

Seamless Disconnect System to Minimize AWD Related Losses

Mechanical AWD systems will maintain a significant market share even with the future environmental challenges. Mechanical AWD will still be used in off-road vehicles but also in future hybrid and electric cars. The increasing pressure to reduce fuel consumption and CO₂ emission is now becoming the key driver for the development of new AWD technology. GKN Driveline as a leading driveline component and system supplier is applying its innovative power and long year expertise with AWD systems to develop unique AWD concepts to meet future requirements.

1 Introduction

Even in future people will not give up in their desire for mobility. But environmental and ecological concerns will get more focus. New technology has to address this and has to help to reduce the total energy consumption of future cars to be successful in the market. This applies particular to AWD technology causing an increase in fuel consumption compared to 2WD vehicles due to additional weight and losses of the AWD components. Mechanical AWD systems will maintain a significant market share even with the future environmental challenges. Mechanical AWD will still be used in off-road vehicles but also in future hybrid and electric cars. The trend to smaller and lighter AWD vehicles derived from FWD platforms with transversal engine arrangement does lead to an increasing number of so called "On-Demand" AWD systems on the market. The On-Demand AWD is using a controlled clutch to redirect power from the primary driven front axle to the secondary driven rear axle when demanded for traction or handling. This AWD concept needs two hypoid gears, one in the front (PTU) and a second in the rear (FDU) and is therefore particularly challenging regarding AWD losses. This less efficient hypoid gears have a major impact on the AWD related losses and CO₂ emission of such driveline.

Significant effort has been spent to minimize weight and losses of the AWD components. But maximum impact will only be achieved, if the whole AWD system is optimized in terms of traction (maximum torque), control strategy (duty cycle) and gear ratios, allowing down sizing of all components. The major part of the AWD related losses is caused by the drag and churning losses of the spinning parts. An AWD tuned for traction is transmitting torque only about ten percent of the vehicle life. Therefore it is obvious, that disconnecting the AWD system when not needed will provide a major reduction of AWD related fuel consumption. The challenge of such disconnect AWD is to make disconnect and re-connect of the system seamless and transparent to the driver and to keep expected AWD performance and driving comfort while achieving maximum fuel saving.

2 AWD Component Optimization

It is known from sources [1, 2] that On-Demand AWD systems are causing additional fuel consumption of 0,7 to 1,2 l/100 km for petrol and 0,4 to 0,7 l/100 km for diesel engines. This fuel penalty is mainly caused by:

- additional weight and inertia of the AWD components
- load related losses (mainly hypoid gears)

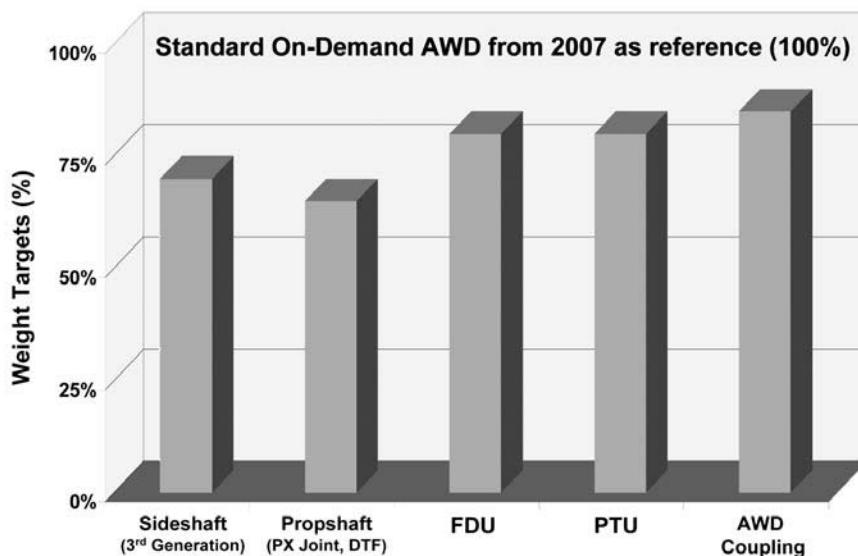


Figure 1: Weight reduction targets for specific AWD components

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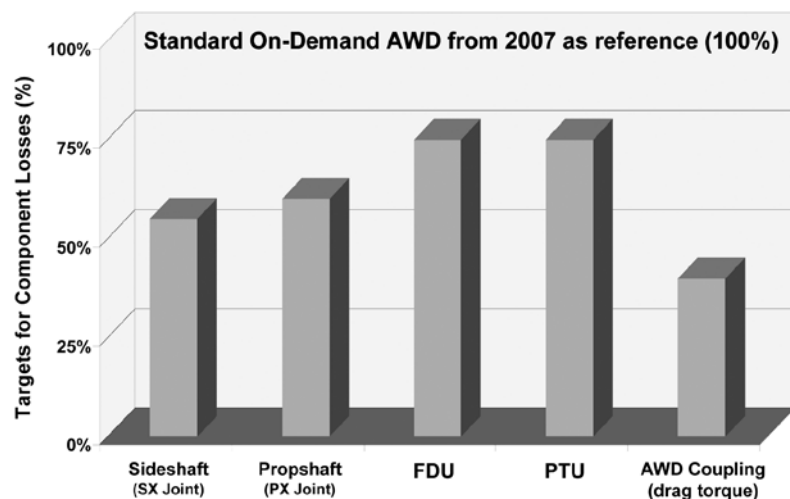


Figure 2: Potential reduction of AWD component related losses

- drag losses (bearings, seals)
- churning losses in the gears.

The detailed analysis of the specific losses identifies following saving potentials:

Calculations based on NEFC (New European Driving Cycle) show that 100 kg additional weight will lead to a fuel penalty of approximately 0,23 l/100 km for petrol and 0,17 l/100 km for diesel engines. Today's average On-Demand AWD systems with a rear axle torque of maximum 2500 Nm have a weight of 80 to 100 kg, which is already pretty good. **Figure 1** gives some weight targets of specific AWD components compared to what is on the market today. It is expected that future On-Demand AWD systems developed for optimized torque and duty requirements will add a total weight of

70 to 80 kg to the vehicle. This would lead to a reduction of the AWD related fuel consumption of approximately 0,05 l/100 km (petrol) or 0,03 l/100 km (diesel) compared to today's system.

The share of drag losses and load related losses on the AWD fuel penalty has been simulated as well based on the specific component efficiency characteristics. The calculation confirms that the drag and churning losses are causing more than 60 %, which is the majority of the losses. This is particular critical in On-Demand AWD systems with a low torque transfer most of the time. Replacing taper roller bearings with low drag angular ball bearings, use of synthetic oil with low basic viscosity and low viscosity/temperature dependency as well

as minimizing oil level and optimizing the oil flow in the gears are measures to significantly reduce the churning and drag losses. New joint designs like SX or PX-joints and/or new low friction greases have helped to improve significantly the efficiency of the driveshafts as well.

Figure 2 provides an overview of realised or intended measures to reduce the losses of typical AWD components. The total of the discussed measures to improve component efficiency will provide an additional fuel saving of about 0,12 l/100 km for petrol and about 0,07 l/100 km for diesel engines.

3 Disconnect AWD

Optimizing all AWD components and the AWD system requirements might provide a total reduction of the AWD fuel penalty of 15 %. This is good but might not be good enough. There are limits to reduce the majority of the losses caused by churning and drag. An AWD tuned for traction is transmitting torque only about ten percent of the vehicle life. So it is obvious, that disconnecting the AWD system when not needed will provide a major reduction of AWD related fuel consumption.

Switchable "Part-time" systems have been used in pickup trucks and SUVs for a long time. They usually come with an T/C disconnect feature allowing the driver to shift from 2WD to 4WD mode. Part-time systems using additional wheel hub, sideshaft or differential disconnect features do avoid spinning the AWD components in 2WD mode to reduce the AWD related fuel consumption. The shift from 2WD to 4WD works only at low or zero speed and requires driver input. This limits the 4WD usage, the performance and the driver comfort of such a system. Transferring part-time technology into an advanced disconnect AWD needs a new set of requirements, clutch and actuator technology and system control. The major challenge developing the new disconnect AWD technology was the integration of appropriate clutch and disconnect systems into PTU and FDU and the development of a suitable control strategy to meet AWD performance as well as NVH, comfort and fuel saving targets.

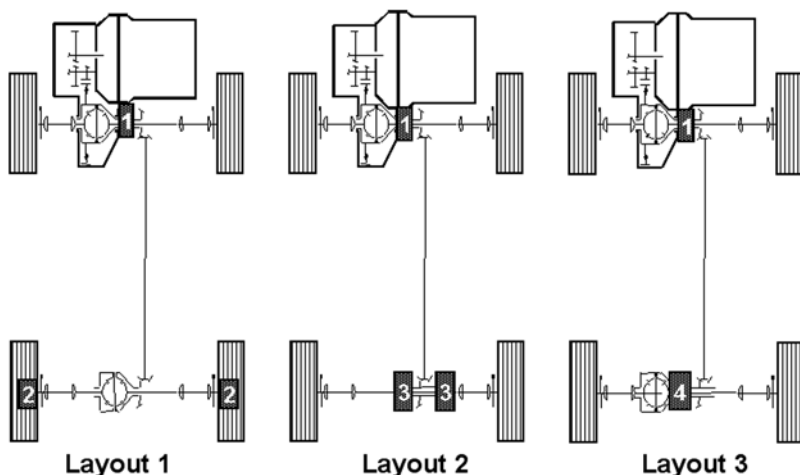


Figure 3: System layouts for AWD disconnect

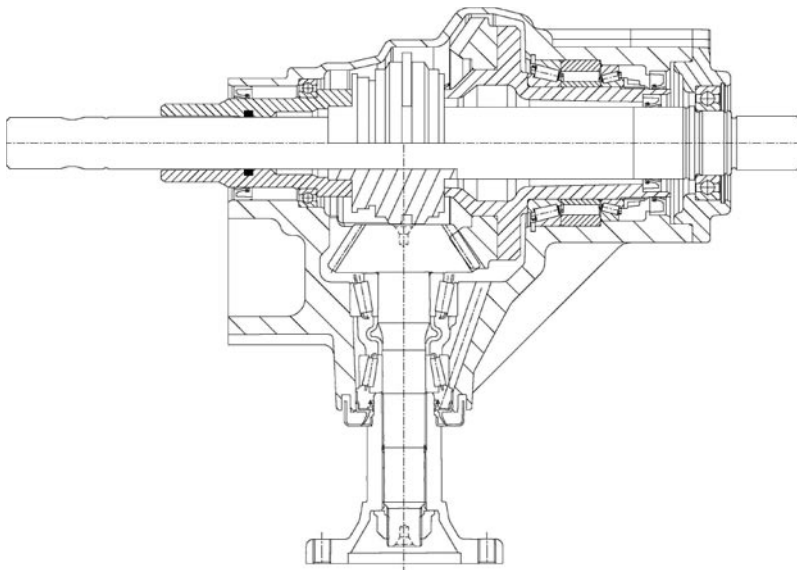


Figure 4: PTU cross section

4 System Layout and Main Components

The number of parts still spinning in disconnect mode have to be minimized to achieve the maximum fuel saving. Hence the AWD driveline has to be disconnected as close as possible to the transmission in front of the PTU hypoid gear and as close as possible to the wheels, downstream to the hypoid gear in the FDU. At the same time drag torque in the disconnect devices should be as low as possible. **Figure 3** shows three potential system layouts for disconnect AWD. All three solutions are comprising a disconnect feature (1) between transmission output and PTU to disconnect in the front. With the wheel hub disconnect (2) even the side shafts are stalling in disconnect mode, which will provide the maximum saving potential. But complexity, tough operation conditions in the wheel hubs and the number of remote actuations are considered as major development challenges and risk. Layout 2 uses a twin clutch arrangement (3) in the rear to control individual rear wheel torque and provide rear axle disconnect. Sideshafts will spin all the time causing little losses, but the two friction clutches with the required actuation will cause high cost and high losses due to clutch drag torque. The third layout uses only one clutch in the rear arranged between ring gear and differential to control torque flow front to rear in AWD

mode and decouples the differential from the ring gear in disconnect mode. This layout has been considered as best compromise between complexity and potential fuel saving and has therefore been selected for further development.

4.1 PTU Disconnect

When excessive slip occurs on the front wheels due to lack of traction the AWD has to be re-connected quickly to redirect the driving power to the rear wheels. The best approach in this case would be to put the on-demand clutch in the PTU and use it to accelerate and synchronise the driveline. A simple dog clutch disconnect feature in the rear would then be sufficient enough to re-connect the rear end as soon the driveline is synchronised. The tight packaging around the PTU does in most cases not provide enough space

to integrate the bulky on-demand coupling with actuation in the PTU. Consequently the on-demand coupling has to be installed in the FDU and the PTU uses a more compact dog clutch type disconnect combined with a synchronizer. The cross section of a single stage PTU with synchromesh disconnect device is shown in **Figure 4**. A high volume synchromesh ring from a manual transmission adopted to the disconnect requirements has been used to minimize cost and development effort. The disconnect feature should be located in front of the PTU ring gear and ring gear bearings to minimize the losses when disconnected. The arrangement of the bearings on one side of the ring gear allows a compact disconnect design and a cost effective two piece housing. A more conventional bearing arrangement on both sides of the ring gear is possible as well but requires an additional pinion cartridge.

4.2 Rear Axle Disconnect

In most of the On-Demand AWD systems the controlled coupling is located in front of the FDU between propshaft and pinion. For the disconnect AWD this coupling now has been sized for rear axle torque and has been integrated into the FDU between ring gear and differential, **Figure 5**. This makes the FDU very compact and frees up desired space in the propshaft area. In disconnect mode the coupling is released and decouples the ring gear from the differential, allowing the differential and sideshaft to spin with rear wheel speed while the ring gear is stalling. The on-demand coupling is the obvious choice for the FDU disconnect but is not made for the needed ultra low drag torque. In on-demand mode a

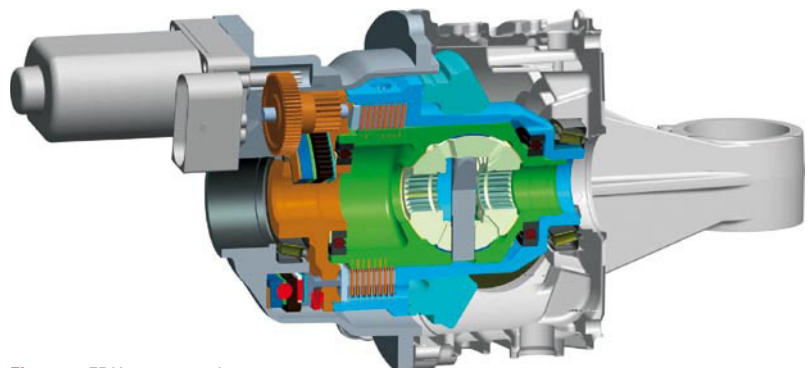


Figure 5: FDU cross section

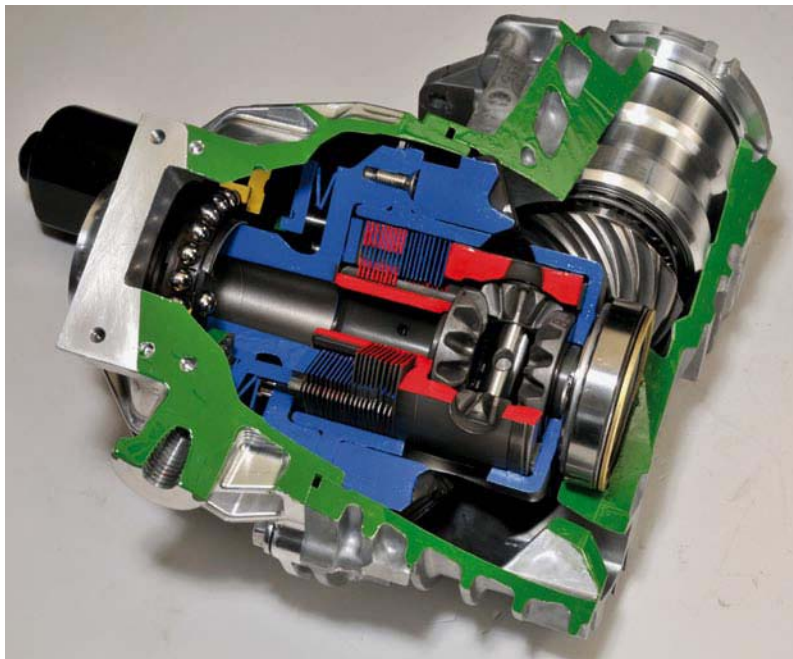


Figure 6: FDU prototype with on-demand & disconnect clutch

high control accuracy and control dynamic as well as good oil flow through the clutch for cooling and lubrication is required. But for the disconnect mode the oil flow has to be small and clutch endplay has to be wide to minimize drag torque and clutch losses. The engineering challenge was to cover both, on-demand and disconnect requirements at the same time. The friction plates have been optimized in terms of oil groove

pattern and outer plate design to minimize drag torque. Specific oil channels in combination with the right oil level have been developed to control the oil flow in a way that good cooling and lubrication is guaranteed in control mode (ring gear spinning) and the clutch is almost empty in disconnect mode (ring gear stalling). An ultra low drag torque of around 1 Nm has been achieved in combination with an extremely wide clutch

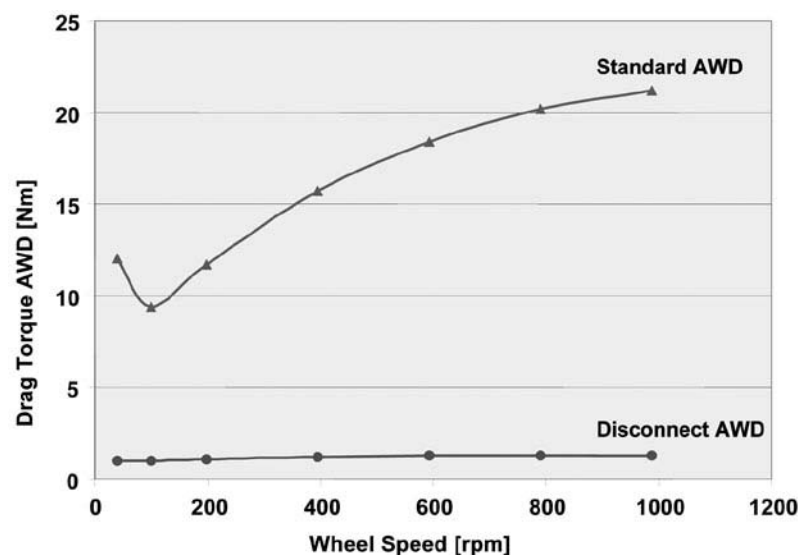


Figure 7: Rig test results of standard and disconnect AWD drag torque

end play. **Figure 6** shows a cutaway model of the FDU hardware tested on the rig and in the vehicle.

4.3 Actuation

The major challenge for the actuation was to meet the requirements for the on-demand and the disconnect operation at the same time and provide quick and precise transition from one to the other mode. Complexity and costs of two remotely located actuators had to be managed as well as to keep overall system on-cost reasonable. An existing high volume electro-mechanical actuator adapted to the disconnect requirement for connecting speed and actuation stroke has been applied for the PTU disconnect.

For the demanding FDU disconnect an electric-motor driven ball ramp actuator used in controlled limited slip differentials has been applied. The unique patented multi stage ball ramp provides a first ramp section for fast engagement and a second ramp section for precise control. Using a suitable rotation sensor and a highly dynamic e-motor control the actuator meets all requirements for a controlled quick synchronisation and re-connection of the AWD and the precise control of the clutch in on-demand operation.

4.4 System Control

Essential for the customer perception and acceptance of an AWD disconnect system is the smoothness and refinement of the dis-connect and re-connect operation. The re-connect operation has to be optimized regarding NVH, comfort, traction and vehicle dynamic. Fast re-connect response almost like today's on-demand AWD will provide maximum traction and stability but the required extreme acceleration of the driveline inertia will cause totally unacceptable driveline clonk and vehicle reaction. Thoroughly tuning in close link with the car manufacturer is necessary to find an acceptable compromise in terms of seamless and transparent operation and best AWD performance. Pre-emptive control strategies considering weather and surface conditions as well as driver intention and driving situation are essential to have seamless operation and to meet AWD performance and fuel saving targets at the same time.

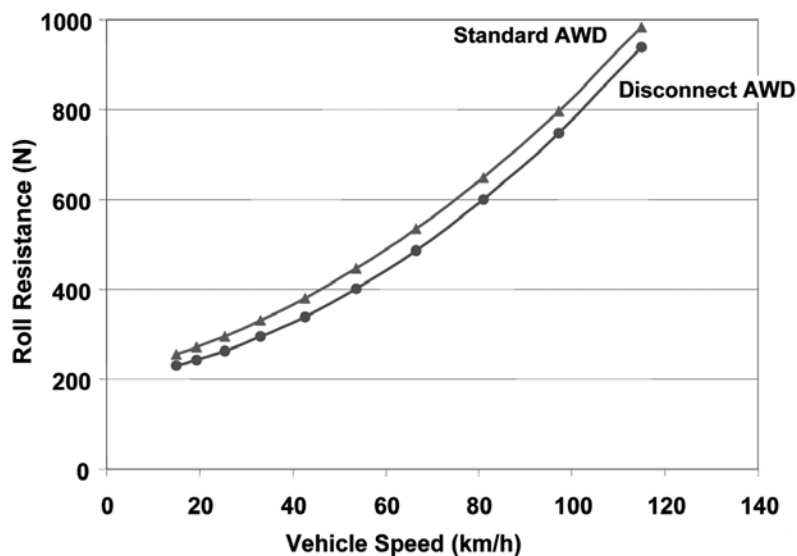


Figure 8: Vehicle test results with standard and disconnect AWD

5 Test Results

5.1 Bench Test

The complete standard and disconnect AWD driveline has been set up on a bench in order to measure driveline drag torque at various speeds and temperatures. The results at 50 °C shown in **Figure 7** demonstrate an impressive effect on the drag torque for the disconnect AWD. The standard AWD shows a pretty high drag torque of 22 Nm leading to 2,3 kW loss at 1000 rpm sideshaft speed. The disconnect AWD has been measured with only 1,6 Nm causing only 170 W losses in the same conditions. Differences are even bigger at lower temperature.

5.2 Vehicle Tests

Vehicle tests have been performed to ultimately prove the AWD disconnect benefits.

The same vehicle equipped with standard and disconnect AWD has been evaluated in coast down tests to define the rolling resistance. The significant reduction of the rolling resistance of the disconnect AWD compared to the standard AWD, **Figure 8**, has confirmed the bench test results. The conducted fuel consumption calculation using the measured rolling resistance and apply a standard driving cycle has shown up to 0,35 l/100 km fuel reduction and roughly 8,2 g/km less CO₂ emission of the disconnect AWD compared to the standard one.

6 Summary

Mechanical AWD systems will maintain a significant market share even with the future environmental challenges. Mechanical AWD will still be used in off-road vehicles but also in future hybrid and electric cars. Fuel consumption and CO₂ emission is now becoming the key driver for the development of new AWD technologies. Optimizing all AWD components and the AWD system requirements might provide a total reduction of the AWD fuel penalty of 15 %. But even for optimized drivelines the majority of the AWD related losses is still caused by the drag and churning losses of the spinning parts, hence disconnecting the AWD system when not needed will provide ultimate fuel savings. Switchable “Part-time” systems have been used in pickup trucks and SUVs for a long time. Transferring “Part time” technology into an advanced disconnect AWD needs a new set of requirements, clutch and actuator technology and system control. The major challenge for the development was the integration of appropriate clutch and disconnect devices into the PTU and FDU and the development of a suitable control strategy to meet AWD performance, NVH, comfort and fuel saving targets. The selected AWD layout with synchromesh disconnect in the PTU and single clutch disconnect in the FDU has shown to be the best compromise be-

tween complexity and fuel saving potential. An existing high volume electro-mechanical actuator adapted to the disconnect requirement has been applied for the PTU disconnect. The on-demand coupling integrated into the FDU between ring gear and differential is used as rear axle disconnect and has been optimized for ultra low drag torque and best performance. The electric-motor driven ball ramp actuator known from controlled limited slip differentials has been refined with a multi stage ball ramp and a highly dynamic e-motor control to meet all requirements for on-demand and disconnect operation. The smoothness and refinement of the dis-connect and re-connect operation is essential for customer perception and acceptance of an AWD disconnect. Thoroughly tuning in close link with the car manufacturer is required to find an acceptable compromise in terms of seamless and transparent operation and best AWD performance. The bench test results demonstrate an impressive reduction of the disconnect AWD drag torque and losses by more than 90 % compared to standard AWD. Vehicle coast down tests have been performed. The conducted fuel consumption calculation using the measured rolling resistance and apply a standard driving cycle has shown up to 0,35 l/100 km fuel reduction and roughly 8,2 g/km less CO₂ emission of the disconnect AWD compared to the standard one.

GKN Driveline has been first to develop a disconnect AWD system and has proven feasibility and performance on bench and in vehicle. The selected layout and the applied disconnect, clutch and actuation technology has been optimized regarding packaging, performance and cost and does provide a convincing base for a production system.

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- [1] Katalog der Automobil Revue 2007
- [2] EPA (www.fueleconomy.gov)



Development All Wheel Drive

ATZ worldwide

September 2009, Volume 111, *Issue 9*, pp 72-77

First online:

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About this Article

Title Seamless disconnect system to minimize AWD related losses

Journal *ATZ worldwide*
Volume 111, Issue 9 , pp 72-77

Cover Date 2009-09

DOI 10.1007/BF03225323

Online ISSN 2192-9076

Publisher Vieweg+Teubner Verlag

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