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Clutch Operation

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Introduction

The articles on clutch operation from the 2002 [1] and 2006 [2] Symposia dealt with the trend towards more torque, higher performance density and thus also mastering higher release loads. As manufacturer of complete clutch systems, LuK has focused on carrying out the design of such systems in a professional manner, based on simulations and vehicle tunings, and on offering the right products to meet customer requirements, such as self-adjusting clutches and hydraulic actuation systems. In addition, we have integrated functions which help make the pedal force characteristic more ergonomic and reduce vibrations and noise. While the development of these technologies continues, it has since fallen under the influence of additional trends.

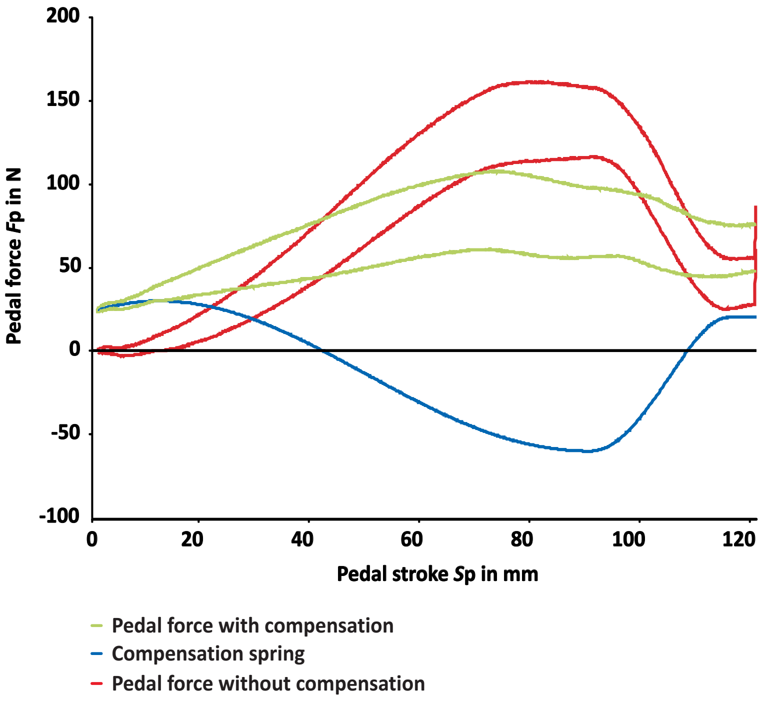


Figure 1 Pedal force curve with and without correction (example)

The changes in the world's economy in 2008 and 2009 and the recognition that we must do a better job at conserving our fossil fuels have led to a rising demand for small cars and lower-consumption technologies for combustion engine drives in all classes of vehicles. Clutch systems for small vehicles are designed to be lighter and less costly today with no major compromise as far as comfort. On the other hand, consumption-optimized drives, such as stop-start systems, hybrids and double clutch transmissions raise the level of technical challenge and complexity.

LuK can offer innovative solutions in both areas, classic manual operation and modern low-consumption drives.

Conventional clutch operation:

- Power density
- Reliability and service life
- Small vehicles

Consumption-optimized drives:

- Stop-start systems
- Hybrid drives
- Double-clutch transmissions

New Developments for Conventional Clutches

Pedal Ergonomics

In the Symposium 2006 [2], energy storage by means of leaf spring and cam plate on the pedal was presented as an option for targeted improvement of the pedal characteristic. As an advantage of this solution, it was described that in tight space, a higher load compensation is achieved than with an over-center spring, and that the course of the curve can be changed almost at will due to the free selection of the cam plate geometry. Thus, for example, a curve with two zero cross-overs of the force is possible, by which means the minimum pedal force can be raised when the pedal is disengaged (Figure 1).

The principle has since been tested in different vehicles with good results. The original design with one leaf spring and one pulley has now become two pulleys and two springs in the form of V-shaped bent sheets (Figure 2). This avoids lateral forces on the pedal and pedal shaft.

Compensation by means of a leaf spring was first developed for vehicles with high engine torque and a strong need for force correction. Since such applications are less in demand from today's perspective, the obvious thought was to change the design to meet the needs of middle class vehicles and, to do this, to reduce the achievable force level somewhat. At the same time, we had to reduce the space and design the pedal and compensation mechanisms as a single unit. The refinement (Figure 3) uses a compensation mechanism which is arranged radially around the pedal shaft.

Multiple spring components of sheet metal are stacked and the ramps designed as resilient bending bars. It is their job to store the introduced energy and to achieve a targeted correction of the pedal force curve by means of their ramp contour. Three needle rollers are arranged between the ramps and the cylindrical housing sleeve. When the pedal is operated, the three needle rollers roll down the ramps and, with the energy released from the springs, support the pedal release movement. When engaged, energy is again stored in the springs. The principle functions invariably and an assembly-friendly solution integrated in the pedal is about to be developed.

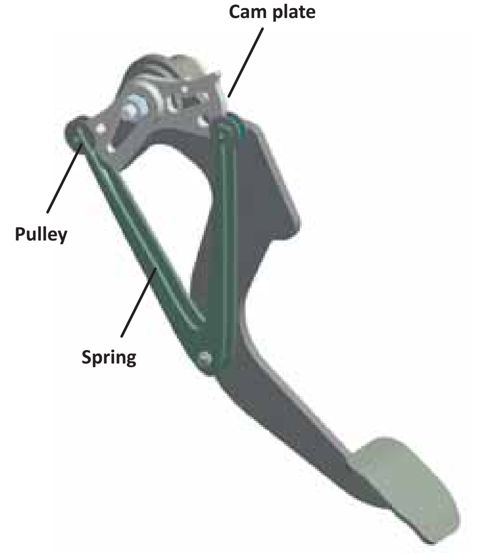


Figure 2 Pedal force compensation by means of springs, pulleys and cam plate

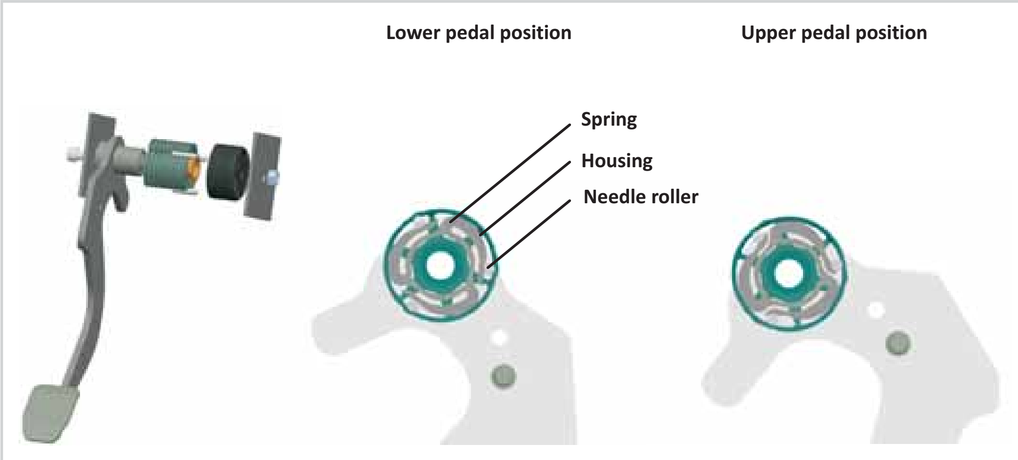


Figure 3 Unit for pedal force compensation arranged around the pedal shaft

Noise/Vibration

Unpleasant pedal vibrations and interior noises are excited by oscillations of the crank shaft and transferred via the release bearing through the hydraulic system all the way to the pedal. At low amplitudes, a simple change in the high pressure line by means of orifices or by adjusting the diameter and length is sufficient to correct the problem satisfactorily. In more difficult cases, damping elements come into play. A distinction is made between what are known as anti-vibration units (AVUs), which close the high pressure line in the manner of an automatic shut-off valve when the pedal is hold stable, and diaphragm units (Figure 4). Both systems are in production, but have specific disadvantages. The anti-vibration unit raises the force hysteresis of the pedal characteristic, while the broadband diaphragm unit raises the volume expansion and thus the release travel losses on the clutch.

In order to avoid the disadvantages of the known solutions, a variety of simulations and tests were run with a wide variety of action principles. A solution related to the damper unit emerged as a possible improvement. It is based on the effect of the Helmholtz resonators, known from acoustics, and is called a compact resonator. Here there is an additional volume, which is connected with the high pressure line by means of a T-shaped connecting piece of a defined length and diameter. In order to keep release travel losses as small as possible, the hydraulic capacity is minimized. The filter frequency and the damping is determined by the geometry of the hydraulic impedance.

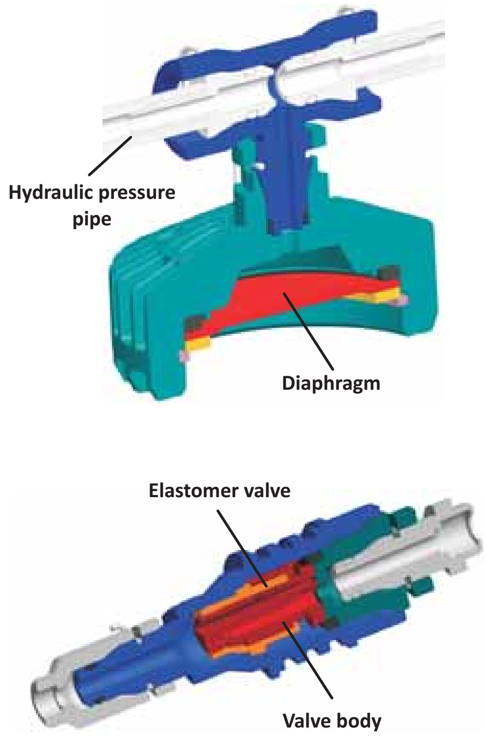


Figure 4 Broadband diaphragm unit (top) and conventional anti-vibration unit (bottom)

The compact resonator takes up only about 1/3 of the volume of a conventional diaphragm unit. It is also significantly smaller and therefore easier to fit into the available space. An adaptation with a rigid plastic high pressure line has succeeded many times in cases that have previously required a steel-rubber line.

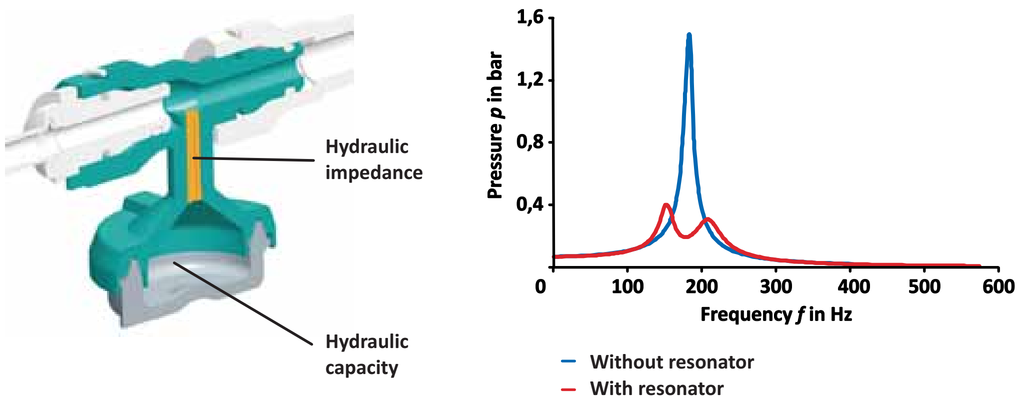


Figure 5 Compact resonator and frequency curve with and without compact resonator

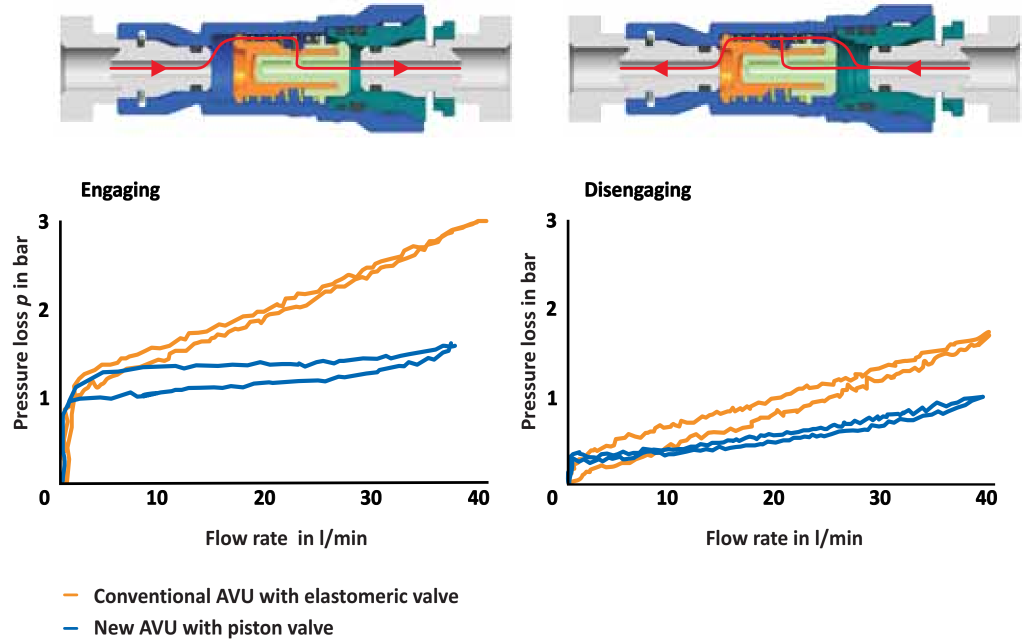


Figure 6 Piston AVU with two pistons, one inside the other, and reduced pressure hysteresis

The previous AVU has likewise been refined (Figure 6) with the goal of reducing the pressure losses while otherwise maintaining the same effectiveness against pedal vibrations. In the improved version, the valves are made up of two pistons, one inside the other, which are pretensioned in their seal seats by means of a spring. As soon as the fluid exceeds the opening pressure, the piston mounted in the direction of flow moves, thus releasing a flow opening. Compared to the known AVU with elastomeric valve, the pressure losses in the piston anti-vibration unit when open are considerably less and remain approximately at the level of the opening pressure. As a result, the piston AVU is practically imperceptible, even when the pedal is pressed quickly, since the pedal force is only slightly increased. A damping chamber between the pistons prevents vibrations and noise.

The best approach physically for avoiding pedal vibrations is the complete decoupling of the axial crankshaft vibration by means of a cover-mounted release unit. Here the hydraulic reaction forces are supported only on the clutch cover and not on the stationary transmission wall; an excitation of the hydraulic column does not occur [1].

In addition to the actual release bearing, the cover-mounted release unit also requires a second bearing for support in the clutch cover. The drag torque of the two bearings is generally supported by the high pressure line if the radial and axial vibration amplitudes of the cover-mounted release unit in the vehicle are not too great. In the pressureless state, the integrated pre-load spring ensures that the release bearings are pre-loaded and that the contact between release bearing and diaphragm spring finger is also always dynamically present. Unpleasant noises and early bearing damage can thus be effectively avoided. For assembling the engine and transmission, the high pressure line must be directed toward the through-hole in the bell housing. Restrictions due to limited axial space when changing the clutch in case of repair did not occur in any of the cases tested. With the CMR, the evaluation ratings against pedal shuddering improve so much that any other filter in the high pressure pipe can be completely eliminated. In test vehicles, it has been found that a cover-mounted release unit can also have a positive influence on the tendency to chatter and the excitation of gear rattle.

Based on dynamic simulation calculations of clutch, release system and pedal, the necessity

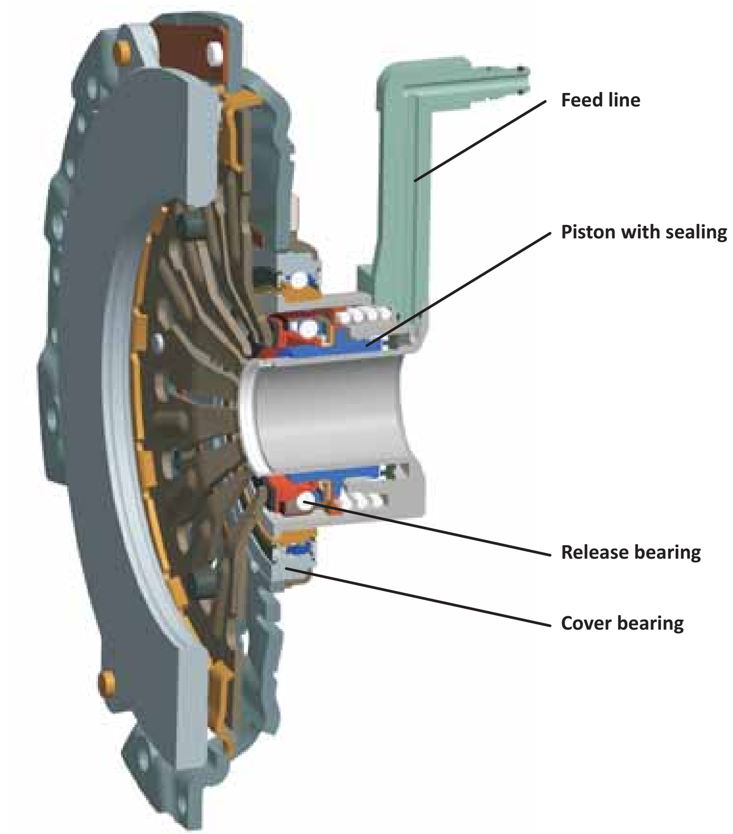


Figure 7 Cover-mounted release unit

of a filter, the design of the filter and the installation site in the vehicle can be predicted very reliably. LuK recommends, therefore, that such calculation takes place at an early stage of a development project to avoid frantic, last-minute changes.

Steel-Rubber Hydraulic Pressure Lines

Clutch lines made from steel pipe and rubber hose are used for long lines and in case of high temperature load. On the ends, the lines have quick connectors to the clutch cylinders, which are traditionally made of steel, but are now increasingly designed as mounted plastic plugs. The plugs shown at the top of Figure 8 ensure a particularly high protection against leakage with an O-ring placed immediately between the pipe and the counter-surface (e.g., in the hydraulic cylinder) as a seal. The quick connector also has an axial stop function, which is realized by means of a notch in the pipe and two half-shell pieces that lock together.

The connection between pipe and hose is traditionally made by means of a metal intermediate piece mechanically embossed on the pipe. Precise metal-forming tools now make it possible to form the end of the pipe with multiple axial undercuts so that a fabric-reinforced hose can be directly pressed onto it using a sheet metal sleeve (Figure 8, bottom). This direct connection has one fewer sealing point and is thus more operationally reliable in principle.

LuK has been making clutch lines of this design for about two years. Cutting the coil to size as needed and highly flexible and automated bending technology minimize tool costs and response times in case of changes. Clutch lines in the steel-rubber design will also remain attractive in the future for a number of applications.

Plastic Hydraulic Pressure Lines

Plastic lines are less expensive than those made from steel and rubber. However their application area is restricted technically by the highest local temperature in the line, the volume expansion due to the temperature and the transfer behavior of pressure pulses.

The materials used are temperature-stabilized polyamide 12 (PA 12H) with a cross section of 8 x 2 mm and polyamide 612 (PA 612) with a cross section of 5 x 1 mm and 5.9 x 1.3 mm for longer lines.

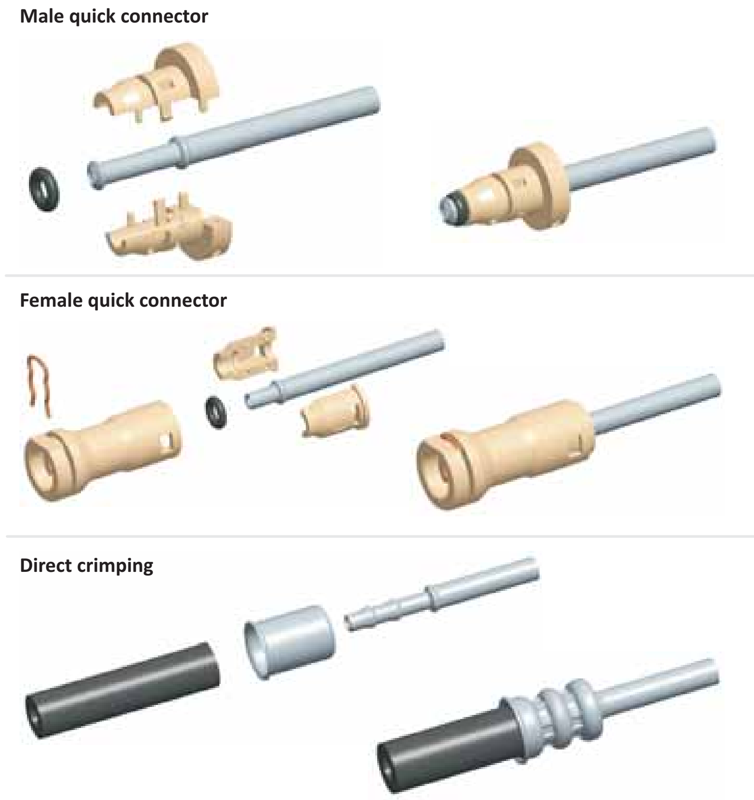
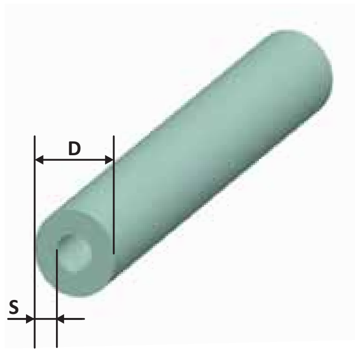


Figure 8 Steel-rubber quick connector for clutch lines

The lines made from PA 12H consist of an extruded and then thermally bent pipe with steel or plastic quick connectors on the ends. They are relatively inflexible and require routing with sufficiently large curves to compensate for movement between the engine and chassis. Their application area is restricted to constant temperatures of no more than 120 °C. The volume expansion of these lines changes significantly above the material's glass-transition temperature of approximately 40 °C, therefore the line length is limited in compact engine spaces and use in right-hand drive vehicles is often not possible.

Newer lines use modified PA 612 for the material and have a geometrically optimized cross section (Figure 9). This material has a higher thermal resistance than PA 12H and is used at temperatures up to 140 °C. The bore diameter of the lines is made just large enough that the hydraulic losses are still acceptable at cold temperatures. Because of the smaller diameter, the strain is less under internal pressure and the wall can be made thinner without having to accept the disadvantages for strength or volume expansion. The surface moment of inertia of the line is smaller so that the lines are generally not thermally pre-bent, but instead are routed relatively freely in the vehicle



	PA12	PA612	PA612
D x S	8 x 2	5.9 x 1.3	5 x 1
Volume expansion at 120 °C and 30 bar in mm³/m	780	405	390
Moment of inertia in mm⁴	189	54	27
Routing	Preforming necessary	Free routing possible	Free routing possible
Burst pressure at 120 °C in bar	80	90	85

Figure 9 Comparison of clutch lines of polymer materials

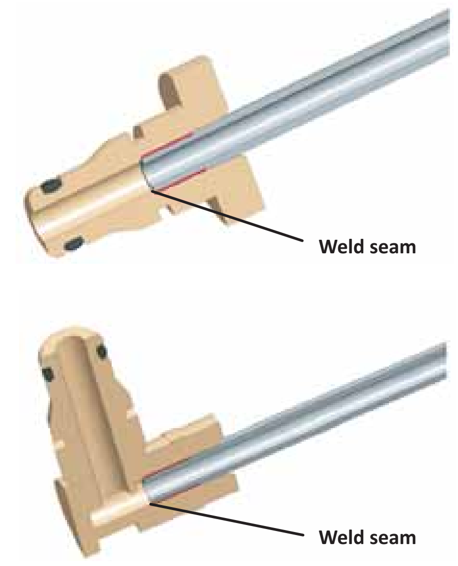


Figure 10 Rotation-welded plastic quick connector

between the master and slave cylinder and affixed with standard clips.

The quick connectors are connected and pressure-sealed with the pipe by rotation welding. This method avoids the restriction of extrusion coating, in which only connectors with a straight hole can be made because of the central core required by the tool. In rotation welding, angular quick connectors can also be used (Figure 10) and the welding machine can be easily integrated in a clean assembly line.

Increase in Concentric Slave Cylinders Performance

A long service life and high reliability of Concentric Slave Cylinders (Figure 11) is essential because of the cost and complexity of repairs in case of failure. The relevant factors are the wear of the central seal and the functionality of the release bearing. Considerable progress has been made in both areas.

The central seal is only one-sided and, due to the system design, wetted only with poorly lubricating brake fluid. With each clutch operation, it moves approximately 8 mm along the dry track and is exposed to environmental influences such as high temperature, dust and microvibrations. The resulting failure mechanisms are wear on the back of the seal and gap extrusion with cracking.

A new concept fundamentally improves the sealing characteristics. The flanks of the seal are protected from wear by reinforcement from a thermoplastic seal carrier. Through the reduced friction on the back of the seal and the smaller gap, the strain in the elastomer material and gap extrusion is also reliably avoided. As before, the carrier is connected axially to the piston with a defined lash, in order to keep micro-movements during pressureless driving away from the seal. This reduces the cumulative wear travel of the seal and increases its service life. The connection prevents impermissible enlargement of the lash between piston and seal during operation with a master cylinder with no resuctioning function. The cylinder faces and the seal itself are lubricated during installation with a high-viscosity silicone oil and PTFE, which does not dissolve in brake fluid and ensures a durable coating of the surfaces. The counter-faces of the cylinders are tribologically optimally designed. This means, especially with steel guide rods, that finishing is mandatory. The new sealing concept enables approximately double the service life in a central release system with an aluminum as well as a plastic housing.

Depending on the application, the seal may also have to be protected against dust penetration. For this, the concentric slave cylinder is provided with a panel to deflect the air flow from the sealing point or a boot.

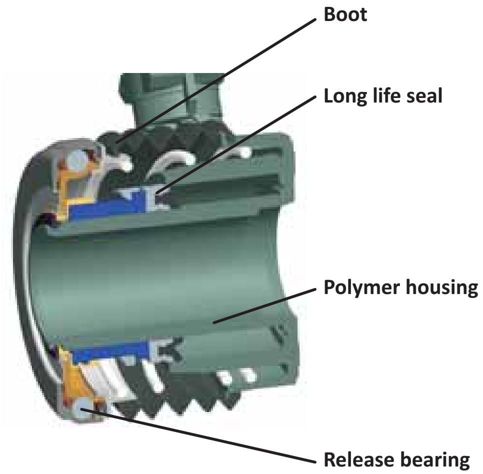


Figure 11 Concentric Slave Cylinder in full plastic design with seal optimized for long service life

The durability life of the release bearing is largely determined by the lubricity of the grease. There is no damage due to rolling fatigue. In order to achieve the desired service life of grease, penetration to the bearing interior by dust, water or brake fluid must be prevented. For applications under central European conditions, this requirement is generally met by means of a well-matched labyrinth seal. In regions with lower quality roads, it is recommended to seal the bearings on both sides with contact seals. This results in a conflict of aims, with adequate seal-tightness set against low friction heat and long service life for grease.

Specialized seals which meet these requirements have been developed. The seal shown in Figure 13 on the left lubricates itself radially with a flexible lip on the outer ring while the right seal next to the radially flexible lip is additionally protected against intensive splash water by a mechanical protective collar. The particular design of the radial seal lip makes its moment of friction in the relevant range independent of the covering of the track. This limits the maximum bearing heat and extends the lifetime of the grease. Release bearings of this design withstand the harshest contamination tests and are suitable for speeds of up to 7000 1/min.

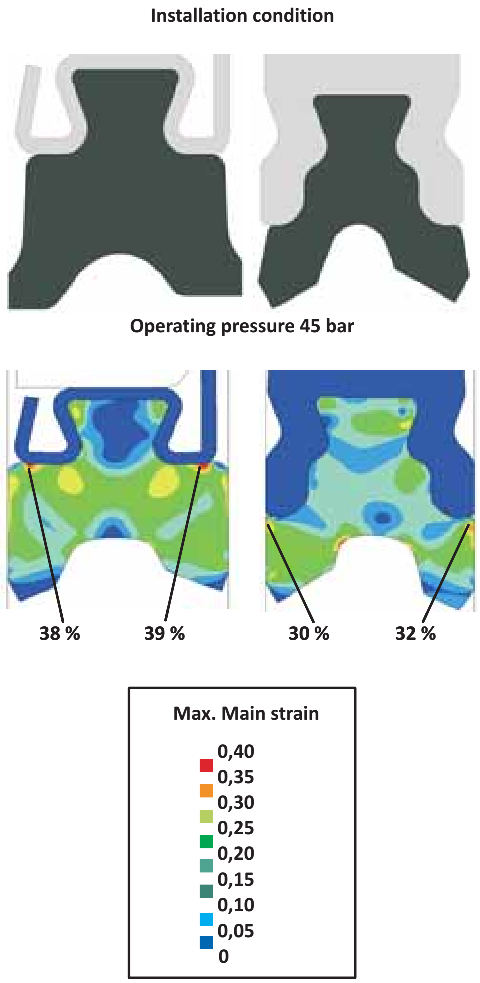


Figure 12 Right: Concentric slave cylinder seal, optimized for long life; Left: Previous design

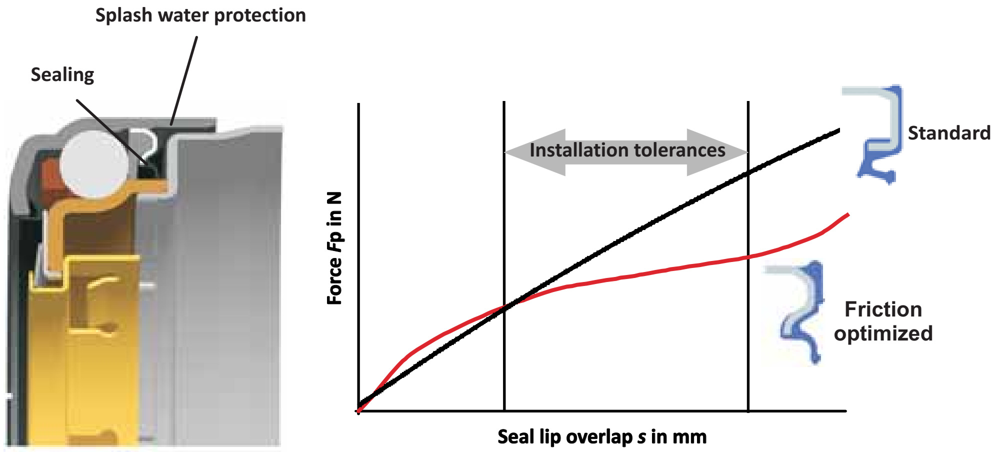


Figure 13 Fully sealed release bearing with friction-optimized seals

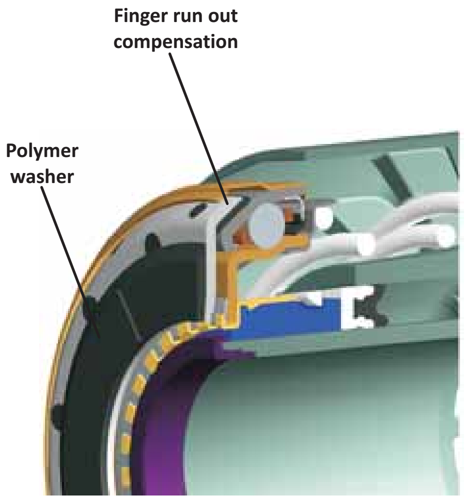


Figure 14 Impact compensation bearing with contact washer for concentric slave cylinders

In a finger runout compensation bearing (Figure 14), a cup ring between the bearing and diaphragm spring finger compensates for crookedness. In this way an angled lift-off of the pressure plate is avoided and the geometrically caused chatter is reduced. It is also helpful to use a contact washer of highly filled polymer material in contact with the diaphragm spring fingers to prevent metallic contact between the diaphragm spring fingers and the bearing ring and keep the friction low. Practical experience has shown that the contact washer also serves to minimize pressure pulsations and pedal vibrations. Crankshaft vibrations are usually spring-cushioned relatively flexibly by the bending of the diaphragm spring fingers. With high friction in contact between diaphragm spring fingers and release bearings, the diaphragm spring is prevented from a compensating motion, and a majority of the vibrations then generate pressure pulsations. If the friction is low, on the other hand, the diaphragm spring fingers can compensate for the crankshaft vibrations.

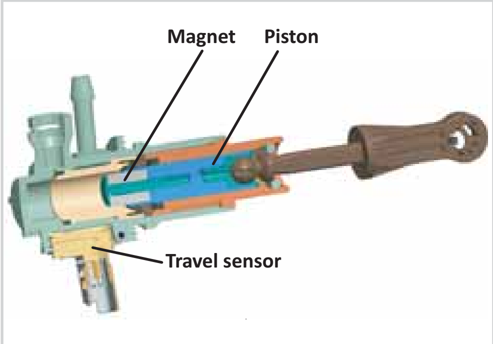


Figure 15 Clutch master cylinder with integrated travel sensor

Innovation for Consumption-Optimized Drives

Stop-start systems

In order to maintain the usual type of operation with stop-start systems, early recognition of the driver's wishes is helpful. Travel sensors in clutch master cylinders fulfill this requirement and can also take on additional functions which were previously reserved for electrical position switches in the pedals. A measuring accuracy of about +/- 3 % and a high dynamic of the measured signal are expected. An "intelligence" is demanded of the sensors, such as to diagnose broken cable or short circuit, which requires the use of a microcontroller or an ASIC. The output signal is either analog or digital as needed. Increased demands for redundancy can be taken into account.

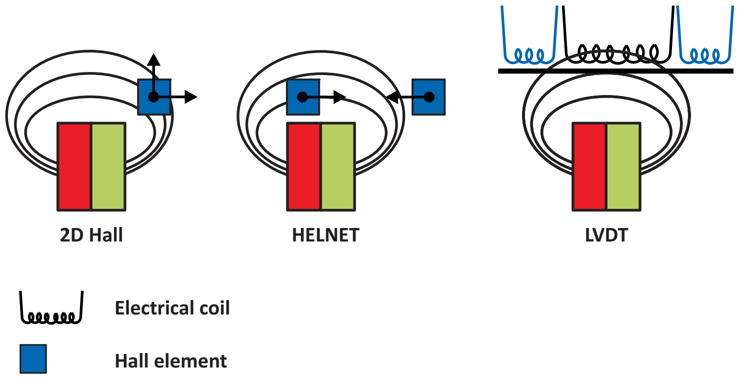


Figure 16 Sensor principles

Realized measuring principles utilize the Hall effect or are designed as linear variable displacement (LVDT) sensors [4], [5]. In all cases, a magnet on the piston of the cylinder is required and the sensor must be attached with a defined spacing about in the middle of the measuring path.

There are two different principles of semiconductor elements used with the Hall sensors. With the highly integrated sensors (2D Hall), two Hall cells are orthogonal to one another and combined into a single assembly with an ASIC [6]. The previously trained position of the magnets is calculated from the resulting field vector. These sensors are compact, but the calibration work in the assembly with the master cylinder is comparatively high. In a different arrangement, two identical Hall cells are positioned at a defined distance from one another in the measuring direction (Conti Helnet). Using the arctan function of the signal of both elements, the position is calculated by means of a programmable ASIC. The advantage of this arrangement is that metallic parts have a less disruptive effect in the surroundings and the calibration goes faster.

With the LVDT sensors, the magnetic field of a primary coil is partially saturated by the magnets and the change is measured by means of two secondary coils attached on the outer ends. The advantage of this principle is that the signal capture is relatively insensitive to variations in the distance of the magnets and to temperature drift. For this reason, LVDT sensors are used not only on master cylinders but also particularly on slave cylinders in the warm environment of the bell housing for automatic shifting systems.

The magnet is a definite weak point in all described measuring principles, because it is relatively expensive and the need for the mechanical axis to be parallel to the magnetic axis is relatively high. In the future, it is conceivable to replace the magnets with a simple metallic target of aluminum if an inductive principle is used for the sensor. The function of this inductive sensor is based on an exciting coil, which generates a magnetic field. Two receiving coils in the middle record the change in the field, which results from the movement of the metallic target along the measuring axis. The electrical signals are

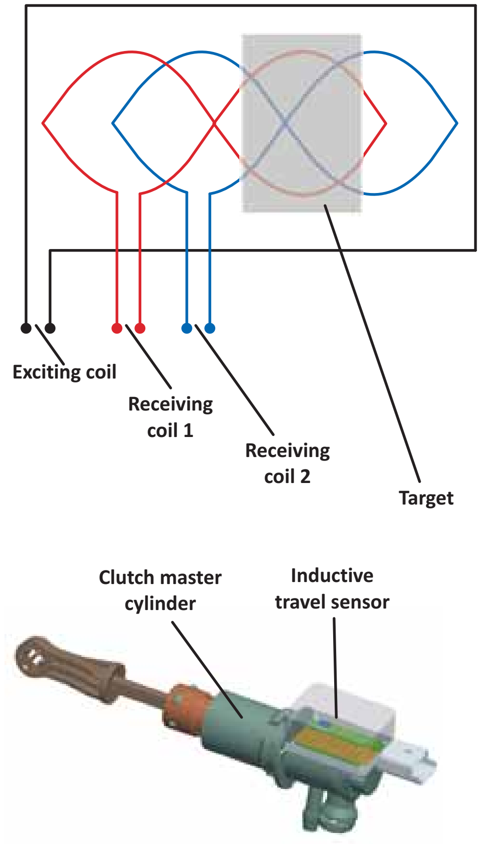


Figure 17 Principle and application of the new inductive sensors (Continental)

processed to the desired output signal in an ASIC specifically developed for this purpose. Because of the low temperature sensitivity, these sensors are as well suited for application in a Concentric Slave Cylinder within the bell housing as for a master cylinder.

Hybrid drives

In hybrid vehicles, a dry separation coupling on the combustion engine may be necessary depending on the design of the drive train. The hydraulic cylinders used are still custom solutions today. They are designed as release units affixed to the clutch cover or the housing. Release units affixed to the clutch cover have the advantage of a very compact construction and relieve the stress of the operating forces from the crankshaft. Figure 18 shows a version currently in production with axially pre-loaded ball bearings. Here, the torque of the rolling bear-

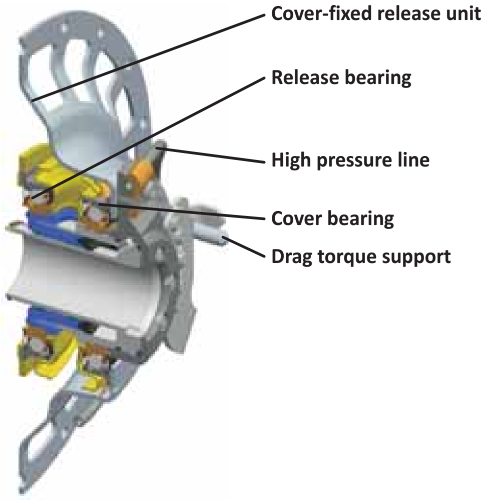


Figure 18 Cover-mounted release unit for a hybrid vehicle

ings is held by a separate torque support because the line routed in a target space cannot handle this.

The release unit affixed to the housing supports itself on the transmission wall and thus is similar in principle to a conventional Concentric Slave Cylinder. The variants shown in Figure 19 consist of a housing and a piston made of aluminum. The cylinder is designed for low pressures up to max. 6 bar and operation with mineral oil. It can therefore be controlled by the hydraulic supply of a conventional automatic transmission. In order to achieve the required operating loads of the clutch, the hydraulic face

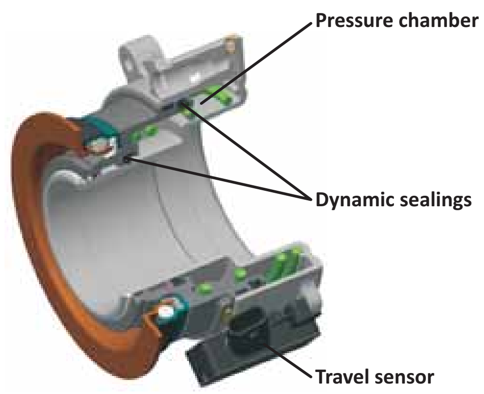


Figure 19 Release unit attached to the bell housing for a hybrid clutch

is made especially large. So that fast operation is nevertheless possible, particular attention was paid to a low flow resistance in the feed line. A travel sensor attached on the side permits a position control.

Engager for double clutch

While the operation units with conventional manual transmissions are often called “release systems,” in double clutches, the term “engagement system” has become established because of the frequently used pressure-closed clutch. Engagement systems require a higher number of roller bearings because of the high, longer-lasting bearing force. In addition, higher stiffness of force transfer, lower friction and precision in bearing guides is required to meet the demand for comfortable shifting. Engagement systems can be divided into mechanical and hydraulic actuation.

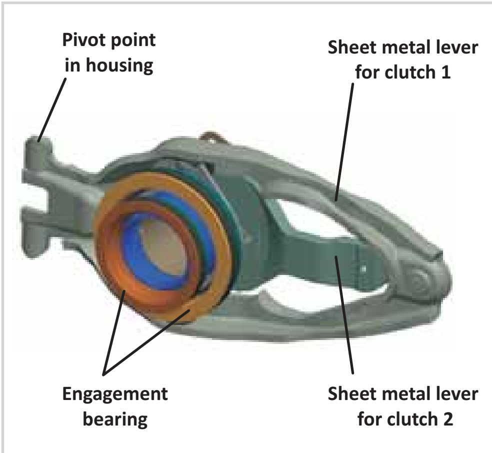


Figure 20 Mechanical engagement system for a double clutch by means of levers

Mechanical action engagement systems are available as assembly units with guide sleeve, two levers and two engagement bearings (Figure 20). The levers extend laterally out of the bell housing and are operated electro-hydraulically. One bearing is taken up by a sliding sleeve into the guide rod with side windows and the other by a slider on the outside diameter. The advantage of the lever mechanism is in the use of already known technology, the disadvantage in the space required by the swivel area of the lever.

The engagement units used in connection with the lever actor are more compact to install [2]. In the version shown (Figure 21), the engagement bearings are both taken up on the outside of the guide rod such that an independent movement in their operating range is possible. The sliding sleeves are slit for this purpose and engage segmentally with one another. A radial misalignment compensation to the operating levers and the use of friction optimized plastics in the guideways reduce the hysteresis and enable a reproducible control of the clutches.

The obvious design for a hydraulic engagement system consists of a central engager with two pistons, one inserted radially inside the other. What appears conceivably simple at first glance turns out to be tricky on closer examination. This solution often cannot be accommodated in the available radial and axial space and the travel sensors sometimes required for the control can in any case be attached to the inner piston.

The requirement can be met more elegantly if we let go the image of a ring piston and allow for a kidney shape instead (Figure 23). Every engagement bearing is operated by a pair of kidney-shaped pistons located opposite one another. The load transfer is similar to the known lever mechanisms with two contact points with the bearings, but avoids radial friction forces. In the channels inserted in the regressive side of the housing provide the hydraulic fluid to the pressure chambers. The unit works with two pressure connections, which are arranged to ensure

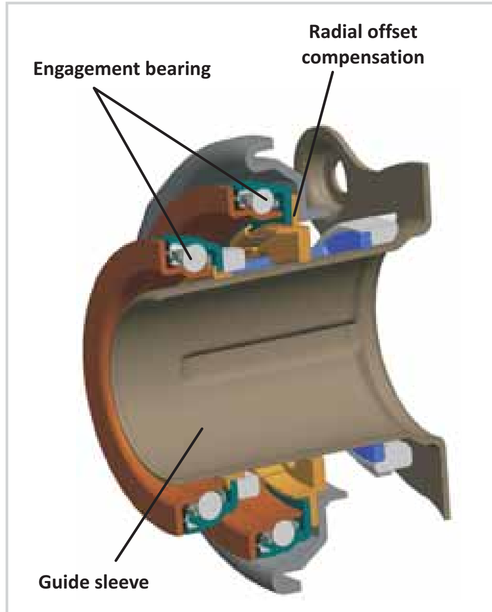


Figure 21 Central engagement system for a double clutch with lever actor

self-ventilation. Travel sensors can be attached to the exterior of the housing using this design principle without problem for any clutch. The piston pairs need not necessarily be the same size. The housing can therefore be radially recessed and thus also fit into a radially narrow space with short intermediate shaft distance.

With transversely installed transmissions there is naturally also the option of attaching a central engager on the exterior of the transmission case (Fig-

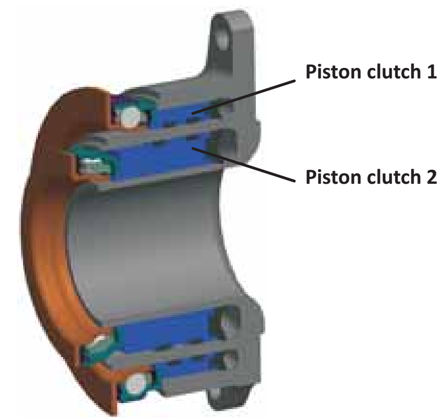


Figure 22 Hydraulic central engager with two ring pistons for a double clutch

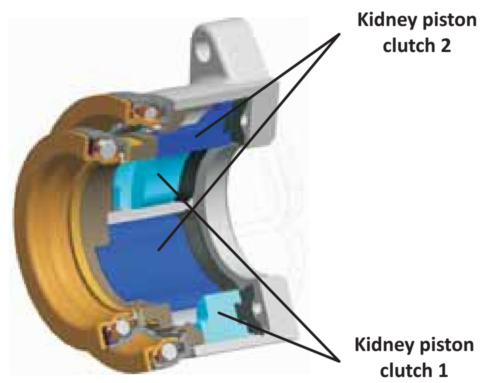


Figure 23 Hydraulic central engager with kidney-shaped pistons for a double clutch

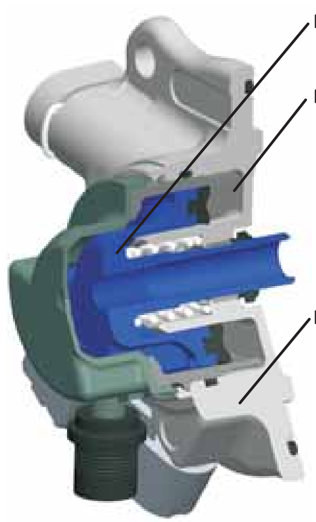


Figure 24 Central engager attached externally to the transmission

ure 24). The clutch is operated by means of a draw rod fed through the hollow shaft of the transmission, which is connected with the piston by means of a thread. A spring provides a permanent preload of the engagement bearing, which is located inside the bell housing. The exterior of the hydraulic unit is protected against dirt and water by a plastic cover. In the version shown, a travel sensor records the piston position and enables automated clutch control.

Summary

While clutch operation would appear to be a well-established matter, there is much going on technically. In modern vehicles with manual transmissions, improved release systems provide greater comfort, longer service life, achieve higher performance density at the same time as a lighter construction at reasonable manufacturing costs. Through the integration of electronic sensors and new drive types such as hybrids and double clutches, completely new technical solutions for operation systems are now emerging, with a great deal higher complexity and variety. At times exotic-seeming designs are now leaving the development phase and will soon be mass-produced in meaningful numbers. This development is driven by the changes that vehicle drives are currently undergoing and will likely also continue dynamically in the near future.

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