HYDRAULIC ACCUMULATOR IN TRANSMISSION CONTROLS

Dual clutch transmissions offering disruption-free traction are in the portfolio of all well-known car manufacturers. Freudenberg Sealing Technologies developed a light hydraulic accumulator to ensure that hydraulic actuations are as efficient as possible even at peak demand. Investigations have shown that this accumulator makes it possible to gear components, such as the hydraulic pump for actuators, to reduced fuel consumption. The hydraulic accumulator needs only about a sixth of energy of a conventional constant pump. Thus, the CO_2 emission is reduced by up to 4 g/km.

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TESTING CONDITIONS

The market share held by automatic transmissions, dual clutch transmissions (DCT) and hydraulic control systems for start-stop applications is growing each year. The variety of technical solutions for hydraulic actuation is also growing. They range from hydraulic accumulators, to constant and adjustable pumps, all the way to one- and two-stage electrically driven pumps.

The following analysis shows how efficiently the piston or membrane versions of hydraulic accumulators perform compared to a torque-dependent, pressure-regulated system with a combustion engine driven constant pump. The investigation is based on various driving cycles, defined load values, pressure and volume flow requirements and the efficiencies of individual components. The test series used a compact vehicle with a turbocharged direct-injection four-cylinder gasoline engine with 1.4 l of displacement, 250 Nm of torque, and 110 kW power. The transmission is a seven-speed, dry clutch DCT with electro-hydraulic control, including an accumulator charging system.

HYDRAULIC ACCUMULATOR FOR COVERING PEAK NEEDS

A hydraulic accumulator consists of a gas segment and a liquid segment which are separated by a gas-tight (piston or membrane) medium divider. The gas side is filled with nitrogen, and the liquid area is connected to the hydraulic circuit. With an increase in pressure, the hydraulic accumulator takes in the pressure fluid and the gas mixture is compressed. This mostly takes place in the stages between shifting. If the pressure declines, the compressed gas expands out again and forces the stored fluid into the transmission's circuit and thus to the actuators.

A hydraulic accumulator is the ideal solution to cover the peak demand that arises as the gear selector is activated, for example. In this way, both the oil pump and the drive electric motor can be designed for average fuel consumption – they are smaller and thus significantly more efficient. Hydraulic accumulators thus make a significant contribution to improved fuel economy and help reduce CO_2 emissions.

One of the best-known examples of the successful use of hydraulic accumulators is the Volkswagen DQ200 DCT transmission introduced with very low energy demand in 2007. The main supplier of this hydraulic accumulator is the Remagen (Germany) based Lead Center Accumulator of Freudenberg Sealing Technologies.

MINIMISATION OF HYDRAULIC LOSSES

The minimisation of hydraulic losses plays a crucial role in the use of hydraulic accumulators. To make a comparison of overall efficiency with the previous solution, the losses due to the inter-connected components were determined. This includes the oil pump with electric drive, battery, generator and belt drive. The basic driving cycles in the investigation are the European NEDC and the US-American FTP75. They differ mainly in acceleration, the driving experience, and trips with air-conditioning. But in the test, these parameters only affect the amount of deviation from the defined cycle fuel consumption and not the efficiency investigated in the test. ❶ shows a summary of energy efficiency at a glance. Here, it becomes visible that the hydraulic accumulator needs only about a sixth of energy of a conventional constant pump.

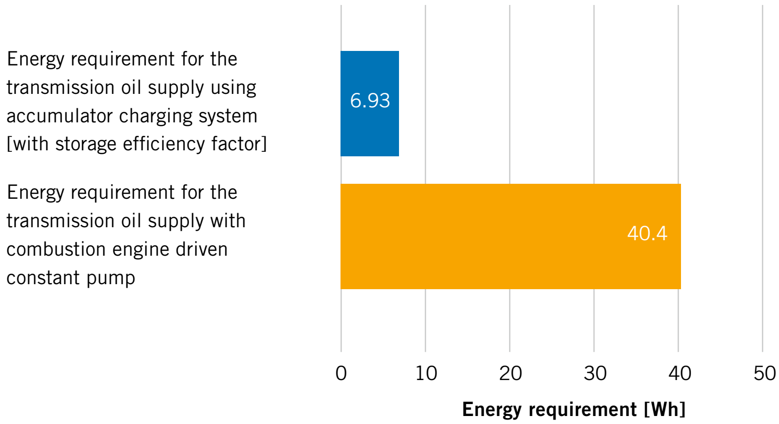
NEDC*	
Energy input from crankshsaft	
Acc. charging system	Mech. constant pump
6.93 Wh	40.4 Wh
Energy consumption [l/100 km] with regard to standard consumption value of 5/km	
Acc. charging system	Mech. constant pump
0.035 l/100 km	0.202 l/100 km
CO_2 reduction [g/km] with accumulator charging system at standard consumption value of 5 l/km**	
Gasoline	Diesel
3.96 g/km	4.43 g/km

FTP 75*	
Energy input from crankshsaft	
Acc. charging system	Mech. constant pump
7.3 Wh	53.4 Wh
Energy consumption [l/100 km] with regard to standard consumption value of 5/km	
Acc. charging system	Mech. constant pump
0.029 l/100 km	0.211 l/100 km
CO_2 reduction [g/km] with accumulator charging system at standard consumption value of 5 l/km**	
Gasoline	Diesel
4.32 g/km	4.83 g/km

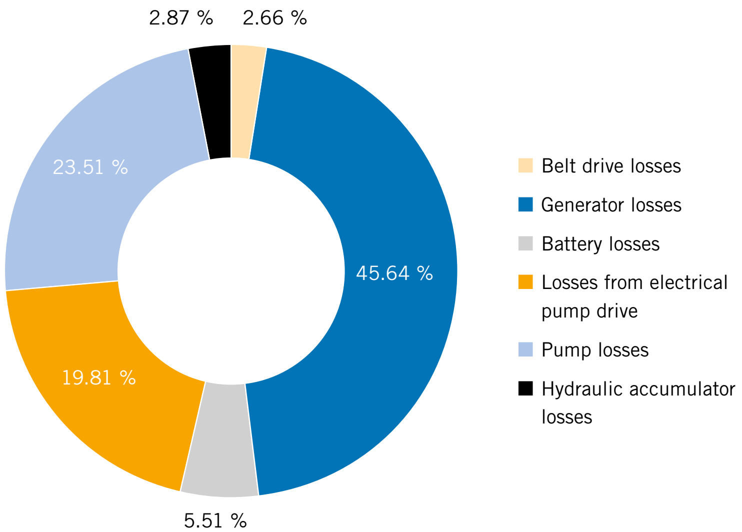
➡ The accumulator charging system requires only about 1/6 the energy of the constant pump

* Values relate to transmission oil supply
** The values shown here assume the operation of the combustion engine at the same load and the same specific fuel consumption in both systems

❶ Energy efficiency considerations at a glance – fuel consumption advantage in the cycles



❷ Energy requirements comparison of transmission oil supply concepts under the NEDC



➡ **The main sources of losses are the generator, pump and electrical pump drive (89 % share)**

➡ **Only slight loss due to auxiliary components-belt drive and hydraulic accumulator**

❸ Loss distribution under the NEDC for an accumulator charging system

To assess the efficiency of the hydraulic accumulator itself, the frequency and the cycle profile were determined. If you compare the charging process in the two driving cycles, the frequencies are about 0.05 Hz for both the NEDC and the FTP75 – the accumulator is charged every 20 s on average. If the measured profile is analysed, the expected sawtooth behaviour does not merely occur during charging and discharging. It also occurs when no gear changes are taking place. This means that a stable pressure level has not developed at this stage. This arises in large part due to leakage at the pressure control and directional valves.

Since two to three pressure control valves, depending on the structure, are continuously active in each sub-gearbox, the loss can reach a magnitude that exceeds the usable accumulator discharge volume. This applies even though special low-leakage valves are involved, with loss levels between about 15 and 50 ml/min. That means a large portion of the control oil stored with the substantial application of energy is unused.

One solution could be a new design with fewer valves. The result is a storage efficiency of 92 % for a hydraulic accumulator, based on the described cycle profile at a frequency of 0.05 Hz and the defined pressure and volume levels.

STABLE WORKING POINT FOR HIGHER EFFICIENCY

To ensure and efficient, trouble-free actuation of the transmission, the volume flow to fill the actuators must be appropriately designed. This is closely related to pump output. A load volume flow of 0.7 l/min and a pressure between 43 and 60 bar were provided in the investigation of the seven-speed transmission with electro-hydraulic control and an accumulator charging system.

The calculation of the energy need of both versions of the oil pumps assumes an average efficiency in the respective pressure and rotational speed ranges, ❷. For the electrical accumulator charging pump, a nominal working point at an average pressure of 51.5 bar and electronic load control at 2200 rpm is taken as the basis. In the case of a mechanical, combustion engine driven pump, it is an average rotational speed of 1372 rpm at a load-dependent pressure range between 10 and 20 bar. If you compare the overall efficiency levels determined in this way, you find that the accumulator charging pump and the combustion engine driven pump are at 60 respectively 75 %. But higher value for the mechanical solution only relates to standardised driving cycles. Outside these ranges, the energy characteristics of the previous solution deteriorate sharply.

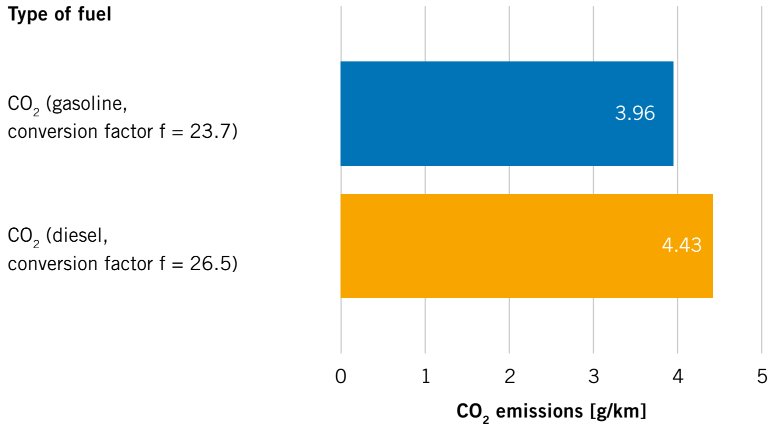
Due to the stiff coupling, the fluctuating rotational speed and the continual pressure adjustments of the previous solution allow no specific adjustment of efficiency. The relatively large pump is another negative factor since the layout leads to a high surplus output even at low cycle speeds during near-idling operation. Outside the driving cycle, a major savings potential would only be offered by a two-stage variable displacement pump with a rotational speed dependent reduction of the displacement volume.

By comparison, the energy attributes of the hydraulic accumulator change very little under real driving conditions. Here, the working point (rotational speed and the pressure of the accumulator charging pump) remains unchanged; only the frequency of actuation fluctuates.

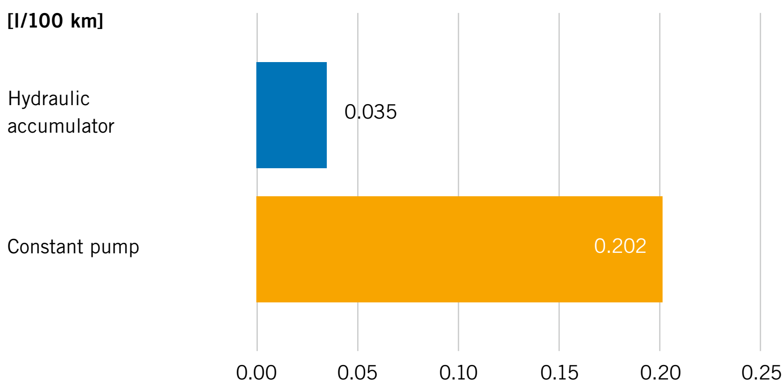
LOW CO_2 EMISSIONS

The investigation showed that hydraulic accumulators for the oil supply to clutch and gear selector actuators offer significant energy advantages. The reason is the lower installed capacity within the driving cycles. The main sources of losses are generator, pump and the electric pump drive. Their total share comes to nearly 90 %. The remainder is assigned to 5.51 % for the battery, 2.87 % for the hydraulic accumulator and 2.66 % for the belt drive, ❸. A high share of losses of 19.81 % attributed to the electric pump drive could still be improved in the future with better recuperation systems.

Taken as a whole, the hydraulic accumulator needs about 14 to 17 % less energy than conventional systems with combustion engine driven constant pump. In CO_2 emission comparisons, the technology comes in 3.96 and 4.43 g/km lower at a cycle fuel consumption level of 5 l/100 km, ❹ and ❺. That shows the considerable efficiency of the hydraulic accumulator for energy storage in automatic and dual clutch transmissions.



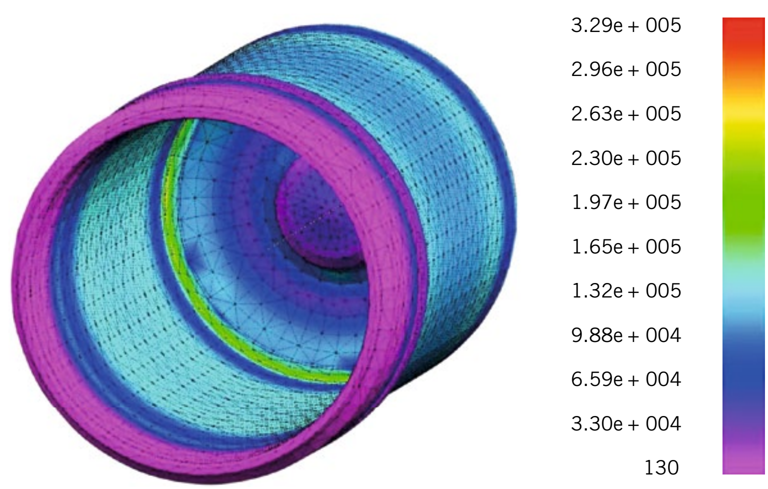
❹ Hydraulic accumulator compared to mechanical constant pump for CO_2 emission difference [g/km] under the NEDC, based on NEDC fuel consumption value of 5 l/100 km (gasoline vehicle with 118.5 g/km or diesel vehicle with 132.5 g/ km)



❺ Fuel consumption difference [l/100 km] for transmission oil supply with regard to NEDC standard 5 l/100 km

MODULAR SYSTEMS FOR INDIVIDUALISED SOLUTIONS

Much has happened since introduction of the DQ200 DSG transmission with dry clutch discs made by Volkswagen. Today, nearly all well-known car makers offer a dual clutch transmission. Freudenberg Sealing Technologies created a hydraulic accumulator and modularised its design and production principle in such a way that the company can respond flexibly to the different requirements of automobile manufacturers and transmission suppliers with regard to storage volume and pressure ranges. Moreover, the hydraulic accumulator's diameter and length proportions can be precisely adapted to the respective installation space.



❻ FEA presentation of stress distribution in a hydraulic accumulator in N/mm²

WEIGHT SAVINGS WITH ALUMINIUM AND PLASTIC

The company's latest developments in the production of hydraulic accumulators include the use of aluminium and plastic. These lightweight materials, used for the first time for pistons and housings, greatly reduce overall weight and contribute to the reduction of fuel consumption and CO_2 emissions. The weight savings compared to conventional solutions are as high as 40 %.

The new lightweight hydraulic accumulators are also designed from fewer individual parts. The best possible design is determined using FEA, ❻. The manufacturing technology for series production has been optimised to provide the maximum impermeability to gases across all conditions and to make the hydraulic accumulator completely maintenance-free over the vehicle's lifespan.