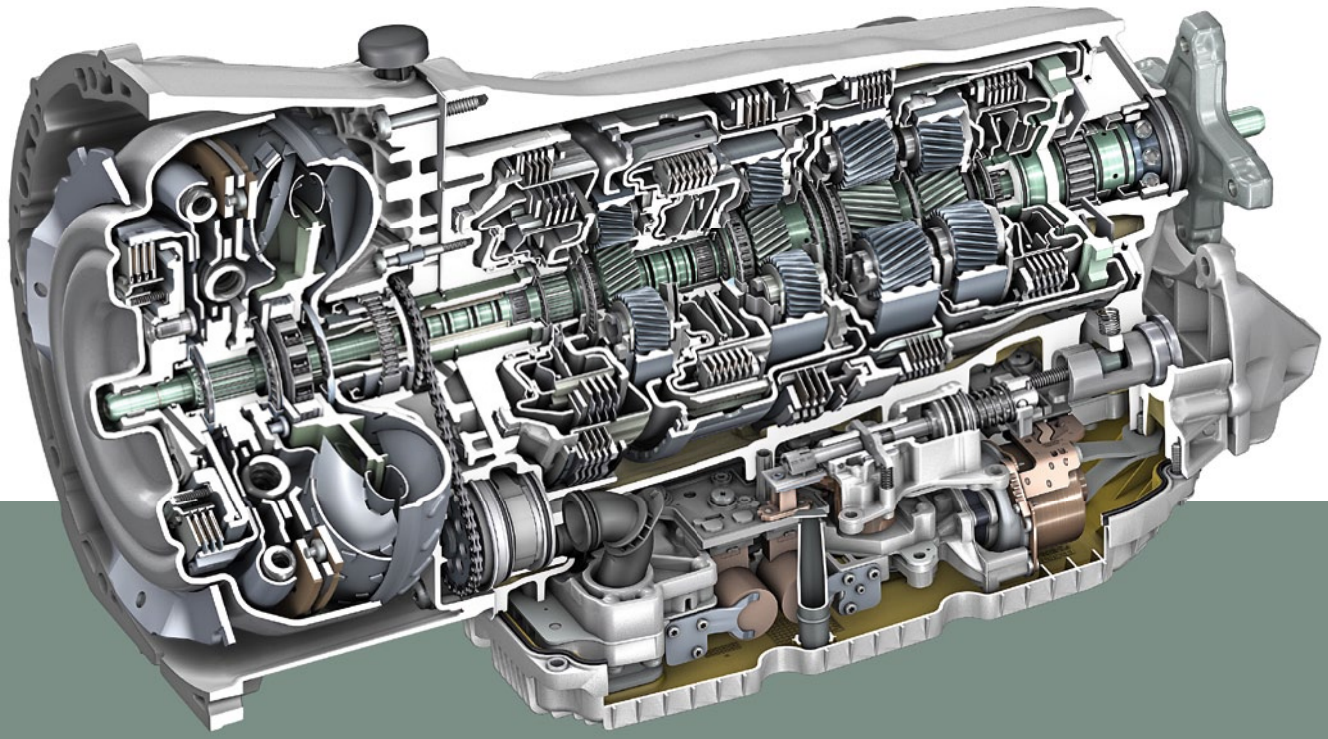


NINE-SPEED AUTOMATIC TRANSMISSION 9G-TRONIC BY MERCEDES-BENZ

Daimler has designed the first nine-speed automatic transmission for longitudinal applications. The 9G-Tronic debuts in the Mercedes E 350 Bluetec and will be introduced in other models later on. Thanks to the higher efficiency of the patented transmission concept, the NEDC consumption of the E 350 Bluetec drops to 5.3 litres Diesel per 100 km. The improvements are primarily due to the new gear set and the on-demand actuation concept with a small main pump and electric auxiliary pump.

AUTHORS

DR.-ING. CHRISTOPH DÖRR
is Senior Manager of Project Development 9G-Tronic at Daimler AG in Stuttgart (Germany).

DIPL.-ING. HENRIK KALCZYNSKI
is Manager of Hydraulic Transmission Development at Daimler AG in Stuttgart (Germany).

DR.-ING. ANTON RINK
is Manager of Transmission Control Development 9G-Tronic at Daimler AG in Stuttgart (Germany).

DIPL.-ING. MARCUS SOMMER
is Manager of Automatic Transmission Development at Daimler AG in Stuttgart (Germany).

AUTOMATIC TRANSMISSIONS AT MERCEDES-BENZ

Mercedes-Benz has been developing and producing automatic transmissions for more than 50 years. Search processes for a concept of planetary gear sets are typically done by analytic synthesis and computer based since many years [1, 2]. For the system search of a new and efficient transmission system for the 9G-Tronic a specific software tool was developed. With specific constraints like size, ratio, spread and optimal gear efficiency, billions of couple systems were analysed, valued and in some cases even designed. Accordingly, the final system of the 9G-Tronic was patented in the year 2008 worldwide, ❶.

TRANSMISSION GEAR SYSTEM

The gear layout of the 9G-Tronic, ❷, consists of four single planetary gear sets, six shift elements, three clutches and three brakes. With these elements, the 9G-Tronic has nine forward speeds and one reverse speed. The 9G-Tronic is designed for torques up to 1000 Nm.

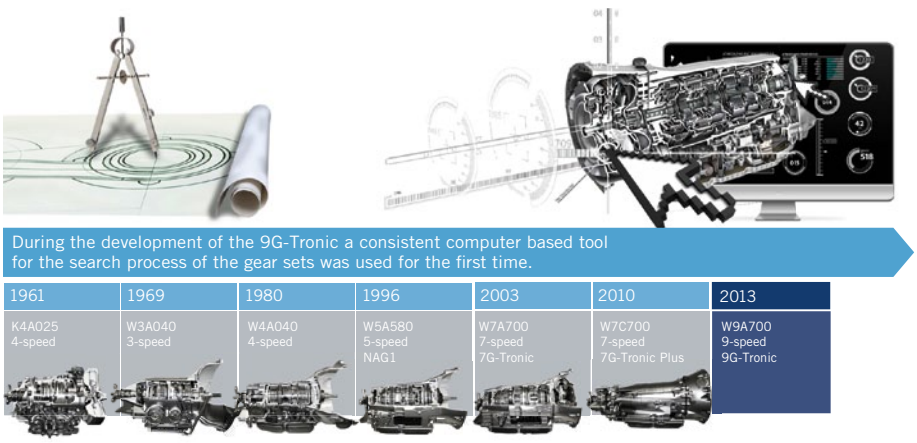
Compared with predecessor transmissions the 9G-Tronic is a complete new development and design. For a comfortable drive, harmonic gear steps and the high ratio of 9.15 are important. The ratio of the reverse gear was set between first and second gear. Thus smooth launches are possible, forward as well as backwards.

TRANSMISSION MECHANICS

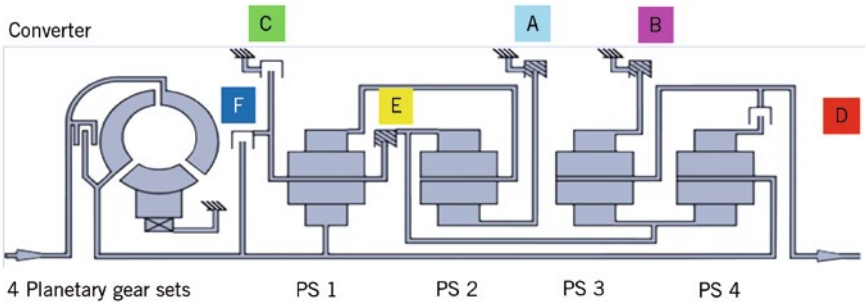
During development big attention was directed to the implementation of the Mercedes-Benz module system, in order to realise all vehicle and engine variants with as few components as possible. Optimal component cost was accomplished by consistent and purposeful development of torque dependent transmission variants – also for hybrid and all-wheel drive. Thanks to further efforts the main weight of major components was reduced compared to the predecessor transmission. Besides the magnesium transmission case many more parts are made by aluminium or plastic material [2, 3]. The oil pan is made of plastic material, with highly integrated filter systems for the two supply pumps. In the case of service it is possible to measure the oil level temperature-independently with an ultrasonic system at any time, without opening the transmission.

The 550 mm long input shaft is one of the major components of the entire transmission concept. It transfers the input torque into the transmission and is the base component for the entire bearing system. Moreover it activates the torque converter and a further clutch, as well as supplying oil for lubricating and cooling the gear set. For this function integration, three drillings with a depth of 361 mm were realised, running parallel on a tenth millimetre.

The shift elements are optimised for highest shift comfort with maximum shift dynamics, without neglecting dura-



❶ Development of automatic transmissions at Mercedes-Benz



Gear	A	B	C	D	E	F	nt/nab
1	●	●			●		5.503
2		●			●	●	3.333
3	●	●				●	2.315
4	●	●		●			1.661
5	●			●		●	1.211
6				●	●	●	1.000
7	●			●	●		0.865
8			●	●	●		0.717
9	●		●	●			0.601
R	●	●	●				-4.932
P	●	●					0.000

❷ Transmission schematic (top) and shifting table (bottom)

bility. The friction element material, the groove pattern and the groove shape are optimised for each shift element by a multiplicity of simulations and attempts to obtain a specific friction characteristic and minimum drag loss over the entire speed range in each element. The shift dynamics is optimised in that the piston and fleeing oil area including their pipes are designed as small as possible. The losses are so small that the transmission is almost constantly operated in the medium temperature range. Using a new synthetic fuel economy low friction fluid of the second generation with reduced viscosity and stable characteristics, further savings in the middle and low temperature range could be obtained.

The actuator of the parking lock system is integrated in the electrohydraulic unit, ❸. Engagement is effected mechanically, disengagement hydraulically. Unintentional actuation is prevented by an intelligent and redundant electrohydraulically driven lever mechanism.

TORQUE CONVERTER

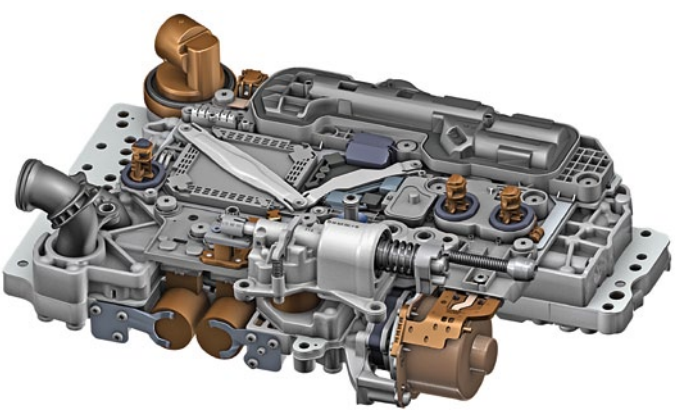
The starting element of the 9G-Tronic is the proven torque converter from the 7G-Tronic Plus [4] that was adapted to the constraints of the 9G-Tronic. All torque converters contain a torque converter lockup clutch and a double turbine damper with a pendulum technology for high comfort at low engine speeds – due to the ratio range of 9.15 even in high vehicle speed ranges. The torque converter lockup clutch has a return spring; thereby an reproducible engagement is possible at low rotational speeds.

HYDRAULIC CONCEPT

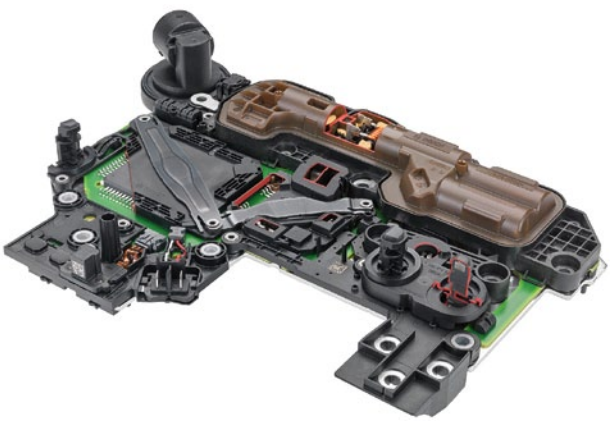
The actuation concept of the 9G-Tronic is a hydraulic direct control system. The advantage of the direct control compared to a conventional system is a more efficient use of the hydraulic output available. The direct control has a direct coupling of the shift element to the electromagnetic valve. The hydraulic regulating valves have only a third of the original diameter. The number of slide valves could be reduced and the leakage is reduced by approximately 80 %. The design of the hydraulic activation with nine identical electromagnets allows for a reduced hysteresis of around 60 %. Thus the repeatability and the response time of the valve body assembly is increased to an unprecedented value. This results in a clearly reduced shift time and much better shift comfort. The employment of a pressure sensor provides a hydraulic system operating with minimum pressure surplus. The direct control offers crucial advantages compared with servo-controlled systems concerning the stability of temperature in the hydraulic behaviour of the valves.

For more efficiency of the gear system the lubrication can be continuously varied with a separate valve in the electro hydraulic unit. Thus the drag loss is further minimised.

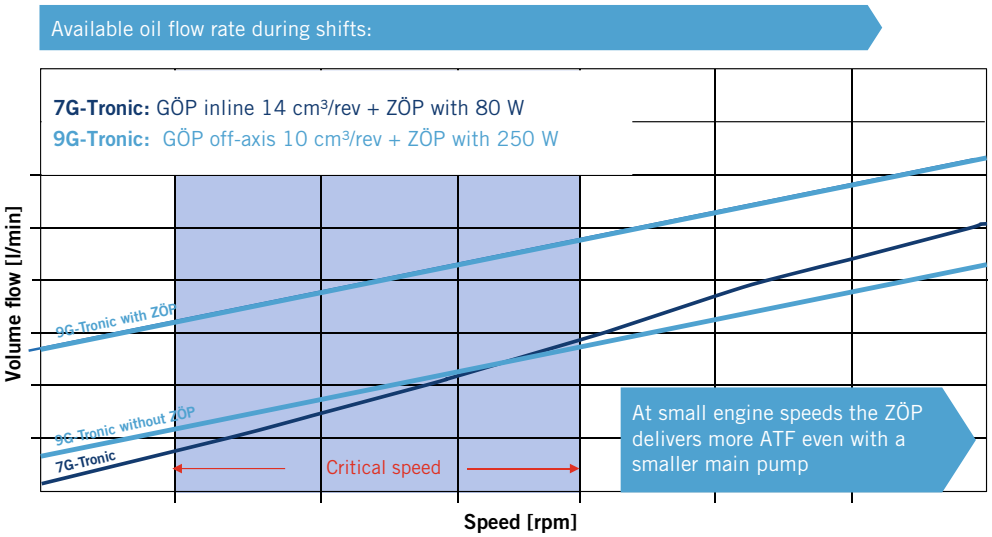
The controller of the 9G-Tronic, ❹, is completely integrated in the sump of the hydraulic actuation unit. Besides a 32-bit micro controller of the newest generation



❸ Electrohydraulic unit with electric auxiliary oil pump and parking lock actuator



❹ Controller unit with processor, electric pump controller and sensors



❺ Flow rates of the transmission oil pumps (GÖP)

Off-axis vane type two stage pump, 10 cm³/rev reduced about 1/3

Internal electric auxiliary pump (ZÖP) for 3S function and support of the main pump, 250 W

it contains all sensors for speeds, temperature and position. The magnets of open-loop control are contacted directly with the control unit plate. The electrical connection to the vehicle system is limited to a four-pole connector.

SUPPLY PUMPS

Two oil pumps are integrated for feeding the electrohydraulic control unit and the actuators, the starting element of lubrication, and for cooling. The main pump is rotating with the speed of the engine, coupled off-axis as a vane pump and positioned in the lower range of the transmission case behind the torque converter. The propulsion system of the pump is made by a chain drive. The hydraulic circuit between sump, pump and hydraulic system are short. High efficiency is reached by this arrangement and the pump principle. The second pump is an electric auxiliary oil pump. This G-rotor pump is driven by a brushless DC motor. The subassembly is mounted as a unit of electric motor and pump in the transmission to the electrohydraulic unit. The electric motor does not need a sensor to control the commutation. Sensing is realised via the induction voltage of the electric motor. This offers advantages regarding building area, weight and costs.

The first pump guarantees a sufficient oil volume for the basic supply of the 9G-Tronic with running combustion engine. The capacity depends on combustion engine speed. In order to keep the losses small with high engine speeds, their capacity is kept low. The second pump offers a variable on-demand flow rate. It is directly controlled by the electronic transmission controller. This pump speed is set depending on the driving condition.

❺ shows the oil volume flows the over combustion engine speed: the basic supply flow rate and the additional flow rate by the auxiliary pump. Furthermore, the characteristics of the 7G-Tronic are shown for comparison. A possible undersupply of the 9G-Tronic with small engine speeds and high volume demand due to reduced capacities of the main pump is compensated by the second pump. By adding volume from the auxiliary pump, there is enough oil volume at low engine speeds, for example during dynamic shifts.

A further task of the electric pump is to enable the stop-start capability of the transmission. In the stop phase (and thus no engine speed) the auxiliary pump supplies the transmission exclusively. The actuators and shift elements can remain closed with the help of this supply while the transmission remains ready for launch. A fast, comfortable launch with engine start is the result.

The two-pump concept with the characteristics described before represents a substantial portion of the good characteristics of the 9G-Tronic regarding efficiency, comfort and dynamics.

TRANSMISSION CONTROL AND DRIVABILITY

Due to the high ratio range and the torque converter with pendulum technology the 9G-Tronic allows for highly efficient driving with low engine speeds and thus low noise level over a wide vehicle speed range. During high performance requirements by the driver, the transmission shifts back fast and comfortably over numerous gears. In addition, new functions of transmission control compute optimal speed and the optimal shift frequency. Downshifting is done directly or interlocked. In this process, up to four of the six shift elements can be shifted at the same time.

For precise control of the shift mechanism a model-based gear change sequence programme is used, considering all crucial features of the mechanical components, hydraulic system and electrics. While driving, changes of the system parameters are continuously observed and compensated via adaptation algorithms. The

THANKS

Designing automatic transmissions can only be successful within a team nowadays. The authors would like to thank Dipl.-Ing. (FH) Eric Müller, manager of transmission pump and mechatronic development design at Daimler AG in Stuttgart, for contributing to this article.

strategies for controlling the gear shifts are based on the torques. During a shift, the torques of the shift elements, the torque converter clutch and the engine are computed and coordinated, ensuring fast and comfortable shifts. To increase the robustness of the transmission, the controller continuously monitors the rotational speed differences of the used shift elements in the gear shift ratio change, and adapts the pressure in case of discrepancies of the desired values. In case of interlocked shifts, an internal speed sensor is used in addition to input and output speed sensor.

Depending on driver request, driving condition, transmission mode and vehicle model, the gear shift sequences can be freely laid-out from extremely sporty to highly comfortable. Engine torque and driver request are permanently monitored while shifting. In case of a changing request, shifting can be interrupted to optimally guide the engine torque through the transmission management.

FUEL CONSUMPTION

The fuel economy benefit of the 9G-Tronic is up to 6.5 % in the standard European cycle NEDC. The portions are obtained as follows:

- 2 % by increased number of speeds and wider gear ratio
- 1 % by optimised shift elements
- 0.8 % by lubrication-on-demand
- 2.7 % by the actuation concept with small main pump an electric auxiliary pump-on-demand and direct control system.

In the Mercedes E 350 Bluetec, the CO_2 savings are between 6 and 8 g/km.

SUMMARY

Compared to the predecessor transmission 7G-Tronic Plus, the 9G-Tronic offers a higher gear spread and more gears as well as a much improved internal efficiency. In combination with the completely new direct control system, the consumption and comfort goals are achieved while offering quick and hardly perceptible shifts. The 9G-Tronic is the base of a new modular system of automatic transmissions at Mercedes-Benz. Further variants will follow in the future, among of them applications for four-wheel and hybrid drives.

REFERENCES

[1] Rösch, R.; Zaiser, W.; Kürschner, M.: Das neue automatische Getriebe W5A330/580 für Personenwagen von Mercedes-Benz – Aufbau und Betriebsverhalten des mechanischen Getriebeteils. In: ATZ 97 (1995) No. 9, pp. 536-545

[2] Greiner, J.; Indlekofer, G.; Nauerz, H.; Dorfschmid, J.; Gödecke, T.; Dr. Dörr, C.: Siebengang-Automatikgetriebe von Mercedes-Benz. In: ATZ 105 (2003), No. 10, pp. 920-930

[3] Greiner, J.; Dörr, C.; Nauerz, H.; Graeve, M.: The new „7G-Tronic“ of Mercedes-Benz- Innovative Transmission Technology for better Driving Performance, Comfort and Fuel Economy. SAE World Congress, Paper Number 2004-01-0649, 2004

[4] Dorfschmid, J.; Döpper, W.; Jäggle, G.; Dr. Heukelbach, K.; Kalczynski, H.; Die Evolution zum Siebengang-Automatikgetriebe 7G-Tronic Plus. In: ATZ 112 (2010), No. 12, pp. 900-907