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Technology survey on smartness added to automotive manual transmissions

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Automotive Engineering
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6-week internship report:

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Chapter 1  Introduction

The reduction in fuel consumption and further strengthening of emission legislation, as well as consumer demands, are leading to further developments in the field of automotive drivetrain technology. The most important aim of these developments is improving drivetrain efficiency. The increase in traffic density and number of traffic jams are reasons for further developments too. The aim here is increasing the vehicle's drive comfort. These two situations have led to a progressive automation of the drivetrain and smart upgrades or layouts of the transmission.

In this report known extensions upon the conventional manual transmission are discussed. The goal of this exercise is increased understanding of these concepts, in order to obtain an objective judgement of DTI's (Drivetrain Innovations) in-house transmission developments.

In the second Chapter a brief description of the latest trends in drivetrain development is made. The third and fourth Chapter deal with the automation of the power train. After that power shift/dual clutch transmissions will be discussed in Chapter 5. In Chapter 6 other smart upgrades or layouts and DTI's (Braked-) Impulse Shift Transmission will be analysed. Chapter 7 will discuss the described drivetrain innovations in comparison with each other. And then judge the (B-)IST of DTI (Drivetrain Innovations) in relation to the others. Finally in Chapter 8 conclusions will follow.
Chapter 2  Transmission innovation trends

2.1 Conventional manual and automatic transmissions

In Europe the manual transmission (MT) has always been very popular. Despite all predictions that the automatic transmission (AT) would get a bigger market share, like in the US and Japan because of its higher comfort. Reasons for this are that the manual transmission benefits from its high efficiency, low weight and costs and optimal space economy. Another important aspect is that Europeans prefer choosing the gears manually, in other words remain in control. This situation has led to developments in the field of manual transmissions. MT developers have been trying to make the MT more comfortable, like an AT. But at the same time it should maintain and further improve the advantages it has over the AT. On the other hand the developments of the AT are focused on giving the driver more control over the transmission and improve its disadvantages, low efficiency, low space economy, high weight and costs.

This exercise is primarily aimed at discussing developments in the area of manual gearboxes. But since a lot of these developments are aimed at closing the gap between automatic and manual gearboxes, a brief description of automatic and semi-automatic transmissions (section 2.2) is made here as well. In the following paragraphs the most recent innovations in the MT area, which are available on the market, are shortly summarized. Prior to that brief descriptions of the conventional MT and AT are presented for a better understanding.

2.1.1 The manual transmission

A layout of a standard drivetrain, engine longitudinally in the front and rear wheels driven, with manual transmission is shown in fig. 2.1.

![Figure 2.1: Standard layout of a drivetrain with MT](image)

The MT can be disconnected from the engine using a clutch. This is required to make shifting and synchronization of the gears possible without transmitting engine torque. This is also one of the biggest disadvantages of the MT the interruption of the torque flow during shifts.

A mechanical link between the clutch pedal and the clutch enables opening and closing of the clutch. Another mechanical link between the shifter in the vehicles interior and the transmission enables the driver to shift gears in any chosen sequence. A differential distributes the torque flow to the driven wheels.

The layout of the gears from a MT and its position in the vehicle depend on the available build space, which wheels (rear, front or four wheel drive) are driven and the position of the engine. The number of stages of the transmission and/or the number of ratio steps making up the individual gears determines in which category a geared transmission can be placed. A stage refers to a gear pair, or the power flow
from one shaft to another. Difference is made between single-, two- and multi-stage transmissions. In a single-stage MT the power flow enters the MT at the input shaft and is transmitted directly to the output shaft by one gear pair. In a two-stage MT a third shaft called counter- or lay shaft is added. The power flow now is transmitted from the input to the output shaft via the counter-/lay shaft. Two gear pairs are involved in this. If three or more gear pairs are used to transmit the engine torque the MT is called a multi-stage MT.

In a standard drivetrain, e.g. fig. 2.1, the transmission is positioned longitudinally in the front. In this case a transmission with coaxial input and output shaft is commonly used. Two-stage countershaft/lay shaft transmissions like the one in figure 2.2 are suited for this.

![Figure 2.2: Layout of a two-stage countershaft transmission with coaxial input and output shaft, with direct 5th gear (ZF)](image)

Single- and multi-stage transmissions are common in front-wheel drive vehicles with the engine positioned in the front. They require no coaxial transmission in the power flow, unlike rear-wheel drive and four-wheel drive vehicles.

In this chapter transmission layouts will not be the main focus. If a different layout is to be discussed, to clarify certain transmission functions, a short description will be given. More information about different types of manual transmissions and their layouts can be found in [1].

### 2.1.2 The automatic transmission

In fig. 2.3 a layout of a standard drivetrain with an automatic transmission is shown.

![Figure 2.3: Standard layout of a drivetrain with an AT](image)
The first difference between a MT and AT equipped drivetrain is the connection of the transmission with the engine. In the case of a conventional AT a torque converter is used to realize this. The second difference is that in a conventional AT the gear steps are defined within planetary gear sets by using brakes and wet clutches. The planetary gear sets are positioned in an axial arrangement. In figure 2.4 a 5-speed AT layout and the paths for the different power flows of the gear steps are shown.

![Figure 2.4: 5-speed automatic gearbox layout and power flow](image)

Due to the torque converter and the transmission braked planetary gear sets the AT can make shifts without power interruption. The brakes and clutches within the AT are hydraulically controlled, an engine driven pump supplies the hydraulic oil. This oil pump, the oil cooler, wet clutches and the torque converter are the principal components that reduce the efficiency of the AT compared to the MT.

The AT has some advantages over the MT. It enables faster and 'smarter' shifting than the average driver. And therefore some AT drivers realize lower fuel consumptions than with a MT, despite the lower AT efficiency. Reduced driver stress, which leads to improved road safety and ride comfort are also benefits over the MT. Because the torque converter is responsible for a part of the change in transmission ratio, an AT theoretically requires fewer gear steps than a MT. 4-speed automatics are the most common automatic transmissions, but recently more and more 5-, 6- and even 7-speed automatics \[e15\], \[e36\] appear on the market. More information about different types of automatic transmissions and their layouts can be found in [1].

### 2.2 Semi-automatic transmissions

In the last few years, car manufacturers have attempted to make the AT more popular by providing the driver with more control. This led to an automatic gearbox with the possibility to select gears sequentially by hand, the so-called semi-automatic. The first large car manufacturer that made this optionally available was Porsche, with its Tiptronic system introduced in 1990 on the Porsche 911.
Based on an AT with torque converter it offers, besides the conventional automatic mode, a manual override allowing the driver to shift. The system is not faster or more efficient than a conventional automatic, but it provides more involvement for the driver. The system does not involve large changes to the transmission itself. The shifter system has to be changed as well as the control software that makes the shifts. Porsche, ZF and Bosch cooperatively developed Tiptronic. Other car manufacturers followed soon with their own systems or licensed the Tiptronic system from Porsche. The semi-automatic gearbox keeps all the other disadvantages of a normal automatic compared to a MT. That is, low efficiency, large installation space and high weight and manufacturing costs.

### 2.3 Manual transmission with automated clutch

The basis for the automation of the MT was the automated clutch. An automated clutch transmission is simply a MT mated to an electromechanically or -hydraulically controlled clutch. Just like in a vehicle with an AT, the car has two pedals in the interior, the accelerator and the brake pedal. When changing gears, the driver only needs to operate the shifter. An electromechanical or -hydraulic actuator can be used to perform the engaging and disengaging of the clutch. It relieves driving effort, making gearshift easier and improves of the comfort with respect to a conventional MT.

In 1993 the BMW ALPINA B12 was one of the first cars with an optional automated clutch system called shiftronic. The system was developed in cooperation with LuK GmbH and was ordered as an option by 60% of the ALPINA B12 buyers. The system does not affect the layout of the conventional drivetrain with a MT. An actuator and sensors replace the clutch pedal and its mechanical link to the clutch. The sensors are used to acquire and monitor relevant information. At the moment a MT with automated clutch is offered in the Mercedes A-class. In chapter 3 this system, developed by LuK as well, is described.

### 2.4 Automated manual transmission

The next step in automating the MT, after adding the automated clutch, was automating the shifting of the transmission gears. Ferrari was the first car manufacturer to offer an automated manual transmission (AMT) optionally to its Ferrari F355. They called their system F1, referring to the formula 1 technology from which it was derived. BMW M came at nearly the same time with their sequential manual gearbox (SMG) system for the BMW M3. At this moment many car manufacturers offer an optional AMT on one or more cars in their range. Most of those systems are available for the smaller cars within the car manufacturer’s range. Since not all systems are suitable yet for the high engine torques of the engines of the larger cars. Every manufacturer uses a different name for their AMT system. An overview of some of these systems with the model on which the system is available:

- Alfa Romeo Selespeed (147, 156)
- Audi AMT (A2)
- BMW SMG I/II (M3, Z4)
- Citroën Sensodrive (C3)
- Ferrari F1 (360 Modena, 575M Maranello, Enzo)
- Fiat Speedgear (Punto)
- Ford Durashift (Fiesta, Fusion, Mondeo and Transit)
- Maserati Cambiocorsa (3200/4200 GT)
- Mercedes Sequentronic (C-class, E-class, CLK, Sprinter)
- Opel Easytronic (Corsa and Meriva)
- Renault Quickshift (Twingo, Clio)
- Smart Softip (Citycoupe)
- Toyota Multi-mode AMT (Yaris)
- Volkswagen AMT (Lupo)

The way in which the driver can perform the shifts differs per system. In many systems the shift lever is still used, but it has to be moved forward or backwards only to make the down- or upshifts. Some systems use buttons on the steering wheel or paddles mounted behind the steering wheel that can be used to make the down- and upshifts.

The mechanical link between the shifter and the selector forks is removed. In most cases two electromechanical or -hydraulic actuators replace it. The first actuator is needed to select the gear and the second one performs the gearshift. The clutch pedal and the link to the clutch are replaced by an automated clutch system as discussed in section 2.3.

In chapter 4 two different AMT systems and their features are discussed.

### 2.5 Powershift transmissions

A disadvantage that the AMT still has, is the torque interruption during the shifts and the time that is needed to finalize a shift. The transmission has to disengage the clutch after which the next gear has to be selected and synchronised like in a normal MT. During these shifts the power flow from the engine to the wheels is interrupted. This leads to a deceleration of the vehicle during the shift, e.g. fig. 2.5.

![Figure 2.5: Qualitative traction force $F_z$ and velocity $V_f$ profile for upshift with power interruption](image)

In an AT this torque interruption does not occur, which is one of the reasons that an AT still is considered to provide the driver with more comfort than an AMT.

A powershift transmission is a (A)MT that can shift without torque interruption. In fig. 2.6 the traction force and velocity of the vehicle can be seen for a powershift.

![Figure 2.6: Qualitative traction $F_z$ and velocity $V_f$ profile for upward powershift](image)
The disengaging of the clutch and synchronisation of the gears are the reason for the torque interruption. So, when designing a powershift transmission something has to be found to eliminate or replace these actions. Changes to the conventional layout of a MT have to be made. These changes can include adding components like clutches, brakes or shafts. In some cases an additional clutch and shaft are added to the system through which the power flow from the engine to the wheels can be continued during the shift. Borg Warner and VW/Audi co-developed the first powershift transmission that was available on the market. The so-called DSG (Direct Shift Gear) transmission is available in the Volkswagen Golf R32 and Audi TT 3.2l V6. It uses a second clutch and extra input shaft to overcome the torque interruption. Systems like that are called dual clutch (DCT) transmissions. In the next paragraph this type of powershift transmission is described in more detail.

2.5.1 Dual clutch transmissions

In a dual clutch transmission the second clutch is used to operate a separate gearbox unit. The clutches can both be attached to the same input shaft or an input shaft of their own. In the case that they are attached to the same input shaft, this shaft is divided into two parts, one solid and one hollow part. In this way there are two routes available for the power flow. Each input shaft part transfers torque to its own gearbox unit. The power flow will go through one of the gearbox units, while in the other unit the next gear already can be pre-selected. When a shift occurs the torque will be transferred from one unit to the other by opening and closing the corresponding clutch of each unit. As a result, the vehicle acceleration will remain positive during the entire gear shifting process and hence the comfort factor as compared to conventional shifting is improved and comparable to that of an AT. In fig. 2.7 an example of a layout of a DCT is shown.

![Diagram of a DCT transmission](image)

Figure 2.7: Layout of a drivetrain with DCT

At this moment only the dual clutch transmission, DSG, of VW/Audi is available on the market. In chapter 5 of this exercise a few powershift/dual clutch systems will be discussed. In addition also innovations that improve the conventional MT with other ‘smart’ layouts or upgrades will be described in chapter 6.

Literature: [1], [2], [3], [5], [e6], [e15], [e16], [e37]
Chapter 3  LuK Electronic clutch management

3.1 Function, layout and main characteristics

The LuK electronic clutch management system (ECM) automates the engaging and disengaging of the clutch. The system reduces the workload for the driver since he does not have to operate the clutch pedal anymore. The ECM replaces the conventional clutch pedal and its mechanical link to the clutch. The driver still has to select the gears by hand with the shift lever. This lever works like in a conventional MT with a mechanical link to the selector forks of the transmission.

The system was introduced in the Mercedes A-class in 1997 and is developed by LuK GmbH. Later the ECM system was used as the basis for an automated manual transmission. This system will be discussed in section 4.2 in this report.

The ECM system is designed as an add-on system. This makes it easy to mate the system to any type of MT. No more changes to the transmission or its layout have to be made than the replacement of the original clutch with a self-adjusting Clutch (SAC). The SAC and the reason why it replaces the other clutch will be discussed in the next paragraph.

3.1.1 Self-adjusting Clutch

In a conventional clutch a number of forces, which work during the engaging and disengaging of the clutch, can be identified. Two of these forces are the force of the diaphragm spring and the leaf spring, e.g. fig. 3.1.

In figure 3.1 can be seen that these forces are counteracting forces. In point 1 there is an equilibrium and represents the position of the springs for which the clutch is engaged. Point 3 is the position where the clutch is fully disengaged. The release load of the clutch (disengaging load) is determined by the difference between these two forces. By altering the force characteristic of one or both the springs the release load can be influenced. In figure 3.2 a force – actuation travel diagram is shown with an altered diaphragm spring force characteristic. By altering the thickness and/or angle of the diaphragm spring this characteristic can be easily influenced.
Diaphragm spring

Leaf spring

Figure 3.2: Release load characteristic of the SAC leaf and diaphragm spring

It can be seen that the two counteracting forces now eliminate each other in the range between 1 and 3. So theoretically no force is needed to operate the clutch. So by choosing a suitable diaphragm spring characteristic the release load of the clutch can be freely determined. LuK has used this method to achieve a lower release load with its SAC.

A disadvantage of a clutch with a diaphragm spring is that the release load gets higher for an increasing friction wear. The travel of the clutch becomes larger due to loss of material and therefore the diaphragm spring will tilt more when the clutch is engaged, e.g. fig. 3.3.

Figure 3.3: Conventional clutch diaphragm spring position, new and with wear

$F_A$ represents the release load needed on the diaphragm spring to disengage the clutch. This load needs to induce a moment that overcomes the moment $M_{DS}$, the moment of the diaphragm spring. Because of the tilting of the diaphragm spring its characteristic will change and therefore the difference between the force characteristic of the leaf spring and the diaphragm spring will get bigger. And thus the release load gets bigger. For the SAC, LuK has managed to solve this problem.

The SAC uses a mechanism that adjusts the tilting of the diaphragm spring due to friction wear, e.g. fig. 3.4. Thus the release load will not increase but remain constant.

Figure 3.4: SAC clutch disc new, with wear and with self-adjusting

The height of the wedge form (yellow), the projected wear range is large enough to cover the clutch wear during its lifespan. In figure 3.5 the release loads of a conventional clutch and of a SAC, new and with wear, are shown.
There can be seen that the operating force of the SAC lies lower than that of a conventional clutch and stays constant during the clutch’s lifespan. In fig. 3.6 a cross-section of a conventional clutch and a SAC are depicted:

As opposed to the conventional clutch, the main diaphragm spring (DS) (green) is supported by a sensor diaphragm spring (red) instead of being riveted to the clutch cover (blue). The point where the sensor DS supports the main DS now functions as the pivoting point. The sensor DS provides a constant load in a sufficiently wide range. This load is designed so that it normally is slightly higher than the release load of the clutch. The sensor DS force works as a counter force on the main diaphragm spring. When clutch material loss increases and thus the release load increases, the opposing load of the sensor DS is overcome and the pivoting point will move towards the flywheel to a position where the release load again falls below the sensor load. An adjusting ring (yellow), between the main diaphragm spring and the clutch cover, fills up the gap that appears. In fig. 3.6 can be seen that a coil spring will move the wedge-formed adjusting ring into a position where the gap will be filled.

Although the SAC requires an extra sensor DS and adjusting ring, the total costs of a clutch system with the SAC will be lower. The reasons for this are:
- Elimination of servo systems (in commercial vehicles)
- Simpler release systems can be used
- Clutch diameter can be reduced
- Smaller electric motor due to lower release loads (for an ECM)

Due to its main advantage, the lower and constant release load, the SAC clutch is well suited to be used in an automated clutch system. In this case the operating force can be further reduced when the shape of the release load curve is disregarded because the driver’s feel when pressing the clutch pedal is not an issue anymore.

### 3.2 Actuators, sensors and control

The ECM system uses an electric motor and intelligent control to operate the SAC. The choice for an electrohydraulic actuator was made because a fully hydraulic actuator system is more complex. Thus the potential to reduce the costs for a system with a fully hydraulic actuator is smaller. Making the system less suitable for mass production. A fully hydraulic system would be heavier too than an electrohydraulic system. In figure 3.7 the clutch actuator can be seen. An electric motor powers a hydraulic master cylinder that is connected to a hydraulic concentric slave cylinder that releases the clutch.

![Figure 3.7: Clutch actuator](image)

In the LuK ECM system only one additional sensor is required. This sensor recognizes the currently selected gear and senses the intention of the driver to shift gears. Sensors that are already used for other functions acquire the remaining information. This information is:

- Engine speed
- Speed at the differential
- Throttle position
- Engine torque
- Foot brake active
- Handbrake active

In comparison with a conventional system the sensor for the transmission speed and the clutch position are not required in the ECM. In fig. 3.8 a scheme of the ECM system is shown, the sensors that are used and their positions can be seen.
After closing the clutch (lockup or clutch stick), the actuation force on the clutch plate is accommodated such that it just exceeds the transmitted engine torque. This method, called ‘torque tracking’, will lead to shorter shift times, see fig. 3.9.

This torque tracking also enables the car to creep like a car with an AT. When the driver uses the foot or hand brake the system control will release the clutch to avoid high clutch wear and fuel consumption.

The electronically controlled clutch enables suppression of torsional vibrations by controlled clutch slip. Furthermore it eliminates overrevving and underrevving when shifting. Finally, misshifts with a closed or partly closed clutch cannot occur for the ECM system.
3.3 **Level of improvement**

The driving comfort of a car with the ECM system is improved, because of the earlier mentioned advantages. This improvement in comfort reduces driver’s stress, which lead to improved road safety too.

Quantitative data about improvements in fuel consumption or performance, in comparison with transmissions without the ECM, was not available.

3.4 **Dimensions, costs and complexity**

The ECM system needs one extra sensor and one clutch actuator. In table 3.1 a comparison of the LuK-ECM system with a hydraulic and conventional electronic system without SAC is made for weight and number of sensors:

<table>
<thead>
<tr>
<th>Actuator type</th>
<th>Weight [kg]</th>
<th>No. of additional sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic (LUK ECM BMW ALPINA B12)</td>
<td>≈ 5</td>
<td>3-4</td>
</tr>
<tr>
<td>Conventional ECM (LUK ECM without SAC)</td>
<td>≈ 6</td>
<td>3</td>
</tr>
<tr>
<td>LuK-ECM</td>
<td>≈ 2</td>
<td>1</td>
</tr>
</tbody>
</table>

*Table 3.1: Comparison of ECM with other clutch actuation systems [2]*

The clutch pedal and its mechanical link are removed. Changes to the transmission are not required. As for the spatial dimensions, the LuK ECM system is smaller and lighter than a conventional system [15]. The use of the SAC clutch system reduces the costs of the system, see section 3.1.1. The lifespan of the SAC is large enough to last during the cars lifespan.

The system is more expensive than a conventional mechanical system, but less expensive than an automatic. In Germany the system is available on the Mercedes A-class for an additional 655 Euro [e5].

* Literature: [2], [4], [5], [6], [7], [8], [14], [15], [e5], [e15], [e36]
Chapter 4  Automated manual transmissions

In this chapter, 2 different automated manual transmissions will be discussed. The way in which they improve the conventional manual transmission and their special features are the main focus.

4.1  Getrag-Ford Durashift transmission

4.1.1 Function, layout and main characteristics

The Getrag-Ford Durashift transmission is a 5-speed automated manual transmission. It is available as an option on the Ford Fiesta and Fusion for the 1.4L Duratec 16V-gasoline engine (\(M_{\text{max}} = 124\, \text{Nm}\)) or the 1.4L Duratorq TDCi-turbo diesel engine (\(M_{\text{max}} = 160\, \text{Nm}\)). The Durashift transmission is a conventional MT (type iB5), which has been slightly modified to enable the automation of the clutch and shifting actions. The system uses a self-adjusting clutch (SAC) from LuK (see section 3.1.1).

The goal was to develop a MT transmission with improved comfort for the driver. The durashift transmission can be driven in manual mode (sequential) or automatic mode. When driving the car in manual mode, the driver does not have to operate the clutch pedal. Gear shifting requires a push forward or backward against the electronic shift lever. When driving in automatic mode the driver only has to operate the brake pedal and gas pedal, similar as in an AT. There are different driving programs available for the automatic mode. The driver can choose for the economical or the traction program (respectively early or delayed upshifting).

In fig. 4.1.1 the Durashift transmission and the additional automation systems are shown. The gray parts replace the mechanical systems for clutch operation and shifting. These systems will be discussed in the next paragraph.

![Figure 4.1.1: Ford fiesta Durashift transmission](image-url)
The layout of the original MT did not have to be adjusted, but the 1st gear ratio has been changed for the automated version of the transmission of the petrol engine, see table 4.1.1.

<table>
<thead>
<tr>
<th>Gear</th>
<th>1.4i 16V Durashift</th>
<th>1.4i 16V Durashift</th>
<th>1.4 TDCi Durashift</th>
<th>1.4 TDCi Durashift</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>3,583</td>
<td>3,154</td>
<td>3,583</td>
<td>3,583</td>
</tr>
<tr>
<td>2nd</td>
<td>1,926</td>
<td>1,926</td>
<td>1,926</td>
<td>1,926</td>
</tr>
<tr>
<td>3rd</td>
<td>1,281</td>
<td>1,281</td>
<td>1,281</td>
<td>1,281</td>
</tr>
<tr>
<td>4th</td>
<td>0,951</td>
<td>0,951</td>
<td>0,951</td>
<td>0,951</td>
</tr>
<tr>
<td>5th</td>
<td>0,756</td>
<td>0,756</td>
<td>0,756</td>
<td>0,756</td>
</tr>
<tr>
<td>Reverse</td>
<td>3,615</td>
<td>3,615</td>
<td>3,615</td>
<td>3,615</td>
</tr>
<tr>
<td>Final drive</td>
<td>4,250</td>
<td>4,250</td>
<td>3,368</td>
<td>3,368</td>
</tr>
</tbody>
</table>

Table 4.1.1: Transmission ratios of the 1.4i petrol and 1.4 TDCi diesel engines [12], [e20]

It is unclear why the 1st gear ratio of the Durashift transmission has been reduced with respect to the original MT. An explanation can be that the powertrain’s dynamics gave problems for the applied controller.

4.1.2 Actuators and sensors

In the Durashift system of the Fiesta and Fusion an electro-hydraulic actuator performs the engaging and disengaging of the clutch. The actuator can be seen on the right in fig. 4.1.1; it consists of an electric motor that provides hydraulic fluid to the cylinder that operates the clutch and a steering device. The steering device controls the automated clutch process with the information provided to it by different sensors. In fig. 4.1.2 the hydraulic cylinder that operates the clutch is shown. In fig. 4.1.1 can be seen that it is bolted on to the bell house, whereas the transmission’s input shaft is connected to the inner race of the cylinder.

![Figure 4.1.2: Hydraulic clutch release cylinder](image)

The hydraulic cylinder is positioned between the transmissions input shaft and the clutch. The piston of the cylinder acts through an axial movement on the release bearing of the SAC. The release bearing presses on the main diaphragm spring and in as such can engage and disengage the clutch.

Integrated in the clutch actuator is a clutch travel sensor. In fig. 4.1.3 a schematic presentation of this sensor is given.
The travel sensor uses an inductor coil. A snail wheel attached to the electric motor turns the sprocket (1) that is linked to a holder (2) by a cam (6). The turning angle of the sprocket is transferred into a translation movement of the holder and the core (3) inside the coil (4). The number of windings differs over the different chambers of the coil (5). In this way the exact position of the core within the coil can be determined. The sensor sends a signal to the steering device and with that signal the steering device can determine the position of the clutch.

The steering device also controls the electromechanical shift actuator that performs the shift actions, seen in the middle of fig. 4.1.1 at the left side of the clutch actuator. The shift actuator consists of two electric motors, one to perform the gear selecting action and one to perform the shift action. In fig. 4.1.4 the actuators and the two directions of gearshift action can be seen.
The first electric motor (1) turns a mechanism (A) to select the right fork with the lever (4) and the second electric (2) motor powers a mechanism that makes the shift motion (B). The two electric motors are equipped with integrated travel sensors, e.g. fig. 4.1.5.

![Figure 4.1.5: Travel sensor scheme of the electric motor](image)

These travel sensors consist of 10 magnetic pole pairs positioned around the electric motor (1). Two Hall sensors (2 and 3) are placed on the side. The circuitry that connects the two Hall sensors makes it possible to determine the RPM, turning angle and turning direction of the electric motors. The steering device needs this information to correctly perform the gear selecting and shifting actions.

Other information the system needs before actually performing a shift is:
- Shift intention
- Gear recognition
- Current running conditions of the engine
- Brake actuation recognition
- Position of the gas pedal.

This information is acquired by various sensors and engine ECU, and is sent to the steering device. To perform a shift, release of the gas pedal is not required. The steering device controls a shift in the following way:
- Drop engine torque
- Open the clutch
- Select the next gear
- Synchronize
- Shift into gear
- Close the clutch
- Rise engine torque

Contrary to an AT there is a power interruption for the Durashift system during shifts. This is because the gears have to be synchronised and therefore the engine has to be disconnected from the transmission. Due to this power interruption the comfort level of the Durashift transmission can be considered less than that of an AT.

Like in an AT, the Durashift features a creeping function. The clutch will slip when the vehicle is in 1st gear or reverse, and in that way transfers a small amount of torque. The SAC uses the torque tracking method (see section 3.2) to achieve this creeping function and shorten shift times. The steering device recognizes an open or closed door so that the creeping function is disabled when the door is opened while the engine is running.
4.1.3 Level of improvement

In terms of fuel consumption and CO₂-emission the Durashift mated to the petrol engine scores better than the normal MT only the extra urban fuel consumption is slightly higher. For the diesel engine there are no differences, e.g. table 4.1.2. In table 4.1.3 the level of improvement for the performance of the Ford fiesta with Durashift transmission can be seen:

<table>
<thead>
<tr>
<th>Fuel consumption¹ (L/100km)</th>
<th>1.4i 16V</th>
<th>1.4i 16V Durashift</th>
<th>1.4i TDCi</th>
<th>1.4i TDCi Durashift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>8.6</td>
<td>8.3</td>
<td>5.3</td>
<td>5.3</td>
</tr>
<tr>
<td>Extra urban</td>
<td>5.1</td>
<td>5.2</td>
<td>3.7</td>
<td>3.7</td>
</tr>
<tr>
<td>Combined</td>
<td>6.4</td>
<td>6.3</td>
<td>4.3</td>
<td>4.3</td>
</tr>
<tr>
<td>CO₂-emission (g/km)</td>
<td>153</td>
<td>150</td>
<td>114</td>
<td>114</td>
</tr>
</tbody>
</table>

¹ All CO₂ emissions figures in g/km and fuel consumption figures in L/100 km are from officially approved tests in accordance with Directive 93/116/EC.

Table 4.1.2: Fuel consumption and CO₂-emission for the normal MT and Durashift AMT, [e7], [e22]

The difference in the urban cycle fuel consumption for the petrol engines can be explained by the different ratio for the 1st gear and the electronic controlled shifting. In automatic mode the shift controls also shift the engine towards more fuel efficient engine RPMs. The slightly higher fuel consumption in the extra urban cycle of the Durashift transmission is not expected. Considering the similar gear ratio sequences (see table 4.1.1)

<table>
<thead>
<tr>
<th>Performance²</th>
<th>1.4i 16V</th>
<th>1.4i 16V Durashift</th>
<th>1.4i TDCi</th>
<th>1.4i TDCi Durashift</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100km/h [s]</td>
<td>13.3</td>
<td>14.3</td>
<td>15.0</td>
<td>16.0</td>
</tr>
<tr>
<td>50-100km/h [s]³</td>
<td>15.4</td>
<td>14.7</td>
<td>13.9</td>
<td>-</td>
</tr>
<tr>
<td>Max. speed [km/h]</td>
<td>168</td>
<td>168</td>
<td>163</td>
<td>163</td>
</tr>
</tbody>
</table>

² Ford test figures.
³ In 4th gear.

Table 4.1.3: Performance of the normal MT and Durashift transmission [e7], [e22]

For the accelerations some differences can be seen. The Fiesta with Durashift transmission is one second slower from 0-100km/h, both for the petrol and diesel version. The explanation for this is a difference in the measuring method. For an AMT the starting point of the measurement lies at the idle RPM. Contrary to the AMT, the MT the engine is already revved up before launch and thus starts with a higher output torque. Apart from a lower output torque at start, the AMT also requests additional energy to accelerate the engine parts. These two factors introduce less wheel torque at the first instant of the launch and thus degrade the 0-100 km/h acceleration time. Another factor is that the shift times of the Durashift transmission are a little longer and for the petrol engine the 1st gear has a lower magnification of the engine torque. The acceleration from 50-100 km/h in 4th gear of the petrol engine with Durashift is faster than that of the normal MT, for the diesel version not all numbers were available. The gear ratio is the same and no shifts have to be made, so no difference was expected. An explanation could be that due to the clutch controls of
the Durashift drivetrain resonances are filtered out faster and therefore the engine revs up faster.

4.1.4 Dimensions, costs and complexity

There was no quantitative information available about the Durashift’s dimensions, but from the available information some qualitative conclusions can be drawn. Because the actuators and their sensors replace the conventional mechanical systems, the size and the weight of the Durashift AMT will not be much higher or even lower than that of the conventional MT.

The space inside the passenger cabin of the car increases due to the omission of the clutch pedal. The electronic shift lever does not have a mechanical connection to the transmission so the positioning within the cabin is easier. The actuators and sensors do not require more space around the transmission than the conventional mechanical systems. Some of the sensors already were in use for other systems that require the same data. Furthermore the systems are more flexible to position, because the mechanical links are removed.

The use of these devices makes it more complex than the standard iB5-transmission. The adding of all the electronics and hydraulics obviously increases the costs the transmission over a standard 5-speed transmission. A consumer in Germany pays an additional 700 Euro (16% tax incl.) for a Ford Fiesta with Durashift transmission.

Literature: [12], [e5], [e7], [e8], [e20], [e22]

4.1.5 Ford Transit Durashift

The Durashift system is also available on the Ford Transit, but in this case it is an automated version of the manual transmission (type MT75), developed by Sachs. It is currently available for rear-wheel-drive Transit models with the 66 kW (90 PS) 2.4-litre Duratorq DI engine ($M_{\text{max}} = 200\text{Nm}$).

In this case electrohydraulic actuators in the clutch and transmission perform the shifting. Sensors help determine the shift timing. These sensors acquire the vehicle speed, engine and transmission RPMs, current and selected gear, accelerator pedal position, driver’s program selection, clutch position, etc. A transmission control unit controls the actuators with this information.

Improvements of the Durashift system for the Ford Transit:
- Up to 20% better fuel economy than an automatic gearbox with torque converter
- Up to 5% better fuel economy than conventional manual transmissions
- Clutch wear is reduced, due to precise electronic control of all clutch operations
- Abuse and damage due to incorrect shifting are prevented

Literature: [e21]
4.2 LuK Automated Shift Gear

4.2.1 Function, layout and main characteristics

The LuK automated shift gear (ASG) is based on the electronic clutch management system, LuK ECM, discussed in chapter 3. In addition to the automation of the engaging and disengaging clutch, the shift actions have been automated electromechanically as well in the LuK ASG. The advantage of the use of a totally electromechanically automation system is that it is less expensive and heavy than a hydraulic system.

The system is developed as an AMT for the Opel Corsa and Opel Meriva and is called Easytronic. In the Corsa it mates with the 1.0i 12v and 1.2 16v petrol engines. It is an automated version of the 5-speed manual transmission (type F13) of Opel. The Easytronic system reduces the driver's stress due to the automation of the clutch actions and gearshifts.

The LuK ASG system was developed as an add-on system, so the gearbox did not need extensive modifications. This characteristic enables any car or transmission manufacturer to install the LuK ASG system onto their gearbox.

With the LuK ASG system the Opel Corsa Easytronic can be driven in automatic or manual mode. In fig. 4.2.1 the Easytronic transmission with the actuators and their positions are shown.

![Figure 4.2.1: Opel Easytronic gearbox](image)

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4.2.2 Actuators and sensors

The LuK ASG system uses the LuK ECM (chapter 3) system as a basis. The mechanical shifting system is replaced by an electro mechanical system. It consists of two electric motors, one to select the next gear and one to make the shift. They make the use of the gear recognition sensor redundant. That is the positions of the electric motors point out in which gear the car is driven. The system can engage gears in any sequence and even skip gears. Bosch has developed the two electric actuators into an integrated unit, e.g. 4.2.2.

![Shift actuator diagram](image)

The rotating movement of the gear selection actuator is converted into a translational movement of the shifting shaft. In this way the right shifting forks are selected. After that the shift motor rotates the shift finger to engage the right gear.

The controls of the shifting process have been designed to make the shift feel as comfortable as possible. In fig. 4.2.3a,b the different phases during an upshifting process can be seen. The torque flow from the engine to the transmission is lowered and the clutch is disengaged. A new gear is selected and is synchronized by actuating the synchronizers via the shift finger. Then the clutch is engaged again and the engine torque is raised again.
The most important disadvantage of the ASG as opposed to an AT is again, power interruption during shifts. This will lead to a short-term deceleration of the vehicle and therefore is considered as uncomfortable. The electronic actuator has to be controlled in such a way that there are no abrupt changes in the acceleration. The driver will experience these abrupt changes as unpleasant. They also can lead to unwanted large vibrations of the vehicle drivetrain. So optimizing the shifting process is an important factor. In fig. 4.2.4 an example of a comfortable and uncomfortable shift measurement are given. The disadvantage of a comfortable shift is that it requires more time and therefore the power interruption is longer. But due to the ‘torque tracking’ method (see section 3.2) that is used by the ECM system the shift times can be optimized.
Another smart way to shorten shift times that is applied by LuK is called Shift elasticity. Four pressured springs, with a low stiffness, are positioned around the gear that is driven by the shift motor. Their combination leads to the spring characteristic that can be seen in fig. 4.2.5.

The flat range of the spring characteristic is the range in which the shift actuator operates. Because of this elasticity in the shift actuator the electric motor does not have to slow down when it synchronizes the next gear. The flat spring characteristic assures that a predefined force acts on the gears during the synchronizing. Another advantage is that the synchronizing force can be tuned more precisely. Due to the shift elasticity the LuK ASG system can shift faster than any other on the market available hydraulic system according to LuK [18]. At maximum acceleration shift times (tractive force interruptions, see fig. 4.2.3a,b) between 170 and 250 ms have been measured during upshifts for the Opel Corsa Easytronic, the total shift process takes up about 1 s [23].
4.2.3 Level of improvement

In terms of fuel consumption and CO₂-emission the Easytronic in automatic mode scores better than the normal manual transmission for the urban cycle, e.g. table 4.2.1:

<table>
<thead>
<tr>
<th>Fuel consumption (L/100km)*</th>
<th>1.0i 12v</th>
<th>1.0i 12v Easytronic</th>
<th>1.2i 16v</th>
<th>1.2i 16v Easytronic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>7.2</td>
<td>6.9</td>
<td>8.2</td>
<td>8.0</td>
</tr>
<tr>
<td>Extra urban</td>
<td>4.7</td>
<td>4.7</td>
<td>5.2</td>
<td>5.2</td>
</tr>
<tr>
<td>Combined</td>
<td>5.6</td>
<td>5.5</td>
<td>6.3</td>
<td>6.2</td>
</tr>
<tr>
<td>CO₂-emission (g/km)</td>
<td>135</td>
<td>132</td>
<td>151</td>
<td>149</td>
</tr>
</tbody>
</table>

* Fuel consumption and CO₂-emission measured in accordance with EEC Directive 99/100/EG.

Table 4.2.1: Opel Corsa fuel consumption and CO₂-emission, [e4]

This improvement in fuel consumption is due to the electronically controlled clutch procedure and the shift controls always shift towards a fuel efficient engine RPM. In the Extra urban cycle, the fuel consumption does not differ. During this cycle not many gearshifts have to be made, so the improved efficiency of the shift control does manifest itself as it does in the urban cycle. In table 4.2.2 the performance figures of the Opel Corsa are shown.

<table>
<thead>
<tr>
<th>Performance</th>
<th>1.0i 12v</th>
<th>1.0i 12v Easytronic</th>
<th>1.2i 16v</th>
<th>1.2i 16v Easytronic</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100km/h [s]</td>
<td>17</td>
<td>18.5</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>80-120km/h* [s]</td>
<td>24</td>
<td>155</td>
<td>18.5</td>
<td>17.5</td>
</tr>
<tr>
<td>Max. speed [km/h]</td>
<td>155</td>
<td>155</td>
<td>170</td>
<td>170</td>
</tr>
</tbody>
</table>

* In 5th gear

Table 4.2.2: Opel Corsa performance [e4]

The 0-100 km/h acceleration is slower for the Easytronic. This is due to the same difference in test procedure as explained in section 4.1.3. For the 80-120 km/h acceleration in 5th gear the Easytronic transmission is significantly faster than the normal MT. The gear 5th gear ratio however has not been changed as can be concluded from the equal maximum speeds and no gearshifts are made. So like for the Ford Durashift no explanation can be give for this only the assumption that due to the clutch controls of the Easytronic, drivetrain resonances are filtered out faster and therefore the engine revs up faster.

4.2.4 Dimensions, costs and complexity

An Opel Corsa with the Easytronic system has got an additional weight of 3.8 kg compared to the MT. The extra weight of an AT compared to a MT would be 24.4 kg [18]. The additional costs for a German consumer who buys the Opel Corsa with the Easytronic system are 700 Euros, only 50% of that of an automatic. Because the Easytronic system is developed as an add-on system, tailoring it for other transmissions is rather straightforward. The transmission itself does not have to be modified and thus keeps the same dimensions and manufacturing process as before.

Literature: [2], [3], [5], [7], [8], [18], [23], [e1], [e2], [e3], [e4]
Chapter 5  
**Powershift transmissions**

In this chapter, 2 different powershift transmissions will be discussed. Special attention is paid to interesting features and the way in which they improve the conventional manual or automated manual transmission.

5.1  Getrag-Ford Powershift transmission

5.1.1 Function, layout and main characteristics

The Getrag-Ford MPS6 transmission is a 6-speed FWD powershift transmission (possibilities for a RWD powershift transmission are being studied too). The main objective of the powershift transmission is: shifting without power interruption. This is enabled using a coaxial hollow twin-input shaft and dual clutch system, e.g. fig. 5.1.1. When driving in a specific gear, the previous or next sequential gear can already be held ready, since they are driven by the second input shaft (fig 5.1.1). When shifting to second gear the first clutch opens and the second one closes, realizing torque transmission through the second gear. The first, third, fifth and reverse gear are positioned on first the input shafts, whereas the second, fourth and sixth gear are positioned on the second input shaft. With this layout it is possible to up- and downshift between two successive gears without power interruption.

![Powershift transmission layout](image)

Skipping gears when shifting is possible without power interruption, but will take more time. When shifting down from the 4th gear to the 2nd, the 3rd gear has to be used shortly in-between to prevent a power interruption. This is because the second input shaft drives both the 2nd and 4th gear. And thus when a shift has to be made the clutch has to open and close to enable synchronizing. Leading to a torque interruption, when the 3rd gear would not be engaged shortly. So a disadvantage of the MPS6 transmission is that only sequential shifting is possible.
In fig. 5.1.1 the positions of the input shafts, output shafts and final drive are not clear. In fig. 5.1.2 mutual positions can be seen more clearly in a side-view. Both the output shafts are attached to the final drive that is positioned in between them at a lower position. The coaxial input shaft arrangement is positioned in between and above the output shafts.

![Diagram of input shafts, output shafts, and final drive](image)

*Figure 5.1.2: Side view input shaft, output shafts and final drive*

The powershift transmissions consists of four mechanical construction groups:

- Two manual gearbox units
- Automated shift and clutch actuation
- Dual clutch system

The two manual gearbox units together form a 6-speed twin-input and double-output shaft manual transmission. The dual clutch system consists of two multi-disc wet clutches with torsion damper positioned after one and other, e.g. fig. 5.1.1. A mechanical park mechanism is included in the transmission.

### 5.1.2 Actuators and sensors

The clutch actuation of the powershift transmission is performed hydraulically and can be operated independently for each clutch. A disadvantage of this is that an engine driven oil pump is needed that will reduce the efficiency of the transmission. The system also requires an external oil cooler, to regulate the hydraulic fluid's temperature.

Electric motors act as shift actuators. The number of electric motors that is needed is not clear. With only two (one to select and one to engage) no gear can be pre-selected unless if there is a special mechanism available that disengages the other gear. Otherwise a separate actuator with 2 electric motors for each gearbox unit is needed. More information on the actuators, their sensors and the information the system needs to perform a shift was not available.

### 5.1.3 Level of improvement

The improvements of the powershift transmission in comparison with a 6-speed automatic transmission with lock-up at 1200 RPM [11] are:

- 8-10% faster acceleration
- 6-11% less fuel consumption
- 2% higher top speed

In the figures 5.1.3 and 5.1.4 the level of improvement in comparison to a 5-speed manual, 6-speed automated manual and a 5 and 6-speed automatic transmission can be seen for fuel consumption, acceleration and top speed.
A manual 5-speed transmission is taken as reference. Both the 5- and 6-speed automatics accelerate slower, have a lower top speed and have a higher fuel consumption than the reference manual 5-speed. A 6-speed AMT accelerates slightly faster than the 5-speed MT and shows the lowest fuel consumption and highest top speed of all tested transmissions. The 6-speed powershift transmission accelerates the fastest and shows a fuel consumption and top speed that are slightly lower than those of the 6-speed AMT. There was no data available on the comparability of the vehicles and engines that were used. Furthermore no indication of independent testing has been given, making careful interpretation necessary.
5.1.4 Dimensions, costs and complexity

Some data about the MPS6 powershift transmission:

- Weight: less than 90kg (incl. approx. 5.5L transmission oil)
- Length: 386 – 401 mm (dep. on crankshaft dimensions)
- Cheaper than CVT, as costly as or cheaper (high volumes) than a 6-speed automatic
- Nominal engine torque capacity of 450 Nm

Due to the use of two output shafts the gears can be divided over the two shafts, this characteristic makes the MPS6 shorter than a standard 6-speed manual transmission. A by Getrag developed 6-speed MT, uses the two output shafts too and only measures 322mm, which makes it shorter than a single output shaft 5-speed MT.

In comparison to the manual transmission, the MPS6 transmission’s primary mass of the clutch is smaller and the secondary mass is the same.

The MPS6 transmission is more complex than a normal 6-speed manual. The reason for this are the added hydraulic and electro mechanic actuators and their controls. The dual clutch and coaxial twin input shaft contribute to its complexity too.

A possibility to add a starter alternator to the transmission has also been investigated, see fig. 5.1.5.

- Full integration in the bell-house
- No increase in length of the transmission
- Starter alternator will run separated from the transmission oil
- Max. outer diameter is determined by the differential diameter and position

![Figure 5.1.5: Example of the integration of a starter alternator](image)

Literature: [11], [24], [e26]
5.2 LuK Parallel Shift Gear

5.2.1 Function, layout and main characteristics

The LuK Parallel Shift Gear (PSG) is a study from LuK to develop a power shift transmission. It has evolved from the LuK ECM and ASG system, who have been developed with the standard MT as a basis. In between the evolution from the ASG to PSG LuK developed another powershift transmission, the Uninterrupted Shift Gearbox (USG). In this USG a power shift clutch is added to the ASG design. With this power shift clutch torque can be transmitted from the engine to the wheels through the highest or second highest gear during shifts. Because the power shift clutch is heavily loaded in the USG design it is restricted to engine torques of maximum 200-250 Nm. The PSG was the next step from LuK to improve the shifting comfort and quality of the MT-based gearbox and to eliminate the limits for the maximum possible engine torque of the USG. The PSG is essentially a dual clutch transmission with a fully torque filled power shift. An example of the LuK PSG can be seen in fig. 5.2.1. The system uses a parallel shaft design with a coaxial hollow twin-input shaft and a single output shaft.

![Example of a PSG system](image)

*Figure 5.2.1: Example of a PSG system*
The gears are positioned alternately on the twin-input shaft in two groups of gears, each with unit with its own clutch.
The PSG has some special design features that distinguish it from other DCTs. LuK uses dry clutches, where almost all other DCT designs use wet multi-plate clutches, and electromotoric actuators, where most other designs use hydraulic actuators. The reasons why LuK has chosen to develop a powershift transmission using a dry twin clutch are:
- Lower fuel consumption
- Option for modular gearbox families (MT, ECM, ASG, PSG)
- Dry clutches are more frequently used as start-up elements
- Lower weight than a wet twin clutch system
- Lower costs than a wet twin clutch system

The use of the dry twin clutch does cause some problems. Because the clutches are loaded more heavily in a powershift transmission, the thermal- and wear capacity of the clutches has to be larger. This affects the packaging size of the dry twin clutch system and therefore makes it less suitable for high torque applications. Wet clutches have a better thermal capacity and show hardly any wear.

An additional feature is that LuK only needs one gearshift actuator to operate both gearbox sections. This is made possible by a feature that LuK calls Active Interlock and that will be explained in the next section.

### 5.2.2 Actuators and sensors

The PSG system uses electromechanical clutch actuators. Each clutch has its own actuator. The actuators consist of an electric motor that is linked with a cable to a mechanical release system. In figure 5.2.2 a single clutch actuator with the mechanical release system (for a single clutch) can be seen. The rotating motion of the electric motor is converted into an axial movement by the lead screw to operate the mechanical release system. The mechanical release system replaces the conventional hydraulic release system and is attached to the transmission input shaft. Ramps and bearing balls convert a rotational movement around the input shaft of the gearbox into the axial release movement of the clutch.

![Figure 5.2.2: Clutch actuator with mechanical release system and close-up of mechanical release system (ramp mechanism)](image)
In figure 5.2.3 can be seen how the two clutch actuators can be positioned onto the bell house.

The gearshift actuator used for the ASG can also be used for the PSG. But to make a powershift possible, two of these gearshift actuators would be needed for the PSG. The first one would have to disengage a gear, while the second one already would have to select and engage the next gear to avoid a torque interruption. LuK has developed the feature called Active Interlock that makes this possible while using only one gearshift actuator. In figure 5.2.4 the active interlock system of a PSG can be seen.

![Figure 5.2.3: Position of clutch actuators in bell house](image-url)
The active interlock uses two additional disengagement geometries positioned onto the centre selector shaft next to the shift finger. When the shift finger is aligned to a rail one of the disengagement geometries is aligned to the other rail of that group of gears. In this way two gears of the same group cannot be engaged at the same time. When the shift finger engages a new gear, the disengagement geometry disengages the selected gear of the same group on the other rail. An engaged gear of the other group can stay engaged, because the clutch of that gearbox will disengage. The advantage of active interlock is that the shift finger can be moved back to its centre position without disengaging the currently engaged gear due to separation of the classical shift fork into various shift rails. Therefore it is possible to make a select movement with the shift finger prior to disengaging gear. An adapted version of LuK's active interlock can be used on the ASG system and there is a version for a MT too. In these cases it does not enable powershifts, but makes it possible for the shift finger to already get in position for the next gear. Information about the number or type of sensors that are used on the PSG was not available. But there can be assumed that the same sensors that are needed for the ASG system are needed for the PSG as well. The number of sensors is expected to be higher. This is because the system requires two clutch actuators and accompanying sensors.

5.2.3 Level of improvement

The benefits for fuel consumption of the PSG are almost as favourable as for the ASG. The powershifts lead to more clutch slip losses than for an ASG and the drag torque of the open clutch will lead to losses too. Because the car’s battery powers the electric motors of the actuators the auxiliary losses of the PSG system will lie above those of a MT. In figure 5.2.5 a graph of the losses of a MT, AT, DCT (DKG) with wet clutch system and the PSG are presented.

![Figure 5.2.5: Losses of different transmission types](image)

It can be seen that a DCT system with a wet twin clutch system has 3-5% more auxiliary losses due to the pump driving the actuation hydraulics and the hydraulics cooler. The drag torque losses for wet clutches are higher too. Compared to a MT the losses of the PSG are approximately 1% higher, but because the PSG shift controls
can shift at the optimal shift moments in automatic mode, the average fuel consumption of the PSG will be lower for the average driver. The area where it improves the ASG is the comfort area. Because the PSG shifts without power interruption no vehicle decelerations like for the ASG will occur. Shift quality of the PSG is comparable to that of an AT.

The PSG is the ideal basis for the integration of a starter generator. This would improve both the fuel consumption (start-stop, regeneration) and the comfort (air-conditioning without the need for a running engine) even more. The PSG with integrated starter generator is called ESG by LuK and is currently under study too. The starter generator would be positioned parallel to the PSG, in that way starting, generating, recovering and power shifting are made possible.

5.2.4 Dimensions, costs and complexity

The twin clutch system of the PSG needs more space than a standard single clutch system as used in a conventional MT, as can be concluded from fig. 5.2.1. In many standard MTs the dual mass flywheel (DMFW) is becoming more and more common. For the twin clutch system LuK has thought of another solution to achieve the same level of vibration isolation as with a DMFW, but with less packaging. The clutches are equipped with conventional torsion dampers and a flex plate is added. Controls that allow the clutches to slip to isolate torsional vibrations help as well to achieve vibration isolation comparable to that of a DMFW. In this way the PSG can be shortened by 15-20mm compared to a PSG with DMFW, the total primary inertia of the twin clutch system can be reduced as well with 0,1 kgm$^2$ to about 0,25 kgm$^2$.

The PSG needs two clutch actuators to operate the twin clutch system. So compared to the ASG system they will need more space. Compared to a conventional MT they are more flexible to be positioned since the mechanical link between shifter and transmission can be omitted.

The costs of the PSG system are expected to lie below those of a conventional AT, but higher than those of an ASG system.

Literature: [7], [8], [10], [35], [e2], [e3]
Chapter 6  Transmission specials

6.1  SDTL Smartmatic

6.1.1  Function, layout and main characteristics

The Smartmatic of Select Design Technologies Limited (SDTL) is an automated manual transmission. However, it does not realize the automatic shift in the same way as most AMTs. The Smartmatic is a hydraulic system that is based on the manual lay shaft constant mesh gear set and configuration. It removes the need for the conventional launch clutch, synchronizer rings and the engagement forks shift rods and associated mechanical parts. A so-called multi-cone selector (multi-plate cone clutch) replaces all these parts. In fig. 6.1.1 an example of the Smartmatic transmission can be seen. Each gear pair has its own cone selector. In the next paragraph the functioning of the cone selectors will be discussed.

![Automated manual 5-speed SDTL Smartmatic](image)

The cone selector of the 1st gear and that of the reverse gear are able to constitute a launch device as well as a synchronizer. Because of this there is no need for a launch clutch or torque converter. The layout of the transmission can be explained by regarding fig. 6.1.1 and a side view of the transmission in fig. 6.1.2.

![Side view of the Smartmatic transmission](image)
The cone selectors of the 1st and 2nd gear are positioned on the transmission’s input shaft. The 3rd and 4th gear cone selectors are placed on the output shaft. To reduce the length of the transmission the 5th and reverse gear as well as their cone selectors are positioned onto a lay shaft. When one of the cone selectors of the 2nd, 3rd or 4th engages a gear the torque is transferred from the input shaft through the selected gear pair to the output shaft. When the gear pair of the 5th or reverse gear is engaged by its cone selector the torque flows from the input shaft through a gear pair to the lay shaft and via another gear pair to the transmission’s output shaft. For the 5th gear an extra gearwheel, between the lay- and output shaft, is needed to assure the right turning direction of the output shaft. The way the torque flows from the input to the output shaft in 1st gear is not clear. It seems that it engages a gear on the layshaft, but there is no gear pair that can continue the torque flow from the layshaft to the output shaft. The Smartmatic, unlike other AMTs, enables shifting without power interruption. When opening one cone selector the next one can be closed with the right amount of slip to synchronise the transmission shafts. As such the engine torque can be transferred to the vehicle’s wheels at all times. This characteristic justifies the classification as a powershift transmission. The cone selectors can be controlled independently, so there is complete freedom to engage the gears in any sequence during up- and downshifts. The controls can easily be adapted to drive the car in a sporty or economical way in automatic mode. A manual mode is possible too.

6.1.2 Actuators and sensors
As opposed to other AMTs the Smartmatic does not need a clutch actuation system. The cone selectors of the 1st and reverse gear, called Quad cones selectors, function as launch devices and shift actuators in a single unit. The thermal capacity and durability of the 1st gear quad cone still has to be examined by the inventors. The cone selectors of the remaining gears, called Dual cone selectors, act as shift actuators. In fig. 6.1.3 a cross-section of the Quad- (top) and Dual (bottom) cone selector can be seen.

![Figure 6.1.3: Cross-section of a Quad- and Dual cone selector](image)

The angle of the selector cones depends on the maximum torque it has to transfer and the ratio of the gear for which it is used. A larger angle of the selector cones implies
more friction surface to transfer torque. In the cone selectors more surface can be packaged than in an equivalently sized multi-plate clutch. The cone selectors also need a lower axial force to engage than a multi-plate clutch requires, because the cones are positioned under an angle. As an example, with a cone angle of 14 degrees the axial force to actuate, it decreases with a ratio of 1:4,133 compared to an equivalent flat multi-plate device. This can be explained by looking at fig. 6.1.4:

![Figure 6.1.4: Cone selector actuation force](image)

The component of the axial force that acts on the cone selector acts under $90^\circ-14^\circ=76^\circ$ so the size of that force component equals $F_{ax}/\cos 76^\circ$ and $1/ \cos 76^\circ=4.133$. The female cone is attached to one of the gears and the male cone is fixed on one of the shafts. When the hydraulic unit is actuated the selector cones are pressed onto one another and the gear is engaged. When the hydraulic pressure is released the return spring assures the disengaging of the gear. Because neither the female nor the male cone is fixed to the outer gearbox, the relative velocities are lower than those in a multi-plate clutch. And thus the cone selectors are expected to produce lower drag levels in free running state.

A disadvantage of using these cone selectors is that they hydraulic pressure they need to engage the gears has to be supplied by a pump. The pump has to keep supplying pressure at all times. This means an efficiency loss of the total transmission. Since the axial force to operate the cone selectors is much lower than the axial force needed to operate the multi-plate clutches that are used in most automatics, the pressure that the pump has to supply can be lower implying an efficiency and cost benefit over ATs.

Drum shoe selectors are another type of gear selector device STDL has thought of, e.g. fig. 6.1.5.

![Figure 6.1.5: Drum shoe collector](image)

The shoes will be pressed against the drum by the hydraulic springs when a gear needs to be engaged. The centre of gravity of the shoes is placed to the left of the
pivot point to assure that the shoes do not make contact with the drum when it rotates in neutral. The spring can position the shoe and the hydraulic spring into neutral position.

To eliminate the pump from the design replacements for the cone selectors have to be found. There is an opportunity to use new high power 42-volt electric actuators when they become available.

6.1.3 Level of improvement

The Smartmatic transmission design is still under development and therefore no figures of the level of improvement on fuel consumption or performance are available yet. So only assumptions can be made about the level of improvement on these points. Because of the use of the oil pump and the drag losses of the multi-plate cone clutches the fuel efficiency can be expected to be lower than that of the conventional MT. The possibility to powershift probably will improve the acceleration of the vehicle, because no torque interruptions during shifting will occur.

6.1.4 Dimensions, costs and complexity

The dimensions of the transmission will be larger than those of the conventional MT from which it is derived. The cone selectors replace the synchroniser rings, selector forks and other engaging parts of the MT, but are expected to need more space. When the 1st and reverse gear cone selectors can be used as launch device as well, the clutch can be eliminated from the conventional MT design. This would reduce the manufacturing costs, assembly complexity and the weight and dimensions. The extra pump and hydraulics diminish this lower weight partially or totally.

The Smartmatic can be build on the same production line as the MT that it is derived from. The selector cones make that it will be more complex to manufacture than the MT.

The costs of the system will lie above those of the standard MT because of the hydraulics and the cone selectors. Compared to an AT the Smartmatic does not require a torque converter or the planetary gearsets. Therefore the costs of the Smartmatic will lie lower than those of a standard AT.

Literature: [32], [33], [34], [e28], [e29], [e30]
6.2 DaimlerChrysler AMT shift time optimization

6.2.1 Function, layout and main characteristics
As mentioned earlier the most pregnant disadvantage of the AMT compared to the AT is the torque interruption during shifts. For this reason the AMT still cannot compete with the AT in the area of comfort. This especially manifests during upshifts, because the vehicle decelerates during these shifts, while the driver desires sustained acceleration. The only remedy for eliminating this interruption of the power flow from the engine to the wheels is to resort to a totally different transmission layout. But this leads to more expensive solutions like dual clutch transmissions. For small cars the AMT still is the least expensive solution to approach the comfort of an AT. One way to minimize the loss of comfort due to the torque interruption the shift times should be held as short as possible. DaimlerChrysler (DC) is investigating the use of engine and transmission brakes to optimise shift times. The limiting factor for the length of the shift times of an AMT currently is the speed rate of the synchronization process. The drag torque due of the engine is not enough to lower the engine speed fast enough to the synchronization point. DC solves this problem by actively decreasing the engine speed with the use of a brake on the engine. This only holds for upshifts, whereas during downshifts the engine should be revved up to shorten shift times. When the clutch is opened the engine brake can rapidly reduce the engine speed and as such quickly reduce the speed difference between the engine and transmission. This enables higher engagements gradients of the clutch, without deteriorating the comfort of the shift. The driver notices this as a reduction in shift time. Another possibility to reduce the upshift times of an AMT is the use of a transmission brake. This transmission brake decreases the transmission’s input shaft speed to that of the next selected gear on the output shaft. The transmission brake can be used to support the synchronization device or even substitute it. The destination gear is synchronized in shorter time by the transmission brake and thus can be inserted faster. This leads to the reduction in shift time and no acceleration time delays of the vehicle. The brakes both can be used in the same transmission design. They both help to shorten the shift time in a different way.

6.2.2 Actuators and sensors
There are a few different actuation principles that can be used as an engine brake. An overview and short explanation of some different possibilities will be given below, all currently already are used in commercial vehicles.
- **Engine exhaust brakes**
  Increase the effort for the piston to expel the emission gasses from the cylinders by adding a barrier in the engine exhaust
- **Decompression brakes**
  Add a valve in the cylinder head to release pressure during the expansion stroke
- **Combined engine brake system**
  Combination of the engine exhaust and decompression braking principles
- **Turbo brake**
  Increasing the air flow through the engine when engine braking is desired
- **Mechanical brake**
  Add a mechanical brake on the engine’s crankshaft
When selecting one of the brakes, or a combination of them, the braking potential has to be taken into account. The required brake moments for each shift step can be calculated when the speed differences and inertias of the shift components are known. Because of the high inertia of the engine and its flywheel the required brake moments of the engine brake will lie much higher than the required brake moments of a transmission brake (when braking with a disengaged clutch).

When choosing a suitable transmission brake the decision if braking actions should occur with a closed or opened clutch has to be taken into account. A closed clutch would mean that the brake has to slow down the engine and its flywheel too next to the transmission. The brake moment would be about a factor 30 higher for braking with a closed clutch than for braking with an opened clutch [37].

A multi-disk brake is a suitable candidate for a transmission brake. To keep the costs of the system low, the clutch actuator can also perform the actuation of the transmission brake. Because the clutch has to be open when the transmission brake is actuated, the actuation mechanism has to be designed in such a way that either the clutch or the brake is disengaged when the actuator does not excite force. To coincide with common practice where actuation is only required for clutch disengagement, the clutch has to be engaged and the engine brake has to be opened when the hydraulic actuator is not bestirred.

### 6.2.3 Level of improvement

With the use of the engine and transmission brake DC has succeeded in lowering the total time of the shift process to 400 ms and the duration of the torque interruption to 50 ms. DC determined that these shift times are experienced as comfortable by the average driver. Compared to the shift times of the Opel Corsa Easytronic (see section 4.2.3), approximately 1 s for the total shift time and 170-250 ms for the duration of the torque interruption, shift times using the engine and transmission brakes are much faster.

### 6.2.4 Dimensions, costs and complexity

With the use of the transmission brake the synchronizers are redundant. This leads to cost advantages cause a single transmission brake is less expensive than all synchronizers.

The engine brake will lead to extra costs of the system because it is an additional component. But since the engine brake is not a very complex addition the extra costs of this brake will not be that high.

The adding of the brakes to the drivetrain will lead to larger dimensions of the transmission, depending of the types of brakes that are used the increase in size is smaller or bigger.

**Literature:** [37]
6.3 DTI Impulse Shift Transmission

6.3.1 Function, layout and main characteristics

In their search for an answer to overcome the torque interruption during shifts with an AMT, Drivetrain Innovations (DTI) has developed the Impulse Shift Transmission (IST). The IST is an upgraded AMT with a powersplit planetary gearing and rotating inertia (typically 0.1kgm²) added on a parallel branch to enable the continuation of the torque flow from the engine to the wheels. The IST system is based on another design of DTI, the Zero Inertia drivetrain (ZI). The difference between these two systems lies in the transmission type that is used and the function that the additional upgrade components have. In the ZI a CVT (no torque interruption) is used, where the IST uses a second generation AMT. In the ZI the inertia of the additional flywheel is used to compensate for the engine inertia during downshifts and accelerations at low RPM. In the IST the additional components provide a torque at the wheels during downshifts and for upshifts up to the 4th gear.

An optional (slipping) brake can be added to the IST system (Braked Impulse Shift Transmission, B-IST). The brake can exert torque in the opposite turning direction of the sun gear. The B-IST has an improved upshift quality compared to the IST. How this is achieved will be explained further on. An overview of the layout of the (B-)IST system can be seen in figure 6.3.1.

![Diagram of IST and B-IST](image)

The annulus of the planetary gear set is connected to the engine’s output shaft, and the sun gear is rigidly attached to the inertia. When driving in 1st or 2nd gear the inertia’s rotating direction is opposite to that of the engine, due to the ratio of the planetary set the inertia does not rotate when driving in 3rd gear. When driving in 4th, 5th or even 6th gear the inertia rotates in the same direction as the engine. When the clutch is disengaged and the gas pedal is released, to enable gear shifting of the AMT, the engine and the inertia want to slow down, creating a reaction torque that acts on the carrier of the planetary gears that is connected to the transmission’s output shaft, termed impulse shift.
A disadvantage of the IST is that the inertia will speed up during upshifts from 1st to 2nd and from 2nd to 3rd gear. As a consequence the torque amplification during these upshifts will be lower. By adding a brake to the IST design this problem can be solved. The brake can slow the inertia down and in that way improve the quality of the upshifts.

6.3.2 Actuators and sensors
The IST system uses an AMT as a basis; therefore the IST will need clutch- and shift actuators and their accompanying sensors. The additional components of the IST system do not need additional actuators or sensors.

The B-IST on the other hand needs an extra actuator for the brake and a sensor to control the brake force. The type of brake that will be used and the brake capacity that is required determine what type of actuator will be the most suitable. For example when a wet multi-disk brake would be used a hydraulic actuator would be needed. But in the case where a dry clutch is used as a brake, the existing actuator of the normal clutch could be used to operate the brake too.

6.3.3 Level of improvement
IST improves the fuel economy of the vehicle compared to the fuel economy of the AMT where it is based on. Because of the use of a much longer overdrive that does not deteriorate driveability during downshifts as of the IST principle.

The comfort level of the IST is improved because the torque interruption is eliminated. The B-IST has an even better comfort than the IST during upshifts comparable to that of an AT.

The performance of the vehicle with IST is improved as well. There always is torque available when accelerating, which will lead to faster acceleration times. The top speed of the vehicle will not be affected.

6.3.4 Dimensions, costs and complexity
The technical complexity of the IST is not very high. It limits to a planetary gear, fixed gear stages and disc-shaped inertia. For the ZI a prototype has been developed that requires 30 mm additional space. The B-IST is more complex due to the extra components and the extra controls for the brake. An example of how the IST components can be built into a front wheel driven vehicle can be seen in fig. 6.3.2.

![Figure 2: Packaging of a front wheel IST](image-url)
The flywheel (red) of the engine is connected to the annulus, the carrier (yellow) has to be beared onto the transmission’s input shaft (in the bell house) and is connected to the transmission’s output shaft (yellow).

The additional costs of the IST range between those of an AMT and DCT. The B-IST will be more expensive due to the additional brake and its actuator and sensors. The costs will a little less or the same than those of a DCT.

The inertia connected to the sun gear can also be the rotor of a starter generator. This enables the possibility to make a mild hybrid vehicle drivetrain with IST.

*Literature: [22], [26], [41]*
Chapter 7 System comparison

The different transmission types that have been discussed in this report all try to improve the conventional MT in one or another way. One of the goals of this exercise was to develop an objective judgment of the in-house developments of DTI, the IST and B-IST system. In table 7.1 the discussed transmissions are compared with each other and with the conventional MT and AT as well. The system are compared with each other on:

- System costs; the total costs of the transmission and its additional features.
- Size and weight; the dimensions and weight of the transmission, the clutch and the systems that are needed for the clutch and shift actions.
- Fuel economy; the fuel consumption of the concerning transmission.
- 0-100 km/h; the acceleration of a vehicle with the concerning transmission.
- Shift comfort; consists of the effort the driver needs to make to shift and the comfort of the shift, as the driver will experience it.
- Modifications with respect to the MT; changes that need to be made to the MT layout and/or additional systems that are needed.

<table>
<thead>
<tr>
<th>Transmission</th>
<th>Syst. costs</th>
<th>Size, weight</th>
<th>Fuel econ.</th>
<th>0-100 km/h</th>
<th>Shift comfort</th>
<th>Modific. wrt. MT</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT</td>
<td>+++</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>LuK ECM</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+</td>
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<td>++</td>
</tr>
<tr>
<td>Ford Durashift</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>LuK ASG</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Ford Powershift</td>
<td>--</td>
<td>0</td>
<td>0(-)</td>
<td>++</td>
<td>++</td>
<td>--</td>
</tr>
<tr>
<td>LuK PSG</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>++</td>
<td>++</td>
<td>--</td>
</tr>
<tr>
<td>Smartmatic</td>
<td>--</td>
<td>-</td>
<td>-</td>
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<tr>
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<td>0</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>0</td>
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<tr>
<td>B-IST</td>
<td>-</td>
<td>0</td>
<td>++</td>
<td>++</td>
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<tr>
<td>AT</td>
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<td>0</td>
<td>++</td>
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</tr>
</tbody>
</table>

*Table 7.1: system comparison table*

These comparisons have been made with the information on the systems that were available within publications on the internet, engineering literature and via the manufacturers themselves. The information was not always objective, but it is attempted to make the system comparison as objective a possible using the acquired knowledge.
7.1 IST and B-IST judgment

When looking at system costs, the IST and B-IST cannot compete with the ECM and AMT systems. But their improved comfort and shift quality amply compensate for this. This makes them a more likeable option as a transmission in the middle- to large sized cars. In the small cars the AMT solution suits best due to its low costs. Even though the IST might stand a chance here when the additional costs of the system can be kept reasonably low (approx. 100 euros).

When compared to the DCTs the IST and B-IST are more favourable due to their lower costs and reasonable modifications with respect to the MT. The lower comfort and shift quality of the IST will not compensate for the lower costs of the system in the larger (more expensive) cars. Therefore, B-IST is more capable to compete with the DCTs in this range of cars.

A big disadvantage of the smartmatic as compared to the IST and B-IST is that it needs a hydraulic pump to operate its cone selectors. Therefore the costs and the fuel economy of the system are less favourable. When the gear engaging devices of the smartmatic can be activated without the use of hydraulics this will make the system more competing with the IST and B-IST.

The competition that the IST and B-IST give to the AT is significant. Due to their much lower costs and weight, smaller dimensions, and better fuel economy they will, especially in the middle and upper range cars, be able to substitute the AT. As of the increased comfort and shift comfort for reasonable additional costs, they also are serious competitors for the AMT and MT in the small to middle range cars.
Chapter 8 Conclusion

The IST and B-IST have been developed to eliminate the torque interruption that makes the AMT less competitive as opposed to an AT or DCT. Due to the relative low costs, enhanced fuel economy and small modifications with respect to a MT these systems are very interesting developments.

The DCTs cannot compete yet with the AMTs in the smaller car range due to their higher costs. The IST on the other hand is far less expensive than a DCT and therefore does form a feasible alternative for the AMTs in the smaller car range.

For the middle and upper car range the B-IST is a competitive transmission for the DCTs. The IST in a lesser extent due to the lower comfort level and shift quality compared to the DCTs. The B-IST is less expensive and needs fewer modifications with respect to a MT. These two advantages make it more interesting than a DCT, which needs a separately developed transmission. The better fuel economy makes the B-IST an even more interesting option, in light of the ever-strengthening legislations.

The smartmatic might be a strong competitor as well for the existing transmissions or the IST and B-IST when the hydraulic pump can be eliminated. This is however eminent only when the 42V electric grid is introduced which also enables many other means of filling torque interruptions.
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