Mercedes Powershift
A New Generation of Automated Gearboxes

Commercial vehicle operation in recent years has seen demands on driver and vehicle steadily increasing. More and more complex workloads, and increasing traffic density resulting from the expansion of the EU eastwards impose maximum requirements on drivers, while skyrocketing fuel prices and transport volumes and the European Union's planned certification of volume trucks of up to 25.25 m total length, make a high performance driveline and low fuel consumption an absolute necessity. And so, in pursuit of the best overall efficiency, Mercedes-Benz is committed to the strategy of offering a direct-drive automated gearbox for the Actros and Axor model ranges. With Mercedes new Powershift gearboxes, direct-drive gearboxes are now available for engines of up to 441 kW.

1 Introduction

Today's truck customers demand a high degree of efficiency together with increased vehicle comfort and safety. Consequently, in developing its gearboxes Mercedes takes into account the many demands that a new gearbox concept must satisfy as far as possible. Among these, low operating cost is fundamental, and so fuel consumption is one of the characteristics that provide a decisive competitive advantage. Here, a modern gearbox can make a significant contribution to improved fuel efficiency.

In long-distance haulage, up to 90 % of the driving is done in the highest gear. Therefore, it is obvious that the best possible efficiency must be achieved for that operating condition. One way to do this is the direct-drive gearbox in which in top gear the gearbox's input shaft is directly coupled with the main and output shafts, eliminating friction loss from the engagement of the gearwheels.

Automated gearboxes also have the advantage that optimum selection of gears and shift points always depends on the driving situation, so that the vehicle is always operating in the most fuel efficient engine speed window. Automatic gear selection also relieves the driver of having to shift gears, which allows him to focus more on the traffic. However, it is always possible to intervene manually, for instance in situations requiring the driver to exercise foresight.

Another advantage with respect to operating costs is the low wear on automated clutches. Reduced rpm differences during the starting and shifting processes increase the clutch lifetime. Automated clutches have no clutch pedal, which significantly facilitates operation for the driver, particularly in stop-and-go traffic or during manoeuvring.

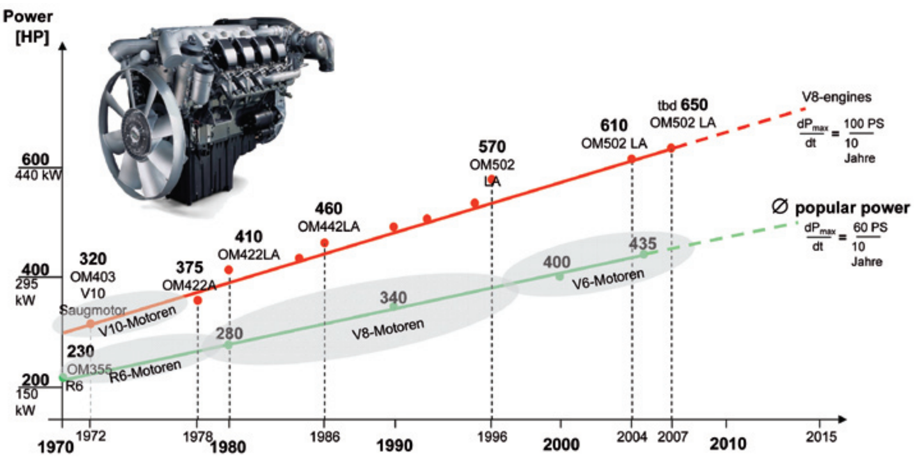

Figure 1: Historical development of engine power

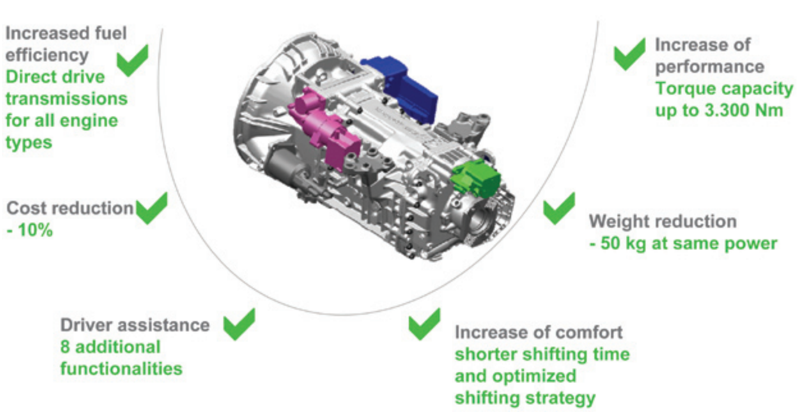

Figure 2: Development goals for Mercedes Powershift gearboxes

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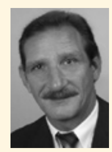
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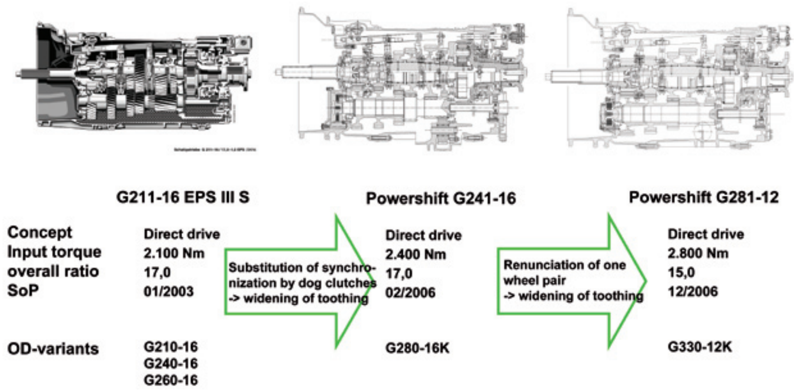


Figure 3: Gearbox torque capacity was raised by 30 % with no increase in space requirement

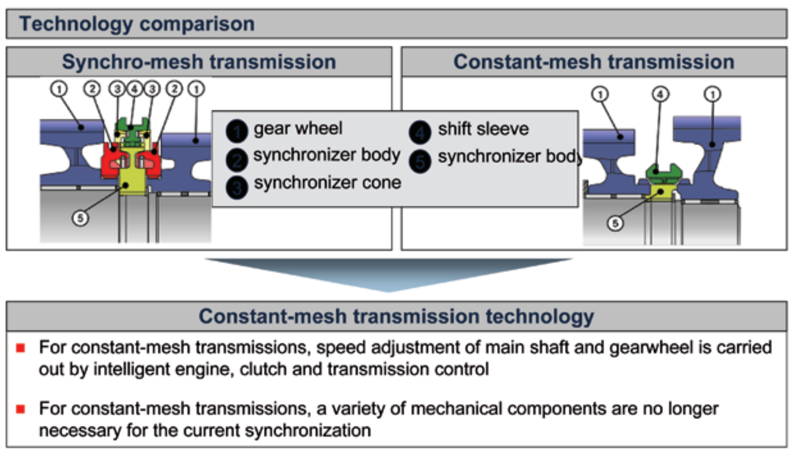


Figure 4: Fewer components and increased robustness thanks to electronics

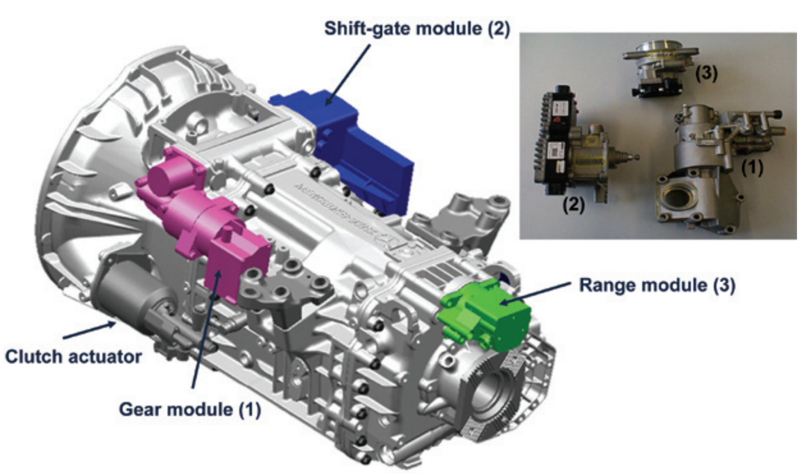


Figure 5: Powershift gearbox with its externally mounted components

In addition, reduction in gearbox weight provides further cost savings, firstly from the purchase cost which is lower due to less material use, and secondly from reduced operating costs through increased payload.

In the meantime the customers' demand for ease of shifting reflects the benchmark set by automobile technology, although in this case limits are set with respect to mass and cost. Low noise emissions are the result of regulatory provisions, but also contribute to a more driver workplace. As well, electronic systems offer greater driver support and offload routine tasks. All this makes for better road safety.

Not least, when developing a new gearbox the long-term viability of its dimensioning must be taken into account, as developments in engine performance over the last 30 years have shown that in just a few more years trucks with a peak power of 515 kW will be a common sight on roads, **Figure 1**, and, in addition, the market's increasing demand for a service life of 1.2 million kilometres will have to be met. During the development of the new Mercedes Powershift gearbox, the sum of all those requirements had to be taken into account, **Figure 2**.

Mercedes-Benz sees itself as a trailblazer in the development of automated gearboxes for trucks. The first product was a semi-automated gearbox with automatic preselection shifting (EPS), which came on the market in 1985 and soon after was standard equipment in Mercedes-Benz trucks. Eleven years later the Telligent automatic gearshift was introduced together with the Actros. It was the first time ever that a fully automatic solution was offered in a heavy truck and 40,000 have been sold since then.

The new Mercedes Powershift gearboxes are the result of continuous further development of the proven range-change gearbox. With respect to their overall transmission ratio, they are specifically designed for the broad speed range of the V6 and V8 turbocharged engines in the Actros and the robust in-line six in the Axor.

2 The new Powershift Gearbox

The Powershift gearboxes are designed as a so-called range-change gearbox with an unsynchronised basic gearbox as well as a synchronised split gear and range gear. The modular design and a three- or four-speed basic gearbox allow the range of gear ratios to be quadrupled to twelve or 16, the latter being provided especially for heavy haulage.

In order to reduce the weight of the gearbox in the lower application range of up to 2100 Nm, a modular design with two different center distances (142 and 152 mm) was chosen. Consequently, in the volume segment up to 325 kW the new G211-12 Powershift gearbox has the best weight/power ratio in that class and weighs 50 kg less than its synchromesh predecessor of equal power. On the other hand, in the upper application range, power has been increased by over 30 % with the same weight and space requirement, so that now direct-drive gearboxes up to an input moment of 2800 Nm are available, which can be further increased to 3300 Nm in the overdrive version, **Figure 3**.

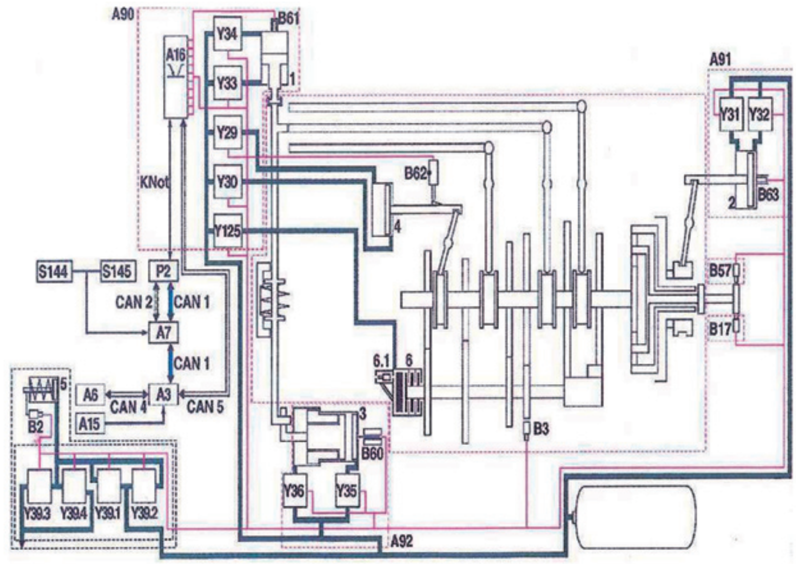
This was made possible by replacing the synchronisations in the basic gearbox with radially smaller shift dogs, the sliding sleeves also being able to grip under the toothing. The resulting space gain was completely transformed into gear width. The gear width of the twelve-speed gearboxes was increased over that of the 16-speed gearboxes because the main gearbox has one pair of gearwheels less.

When shifting down, the rpm synchronisation of the speed change gear and main shaft necessary for the shifting process occurs through a precisely metered acceleration up to the target rpm with closed clutch and gears in neutral (with manually shifted dog-type constant mesh countershaft gearboxes, this intervention is still known as double clutching). This is made possible through the CAN communication between the gearbox and engine control units.

An additional gearbox brake is necessary for shifting up and is designed as a pneumatically actuated multiple disc brake. The shifting sequence can be described as follows:

Shifting up:
- reduce engine torque
- disengage clutch and relieve the driveline
- shift gears to the neutral position
- actuate the countershaft brake in a controlled manner (rpm equalisation between the speed change gear to be shifted and the main shaft)
- engage the gear
- re-engage clutch
- increase the engine torque again.

Shifting down:
- reduce engine torque
- disengage clutch and relieve the driveline



1	Shift cylinder, shift gate	S144	Button group, multi-function steering wheel left
2	Shift cylinder, range	S145	Button group, multi-function steering wheel right
3	Shift cylinder, gear	Y29	Solenoid valve, split 1
4	Shift cylinder, split	Y30	Solenoid valve, split 2
5	Adjustment cylinder, clutch diaphragma	Y31	Solenoid valve, range 1
6	Countershaft brake	Y32	Solenoid valve, range 2
6.1	Mechanical bleed valve	Y33	Solenoid valve, shift gate 1
A3	Control unit, driving	Y34	Solenoid valve, shift gate 2
A6	Control unit, engine	Y35	Solenoid valve, pressurization of indirect gears
A7	Basic module	Y36	Solenoid valve, pressurization of direct gears
A15	Transmitter unit, gear control	Y39.1	Solenoid valve, pressurization of clutch 1
A16	Control unit, gear control	Y39.2	Solenoid valve, pressurization of clutch 2
A90	Shift-gate module	Y39.3	Solenoid valve, depressurisation of clutch 1
A91	Range module	Y39.4	Solenoid valve, depressurisation of clutch 2
A92	Gear module	Y125	Solenoid valve, countershaft brake
B2	Clutch pedal position sensor	CAN1	Vehicle CAN
B3	RPM sensor, countershaft	CAN2	Interior CAN
B17	Speed transmitter	CAN4	Engine CAN
B57	RPM sensor, gearbox output rpm	CAN5	Gearbox CAN
B60	Sensor, gear	KErs	K-line, spare shift
B61	Sensor, shift gate		
B62	Sensor, split		
B63	Sensor, range		
P2	Instrument		

Figure 6: Circuit diagram of sensors and solenoid valves

- shift gears to the neutral position
- re-engage clutch
- increase the engine rpm (rpm equalisation between the speed change gear to be shifted and the main shaft)
- engage the gear
- increase the engine torque again.

The resulting “electronic synchronisation” allows comfortable shifting and significantly shorter shifting times. The elimination of the sometimes filigree synchroniser components that were necessary up to now contributed to a more robust gearbox, **Figure 4**.

The clutch is a standard dry clutch that is operated fully automatically via a pneumatic clutch diaphragm. All the actuators for gear, shift gate, split and range are maintenance-friendly individual modules flanged on or integrated in

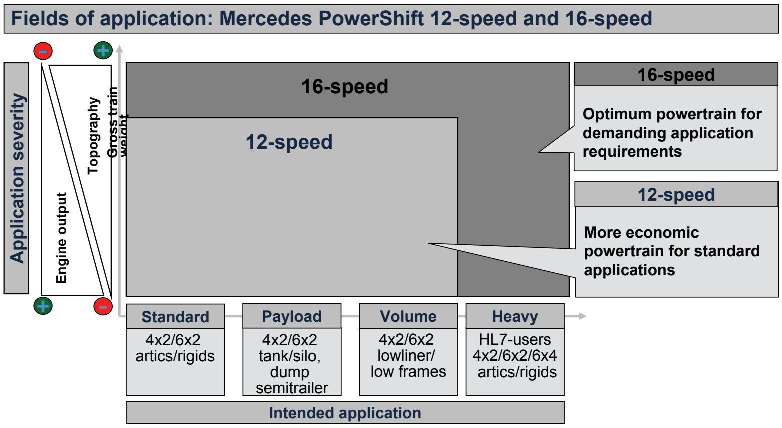


Figure 7: Mercedes Powershift provides solutions for all Actros long-distance and distribution haulage

Table: Overview of the transmission ratios of the Powershift gearboxes

Name	G211-12	G241-16	G281-12	G280-16	G330-12
Model	Direct drive	Direct drive	Direct drive	Double overdrive	Single overdrive
Code	GH2	GH7	GH3	GH4	GH8
Type	715.350	715.515	715.370	715.525	715.380
1st gear	14.93	17.03	14.93	11.72	11.64
2nd gear	11.67	14.19	11.64	9.75	9.02
3rd gear	9.02	11.50	9.02	7.92	7.04
4th gear	7.06	9.58	7.04	6.58	5.45
5th gear	5.63	7.80	5.64	5.29	4.40
6th gear	4.40	6.50	4.40	4.40	3.41
7th gear	3.39	5.28	3.39	3.64	2.65
8th gear	2.65	4.40	2.65	3.02	2.05
9th gear	2.05	3.87	2.05	2.66	1.60
10th gear	1.60	3.22	1.60	2.22	1.24
11th gear	1.28	2.61	1.28	1.80	1.00
12th gear	1.00	2.18	1.00	1.50	0.78
13th gear	–	1.77	–	1.20	–
14th gear	–	1.48	–	1.0	–
15th gear	–	1.20	–	0.83	–
16th gear	–	1.00	–	0.69	–
1st reverse gear	14.93	15.48	16.39	10.66	12.77
2nd reverse gear	11.67	12.90	12.77	8.86	9.90
3rd reverse gear	3.39	3.52	3.72	2.42	2.90
4th reverse gear	2.65	2.93	2.90	2.01	2.25

the gearbox housing and are also pneumatically operated.

Coordinated actuation of the automation components and the countershaft brake is conducted via the electronic control located in the shift-gate module, **Figure 5**. The control unit is connected with the other control units of the vehicle's CAN architecture via the gearbox CAN and the higher-order drive control, which gives it access to all the shift-related data and actions.

To monitor the shifting and operating status of the gearbox, the following sensors are continuously interrogated:

- clutch pedal position sensor (records the clutch release path)
- rpm sensor, countershaft (records the rpm of the countershaft)
- speed transmitter (records the rpm of the gearbox output shaft and provides the speedometer signal)
- rpm sensor at the gearbox output (records the gearbox output rpm and, together with the speed transmitter, monitors the direction of rotation)
- travel sensors for gear, shift-gate, split and range (records the current switch positions of the respective actuators).

The gearbox control determines the shift and operating status of the gearbox from the sensor signals. That, together with the drive control and the CAN data, determines the next gear to shift, and the appropriate solenoid valves are actuated, **Figure 6**.

Even if the sensor signals are not available, e.g. due to disconnected lines, limited driveability is still ensured. A comprehensive system analysis using the FMEA and FTA methods resulted in a perfected safety and emergency drive concept. Therefore, even in the event of a defect, a high degree of vehicle availability is ensured. Losses due to down time and cancellations are minimized by maintaining a high degree of mobility. Locking synchronisations are still used in the split and range gears.

The reason for this is, on the one hand, that the large gear ratio jump of 4.4 in the downstream group cannot be achieved via a corresponding engine rpm jump (with an idling rpm of 600 rpm and a nominal rpm of 1,800 rpm, the max. bridgeable ratio jump is 3). And on the other hand, with respect to shifting speed, the synchronised split shifting is still superior to the electronic rpm synchronisation due to its very low ratio jump.

As with synchromesh gearboxes, the oil supply is provided via a pressure circulation lubrication system whose oil pump is driven by the countershaft. All the bearing and gear engagement points are specifically supplied with fluid under pressure so that the fluid level is lower and splash losses to a large extent prevented. If necessary, fluid can be cooled by a cooler located in the radiator plenum.

Because of the higher transmissible torques, the planetary gear of the downstream group was strengthened, particularly the ring gear and the planetary carrier. However, because the modular principle was applied throughout, all MB PTOs can still be flanged to the rear of the housing and driven via a solid shaft that replaces the fluid pump shaft.

With its new Powershift family, Mercedes-Benz is currently the only manufacturer of trucks offering automated twelve-speed and 16-speed gearboxes. The overall transmission ratio of the 12-speed gearbox is 14.9 and its design is tailored to European long-distance haulage. However, for tough applications with high tonnages and/or difficult topographies 16-speed gearboxes are still available which, with an overall ratio of 17.0 together with the HL7 planetary axles, are able to meet the most challenging transport jobs, **Figure 7**. An Overview of the transmission ratios of the Powershift gearboxes shows the **Table**.

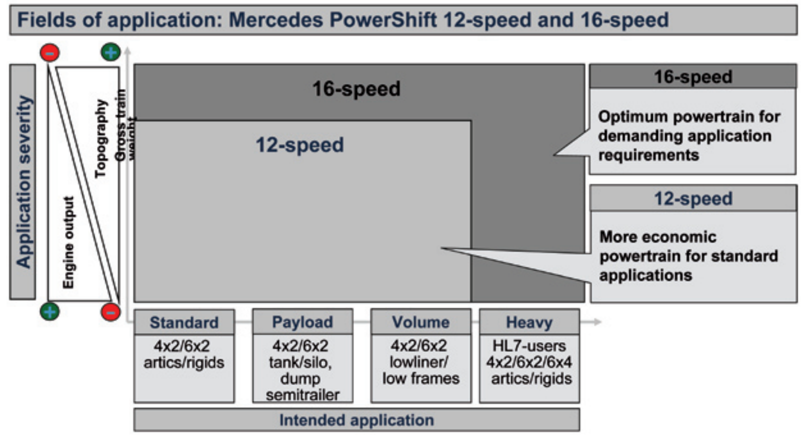


Figure 8: Mercedes Powershift provides additional customer benefits in efficiency, ease of operation and comfort

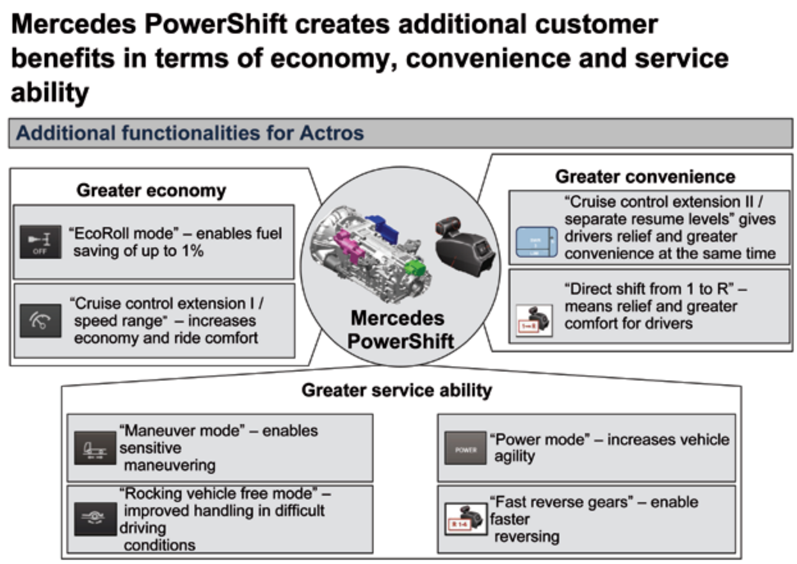


Figure 9: High-resolution RPM sensing at main shaft and countershaft

3 Additional Functions

With the introduction of the Powershift gearbox in the Actros, additional functions were also installed which assist the driver in a variety of driving and shunting manoeuvres and also contribute to the further improvement of overall efficiency.

Of particular interest is the Eco Roll mode which, in order to make use of the high inertia of the vehicle for fuel-saving coasting phases, automatically shifts to neutral on flat or slightly hilly terrain when the accelerator or brake pedal is not pressed. This reduces fuel consumption by up to 1 %. However, for safety reasons, if certain speed gradients are exceeded or if the accelerator or brake pedal is pressed, the vehicle immediately shifts into the appropriate gear in order to close the driveline.

The Power mode was designed for performance-oriented driving and allows the short-term utilisation of full engine power at nominal rpm, for instance for passing or on ascents. In order to ensure low fuel consumption it is automatically deactivated after 10 minutes. All the additional functions are shown in detail in **Figure 8**. With the press of a button all the functions can be activated from the cockpit.

4 Outlook

Powershift gearboxes are currently being installed in other Daimler truck models; in addition to its application in the Actros as well as the Axor tractor and platform trucks, the light-weight G211-12 in particular will also be used by the concern's Japanese subsidiary Fuso in the Super Great truck. Even today the worldwide use of uniform gearboxes has begun, prior to the planned worldwide use of a joint engine platform

Therefore, future developments will focus on fulfilling regional brand and customer needs with respect to automated gearboxes, chiefly through tailored driveline management across the complete range of control units. From the aspect of mechanics, sufficiently precise sensor signals for rpm, vehicle weight and gradients must be provided; therefore over the short term, depending on the application, the Powershift gearboxes are being equipped with additional sensors, **Figure 9**. ■