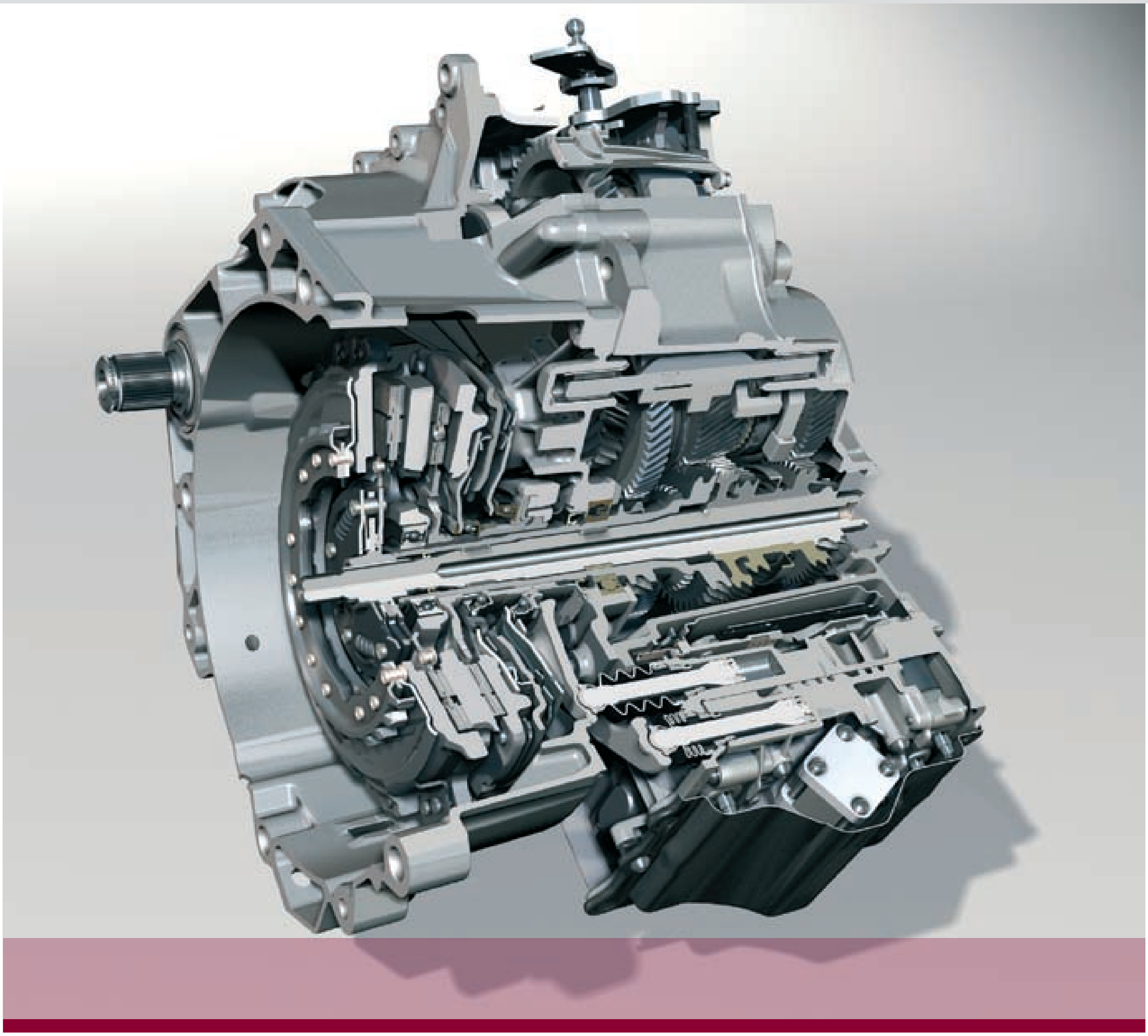

# The Seven-speed Dual Clutch Transmission from Volkswagen

Volkswagen is making two world premieres with the new seven-speed dual clutch DSG transmission. It is both the first seven-speed transmission for front transverse mounting and the first dual clutch transmission with a ‘dry‘ dual clutch. The transmission is designed for a maximum torque of 250 Nm and use for vehicles in the compact class as well as, also a world premiere, for vehicles in the small class. As a build feature, the dry dual clutch has considerable benefits for the entire transmission concept. Compared to Volkswagen’s current six-speed dual clutch transmission, it comes with an even higher efficiency rating and therefore makes a significant contribution to reducing fuel consumption and emissions levels in the design of new vehicles.

## 1 Introduction

The current world of transmissions continues to be dominated by the traditional manual transmission systems in Europe and shift control automatic transmission with torque converters in the USA and Japan. Both types of transmission have their own advantages and disadvantages:

- The main benefit of manual transmissions is superior efficiency rating, excellent durability and low production costs. Above all, due to the direct connection between engine and vehicle, it offers motoring pleasure and sporty driving dynamics.
- The automatic transmission, on the other hand, offers the driver an excellent level of comfort, first and foremost. Start-up and automatic gear changes are done smoothly and without breaking the driving force.

In this context, Volkswagen has brought together the best of both worlds in a new generation of transmissions. Based on the dual clutch principle best known in the world of motor sport, the DSG dual clutch transmission from Volkswagen was born, enjoying success since it was launched on the market in 2003 [1].

With its design based on two wet clutch discs and different automatic transmission programs, this transmission satisfies the high comfort requirements of the automatic transmission driver“. At the same time, and of particular importance to the European market, it brings a totally new ‘automatic perspective’ to drivers who have driven exclusively manual systems such as Volkswagen’s Tiptronic function which allows the driver to switch to manual mode even with the DSG. The DSG changes gear much more rapidly and is just as comfortable as standard automatic transmission and convincingly solves the debate between sporty/dynamic performance and smooth gear changes,

leaving fuel consumption – the significant advantage of the DSG – on the same low level as a manual transmission. The prejudices, particularly of drivers of compact and mid-sized class vehicles against automatic transmissions will soon become a thing of the past.

Since its introduction on the market, the benefits of this system have meant that Volkswagen customers are increasingly starting to favour vehicles fitted with DSG. Volkswagen primarily offers the DSG with TDI and powerful petrol engines. In the European compact class sector, there was a sustainable shift in the installation rate from 5 – 10 % in traditional automatic transmissions to 20 – 30 % with the DSG.

This success is a clear indication that the often-repeated but never-achieved forecast in Europe that the installation rate for automatic transmission can be increased – through a combination of:

- driving pleasure and
- reduced fuel consumption.

Merely focusing on increasing comfort levels, a significant strength of previous automatic transmissions is, however, insufficient.

The success of the DSG has meant that even the major manufacturers of automatic transmissions are now basing their latest generations of multi-ratio automatic transmissions on the benchmark established by the DSG in terms of shift speed, sports performance and efficiency rating. In this way, the DSG has made a substantial contribution towards achieving substantial progress in the automatic transmission sector as a whole.

The DQ250 six-speed dual clutch transmission has already set a standard in fuel consumption in automatic vehicles. To some extent, standard consumption could be achieved, which is less than half the manual transmission value. [2-4].

## 2 Differences with DQ250 Dual Clutch Transmission

The type of dual clutch sets a standard for the design of the whole transmission. In contrast to the DQ250, introduced in 2003, which consisted of twin clutch plates immersed in oil, the new seven-speed DSG DQ200 has dry, organically-bonded friction linings.

In the DQ250, the transmission oil fulfils several tasks with conflicting requirements. In the transmission itself, the gears and bearings need lubricating and the heat needs to be dissipated. The same oil must however fulfil different friction requirements for the dual clutch. Finally, the mechatronics require an oil with good viscosity qualities which also has good controller characteristics at low temperatures.


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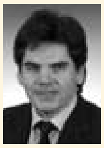

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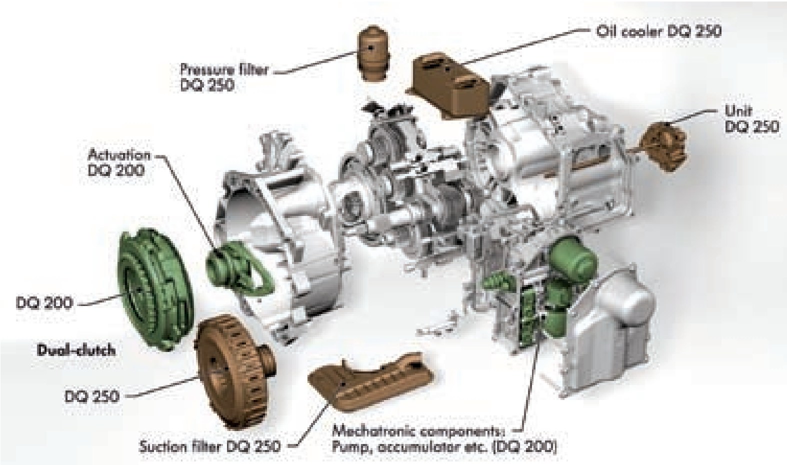


**Figure 1:** Design differences between six-speed transmission DQ250 with wet clutch and seven-speed transmission DQ200 with dry clutch

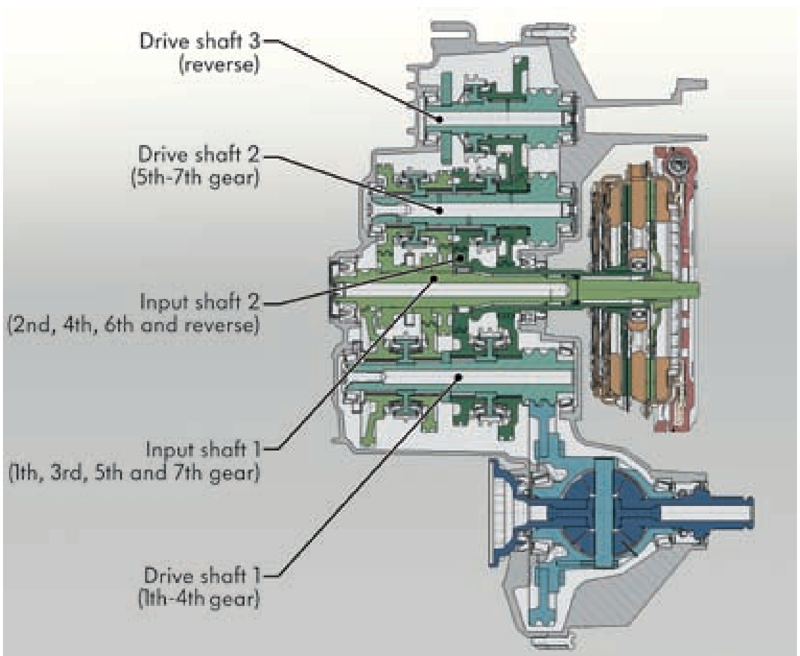


**Figure 2:** Schematic drawing of the seven-speed dual clutch transmission DQ200

The DQ200's two separated oil circuits and the dry friction contact has completely solved this problem. As in traditional manual transmissions, the transmission oil fulfils the role of lubricating and cooling the gears and bearings. Because the clutch does not require cooling, the amount of oil used in the transmission can be reduced from 6.5 l in the DQ250 to 1.7 l in the DQ200. The significantly reduced churning losses are a significant factor in the transmission's improved efficiency rating. Specific components in the oil circuit can therefore be dispensed with: suction filter, oil cooler and oil pressure pipes in the transmission housing, **Figure 1**. This way, the system has been internally simplified and the number of interfaces with the vehicle reduced (oil cooler in the water cooling circuit.)

For use in smaller engines, in particular diesel engines with low ratio spread at different shaft speeds, the following target parameters were derived, which were to be taken into account at the development stage of a DSG for use in the compact and small sectors as well for torques of under 250 Nm:

– tailored provision of auxiliary power to clutch actuation and control
– increased transmission ratio spread for better setting off performance and reduction of clutch load including lower engine speeds and lower consumption in top gear
– simplified basic system and peripherals for further improvement of endurance.

## 3 Build Features

The DQ200 was designed for a specific area of application, which has now become part of the current DQ250. Maximum torque is 250 Nm, transmissable engine power is 125 kW. Application is intended for vehicles in model ranges A0, A and B (Polo to Passat.). With a length of 369 mm, a centre distance of 179 mm (crankshaft to output) and a total weight of 77 kg – including a dual-mass flywheel – it is perfectly suited to the compact car sector.

### 3.1 Transmission Construction, Gears and Shafts

In contrast to the DQ250 six-speed dual clutch transmission, the DQ200 was designed as a seven-speed transmission. This increase in the number of gears resulted in some fundamental considerations:
– The first gear can have a higher ratio which improves setting off.
– Despite higher setting off ratios, the seven-speed design has comfortable short steps and an overdrive which should make a difference for customers, both in terms of fuel economy and noise emission levels.
– The DQ200 has 4 gear actuators. Together with reverse, there are seven forward gears, without incurring the additional costs of sensors and actuators. The extra cost of the twin gear wheels and a synchronizer ring, compared to six-speed, are proportionally low compared to operational usage.

The dry dual clutch requires a larger installation space although they were designed for lower torque levels than the wet DQ250 dual clutch. This increased space is due to specific conditions with regard to cast dimensions for heat storage and transfer, friction lining wear reserves and both clutches‘ actuation systems.

The space needed for the double clutch is therefore particularly compact, especially as the field of application is the compact vehicle class. The forward and the reverse gears are arranged on three drive shafts, **Figure 2**.

The coaxially arranged input shafts each have Bearings for countershaft and mainshaft gears (fixed and idle gears.) Input shaft 1 is for odd-numbered gears (1-3-5-7) while input shaft 2 is for even-numbered gear (2-4-6) and reverse. The division of '1' and ‚R' allows for a quick change between forwards and reverse through actuating both clutches. All 5 sliding sleeves on shift forks coupling are actuated by 4 shift gears. Here the shift forks use the two sliding sleeves for gears "6" and "R" [5], both arranged on different shafts.

During construction of the transmission, care was taken to ensure a largest possible field of application was covered. While the Compact class is the primary application area, the power and torque data also enable this transmission to be used in larger vehicles such as the Touran and Passat. To accommodate the increasing diversification of vehicle classes and the new crossover concepts, the transmission ratios were very well-defined. While the ratio spread can have a value above 8, the shortest starting ratio is 19.77 and the longest total ratio in seventh gear is 1.85.

## 3.2 Dual Clutch

The principle of the dry friction clutch is well-known in the field of manual transmission. The comfort of this system has reached a high level thanks to diverse developments including wear adjustment and modern friction linings. Dependability levels are excellent. The DQ200 dual clutch is mainly based on this well-known technology, but is clearly more than a doubling of well-known components in a new arrangement. Fundamental construction differences exist, as can be clearly seen in **Figure 3**.

The dual clutch consists of a central plate, located on the input shaft. Clutches K1 and K2 are located on either side of the central plate. The engine torque is transmitted via the dual mass flywheel and a plug-in spline on to the central plate and on both pressure plates. The DQ200 dry dual clutch is actuated by the release lever which is in turn actuated hydraulically by the clutch piston in the mechatronic section. These entirely interconnected levers transmit actuating force to the rotating system of the dual clutch via two release bearings.

The biggest difference between manual transmissions and dual-clutch units is that the clutch on a manual transmission is opened actively, i.e. it needs to be released. For safety reasons, dual clutches must open independently in the event of a system shutdown. The reversal of the principle, from "active opening" to "active closing" represents more than a simple change in prefix. Whole construction principles and design criteria must be reconsidered and recreated.

The design principle of the actively closing clutch results in permanent engagement force being applied during operation. To prevent any need for this engagement force to be supported against the crankshaft, the dual clutch unit is mounted in a thrust bearing on the outermost input shaft. The clutch is also protected from vibrations, which could be transmitted from the crankshaft. Another advantage of this form of mounting is that the dual clutch unit – in keeping with the DQ250 – is a fixed component in the transmission and the tolerance chain in the clutch actuation process, so critical in terms of shift quality, can be reduced substantially. The transmission can be completely inspected and calibrated after assembly.

First and foremost, it must be possible to control dual clutch units in a very good and reproducible manner. This requires precise knowledge of friction coefficients and friction linings, which need to have a constant performance in the largest possible scope of operation. Not only the minimum friction value limits but also the maximum friction value is of considerable significance.

Particular attention during the design stage was placed on stability of the characteristics curves for torque capacity over the actuation stroke. At the same time, special care had to be taken concerning the restoring force and control dynamics of the lever springs.

The three-plate design, comprising two clutch pressure plate and the central plate, offers high thermal stability in a relatively small installation space. The friction linings are made from organically bound friction material, mounted on metal supports. They have particularly efficient friction qualities, high resistance to wear and a high torque stability.

## 3.3 Clutch Temperature Model, Thermal Capacity

Hill starts in particular with maximum system weight leads to high heat input in the setting off element. Wet clutches are actively cooled, the heat can be dissipated to the engine's cooling circuit. Repeated starts can, however, cause excess heating of the transmission, despite the heat transfer. When the DQ250's critical oil temperature is reached, the appropriate

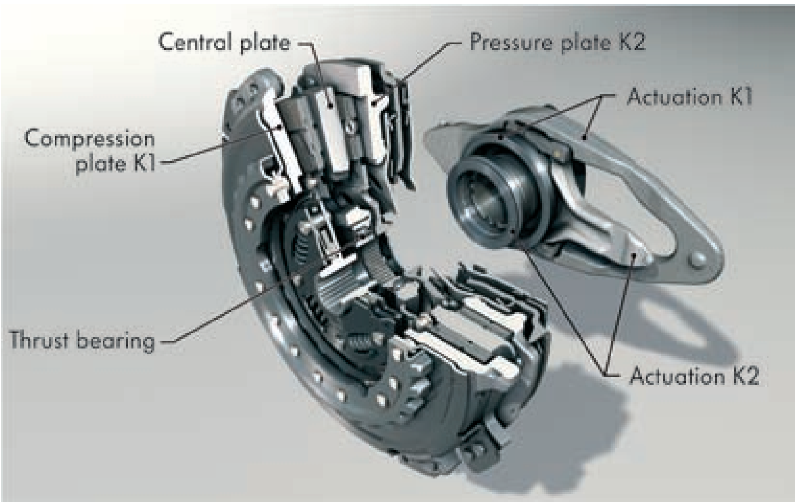


**Figure 3:** Dual clutch and actuation

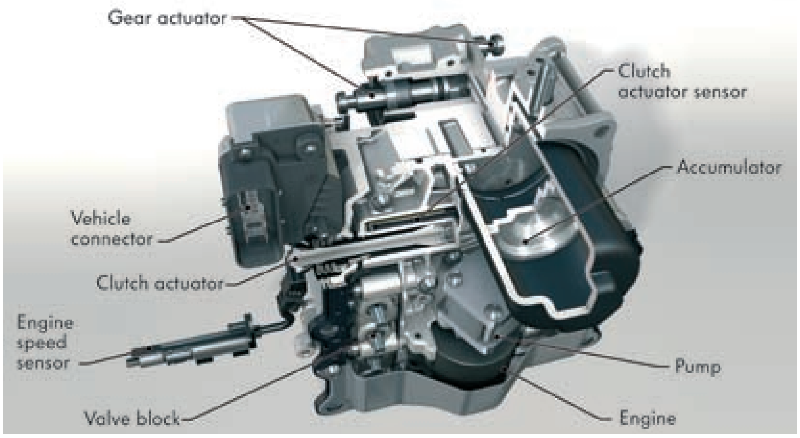


**Figure 4:** Mechatronics module

protective system is activated, preventing transmission overheating. This kind of protection is also available and commonplace on torque converter transmissions.

The separate clutch pressure plates on a dry dual clutch heat up every time the vehicle sets off. The stored heat is dissipated to the surrounding air through convention. By virtue of a shortened starting ratio, a further substantial reduction of the thermal load is possible because changes in the starting ratio have a quadratic effect on the heat intake.

The ample dimensions of the clutch pressure plates in conjunction with an optimum starting ratio requires a virtually identical load on the dual clutch in wet systems . For monitoring temperature parameters, a temperature model is accessed, which is permanently incorporated in the transmission control unit. This makes it possible for the clutch to be protected from overloading, whereby suitable measures for reducing the clutch power input have been taken. In extreme cases – in keeping with the DQ250 - the driver is informed and/or the clutch is opened. Based on extensive readings, the model was calibrated, so that it gives a high-quality representation of actual temperatures at different points of the dual clutch.

## 3.4 Mechatronics

The DQ200 mechatronics shown in **Figure 4** is a closed unit. They have their own oil circuit, separate from the transmission, which results in a series of advantages:

- The hydraulic fluid can be defined specially for the mechatronic module, while a standard manual transmission oil is used for the transmission.
- The low temperature performance of the mechatronic system is excellent, because, compared with the viscosity performance, no compromise with the transmission specifications is necessary.
- Dust and particles from wear and tear in the transmission do not make their way into the mechatronics. The hydraulic fluid is not contaminated.
- The fact that the hydraulic fluid is very clean means that cartridge valves with very small filter pores can be used. This way, leakage is reduced considerably.
- There is no need for hydraulic clutch cooling with the dry clutch, where the volumetric flow rate requirement drops and using an electrically operated pump in combination with the cartridge valves is an economic alternative.
- Compared to an open hydraulic system, the pressure level can be increased, the actuators can be reduced in size, due to the high power to weight ratio and the total weight of the transmission reduced.
- The mechatronics can be completely assembled and fully tested outside the transmission.
- Actuation of the clutches and changing the gears is also possible without the combustion engine. This is the prerequisite for a hybrid drive with a start/stop function.

The oil circuit comprises the following components:

- pump with electric motor
- pressure filter
- pressure retaining valve
- pressure accumulator in the form of a gas pressure piston accumulator
- two identical valve blocks for actuating the transmission
- two clutch actuators
- four gear actuators
- transmission Control Unit (TCU): gear computer, sensors and vehicle connector.

The electrical synchronous motor for driving the pump is totally immersed in oil. The pump supplies hydraulic fluidity via a pressure filter and the pressure valve in the piston accumulator. While the mechatronic system operates with a maximum pressure of 40 bar, the accumulator pressure can reach 60 bar. The

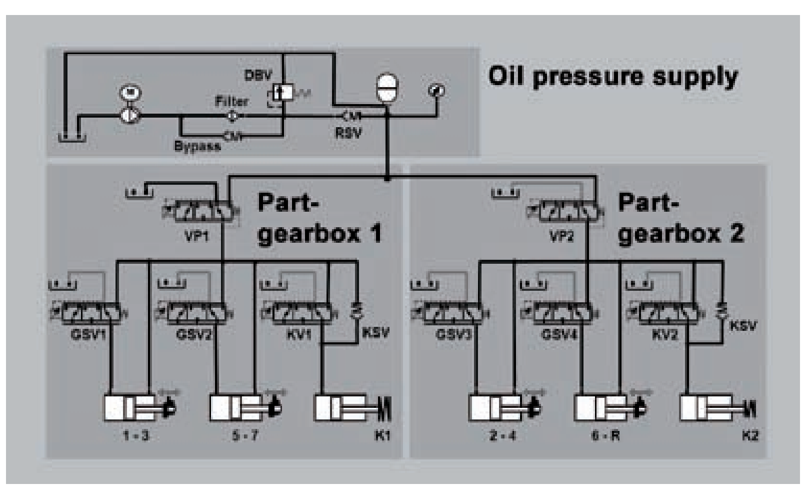


**Figure 5:** Hydraulics circuit diagram

pump is actuated when necessary. While the average start up time of the pump in the New European Driving Cycle NEDC is approx. 20 %, it can reach 50 % with very dynamic driving.

### 3.4.1 Valves

**Figure 5** shows the valve layout. This is a further reflection of the symmetrical structure of the dual clutch transmission: in the twin identical integrated valve blocks, there is a combination of a pressure control valve and three volumetric flow valves.

The pressure control valve (VP) sets the partial transmission pressure. If required, a complete partial transmission can be switched off. This way, the flow consumption on one side can be reduced during operation. In the event of a system error, the remaining partial transmission still enables the vehicle to be driven. this function is a clear benefit of the system availability.

The volumetric flow rate valves (GSV, CV) control the clutch and both gear actuators of each partial transmission. While the clutch piston is actuated against the release forces of the clutch, the gear actuator pistons are used as differential pistons. The smaller piston surface is permanently loaded with partial transmission pressure. The thrust surface which is twice as big as usual, is supplied with oil via the gear actuator valve and the gear actuator actuated.

### 3.4.2 Control

The control system is located between the transmission and the hydraulics, **Figure 6**. It includes the control unit, the sensor system and the power electrons for controlling the hydraulic system and the pressure supply. An aluminium pressure die-cast frame constitutes the fundamental element, which connects the single elements. As the control unit is an integral component of the transmission, high environmental requirements need to be respected:

- temperature range from −40 °C to 140 °C
- maximum vibration resistance 33 *g*
- resistance to two different media (hydraulics and transmission oil)
- sealing function with very different media (hydraulic, transmission oil, water, dirt).

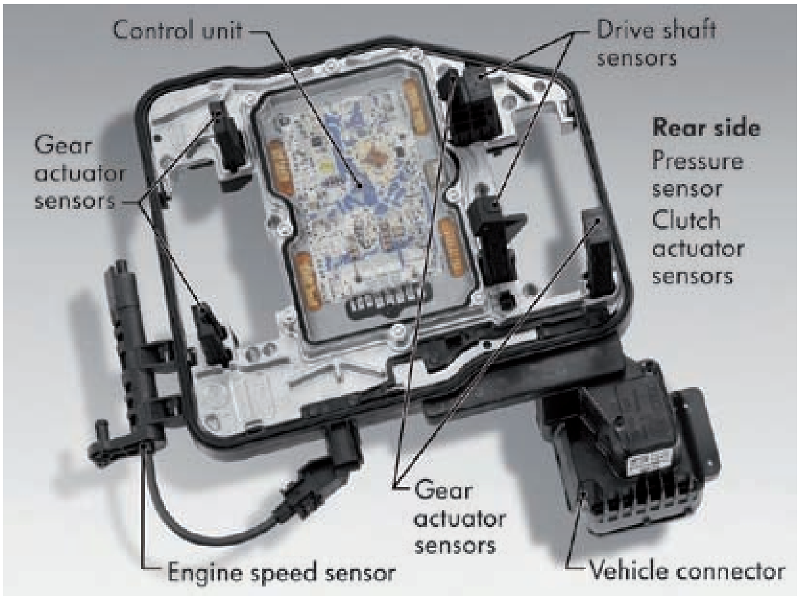


**Figure 6:** Control unit

To meet these high requirements, the electronic control unit is made of ceramic substrate. This technology meets the high temperature requirements and makes a very compact design possible.

The control unit is intrinsically safe in full compliance with VDA EGAS 2.0. At the heart is a 32 bit processor from the Infineon Tricore range.

The sensor unit comprises:

- proximity sensors for measuring the position of the clutch and shift fork position
- sensors for recording engine and input shaft torque
- sensor for system pressure
- sensor for mechatronics temperature.

Shift fork distance measuring is carried out via two Hall sensors, with the solenoids mounted directly on the shift forks. The non-contact PLCD sensors are used for the clutch movement, Figure 4. The hydraulics controller unit comprises Flow-controlled valve driver and Power electronics for the electronically controlled engine.

For the most part, connections from control unit to sensors, power outputs and vehicle connector take the form of what is known as 'flex-film technique' – i.e. printed circuits embedded in plastic. The high level of multiplexing in the vehicle enables the interface to be reduced between control and vehicle (vehicle connectors) on the voltage supply including the CAN bus. The complexity of a dual clutch transmission can be observed in the number of software parameters. In this way, the system can be calibrated with approximately 6000 single parameters, 600 characteristics curves and 150 characteristics fields.

## 4 Transmission Efficiency Rating and Fuel Consumption

The transmission efficiency rating results in mechanical, hydraulic and electrical losses. Efficient automatic transmissions require mechanical efficiency ratings at the same level as manual transmissions and the lowest possible power requirement for automatic-functions. In this respect, the DQ200 transmission has significant benefits over all currently available automatic transmissions.

### 4.1 Electrical Power Consumption

**Figure 7** shows an extract from driving out of town (EUDC) in NEDC. The vehicle speed profile and the selected gear are shown as overlapping. When the minimum pressure of 40 bar is reached, the pump loads the pressure accumulator back to 60 bar.

The low number of gear changes during continuous driving results in low fuel consumption and therefore longer accumulator pressure retention. The com-

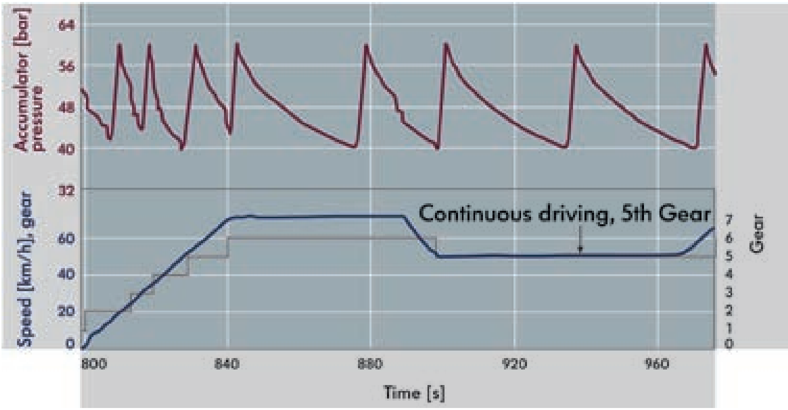


**Figure 7:** NEDC cycle, non-urban section

plete NEDC requires electrical power to the valves, the control device and the sensors at a virtually constant 30 W. The average NEDC power requirement of the pump motor stands at 20 W. The total electrical power requirement is therefore 50 W. Compared to the DQ200's electrical pump power of 20 W, the average requirement of the mechanical pump power in the NEDC for conventional automatic transmissions and the DQ250 is approx. 500 W.

### 4.2 Mechanical Efficiency Rating

**Figure 8** shows an example of the average mechanical efficiency rating in 5th gear. The average characteristics field values are delivered by a power rating of 2.5 kW to 125 kW at a transmission oil temperature of 90° C. The MQ250 manual transmission and the seven-speed DSG exhibit the best mechanical efficiency ratings. A major benefit of the DSG compared to other automatic transmissions is the low transmission oil volumes of 1.7 l, which help to minimize churning losses. Added to this is the aforementioned requirements-based delivery of auxiliary power.

The marginally better mechanical efficiency rating of the MQ250 manual transmission compared to the DQ200 results from the transmission construction with a single drive shaft. This contrasts favourably with the shorter DQ200 transmission construction featuring three drive shafts. It is clear that the introduction of the DSG with a dry dual clutch represents a new milestone in the efficiency rating of automatic transmissions. This benefit is such that it cannot be met by conventional automatic transmissions.

### 4.3 Fuel Consumption in the NEDC

For the customer, fuel consumption, alongside the transmission efficiency rating, is a deciding factor when it comes to making a purchase. **Figure 9** compares an example of different drive concepts in the NEDC. Compared to previous designs with a traditional six-speed automatic transmission with torque converter and 1.6-l FSI engine, the modern seven-speed DSG power unit and the turbocharged direct injection 1.4-l 90 kW TSI produced better acceleration values and increased driving dynamics with substantially lower consumption. In total, fuel consumption fell by up to 22 %.

This engine combination's consumption is 6 % lower than a manual transmission.

## 5 Summary and Outlook

With their DQ200 dual clutch transmission, Volkswagen has added to the range of transmissions four years after the successful launch of the world's first DSG. While the DQ250 was intended for the Golf and Passat model ranges for engines

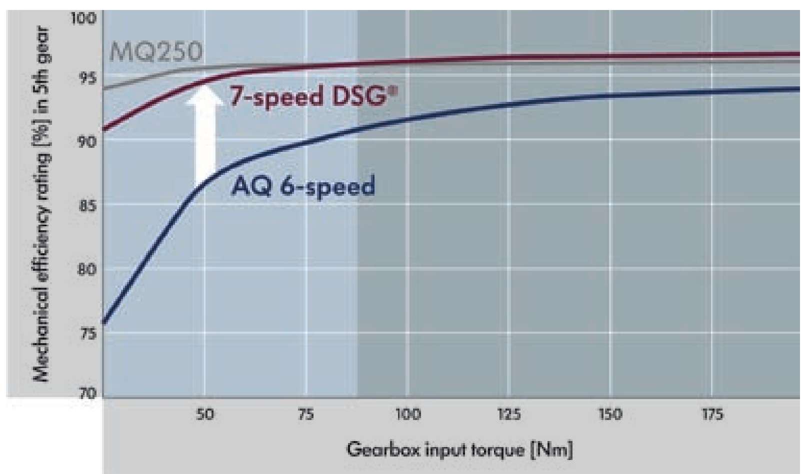


**Figure 8:** Mechanical efficiency rating comparison

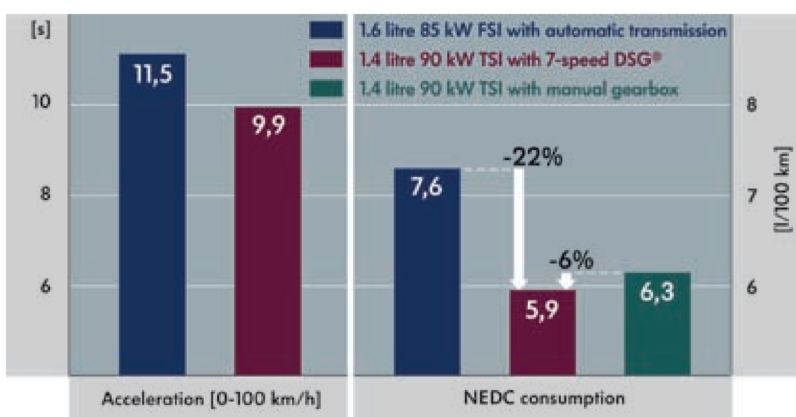


**Figure 9:** Comparison: VW Golf with petrol engine and automatic transmission

up to 350 Nm, the DQ200 is intended for use in the same ranges with engines up to 250 Nm. There are even plans for application within the Polo range.

By using a closed unit mechatronics system with an electrically driven pump, dry dual clutch and a consequential transmission design with optimum overall efficiency rating, it is the basis of vehicles with an automatic transmission with reduced fuel consumption. At the same time, the new DSG has reached new levels of comfort.

With the development and launch of this innovative transmission with a dry dual clutch, Volkswagen has made a considerable contribution in the field of vehicle transmissions to the reduction of fuel consumption and emission levels.

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