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Automatizace převodovky – minulost a budoucnost

Gearbox automation – past and future

Summary

The lecture summarizes known solutions of semi and fully automatised gearboxes from the beginning of their usage in motor vehicles (from approximately 1930‘ies of last century) till nowadays. From recent designs are involved typical representatives from passenger cars and trucks. In the overview we are focusing on typical members from the family of automatised gearboxes only, i.e. on the transmissions where the gearshift occurs with interruption of torque flow. The Direct Shift Gearbox (DSG) – also known as Dual Clutch Transmission − is not included in the description. The lecture ends with description of possible future evolution of automatised gearboxes. Two domains are described:

- The adaptation of internal gearshift mechanism intended for automation.
- Possible cover of the power gap due to the interruption of torque flow during gear shift.

The author’s expectations and research work in this field are discussed.

Souhrn

Přednáška shrnuje známá řešení částečně nebo plně automatizovaných převodovek od jejich prvního použití v motorových vozidlech (přibližně ve třicátých letech minulého století) po současnost. Ze současných převodovek jsou zahrnuty jak představitelé konstrukcí v osobních, tak nákladních vozidlech. V uvedeném přehledu se zabýváme zejména typickými členy této skupiny převodných ústrojí, tedy automatizovanými převodovkami, kde k zařazení rychlostních stupňů dochází při přerušení toku výkonu. Dvouspojkové převodovky nejsou zahrnuty. Přednáška je uzavřena okénkem do možného směřování dalšího vývoje automatizovaných převodovek. Popsány jsou dva hlavní směry:

- Úprava vnitřního mechanismu řazení pro následnou automatizaci.
- Možná vyplnění výkonové prodlevy vzniklé řazením s přerušením toku výkonu.

Přiblížena je autorčina představa dalšího vývoje a vlastní výzkumná práce.

Klíčová slova: automatizované převodovky osobních a nákladních vozidel, řazení s přerušením toku výkonu, úprava vnitřního systému řazení, vnější synchronizace, systémy pro překlenutí toku výkonu.

Keywords: automatised gearboxes for passenger cars and trucks, gearshift with interruption of powerflow, adaptation of internal shift system, external synchronisation, systems for power gap cover.

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1. Introduction

In the present text we will focus on the geared stepped constant-mesh transmissions for usage in motor vehicles. This particular group of transmissions can be further divided according to the following criteria (the underlined behaviours are typical for automatised gearboxes):

Control:
- Manual.
- Semi-automatic.
- <u>Automatic.</u>

Shifting:
- With interruption of torque flow.
- <u>Without interruption of torque flow.</u>

Used gears:
- <u>Spur gears</u>:
  - <u>with fixed axes.</u>
  - planetary gear sets.
- Bevel gears.

1.1 Definition of automatised gearbox

The automatised gear-box is characterised as a conventional manual gear-box which is converted by retrofitting automatic controls for clutch operation and/or gear shifting [1]. The countershaft architecture of manual gearboxes (with or without integral final drive – depending on drivetrain disposition of the vehicle) is very versatile: it is the most efficient solution with compact dimensions and almost unlimited capabilities of torque transfer from all currently used transmission types. A main characteristic of the manual gearbox is that the gear shift (by means of synchromesh shift of spur gears) occurs with interruption of torque flow.

Automating the previously described manual gearbox currently has negative consequences for the shift comfort, due to the interruption of torque flow during gearshift. The shift time is constrained by the capacity of synchronisers, and the shift logic can not completely respond to the driver's intentions. Although such a gearbox is low cost, keeps all advantages of the manual gearbox and offers the driver automatic interface, it will have limited shift comfort.

A new transmission type dedicated for passenger vehicles denominated as DSG (Direktschaltgetriebe; Direct Shift Gearbox) appeared in mass production in the last few years. From the point of view of the architecture and actuation of gearshift, this transmission is a typical member of the group of automatised transmissions. Thanks to the specific disposition of a dual clutch actuating two coaxially mounted input shafts of the gearbox, the gearshift of DSG (the change between actually shifted to the preselected gear) occurs without interruption of torque flow (the preselection shift occurs on not-loaded shaft). From the point of view of price, of the shift control and shift comfort that belongs to DSG would place it in the group of automatic transmissions.

Our interest will be especially in the first mentioned group, where we feel there is big potential for new inventions, which will lead to low cost, compact and efficient gearboxes with automatic gearshift.

2. Past of automation of passenger car gearboxes

In this chapter an overview is provided of some existing solutions of automated passenger car gearboxes. We can distinguish two different developments to help the driver shift gears:

- Semi-automated transmission (two pedals and shift lever; the driver shifts the gears, the clutch is automatically controlled by electro-mechanical, hydro-mechanical, or pneumatic-mechanical device).
- Fully-automated transmission (both clutch and transmission are automatised. The gears are shifted after implemented shift logic).

2.1. Semi-automated transmissions: automated clutch systems

In the group of semi-automatic transmissions, we can cite from the early years (around 1940'ies) systems such as Bendix clutch control (which used vacuum-servo cylinder and piston) [2], Gillett control (hydraulically operated), or Hudson "Drive Master" (vacuum operated clutch).

In the 1950'ies and 1960'ies, examples include the Vauxhall Manumatic (centrifugal clutch plus vacuum servo operation), Newton drive (centrifugal clutch for drive-away and vacuum servo operation for gear change), Smith two pedal actuation (electromagnetic clutch), Mercedes Hydrak (freewheel plus hydraulic clutch and single dry-plate clutch operated by vacuum servo), Renault Transfluide (torque converter and electromagnetic clutch), and the German Saxomat (centrifugal clutch and vacuum servo unit). All systems can be found in [3].

In the 1980'ies and 1990'ies, semi-automatic transmissions witnessed a revival. Of the automated clutches available at that time on the market, the best known were: Renault Twingo Easy (electro pneumatic system) [4], Volkswagen Golf Ecomatic (electro hydraulic system), and Saab Sensonic (electro mechanical operation). Since the comfort requirements for modern day cars are increasing, the purely automated clutch systems will probably never come back. Nevertheless, in combination with automated gearboxes where they are employed to interrupt the power flow necessary for gear shifting, automated clutches have potential use in car and truck transmission design [5].

2.2. Fully automated transmissions

Before fully automated transmissions completely controlled gear shifting including the decision of right gear in right time, several systems were built with the driver dispensed from the physical force, but not from the mental work of shifting decision. The best known systems (from 30'ies) were the English Wilson pre-selector gearbox and French Cotal; both worked with planetary gear sets. In the Wilson system the gear was chosen with a lever, and the engagement was executed by pressing down a special foot pedal. The Cotal system shifted by means of disc clutches actuated electromagnetically. Some years later the German firm ZF presented a countershaft two stage gearbox with helical gearing shifted by electromagnetic clutches [6].

In the 1960'ies, the Renault gearbox automated by Jaeger with use of an electromechanical shift system and electromagnetic driveaway clutch, was a genuine automated transmission [7] – see Figure 1. It existed in a mechanical version (driver actuated) and automatic version. From German solutions we can cite for example Saxomat.

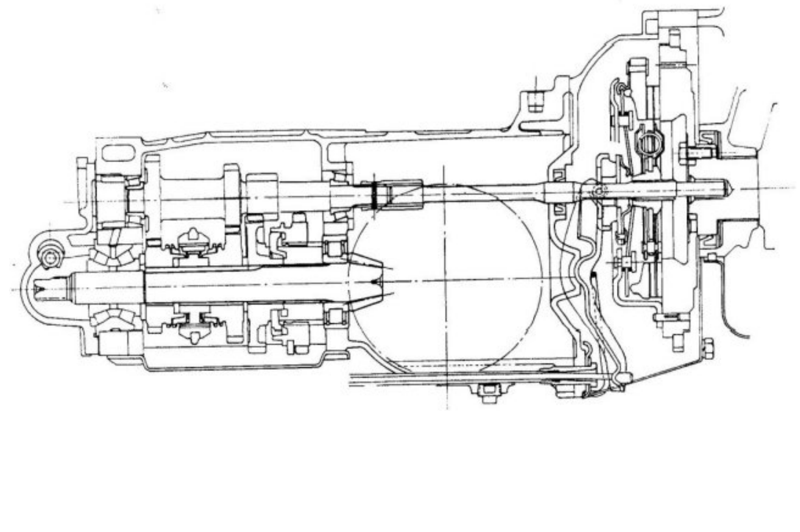
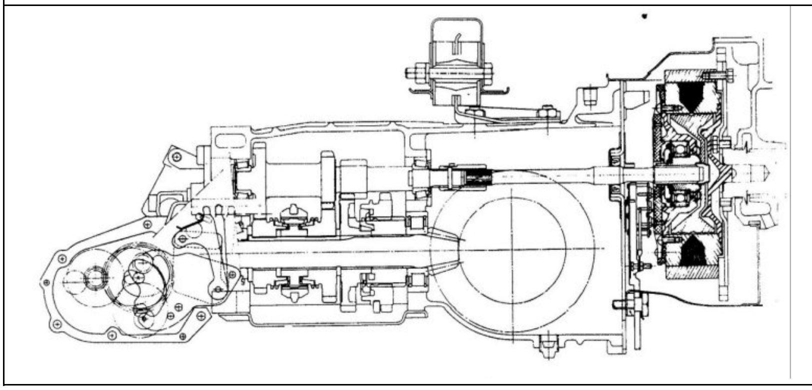


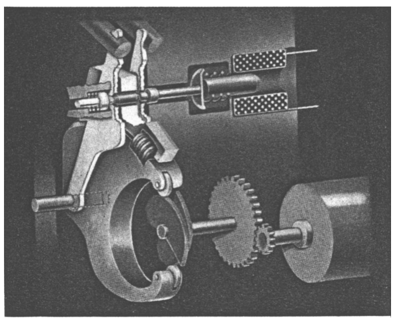
Figure 1: Renault Jaeger Transmission [7].

◄ Manual three gear transmission with single plate clutch.

▼◄ Automated gearbox equipped with magnetic particle clutch and electromechanical shift actuator.

▼ Detail of electromechanical shift actuator.





Together with the revival of automated clutch in the 1980'ies naturally also automated gearboxes witnessed a revival. This was stimulated very much by the fast development of electronics. Examples created at the end of the 1970'ies and 1980'ies are the automated truck gearboxes by electromechanical system [8], or electrohydraulic system of passenger car transmissions prepared by Renault [9], or PSA [10]. In both mentioned systems all shift rods were separately actuated.

3. Present of automatised gearboxes

More recent projects in passenger vehicles usually aim to simplify the actuation. As example can be mentioned Opel MAAX (mid 1990'ies), which shifted sequentially by means of shift cylinder actuated by electromotor – depicted in Figure 2, or by additional equipment [11] to be fitted to serial transmission to change the H-shift into sequential shifting in line which can be easily automated – see Figure 3.

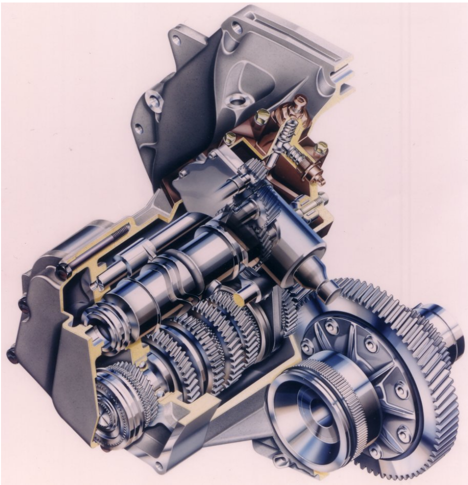


Figure 2: Opel automated five speed gearbox with sequential shift by shift cylinder [12].

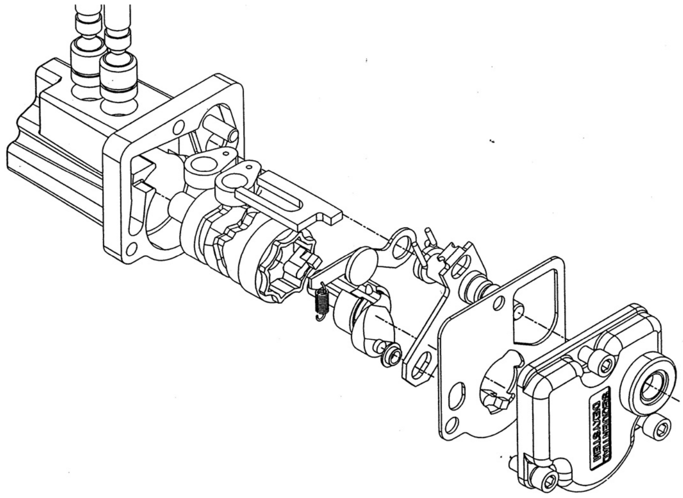


Figure 3: Mechanism for follow up automation of H shifted manual gearbox by means of shift cylinder. After equipment with this system the gearbox will be shifted sequentially only [11].

The Opel Easytronic is another recent example. It uses electromechanical actuators retaining the H mechanism. The section of this gearbox and its actuators can be clearly seen in Figure 4. Other recently introduced automated transmissions are BMW and Mercedes with electrohydraulical shifting, as well as a solution such as the VW Ecodrive (5 speed gearbox, where only the 5th speed is shifted automatically) [13].

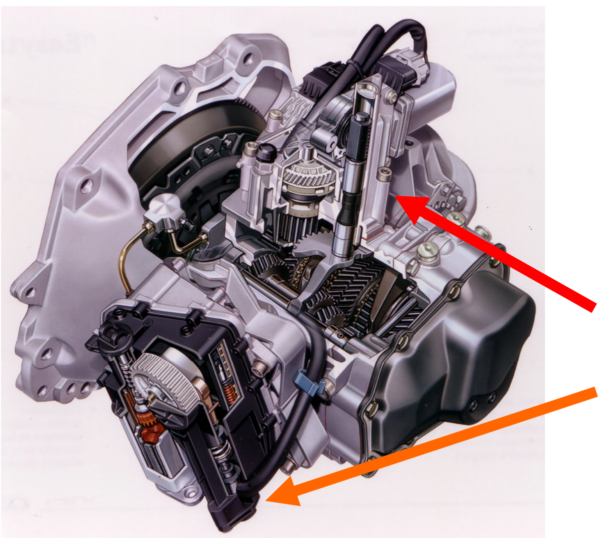


Figure 4: Opel Easytronic [12].

Concept of automated gearbox consists of single disc dry clutch with self-adjustment mechanism automated by electromechanic actuator which controls the pressure in the hydraulic line.

Electromechanical actuation of shift forks.

Clutch actuator.

3.1 Truck solutions

Commercial vehicles up to the weight class of about 5 tons have similar drivetrain as passenger cars. Therefore the observations about the automatised gearboxes in the previous chapter also apply to this group of commercial vehicles.

The other types of vehicles are mostly equipped with 6 to 16 speed transmissions with non-synchronised or synchronised constant mesh gears. The actuation is manual or semi/fully automatised. The conventional automatic transmissions are rarely used in trucks (mostly only in heavy special purpose vehicles). To obtain as many speeds as possible with as few of gear pairs possible, the multistage structure is used [1].

The requirements for shift comfort are in this market segment low. The priority of the market is price, reliability and efficiency. The automation of actuation is also easier than for passenger vehicles, since the trucks are always equipped with compressed air system – which is suitable as a source of shift actuation energy. The first usage of electronically controlled gearshift algorithm was introduced by Mercedes-Benz in 1985, denominated as EPS (Elektronisch-Pneumatische Schaltung) [14].

One of the recent automated gearboxes for long-distance trucks can be seen in Figure 5. A short description of the gearbox is included in the legend. One speciality of the shift logic in this case is the possibility of neutral shift during downhill or flat road drive. By excessive increase of vehicle speed the appropriate gear is engaged and the engine brake with retarder starts functioning.

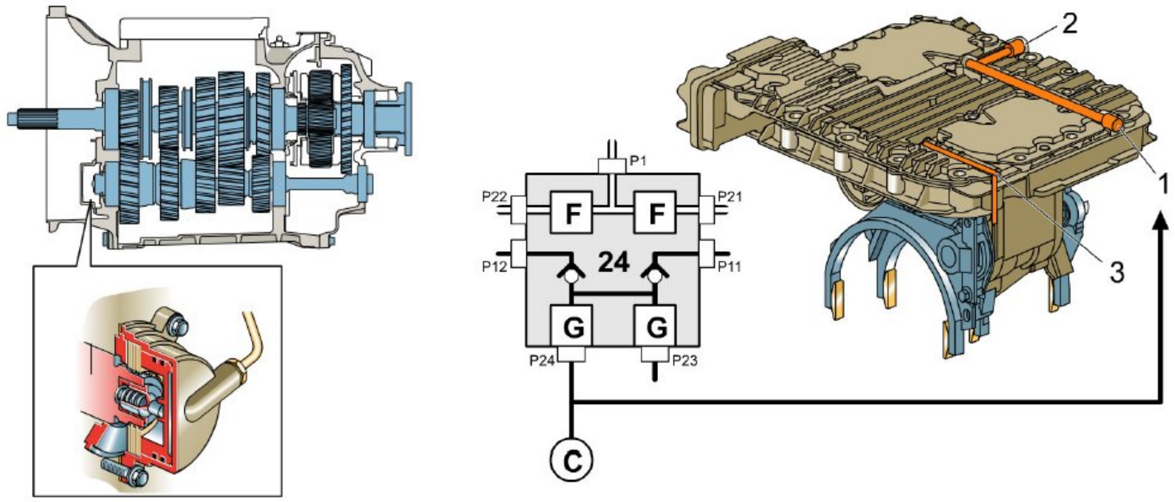


Figure 5: [15] **Left:** Three range 12-speed automated gearbox with front mounted constant mesh splitter unit and rear-mounted planetary range unit. Three speed main gearbox is synchronised externally by countershaft brake for upshifts (see detailed window) and by means of engine match for downshift.

Right: Shift case, which comprises the electronical control unit, actuating cylinders for clutch and all shift forks, sensors, etc. Legend: 1 - Input of pressure air, 2 – Output of pressure air to the clutch actuator, 3 – Output of pressure air to the countershaft brake.

4. Future of automatised gearbox

From the comparison of automated gearboxes with other transmission types we can conclude that the automated gearboxes with torque flow interruption can nowadays compete especially in low or lower mid class passenger cars and in the truck transmission segment (although important exceptions like BMW, Alfa Romeo Selespeed, and Ferrari exist). The characteristic of automatised gearboxes is so interesting, and can lead to efficiency improvement of the powertrain, that they should remain in the focus of vehicle manufacturers. We see the future of automatised gearbox especially in the improvement of the three following domains:

- Shortening of the shift time (by introduction of new internal shift mechanism intended for automation).
- Filling the power gap which arises during the interruption of torque flow.
- Improvement of shift algorithm, which will better correspond to the driver's intention and feelings.

The first two points will be further elaborated in the specialised chapters. The last point falls outside the scope of this presentation, so it will not be included in the remainder of this text.

4.1 New internal gearshift systems intended for automation

For the automatised gearboxes (where the gear shift occurs with interruption of power flow) the use of synchroniser is inconvenient because the shift time is limited by the synchroniser's capacity. When applying a powerful shift actuator to allow rapid speed shift, the synchroniser suffers increased wear and its service life rapidly decreases. A long shift time ensures a correct use of the synchroniser but has significant influence on vehicle dynamics and driving comfort. The increase of capacity of the synchroniser leads to increase of complexity or to solutions which are advantageous only in some special gearbox designs.

In our view, an interesting way to improve automated transmission lies in adaptation of internal shift mechanism, which will also lead to shortening of the shift time. Some related work in this area based on adaptation of synchronisers is known. In Figure 6 some of existing internal shift mechanisms with regard to their applicability in automatised gearboxes are summarized. The blue area points out the field of expected future research and the focus of the author's interest of search of new mechanism. Our work in this area to the best of our knowledge is new and different from other developments. The "Ease of automation" criterion (displayed on x-axis) is based on estimation of achievable shift time (how much the shift time is limited by capacity of the mechanism). On the y-axis the number of elements of the shift mechanism is displayed – the value indicates the costs, weight and dimensions.

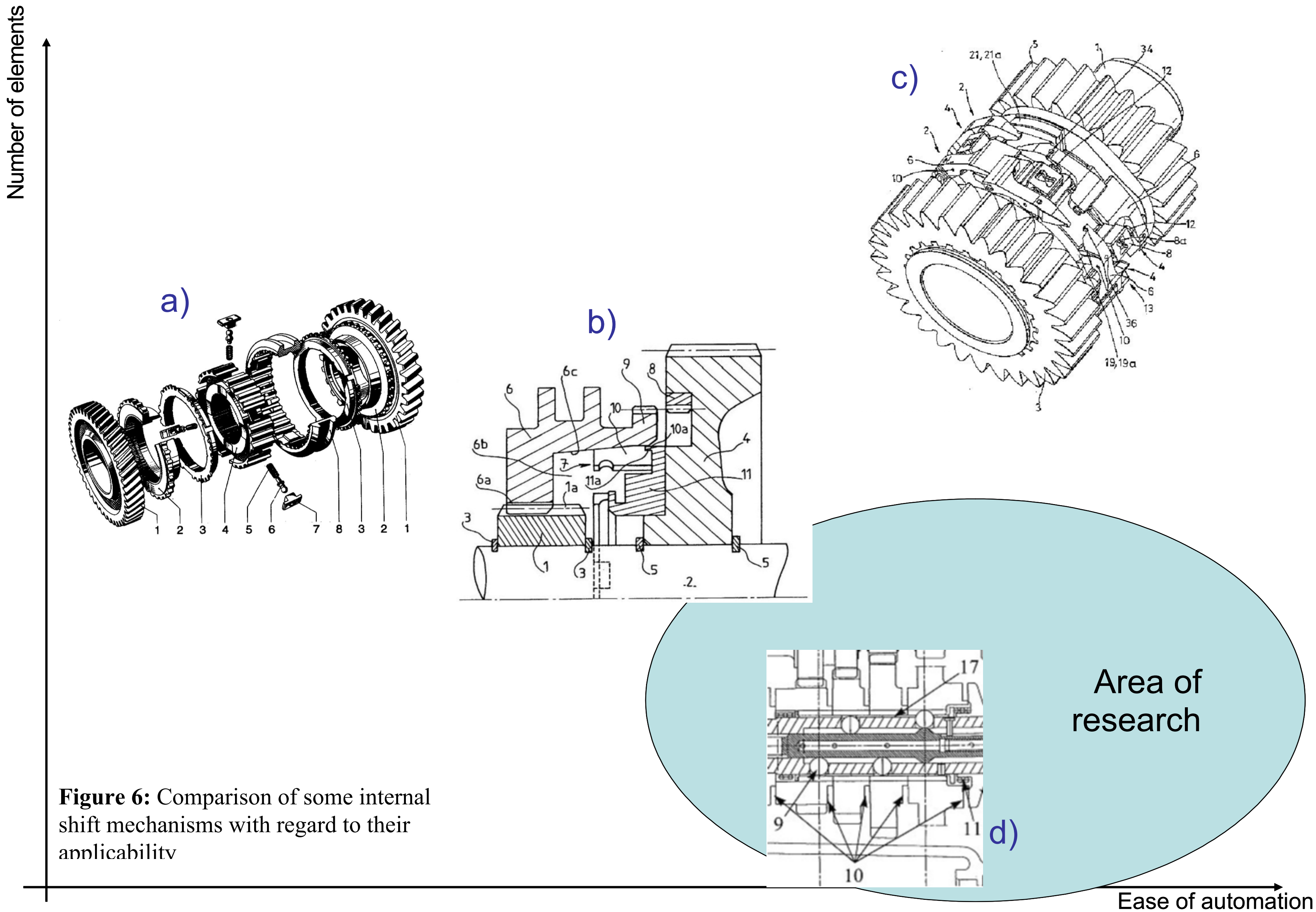


Figure 6: Comparison of some internal shift mechanisms with regard to their applicability

◄ Detailed legend to shift mechanisms shown in Figure 6:

Comparison of some internal shift mechanisms with regard to their applicability in automatised gearboxes.

a) Single cone synchroniser for manually shifted transmissions

Single cone synchroniser type Borg-Warner with blocking teeth ensuring the gear engagement after the complete speed synchronisation.

b) Synchroniser for automated transmissions [16]

The synchroniser of previously mentioned type contains a synchroniser ring usually manufactured from brass. In automated gearbox the sleeve is axially moved by hydraulic or electric system exerting high force on synchroniser ring. In automated gearboxes the synchroniser ring is submitted to high wear, which can cause low durability. The system presented in this patent aims to counter this disadvantage.

The synchroniser consists of three separate arc segments (10), which form the synchroniser ring (7) mounted on the hub (11) of pinion (4). Contrary to classical synchroniser, the sleeve does not directly force the synchroniser ring, i.e. the synchroniser cones, but the rotation of sleeve (6) - due to the synchronisation moment – brings in contact the three segments (10) with cones of hub (11). The angle of cone can be even lower than 5°, while the self-locking problem is eliminated by replacement of ring via three separate segments, which – when engaged - are pressed to lower diameter.

Legend: 1 – Hub, 1a – Splines, 2 – Shaft, 3 – Retaining ring, 4 – Idler wheel, 5 – Retaining ring, 6 – Sleeve, 6a – Splines, 6b – Inner part of sleeve, 6c – Cone, 7 – Synchroniser segments, 8 – Dog teeth, 9 – Sleeve dog teeth, 10 – Arc segments, 11 – Hub of idler wheel, 11a – Shoulder.

c) Dog clutch Zeroshift system [17]

The invention is based on replacing the dogs machined on the faces of shift sleeve of the racing-style gearbox by six so called bullets. Each bullet has a ramp face and dog face. Two bullets engage and clamp the dog of engaged wheel, i.e. this system has no backlash, and therefore produce no noise when changing the direction of torque (drive or brake). The shift occurs under power.

Description of the system: By moving the fork to engage next speed only unloaded bullets move and engage with the dogs of next gear wheel. At that time two speeds are engaged at once. The second pair overdrives the first. The 1st gear starts to rotate faster than the shaft and hits the ramp of bullets still engaged which are forced by the spring to slide and mesh also with the dogs of the 2nd gear. The system depicted in Figure 7 does not have speed synchronisation, but allows fast gear shift without interruption of torque flow.

The invention depicted in Figure 6 provides a solution of coupling device for coupling rotatable bodies together via an alternative electromagnetic actuator, which can be electronically controlled.

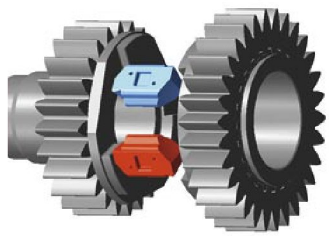
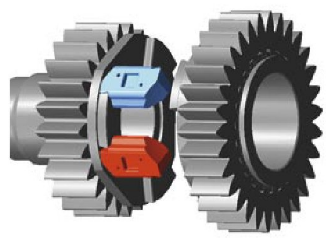


Figure 7: Zeroshift bullets [18] ▲ Neutral position ▼ 1st gear engaged



d) Internal shift system adapted for automation

This is the system under development by the author. The system is in detail described in the following chapter.

4.1.1 Adaptations of hollow shaft shift mechanism for passenger car use

Figure 8 shows the developed system - the 3 speed functional model which was realised in cooperation with an automobile manufacturer. The hollow shaft ball shift mechanism is used in small motorcycles. For passenger car implementation the following adaptations were designed:

- Cages to close the balls (submitted to the centrifugal force) in radial holes.
- Spur helical gears.
- Reverse gear.
- Mechanism for speed skip.

More details on the proposed solution including results from shift and endurance tests can be found in [19]. All wheels have helical gearing. Because the cages do not allow the fabrication of shoulders on the shaft for interception of axial force, and as the wheels are mounted one next to another, the force is transmitted through friction surfaces of each gear wheel. To minimize the friction, needle bearings are inserted between gears.

The reverse gear has the same disposition of gear-wheels as a "classical" mechanical transmission. The shifting is also provided in the hollow shaft, so the wheels can be equipped with helical gearing.

The shift system was mounted in a gear casing from a serial fabricated mechanical five speed gear-box. The torque transmitted via the "ball system" during the endurance test was between 100 and 150 N.m.

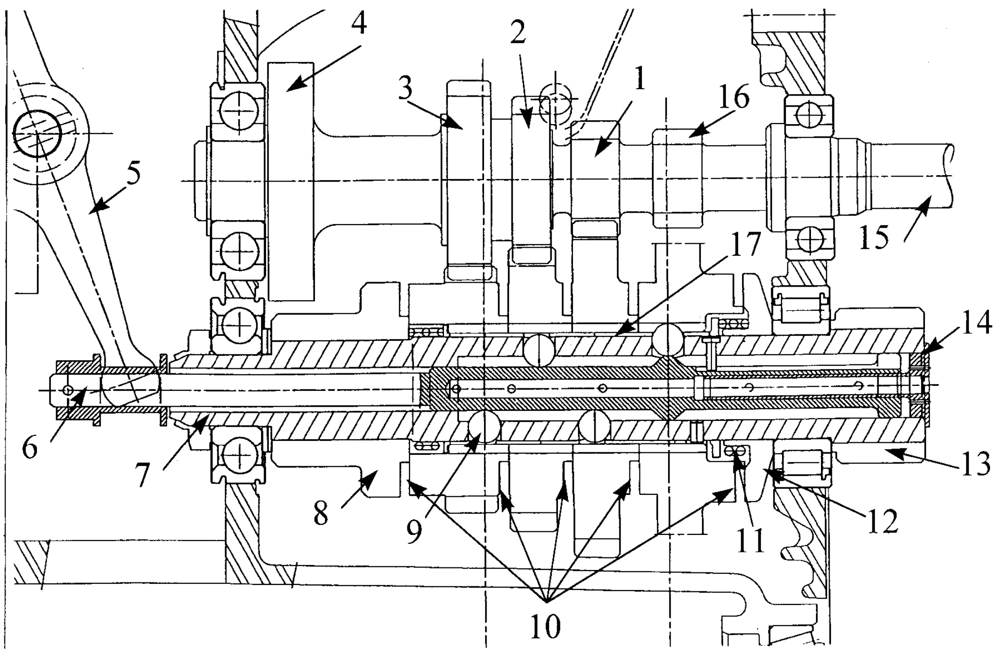


Figure 8: Sectional view of functional model in position „Reversed gear engaged“ [19]. Legend: 1 - Pinion of the 1st gear, 2 - Pinion of 2nd gear, 3 - Pinion of 3rd gear, 4 - Pinion of 4th gear not machined, 5 - Control-lever, 6 - Shift-lever, 7 - Output shaft, 8 - Distance-piece, 9 - Ball, 10 - Spaces for needle bearings, 11 - Spring, 12 - Thrust washer, 13 - Axle pinion, 14 - Tube for lubrication, 15 - Input shaft, 16 - Pinion of reverse gear, 17 – Cages.

4.1.2 Maybach dog clutch

Characteristic for the Maybach clutch are the bevelled fronts of dogs, which prevent the engagement as long as there exists relative movement between clutch and shifted wheel.

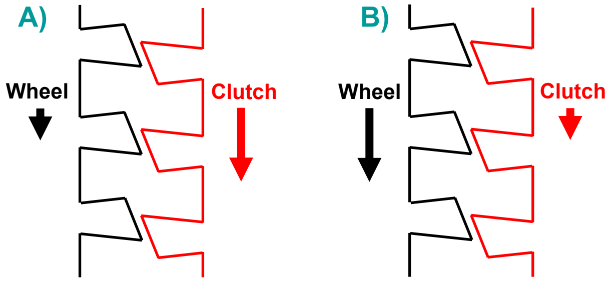


Figure 9: Maybach dog clutch.

The arrows indicate magnitude of angular speed for A) = Upshift.
B) = Downshift.

When shifted in the upper gear, the bevels eject the clutch from mesh until the angular speed of clutch and wheel is not unified, or eventually until the wheel does not rotate faster than the clutch. The contact surface of bevels brakes the clutch rotation, so after some time the dogs can mesh easily without shock. The dog rebound produces clashes. For shifting to the lower gear, the clutch rotates slower than the shifted wheel. In this case the dogs mesh promptly, but this causes a shock of immediate unifying of angular speeds.

From the description of the Maybach clutch function it is evident, that if one will succeed to regulate the angular speed of shifted gear by means of external synchronization, the shift mechanism with Maybach clutch can be quiet, shock free, and with compact dimensions. We set out to create such a system by means of external synchronisation. To test the behaviour of the Maybach dog clutch in the real gearbox with external synchronisation, the MQ200 gearbox was used – see Figure 10. The external synchronisation is prepared by means of electromechanical devices actuating the gearbox input shaft.

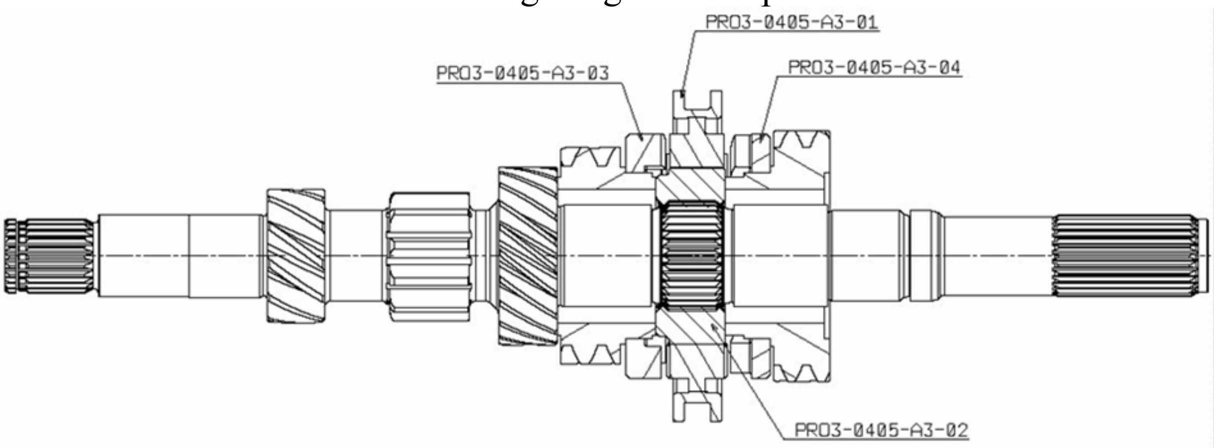


Figure 10: Assembly drawing of the Maybach dog clutch mounted on the MQ200 input shaft [20].

The tests of the current setup will be held in the beginning of 2007. If the dogs will satisfy the test the development will continue on a retaining system to minimise radial backlash to avoid the unpleasant noise and shock when changing the sense of torque (engine is driving or braking).

4.2 Systems for power gap cover during gearshift

Another interesting idea how to improve the shift comfort of an automatised gearbox is to partially or fully fill the gap in power flow when shifting. In the following text we will mention some of the possible solutions.

4.2.1 Flywheel based systems

The first mentioned group uses for power gap cover the inertia of implemented flywheel. A solution lies in the adaptation of the mechanical hybrid system called Zero inertia [21], [22] and [23]. The basic idea is in implementation of planetary powersplit unit with linked small inertia. The design applied for automated gearboxes is patented under the name "Impulse Shift Transmission (IST)". IST is based on an automated manual transmission (AMT) with powersplit planetary gear set configured between the engine (ring gear) and the output shaft (spider). A small flywheel is connected to the sun of the planetary gear set. The flywheel prevents torque interruptions in up- or down-shifts, and enables higher overdrive gearing (for improved fuel economy) without penalizing downshift behaviour. The scheme is depicted in Figure 11 and AMT transmission equipped with powershift IST module in Figure 12.

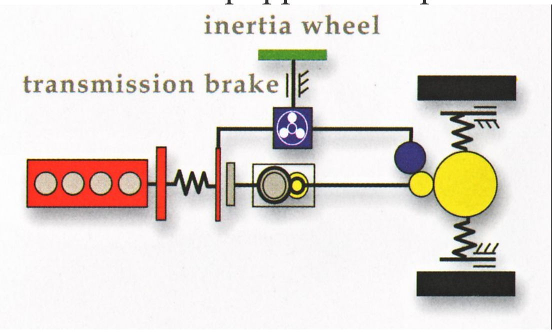


Figure 11: [24] ▲Functional scheme of Impulse Shift Transmission of DTI.

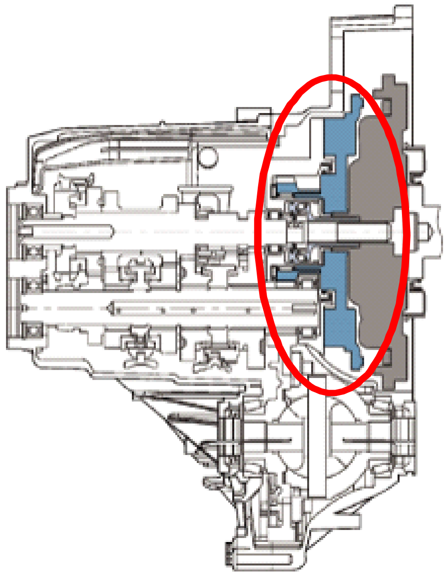


Figure 12: Cross-section of an AMT with the IST; ► IST module is marked in ellipse.

4.2.2 Hybrid configuration based systems

Several systems based on hybrid stepped transmissions are described in [25]. In the article are presented several architectures of synchromesh gearbox dedicated for hybrid drivetrain. The electromotor is not located behind the internal combustion engine (as usual in soft hybrids), but propels one of the gearbox countershafts. The electromotor can serve during the drive as power help to the internal combustion engine. During the gearshift it covers the power gap of torque interruption by synchromesh shift.

4.2.3 Possibilities of exploitation of external synchronisation

In chapter 4.1 we explained that we see one of the possible ways of automatised gearboxes in replacing the synchromesh mechanism with pure shift mechanism in combination with external synchronisation.

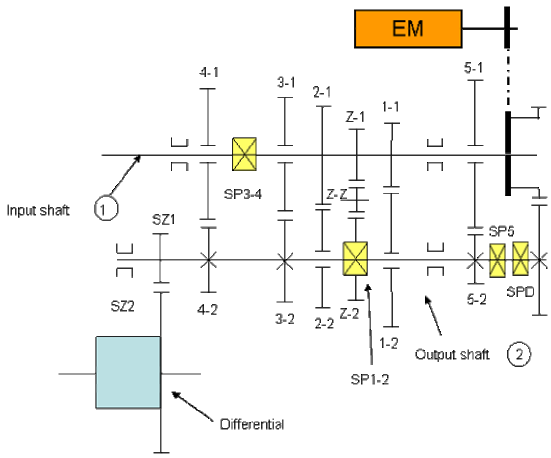


Figure 13: External synchronisation with possibility of electro drive for small vehicle speeds [26].

If a sufficiently powerful electromotor will be adapted for external synchronisation, the electromotor can be used to power the vehicle during low power demands. Thus, the vehicle can be operated on electric power only. The counter shaft can be equipped with shift clutch SPD (see Figure 13). When the shift fork engages the electromotor drive via the shift clutch SPD the drive-away clutch will be automatically decoupled, and when enough battery energy is available, the internal combustion engine can be switched off.

Another idea is to actuate external synchronization via a differential which will split the energy into two ways (see Figure 14):

- Gear synchronization.
- Vehicle drive.

We estimate that the mentioned electromotor requires 2 kW power, and that the differential splits the torque in ratio 35 % for vehicle drive and 65 % for synchronization. We chose this ratio because we consider very quick gear shift, with only small "help" to keep vehicle speed more important than longer synchronization with power which can only partially help the vehicle to keep its speed anyway. We know that the power flowing to the wheels will be too low to keep the vehicle speed constant. Therefore we introduce the term "partial interruption of torque flow".

The differential is a double satellite type. The sun gear has double gearing; one mesh with differential satellite, and the other mesh with the gear wheel rigidly mounted on the output shaft. Double satellites ensure the same direction of rotation for both outputs. The ring gear has inner gearing which meshes with differential satellite and outer gearing which is driving gear from the electromotor. The spider is rigidly connected to the input shaft, and drives the primary part of gearbox ensuring the synchronization.

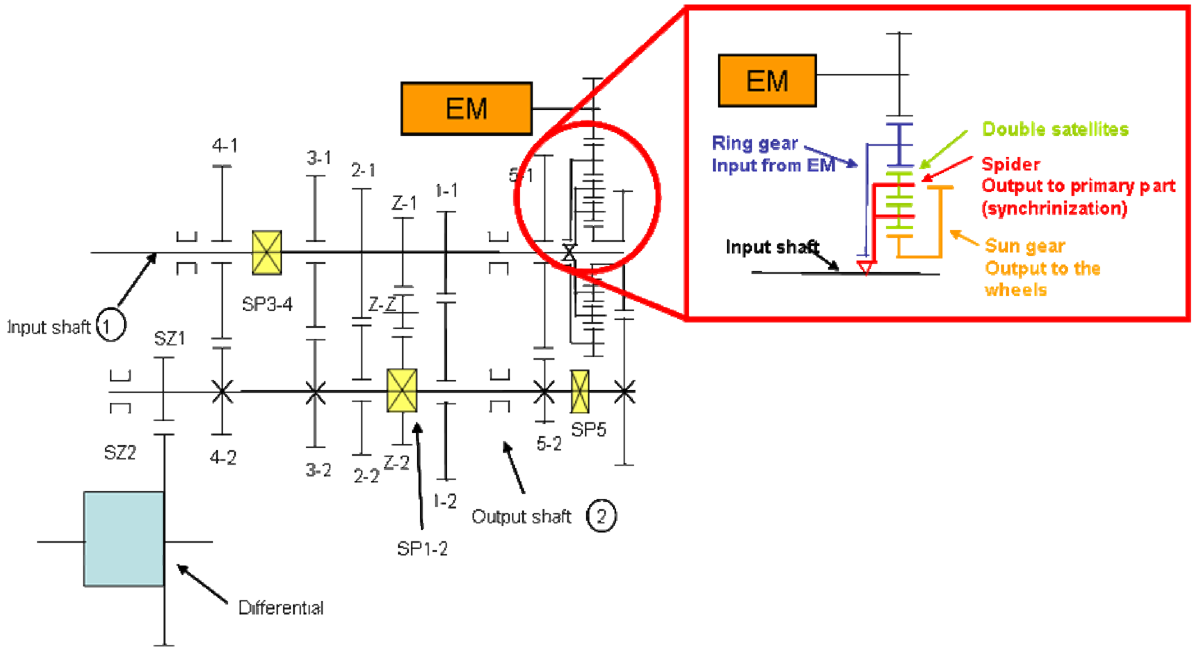


Figure 14: External synchronization with partial continuation of vehicle drive with low power from synchronizing electromotor.

5. Conclusion

The automatised gearboxes offer an interesting option for combination of the most convenient behaviours of synchromesh and powershift transmissions. Their low shift comfort limits the usage to only two market segments, where the price and efficiency plays more important role than the comfort: lower and lower-mid class of passenger cars and trucks.

In the text was presented the past and present of automatised gearbox. Concerning future developments were outlined several possible ways how to improve the behaviours of these transmissions, so that they can be acceptable in the whole range of motor vehicles, and thanks to their advantages help to further increase the efficiency of vehicle drivetrains. The possible improvements are seen especially in the following domains:

- Shortening of the shift time (by introduction of new internal shift mechanism intended for automation).
- Filling the power gap which arises during the interruption of torque flow.
- Improvement of shift algorithm, which will better correspond to the driver's intention and feelings.

In this text are discussed the first two points. All three domains form the main direction of our research work. Our primary focus will be firstly on shortening the shift time. Thanks to a recently finished test stand we can perform both theoretical and laboratory tests.

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Studies

1989 – 1994	Engineering studies on Czech Technical University (CTU), Faculty of Mechanical Engineering, Department of Automotive and Aerospace Engineering (AAE).
1994 – 1998	PhD studies on CTU, department of AAE. Subject: Automation of passenger car gear-boxes.
1995 – 1998	Scholarship of French government for combined thesis (Doctorat en co-tutelle) on CTU and on University in Orléans (Ecole Supérieure d´Energie et des Matériaux). Collaboration for realisation of thesis with research Center of Group PSA (Paris, France).

Employment

1994 – 2001	Senior editor of journal OFF Road
1999 –	Assistant professor, Department AAE, CTU in Prague Since 2003 start of publishing and senior editor of MECCA – Journal of Middle European Construction and Design of CArs.
2000 –	Research worker, Josef Božek Research Center of Engine and Automotive Engineering
2005 –	Coordinator of European Master of Automotive Engineering (double degree Master studies with partner Universities in The Netherlands and France)

Research fellowship

2001	7 months stay on Technical University in Delft (The Netherlands). Research project: Delft Active Suspension – II. generation

Awarded research grants

2000 – 2001	Grant from Czech grant agency, Subject: Active and semi-active damping of torsion oscillations for car powertrains.
2003 – 2005	Grant from Czech grant agency, Subject: Automation of the passenger car gear-boxes with external synchronization.

Publications

Author or coauthor of more than 50 papers at conferences, journal articles and research reports.

Languages

Mother language: Czech. Knowledge of foreign languages sorted by level of competence in descending order: French, English, German, Dutch, Russian.