

EVOLUTION TO THE SEVEN-SPEED AUTOMATIC TRANSMISSION 7G-TRONIC PLUS

Daimler finalized the advanced development of the sixth generation of its seven-speed automatic transmission for more comfort, less fuel consumption and more driving pleasure. Assembled in E-, R-, S- and CL-Class, the 7G-Tronic Plus has a new fuel efficient torque converter with centrifugal pendulum damper and regulated zero slip at the torque converter lock-up clutch as well as a new automatic transmission lubricant (FE-ATF).

AUTHORS



DIPL.-ING. (FH) JENS DORFSCHMID
 is Project Manager 7G-Tronic Plus at Daimler AG in Stuttgart (Germany).



DIPL.-ING. WERENFRID DÖPPER
 is Manager Testing Automatic Transmission at Daimler AG in Stuttgart (Germany).



DIPL.-ING. DIPL.-WIRT.-ING. GERD JÄGGLE
 is Manager Transmission Fluid Pump /Electromotive Actuator at Daimler AG in Stuttgart (Germany).



DR.-ING. KAI HEUKELBACH
 is Development Torque Converter at Daimler AG in Stuttgart (Germany).

TRANSMISSION EVOLUTION

In the fall of 2010, Mercedes-Benz Cars launched the latest version of its seven-speed automatic transmission 7G-Tronic [1] called 7G-Tronic Plus for passenger cars in the S-Class, R-Class, and E-Class with the V6 diesel engine and in the CL-Class with the new V8 gasoline engine. The S-Class will also be offered with the four-cylinder inline diesel engine and with the new V6 and V8 gasoline engines from the start of 2011 with this new transmission.

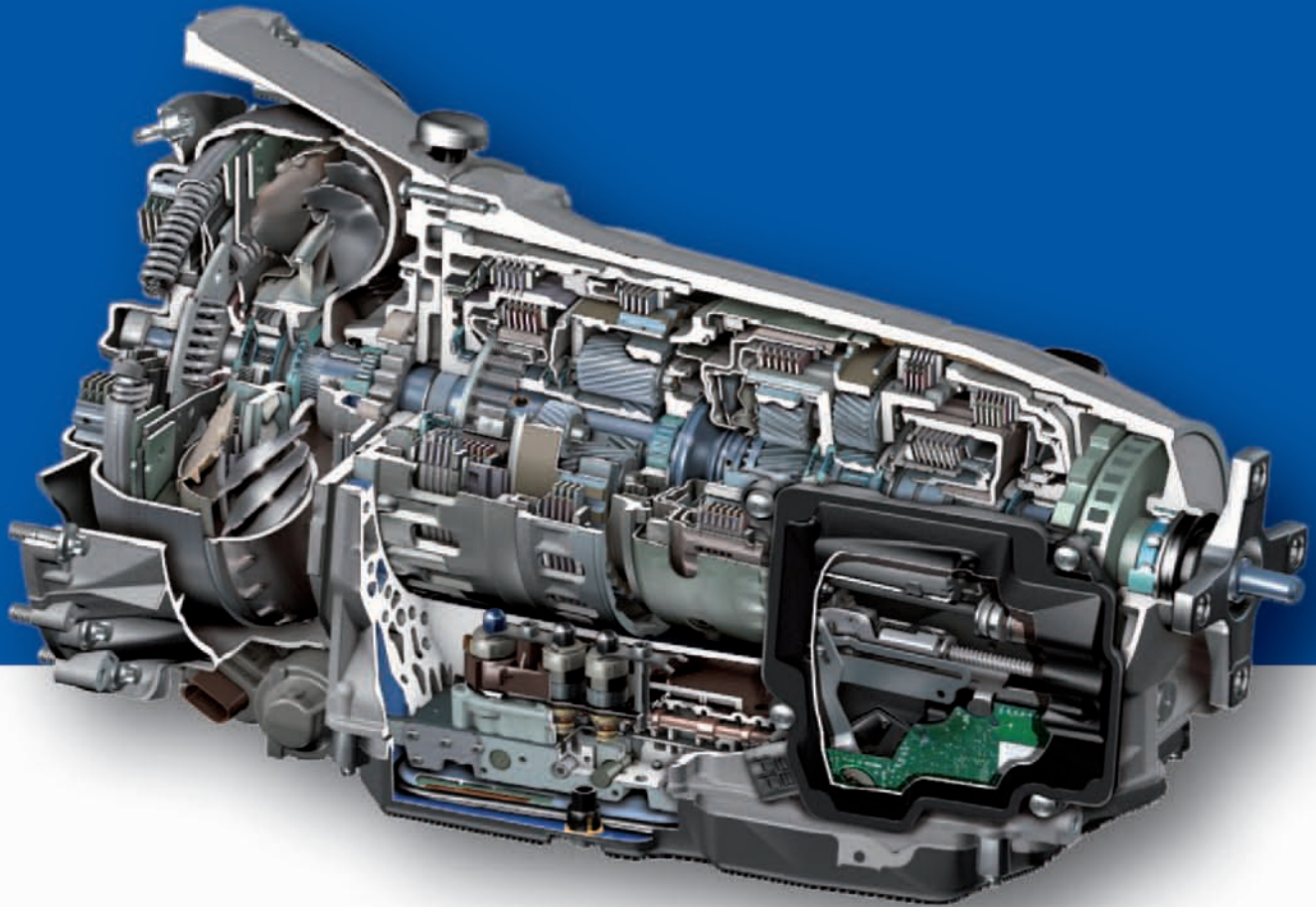
With this transmission evolution, the five-speed automatic transmissions W5A330 and W5A580 currently available will likewise be discontinued, albeit successively, for passenger cars and vans with a four-cylinder engine but also from 2012 the

reinforced five-speed automatic transmission W5A900 in connection with twelve-cylinder gasoline engines. The new, sixth generation automatic transmission 7G-Tronic Plus, which dates back to 1960 and has been continually developed and manufactured by the company ever since, is internally designated the W7C700 and W7X700 (for the integrated all-wheel-drive version 4Matic and W7C1000 for the reinforced transmission version [2]). This automatic transmission delivers approximately 7 % better overall fuel economy than the predecessor transmissions W7B700 and W7X550 (as tested in the NEDC cycle) while making a significant contribution to reducing the CO₂ emissions of the Mercedes-Benz fleet. Using the six-cylinder diesel engine in the S-Class as an example, this equates to 17 g of CO₂ per km or 0.64 l per 100 km [3].

DEVELOPMENT OBJECTIVES

Further improving the energy efficiency (fuel economy, FE) of the current transmission 7G-Tronic [1] was one of the main development objectives, ①. The transmission design incorporated a wide variety of measures designed to lower fuel consumption:

- : an extreme reduction in torque converter slip thanks to a new converter generation
- : new FE low-friction automatic transmission fluid with accompanying changes to the geometry and materials selected for the transmission
- : an improved Eco shift program that considerably reduces engine speed in conjunction with optimal damping systems in the converter



: friction-reducing measures for bearings and disks.

Compared to other measures for reducing individual vehicle consumption as required by the markets and international legislation, the new transmission provides exceptional performance and value when it comes to reducing CO₂ emissions in line with target objectives. This could only be achieved by leveraging available technologies and processes as far as possible.

Additional improvements and functions that the customer will experience were also realized, ②:

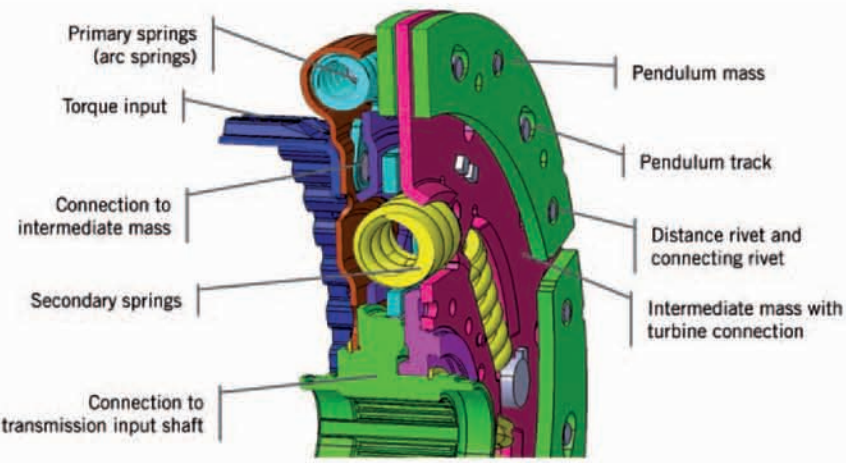
- : improved dynamic response to movements of the accelerator pedal as a result of a more direct connection to the engine
- : better shift quality thanks to improvements made to the electro-hydraulic control

FEATURE	VALUE	UNIT
Maximum sustainable transfer capacity of transmission input coupling downstream of converter	700 / 1000	Nm
Maximum permissible output torque	2700	Nm
Diameter of converter	270	mm
Total length (depending on joint flange and converter)	619 – 640	mm
Weight (including converter and fluid; depending on the engine, the optional shift-by-wire system, and optional start-stop system with auxiliary oil pump)	83 – 93	kg

① Technical data of the automatic transmission 7G-Tronic Plus

LOCK-UP CLUTCH	VIBRATION DAMPER	HYDRAULICS
: Optimized engine launch behavior under cold conditions and low barometric pressures : Improved clutch cooling	: Opportunity of “zero slip” lock-up clutch and lower enginespeeds (eco-shifting), reduced fuel consumption : Improvement NVH	: Better launch and driving performance : Higher efficiency, reduced fuel consumption, more comfort in lock-up clutch control
Surface pressure –15 %	Torsional angle 42° (currently 17°)	Efficiency 90 % (currently 85%)

② Basic new design of the torque converter enables improvements in fuel consumption, NVH und cooling



3 New speed adaptive twin-turbine torsional vibration damper with centrifugal force pendulum

- : lower levels of noise, vibration, and harshness (NVH) and lower engine speeds via Eco shift programs
- : start-stop capability by way of an additional electric pump
- : extended service life of transmission fluid due to reduced friction and optimized formulation.

TORQUE CONVERTER

A modular, next-generation torque converter was designed with an improved hydraulic circuit, torque converter lock-up clutch, and dampers to accommodate, in particular, the dramatic increase in torque generated by the new V8 gasoline engine and the torque increase of the four and six-cylinder diesel engines. This corresponds also with increased demands on damping the imbalances and on aggravated consumption targets with minimum frictional loss.

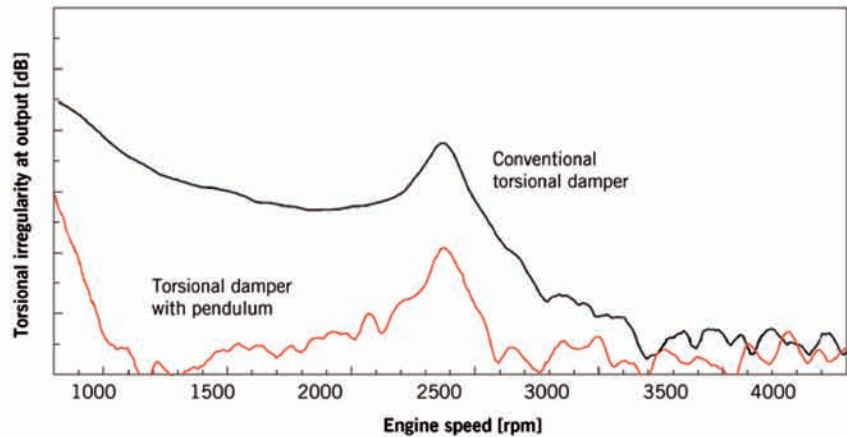
The torque converter, 3, assumes many functions in modern automatic transmissions. When the vehicle accelerates from a stop, for example, the engine must be smoothly connected to the drive line and output efficiently transferred to ensure high performance. Both tasks are carried out exceptionally well due to the hydraulic power delivery, which also bumps torque. An output unit, the torque converter must likewise convert power with as little frictional loss as possible. This is managed by a torque converter lock-up clutch, which splits the power as per the hydraulic characteristic curve. Efficient delivery via the lock-up clutch

also means that imbalances created by the combustion engine are channelled directly into the drive line. In order to provide a high level of comfort here as well, a performance torsional damper is required.

The development goal in defining the hydraulic characteristic curves was to find the ideal balance between a suitably high stall torque ratio and a high level of efficiency. Since the two variables cannot be optimized independently of the other, achieving this balance was key to ensuring good start-off performance. Realizing very high efficiency also facilitates a comfortable transition between the hydraulic characteristic curve and the torque converter lock-up clutch within the power split. The power curve was defined using turbocharged engines, which resulted in flat to slightly upward sloping curves.

The torque converter lock-up clutch continues to utilize the proven three-channel system, which has since been improved in key areas. The path that the cooling oil takes to the clutch plate set, for example, has been redesigned to flow directly toward the coupling package. This provides for especially effective and efficient cooling. Another change was to increase the gap between the clutch disks so that the clearance of the coupling package could be optimally used and drag torque significantly reduced. The result is much improved performance, especially under cold-starting conditions, when engaging a gear typically reduces the rotating speed of the engine.

Damper development was mainly influenced by three factors with respect to the torque converter, all of which target a reduction in CO₂ emissions. First, the trend in engine design is toward increasing output and torque with ever-smaller engines (less displacement). This can only be achieved through heavy turbocharging or supercharging, which further increases rotational imbalance. This imbalance, in turn, is channelled directly into the drive line. Second, the good power delivery of the engines at low speed, in conjunction with today's typically wide gearbox ratio, makes it possible to introduce an exceptionally low-speed drive program, whereby the engine is principally driven at higher excitation levels. Last but not least, developers wanted to eliminate slippage of the torque converter lock-up clutch in order to promote efficient power delivery, which would be impossible using the damping characteristics of this setup. The answer to these



4 Torsional de-coupling to a six-cylinder diesel engine

three challenges came in the form of a centrifugal pendulum damper, ③, designed in conjunction with the company LuK.

This damper initially comprises a conventional twin-turbine damper. Its distinctive characteristic, however, is the fact that a pendulum mass is connected to an intermediate damper mass and functions as an additional damper. A standard damper comprises a spring mass oscillator that responds to a specific excitation frequency, which is determined by spring stiffness and mass. With a pendulum, however, the natural frequency depends on gravitational acceleration and the length of the pendulum. Since gravitational acceleration in the rotating reference system of the torsional damper can be replaced with centrifugal force, the natural frequency fluctuates with the speed of the engine. Designed appropriately, the natural frequency is always in line with the engine order, allowing the main excitation frequency to be almost fully compensated (dampened). This damper design makes it possible to operate the torque converter lock-up clutch without slip – while ensuring maximum comfort with respect to the drive line noise caused by torsional excitation.

The only way to realize a similar outcome using conventional technology would inherently require more space and significantly increase the weight of the drive line, ④. Another advantage of the pendulum approach and the regulated zero slip associated with it is a more direct connection between the engine and the drive line, which increases driving pleasure while reducing CO₂ emissions.

TRANSMISSION MECHANICALS

The basic transmission 7G-Tronic [1] was systematically refined to further reduce frictional loss. This was achieved by using the world's lowest-viscosity automatic transmission fluid (ATF), which was formulated in close collaboration with Shell, Afton, and Fuchs.

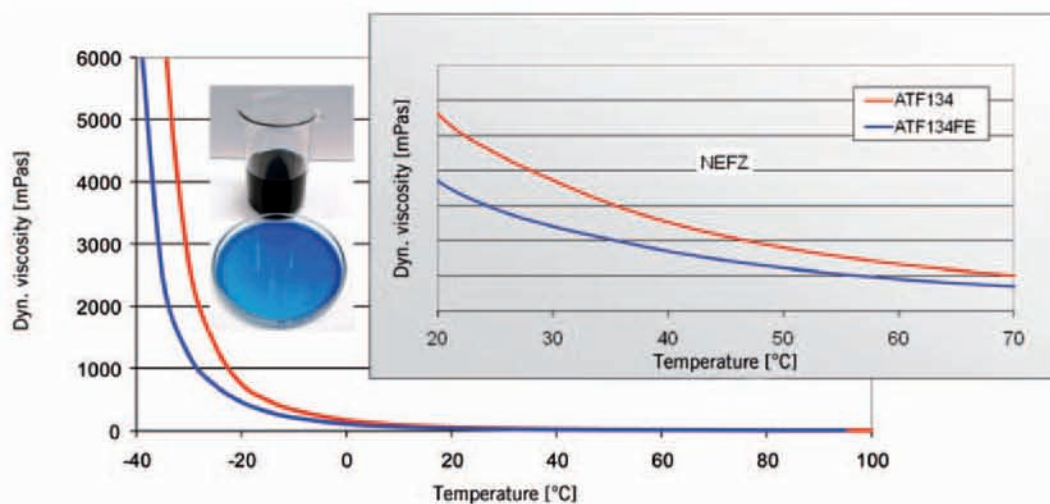
In particular, the new ATF134FE had to provide an optimum balance between reduced dynamic viscosity, temperature, friction level, and volumetric and mechanical efficiency, ⑤. Internal leakage and seals, foaming, lubrication properties, and bearing construction were therefore key design challenges. These problems were solved by harmonizing the base oil, viscosity and friction characteristics (viscosity index), and lubrication and pressure-transfer additives in the fluid with tribological and anti-leak adaptations made to various transmission components (for example planetary gear set materials, seals, transmission oil pan) and temperature-related improvements to the control software. The new transmission oil is not backwards compatible due to the target-oriented optimization measures implemented for all tribological systems, which encompass the oil itself and the bearings, seals, gearing, and friction plates. To visually reinforce this, the transmission fluid has been dyed blue instead of the previous red to prevent confusion during maintenance. Optimized vehicle cooling, an improved fluid formula, and reduced friction throughout the transmission translate into extended service intervals, whereby the fluid no longer must be replaced the first 50,000 km, but every 125,000 km only.

TRANSMISSION MECHATRONICS

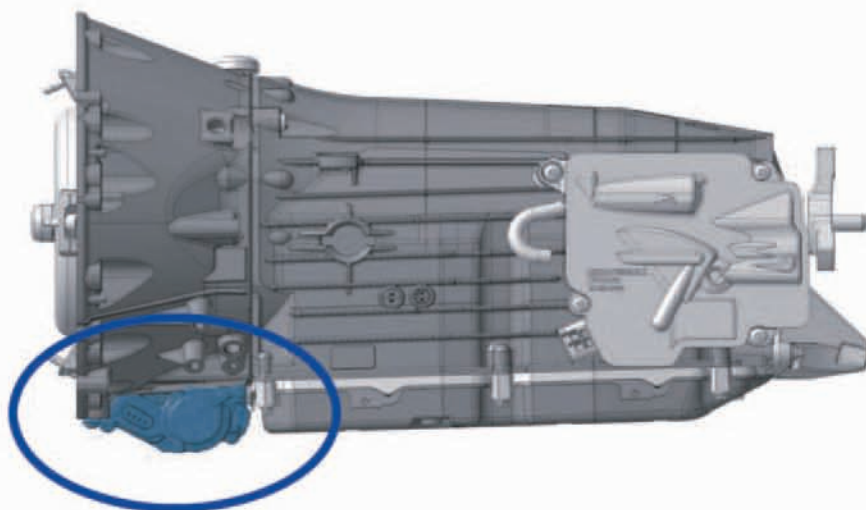
Detailed improvements to the electrohydraulic control unit, integrated in the transmission, and reduced friction in conjunction with optimized engine and transmission software, likewise better shifting dynamics and shifting quality. The focus of development work was on more effectively leveraging the volumetric oil flow rate available by lowering engine speed at idle and using a low-viscosity transmission fluid to minimize the hydraulic loss associated with the transmission controller. To this end, the hydraulic channels in the shifting plates were optimally positioned and arranged to reduce such loss.

The new seven-speed automatic transmission is equipped with a start-stop system for the first time. This makes possible with the addition of an electric auxiliary transmission oil pump, ⑥, that safeguards the pressure supply when the mechanical transmission oil pump is not running (engine off). When the driver comes to a stop at a red light, for example, the engine switches itself off. As soon as the foot brake is released or the accelerator pedal pressed, the engine starts as if it were running the entire time.

Intelligent technology provides for comfortable, instantaneous engine starts. A crankshaft rotation sensor detects the resting position of the pistons. The electric auxiliary transmission oil pump, mounted externally to the converter housing for the transmission with start-stop system, maintains the minimum level of pressure required in the transmission when the engine is switched off. The shift elements remain filled and the transmission can be



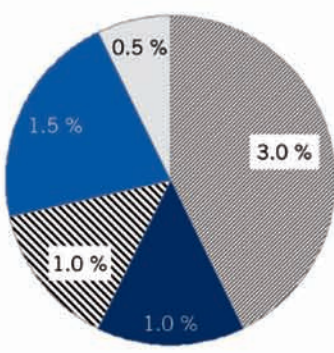
⑤ Comparison of viscosity of the old transmission fluid ATF134 versus the new one ATF134FE



- : Shifting elements of the transmission remain oil-filled with stopped transmission constant pump because of engine-off during start-stop mode
- : Opportunity of a quick relaunch of the vehicle after engine start
- : Electric pressure supply, comfort-oriented and reproducible

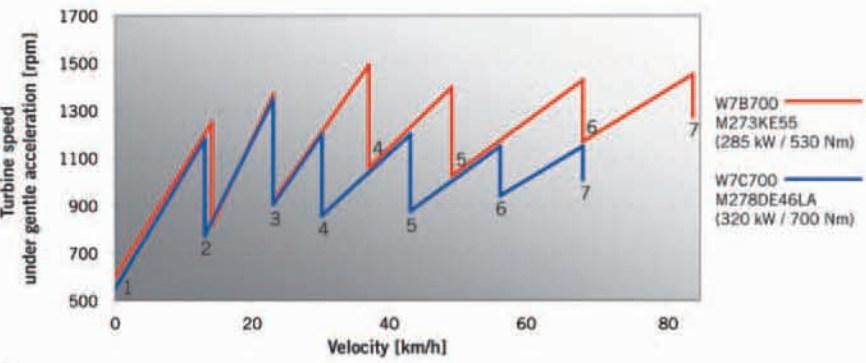
HYDRAULIC PRESSURE	Max. 2.5 bar at 6 l/min
ATF TEMPERATURE (WORKING)	10 – 125 °C
BATTERY VOLTAGE	9 – 16 V
POWER ELECTRONICS	Integrated
CONTROLLED BY CAN	Motor current controlled
CURRENT CONSUMPTION	Max. 8,5 A
MAX. OSCILLATION	Up to 50 g

6 Auxiliary electro-hydraulic pump for start-stop operation



- FE torque converter / lock-up clutch slip reduction
- Line pressure optimization
- Reduction of drag losses
- FE-ATF
- Eco shifting program optimization

7 Average percentage fuel economy improvement of 7G-Tronic Plus (NEDC)



8 Comparison of shifting programs for an eight-cylinder gasoline engine (blue: improvements by W7C700 transmission)

smoothly engaged immediately after the combustion engine has started. This process can be repeated in shortest time. It is realized by a G-rotor pump (crescentless internal gear pump) powered by a direct current motor with integrated electronics, which are controlled by the transmission controller via CAN.

The starter then simply has to provide the initial impulse to automatically start the engine. The engine control unit only switches the engine off if critical predefined criteria have been met. These encompass the starter battery, which must have a sufficient charge, and the engine, which must be warm enough for the exhaust gases to be optimally treated upon start-up. The same applies to the interior temperature set by the driver. If this temperature has not yet been reached, the engine will not be switched off at a standstill. The on-board management system ensures that any active audio, telephone, or video signals are not interrupted by the Eco start-stop function. A yellow "Eco" icon indicates to the driver that the Eco start-stop function is enabled but has been temporarily overridden because of a conflict with one of the mentioned criteria. When all criteria for switching the engine off have been met, the "Eco" icon turns to green.

The average percentage fuel economy improvement by the improved transmission is shown in 7 with 7 % in total. Using start-stop further 4 % are possible due to shut-down of the combustion engine in idle of the consumption cycle.

SUMMARY

Finally, the new seven-speed automatic transmission from Daimler is equipped with a start-stop system for the first time, made possible with the addition of an electric auxiliary transmission oil pump that safeguards the pressure supply when the constant-flow pump is not running (engine off). The vehicle can start off again without delay following a brief stop.

A next-generation torque converter optimizes NVH levels thanks to more advanced dampers, which also noticeably reduce fuel consumption. This is achieved by greatly reducing the slip of the lock-up clutch (actively regulated zero slip) in conjunction with better mechanical damper insulation from very low engine

speeds and during gear shifts, despite the fact that the nominal and reaction torque of the engines has increased. The gear shift program has also been modified to reduce engine speed in Eco mode, ④. In addition, the new FE converter provides for optimal acceleration from a stop, smoother operation of the torque converter lock-up clutch, and better response to movements of the accelerator pedal.

Consumption-reducing measures were implemented for the transmission as well and include new automatic transmission fluid (ATF134FE) with reduced viscosity in conjunction with an optimized additives package, redesigned internal componentry for the transmission, with new materials, bearings, disk linings, and geometric enhancements, and adapted software, lower service pressure at many operating points, and better internal seals. The reworked electronic control unit for the transmission, together with improved software, make shifting smoother.

REFERENCES

- [1] Greiner, J.; Indlekofer, G.; Nauerz, H.; Dorfschmid, J.; Gödeke, T.; Dörr, C.: Siebengang-Automatikgetriebe von Mercedes-Benz. In: ATZ 105 (2003), Nr. 10, S. 920-930
- [2] Wieland, D.; Schröder, R.; Tennert, P.; Gansloser, P.; Nied, H.: Der Antriebsstrang für die S-Klasse 4Matic – Effizient und leistungsstark. In: Die neue 4Matic in der S-Klasse von Mercedes-Benz. Sonderausgabe von ATZ/MTZ, September 2006
- [3] Henning, G.; Dorfschmid, J.; Gödecke, T.: Das Getriebe als Schlüsselement im modernen Antriebsstrang. Vortrag, AVL Konferenz Motor & Umwelt, Graz, Österreich, September 2010

THANKS

Today, the development of the components of an automobile is teamwork everywhere. The authors like to thank Dipl.-Ing. (FH) Henrik Kalczynski, Team Leader Hydraulic Control Units Automatic Transmissions, at Daimler AG in Stuttgart (Germany), for his contribution to this article.