28

New measures for reducing friction in the drive train

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Summary

In a joint advanced development project, Dr. Ing. h.c. F. Porsche AG and Schaeffler KG developed a CO_2 demonstration vehicle. New optimized components for the drive train and chassis were incorporated in this vehicle in order to reduce the fuel consumption in the New European Driving Cycle (NEDC) by around 10 % compared with the current volume produced vehicle. The saving is split at a ratio of 70 to 30 in the utilization of technologies with optimized energy requirements and the reduction of friction on contacts respectively. The CO_2 demonstration vehicle was created on the basis of a current Porsche Cayenne with a V8 engine, where Schaeffler designed and verified the individual components and Porsche was responsible for system adjustments and validation in the entire vehicle. Each measure was backed up by calculations and various experiments, and the overall reduction was verified in the vehicle model and in vehicle measurements.

Reducing the losses in the engine generated a reduction in fuel consumption of 5.8 % in the NEDC. Modifying the valve control VarioCam Plus by means of electric camshaft phasing and an optimized switchable tappet on the intake side contributed to 4.1 % of this reduction. The reduced friction power in the valve train, belt drive and chain drive by means of lightweight components and coated engine components reduced the overall fuel consumption a further 1.7 %.

The tapered roller bearings in the front and rear axle final drive units were replaced by double row angular contact ball bearings thereby reducing the fuel consumption in the NEDC by a total of 1.1 %. Compared with conventional volume produced units, the friction power was reduced by 42 % on the rear axle final drive unit and 35 % on the front axle final drive unit.

Using wheel bearings with optimized friction characteristics and replacing the hydraulic roll stabilizer with an electric roll stabilizer reduced fuel consumption in the NEDC by 3.2 %. The reductions on the rolling test stand are already generated when traveling straight ahead by eliminating the drive power of the hydraulic pump, so that even higher savings can be expected during measurements in more customer-oriented vehicle tests on winding roads.

Further optimizations to the chassis and drive train of the demonstration vehicle that were not previously included in the measurements will be carried out during the next few months.

Figure 1 The demonstration vehicle

Collaboration between Schaeffler and Porsche

Today, engineers of both companies are working closely on assessing and implementing ideas for developing new components while taking all the appropriate steps right from the start. This is because this is the only means of taking on the challenge of a future that categorically and quickly requires lower contaminant emissions, lower CO_2 output and lower fuel consumption. This article shows that this strategy can lead to very unconventional solutions. However, it cannot be overlooked in this very special case that progress can only be made in small steps in such a young and modern vehicle such as the Porsche Cayenne. Lowering the fuel consumption by around 10 % is the result of several, in some cases far-reaching, measures.

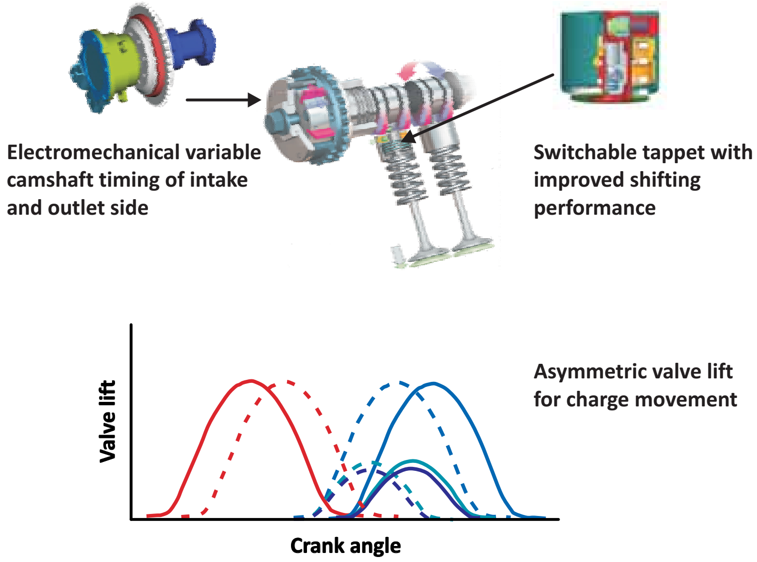

Figure 2 Optimized VarioCam Plus system

Together, these two companies carried out advance development on new components that were tested in a demonstration vehicle based on the current Porsche Cayenne. The demonstration vehicle is easily recognizable since it features the "Co_2ncept-10 %" logo as well as pictures of the various new components it contains.

High-tech valve timing adjustment – electric camshaft phasing and optimized valve lift activation

The first step of the task was to demonstrate how the fuel consumption and CO_2 emissions can be reduced in a V8 engine from a Porsche Cayenne by optimizing the already very successful VarioCam Plus system. To do so, engineers at Schaeffler and Porsche replaced the hydraulic camshaft phasing system in volume production with an electric system. This solution involves very compact electric motors that adjust the timing of the valves on the intake and exhaust camshafts. The high torque required for this is due to the high power transmission ratio of the small electric motor that can reduce the speed by a ratio of 66:1 and, at the same time, increase the torque of the electric motor by the same ratio.

The electric system has two advantages compared with the conventional hydraulic solution:

- Less energy is required since the motors only operate when adjusting the valve timing is necessary. There are theoretically speaking also no longer any limits to the timing angle. In practice, this means that a larger timing angle can be used,
- as well as faster adjustment.

Both these improvements not only lower fuel consumption, the engine performance characteristic of the engine is also improved.

Along with the valve timings, the valve lift on the intake side plays a decisive role in the energy-saving plans of our engineers. The lift is adjusted by electro-hydraulic valve tappets. This effect that reduces both fuel consumption and emissions is generated by two variable values:

- Less valve lift and shorter opening times reduce the charge-exchange losses in the partial load range and increase the speed of the incoming air for more effective mixture preparation.
- Furthermore, the system facilitates the deactivation of the intake port (to generate high charge movement) when the engine is operating in the lower partial load range and varies the level at which both intake valves of each cylinder are opened when the engine is operating in the higher partial load range.

These ingenious measures trigger a small "whirlwind" in each combustion chamber that permits the creation of an especially homogenous and ignitable gasoline-air mixture that ensures very efficient combustion cycles even at low loads.

The improvement generated by the optimized VarioCam Plus system lies in the partial load range (Figure 3). According to current results, adjusting the valve timing, valve lift and charge movement lower the fuel consumption calculated for the NEDC by 4.1 %.

A very informative diagram (Figure 4) shows the possible new designs for the valve tappet of the future. For example, the valve tappet of the future may no longer be round and similar to a cup, but may be shaped in such a way so that it only has

Fuel consumption reduction of VarioCam Plus in comparison to VarioCam Plus optimized

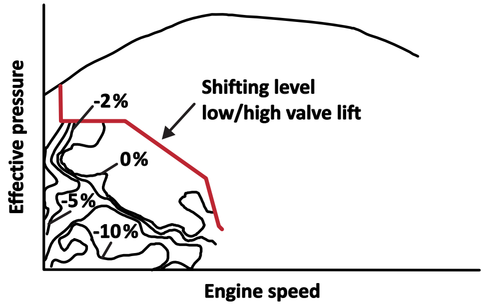

Figure 3 Improving fuel consumption in the characteristic diagram with the optimized VarioCam Plus system

contact surfaces for the tappet where a certain function is fulfilled.

Lowered friction power in the internal drive systems of the engine

The diameter of tappets has significantly reduced during the last decade and the new design has enabled us to reduce the moving mass to

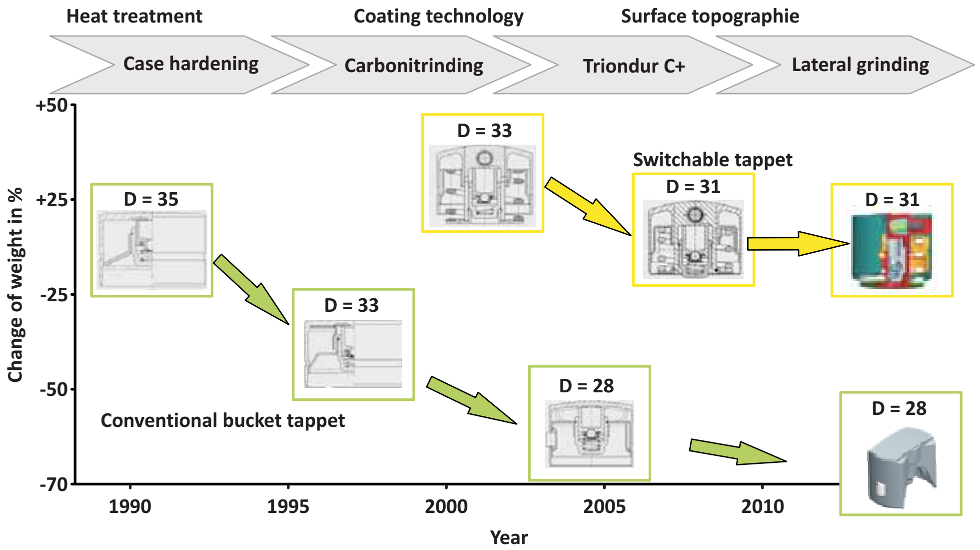

Figure 4 Measures for the valve train

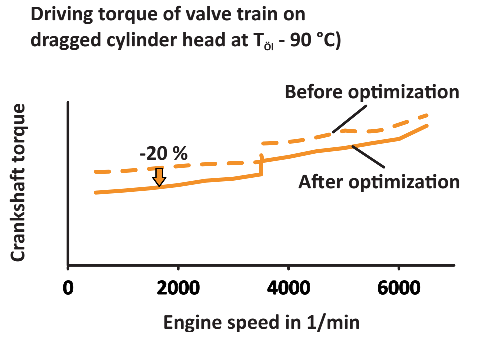

Figure 5 Reduction in driving torque due to measures on the valve train

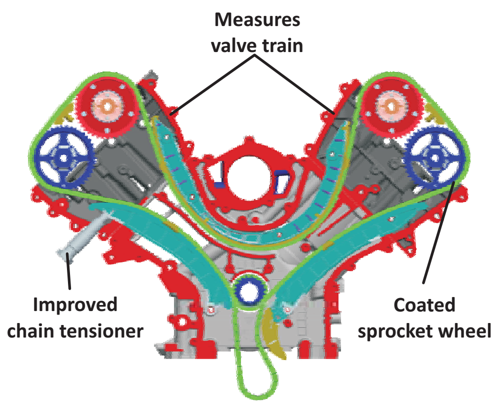

Figure 6 Measures in the primary drive

only 30 %. For optimum smooth running, the cast camshafts and the tappets they actuate undergo intensive surface treatment. After intense development, the contact surfaces of these parts are now coated with TriondurC+, a DLC coating system that is around 3 µm thick and has a hardness of up to 3000 HV, which can significantly reduce friction and offers an extremely high resistance to wear. Furthermore, the valves of the V8 engine of the future could be significantly lighter, despite not being any smaller in size.

This general reduction in moving masses not only promotes the running smoothness and lively revving ability of the engine, but also curbs the fuel consumption.

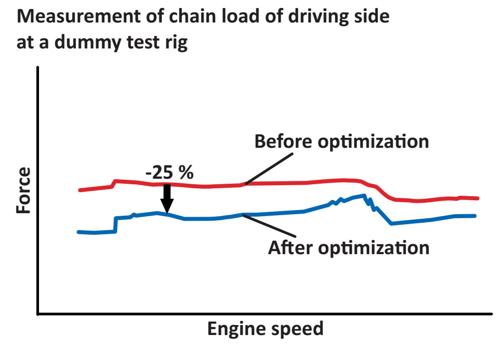

Figure 7 Reducing forces in the primary drive

Here too, the frictional torques were clearly lowered by more than 20 %.

Using similar fine tuning, our engineers also lowered the required drive power for the chain drive that operates the four camshafts. Chain tensioners optimally adjusted to the drive and coating the chain sprockets also lower the friction.

The forces in the primary drive can be lowered by around 25 % if all changes to the primary drive and valve train are made simultaneously.

The V-belt drive on the front of engines has become more complex during development, since the desire for improvement and comfort has increased the number of units to be driven. This results in increasing power expenditure that has to be compensated with targeted measures.

Porsche and Schaeffler have taken on this challenge and have found the solution for reducing losses in the presented project with a series of

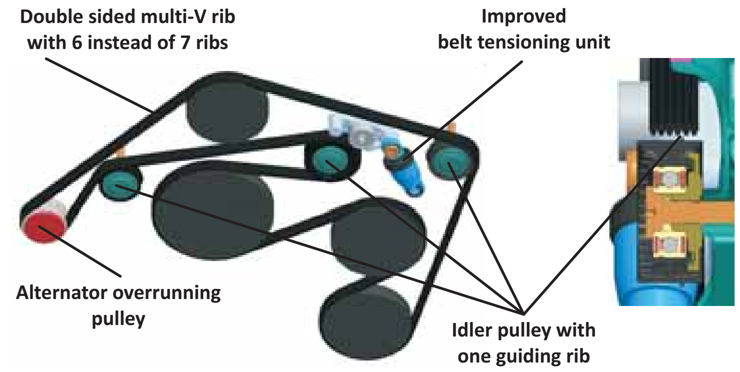

Figure 8 Measures in the ancillary drive

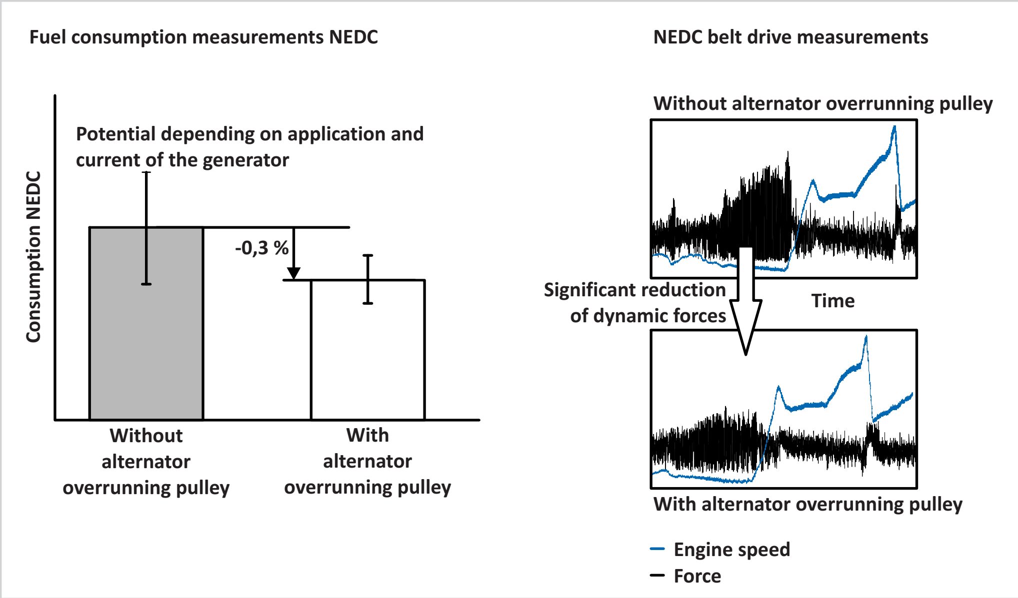

Figure 9 Improving fuel consumption and reducing forces by means of overrunning alternator pulleys

measures. More effective chain tensioners and the use of a narrower belt (six ribs instead of seven) facilitate the smooth transmission of power. Even the drive force requirements of the idler pulleys were reduced by limiting the roller to one guide profile.

A further important role is played by the overrunning alternator pulley in the efforts to lower the required power for the belt drive. This is because it enables the generator to keep a near constant speed, despite irregular stimulation from the crank drive and valve train. The more constant speed of the generator reduces the dynamic forces in the belt drive and therefore the friction and power loss in the system. However, the potential for reducing losses is heavily dependent on the relevant application and on the actual charging current of the generator, since high performance delivery produces a high braking torque in the generator. This, in turn, influences the dynamics in the belt drive.

The diagram clearly shows the level of fluctuations in speed in the drive and therefore the forces in the belt drive of the generator in city traffic without an overrunning alternator pulley. The mean of several very precise measurements taken in the NEDC when using an overrunning alternator pulley is a 0.3 % reduction in fuel consumption. In addition, reducing the load placed on the belt by means of the pulley can increase the life of the V-belt.

Measures on the front axle and rear axle final drive units and wheel hubs

With its INA and FAG brands, the Schaeffler Group is one of the world's leading experts in rolling bearing technology. This is also one of the reasons why the Schaeffler Group is a perfect development partner for Porsche when it comes to smooth running in vehicles. Schaeffler then also pointed out that friction losses in the final drive units on the front and rear axles can also be significantly reduced.

The recommended measures involve replacing the traditional tapered roller bearings on the universal shaft drive side with tandem ball bearings and more efficient single-row ball bearings on the left and right sides of the differential housing for driving the axle shafts.

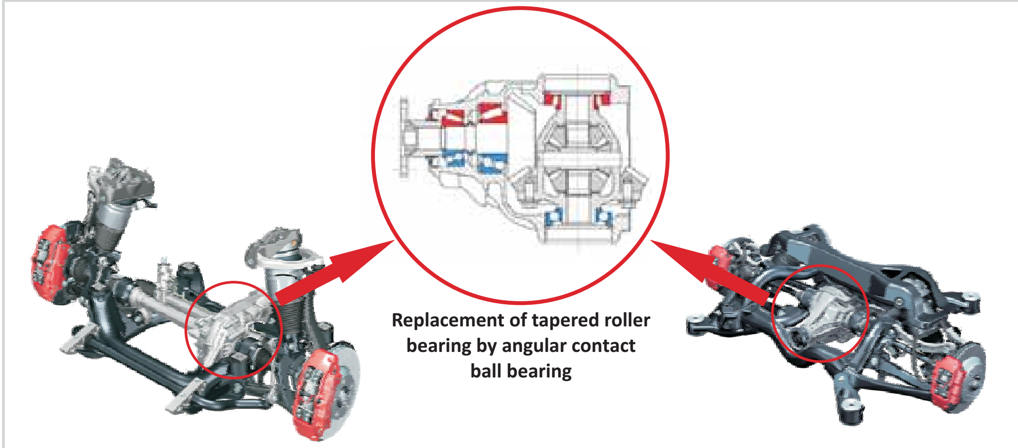

Figure 10 Measures on the front and rear final drives

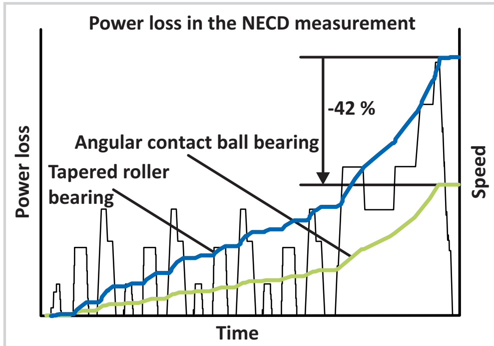

Figure 11 Reducing power loss by means of an optimized rear axle final drive unit

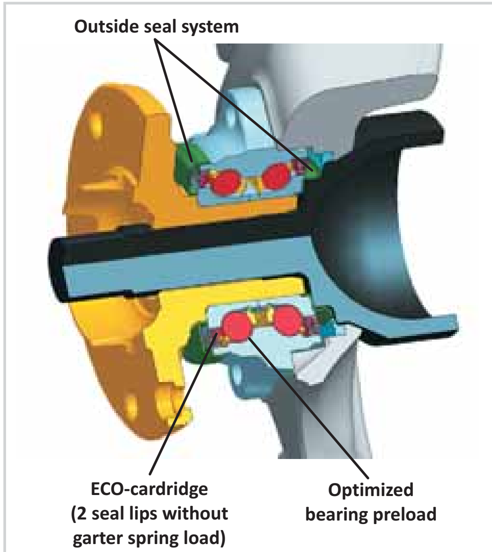

Figure 12 Measures for wheel bearings

The results are remarkable. The power loss on the front axle is reduced by 35 %. This increases to 42 % on the rear axle due to the increased load.

The Porsche Schaeffler project also generated more improvements and smooth running in the wheel bearings.

In this case, improvements were made due to the optimized preload of the double-row ball bearings and by redesigning the seal system including the outer seal. Together with a minimized bearing preload, the omission of garter spring load by means of a modern seal without steel springs as well as reducing the sealing interference led to a 30 % re-

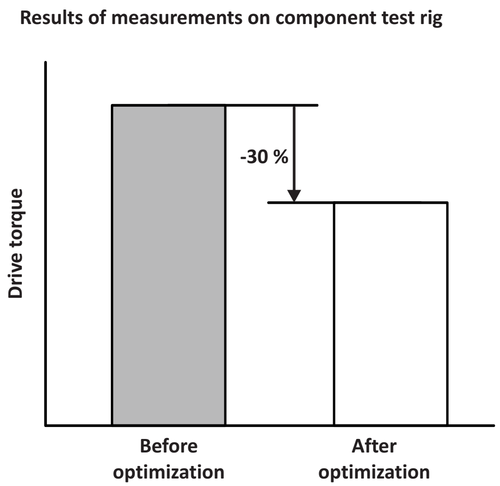

Figure 13 Reduction of torque loss with optimized wheel bearings

duction of friction losses with constant sealing action.

Overall, the potential for reducing fuel consumption is far below 1 %. Despite this fact, the energy efficiency is generated by the sum of all individual measures and the optimization of individual potential that seems low at first glance is also worthwhile.

Electrically adjustable roll stabilizers

The requirements placed on a sporty SUV such as the Porsche Cayenne are extremely varied. In road traffic, the vehicle must master bends in the road without roll movement. Off road, this “taming” is not desired: Severe axle articulation ensures contact with the ground and traction. Up to now, Porsche has met this challenge with an active hydraulic control system for the stabilizers on both axles. However, due to the permanent supply of oil to the hydraulic pump, this solution requires permanent operation of the pump and therefore leads to permanent losses.

Experience has shown that some hydraulic systems can be efficiently replaced by electric systems. This knowledge generated a solution that sets the required stabilizer torques as needed. During this process, the electric motor only requires power when the pivot actuator turns and thereby generates torque. When maintaining torques, only the relatively low electric resistance losses must be compensated for. The roll stabilization system is relatively inactive on a freshly laid motorway, but has to be considerably more active on a normal road depending on the condition of the road, the number of bends, and the driver’s driving style. This is why the electromechanical roll stabilizing system has an extremely large potential for savings compared with the uncontrolled hydraulic system where the supply of oil to the pump is constant.

Adjusting the roll stabilizers using the electrical system lowers the consumption in the NEDC by 3 %.

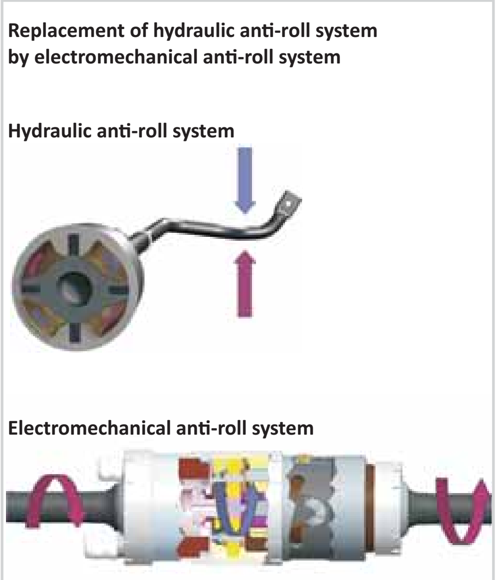

Figure 14 Measures for roll stabilization

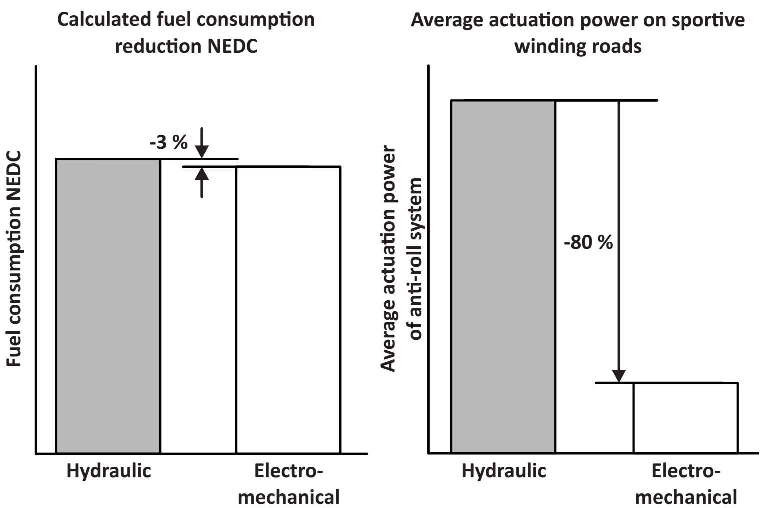

Figure 15 Reducing fuel consumption and drive power by means of optimized roll stabilization

Taking stock of fuel consumption and emissions: 10 % reduction

Figure 16 shows the simulation model and the variety of factors that facilitate a reduction in fuel consumption. Before implementation, all measures were evaluated in prototypes and during experiments regarding their contribution to lowering fuel consumption using calculations in a vehicle model. Specific simulation models for individual road resistances are shown in the relevant functional blocks along the drive train. During the project, the advance development tasks for the components were split between Schaeffler and Porsche, which meant that data and characteristic diagrams were determined on component test stands at Schaeffler, on fired engine test stands at Porsche and in vehicle tests that provided a physical representation of the function behavior of the components. This data was used to adjust the simulation program during the early stages of development, which made it possible to make statements about the influence of each measure on fuel consumption. More detail was given to these statements during further steps of development.

The overall savings realized on an existing volume production vehicle are currently around 10 % when all measures are considered together. However, this is not the end of the line. Porsche and Schaeffler are using their growing experience to reduce fuel consumption even further. 70 % of the improvements made so far involve technology with optimized energy requirements and 30 % involve reducing friction in the drive systems.

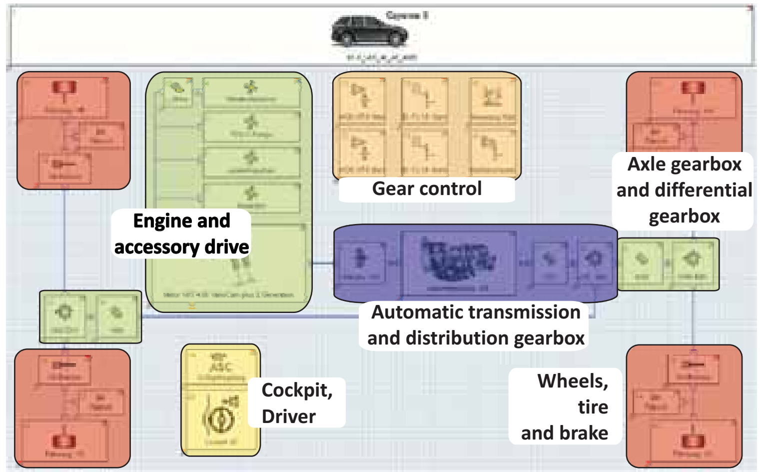

Figure 16 Simulation model for NEDC calculation

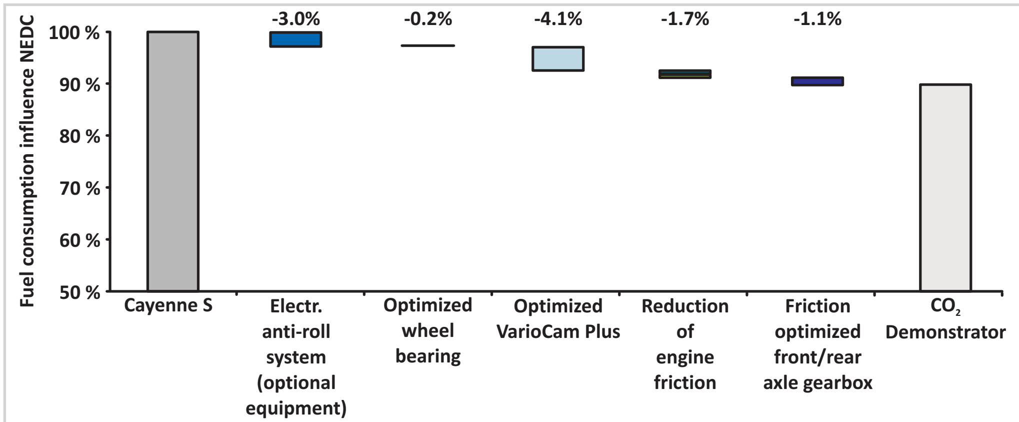

Figure 17 Results of NEDC calculation

The calculations made on the basis of measurements taken on test stands show that fuel consumption and consequently CO_2 emissions could be reduced a further 10 % at the current stage of advance development. Here, optimized valve control has the lion's share. It is also worth noting that the 3 % saving generated by the electrically controlled roll stabilizer will probably be even higher during normal day-to-day operation that deviates from standardized test stand cycles. The countereffects of the measures with each other can influence the potential of single measures to reduce fuel consumption.

In addition, Porsche and Schaeffler will work intensively on successfully tapping further potential thereby reducing fuel consumption and CO_2 emissions.

Safeguarding a reduction in fuel consumption during vehicle tests

The next step involved fitting the various components in a demonstration vehicle. Measurements on the road and on a rolling test stand were made with this vehicle to confirm the calculated potential of the measures for cutting fuel consumption.

In order to evaluate the benefit in relation to the outlay, it is important to verify the potential of each measure in the vehicle itself. As mentioned above, the bearings in the front and rear axle final drives were replaced with optimized bearings. The individual potential of these bearings was determined in coast down tests with volume production final drive units and modified final drive units on a rolling test stand.

During these tests, the vehicle coasts down from a starting speed of 120 h/km to 5 h/km. A comparison between the optimized rear axle final drive unit and the volume produced unit shows that the coasting time is 2.5 % longer. Adjusting the rear axle final drive unit road resistance functional block of the simulation model using this result leads to a calculated improvement in fuel consumption in the NEDC of around 1 %. This means that it was possible to confirm the total reduction in fuel consumption of 1.1 % for front and rear axle final drive units previously ascertained from component tests.

Figure 18 Measurements taken with the vehicle on the rolling test stand

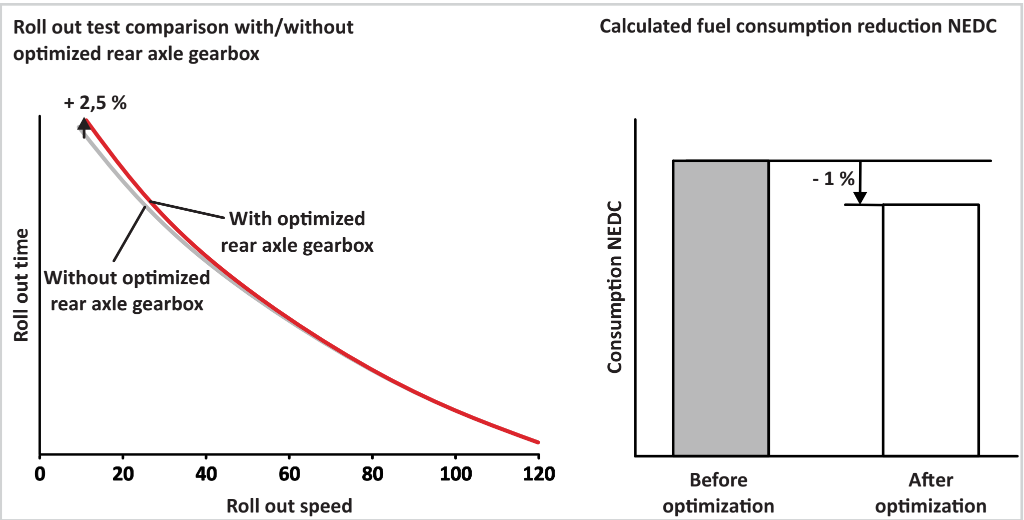

Figure 19 Results of measurements on the vehicle

Conclusion

Taking stock of this joint project between Porsche and Schaeffler using the Cayenne opens up a wide range of possibilities for the future. The combination of the measures illustrated for minimizing losses shows that it is possible to reduce the fuel consumption of a conventional drive with a gasoline engine in a two-digit percent range without hybridization. The solutions presented are not limited to SUVs and can be transferred to other types of vehicles and drives.

Individual improvements such as the more smooth-running rolling bearings can easily be transferred to volume production. Other components must undergo a cost benefit analysis to show whether volume production development can begin.