

Optimization Potential for a State of the Art 8-Speed AT

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ABSTRACT

The legislative and market pressure for CO₂ reduction and fuel efficient powertrains lead to a variety of automatic transmission concepts in recent years. The CVT technology, the dual clutch technology (DCT) and optimized architectures of torque converter / planetary gear based automatic transmissions (AT), such as 6, 7, and 8 speed ATs entered the market in the last decade.

Also different hybrid technologies have entered the market offering further improvement for fuel consumption especially in city driving. Helpful for OEMs and suppliers to flexibly meet market demands proofed the use of modular hybrid solutions. Clear demand to meet were packages of existing vehicles and powertrains with AT and hybrid transmission (HT), e.g. the modular transmission kit based on the ZF 8 speed AT.

Hybrid technology is offering fuel efficiency benefits, but there are also reasons for a slow market penetration. Major obstacles are weight, battery performance, cost, complexity and low benefits for driving conditions outside of urban rush hour traffic, when missing frequent accelerations and slowing down situations for recuperation.

Current market expectations foster the necessity, to further develop and optimize the major portion of the market penetration, the conventional powertrain technology.

A focused investigation is done for the automatic transmission technology, based on ZF 8-speed family 8HP first generation.

To understand the future potentials for a second generation of 8-speed transmissions, a detailed analysis of remaining losses of the current technology for different fuel cycles is provided. Although the results underline the challenge for further improvements on transmission side, a solid engineering base is given to generate and develop innovative ideas for affordable CO₂ reductions of a 2nd generation of ZF's 8-speed automatic transmission.

Different optimization approaches were investigated in detail and are compared. Furthermore the scope of the 2nd generation 8-speed AT, currently under development and planned for market introduction in the near future, was identified.

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1. INTRODUCTION

For many years, the dominating automatic transmissions were torque converter / planetary gearset automatic transmissions (AT). More recently however, CVT technology and dual-clutch transmissions have created market competition for traditional AT. As a result of the competition from CVT [1], [2], [3] and DCT technologies [4], [5] with regard to fuel efficiency, CO₂ emissions and shifting dynamics, ATs have undergone additional evolutionary

stages to ensure their continued relevance and competitiveness [6], [7], [8], [9], [10] and [11]. The fuel efficiency improvement of automatic transmission over time can be shown - simplified with respect to the number of gears - for the different generations over time for the European Drive Cycle NEDC, s. Figure 1. This fuel efficiency improvements are not only achieved due to more gear ratios and increase ratio coverage. The improvements also include innovative developments in basic transmission components, e.g. pumps and clutches.

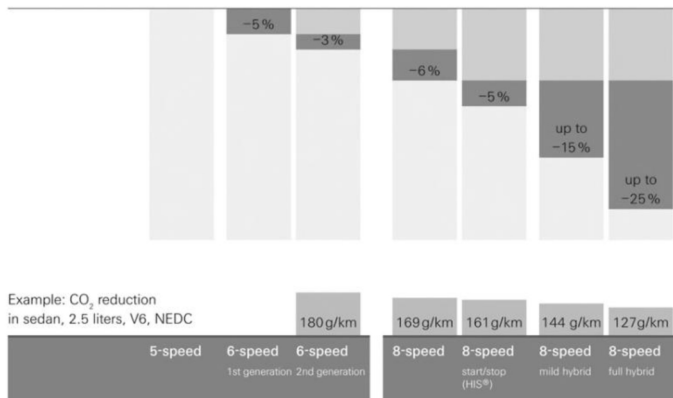


Figure 1. Fuel Efficiency Improvement by ZF Transmission Technology,, sedan, 2.5L V6, NEDC

The ongoing legislative pressure on fuel efficiency and CO₂ reductions also drove development of hybrid powertrains. Hybrid technology can offer clear fuel efficiency benefits, as also shown in [Figure 1](#). But there are also shortfalls and reasons for a slow market penetration of electrified systems. Major obstacles for car manufacturers and customers are weight, battery performance, cost, complexity and low benefits for driving conditions outside of urban rush hour traffic when missing frequent accelerations and slowing down situations for recuperation. Consequently the development for these systems is continued towards plug in hybrids, to at least take advantage of available electricity sources. The reduced fuel consumption does not necessarily reduce CO₂ emissions over all. Regarding the well-to-wheel efficiency, the results very much depend on the electric power plant technology in place in the respective market place. Also the other disadvantages (cost, weight, battery capacity and durability) are not finally solved for the new technologies, leading to a slow market penetration.

To further progress with regard to fleet consumption, the OEMs are faced with the necessity to further optimize the technology with a high volume effect, the conventional powertrain technology.

The analysis presented in this paper uses a state of the art 8-speed automatic transmission and power train, referred to as bench mark by competitors [12], and brought to US market in the Chrysler 300 in 2011 [13] and in the Dodge Ram 1500 in 2012 [14]. For this specific examples, the remaining losses in an 8-speed automatic transmission are identified for the valid US fuel efficiency cycles (US-City, US-Highway, US-Combined). Also further optimization potentials for a 2nd generation of this transmission and powertrain are derived.

2. 8 SPEED AUTOMATIC TRANSMISSION

The base of the analysis is the ZF 8-speed transmission as shown in [Figure 2](#), consisting of a torque converter, 4 planetary gear sets (GS1 - GS4), 5 shifting elements (brakes

A & B, clutches C, D and E), and an off axis vane pump. The torque rating of the 8HP45 transmission is 450Nm for gasoline engines and 500Nm for diesel engines.

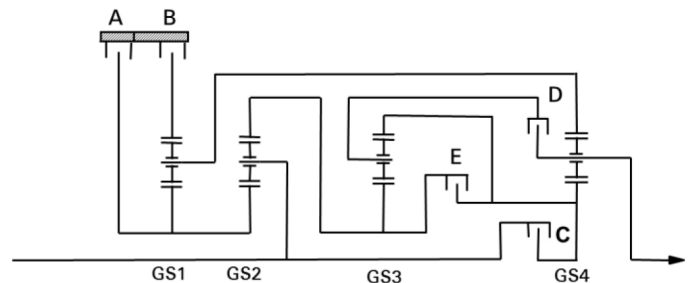


Figure 2. Transmission Schematic 8HP45

A significant contribution to reduced losses of this system are reduced drag torques of the shifting elements. Only 2 clutches are creating drag losses for all gears ([see Figure 3](#)) and a ratio coverage of 7.07 is allowing low engine speeds.

Gear	Brake		Clutch			Ratio i	Ratio step
	A	B	C	D	E		
1	●	●	●			4,714	1,50
2	●	●			●	3,143	
3		●	●		●	2,106	1,26
4		●		●	●	1,667	
5		●	●	●		1,285	1,29
6			●	●	●	1,000	
7	●		●	●		0,839	1,19
8	●			●	●	0,667	
R	●	●		●		-3,295	Total 7,07

Figure 3. Shift Pattern and Ratio Steps 8HP45

The cross section of this production transmission is shown in [Figure 4](#), more details of this technology can be found in papers and publications presented earlier [8], [9], [10].

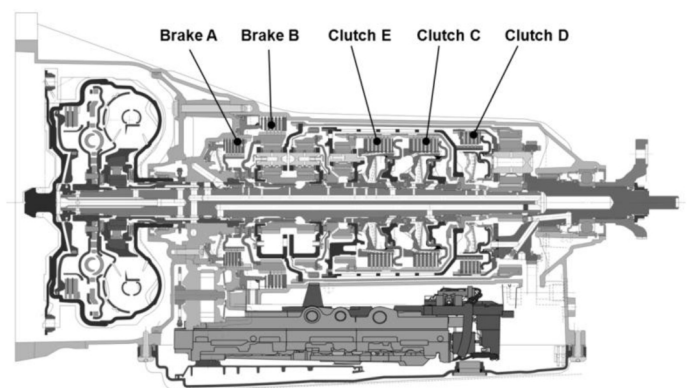


Figure 4. Cross Section 8HP45

4. TECHNICAL DATA

The technical data base for the simulation model of the transmission is shown in [Table 1](#).

Table 1. 8HP45 Technical Data

Transmission type	Automatic car transmission 8 gears; standard drive - line		
		Petrol	Diesel
Torque / Power Rating	T_{max} Motor	450 Nm	500 Nm
	P_{max} Motor	250 kW	180 kW
	T_{max} Turbine		550 Nm
Max. Engine Speed	n_{max} 1. to 7. Gear	7200 min ⁻¹	
	n_{max} 8. Gear	5700 min ⁻¹	
Torque Converter		NW235 TTD	NW235 ZDW
Gear ratios	4,714 – 3,143 – 2,106 – 1,667 – 1,285 – 1,000 – 0,839 – 0,667 R=3,295		
Weight		76 kg	78 kg

The technical data base for the engine and vehicles of the simulation model is given in [Table 2](#).

Table 2. Vehicle (Sedan/Truck) and Engine Data

	Chrysler 300 C Limo	Dodge RAM DS Truck 1500
Calculation weight [kg]	1900	2300
Frontal area [m ²]	2.36	2.7
Drag coefficient [-]	0.34	0.424
Dynamic running radius [m]	0.353	0.401
Final drive ratio [-]	2.65	3.21
Torque converter	K-Faktor 179	K-Faktor 131
Engine	Generic 3.3L V6 Engine – 325Nm / 219kW	

Fuel efficiency simulations are done with the ZF simulation system OASIS, details s. [Appendix 1](#) and [Appendix 2](#). Further engine data used s. [Appendix 3](#).

5. FUEL EFFICIENCY SIMULATIONS

5.1. Parasitic Losses of Current Transmission

Fuel efficiency simulations were first performed for the official European Drive Cycle NEDC for two vehicles, a sedan (Chrysler 300) and a truck (Dodge Ram 1500), results are shown in [Figure 5](#). Simulations of the NEDC cycle are performed with an average oil sump temperature of 40°C, the simulations for the US-City Cycle with 40°C, the US-Highway with 80°C average transmission oil sump temperature.

Generally, for all results in this chapter, there is a distinction in different losses given in the figures, distinguishing in losses created by the oil pump, losses by needed electricity for the transmission, losses by drag torque, gearing efficiency losses, losses during engine idling and losses due to not using the optimum range of the engine fuel map due to the given number of gears and other limitations.

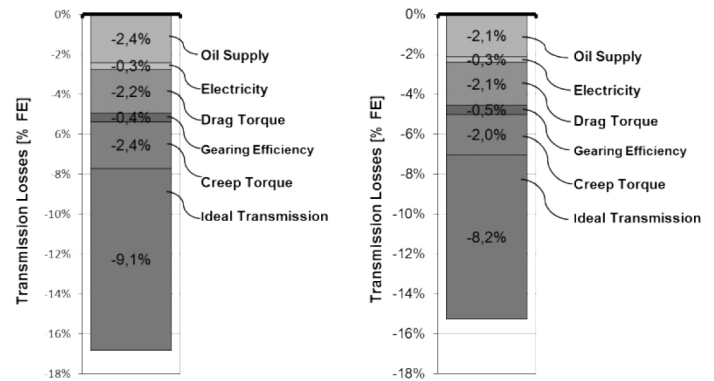


Figure 5. Remaining Transmission Losses in NEDC, Sedan and Truck, 3.3L V6 engine

Fuel efficiency simulations were done for the drive cycles US-City, US-Highway and US Combined for the Chrysler 300 (s. [Figure 6](#)) and for the Dodge Ram 1500 (s. [Figure 7](#)).

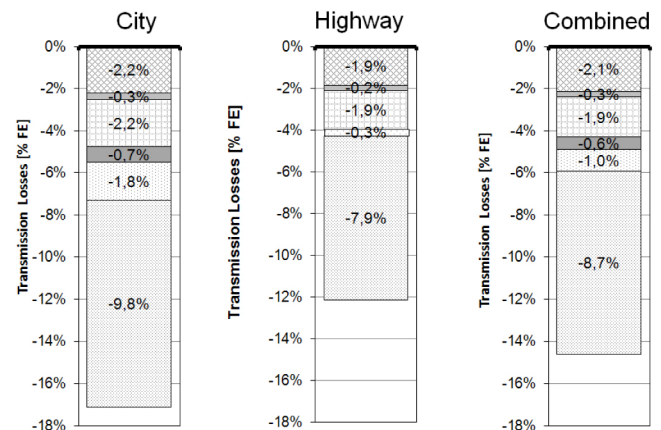


Figure 6. Remaining Transmission Losses in US-City/Highway/Combined Cycles, Sedan, 3.3L V6 engine

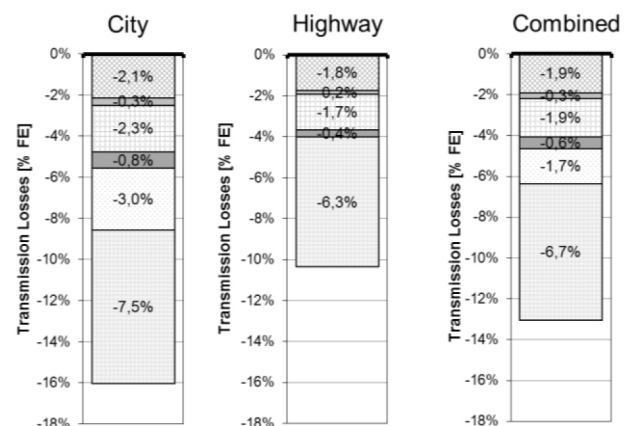


Figure 7. Remaining Transmission Losses in US-City/Highway/Combined Cycles, Truck, 3.3L V6 engine