New Transmissions Make the Gas GREENER

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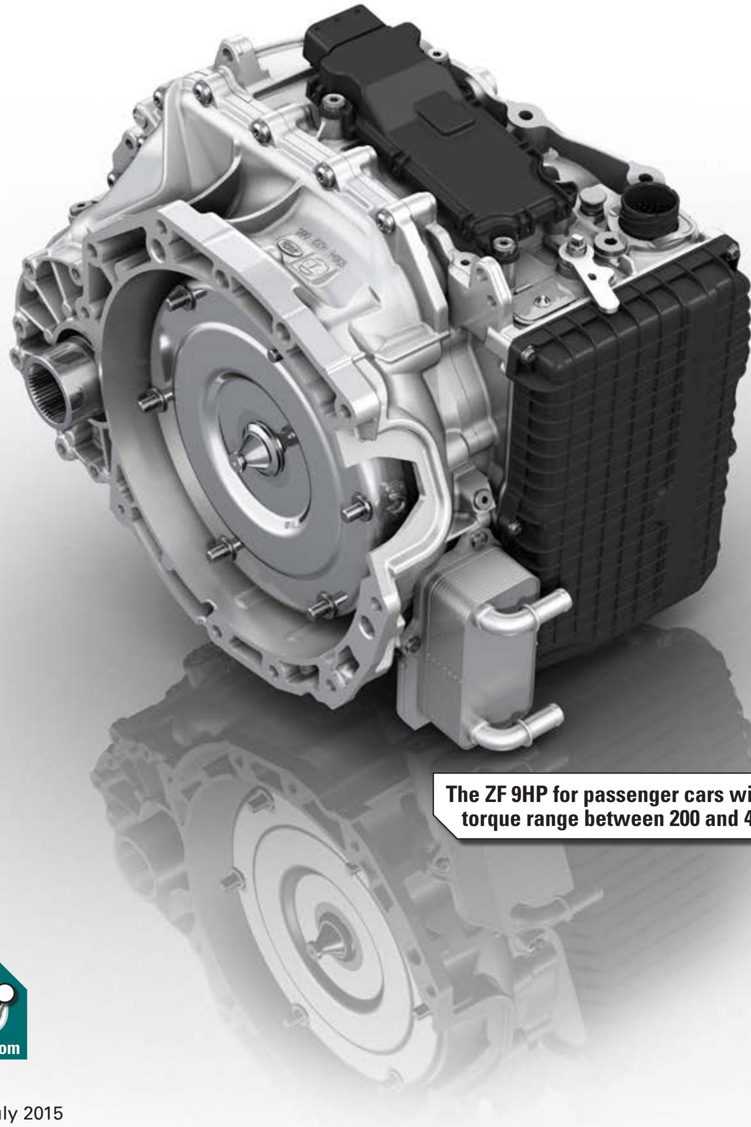
***"Highway vehicles release about 1.7 billion tons of greenhouse gases (GHGs) into the atmosphere each year—mostly in the form of carbon dioxide (CO_2)—contributing to global climate change. The CO_2 emissions of a car are directly proportional to the quantity of fuel consumed by an engine. In 2013, U.S. greenhouse gas emissions from transportation were second only to the electricity sector—an increase of about 16% since 1990."* (EPA.GOV).**

Want to know what is *truly* hot in the automobile industry these days? Not just here in North America, but like—*everywhere*? Want to know the industry's singular issue that can literally affect national elections, the world economy and whatever passes these days for stability in the Middle East? An issue that in fact affects the very quality of life on this Planet and we "driving enthusiasts" who motor around it? It is keeping engineers' hair on fire—with clattering slide rules juggling gear ratios high and low—in order to produce more power and torque for an ever-bigger-bang in an ever-shrinking gearbox.

Boil it to the bone and the Number One issue is revealed: How to extract more clean driving miles from a gallon of fossil fuel-based gasoline? (But, of course, without any sacrifice to speed and "drivability.")

It's about e-n-e-r-g-y. About fuel—and how your Ford or Toyota burns it.



The ZF 9HP for passenger cars with front-transverse drive covers a torque range between 200 and 480 Nm (Photo courtesy ZF).

More precisely, it's about the regular unleaded that powers our cars. And more importantly, it is about the CO_2 gas that is created as a result and then released into the ether via your car's exhaust system. And the hard truth for automakers and consumers alike is that one of the most targeted generators of greenhouse gas is — Ford Help Me — the internal combustion engine. For years it was thought the chemists could solve the problem via re-engineered fuels; e.g., ethanol — a pricey alternative if you happen to live in some parts of the Midwest.

It has taken decades for an industry, its customers, and the governments that regulate them to even begin facing the question: How to extract more CO_2-friendly driven miles from a gallon of gasoline?

We have less than a decade to find the answer. Consider: U.S. automakers face a federal mandate for an industry-wide fuel economy average of 54.5 mpg by 2025. (European carmakers have been dealing with CO_2 mandates for some time now.) To reach that 54-plus mpg target, engineers of all stripes are looking from bumper to bumper for potential efficiency gains and energy savings. (*By design, the scope of this article does not include hybrid or all-electric engine technology. That said — you will see later that it is impossible to discuss today's latest-technology combustion engine-based transmissions without some mention of electric motors.*)

But above all, engineers are zeroing in on transmissions. Why is that?

Before even mentioning gears and transmissions, Dr. Hermann Stadtfeld, Gleason Corporation vice president, bevel gear technology and R&D, explains the answer in part derives from the constant market-driven push for smaller engines to fit today's smaller cars. Smaller engines, smaller gearboxes, smaller gears.

"The development of down-sized engines has led to small-displacement engines — in most cases using turbo chargers, not only for diesel engines," he says. "The newer transmissions consider the changed power and torque distribution of these engines and support the fuel-efficient behavior by offering more transmission ratios (eight-speed and higher). This helps to lower the engine RPM (and) fuel consumption. In case of higher power output requirements, the new transmissions enable the engines — due to more gears — to always operate at or near their torque-optimal point."

Buttressing Stadtfeld's explanation, consider this from Sebastian Strunk, a Gleason applications engineer at their Ludwigsburg, Germany facility.

"In addition to lowering the overall RPM level, several techniques are used to lower the internal transmission losses. For example, by reducing friction and oil churning due to active, targeted lubrication, and by earlier engagement of the lock-up clutch in the case of automatic transmissions with hydraulic torque converters. Automatic transmissions are very complex. In most common automatic transmissions the required ratios are realized via the combination of planetary gearset stages. In the design phase, millions of combinations are possible and are pre-calculated on fast computers, still taking several weeks to come to reasonable results. From these results a preferred combination has to be chosen by a team of human experts, which is a very big responsibility. Because not only the ratios have to be taken into account, but also the future behavior and interaction of the lamellae-clutches and lamellae-brakes in the transmission have to be predicted to anticipate the shifting quality, efficiency and noise emissions.

"Also the manufacturability, strength and wear behavior are crucial, as well as cost-effectiveness. Taking into account that such automatic transmissions will be part of the manufacturer's vehicle lineup for a decade and longer, already during development it must be assured that there is potential for a Generation II and III of the newly developed design in order to adjust to future requirements, and to be able to present frequent product improvements to the customer."

Joining the conversation is Noel R. Mack, director and business unit leader for Riccardo Driveline & Transmission Systems. "(Reducing) CO_2 emissions goes hand-in-hand with using less fuel. Quite simply, the newer transmissions assist in improving the efficiency of the propulsion system. This is achieved by a) implementing more gear ratios, allowing the engine to spend more time operating in the zone of ideal or optimized efficiency; b) with a greater ratio spread, we can operate with smaller engines and still achieve the acceleration levels and top speeds that we are accustomed to; and c) the transmission itself operates more efficiently, wasting less energy and transferring more torque to the wheels."

> "The tendency is that the market share of conventional automatic transmissions is going to decrease in certain segments, like medium and smaller vehicle classes, and the diversity increases. Other forms will appear — like DCTs, or more exotic transmissions like IVTs — and will deliver the torque and efficiency requirements while having lower costs and acceptable comfort."
>
> **— Hermann J. Stadtfeld**

Dr. Jürgen Greiner is the development head of passenger car transmissions for ZF. And while he agrees, "in principle," that "transmissions with higher transmission-ratio spreads and more gears with smaller gear steps… reduce fuel consumption," it is also his position that , "Generally, the number of gears is not a primary feature of a transmission for ZF. When it comes to developing transmissions, the relevant factor is not the number of gears but the spread of gear ratios and drivability that plays an important role; the number of gears is simply the result. Only with excellent shift quality is a high number of gears perceived as comfortable — with no tractive force interruption."

But of course the need for speed will always exist for drivers of all stripes. As Stadtfeld points out, "Although efficiency is very important today, the higher number of gears also manages an immediate adjustment of the ratio to a point where the engine is capable of the highest possible power delivery in order to

Premiere in the BMW 5 Series: The 520d is the first production model to come off the production line with the new ZF 8HP transmission generation (Photo courtesy ZF).

realize fast acceleration."

By the way — just *what kind* of transmissions are we (or should be) talking about? For our general purposes, two — 1) the best-known-in-the-U.S. automatic transmission (AT); and 2) the continuously variable transmission (CVT), well known and used in Japan. Though others exist, the talk is mainly about ATs vs. CVTs, along with some "hybrid-type" transmission talk as well. ZF's Greiner begins some transmission anatomy for us:

"An *automatic transmission* (AT) comprises several (planetary) gearsets, in different quantities and combinations. For example, there are four planetary gearsets in the new ZF 9-speed automatic transmission. The various ratios — i.e., gears — of the planetary gearset are generated by fixing one gear and by connecting and disconnecting various shafts. This is done using so-called shift elements (friction shift elements such as multi-disk clutches or multi-disk brakes), and constant-mesh elements. In the new 9-speed automatic transmission, there are a total of 6 shift elements, two sets of multi-disk clutches and brakes, as well as two dog clutches — a first in passenger car automatic transmissions.

"Most types of transmissions are stepped transmissions. This means they have a specific number of gear pairs that offer a fixed number of gear ratios, depending on the design. The power range of the combustion engine cannot be fully harnessed, however, with this limited number of transmission stages. In contrast, a *continuously variable transmission* (CVT) is, as the name suggests, a transmission that can change seamlessly through an infinite number of effective gear ratios. This is particularly beneficial for the characteristics of a combustion engine. Along the entire engine performance graph, operation can be adjusted with a continuously variable transmission ratio to achieve optimum fuel consumption or fastest acceleration on request."

But, as Greiner then adds, "Unlimited speeds, like in the case of the CVT, reduce efficiency since you need energy for the transmission of power. The system-related lower efficiency; limitations when transmitting torques; the maximum transmission ratio range to be achieved; and the higher weight reveal the physical limits of (CVT) design. The CVT is the most demanding and most expensive (to manufacture)."

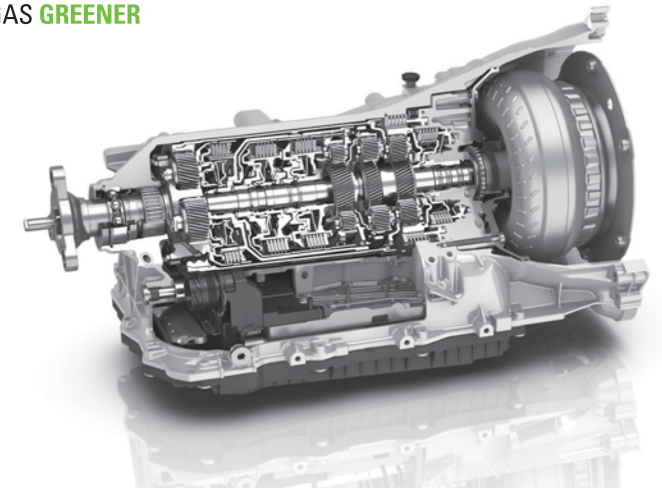
"A 'conventional' gear transmission is really region-specific," Mack points out. "In, say, North America, it (transmission) would be a torque converter, planetary automatic. In many other parts of the world (e.g., most of Europe) it would likely be a manual transmission.

"There are also many variants of 'hybrid transmissions' under consideration," says Mack. "Most current hybrids in passenger cars today are electric hybrids. With many possible variants — from an inline electric motor on the transmission input to the well-known input split transmission as used in the Ford Escape, which has two electric motors with an internal combustion engine, with one motor operating across a planetary gearset—creating an (IVT)."

But, "Maybe the name 'conventional' automatic transmission becomes outdated," suggests Stadtfeld. "In the U.S., from the 1950s until the early 2000s, these kinds of transmissions with three and later mainly four-speeds were most popular. Then even more speeds were introduced in conventional ATs. In addition, CVTs and double-clutch transmissions (DCTs) had been introduced. For example, the market share of CVTs in 2014 is around 19% of all automatic transmissions (*Source: EPA Technology Trends 2014*).

"The gears transmit the power via positive-form engagement, whereas the clutches transmit the power via friction contact. Nevertheless, due to the intelligent use of other positive-engagement units like dog couplings, lamellae brakes can be replaced, helping to reduce friction losses. An additional standard element to improve the efficiency is the lock-up clutch to bypass the torque converter in situations when it is not required and would only lower the efficiency due to slippage.

"CVTs require, next to their variable transmission unit, either a lamellae clutch or a torque converter as a start-up-element. The power is then transmitted to one of the variable cone-shaped pulleys. This pulley transmits the power via a metal push belt to the other pulley that transmits the power to the output shaft. The required ratio is generated by an adverse variation of the two pulley diameters. The power is transmitted via friction contact. For this reason the pressing forces between the pulleys and the belt need to be high enough to avoid slippage at the required torque. This leads in general to a high power consumption of the internal hydraulic system and the friction between the belt joints, lowering the efficiency of the system."



ZF's enhanced second-generation, eight-speed automatic transmission (8HP) is designed to provide effective support for automotive manufacturers in meeting the ever-stricter legal CO_2 standards—and in a cost-effective manner in combination with conventional or hybridized drives (Photo courtesy ZF).

Well what then of the ballyhooed (gas-and-electric-powered) hybrids?

Says Stadtfeld, "Today there is a large diversity, with increasing numbers of automatic transmissions based on different concepts. The tendency is that the market share of conventional automatic transmissions is going to decrease in certain segments, like medium and smaller vehicle classes, and the diversity increases. Other forms will appear—like DCTs, or more exotic transmissions like IVTs— and will deliver the torque and efficiency requirements while having lower costs and acceptable comfort."

Is it harder to design these new transmissions for Cadillacs than Fiats, for example?

As Mack explains it, "The role of the transmission is to most effectively integrate the requirements of the vehicle to the characteristics of the engine. It is really all about transferring the power from the internal combustion engine to the wheels. The transmission ratio essentially defines the speed at which the engine operates, and we need to get the engine into its most efficient zone of operation. If the engine torque is reduced and the vehicle requirements remain the same, the transmission will need to be "longer lever"—i.e. more ratio coverage. We also need smooth transitions from one discrete ratio to the next and sufficient refinement. The level of challenge in designing for a powerful-luxury vehicle or a smaller segment is very much the same."

Greiner believes that, "In principle, it makes sense to use transmissions with higher transmission-ratio spreads and more gears with smaller gear steps to reduce fuel consumption."

But with increasing ratios come, it would seem, greater complexity.

Greiner responds that, "If we could fit even more gear steps in the space currently available, it is initially technically possible for the number of gears to reach double-digit figures. Gradually, we are reaching the boundaries of what is sensible. For example, the transmission's spread of gear ratios is now so wide that engines are at the limit of being drivable. Electric motors and combustion engines need to be combined to work together in harmony. Integrated electronics as well as an intelligent drive management embedded in driver assistance functions are necessary to achieve this."

While it is hoped the above back-and-forth has brought some clarity to the discussion of newest-technology, CO_2-friendly automobile transmissions, the question arises: If there were no air pollution, would we even be having this discussion, or is this transmissions evolution simply a marketplace inevitability?

What a stupid question to ask engineers.

"In our nature as humans, essentially we always want to improve upon the status-quo, and strive for a competitive advantage," says Mack. "The competitive marketplace drives the need for more features, more performance, driving 'fun' and, of course, higher value. The government regulations are merely accelerating the rate of development with certain criteria in mind. The drive for lower CO_2 emissions or higher MPG can also be viewed as wasting less energy. Over the prior century we have constantly evolved the science of transmission engineering with a common goal—to increase efficiency, transfer more of the torque, and waste less."

"Pollution is only one aspect why we have this transmission evolution," says Stadtfeld. "Besides the cost of gasoline for the consumer, also the production of gasoline is connected to certain environmental implications. Vehicles with automatic transmissions newer than model year (MY) 2010 already consume, on average, the same or less amount of gasoline than their manual counterparts, while offering other advantages. For example, current and future automated driving systems would be impossible with manual transmissions. In addition, more gears deliver a smoother driving experience with better capability to use the engine's power. But more gears require the transmission to be automatic because only a very few people would accept shifting through 9 or more gears in a car while constantly watching the optimal shift timing to achieve smooth and efficient driving." Here's one last big question: Which of the new technologies has the best chance of replacing "conventional" transmissions? Is there a logical endgame?

It depends. Good luck defining "conventional," for instance, when describing transmissions.

"This is not an easy question to answer, and I wish I had a crystal ball," Mack admits. "The definition of a 'conventional transmission' is not standing still, and is regionally defined. There are two primary factors to consider. First, from a propulsion system viewpoint, we need to attain an optimum system efficiency, which includes using the transmission to "move" the operating point of the engine into its sweet-spot; and secondly, the transmission itself, regardless of architecture chosen, will evolve to constantly improve the state of art. Gears have been and will likely remain the most efficient method of transferring torque. Amongst the 'new transmissions' we would include DCTs and many hybrid electric variants. With recent developments in some CVT technologies, there may be a challenge on the horizon. There are multiple technologies with promise and the potential means to effectively achieve the goals. We continue to see an evolving mix of technologies — with no single winner. Consumer demand will also play a role in the proliferation of technologies on our roads. Pros and cons are unfortunately not based merely on technical merit, but also on many other market drivers; e.g. — legislation, consumer acceptance, cost, manufacturing investment, etc."

"We see new focal points" Greiner allows — if not so much for gears — "in the field of power electronics, the intelligent driving strategy, the development of ever improved electric motors, or the integration of the electric drive in the installation space which before was

ZF's 7-speed DCT. Direct-drive and rapid gear changes with no interrupting shear force make for very sporty driving. This DCT also achieves better fuel economy than that of a manual transmission thanks to enhanced fuel engineering.

reserved exclusively for the transmission. The further you go in the direction of hybrids or electric vehicles in the future, the less gears will be needed, dependent on to what extent combustion engines make up the drive. Electric motors and combustion engines need to be combined to work together in harmony."

We had to ask for predictions of what kind of transmission will be used in the first *truly popular* car with an *all-electric* engine? Will torque control still rule?

Gleason's Strunk: "Due to the significant difference in power output characteristics between ICEs and vehicles with electric motors that deliver instant torque over a wide RPM-band, theoretically no transmission is required to fulfill standard requirements regarding drivability and efficiency.

"Of course the development of transmissions for ICE engines showed soon that "standard" is not enough. From an objective point also electric motors have a peak point of efficiency which can only be utilized over a wide range of driving conditions with a multiple speed transmission. Based on the limited and expensive battery capacity it seems even more important to save precious energy onboard the electric vehicle by optimizing the drivetrain.

"Recent developments show that a two to four speed transmission in an electric vehicle will contribute to achieve higher efficiency levels, higher top speeds and even higher performance levels with better packaging. But apparently there is also a subjective component of being the first to offer a multi speed transmission in electric vehicles similar to the raise in 8, 9 and 10 speed automatics in fuel burning vehicles."

Says Riccardo's Mack. "With the nature of the torque-generating capability (the torque curve) of an electric motor, a single-speed transmission should be adequate in a small passenger car-type application. When applied to a larger or more luxurious vehicle, a single reduction ratio will either limit the lower-end torque or the higher-end speed capability. To overcome this, a two-speed transmission will be utilized to provide more low-end torque at the wheels while being able to operate at a higher top speed. A two-speed transmission will also allow the electric motor to spend more time operating at or near the motor's area of optimum efficiency. We would predict that we will still use multi-ratio transmissions with many of these electric vehicles."