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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

Helmut Beier

President
of the LuK Group

Content

Clutch Release Systems

Matthias Zink
René Shead
Roland Welter

Introduction

Nowadays, the link between the pedal and the clutch – the clutch release system – in passenger cars and small commercial vehicles with a manual transmission is based almost exclusively on hydraulics. Despite being less expensive for initial installation, cable actuation systems have almost completely disappeared from the market. The hydraulic system is widely used because its hydraulic pressure line is easier to install in increasingly tighter packed engine compartments (right- and left-hand drive), it is self-adjusting and allows the integration of additional functions with little expenditure.

Through the use of hydraulic concentric slave cylinders, which have increasingly gained market share in Europe since 1995, a great simplification in transmission assembly has been achieved.

Further development of the hydraulic release systems currently focuses primarily on reducing costs by using polymers instead of metal, for example, as well as on measures for increasing the actuation comfort while reducing the pedal effort hysteresis and avoiding pedal vibrations [1].

In addition, the transition to polymers allows additional functions such as vibration damping and peak torque limiting to be economically integrated.

Furthermore, LuK has set a goal for itself to develop new technological solutions by completely rethinking of the 'clutch and actuation' concept.

The first milestone on this path is to implement an 'error-tolerant clutch system'.

Development Trends

Clutch Master Cylinder

The housings for the first hydraulic clutch master cylinders were made of metal, which requires costly processing. Despite the introduction of plastic master cylinders the design potential has not yet been fully exploited.

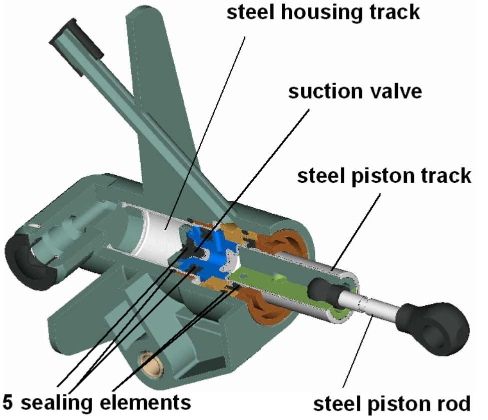


Fig. 1: *Master Cylinder - Previous Design*

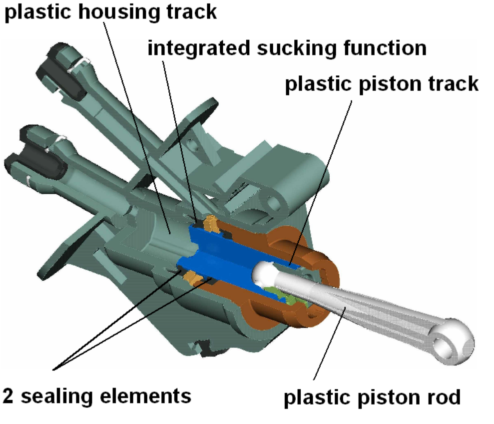


Fig. 2: *Master Cylinder – Current Design*

The piston and the seal tracks were made of case hardened metal. The connecting rods were made of steel and the cylinders had numerous individual seals (figure 1).

In the meantime, LuK's consistent development efforts have enabled to reduce by half the number of individual parts and largely to eliminate the use of costly metal parts (figure 2).

Operationally sound plastic seal tracks reinforced by suitable material combinations and fibreglass thermoplastics are increasingly replacing steel connecting rods.

By combining functions, the number of seals was reduced from originally five to two.

The disadvantage of the light-weight plastic master cylinder housing is its tendency to squeak, which is due to the speed-dependent friction coefficient between the elastomer seals and the seal track.

In the meantime, effective countermeasures have been developed for this problem. If a steel piston is used, a carbon coating is a very effective but somewhat costly solution. Alternatively, LuK offers a piston made of a duroplastic material. This allows the use of various brake fluids even under extreme climatic conditions without the occurrence of squeak.

Hydraulic Pressure Lines

Even though the hydraulic pressure lines are regarded as simple, off the shelf components, the necessity for cost reductions has led to numerous developments; in particular the quick fit connectors have undergone considerable improvements. Current design solutions are shown in figure 3.

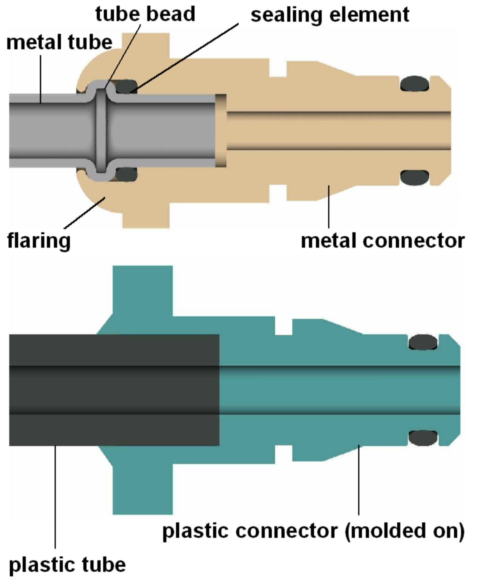


Fig. 3: Connector Technology

PA 12 plastic lines are becoming increasingly important compared to steel / rubber assemblies. Extensive use of these plastic lines is still limited due to low durable operating temperature of around 120 °C, the temperature dependence of the volume expansion and the poor damping of pressure vibrations.

Significantly increased market penetration is expected in the future as a result of new developments, such as improved raw materials and optimised extrusion methods (multi-layer pipes).

LuK as a full system supplier not only deals with the line routing and its tuning, but is also committed to further developing pressure line technologies with competent partners.

An example of this is the positioning of the connector within the cylinder housing; this ensures increased functional safety of the joint between the line and the cylinder (figure 4).

This simplifies the line manufacture and, particularly, the control processes during production. The functional test for the connection is conducted during the leakage test for the cylinder, which is a standard procedure.

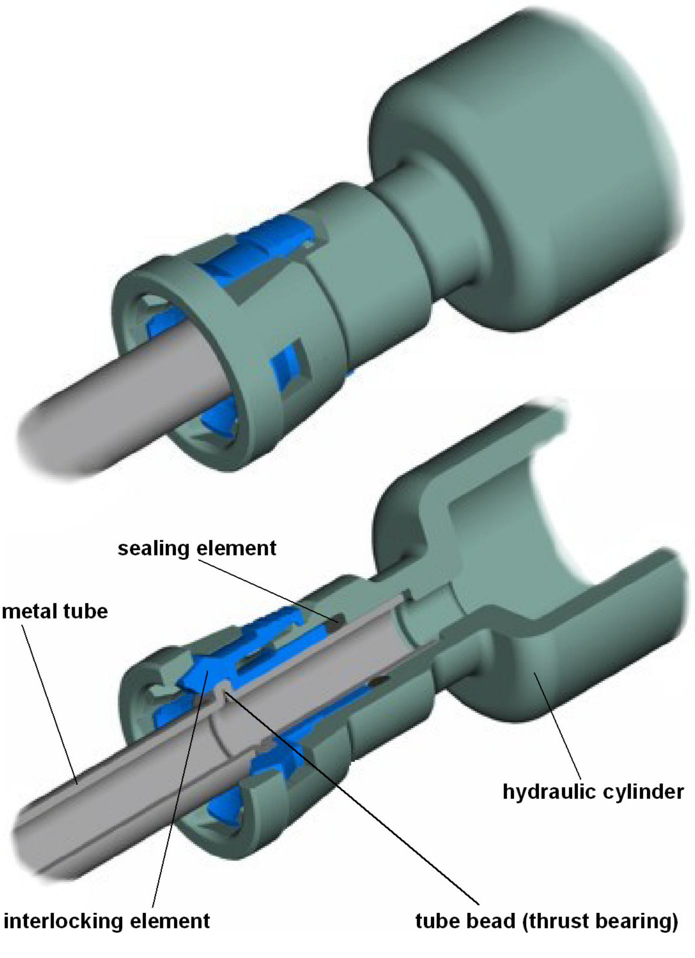


Fig. 4: Integration of a Line Connector in the Cylinder

Slave Cylinder

With hydraulic concentric slave cylinders (CSC), various functions are integrated into a compact unit that is easy to mount to the transmission.

Current concentric slave cylinder housings are made of die cast or forged aluminium, which requires costly processing and subsequent anodising treatment (figure 5).

The processing expense was reduced by using injection moulded housings made of reinforced thermoplastic material (figure 6).

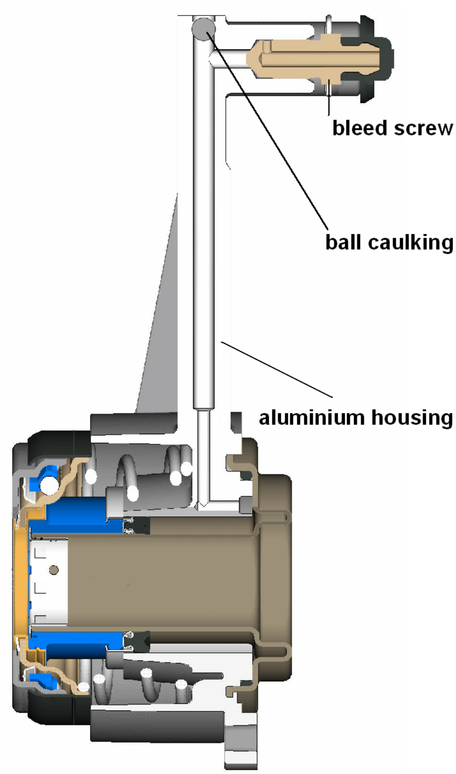
The high temperature resistance of the selected material (polyphtalamide, PPA) guarantees that the functionality and robustness of the plastic housing are comparable to current aluminium solutions. PPA exhibits outstanding medium compatibility with regard to brake fluid and other materials in the engine compartment.

Due to the advanced design of the housing assembly, the expansion load between the guiding sleeve and the housing is neutralised; thus the operating load on the CSC mounting joints is negligible (figure 7).

For example a release load of 2000 N with the CSC design on the left in figure 7 leads to an expansion load between the guiding sleeve and the CSC housing of 4400 N (!). This force needs to be borne by the threaded joints.

The CSC design shown on the right completely relieves the threaded joints.

The volume expansion of aluminium and plastic concentric slave cylinders is comparable for temperatures up to 120 °C.



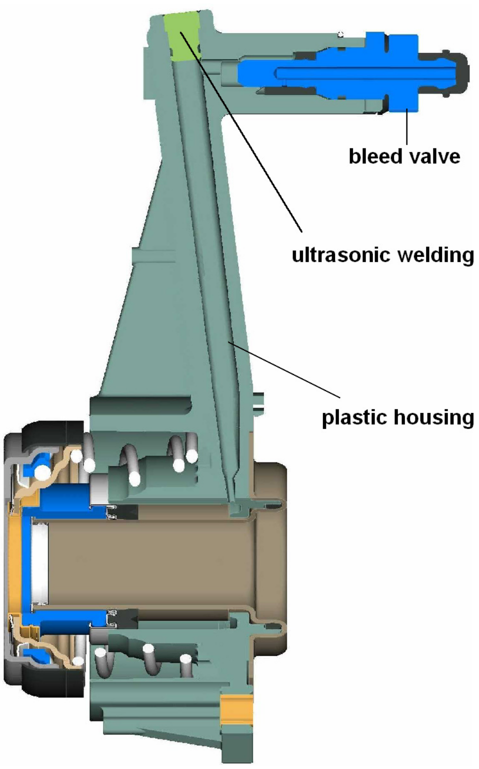


Fig. 5: *CSC – Previous Design*

Fig. 6: *CSC – Current Design*

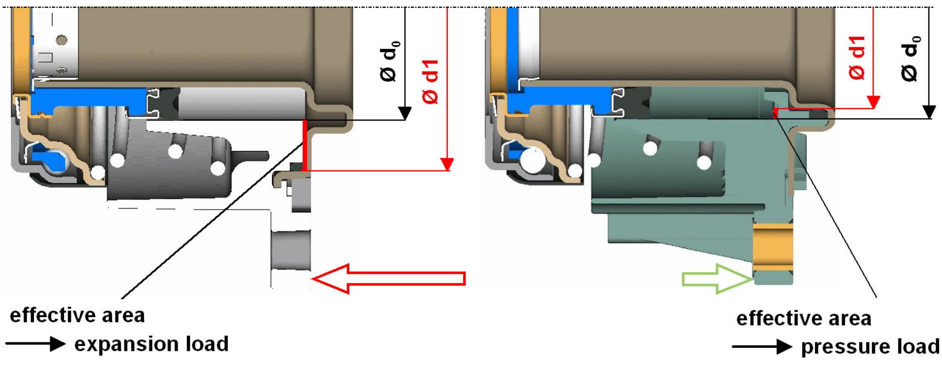


Fig. 7: *Avoidance of Expansion Load Housing / Guiding Sleeve*

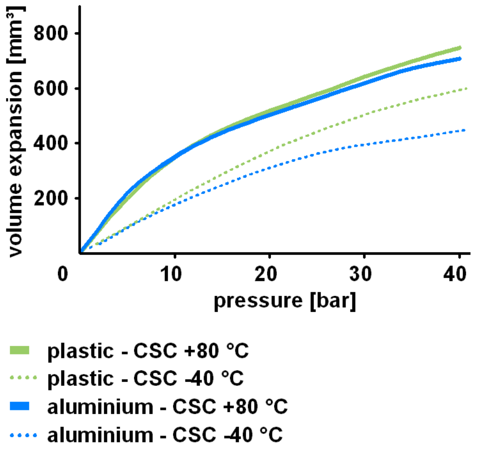


Fig. 8: *CSC Volume Expansion*

The slightly greater volume expansion of the plastic housing at higher temperatures can easily be compensated by an appropriate clutch and actuation system design.

With the new housing material a new quality of grease was introduced. This innovation provides constant low friction during the entire service life of the assembly.

The resulting low load and travel hysteresis are the prerequisite for exact clutch modulation in foot-actuated and automated clutch systems.

LuK uses the full potential of the plastic design to increase the degree of functional integration.

A two-stage bleed valve was developed for the plastic slave cylinder, which allows easy manual manipulation (without tools) during servicing (figure 10).

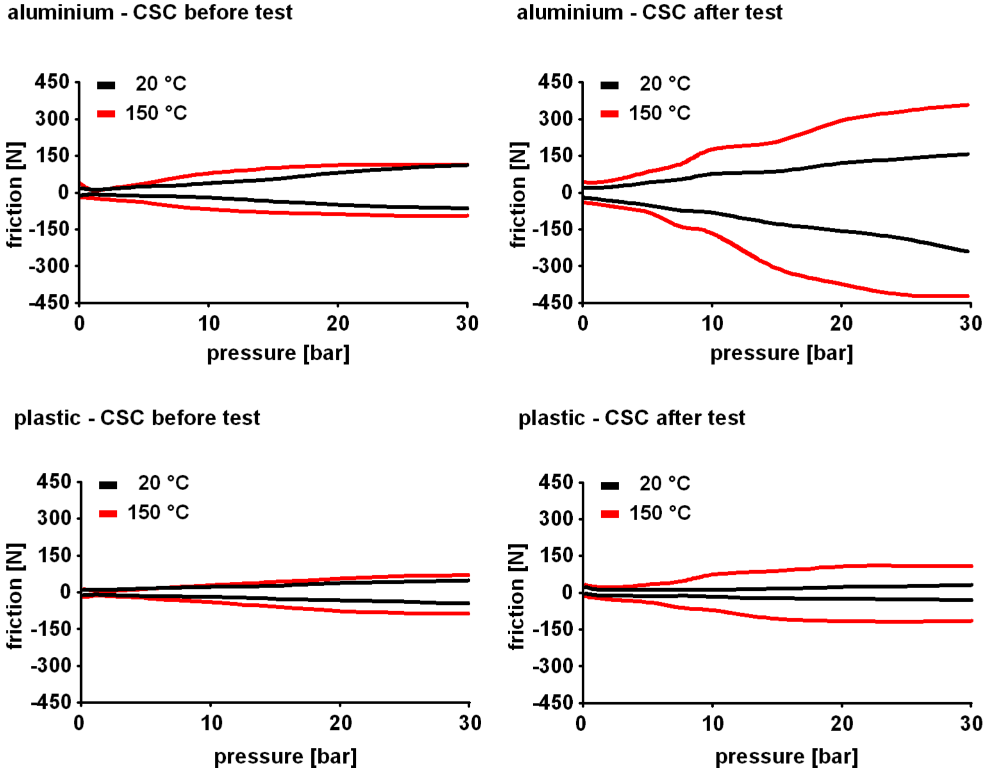


Fig. 9: *Performance of Low Friction Grease*

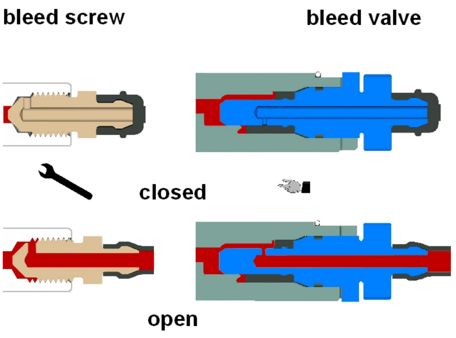


Fig. 10: New Bleed Valve Design

The peak torque limiter function was integrated as a switchable orifice in the slave cylinder. The volume flow is slowed down by reducing the size of the orifice during clutch engagement thus increasing the engagement time. When disengaging the clutch, the fluid flows almost freely through the supply bore and provides no pressure resistance (figure 11).

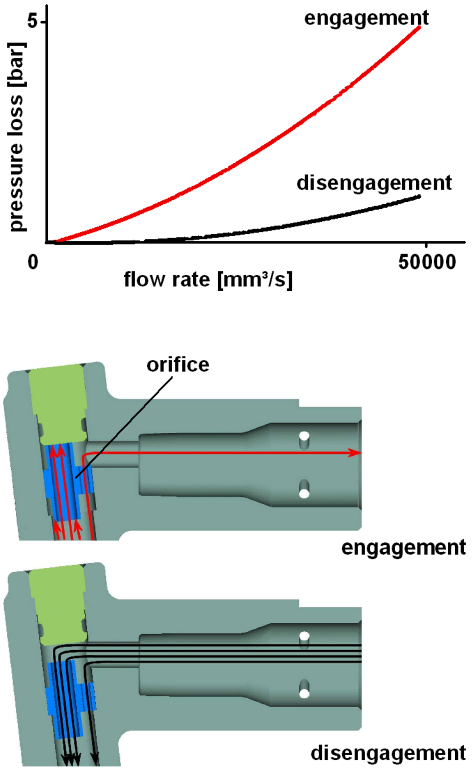


Fig. 11: Integrated Peak Torque Limiter

A new version of the existing vibration damper replaces the previous spring-valve design with simple gaskets. Different pre-loads on the gaskets allow a tuning of the opening pressure and thus the amplitude of the filtered pressure fluctuation is adjusted for the specific application. The design allows for simple integration into the housing and the connection adapter (figure 12).

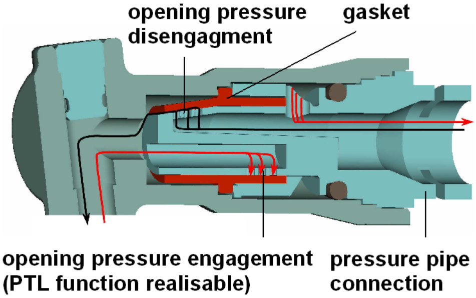


Fig. 12: Gasket Vibration Damper

Due to larger shaft bearings and shift rail supports that protrude into the clutch area, the available space for slave cylinders in the transmission bell housing become increasingly smaller.

Figure 13 illustrates a compact design for a concentric slave cylinder with a plastic housing, which uses only two mounting bores.

A special feature of this design is that the mounting is only for securing the position and is not subject to any load during clutch operation. The pressure neutrality is achieved by attaching the guiding sleeve to the housing during the assembly process.

This design also has the shortest package requirement.

The connection to the pressure line through the bell housing opening is achieved via an appropriate adapter.

Additional functions, such as bleed valve, peak torque limiter and vibration damper can also be integrated into these adapters.

This modular design allows for various transmissions from one manufacturer to be combined with the identical CSC base body with the usage of different adapters.

According to LuK terminology both designs are termed 'semi-plastic CSCs', meaning that the concentric release cylinder has a plastic housing and steel guiding sleeve.

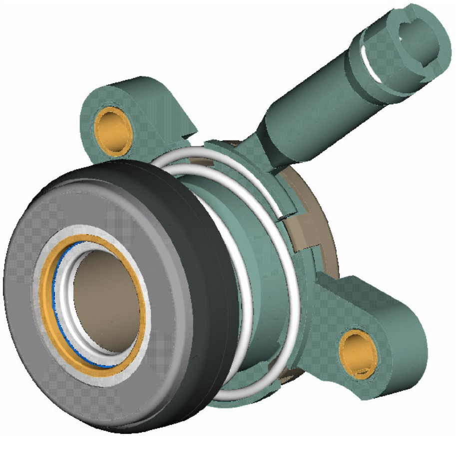


Fig. 13: *Two-Point CSC*

The development of a plastic guiding sleeve for a completely plastic CSC is well progressed. The plastic guiding sleeve is given special consideration with regard to the material and surface definition because it must function simultaneously as seal track and guide for the piston.

The development of external slave cylinders is comparable to that of clutch master cylinders (see chapter *Clutch Master Cylinder*).

As with the concentric slave cylinders additional functions can be similarly integrated.

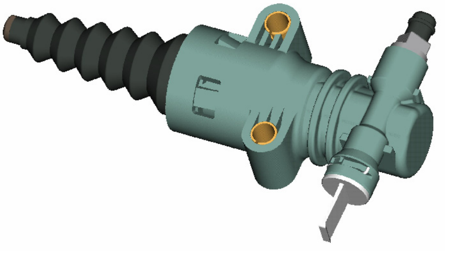


Fig. 14: *External Slave Cylinder*

Error-Tolerant Clutch Systems

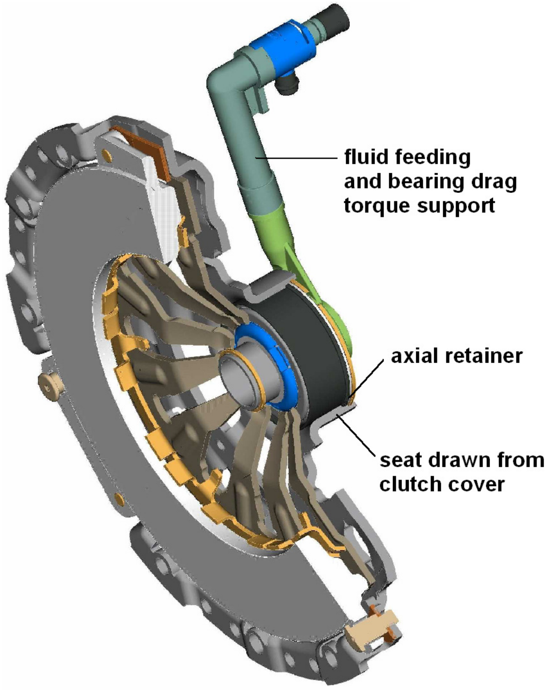
With increasingly sensitive drive trains and increasing vibration excitations from higher engine irregularities clutch systems are kept at the limit of economic feasibility with respect to production tolerances.

Connecting the CSC to the clutch to form a single module is a major step towards achieving an 'error-tolerant clutch system' (see figure 15).

Here, a concentric slave cylinder is equipped with an additional roller bearing on the housing, which is supported against the clutch cover (figure 16).

The unit, which consists of a clutch and CSC, is bolted to the flywheel as shown.

Axial vibrations from the crankshaft, which are caused by the engine combustion process, pulsate against the transmission-mounted CSC's in today's 'clutch and actuation' system. On the one hand, this leads to pressure fluctuations in the release system and subsequently pedal vibrations. On the other, it causes torque fluctuations in the clutch unit (figure 17 on the left).



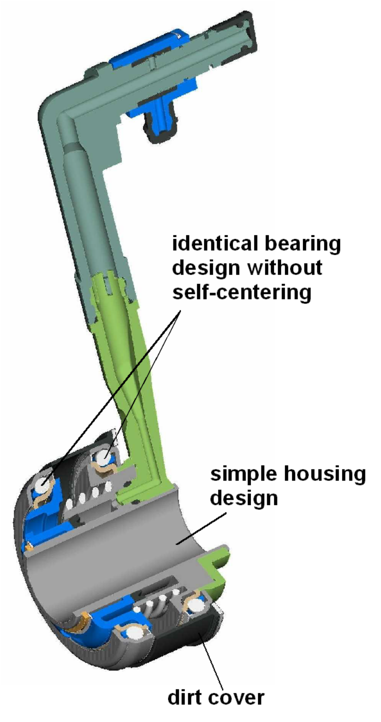


Fig. 15: *Module Clutch / CSC*

Fig. 16: *Bearing Design*

By interrupting the connection between the release cylinder and the transmission, clutch-side axial and bending vibrations are no longer transferred into the hydraulic system. Thus pedal vibrations can be effectively reduced (figure 17 on the right).

Measurements on a prototype vehicle are shown in figure 18.

All torque fluctuations created by the axial vibrations during the slip phase are also reduced to a minimum. In a test vehicle (diesel engine with direct injection, 1.7 l engine displacement) the improvement in speed fluctuation shown in figure 19 was achieved. This correlates to a reduction in torque fluctuation of $\pm$ 6 Nm. This is a substantial decrease considering that sensitive drive trains tend toward slip vibrations even at fluctuation as low as $\pm$ 1 Nm.

Another advantage is that the crankshaft bearing is completely relieved from the release loads.

The travel configuration for the CSC is limited to the release and wear travel, meaning the total unit is approx. 11 mm shorter referenced to the crankshaft mounting surface because the tolerance from the crankshaft protrusion to the rear face of the clutch housing no longer needs to be taken into consideration.

In addition, this module makes it possible to deliver the clutches in disengaged condition; thus they can be mounted to the flywheel without counter-load and with low distortion.

Technically and organisationally, the number of interfaces is minimised; the clutch and cylinder are mounted to the engine as one module at the engine plant. The CSC no longer needs to be designed to the transmission interface (fastening, input shaft seal, etc.), which is currently a standard practise.

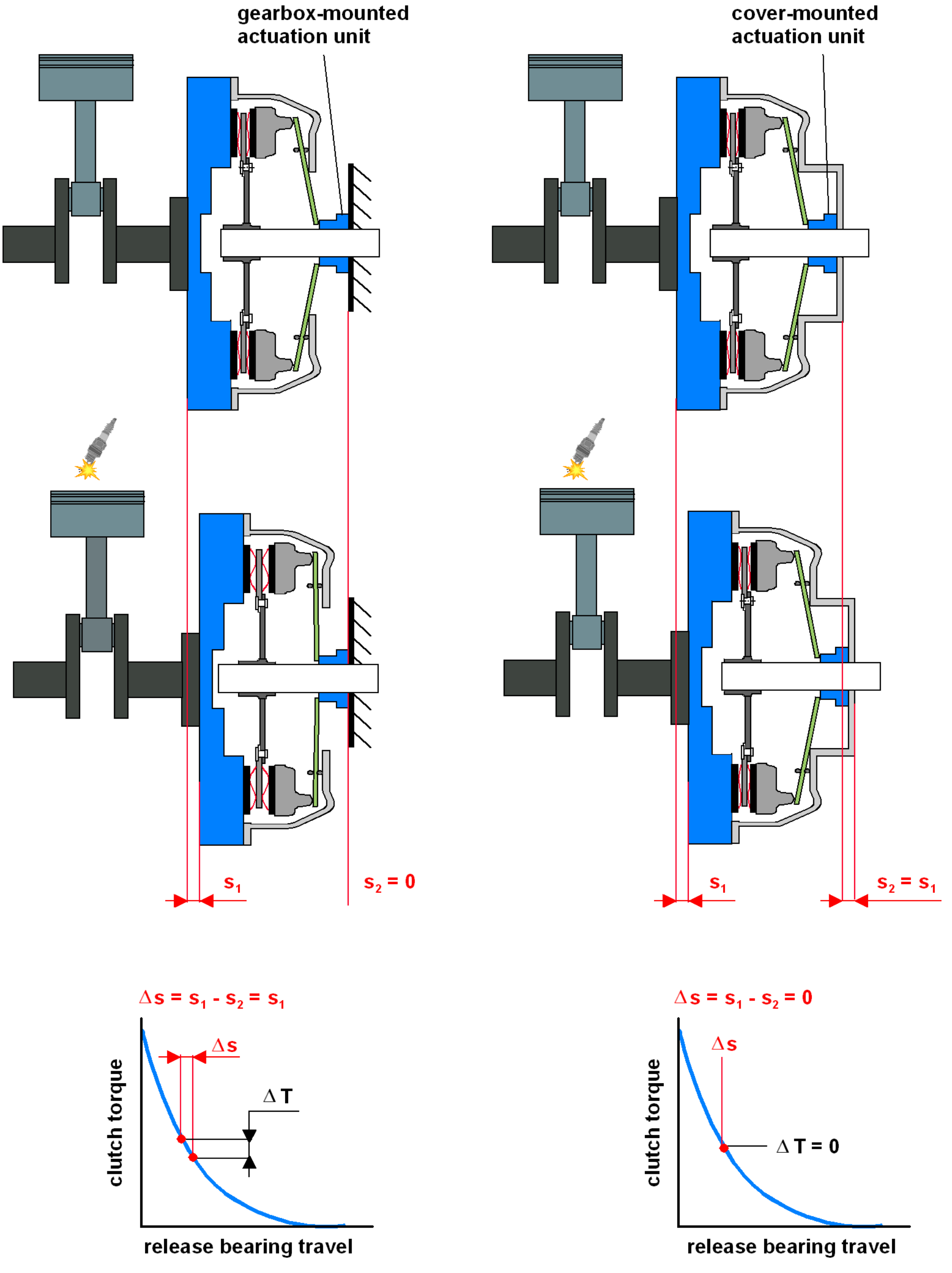


Fig. 17: *Torque Fluctuations*

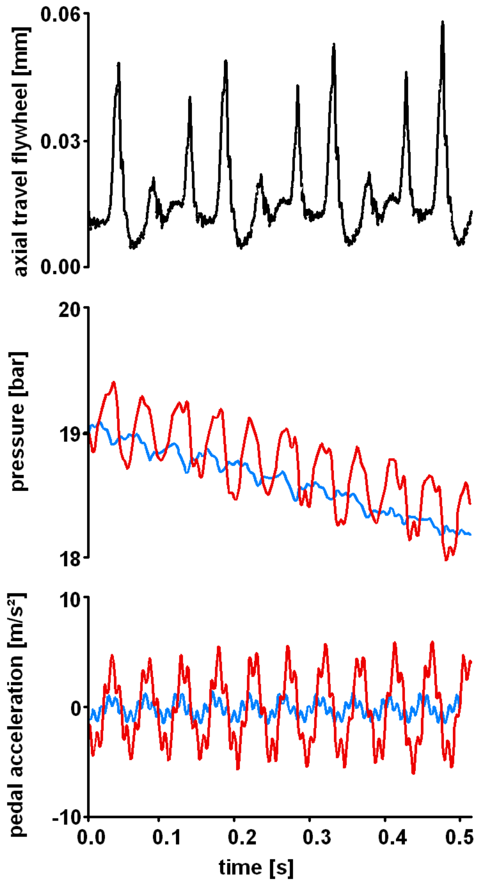


Fig. 18: Performance in the Vehicle (see Legend Figure 19)

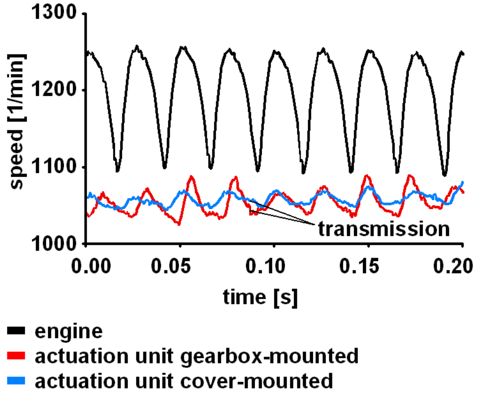


Fig. 19: Speed Fluctuations with Different Release Concepts

LuK tested the ease of transmission removal in various vehicles. Despite the increased length of clutch / CSC no installation condition has been found in which this module could not be assembled.

By using a runout compensation release bearing, the clutch system achieves another degree of freedom. Geometrically induced judder in sensitive drive trains generated by high clutch finger runout can now be compensated for.

Active Clutch Torque

Driving students are not the only ones who have complained about the difficulty of a controlled engagement action.

Experienced drivers have voiced the same complaint when they get into an unfamiliar vehicle. The low idle speeds and torques as well as the practically ‘explosive’ torque curves for today’s diesel engines are difficult to modulate using only clutch pedal and accelerator [2].

Who would not want a helping hand to automatically prevent the vehicle from stalling?

This is comparable to the ABS function that avoids blocking of the wheels during braking actions in extreme conditions or ESP, which holds the vehicle in a curve despite excessive steering.

To prevent stalling during launch, the launch action is monitored and assisted if needed. The monitoring is performed by a control unit, using the signals that are already available (engine and wheel speeds, etc.); additional sensors are not required. A control strategy evaluates the likelihood of stalling during start-up. If a critical condition is reached, the clutch engagement speed is restricted.

This task is performed by a solenoid valve in the hydraulic release system which actively reduces the pressure line diameter, thereby increasing the flow resistance. This delays the clutch torque build-up and, if needed, even briefly stops it.

This system significantly reduces the risk of stalling. During normal driving operations, the system is deactivated and not perceptible to the driver.

To test the system, launch measurements in idle were taken on a test vehicle (figure 21). A clutch pedal actuator was used so that the clutch engagement could be defined and reproduced [3].

The pictures in the left column show the result without launch assistance.

When the accelerator is not used, the vehicle condition barely still launches at an engagement speed of 25 mm/s with strong jerking.

The pictures in the right column show the result with launch assistance. The vehicle condition exhibits considerably better launch behaviour. The critical situation was recognised by the control unit and engine stall was avoided by reducing the pressure line diameter, resulting in a discernible improvement in comfort. The system reaches its limit at an engagement speed of 55 mm/s (figure 20).

In addition, the system described also incorporates a peak torque limiter function.

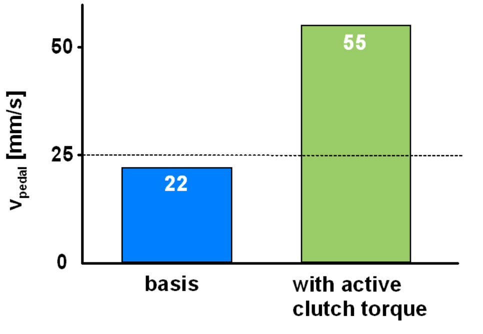


***Fig. 20:** Pedal Limit Speed*

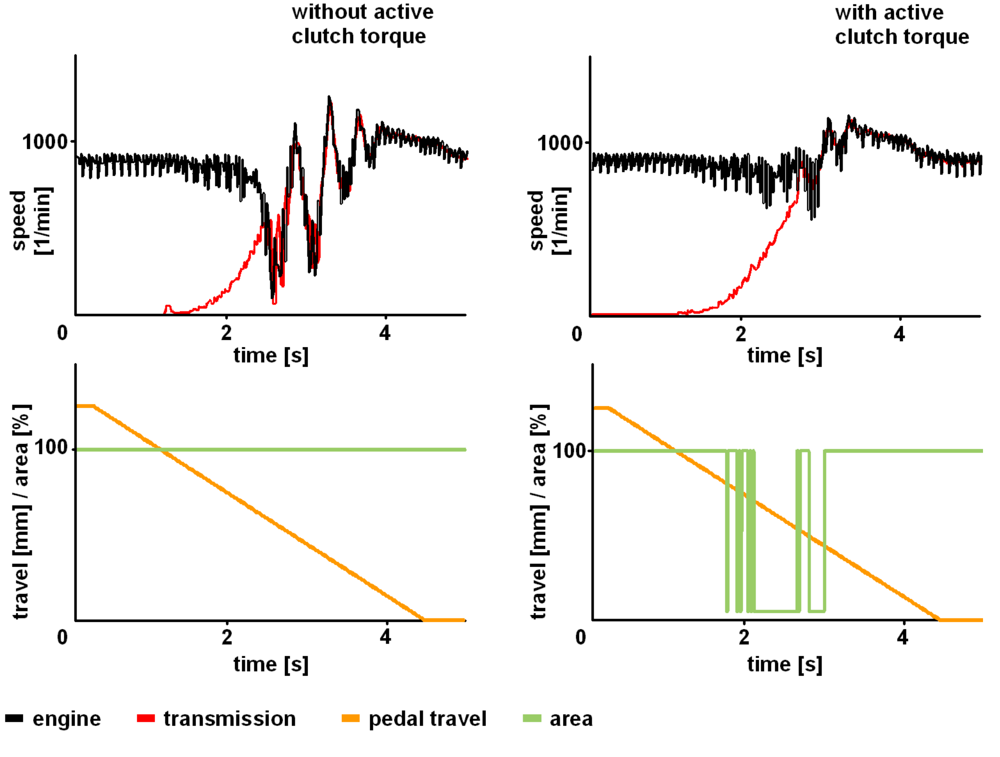


***Fig. 21:** Vehicle Measurements (22 mm/s)*

Summary

By using plastic materials and more intelligent designs, cost savings can be attained for clutch actuation products, which seemed to have reached their pinnacle. At the same time, the functionality has been expanded, thus increasing actuation and driving comfort.

The following solutions have been implemented for use in large scale production:

- Clutch master cylinder with duroplastic pistons to prevent noise
- Concentric slave cylinder with plastic housing and neutralised expansion load
- Optimised bleed valve
- Integrated peak torque limiter

LuK emphasises the development of error-tolerant systems in which the increased demands for driving and shifting comfort can be economically met.

- A module consisting of the clutch and the actuation unit
- An intelligent release system that can automatically compensate for errors during clutch engagement

The expectation is that this Total System Development will lead to completely new technical solutions in the future.

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[2] Seebacher, R.; Zink, M.: Anfahruntersuchungen mit Simulationsunterstützung, Systemanalyse in der KFZ-Antriebstechnik, Expert-Verlag 2000.

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