varied by changing the active length of the e-machine by reducing the number of stator and rotor steel plates.

The HybridDrive 7HDT300 Getrag showed at the Frankfurt Motor Show 2013 comes with a built-in high-speed e-machine running with up to 18,000/min. It is integrated into the oil flow that is supplying the clutch cooling as well. Even in a 48 V mild hybrid configuration, the oil cooling allows for a peak output of 16 kW and a constant output of 10 kW. The high continuous output, in combination with the torque-split operation described above, makes for a capable hybrid at rather low cost. Compared to a parallel belt solution with a fixed ratio, the torque-split mild hybrid consumes around 7 percent less fuel in the WLTP cycle (worldwide harmonized light duty test procedure).

The torque-split mild hybrid has a number of advantages: There is considerably more usable torque for boosting, due to the torque distribution and dedicated gears. Boosting as well as recuperation are working with minimal losses. The system provides an extended sailing function that mild hybrids usually cannot offer. It allows pure electric driving up to about 13 mph, battery capacity being the limitation. In short, the torque-split mild hybrid drive offers some full-system functions, while remaining a mild hybrid in terms of the 48 V electrical system. This allows for worldwide applications even in areas where garages and workshops cannot deal with usual higher voltages of full hybrids. At the same time, the mild torque-split hybrid is a responsive and efficient performer for cost-conscious drivers in NAFTA or Europe.

Summary and Outlook
Besides saving fuel, hybridization can improve responsiveness and comfort. But finding the right amount of hybridization is demanding within a globalized market. There might even be a need to readjust a hybrid drive layout within the lifecycle of a vehicle. As a consequence, OEMs need the utmost flexibility in scaling the hybrid drivetrain. Compared to parallel and power-split hybrid drives, the torque-split hybrid is the most flexible concept in this respect. Moreover, it enables an efficient drivetrain that offers more comfort and dynamics than a conventional powertrain. Its flexibility enables drivetrains that can be exactly designed for the specific needs of global markets.
A plug - yes, but not at any price

High Voltage Power Connector for Automotive Hybrid and Electric Drive Components

The currently available high-voltage plugs for cable cross-sections from 35–50 mm² require a lot of space, they consist of many components, and are expensive to manufacture. With the so-called screw and spring-tensed tie bar, ZF Friedrichshafen AG presents two alternative designs.

High durability and safety requirements
There are ambitious requirements for high-voltage power connectors for automotive hybrid and electric drive components. Especially in the vicinity of the electric motor, the environment is tough. There are vibrations from the road and the combustion engine, high temperature changes, humidity, and a corrosive environment. Over the service life of the vehicle, the high-voltage connection is repeatedly connected and disconnected. This happens, when it is mounted on the assembly line or outside in the field in order to perform maintenance or repair work. The connecting process should be fail-safe (poka-yoke) to avoid unfortunate errors. In many cases, the installation space in the area of the terminal box is strongly restricted. An oil-tight sealing is also required. Besides the technical requirements, manufacturing costs are an important issue as well. However, for this specific application it is difficult to find suitable high-power connectors which are available on the market, e.g. as a type of plug.

Screw or spring clamp
Two design concepts are shown that were developed especially for the electric motor of a hybrid bus transmission with limited installation space. The first concept is called “screw-tensed tie bar”. It is more or less a conventional cable shoe connection. However, the components subject to tensile stress are entirely made of steel and the components under pressure load are manufactured from electrically conductive copper. So to speak, the screw-tensed tie bar connects the cable shoe via a conductor sleeve with the conductor rail of the electric machine. The connector was designed in such a way that no torsional load acts on the conductor rail when tightening the screw. Thus, damage which cannot be immediately recognized inside the machine is avoided during assembly. In addition, this connector is completely sealed with radial O-rings against transmission oil (s. Fig. 1a). The second design concept is called “spring-tensed tie bar” (s. Fig. 1b). This is the result of a special safety requirement during assembly. In the first approach, an incorrect mounting was possible. For example, the screw is tightened with a wrong torque or an incorrect screw is used. This can be excluded with this concept. The cable shoe, conductor sleeve, and conductor rail are not clamped with a screw here, but with a spring. This spring is tensioned via an eccentrically mounted lever. It is evident that the preload during assembly is much lower in this case. However, the high clamping force of the first concept is only required in order to achieve the self-locking of the screw connection. It is not mandatory for obtaining the high-voltage power connection. The maximum clamping force of the spring is limited by the available installation space. In this case, a clamping force of about 300 N is reached. This force includes the safety against failure of the spring. If there is some more installation space available to increase the size of the spring, the clamping force can be enhanced significantly.

Installation example
Fig. 2 shows an installation example of a high-voltage power connector installed in a traction motor of an electric vehicle drive. In this case, it is the spring-clamped connection. The screw-clamped connection could be installed in a similar way. The conductor rail assembly and the cable shoes are the only components that have to be slightly changed. It goes without saying that the mounting with the screw is different. As it is shown in the exploded view, the conductor rail assembly with the three springs is mounted on the end face of the electric motor. Then, the terminal box is mounted from the top side together with the insulation bushing. The three connectors with the conductor sleeve and the latch lever are individually placed from above into the insulation bushing, pressed down, and rotated by 90 degrees so that the lever is aligned with the cable opening. This way, the tie rod and the spring are connected. In a further step, the cable assembly is screwed on the terminal box via the cable feed-through and the three levers of the power connection can be flapped down. As a result, the spring is tensioned and the electrical conductors are pressed together with the required force. In a final step, the terminal box cover is mounted. It additionally prevents the opening of
the lever. Furthermore, the wire harness is fixed to the housing and the cable feed-through is protected from damage.

**Vibration test according ISO16750-3 Test VI**

Fig. 3 shows the experimental setup for the vibration test. Six terminal boxes are mounted on the test cells which represent the section of the hybrid bus transmission with regard to the installation position within the bus. The three terminal boxes on the right side are equipped with the spring-tensed tie bar and the terminal boxes on the left side feature the screw-tensed tie bar connector. The vibration test was carried out in all three axes in accordance with ISO16750-3 Test VI – Commercial vehicles, engine, transmission, sinus via broadband noise $\text{a}_{\text{eff}} = 177 \text{ m/s}^2$, 94 h per axis with temperature changes between $-40$ to $+120 ^\circ \text{C}$. This type of test is challenging and mostly the actual load in the vehicle is exceeded. Therefore, the weaknesses of the design can be detected and optimized. In the light of this highly mechanical and thermal load, both power connector variants have mainly passed this test. They present a good alternative to a plug especially in restricted spaces and when costs are an important issue.
Extended range transmission at low cost and with short time to market

Affordable Hybrid Drive for Delivery Truck and City Bus

Introduction of a passenger car hybrid concept and it’s applicability into delivery trucks and city buses with special focus on feasibility and affordability.

by M.Sc.E.E. Pär Freudenthaler and M.Sc.M.E. Mikael Mohlin, Senior technical specialists, Vicura AB, Trollhättan, Sweden

Extending the extended range transmission

Vicura is developing and designing driveline components covering a vast variety of torque transfer concepts. And therefore initiated the design of an extended range electric vehicle (EREV) powertrain, where low add-on cost (compared to a conventional vehicle) and emission level below 50g CO2/km have been considered two of the most important design criteria. As Vicura has interest in applications ranging from passenger cars to commercial vehicles also buses, delivery trucks and other applications has been considered and included. This article is focusing on presenting rationale, layout, functionality and performance for an extended range gearbox installed in a delivery truck. With prerequisites as comparable performance, increased efficiency and low add-on cost the system principals are retrieved from the Vicura passenger car project where rationale, gearbox setup and functional principle have been revised.

Extended range transmission in passenger car

The main goal with the passenger car EREV solution was to design a cost effective driveline to meet emission level legislations and decrease fuel consumption. The starting point of such a setup was a passenger car with an already low certified emission level, hence a fuel efficient engine setup to base the design on. By doing so, the vehicle design and manufacturing may inherit components and processes. Together with a standard electric motor and a straightforward gearbox design there was a strategy to have low add-on costs.

For the EREV vehicle, electric machine, power electronics, shift/clutch actuation system and energy storage will have to be added to the total car cost. The original gearbox is excluded and replaced by the EREV gearbox. The gearbox cost will be reduced compared to the baseline vehicle with a simplified design and fewer gears. Between a large and a small car, the cost is not that different for the electric machine and power electronics. The component that has a clear dependency to cost is the size of energy storage. Performance target was to provide a similar vehicle performance but with significantly improved fuel consumption. The performance of the electric motor should be enough to fulfill the original performance without requiring a shifting gearbox in the speed range 0 - 130kph. If the vehicle speed exceeds 130kph, the vehicle had to be driven by the combustion engine which is acceptable since this means that all fuel consumption cycles can be fulfilled fully electric. It also means that the vast majority of real life drive cases also were covered.

How to apply to commercial vehicle

Also for the commercial vehicle it is important that the EREV version is based on an existing baseline vehicle to maximize inheritance on carry-over components. The practical driving cycle for a city delivery truck with short distances and many start and stops motivates the extended range concept to work in hybrid mode compared to the passenger car setup. Instead of waiting for low state of charge of the energy storage...
the vehicle would be setup to combine electric drive with combustion drive at already low vehicle speeds. The major differences between the passenger car setup and the delivery truck drivetrain will therefore be, to configure the truck drivetrain towards hybrid mode and downsizing the energy storage.

**Transmission and drivetrain layout**
The most pronounced design features are the electric driven one forward gear, electric driven reverse gear and four forward combustion driven gears. In addition, the shifting is performed automatically by the shift/clutch actuation system. The electric motor would perform torque fill during combustion drive shifts. This further simplifies the mechanical gearbox without decreasing shifting performance. The gearbox has two input shafts where one is dedicated to the electric motor and the other to the combustion engine. The electrical motor drives the output shafts via one ratio step as a forward gear or reverse gear, and through final drive. The combustion engine drives the output shafts via a four ratio step transmission, and through final drive. The engine torque path is decoupled by a dry clutch system on the input shaft and dog clutches as gear couplers. The electrical torque path is decoupled by a dog clutch. See figure 1. The available torque paths are therefore:

- Electrical motor driving output shafts.
- Combustion engine driving output shafts.
- Electrical motor driving combustion engine.
- Combustion engine driving electrical motor.
- Electrical motor and combustion engine driving output shafts.

The EREV equipped delivery truck driveline uses the existing inline four cylinder diesel engine and the original gearbox is replaced with the EREV gearbox and components. To get same tractive force and performance in the delivery truck the electric motor has comparable power to the diesel engine. The ratios are chosen as the electric one step ratio is matching the original first gear ratio. The combustion four gear torque path is matched to the original second to fifth gear ratios. This setup is therefore acting in hybrid mode as a combined five speed gearbox with a mix of electric and combustion drive. See figure 2. As the delivery truck is setup for hybrid mode with stop/start, the energy storage is downsized compared to an extended range passenger car. Where extended range vehicles has more than 10kWh and electric vehicles even more, this concept is sufficient with 2-3kWh. At these combinations of power levels, super capacitors should be considered. The downsized energy storage will save money, space and weight compared to the passenger car setup.

**Electric drive**
All low speed driving within first gear range is performed fully electrical without assistance of the internal combustion engine. In electric mode the regeneration is possible during coast and braking. The braking system could enable active blending between the electric motor (as generator) and the conventional brakes. The gear ratio for electrical first gear should provide the best possible combination of tractive force at standstill and a suitable top speed. This enables a compromise between the electrical top speed and use of combustion engine drive. The electric motor would be declutched from the driveline to enable vehicle speeds over the electrical drive top speed. The gearbox is providing the opportunity for the electric motor to be driven by the combustion engine without moving the vehicle to ensure that the battery can be charged at all times. The delivery truck setup will use the electric drive as emulating the first gear of a conventional drivetrain, with automated shifting.

**Hybrid mode**
The state of charge condition on the energy storage is normally used for decide on entering or leaving hybrid mode. However, for the delivery truck the gearbox will be setup and emulate a combined five speed transmission with automated shifting configured for low fuel consumption. The state of charge is still an important parameter to monitor and act on. Speed matching during shifting is performed by the combustion engine and electric motor. During shifting the electric motor is
providing torque fill to ensure continuous tractive force. Shifting is fully automatic with possibility for tap shift. The combustion engine is preferable declutched and turned off during driving at the electric gear, and coasting or braking at any gear. When reinitiating acceleration the vehicle is initially being driven electrically and the combustion engine is push started through the gearbox via the dry clutch. Regenerative braking is available in all gears.

**Performance and fuel efficiency**

The performance and fuel efficiency figures have been simulated with Vicura proven models. The delivery truck diesel engine is originating from the reference commercial vehicle and is an inline four cylinder at 120 kW. The electrical motor is suggested to be at 120 kW to get comparable performance to the reference vehicle. Ratios are selected according to the reference truck gearbox system but could be altered to better fit alternative vehicle weights and performance needs. With above drivetrain setup comparable tractive forces and performance are achieved. Fuel consumption improvements are significant. A large step is achieved directly with electrical first gear, enabling start/stop and automated shifting. Further improvements are available if gear selection is state of charge dependent. The reference delivery truck has certified fuel consumption according to New European Driving Cycle, NEDC, of 7.33/100 km. See figure 3. If the extended range concept is applied to the reference vehicle with an electrical first gear to 11kph, rolling start/stop of the combustion engine and optimized automatic shifting, the fuel consumption will be 5.1l/100 km. The shifting from electrical first gear to next gear may be rather freely chosen because of the powershift capability and the matched torque sources. If the upshift speed is increased to 15kph the fuel consumption will be 5.0l/100 km, and with 20kph that will be 4.7l/100 km. See figure 4. The moving of upshift speeds could be controlled by the state of charge of the energy storage. If the vehicle is equipped with similar braking system as may be found in electrical vehicles, with a dead-band in the brake pedal travel, which is dedicated to regenerative braking, further improvements will be made. It is possible to manage the complete NEDC cycle with regenerative braking. A benefit with the integrated extended range concept is that the motor is acting on the front axle of the vehicle, which is a prerequisite to enable full regenerative power and not compromise vehicle stability.

**Conclusions**

The transfer of a passenger car extended range concept to a delivery truck has been successful. The vehicle equipped with the extended range concept has comparable performance to the reference vehicle and significant fuel savings. The design uniqueness with electrical first gear and rolling start/stop provides most of the fuel efficiency increase. State of charge dependent shift speeds and regeneration is further adding to the fuel savings. Integrating the concept in a vehicle platform with an already efficient combustion engine by adding an off-the-shelf motor, the straightforward low cost powershift extended range transmission and reasonably sized energy storage ensures a realisable and affordable drivetrain solution with short development time and short time to market.
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Fuel consumption reduction by optimizing the system efficiency

Efficiency Optimized Shift Strategy for Commercial Vehicles

Optimizing the efficiency of individual transmission components will reach its limits by technology or costs. System optimization, i.e. the interaction between transmission and drivetrain efficiency, therefore becomes more important. An optimal adjustment of the drivetrain to the typical customer-related behaviour is the solution. This will be explained in the following article using the optimization of the shift strategy.

Today’s commercial vehicles usually have automated transmissions with 12 or more gears. Depending on the situation (road gradient, vehicle mass etc.), a starting gear and a shift strategy are selected. The shift strategy depends on driven vehicle, driving environs and driver and affects the shift sequence and the shifting speed. As opposed to most passenger-car transmissions, acceleration does not result in sequential shifting. For the application in commercial vehicles, this means that one more degree of freedom – and therefore additional effort – is required for the adjustment of the shift strategy. With regard to CO₂ emission and fuel consumption restrictions, individual shift strategies will become more important for commercial vehicles. The 3D method, which considers the influence of driver, driven vehicle and driving environs in an orthogonal system, can be used to evaluate them in customer use.

3D parameter space for commercial vehicles

The 3D parameter space is a three-dimensional, orthogonal space in which the major influences on the vehicle are specified independently. The axes of the 3D parameter space represent Driver, Driven vehicle and Driving environs. In terms of drivetrain and load on the chassis of commercial vehicles, the method differentiates between economical and dynamic driving styles for ‘driver’. ‘Driven vehicle’ comprises light, average and heavy (load of the vehicle), while ‘driving environs’ refers to the use of the vehicle: distribution, short-distance transport, long-distance transport and offroad use.

Figure 1: 3D parameter space with 24 customer types commercial vehicles
Test setup

In order to optimize the shift strategy, the vehicle characteristics such as fuel consumption and acceleration behaviour have to be known. The parameters required for the optimization – e.g. fuel consumption depending on gear and transmission input speed before shifting, accelerating capability/acceleration time for each gear and distance covered during acceleration – were measured on a chassis dynamometer. The used dynamometer has a power of 560 kW and a maximum force of 50 kN at the tyre contact centre for the target vehicle. Relevant parameters for the adjustment of the driving resistance (control computer of the chassis dynamometer) were determined based on coast down curves of the target vehicle. The target vehicle is a standard tractor unit, 330 kW and a gross weight rating of 40 t (incl. semi-trailer). The optimization was done with a vehicle mass of 15 t, which complies with “light” for driven vehicle in the 3D parameter space.

An external measurement system by AVL (AVL Excite), which was connected to the test rig computer via an interface, was used to determine the instantaneous fuel consumption. The test rig computer records the measured data and controls the automatic test rig operation. For this purpose, a module was added to the test rig computer which controls an electronic unit via an independent CAN bus. The electronic unit with LIN bus, relay control, pulse width modulated signals etc. can be used to specify reproducible shifting strategies, accelerator positions, retarder positions etc. The interface was developed at the Institute of Automotive Engineering for Mercedes, Volvo and MAN commercial vehicles. Fig. 2 illustrates the systematic structure of the signal flow during automatic operation. After validating the automation on the chassis dynamometer and verifying the reproducibility, an automatic process was programmed to run a time optimized experimental plan.

In this way, the relevant objective parameters (consumption, time and covered distance) for the optimization of the shift strategy were determined. The test results included acceleration times depending on gear and accelerator position, distance covered and instantaneous fuel consumption. The results (time, distance, fuel consumption) were evaluated for each gear and were determined depending on transmission input speed after shifting (resolute by the speed before shifting of the previous gear) and transmission input speed before shifting, i.e. there is one result depending on speed after shifting and speed before shifting for each parameter and gear (cf. figure 3). The speed before shifting is the engine speed at which the gear change was initiated. The speed after shifting results from the speed before shifting of the previous gear and the gear step. It is therefore the speed that would result from a gear change without delay and vehicle speed reduction. The shift duration and shift energies are also taken into account into the next gear in this definition. A further evaluation of the shift duration and shift energies revealed a significant dependence of gear change on vehicle speed. Since the information is already included in the objective parameters of each gear, they do not have to be taken into account.
Optimization of the shift strategy

Statistics derived from several measurements give information about the frequency of acceleration (initial and final vehicle speed, accelerator position) in 3D customer use. They were evaluated based on an orientation vehicle speed profile (OSP). The OSP specifies the vehicle speed using a rectangular speed profile which adjusts the speed level to the target speed according to the driver intentions. Based on the measured and evaluated objective vehicle parameters and a selected shift strategy, the fuel consumption \( V \), the acceleration time \( t \) and the distance covered \( d \) can be determined for each acceleration manoeuvre in customer use (cf. fig. 3). This can be expressed by the following equation, using a specified acceleration manoeuvre with a shift sequence of 5-8-10 as an example.

\[
V_{\text{start speed; target speed}} = V_5 + V_8 + V_{10} \\
d_{\text{start speed; target speed}} = d_5 + d_8 + d_{10} \\
t_{\text{start speed; target speed}} = t_5 + t_8 + t_{10}
\]

Based on the information from the customer’s use of the acceleration frequencies and the shares of the distance covered at different constant vehicle speeds, the overall customer’s fuel consumption and required driving time (vehicle dynamics) can be determined for a specified shift strategy. It is therefore possible to determine a shift strategy with optimum fuel efficiency by using optimizers. For this task, an optimizer with genetic algorithm was used. The optimizer uses the shift sequence and transmission input speeds before shifting as optimization parameters. Since the fuel consumption conflicts with vehicle dynamics and therefore with driving time, a Pareto front showing this behaviour was analyzed. Pareto fronts are used if several optimization goals (here: driving time and fuel consumption) conflict with each other and a goal cannot be improved without having the opposite effect on the other. Fig. 4 (for dynamic urban driver with light loaded vehicle) shows the Pareto front and different weighting combinations of both target parameters (time and fuel consumption). The behaviour of optimisation target is unstable by changing the shift sequence so the connection between the points does not result in a smooth Pareto front.

This example of a Pareto front shows that the fuel consumption increases significantly with increasing vehicle dynamics (shorter driving time). In order to identify the optimization potential, a comparison to the shift strategy of series-production status is necessary. Fig. 4 shows the series-production status, which has potential in the direction of dynamics and fuel consumption. For the considered urban driver, the fuel consumption could be optimized by up to 2.3 % for an unloaded vehicle without compromising vehicle dynamics. The resulting was validated by further rig tests. The shift strategy in this paper is optimized for the vehicle dynamics, but does not take further parameters such as driving comfort and emission performance into account.

Fig. 3: Determination of objective parameters (e.g. fuel consumption, time and distance) using a selected acceleration manoeuvre with a shift sequence of 5-8-10 and the related transmission input speeds before shifting for each gear as an example.

Fig. 4: Pareto front of the conflicting goals fuel consumption and vehicle dynamics using a dynamic urban driver, light loaded; the standardization of driving dynamics is related to the time required to cover the distance with OSP and the standardized fuel consumption to the OSP without taking the acceleration energy into account.
Can a ‘One-Size-Fits-All’ Strategy Work, in the Global Transmission Market?

Many OEMs have chased the ‘holy grail’ of a global powertrain line-up, which meets the requirements of their customers, in all regions of the world. But can this be achieved?

IHS Automotive

Introduction

OEMs frequently strive to increase their production volumes, by selling their vehicles in new markets or regions. Beyond the modifications which are required to meet local legislation/regulations, the next question is, ‘should we invest in tailoring our products, or can we simply sell them as they are?’ And as part of that process, the OEM needs to decide what transmissions to offer its potential new customers. After all, the regions are all very different, as is clear from Fig. 1. So, what can history tell us about the kinds of decisions which OEMs have, and will continue to face, in a global market place?

Manual Transmissions

Manual transmissions (MTs) are produced in every region of the world, and were used in about half of all light vehicles produced in 2013. This is due to the unique consumer preferences in Europe, where a large proportion of MTs are manufactured, combined with the low-cost requirements from the BRIC countries, plus a small share for enthusiast drivers, who relish the interaction with their vehicle. Although Europe has long been dominated by the Manual transmission, its market share is falling. The improvements in areas such as shift-quality and shift-speed, in both Automatics (ATs) and Dual Clutch Transmissions (DCTs) have seen the MT penetration decline steadily. Year-on-year, the Manual penetration has fallen by 3-4%, since 2010. But how have transmission suppliers/OEMs ensured that their products are successful globally? Despite the slow shift in consumer preference, the Volkswagen Group has managed well in the MT market. The MQ transmission platform is manufactured at 7 plants, in 6 countries. Over 50% of the MQ platform is still produced in Europe, while the remaining is evenly split between South America and Greater China. This places Volkswagen in a strong strategic position.

Fiat has also strategically positioned its MT plants in key regions. The C5 and C6 platforms are manufactured in 7 plants, in 5 countries. Fiat has targeted the same regions as Volkswagen, but has additional production capabilities in India. The Indian production could be a profound asset in the coming years, due to the likely boom of Automated Manual Transmissions (AMTs). More on this later.

Automatic Transmissions (AT)

Planetary Automatics made up 35% of the global light vehicle market in 2013. North America consumed over 40% of these, double that of the 2nd largest consumer, Greater China. Japan/Korea and Europe follow behind respectively. The fundamental AT design has been around for over 70 years now. The driving sensation it delivers is ingrained in consumers, often from a young age, and the torque multiplication factor has become a deeply rooted expectation. Combining that customer expectation, with the significant number of improvements and refinements made recently, results in a technology which some believe is close to perfect, for a global market.

General Motors has focused its energy on two families of ATs, both of which are 6-speed, with the 6T/GF6 platform for transverse applications, and the 6L platform for longitudinal layouts. In regards to technological development, these families are probably not considered ‘market leaders’, but are certainly good enough to appeal to the average consumer. This has resulted in an excellent presence in North America and Greater China, but little use in Japan/Korea and Europe, although this is changing.

Another big player in the MT market is Ford, or rather Getrag-Ford. Part of its success has come from the 5-speed IB5, and its variants, which are also manufactured in numerous plants, in strategic locations. Within the next 6 years we expect to see the gradual replacement of the IB5, as Getrag-Ford introduces more programs (e.g. MX65) to its new Modular MTT platform.
edge technologies available at the other end of the spectrum (e.g. ZF 8HP or Daimler NAG3). Although GM may be a step or two behind technological leaders such as these, it does not compromise in keeping pace, albeit a few years later. With the launch last year of the transverse ZF 9HP, GM and Ford are now jointly working on a similar product, to be launched in a few years’ time.

A similar story is true for Ford (USA), which has very high AT presence in North America, but comparatively low volumes in the rest of the world. However, we expect to see Ford increase its global footprint, as it localises production of the transverse 6-speed AT (6F-Mid), in both China and Europe. The decision to manufacture in Europe was partly political, relating to the unusual situation at the Bordeaux plant, in France. But in China, the increasing demand for modern non-manual transmissions, meant that the decision was much more to do with market expectations and potential cost savings.

For the transmission supplier Aisin AW (including production by Toyota), its largest customer is Greater China, but nearly 90% of its AT production is in its home country of Japan. With planned localisation of the transverse 6-speed AT (TF-60 and TF-80 platforms) in China, Aisin will soon begin to reap the rewards of this growing economy. Moreover, Aisin’s close relationship with Toyota will result in a rise in production volumes in North America. This is due in part to the consumption of the new 8-speed AT (TG platform), on several new vehicles with transverse layouts. This new 8-speed AT was launched as part of a new generation of ATs, with improved shift speed and efficiency, but minimal impact on the package size, compared to the existing 6AT. These achievements helped win the business for the latest generation Minis, and the forthcoming Front-Wheel-Drive (FWD) BMWs. Whilst Aisin may be the choice for brands such as Toyota, VW, Volvo and Mini, the likes of Audi, Mercedes and BMW (RWD applications) demand the absolute premium, albeit at a premium cost.

The ZF Group (and hence BMW) prides itself on being the market leader for transmission innovation, but faces an ongoing battle for that title with Daimler, at least in terms of the number of forward gears. However, if you consider global production volume, then ZF certainly has the upper hand. The 8HP, an 8-speed RWD AT, is at the centre of ZF’s current transmission business. The target customer is strikingly different to the previously mentioned manufacturers. Indeed, many of Daimler’s main competitors, such as Audi, BMW, Jaguar, Jeep and Land Rover all use the 8HP. Approximately 2.3 million 8HPs were manufactured last year alone, but ZF keep things close to home. Over 80% of those 8HPs came from the Saarbrucken plant, in Germany, although a second European ‘overflow’ plant in Strasbourg, France, is expected to come online this year. In the USA, ZF manufactures the larger 8HP70 variant at its Grey Court plant, while Fiat/Chrysler has a license to manufacture the smaller 8HP45, at the Chrysler Kokomo plant.

Two other major technologies are currently trying to compete with the AT – the CVT and the DCT. The first has a smooth shift feel, which is probably more aligned with the existing AT technology, while the DCT is more closely associated with the manual transmission experience. It is this fundamental difference which gives OEMs a dilemma, when they consider what technologies to offer, in what regions.

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Fig. 1: Transmission design by vehicle production region – 2014
Continuous Variable Transmissions (CVT)

The CVT market share in 2013 was just under 10%, globally. Japan is most definitely the home of the CVT, with 3 manufacturers – Jatco, Aisin/Toyota and Honda – accounting for 75% of the global volume. Despite a turbulent past in Europe, some OEMs have tasted success with CVT, such as Volkswagen with the VL3xx (Chain-driven) and Daimler with WFC280 (Belt-driven). Both of these CVTs were well received by consumers, although Daimler has since dropped the CVT in its FWD applications, in favour of its own DCT. And Volkswagen will do the same thing in the coming years, replacing the VL platform with the new DL382 DCT. This could be due to cost issues, or possibly due to the torque limitation associated with the CVTs. For example, Daimler’s WFC280 was capable of handling 300N.m, while the F-DCT350 which replaces it can handle 450N.m, and hence can be used with all of the diesel, and performance gasoline engines in Daimler’s FWD fleet. CVTs seem to be best-suited for use in smaller segment vehicles, where mass and hence inertia are lower. Yet the history of the CVT in some applications still haunts both OEMs, and consumers alike. Ten years ago Ford launched the CFT23 and CFT30, for use in Europe and North America respectively. Unfortunately for Ford, it suffered with technical and customer acceptance issues and a few years later they were dropped from the powertrain line up.

GM/Opel faced similar issues when it launched the VT20E and VT25E CVTs, in 2002, again for Europe and North America, with production stopping within 3 years. However, GM/Opel has hinted that CVTs may reappear in the future, on some applications.

Globally, Jatco is the undisputed leader of CVT production, with more than 3.7 million CVTs produced in 2013. Unlike Aisin, Jatco seems more open to the idea of production outside Japan, with CVT plants now operating in China, Mexico and Thailand. Many OEMs use Jatco CVTs, although the majority are used by the Jatco affiliate, Renault/Nissan.

In Europe, in addition to the perceived ‘strange’ shift feel, the higher penetration of diesel engines may have conflicted with the torque limitations of the CVT. As the diesel penetration falls in the smaller A- and B-Segments in the coming years, resulting from the introduction of Euro 6 emissions legislation, we might have expected to see an increase in CVT penetration, but as yet there is little evidence of this. Contrast this to the A-Segment vehicles in Japan/Korea, where a high penetration of ATs has already given way to a high penetration of CVTs (Fig. 2).

Dual Clutch Transmissions (DCT)

DCTs currently command a lower global penetration, compared to both CVT and AT, but we need to remember that DCTs are very much in their infancy, having been on our roads for only 11 years. This compares to the much more mature AT technology, which has been continually developed and refined. The first production car to feature a DCT was the Volkswagen (VW) Golf, and Volkswagen is still very much at the forefront of this technology.

The VW Group produced approximately 2.2 million units in 2013, accounting for 55% of all DCTs manufactured globally. VW has been on a mission to bring DCTs to the world, but it hasn’t been as easy as it had hoped. In particular, the North American market has been hard to break, due to the customer expectations. Specifically, the type of launch and shift feel which a DCT gives, is very different to that of a torque converter automatic. In the next couple of years, VW is expected to introduce an 8-speed FWD automatic transmission to the American market, although it will retain DCTs on some of its smaller applications. But this smooth shift feel is also sought after in the larger vehicle segments, outside North America. Indeed, VW was planning to replace the existing DL501 longitudinal DCT (550N.m), with the new and stronger DL702. However, late in the development process, the DL702 was dropped from the powertrain line up.

North America has proven to be a difficult market for Fiat/Chrysler too. The C635 DCT (6-speed, dry clutch) was launched on the Dodge Dart in 2012, but will only survive until the mid-cycle refresh. Initially this DCT was going to be used in many Fiat and Chrysler applications, in North America, before the strategy changed, and the ZF 9HP was brought in. In general, an American consumer’s expectation from a native brand (i.e. Chrysler/Dodge/Ram/Jeep) differs to that of a foreign brand (i.e. Fiat). In other words, a car buyer in the USA is more likely to oppose an unfamiliar driving dynamic, from a brand they are accustomed to. As a result, Fiat can probably feel slightly more comfortable in offering the Fiat 500L, with the C635 DDCT.

Ford USA has already been mentioned above, in the AT section, but Ford Europe is afforded a significant degree of autonomy, which is probably a good thing. Ford’s transmission division in Europe is now largely under the umbrella of Getrag (initially operating as Getrag-Ford). This close relationship between an OEM and an independent transmission supplier has probably been good for both parties. Following the issues with the Ford CVT, in the early 2000s, Getrag-Ford launched the MPS6 (6-speed, wet clutch, 450N.m.) DCT on the Ford Focus. The MPS6 belongs to the XPS platform, which has been much more successful than the Ford CVT. More recently Getrag launched the smaller PS250 (6-speed, dry clutch), which allowed Ford to use the technology on smaller applications.

Whilst Ford, via Getrag, may have had success in Europe with DCTs, the same story does not hold true for North America. When Ford launched the Fiesta and Focus with the Getrag dry DCT, American customers were
not responsive to the unfamiliar driving dynamics. Although torque interruption is minimal on a DCT, it can prove difficult to calibrate it to feel like an AT. It is probable, therefore, that Ford will revert back to an AT, on the next generation Focus [C519]. North America may have been a slight stumbling block, but Getrag is continuing to push the PS250 (6DCT250) in Greater China, where production started in 2013. Unlike Ford, which partnered with Getrag, GM (including Opel) does not have that kind of asset. For many years GM has been developing a series of DCTs, but as yet has never managed to put one into production. This could be about to change in 2014, with plans to start production of the new X44F/SHDT250 (7-speed, dry DCT). The X44F was originally going to be produced in both North America and China, but it appears that the plant in Mexico has now been dropped. The implication is that GM USA is not now planning to use this DCT in many, or even any applications in North America. This leaves just the Shanghai plant in China, which is operated by SAIC Gear. Associated with this story, PSA had been searching for a mid-size DCT, and the X44F could have been a potential solution (as part of the PSA/GM alliance), but it seems that PSA has decided not to pursue DCTs for the time being, reflecting its conservative transmission strategy.

Whilst a DCT can be calibrated to feel like an AT, it can never quite replicate the torque multiplication effect from the torque converter. OEMs have considered using a torque converter in tandem with a DCT, but no such combination has been launched on the market, whilst OEMs have considered using a torque converter in tandem with a DCT, but no such combination has been launched on the market, whilst

One aspect of transmission design, which has not been discussed so far, is that of vehicle electrification/hybridisation. Honda, historically, has used CVTs for its hybrid applications, but these will largely be replaced by an EVT (planetary system operating as a CVT) and several DCTs. The DCTs allow a complete disconnect from the engine, which results in greater efficiency. It also enables Honda to install a variety of electric motor sizes, between the engine and transmission. Honda will also benefit from its established production facilities, since Honda ATs are of a layshaft design (rather than planetary), which use the same type of components as an MT/AMT.

Automated Manual Transmission (AMT)
An AMT is, quite simply, a manual transmission with a ‘robot’ performing the shifts. AMTs suffer from the same torque interruption as a manual, but because this isn’t under the driver’s control, it can happen when you least expect it, resulting in poor customer acceptance. On the other hand, it can be designed and calibrated to give rapid gear-shifts, with a sporty feel, hence its presence in some sports/performance applications, although there are few examples of these left now.

The AMT seems to be an obvious choice for European OEMs, considering the existing MT infrastructure. However, several OEMs have tried to offer this technology in the past, with very little, if any, applause. With global AMT penetration at just 1%, you may be wondering why this technology deserves to be mentioned at all? In two words: simplicity and cost. It is by far the cheapest option currently available, to achieve an automatic drive. Whilst a small number of AMTs are used in most regions, it is the Indian market which is most interesting at the moment. It is the low-cost, combined with open-minded customers, in a fast-growing market, which gives the AMT some real potential. In a country where traffic jams are frequent, and average engine torque is relatively low, the AMT could be the ideal solution. Consequently, Tata, Maruti-Suzuki, Mahindra & Mahindra and Renault have, or are expected to offer AMTs in India, as are other Western OEMs who sell cars in this market. One of the factors which has facilitated this trend, is the development by Magneti Marelli of its new GEN IV actuation module. The new modular design of this simplified system, allows several different products to use common components, enabling more OEMs to attempt their own AMT, whilst minimising complexity and hence cost. But could this situation equally apply to Brazil, where MT penetration is currently very high? No doubt South American drivers aspire to automatic drive, but it seems that other customer options may take priority, in the vehicle segments where AMTs would be most appropriate. Specifically, customers buying A- and B-segment vehicles in South America are more likely to spend a bit more on air conditioning, or power steering, than on an AMT. Combine that with the close relationship with the North American OEMs, and the future of the AMT in South America might not be as promising as first appears.

BMW – The anomaly
One OEM hasn’t been mentioned much, and that is BMW (excluding Mini). This OEM stands out because it does not manufacture any of its own transmissions, which gives it ultimate supplier and technology flexibility. In other words, it has no investments in the production of any particular transmission technology, and it can choose who it buys transmissions from. BMW’s current strategy is to offer manuals and cutting edge automatics, with a limited volume of DCTs on niche/performance applications. The take rates for these vary by region/ market, but essentially the strategy is applied globally. However, even BMW has made mistakes in the past, after it adopted, and then dropped AMTs, in some of its products.
Conclusions

So what have we learnt? If you look at any vehicle segment in any major region, you will see a different story, in terms of transmission design. If BMW is anything to go by, the closest thing to a global strategy is to simply offer manuals and automatics. But you could argue that BMW can only do this because it can afford to pay for a premium transmission option, whereas other OEMs have to try and balance their budgets, in addition to the other factors like CO2 and customer acceptance.

Although ATs are globally acceptable, it is not a guaranteed solution for all transmission needs. Consumer preference aside, all other non-manual technologies mentioned have a potential space in the market. AMTs and DCTs are eye-catching non-manual solutions, for OEMs who already have a well-established infrastructure for MTs. These two manual based technologies serve well for a wide range of engine torques, and modularity, resulting in cost savings. CVTs can deliver a drive, free of torque-interruption, in a compact package. For the small A-Segment vehicles, the CVT’s main competitors are 4ATs and AMTs, which are less attractive propositions in the global market.

Therefore for the majority of OEMs, it would not be possible to follow a ‘One-Size-Fits-All’ strategy. Products should be tailored according to a number of different factors, such as regional preference and vehicle segment. Some OEMs are good at this, whilst others it seems, are in a constant state of confusion about what to do – possibly because they are too inward looking. What cannot be denied is that making the wrong choice can be time consuming, and very expensive.
Efficient, Cost-effective and Durable Material Solutions

VICTREX® PEEK Polymers: Performing Beyond the Limits of Metal

In a world demanding more from less, the automotive industry has identified three main opportunities to improve the performance of the powertrain: downsizing, electrification and automation, all combined with cost-effectiveness. With its proven track record in automobile applications, Victrex Polymer Solutions is able to address these trends by supporting customers in the design of VICTREX® PEEK polymer components that help deliver cost-effective solutions enabling greater fuel efficiency, durability and driving comfort.

by Dipl.-Ing. (FH) Jürgen Reinert, Senior Market Development Manager, Victrex Polymer Solutions
Fuel efficiency is driven by the combination of reducing wear which minimizes energy losses along with significant weight reductions achieved by converting metal to plastic. Recently announced at end of February 2014, the European Parliament backed the law to cut CO₂ emissions of new cars by 2020 to 95g/km. For each gram above this figure, manufacturers will have to pay a legislative penalty of 95 €. Studies have shown that a car that reduces its mass by 100 kg will lower its emissions by 8.5 gr CO₂ per 100 km. This resembles 0.085 gram per one kg weight savings and functions as an additional incentive for lightweight plastic solutions compared to today’s heavy metal. For transmission manufacturers, this offers the opportunity to invest in lightweight polymeric solutions to help achieve fuel cost savings.

In cases where weight is reduced in dynamic components like gears, the lighter weight parts can reduce the moment of inertia by 78% resulting in efficiency improvements such as 9% lower torque. Achieving higher operating efficiencies is promoting the metal-to-plastic trend. The trend does not only focus on reducing weight, but also on improving strength and corrosion resistance to enhance durability, as well as consolidating multiple metal parts into one plastic part to enable overall system cost reductions.

The reason that VICTREX PEEK is specified in the automotive industry is because some engineering plastics and even metals are reaching their performance limits. Engineers are designing to achieve highly efficient, smooth-shifting transmissions that can help deliver power while keeping fuel economy and environmental standards in mind. VICTREX PEEK can help meet these requirements as the high performance polymer
- is resistant to the latest transmission oils,
- performs in both lubricated and temporary non-lubricated settings caused by stop-start systems,
- demonstrates a low coefficient of friction, which has enabled parts to withstand extreme pressure/velocity values under lubricated conditions and even allows for temporary dry run performance,
- is dimensionally stable, and
- can operate in a broad temperature range.

Seal applications are a case in point. Typically they are used to prevent leakage, contain pressure, or exclude contamination where two systems join. In transmission applications, seals are also positioned against rotating steel shafts which require a defined leakage and minimal wear and friction in order to reduce energy losses. In the latest tests, VICTREX PEEK seal rings demonstrated up to 25% less drag at 5,627 psi (38.8 MPa) and generated 8°C (18°F) less heat next to the ring compared to other thermoplastics. Low and defined lubrication leakage is also a desirable feature when specifying a seal ring material. The objective is to considerably reduce friction losses with a focus on hydrostatic relief of the sliding surfaces to achieve a higher efficiency. In performance testing, VICTREX PEEK seal rings ensure proper lubrication with consistent leakage levels of 0.066 gpm (0.25 l/min).

Due to increasing fluid pressure and sliding speeds in combination with greater shaft diameters, seals reach their load (P) / speed (V) limit in some applications. Latest lubricated testing proved that VICTREX PEEK polymer in hydrodynamic lubricated settings withstands pressures up to 13,053 psi (115 MPa x m x s⁻¹). In these extreme environments, the polymer provides the desired performance enabling the design of highly-optimized transmissions. Surface modification, or microstructures, on the wear surface is a cost-effective way to use injection moulding technology. This can help provide up to 45% less energy loss when compared to standard surface roughness at shaft speeds of 500 to 9,000 rpm and 2 MPa oil pressure.
Durability: the road to “no wear” for enhanced part and vehicle lifetimes

In the mechanical components found in manual transmissions (MT), automated manual transmissions (AMT) and dual clutch transmissions (DCT), typically metal-based wear surfaces are used in friction areas where wear is expected. VICTREX PEEK has proven that, under extreme testing procedures, it can withstand friction at least 19 times longer than brass which wore down after 800 cycles. When exposed to 1,000 N shift forces on a rotational shaft turning with 5,000 rpm, the VICTREX PEEK solution showed no visible wear facilitating precise and reliable gear shifting during the entire lifetime. The latest commercialization of a VICTREX PEEK actuation lever in a dual clutch system withstood two times more oscillations at 2,000N on the clutch fork when compared to metal fabric sintered between two layers of filled fluoropolymer. The higher wear resistance enabled by VICTREX PEEK leads to an increase in lifetime by more than one million cycles. Longer reliability and clearance-free operation are the result and at the same time the competitive advantage as they enable longer warranty times. The consistency of the material’s coefficient of friction improved shifting comfort over the lifetime of the transmission as well.

Furthermore, VICTREX PEEK offers the performance properties for use in the high voltage electrical machines found in today’s hybrid vehicle transmissions and hybrid modules. For example, APTIV® film insulation used in electrical motor components showed little or no loss of properties after being exposed to high temperature and humid environments. It also enables 200-300% higher dielectric strength over a wide range of operating conditions compared to other high performing laminate slot liners. The ability to insulate with a thinner substrate helps to reduce heat in the operating environment and can even support higher-density packaging of the copper windings. Hence overall greater power output and reliability of the electric machine can be achieved.

Comfort: precise shifting and noise dampening effect

Specifically developed VICTREX PEEK grades not only help to reduce frictional losses, they also have decades of proven performance in demanding transmission environments. An example is VICTREX PEEK 650G for use in gears as well as newly-introduced variants that enable automotive designers to take advantage of a wide range of benefits. These include enhanced lifetime for parts in lubricated applications, improved corrosion resistance, a reduced need for lubrication, and less noise and vibration.

The VICTREX PEEK gear was selected to replace grey cast iron gears due to its ability to provide a smoother running, higher efficiency solution that resulted in better driving comfort and pleasure including benefits such as:

- Up to 50% noise reduction – corresponding to a 3 dB improvement in noise, vibration and harshness (NVH) compared to the grey cast iron gear set.
- Up to 69% weight reduction, which resulted in up to 78% reduced moment of inertia, which improves responsiveness, and a 9% reduction in torque requirements.

Cost reduction: from less production steps to faster time to market

Due to the ease of processing and the ability to consolidate designs using VICTREX PEEK, the overall system costs are actually competitive or even cheaper than metal. Compared to process intensive metal manufacturing, polymers enable economic production thanks to:

- High reduction of conversion steps due to injection moulding and integration of functions
- High return on capital / low investment in tooling and machines
- Less vulnerable regarding economic cycles due to much lower fixed costs
**Proven industry successes**

In the automotive arena, Victrex has collaborated with industry-leading customers to transform their challenges into tangible benefits and successes. VICTREX PEEK wear grades, for example, have shown stability in transmission fluids as well as matched the thermal expansion of cast aluminium. The polymers perform well in temperatures as cold as -40°F (-40°C) and in excursions up to typical transmission temperatures of 320°F (160°C). A recent study even confirmed that the polymers do not show mechanical loses respectively from thermal oxidative aging over the test period of 5,000 hours when exposed to 260°C (500°F).

With several millions of transmissions produced so far, none of the transmission manufacturers have reported appreciable property changes when VICTREX PEEK is even exposed to transmission oils containing extreme-pressure additives. The role of these additives is to decrease wear of the parts, like gears for example, which are exposed to very high pressures. Consequently, the proven data that design engineers now have gives them higher confidence and safety, instead of doubts or even fears, when converting metal components into efficient, cost effective and durable plastic components. The VICTREX® WG™ polymers offer up to 20% reduced coefficient of friction which enables wear components, such as thrust washers and seal components, to withstand extreme pressure/velocity values under lubricated conditions and even allows for temporary dry run performance eventually caused by stop-start systems. Friction induced heating as well as wear associated losses are prevented, leading to a more reliable operation.

Strategically, through the research and development effort that has been invested into key polymer materials for the automotive sector, Victrex is poised for decades to apply its polymer solutions throughout a wide range of applications with its dedicated industry experts covering specific markets globally. The company’s technical expertise includes support for testing, prototyping and application development. Meanwhile, further investment in production capacity will guarantee security of supply, which is important to meet the industry’s just-in-time targets. Victrex will continue to work closely with its automotive customers from design concept to the start of production throughout the entire supply chain. Victrex Polymer Solutions, headquartered in Thornton Cleveleys, UK, and with own locations in the USA and in Asia now has 35 years of experience in the application of its high performance thermoplastics, including many applications for significant reductions in CO₂ emissions and improved fuel efficiency. VICTREX PEEK is being used in the most demanding environments due to its excellent resistance to grease, oil particle contamination and current automotive fluids making it the key proven material of choice in automotive design and manufacture.

**Information/Contact:** www.victrex.com | contact automotive@victrex.com
Due to growing cost pressures, engine and transmission manufacturers require increasingly more flexible production solutions. Over the past few years, M&R Automation GmbH has developed the Powertrain Production Systems (PPS) modules into intelligent and highly flexible technology building blocks, to deliver efficient, lean solutions to meet global challenges and requirements including hybrid and electronic drive systems. The PPS modules unite innovation, quality, and efficiency.

by Norbert Kahr, Director of Sales, M&R Automation

Various types of engines as well as automatic, manual, and dual-clutch transmissions together with transfer gears, axle drives and their components are high-end automotive parts that call for high-end production solutions. It is in exactly these areas, with increasing cost pressure, that demands for intelligent and cost-effective production systems are becoming ever more pronounced in the race to maintain market leadership as a manufacturer. At the same time, efficiency, quality, flexibility, and availability in production must continue to increase. Process reliability cannot be left by the wayside in the wake of cost-saving measures. The solution lies in modular production systems, which M&R Automation GmbH (M&R) has developed using years of tried and tested technological expertise paired with the latest developments in measurement and testing technology. The PPS modules from M&R unite innovation, quality and efficiency under one roof.

Principals of the Technology Building Blocks – Stations for Every Need

The required sub-processes in the assembly of various powertrain components are, in principle, very similar. Depending on sequencing and scope, individual production steps will come together to form a process sequence that will accommodate the interactions of gear and bearing adjustment processes. To meet project requirements, individual technology modules from the PPS building blocks can be developed into stations and brought together in an overall system. Highly efficient manual, semi- and fully automatic assembly and measurement modules can be selected to meet requirements, resulting in the highest level of cost-effectiveness and process reliability producing high-quality parts with minimal rates of rework. M&R will of course adapt modules to individual customer specifications to ensure factory-oriented standards.
are met for operators and maintenance personnel (e.g. unified operating interface and machine components). No advantages of M&R’s tested and proven technology are lost in this process. Highly technical measuring processes play a key role in many production lines. Experience and technological expertise are of extraordinary importance in these operations. Particularly when adjusting gears, highly precise systems such as dynamic circumferential backlash measuring devices built according to patented M&R technology are a sure way to construct premium powertrain assemblies. M&R pays special attention to the energy efficiency and sustainability of PPS modules. The mechanical and electrical design of PPS modules is in line with the most modern manufacturing principles and processes.

Lean Manufacturing – Adjusted for the Realities of the Project

The expressions “lean manufacturing” and “lean production” as a so-called manufacturing panacea first appeared at the end of the 80s when the simple, sleek production concepts from Asia confronted the complex industrial solutions from North America and Europe. Ever since then, production experts have been trying in vain to lay out standard worldwide criteria for successfully making manufacturing processes “lean”. The range of economic considerations has failed to yield a unified system for all global applications. Differences in requirements are enormous: OEM or parts supplier (product life cycle), industrialized nation or emerging market (salary costs, level of education), high-volume or low-volume product (investment costs per part). PPS modules attempt to bridge the gaps between the many different manufacturing requirements and to unite the demands of global lean production thought in a system of building blocks for every need - without trade-offs in production technology and therefore without sacrificing quality. In addition to these demands, the impact of aging workforces must also be taken into account in Europe - something that the PPS module series has mastered. In Southern Germany, several systems suited to the age of the workforce have been installed by M&R - one of them being the world’s fastest production line for axle drives with a cycle time of 16 seconds. The large markets of the USA and China are currently investing intensively in new production systems, but with very different lean parameters. While nearly identical production conditions prevail in the USA and Europe, in China it is necessary to carefully consider which system concept would be suitable for each site. Even within China itself, the requirements for lean parameters can vary greatly. While western companies in China will not allow for quality to be sacrificed when dealing with production for Europe or the United States, Chinese OEMs and parts suppliers currently face a different situation. This inevitably results in different production concepts for very similar products.

Idea to Market – And Fast!

In addition to growing pressure to reduce costs and fuel consumption, time to market also plays a central role in powertrain production. New versions of products must be delivered quickly and efficiently to remain marketable. Increasing numbers of product variants released by project development departments and meant for production on flexible lines shorten the acquisition time for production systems. To relieve pressure on product development and launch timelines, it is necessary to further shorten supply times for production systems. M&R’s PPS modules are prepared to meet even these demands, since much of the engineering is already done and risks are lowered by using proven processes to shorten production ramp up time for new assembly lines. Time will therefore be an important factor for decision-making in the future when acquiring new production systems.
Best Practice at Daimler AG

One of the most successful automobile companies in the world relies on M&R’s proven and efficient solutions. The Daimler Group is one of the biggest producers of premium cars and the world’s biggest manufacturer of commercial vehicles with a global reach and has been using M&R production systems to manufacture powertrain components for several years. Two of the many technical innovations from Daimler AG are a friction-optimized drivetrain and a new generation of fuel-efficient axles. Several M&R modular lines with integrated laser welding cells and testing stations are currently being constructed for production of the new FE front- and rear-axle drivetrain. The PPS technology building blocks provide the foundation for assembly, measurement, and testing stations that are optimized for operator ergonomics and the product-specific manufacturing processes.

Flexible Laser Welding of Powertrain Components

Laser welding of powertrain components requires the highest standards of quality and process reliability. Since 2008, TRUMPF and M&R have been intensively collaborating in the area of powertrain laser welding and have jointly developed technologically advanced solutions for the creation of laser welded joints and the flexible integration of this technology into assembly lines. The TRUMPF group is one of the world’s leading manufacturers of CO₂ and solid state industrial lasers and has played a major role in partnership with the assembly and test device specialists at M&R. The partnership enables M&R to offer fully integrated powertrain production systems.

M&R Automation GmbH

M&R Automation is a global supplier that offers its customers innovative production systems in the areas of assembly, measuring and testing technology. Since 1989, the M&R team has been developing and producing customized production and testing systems for the automobile, electronics, and consumer goods industries as well as for medical technology. Emphasis is put on the manufacture of systems for powertrain production. With its locations in Europe, North America, and China, M&R Automation employs more than 400 employees.

The company headquarters for M&R Automation in Grambach/Graz: the development site for the most advanced systems for power train manufacturing for over 20 years.
Expertise and superior simulation tools for advanced engineering design

- Product design validation and optimization
- Optimized model code for in-the-loop simulations
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Feintool introduces a new 1600-ton direct servo-transfer press for advanced drivetrain parts.

A North American First

Commissioning a state-of-the-art press specially designed to manufacture three-dimensionally formed transmission/powertrain components.

by Lars Reich, Vice President Sales and Marketing, Feintool System Parts USA

Transmission manufacturing technology is now at the forefront of the industry

In the quest for fuel economy, automotive drivetrains are regarded as a critical component in total vehicle design, passenger comfort and overall vehicle performance. The introduction of eight-nine- and ten-speed transmissions translates into complex metal-formed sheet metal parts that live up to the automotive industry’s well-known quality, precision and cost requirements. “This state-of-the-art direct servo press was developed by Schuler according to Feintool specifications and we are delighted that after years of planning and six months of installation we are in production,” says Rick Garner, Feintool’s Nashville plant manager.

Feintool has taken the next step in advanced metal forming

After months of onsite assembly work, programming and testing, Feintool’s $14M investment at its plant in Nashville, TN, will push the envelope in metal forming. The 18-foot press table, combined with the advanced servo drive and a three-axis transfer system, will open a new dimension of parts accuracy and metal forming excellence at a very competitive cost. Equipped with 12 individual tooling stations, the servo press allows for total freedom in part design; disc carriers, pistons, gear spiders, driveplates and more, can be formed, in-tool-rolled and finished in a single transfer press run.”

The 1600 ton Servo Press is anchored in a massive 18 feet deep foundation and stands 30 feet tall above ground.

1600 ton Direct Servo Press with moving bolster and automated slug loader.

The heart of the operation...
At the heart is a hydraulic power unit from a 700-ton Feintool Fineblanking press

At the heart of the Fineblanking & Forming System (FFSTM) configuration is a hydraulic power unit adapted from a 700-ton fineblanking press. The hydraulic unit, located in the foundation of the transfer press, delivers high volumes of oil at precisely controlled ram positions and pressures to fully integrate multiple fineblanking operations at any of the forming tool stations. The FFSTM configuration eliminates the usual limitations of a fineblanking press by incorporating relative small bed size and adds, with additional hydraulics, the possibility to introduce fineblanking stations into a transfer press to achieve precision and finishing results that is only possible with the fineblanking process. “The FFSTM configuration brings both worlds together: The large bed size of a transfer press and the precision and finishing capabilities of a fineblanking press,” adds Paul Frauchiger, vice president of Engineering, Feintool U.S. Operations, Inc. A three-axis CNC controlled transfer system guarantees a quick transfer of the components through all tooling stations. Positional accuracy and speed of the transfer system is the key to unleashing the stroke rate capabilities of the direct drive servo press. The moving bolster is another key feature of the press system that allows quick die changes, within 20-30 minutes. The servo press is equipped with two moving bolsters that alternate moving from the front to the back of the press. The entire tool can be set-up externally on the spare moving bolster, including the transfer arm and all of the sensors for parts detection. When it comes to an actual tool change the moving bolster can simply be swapped and the machine is ready and back in production with minimal interruption.

The capacity for growth is now unlimited

“The start of production with the new servo press line relieves immediate capacity constraints for our customers and allows for future growth!” concludes Mark Stowe, Vice President Operations Feintool US Operations, Inc. Feintool is the world’s leading technology group specializing in the development of fineblanking systems and the production of ready-to-install fineblanking and forming components, notably for the automotive industry. In addition to fineblanking, Feintool Group also deploys other key processes, such as precision forming and orbital technology, and is the world’s only supplier of all-round solutions for cost-effective manufacture of complex precision components. With locations in Europe, Japan, China and the USA, Feintool Group is represented in the world’s major automotive markets. Headquartered in Lyss, Switzerland, the Group has a headcount of just under 2000.

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Photos: Feintool, Todd Joyce
Hardware-in-the-loop simulation (HILs) for 2-step continuously variable transmission control unit Test environment with dynamic plant model and test automation under NI VeriStand

Hardware-in-the-loop Test Environment for 2-step Continuously Variable Transmission Control unit

The HIL environment for testing 2-Step continuously variable transmission control unit includes 2-Step CVT dynamic plant model and automatic testing environment under NI VeriStand.

by Daeyeun Lee and Seojeon Cho, Transmission Control Team, HYUNDAI AUTRON Co., Ltd.

HIL environment under NI VeriStand
Hardware-in-the-loop simulation (HILs) is a key part of testing electronic control unit (ECU). The HIL test environment provides a virtual test environment similar to a real vehicle and enable to test under extremely dangerous situation which causes car accident. In addition, it has several advantages of overall development time reduction and reliability improvement. Generally, HILs environment is implemented as closed loop system which comprises real ECU and plant model consisted of engine model, transmission model and vehicle model. Each model is possible to describe in detail as similar as real vehicle but a lot of effort is needed to find inherent parameters of model and to match characteristics of real vehicle. For the purpose of testing ECU, the level of implementation is enough if ECU recognizes all input/output hardware signals correctly and the plant model can handle and calculate main signals of ECU. NI VeriStand provides test environment to perform MATLAB Simulink plant model in real time as well as processing and monitoring of several kinds of input and output signal. Besides, the Plug-Ins including LABVIEW and support functions like alarm, procedure, calibration and stimulus profile enable to configure suitable test application for a specific purpose. In this reason, NI VeriStand is an appropriate solution for real-time testing with plant model and to build automatic test environment reducing test effort and cost.

2-step CVT dynamic plant model
Figure 1 shows the structure of a 2-step CVT vehicle. The 2-step CVT consists of metal push belt variator and a planetary gear set which has 2-step gear ratio.

Fig. 1: Structure of the 2-step CVT
The 2-Step CVT has a widely gear ratio than 1-step CVT. The total gear ratio is in the range of 0.54 to 4.3; the first and secondary gear ratios of the planetary gear set are 2.125 and 1. The 2-Step CVT plant model was implemented using MATLAB Simulink. It consists of engine, torque converter, variator, planetary gear set, solenoid valve and vehicle dynamic model. The engine torque was modeled by engine characteristic maps. The engine characteristic map is a torque about air flow, intake pressure. The input signal is a throttle valve opening to be received from CAN communication. The torque converter transfers the torque to a 2-step CVT from the engine through the fluid. This was modeled by the performance curves at steady state. The performance curves are represented by a speed ratio, a torque ratio, a capacity factor.

\[
SR = \frac{\omega_T}{\omega_i} \quad TR = \frac{T_T}{T_i} \quad CF = \frac{T_T}{\omega_T} \quad \text{(1)}
\]

where \(\omega_T\) is a turbine speed, \(T_T\) is a turbine torque, \(\omega_i\) is an impeller speed, \(T_i\) is an impeller torque. There is a lock up clutch in torque converter for efficiency. The clutch is operated by TCU solenoid current. The variator model consists of a shifting dynamic model and a variable ratio gear model. The shifting dynamic model is defined by the equation of IDE [1].

\[
\frac{di}{dt} = \beta(i) \cdot \omega_p \cdot (P_p - P_{*}) \quad \text{(2)}
\]

\(\beta(i)\) is a function of the CVT gear ratio to be determined by an experiment.

\[
\beta(i) = C_1i^3 + C_2i^2 + C_3i + C_4 
\]

The simulation results were compared with the experiment results for verifying the shifting dynamic model at figure 2.

The hydraulic model such as a line pressure solenoid valve, a primary pressure solenoid valve and a secondary pressure solenoid valve is necessary for the shifting dynamic model. The pressure control valve was modeled with 2nd order dynamic equation [2]. The line pressure control valve model is represented as equation (4).

\[
P_{\text{line}} = \frac{K_1(\omega_{m})}{s^2 + 2\zeta_p s + \omega_p^2} \cdot \text{current} \cdot K_2 \quad \text{(4)}
\]

where \(\omega_m\) is a natural frequency and \(\zeta_p\) is a damping coefficient. \(K_1\) and \(K_2\) are a coefficient to determine the maximum and minimum pressure. The parameters are obtained from experiment results. The primary and secondary pressure solenoid valve model is also represented as equation (5).

\[
P_{\text{pump}} = \frac{K_3}{s^2 + 2\zeta_p s + \omega_p^2} \cdot \text{current} \cdot K_4 \quad \text{(5)}
\]

\(K_3\) is a coefficient to determine the maximum pressure and are a function of line pressure. When a current of 1200 ~ 0mA and 1200 ~ 550mA is sent as step input, the different characteristics is appeared. It is caused by a difference of damping coefficient. The perturbation is added to consider the uncertainty of the damping coefficient. For this purpose, a linear fractional transformation (LFT) was used as Figure 3. [3]

\[
\zeta_a = \frac{\zeta_a + \zeta_b}{2} \quad \Delta \zeta_b = \frac{\zeta_a - \zeta_b}{2} \quad \text{(6)}
\]

The simulation results were compared with the experiment results for verifying the line pressure control valve model at figure 4.
The planetary gear set that is connected to the secondary pulley of the CVT is composed of two single pinion planetary gears (SPPG), clutches and brakes to realize the first, second and reverse gear. The planetary gear set was implemented using Simulink SimDriveline. Figure 5 is the dynamic plant model developed for the HILS of 2-Step CVT control unit. The input signals are solenoid control currents, an accelerator pedal, a brake pedal, a target gear and request of an engine torque increase/decrease. The output signals to send to TCU are an engine torque and speed, a primary and secondary speed, an output speed, a secondary pressure, etc.

Except 2-Step CVT dynamic plant model, the open loop model with additional user interfaces and monitoring windows was developed for quick and efficient testing. The user can control various sensor signals such as position, turbine/output speed and oil temperature as well as vehicle CAN signals manually and synchronize them as circumstances demand. For example, throttle position value and brake signal affects output speed and input speed is obtained by multiplying an output speed by a gear ratio. In other words each signal can be controlled independently and also one signal can be calculated from another signal by synchronization switch between two signals. This concept is very useful when the user tests algorithm or logic of a certain module directly. Otherwise the 2-Step CVT plant model is selected when the user wants to test under real CVT vehicle environment.

Figure 6 shows Simulink model consisted of 2-Step CVT plant model and open loop model including I/O interface handling model. These two models are operated selectively and the switching is possible in real-time during testing.

**Test Environment for Test Automation**

As Figure 7 shows, automatic testing environment was built to help repetitive task of developer and tester. Test automation is separated automatic test case generation and automatic test case execution. For this, the necessary tools were designed and developed alone or by using NI VeriStand.

Automatic Test-case generation tool extracts test cases automatically from SW model. It generates test cases which meet state coverage, transition coverage and MC/DC coverage from Simulink stateflow of user model. By using this tool the developer can verify his own implemented model on real target with less effort. And the measured signal from a real vehicle is used as test case. With measured signals under various driving modes like FTP mode, kick-down mode, hill mode and highway mode in real vehicle it is able to test under same driving situation without a vehicle automatically. In case of manual test case, it is to
check basic I/O signals of TCU like digital, analog and PWM and CAN and also check whether substitute value is applied and whether safety function is activated when electrical fault or plausible fault is detected. These repetitive tasks convert into test script and are executed automatically. All test cases and scripts are transformed to Stimulus Profile as executable format of NI VeriStand and saved in test case database. Finally, Test automatic execution and management tool makes test cases and scripts execute on NI VeriStand. Additionally, the captured signals on NI workspace by macro function built in NI VeriStand can be used for repetitive testing.

**Other Transmission Control Unit Testing**

Under this HILs environment, it is possible to substitute other control unit like Step-AT (Automatic Transmission) or DCT (Dual Clutch Transmission) control unit. Normally, during verifying algorithms or logics of control unit the simulation model is also developed simultaneously and this simulation model can be modified into plant model with less effort. To build the test environment for other transmission control unit it is specific that interfaces for control unit are created and connected to user channel defined in NI VeriStand and that current plant model is replaced with corresponding plant model. From our experience, kinds of transmission control unit like 6 step-AT, 8 step-AT, CVT and DCT can test under the same HIL environment without additional device and tool.

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**Reference**


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Model based software development

Modern Transmission Control Software

Development of flexible and reliable transmission control software by using innovative development approaches

Introduction
In the past decade there has been a clear development trend towards complex and closed loop controlled transmissions like DCT’s or hybridized transmissions. In addition to the system design challenges of such systems, the complex control requirements led to big challenges within the functional frame of the control units. Excellent knowledge about transmission, powertrain and software development must be combined to match these requirements. In addition the aspect of functional safety with standards like ISO 26262 must be fulfilled during the development process.

Requirements
To effectively develop complex series transmission software, three different main requirements have to be met. State of the art transmission systems have a much bigger number of sensors, actuators and software functionalities than e.g. classical AT transmissions. A major difference in the functional software is the larger number of feedback control loops compared to other automated transmissions where most functions are feed forward acting. Therefore a key factor for control system development is a structured approach that involves classical knowledge of control theory, system identification and modeling in a very early stage of the project. This approach must ensure system understanding to reduce the number of development iterations by frontloading. In parallel to the increasing complexity of transmission systems the development cycles are getting shorter. Therefore function development takes place in teams with an increasing number of specialized engineers working simultaneously on the same functional frame. Bug tracking and oncoming change requests are also complicating the coordination of development tasks, because changing functional requirements may influence several parts of software. Keeping the overview over all changes requires traceability from the first system requirement to the last released software including all test cases and vice versa. The complete development process is also influenced by process requirements coming from standards like ISO 26262 that became necessary with the increasing demands of functional safety. Failure statistics show that the desired quality for production software is not achieved in many cases. In fact, software failures remain being a substantial risk in order to design suitable countermeasures, an integrated quality assurance approach is necessary. The possible verification and validation methods have to be integrated into a testing strategy. Moreover, this strategy has to be realized by an agile framework that allows for minimized manual testing effort, continuous software inspection and traceability of test results over the entire project to re-enable frontloading of software error mitigation.

Systematic approach of utilizing control theory in transmission development
The so called 4-Step-Approach [1] increases the effectiveness of controller design by gathering system understanding with the help of simplified modeling techniques. It is divided in 4 steps of systematic controller design (see figure 1). This first step of the approach is used to extract simplified models of all involved components. Aim of this step is to simplify the control loop in a way that includes the main dynamic characteristics of the system but neglect effects of low importance. The simplified model should be linearized around an operating point to enable the engineer to perform a simple analysis of the system characteristics. In the second step, the simplified model is used to analyze the system according to dynamics, stability, command following behavior and robustness. For this analysis typical methods are used like root locus methodology or stability analysis by Nyquist’s criterion. In opposite to commonly used methods, the simplified models allow an analysis in the frequency domain, too. With
system understanding gathered in the previous steps a controller can be designed that is optimal for the specific system in its structure and its gains. With this specific structure the following implementation and testing becomes much more straightforward than in commonly used iterative approaches.

In the last step the designed and optimized controller is implemented and tested in the vehicle or on a test bench. This structured approach of system identification, modeling with simplified models, controller design and testing leads to shorter development time and lower costs for function development as well as lower CPU load and memory usage.

Function and software development process

The process philosophy, which has been successfully used for the last years, is based on the well-known V-cycle but enhanced to a nested version (figure 2). This nested V-Cycle accommodates the standard V-cycle with selected agile process elements. Customer system requirements are always identified before every first development step. In some occasions, these requirements are not sufficient to execute a complete software development and therefore, FEV supports customers by conducting detailed system analysis which allows the definition of further requirements and the creation of a complete system specification document. Each requirement is seen as a unique atomic element and is included in the requirements management tool. For each one of these requirements a set of acceptance criteria is defined to be used as the basis for the validation and the release of the final implementation. The next step in the FEV software development process is the construction of the appropriate software architecture based on the system requirements including safety requirements and target hardware. This step is executed under the light of the AUTOSAR standard enhanced by FEV’s sophisticated architecture development framework PERSIST [3] which e.g. indicates explicitly a separation of physical and logical components inside the software. The system requirements are respectively assigned to each component. The functionalities are separated in small testable functions according to the architecture. All the functions are linked with their respective base system requirement. Each one of the described steps is executed under an acceptance process, starting with the creation of a draft by the project engineer and proceeding with a mid-term release by the senior engineer. The released documents are then reviewed by the specification team which accepts the specification document and allows the final release. This final milestone guarantees the release of error-free documents and the transmission of detailed technical knowledge to the rest of the team members. In this way, the development may be easily continued in case one of the team members is not available. Also for the ascending branch of the V model, the procedure is similar. First, an implementation proposal is created, which is released in cooperation with the specification team. Only then the actual implementation is started, and later by a code review and the execution of corresponding test cases for the MiL/SiL verification, released. For the start upon the HIL simulator the validation test cases are used. The overall system performance is tested together with the specification team on the HIL, in order to release the software for use in the vehicle. Only then the SW start up in the vehicle is performed, and the required calibration is started. In addition to the
normal software development, the entire change management (change request tracking) and error handling (bug tracking) are performed in the same tool. This way and by the corresponding links, it is possible to get an overview of the software releases and its contents at any time. Only by incorporation of the entire software development process in a single tool environment, such a high level of traceability for both FEV and for the customer could be established.

Continuous integration as key factor for effective software testing

One possible strategy to achieve an efficient development process within a framework as mentioned above is to introduce the agile development method continuous integration [2] (CI). Core element is to automate as many verification, validation and software integration procedures as possible for the execution of the complete software integration on a continuous (e.g. daily) base. In this context, software integration is understood as the complete process starting with the planning of verification and validation (V&V) measures and their execution, model and code development on unit and integration level, integration of units into one piece of software deployment on the target, hardware verification and final validation and release to the customer. Once, this chain of development measures is automated and executed continuously, quality risks are detected immediately and mitigation can be started without risking schedule shifting delivery milestones. This allows for frontloading and parallelization of quality assurance activities. Therefore, a framework was developed that consequently follows the approach to develop software on the model-level and with domain-specific modeling languages for the first time (figure 3).

Test plans depending on the required product maturity are implemented. Formal review is conducted by automated checking of modeling guidelines. Unit test is executed on model level, C code is generated from software units and integrated and compiled to executable code for the hardware target. Software Design Descriptions (SDD) are generated from the model and a software release candidate is generated if all preceding steps have been executed successfully. Since all measures are executed nightly and end with the build of the software, we also refer to the framework as “nightly build”.

Process Validation

The compliance of the software development process is ensured by different institutions. On the one hand the project monitoring staff section permanently observes the conformity and the efficiency of the process, on the other hand a superior quality management department ensures the CMMI compliance. Lessons learned lectures at the end of each project and inter project information exchange about strengths and weaknesses provide optimization approaches. The usage of these tools leads to a continuous improvement of existing processes and methods.

Conclusion

In this paper the major key success factor in FEV’s transmission software development have been briefly described. These methods and processes mainly focus on performing as much automated frontloading as possible in order to reduce iteration steps that are very expensive in late phases of the development. The described approaches have been used in various powertrain software development projects over years and proofed to be very efficient.

Fig. 3: Continuous Integration framework for software development [3]

References

Rome Wasn’t Built in a Day

Review about the 12th International CTI Symposium in Germany – THE international industry event in Europe for people seeking latest information on developments in automotive transmissions and drives for passenger cars and commercial vehicles!

The arrival of electromobility is still an ongoing process that moves ahead one small step at a time. During the as-yet uncertain transition phase towards electromobility, the conventional drives as well as their hybrid varieties must still be further advanced and improved. Transmissions will continue to figure prominently in this development. – This was one message of the 12th International CTI Symposium on Automotive Transmissions, HEV and EV Drives. Moreover, the developments in the area of CVTs have drawn a great deal of attention. However, the issues of functional safety and the upper limit for the number of gears were also discussed with more than 1,100 participants on December 3 and 4, 2013 in Berlin.

by CTI – Car Training Institute
Prof. Ferit Küçükay welcomed the participants of the 12th International CTI Symposium on Automotive Transmissions, HEV and EV Drives in an “atmosphere of positive trends in the automotive industry.” He was effusive in his use of superlatives: on a global level, he reported, the automotive industry is producing and selling more vehicles than ever before, and even the sales situation on the European market, which had been deteriorating for many years, is on its way to recovery. What is more, greater amounts of money are invested in research and development than previously. The automotive companies, he suggested, are preparing for the stricter environmental requirements and had never presented as many hybrid and electric motor vehicles at the IAA as in 2013. However, according to Küçükay there is still great uncertainty as to when the breakthrough of electromobility is going to take place.

Dr. Herbert Demel, Special Advisor to the CEO and the Board of Directors of Magna, believes that the total volume of vehicles will stagnate in such saturated markets as Europe and NAFTA. Therefore, he said, the significance of the markets will decrease, and by 2027 even make up no more than one-fourth of the global market, whereas by then Asia will constitute 57 and the rest of the world 20 percent.

Green and clean into the future

Dr. Ulrich Eichhorn, Director of Technology and the Environment of VDA, says that we “have already done our homework, because over the past few years we have already cut CO2 emissions by 40 percent and reduced pollutants by 96 percent. Nearly all previous CO2 savings were achieved through improvements in classic automotive engineering: by way of lightweight construction and advances in transmissions, by optimizing the efficiency of the engine as well as through reductions in rolling resistance and aerodynamic drag. It hasn’t been that long that a combustion engine had eight cylinders and four gears. Today it is the other way around.” The method of energy production must also be taken into consideration: he submitted that the generation of carbon from the EU electricity mix is not recommended. While its production fulfills the requirements for the additional battery weight. Moreover, hybridization here means that the combustion engine is combined with only one six-gear automatic transmission. The e-drive itself, on the other hand, has two gears, which ensures excellent driving performance as well as efficiency. According to Breitfeld, the electrification of power trains will eventually reduce the number of gears.

Internet-connected and autonomous vehicles

Another trend is the Internet-connected car with numerous innovations, such as obstacle warning, traffic light assistant, weather warning for specific routes, electronic brake light, vehicle-to-vehicle communication, and location place services. Driverless driving finally opens up entirely new possibilities: “When I leave my hotel early in the morning, my car is already there,” Dr. Eichhorn said jokingly. Mr. Küçükay also sees further potential for fuel and CO2 reduction in the technologies for predictive vehicles with so-called car-to-X communication and driver assistance systems, all the way to autonomous driving, which is receiving more and more attention.

Driving fun for demanding customers

“A revolution is called for, no longer an evolution,” maintained Carsten Breitfeld, head of the car product line i8 at BMW, referring to the “most progressive sports car in the world,” the BMW i8. It has, he said, all the genes a sports car requires, such as performance, driving pleasure, uncompromising driving dynamics, and sustainable driving. “To build a sports car with low consumption and no-emission driving, it won’t do to replace the combustion engine with an electric drive. Rather you have to go into an entirely new direction,” suggested Breitfeld. Therefore the premium car manufacturer from Bavaria developed a completely new architecture, the so-called Live Drive concept, where the battery is mounted very low in the car, for example, and a carbon body compensates for the additional battery weight. Moreover, hybridization here means that the combustion engine is combined with only one six-gear automatic transmission. The e-drive itself, on the other hand, has two gears, which ensures excellent driving performance as well as great power train efficiency. According to Breitfeld, the electrification of power trains will eventually reduce the number of gears.

Takashi Hata pointed out several times the great successes in the development of his transmission concept: “Today our CVTs offer the desired driving fun and the efficiency that people demand.” By contrast, for BMW manager Breitfeld CVT is “certainly out of the question.”

Electromobility in small steps

It is interesting to note how much room the issue of electrification occupied at the symposium: several speakers emphasized that electromobility is definitely going to come; however, it can only arrive in small steps. Batteries and the limits they place on the cruising range, but also the development of the infrastructure, were identified as the biggest challenges.
Dr. Dirk Uwe Sauer, a professor of electrochemical energy transformation and storage system technology at the Institute for Electric Power Converter Technology and Electric Drives at the RWTH Aachen, brought the participants up to date on the latest developments in battery technology. "It will all come down to lithium-ion batteries, all other technologies only play a minor role by now," he said. However, he does not believe it will be possible to answer all fundamental questions regarding lithium-sulfur or lithium-air batteries before 2025. The large, and still growing, number of battery manufacturers on the market is already resulting in considerable cost reductions, Sauer said but predicted that many of them will not survive. He stated that batteries currently have a specific energy of 140 to 170 Wh/kg, with a cruising range of 100 km (approx. 60 miles) and a weight of 100 to 150 kg. “We will not witness an explosion in energy density with respect to lithium-ion batteries—there are physical limits." Sauer believes that a rate of three to four percent per year is a realistic estimate for the energy density increase. The central challenge is to gain a better understanding yet of the ageing process of batteries. He also called on the transmission manufacturers to give the development of batteries a bit more time. At the cell level, he said, costs amount to approximately EUR 200/Wh, a figure that was originally forecast not to be achieved until 2020.

From Dr. Eichhorn’s point of view, electromobility has arrived at the IAA and at the dealerships; it now still has to reach the customers. In his opinion, whether the goal of bringing one million electric cars onto the roads in Germany by 2020 is realistic, no one can tell yet. He pointed out that the development of electromobility is still highly uncertain and up in the air.

Transmission concepts more diverse than ever
According to Küçükay, having a number of different concepts simultaneously will increasingly become the norm in the transmission and drive industry. He said that the power train sector is undergoing a profound transformation, driven by the endeavor to achieve great efficiency, wide gear ratio spread, low oil viscosity, needs-oriented intelligent actuators, and fast starting acceleration—all this while offering good comfort and a large number of gears, with the upper limit apparently having been reached: “The focus is on increasing drivability and efficiency by selecting the right transmission ratio and operating strategy," said the chairman of the event.

For Magna advisor Demel it is obvious that “the global car” in the volume segment does not exist. Europeans and Americans pay an average of 30,000 US dollars for their cars, while the medium price paid in China and India is 17,000 and 10,000 US dollars respectively. In his opinion this explains that the technical solutions are vastly different in the respective countries. Moreover, a minimum degree of electrification in cars, for instance such features as the start-stop technology, will not become 100 percent established by 2020 but only about 50 percent. Therefore manual transmissions are still going to dominate at a rate of over 50 percent in 2019. Even though Demel believes that the four gears of Dr. Robert Fischer, Executive Vice President of AVL List, is still “in the distant future,” he generally confirmed the trend toward a reduced number of gears. Like some of the other speakers, he sees the necessity of gradually shifting transmission production to the suppliers, which has great potential in his opinion. Briefly summarizing his outlook, the full-blooded motorist stated that the eCVTs will show slow growth, the ATs will decline, the CVTs will continue to grow enormously, production of DCTs will drop, the AMTs will overcome their weaknesses in the quality of shifting gears by way of electrification and garner greater market shares, and the MTs are going to remain at the current level.

CVT transmissions on the rise in Japan
It came as a surprise that the content of the papers on the CVTs met with so much interest. These are currently becoming ever more popular in Asia, especially in Japan, but also in the US. Takashi Hata said about progress in this transmission application: “The CVT technology is flexible, it always provides a solution, especially when you consider that people throughout the world must adapt to the diversity of traffic situations, from the countryside to the mega cities.” Jatco, he said, is pursuing the goal of building an ultimate CVT and combining it with a flywheel drive as well as hybridization. Coen Rooijmans, Senior Vice President of the Dutch company Bosch Transmission Technology, considers the CVT, which makes up 20 percent of the automatic transmissions market, the most popular concept. He believes that this figure will climb to 25 percent over the next few years. For the light to medium-heavy cars, he said, the fuel savings figure is excellent. At the same time, he argued, the CVT for hybrid systems is an attractive solution, as it offers good drivability and fuel savings. In his paper Dr. Demel confirmed the increase in CVT sales.
Discussion about legal requirements and transmission concepts

The challenge of CO₂: How can the future targets be achieved? The panel discussed this issue, which the attendants were able to influence by participating in an electronic survey. As for the question of “In your opinion, what are the legal requirements concerning the CO₂ limit for 2030 for which the automotive manufacturers in the relevant markets have to prepare?” two-thirds of the participants checked 75 and 50 g CO₂/km respectively. Panelist Dr. Carsten Breitfeld would relax if that were to happen, but he said he was afraid that considerably stricter limits will be set by 2030, and in certain areas even zero emissions. Jörg Grotendorst, CEO of the Inside e-Car business unit of Siemens AG, concurred with Mihir Kotecha, CEO of the Getrag Corporate Group, that there will be different CO₂ target values for different regions. Driving in the conurbations, for instance, he believes, will without a doubt have to be emission-free. On the other hand, he pointed out that one must not forget the grid requirements, especially in the mega cities, which would have to be met if every car were electric. Rolf Najork, Chief Operating Officer of Heraeus Holding GmbH since the beginning of 2013, emphasized that all the new developments in the direction of CO₂ savings will also have to be paid by the customers. In view of the emission laws, he argued, more and more technology has to be built into cars which, however, will not necessarily bring the customers more benefits. (Rolf Najork was previously head of the E-Mobility, Mechatronics and R&D Transmission business division as well as a member of the Board of Directors of Schaeffler Technologies AG & Co. KG.)

MT, AMT, DCT, AT, or CVT: when answering the question of which transmission concept can contribute the most to boosting the efficiency of conventional engines by 2030, 41 percent of the participants opted for the dual clutch transmission (DCT). Mihir Kotecha was happy about this result, but with respect to the CVT technology, for which 17 percent of all participants voted, suggested: “We are only just at the beginning of the learning process, and the CVTs are opening up incredible opportunities for us.” And yet, Takashi Hata—who incidentally would personally not spend a lot more money on an electric car—replied, this technology is so simple. According to Dr. Robert Fischer, “AAT is exerting a great deal of pressure on other transmission manufacturers with its CVT.” Fischer believes that the transmission concept for 2030 will depend on the engines that are going to be used in the future. He stressed that “the CVT can get a whole lot” out of engines with very tight fuel consumption maps, “which otherwise is only possible with very finely graded transmissions.” According to Fischer, four gears are definitely enough in hybridized systems. Therefore he stuck to what he had said at last year’s symposium. Breitfeld called for focusing more on weight and efficiency and also said he believed that the number of gears should be reduced.

The panel furthermore engaged in a lively discussion of other issues, such as efficiency, future motorization, and political measures. The development of transmissions, however, is already extremely far advanced, and that, after all, was ultimately the central concern in Berlin transmissions.

More information: www.transmission-symposium.com/germany
Photo gallery: www.konferenz.de/fotos-getriebe2013

Transmission Expo with over 90 international exhibitors

In addition to the convention program, the 12th international Transmission Expo took place. The trade fair with more than 90 exhibitors from Europe, the US, and Asia offered the audience the opportunity to gather information about global industry trends. This year’s exhibitors included AVL List, BorgWarner Drivetrain Engineering, Diehl Metall, GETRAG, Magna International, and PETRONAS Lubricants International, among others. www.transmission-expo.com

For the fifth time already, the organizer, CTI, distinguished young talented scientists for their work in the field of transmission and drive technology by handing out the Young Drive Experts Award. Three applicants received an award for their work: www.transmission-symposium.com/award

Prior to the two-day symposium on December 3 and 4, an introduction day was held which offered newcomers and career changers some insight into the practice of basics of automotive transmissions, HEV and EV drive technology. The CTI test drive at the conclusion of the event gave the participants the opportunity to collect hands-on experience of interesting new and further developments in the field of transmissions, hybrid, and electric drives in almost 20 cars.

CTI symposia in China and the US

With more than 1,100 participants from all over the world, the CTI Symposium in Berlin is considered one of the largest gatherings of transmission and drive experts. In May 2014 CTI will organize a transmission symposium in the US for the eighth time. This year the event took place in China for the second time already. A total of about 1,800 participants attended the last conference in each of the three regions.

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