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Foreword

Innovations are shaping our future. Experts predict that there will be more changes in the fields of transmission, electronics and safety of vehicles over the next 15 years than there have been throughout the past 50 years. This drive for innovation is continually providing manufacturers and suppliers with new challenges and is set to significantly alter our world of mobility.

LuK is embracing these challenges. With a wealth of vision and engineering performance, our engineers are once again proving their innovative power.

This volume comprises papers from the 7th LuK Symposium and illustrates our view of technical developments.

We look forward to some interesting discussions with you.

Bühl, in April 2002

Helmut Beier

President
of the LuK Group

Content

Electro-Mechanical Actuators

Shifting Transmissions Into Gear

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Introduction

With the introduction of Electronic Clutch Management (ECM) as in the Mercedes A-Class, the demand for the automation of the gearbox itself soon followed. The LuK ASG is the first Automated Shift Gearbox with electro-mechanical gear shifting as an add-on design. The system was originally installed in the Opel Corsa Easytronic® [1], with Opel and Bosch involved in the development.

The actuator modules were fitted to existing gearboxes on the first generation. The interfaces to the release system, including the hydraulic lines, were carried over. This concept supports the demand for modularity, enabling the function of existing components to be extended simply.

Figure 1 shows both actuator modules. The clutch actuator is integrated with the control unit. A hydraulic concentric slave cylinder is used. Engagement of gears is achieved using an actuator with two motors. To change gear, select is performed by translation movement and shifting by rotation.

Greater integration is possible when a new gearbox is developed, since automation can be taken into consideration from the start.

Clutch Actuator

Requirements and Operating Principles

The basic functional requirements for the clutch actuator are derived from the manual transmission. These are the take up from rest, gear shifting and stopping processes.

Take up from rest, particularly when manoeuvring, requires precise clutch control. This must be done differently depending on the respective operating conditions; for example, a hill start differs considerably from starting up on a level road.

During gear shifts the clutch must be disengaged and re-engaged. This must be a highly precise and accurate process to ensure comfortable gear shifting. However, it must also have the appropriate dynamics to ensure gear shifting is executed swiftly.

Stopping under normal conditions typically requires less precision. However, in the event of emergency braking or a rapid stop, there are extreme dynamic demands on the clutch actuator that must be fulfilled.

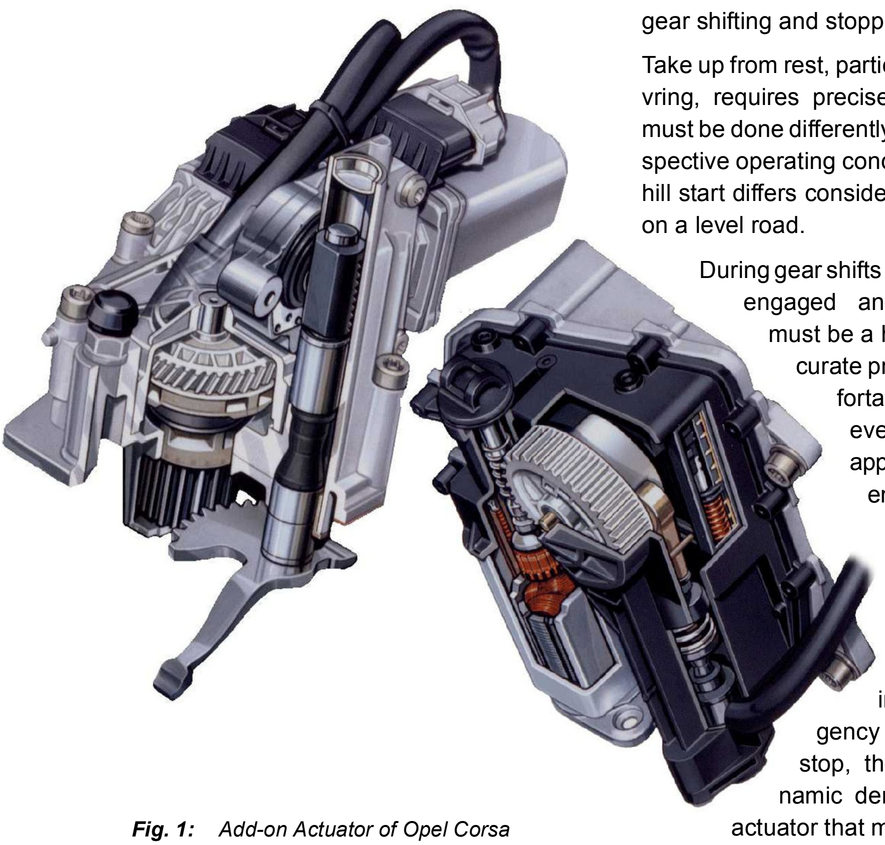

Fig. 1: Add-on Actuator of Opel Corsa

The demands on accuracy, dynamics and service life are also influenced by other additional functions. These additional functions particularly increase the comfort of the XSG family members, and only become possible due to the automation of the clutch.

- Adaptation routines accurately monitor the operating condition of the drive train.
- Creeping of the vehicle for easy and comfortable manoeuvring
- Slip control for vibration damping of vehicles without DMFW [4]

The clutch actuator currently successfully used, shown in figure 1, is designed for a maximum engine torque of 300 Nm depending on clutch size. However, the future design of the XSG family will support even larger engines.

The limiting element in this is the worm gear. It has therefore been replaced in the next generation by a new drive element. The gearbox wear rates and strength of the gear set must be suitable for higher clutch release forces – especially for the Parallel Shift Gearbox (PSG) [2], [3].

The acknowledged safety design of the XSG family [3] demands self-locking features. Examples of two design solutions are presented below:

- a lead screw and nut having surface contact,
- the spring band principle, which was presented in [5] in connection with the electrical concentric actuator (ECA).

Both solutions work without a hydraulic line. The forces can be transferred to the release bearing via a lever or concentrically to the input shaft with ramps. This results in the following combinations:

	lead screw	spring band
concentric	RCA	ECA
lever	external release system	

Examples of RCA and a variant of an external release system are presented below.

Automation with Mechanical Concentric Release System

The mechanical concentric release system (MCR) replaces the hydraulic release system. Ramps or ball ramps convert a rotational movement around the input shaft of the gearbox into the axial release movement. Figure 2 shows a diagram of such a release system, as it was presented in [6].

The combination of the MCR with a lead screw drive and a cable, results in a clutch actuator for the XSG family, the Robotized Clutch Actuator (RCA), shown in figure 3. The rotary motion of the electric motor is transferred directly to a lead screw. A nut, which is rotationally fixed and connected to a cable, runs on this lead screw pulling on the MCR to produce the release motion.

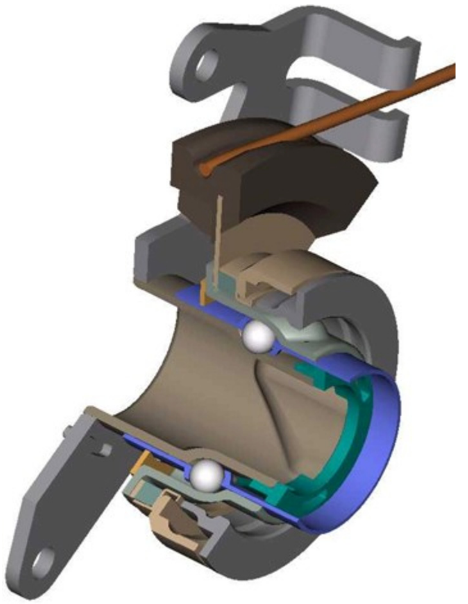

Fig. 2: *Mechanical Concentric Release System*

With a brushless motor [2] such a system can also be installed in the compact packaging space of the clutch bell housing. Figure 4 illustrates an example of this.

The RCA increases the maximum release force capacity and improves the dynamics considerably compared to the clutch actuator shown in figure 1. Increased potential is achieved by using a compensation spring.

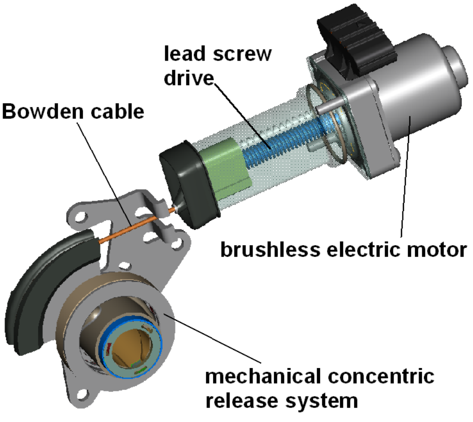

Fig. 3: Clutch Actuator with Lead Screw Drive

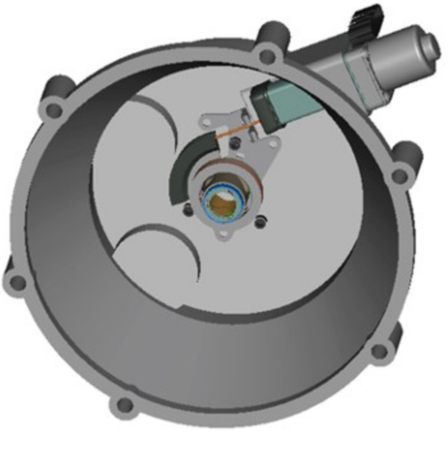

Fig. 4: Example of an RCA Installation

Clutch Actuation with Levers

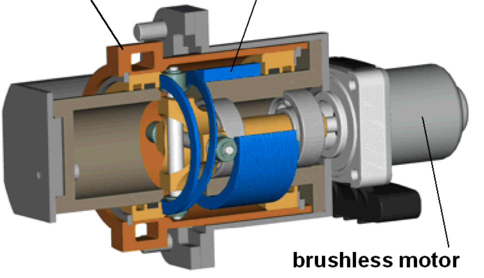

Fig. 5: External Spring Band Release System

Clutch actuation with a lever has been around considerably longer than the hydraulic concentric slave cylinder [7]. An actuator with a spring band gear set or a lead screw takes on the function of the clutch master cylinder for the XSG family.

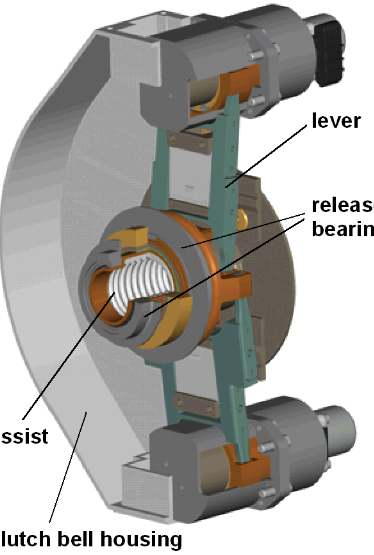

Fig. 6: PSG Actuation with Levers

Figure 5 shows an illustration of an external spring band release system. A spring band is wound and unwound by the rotation of a brushless motor. This results in axial movement analogous to the electrical concentric actuator (ECA) shown in [5].

A lever mechanism transfers this movement directly to the release system. Figure 6 shows a layout for a PSG system [2], [3] where two clutches are actuated by two levers. The layout of both levers opposite one another reduces the required axial space.

Torque of up to approximately 900 Nm can be actuated by optimising the entire release system from the brushless motor to the SAC.

Gear Actuator

The starting point for the gear actuator is the production solution shown in figure 1. The current development objectives are reduction of packaging space, modularity, and integration.

Shift Drum Concepts for Gear Actuation

One of the concepts being investigated is the use of shift drums for integration of the actuator into the gearbox. A single electric motor is used to drive this type of actuator. The effort is reduced compared to that of the shift-select actuator shown in figure 1. However, such solutions have two critical disadvantages:

- The great effort of gearbox redesign is only justified by total automation (e.g. as in the Smart car).
- If a shift drum is used, arbitrary gear selection is not available. Gear changes are inevitably sequential.

The latter can be avoided to a large extent by using two shift drums. For example, figure 7 shows a solution with an external drive to the shift drums. The ratio is achieved with two spur gear stages.

Integrating the motors inside the shift drums reduces the packaging space required (see figure 8). The smaller design of the brushless motors [2] supports this. The ratio is achieved with integrated planetary steps.

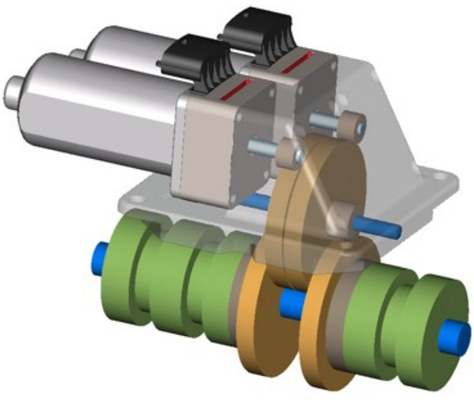

Fig. 7: *Double Shift Drum with External Drive*

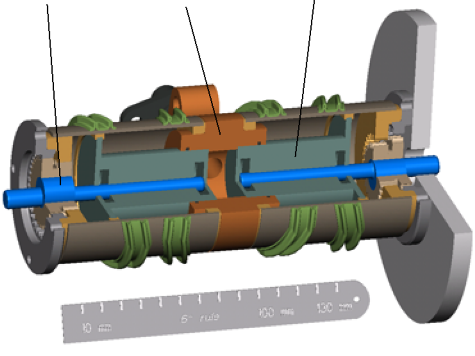

Fig. 8: *Double Shift Drum with Internal Drive*

The entire shift drum unit with the integrated motors can be tested prior to installation. It is fitted directly into the gearbox between the casing walls.

However, two motors are necessary with this twin shift drum just as with the normal shift-select actuator, but in the twin shift drum both motors must be sized to apply the shift forces. The use of an expensive twin shift drum arrangement would therefore appear to make more sense on a PSG than on the ASG. The two gear groups of the PSG gearbox can be actuated independently of each other with either of the two shift drums.

This is also possible with the newly developed concept presented below, but with even more advantages.

Active Interlock

The demand for modularity is not sufficiently satisfied by existing concepts. The vision is to actuate both a manual transmission and the members of the XSG family with one and the same concept.

Analysis and Breakdown of Shift Movements

A totally new solution emerged when the shift process of a known gearbox mechanism was broken down and analysed.

On a manual transmission or an ASG with a shift-select actuator three actions run in a fixed sequence.

- Disengage the current gear
- Select
- Engage the new gear

In the sequence **disengage – select – engage** it is mandatory that disengagement occurs prior to engagement. On the other hand, the select movement could occur prior to the disengagement movement.

To make this happen a ‘trick’ is used, through an additional disengagement cam on the central selector shaft and a modified slot in the shift rail. They take on the disengagement function with the shift finger still responsible for gear engagement. Details of this are described in paragraph *Geometry and Modularity*.

The disengagement cams work in all gates where the shift finger is not active. The fixed relationship between shift finger and disengagement cams simultaneously represents an active gear lock. For this reason, this design approach is called **Active Interlock**.

Basic Principle

The advantage with Active Interlock is that the shift finger can be moved back to the centre position when a gear is engaged, without disengaging that gear. A select movement is therefore possible before the gear is disengaged.

Disengagement cams act in all gates where the shift finger is not positioned. The cams disengage the old gear immediately prior to the new gear being engaged by the shift finger in the same motion.

Figure 9 shows a gear shift sequence where the old and new gears are on different rails. In the first picture 2nd gear has been engaged by the shift finger. The finger is moved back to the central position, without the 1st/2nd rail being moved. Then the 3rd/4th rail is selected. 2nd gear remains engaged as previously.

Now the selector shaft is rotated to make the gear shift. Initially the cam disengages 2nd gear. When disengagement is complete the rotation continues and the finger engages 3rd gear.

A 4th → 2nd downshift follows a similar sequence, but the shift rail direction is the same for both gears in this case.

Figure 10 shows the sequence. The 4th gear is engaged by the shift finger. The central selector shaft rotates back into its centre position. Then a select movement into the 1st/2nd gate can occur. This select action and the opening of the clutch can happen simultaneously. Next the selector shaft is rotated, which disengages 4th and then engages 2nd, in one rapid movement.

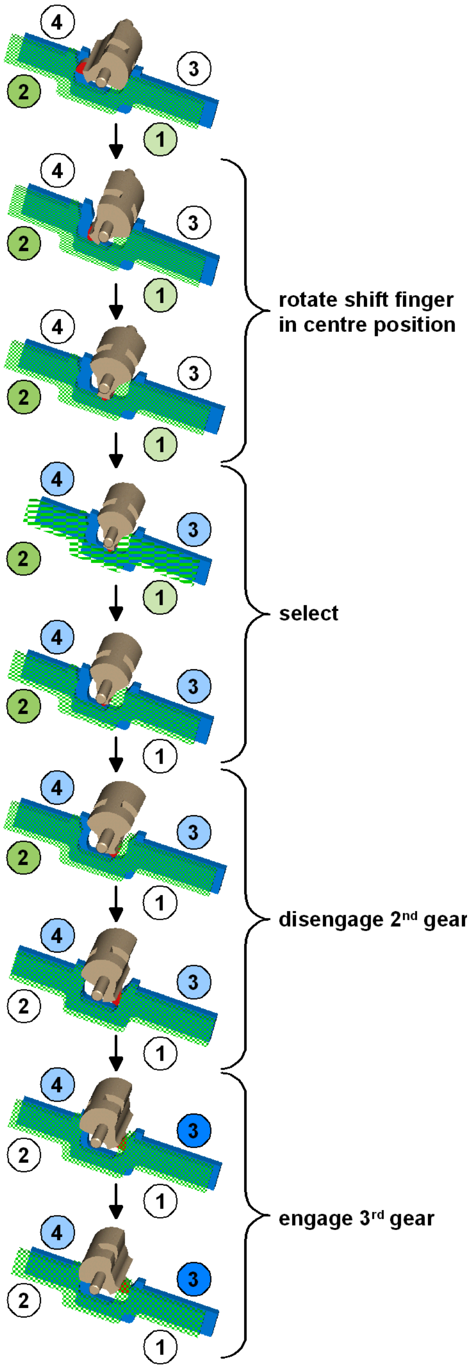

Fig. 9: 2nd → 3rd Gear Shift with Active Interlock

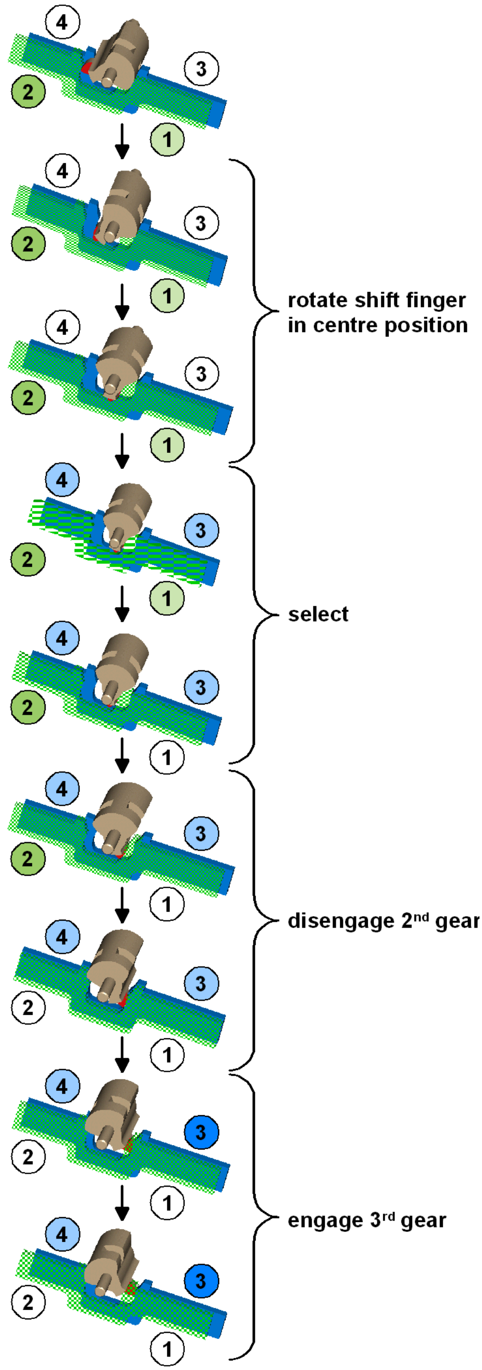

Fig. 10: 4th → 2nd Gear Shift with Active Interlock

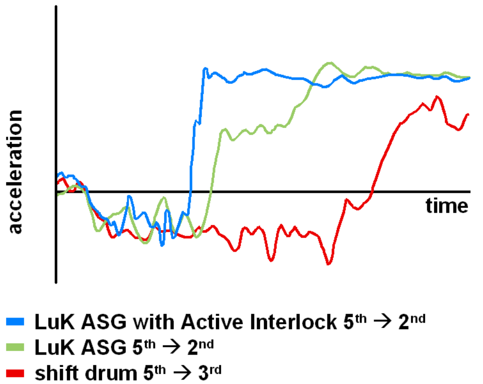

Fig. 11: *Comparison of Shift Times*

A sequence with a double shift gate change is the same in principle (e.g. 5th → 2nd). These double shift gate changes are more frequent on the auto shift gearboxes of the XSG family, than on a manual transmission, due to shift strategies being optimised for fuel consumption. As high a gear as possible is used during part load driving, then these kinds of downshifts are demanded when the driver presses the accelerator pedal. Systems with a shift drum have distinct disadvantages here.

Figure 11 shows examples of tractive force characteristics of downshifts with the various systems.

It compares the torque pattern of a 5th → 2nd shift with an ASG with conventional shift-select actuator. On the system with a single shift drum the traction interruption is significantly longer. In this case it relates to a 5th → 3rd shift.

With the Active Interlock the gear shift is noticeably shorter compared to the conventional system due to the elimination of select time. The reduction of traction interruption time is achieved without increasing the synchronisation forces.

Active Interlock for PSG Application

Active Interlock is the simplest solution for operating a PSG. Due to the active locking mechanism and the possibility of selecting with a gear engaged, then **both** gearbox units of a PSG can be operated by **one** Active Interlock actuator. Disengagement cams and shift fingers are arranged together, so that they act for one gearbox unit.

The central selector shaft shown in figure 12 has two disengagement cams and a shift finger in the middle. The distance between the cams and finger matches the distance between the shift rails. The shift rails shown in the same colour are from the same group. The odd gears are arranged in one group, the even gears in another. Whenever the shift finger is aligned to a rail, a disengagement cam is aligned to the other shift rail of that group.

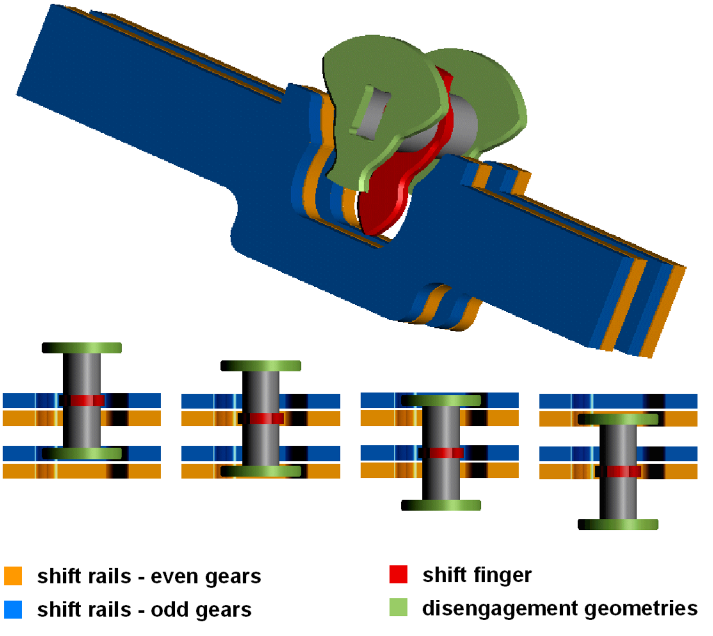

Fig. 12: *Active Interlock for PSG*

This ensures that only **one** gear in a group can be engaged. However, a gear from each group (an odd and an even gear) can be engaged simultaneously. If a gear from a group is engaged or disengaged, everything remains unchanged in the other group.

The layout in figure 12 shows the simplest arrangement. If there are larger distances between the shift rails, a second shift finger is used (as in all variants in figure 17).

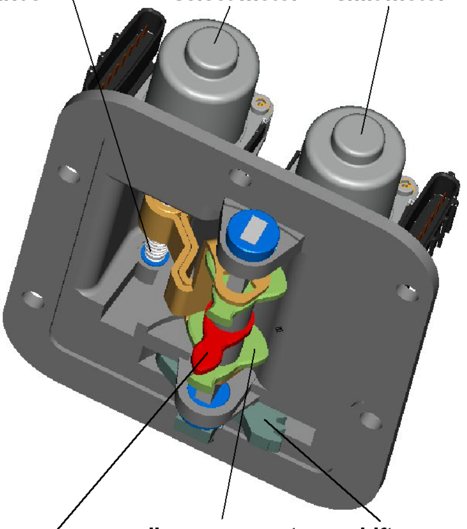

Fig. 13: *Active Interlock for Inline-Gearbox with Parking Lock Actuation*

Figure 13 shows an Active Interlock actuator for application on vehicles with rear-wheel drive. The module is flange-mounted at the side. In this particular application the central selector shaft possesses a shift finger and two disengagement cams. These are positioned so that during select they can slide along the rectangular selector shaft. This makes the actuator very compact.

A brushless motor rotates the selector shaft via a double planetary gear step and a tooth segment. A second motor drives a lead screw, which slides the shift finger and disengagement cams up and down the selector shaft.

It was shown with Active Interlock that two gearbox units could be shifted independently from one another on a PSG. This raises the question whether further operation tasks could be conducted with the actuator. It is actually conceivable that the parking lock often required for a PSG system could also be actuated with the Active Interlock gear actuator.

To do this, a further shift rail is required between the two upper and two lower rails shown in figure 12. This actuates a parking lock, an example of which is found in [3].

Geometry and Modularity

Active Interlock provides a system which can be used in both ASG and PSG systems. The difference is merely one of size, quantity, and layout of shift fingers or disengagement cams. The new shift slots are the same for ASG and PSG.

The basic shapes are shown in figure 14. The red shift finger is responsible for the engagement of gears. The green geometry takes over disengagement of gears. Depending on the direction of actuation, different sections act to move the shift rails into the Neutral position. The circular surfaces ultimately form the locking cylinder – as known for solutions in manual transmissions.

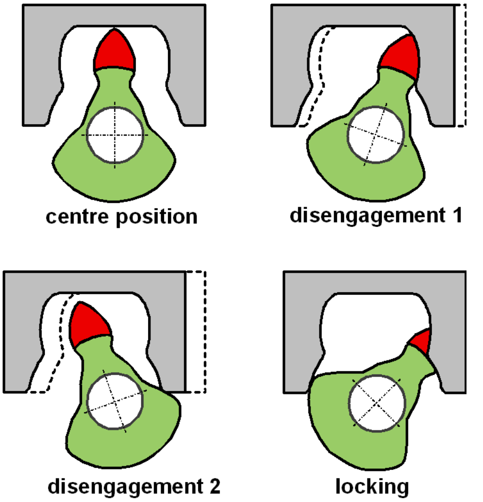

Fig. 14: *Active Interlock Geometry*

Figure 15 shows a detailed example of an Active Interlock gear actuator.

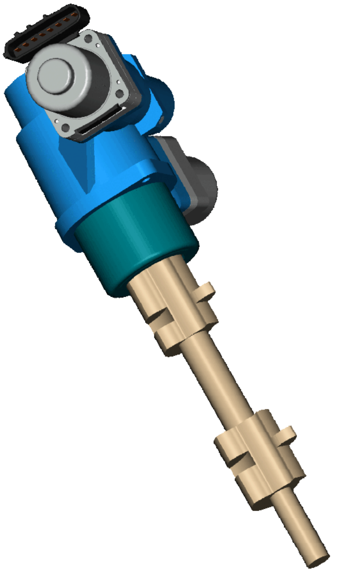

Fig. 15: *Detailed Example of a Transverse Active Interlock*

The interfaces for assembly are identical on the manual and automated gearbox. The thrust bearing for the central selector shafts is also used by the gear actuator if necessary. The actuators are very compact due to the brushless motors shown in [2]. As a rule, the gear actuator has no greater packaging space requirement than the manual transmission module (see also figure 17).

By using the incremental travel measurement for the electronic commutation of the motors and determining the position of the gear actuator, additional sensors or redesign of the gearbox are unnecessary.

In the case of a manually operated gearbox, the new shift slot geometry from figure 14 is combined with a wide shift finger, as illustrated in figure 16.

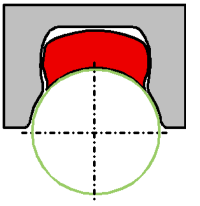

Fig. 16: *Shift Finger and Shift Slot for Manual Transmission*

Hence the manual transmission variant is a part of the modular system. The individual variants are illustrated alongside each other in figure 17:

- Left: Manual Transmission Version,
- Centre: ASG Version,
- Right: PSG Design.

Both variants shown to the left in figure 17 can be used in the same transmission. By using the same interfaces for the manual transmission and members of the XSG family, the concepts offer the greatest flexibility for planning manufacturing equipment.

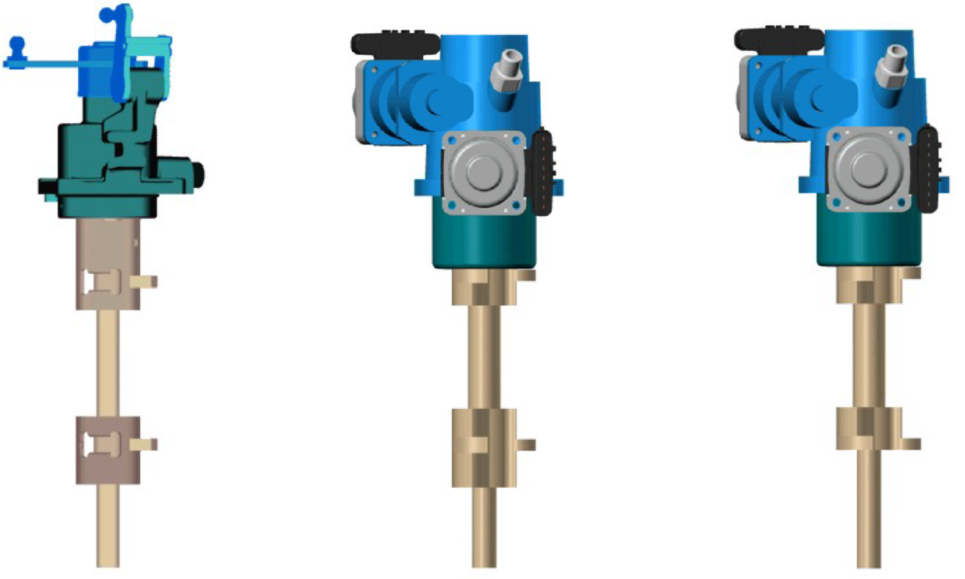

***Fig. 17:** Actuation Modules for Manual Transmission, ASG and PSG*

Summary

With RCA, the external lever release system, and the ECA presented in [5], customised clutch actuation is available for various gearboxes. These actuators can operate clutches with higher torques with low packaging space requirements and high dynamics. Just as with the gear actuator, an essential feature is the use of brushless motors [2].

Active Interlock is a compact and universal gearbox actuation for the XSG family. The initial ASG prototype impressively demonstrates the advantages of the operating principle. This is reflected in the positive feedback from numerous test drives. Active Interlock is currently being implemented in its first production projects.

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