The Self-Adjusting Clutch SAC of the 2nd Generation

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Introduction

The self-adjusting clutch (SAC) has proven itself in almost 1 million vehicles. in particular vehicles with large engines, the actuation of the clutch is achieved far more comfortably with the SAC. In addition, the goal of having a clutch which lasts the entire service life of the vehicle was also achieved with the SAC.

Despite the additional expense of the SAC, the total costs for the clutch system (clutch + release system) were actually reduced in several cases, for e.g., by:

- Elimination of a hydraulic booster
- Reducing the clutch size
- Standardizing clutch types and actuation system
- Eliminating one over-center spring

Figures 1 and 2 illustrate an overview of the current SAC applications and the expected development up to the year 2000.

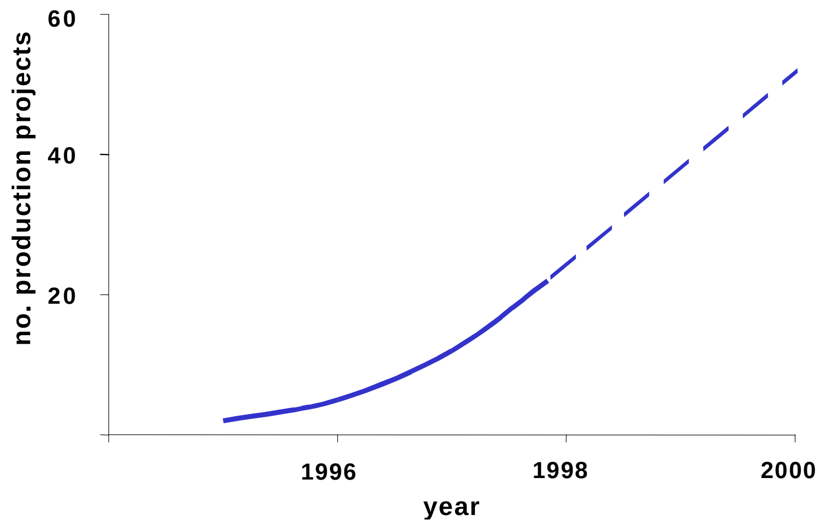

Figure 1: Trend in the number of SAC applications

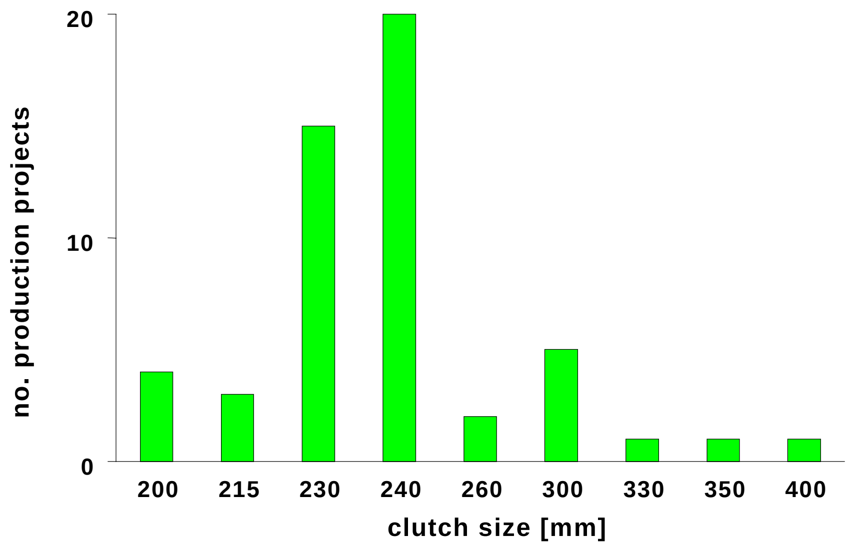

Figure 2: Distribution of SAC projects

The following summary can be made from the experience gained from the production projects:

- The SAC has a high functionality and functional reliability.
- The system can be manufactured without problems in mass production, despite the high demands of detail parts such as springs, adjuster rings, clutch covers and cushion segments, as well as having a more complex function.
- The introduction of the SAC significantly reduces pedal effort in comparison to conventional clutch assemblies. However, the possibility of drastically reducing pedal effort has not yet been fully exploited with the production designs, due to the clutch modulation and tendency to judder.

Ideas have been considered in previous years on how the SAC can be further improved, with regard to pedal effort and torque increase characteristic curve. In addition, there is extensive development potential to reduce the material and manufacturing costs with comparable functionality.

The various solutions are described in greater detail below.

Description of the SAC (Self-Adjusting Clutch) Function

With conventional clutches, the actuation force increases with increased facing wear. With the SAC, the facing wear is compensated for means of a wear adjusting system, so that there is no change in the actuation force.

The SAC differs from the conventional clutch by adjusting the position of the diaphragm spring during wear (Figure 3). The adjustment occurs such that the angle position of the diaphragm spring, and hence the actuation and clamp load, remain constant regardless of wear (primarily facing wear). In order to realize this wear compensation, the main diaphragm spring is not permanently riveted to the clutch cover or mounted with keyhole tabs, as with conventional clutch assemblies, but is only retained axially against the cover by a defined force (sensor force). A ramp ring, which extends into the ramp of the cover, is located between the diaphragm spring and the clutch cover, and is rotated by the coil springs.

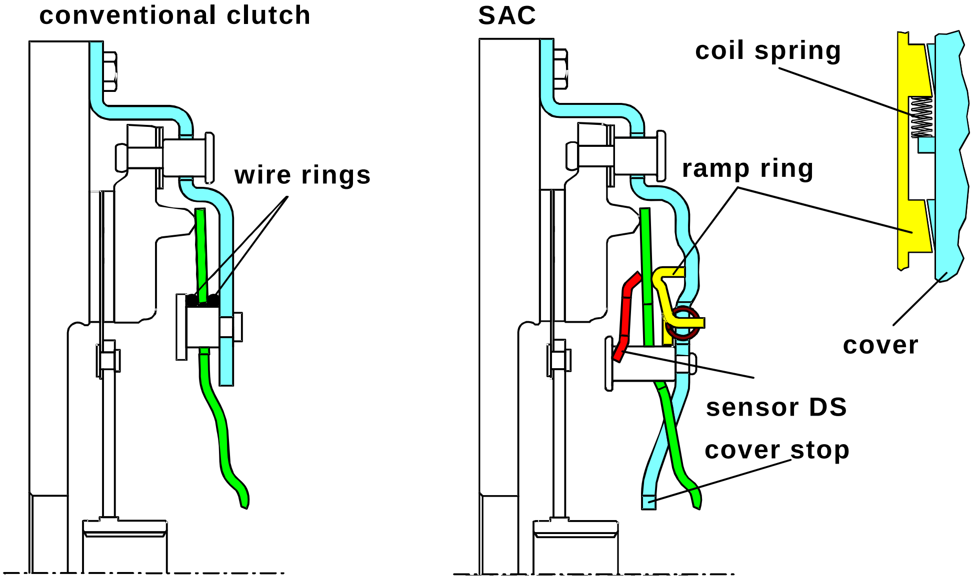

Figure 3: Comparison of a conventional clutch to a SAC

The sensor force is sized such that it can normally resist the actuation force. When the actuation force increases because of wear to the facings and the sensor force is no longer sufficient as a counter force on the main diaphragm spring, the main diaphragm spring moves axially away from the cover contact position, towards the engine. The resulting play is compensated by the preloaded ramp mechanism mounted between the diaphragm spring and the clutch cover. The adjustment procedure lasts until the actuation force has dropped to the sensor force, i.e., to the desired level, and the original diaphragm spring angle position is again achieved.

Figure 4a and 4b schematically illustrates the procedure of wear adjustment by the forces acting on the diaphragm spring.

Figure 4a: Conventional clutch new and worn

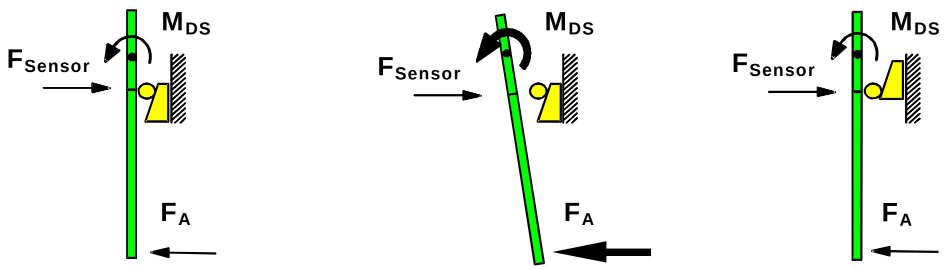

Figure 4b: SAC new and worn, before and after wear adjustment

In Figure 4a, the diaphragm spring of a conventional clutch is permanently seated symbolically at the rotation point. Due to its shape, the diaphragm spring supplies a torque, which is overcome via the actuation force on the diaphragm spring fingers during the actuation (rotation) of the diaphragm spring. The angle position of the diaphragm spring changes during wear, which causes an increase in the diaphragm spring torque and the actuation force due to the characteristic curve typical of a diaphragm spring.

With the SAC, the diaphragm spring - in contrast to the conventional clutch - is not permanently seated, but is only supported axially via the sensor force (Figure 4b). In the new condition, there is a force equilibrium between the sensor force and the actuation force. During wear, the actuation force increases and presses the diaphragm spring to the left, against the sensor force, so that the spring preload is relieved on the ramp on the right side of the diaphragm spring and it can then readjust. At the end of the adjustment procedure, the diaphragm spring again assumes it's initial angle position and there is a force equilibrium between the sensor force and the actuation force.

SAC Actuation Force Characteristic Curve

With the SAC as it is currently used in a wide variety of vehicles in production, the pedal effort was reduced significantly and hence the clutch comfort was increased in comparison to the conventional clutch.

The actuation force curve is, however, somewhat unfavorable with the SAC because there is a greater system-related difference between the maximum and minimum actuation force. Hence it is necessary to adapt the release system to the modified actuation force characteristic curve.

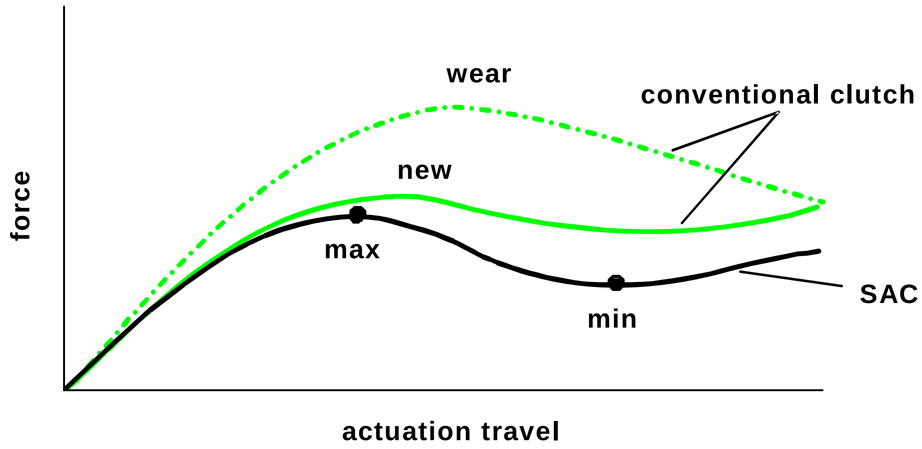

Figure 5: Comparison of the actuation force characteristic curve of a conventional clutch to a SAC

The reasons for this specific actuation force curve can be explained by the force equilibrium on the clutch diaphragm spring. If a free-body diagram of the diaphragm spring is made (Figure 6), it can be seen that the force of the cushion deflection (F_C), the leaf springs (F_L) and the sensor diaphragm spring (F_{SDS}) on the one side acts to counter the actuation force (F_A) on the other side. The sum of the facing, leaf and sensor spring forces can be designated as the total sensor force (F_S), which limits the amount of actuation force. If the actuation force becomes greater than the total sensor force during clutch release, which occurs during wear, the diaphragm spring is pressed away from the clutch cover (ramp ring) and the ramp mechanism can readjust.

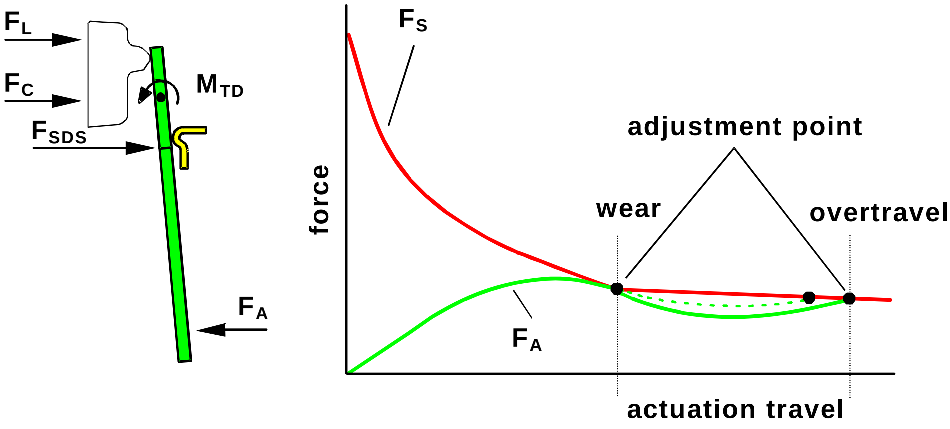

Figure 6: Forces on the main diaphragm spring in the SAC

In Figure 6, it is evident that the actuation force can exceed the total sensor force basically at two points over the actuation travel. The first point is the wear adjustment point. This point is in the range where the cushion deflection force is almost zero. The adjustment for wear occurs at this point. During continued release stroke, there is a second point (the overtravel adjustment point), at which undesired adjustment occurs. At maximum actuation stroke, there must be sufficient reserve to the overtravel adjustment point. This can only be ensured if the actuation force minimum is significantly lower than the total sensor force and / or overtravel can be avoided by a stop integrated into the cover.

From the current perspective, there are two technical options that can be realized with the SAC: there can be greater flexibility in the actuation force characteristic curve and the actuation forces can be further reduced.

SAC with Compensation Spring

A relatively simple way of generating an actuation force characteristic curve on the clutch, that is as flat as possible, is by adding a spring with a linear spring characteristic curve which is riveted onto the clutch cover. The compensation spring increases the minimum actuation force - related to the actuation force curve - and thus leads to a flatter total characteristic curve.

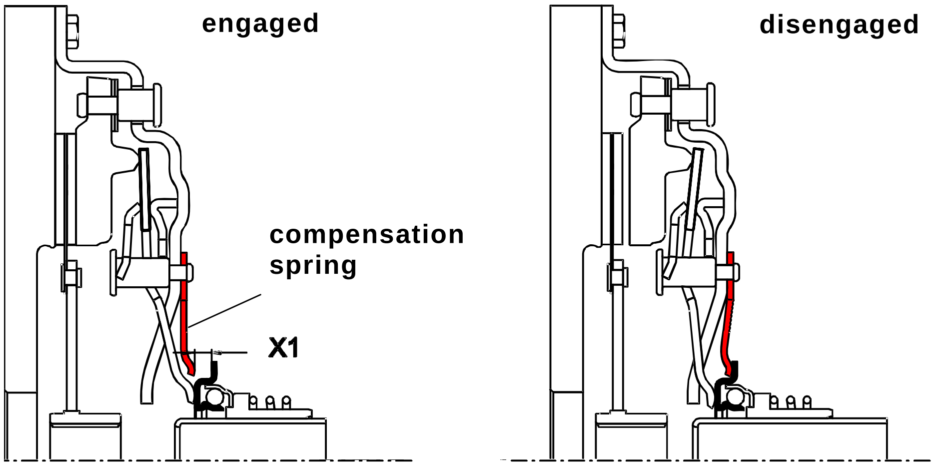

Figure 7: SAC with compensation spring

The compensation spring, as shown in Figure 7, directly affects the release bearing and only influences the actuation force characteristic curve and not the inner forces of the clutch. Hence, the adjustment mechanism and the adjustment function of the SAC are not influenced. Due to the migration of the diaphragm spring finger toward the engine during wear, the maximum actuation force remains almost constant only up to approximately 1.5 mm facing wear. If there is more wear, e.g., at 2.5 mm, the actuation force increases slightly by approximately 10%.

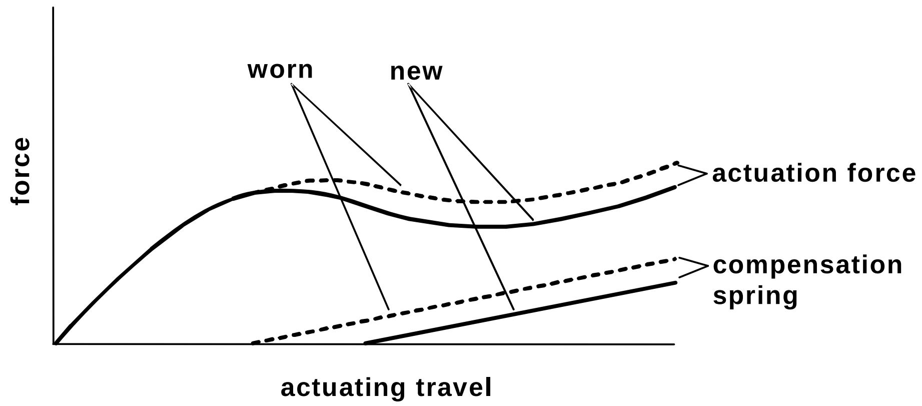

Figure 8: Actuation force characteristic curves with compensation spring

Without a compensation spring, the same function can also be achieved via diaphragm spring fingers that are seated deeper. When actuating the clutch, the deeper seated fingers contact the cover stop after reaching the maximum actuation force and are elastically stressed during further actuation.

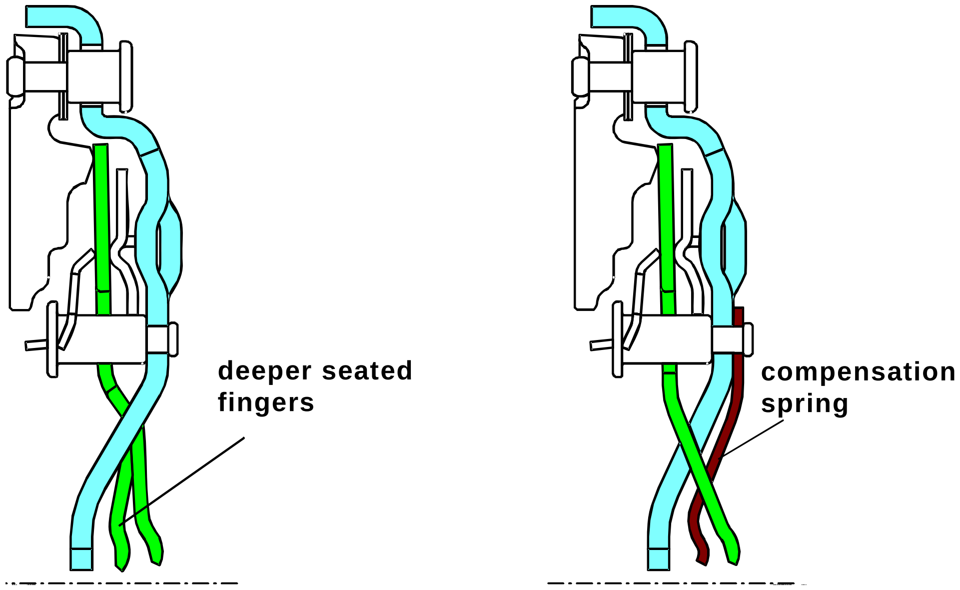

Figure 9: Comparison of the SAC with deeper seated fingers and SAC with compensation spring

SAC with Sensor Force Increase over Release Travel

Adding a compensation spring produces a flat actuation force curve by increasing the minimum actuation force. It would be better, however, to lower the maximum in order to achieve lower actuation forces in general.

This can be achieved if the total sensor force increases over the release travel after the adjustment point, by changing the tuning of existing spring elements, such as the main diaphragm spring, the sensor diaphragm spring and the leaf springs.

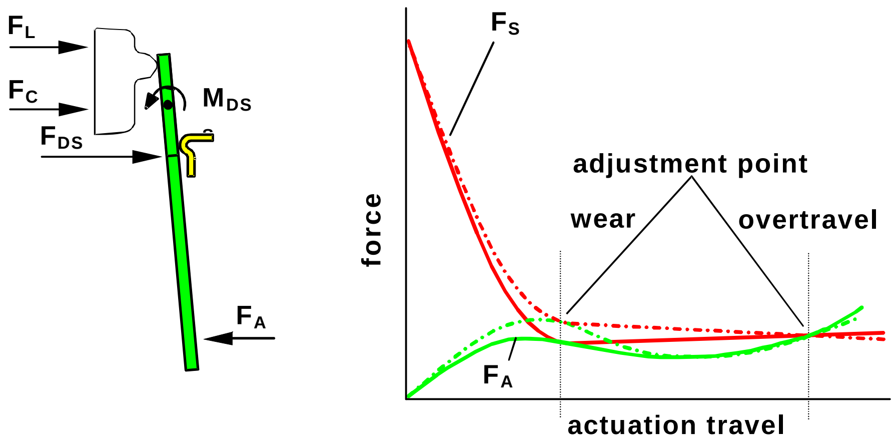

Figure 10: Actuation force characteristic curve for decreasing and increasing total sensor force

The effect is illustrated in Figure 10. Based on the force equilibrium on the diaphragm spring, the maximum actuation force is reduced while the overtravel safety and the minimum actuation force remain the same, if the total sensor force increases between the wear and overtravel adjustment points. The total sensor force between the wear and overtravel adjustment points decreases slightly in the current SACs, because the leaf springs relax with increasing actuation travel or lift.

It is possible to achieve an increasing sensor force in this range if leaf springs with degressive characteristic curves are used, instead of the leaf springs having linear characteristic curves.

Corrugated leaf springs maintain a degressive characteristic curve if they are fixed tightly to the clutch cover on both ends and if they are deflected in the center by the pressure plate. This causes a snap effect that is dependent on the corrugation.

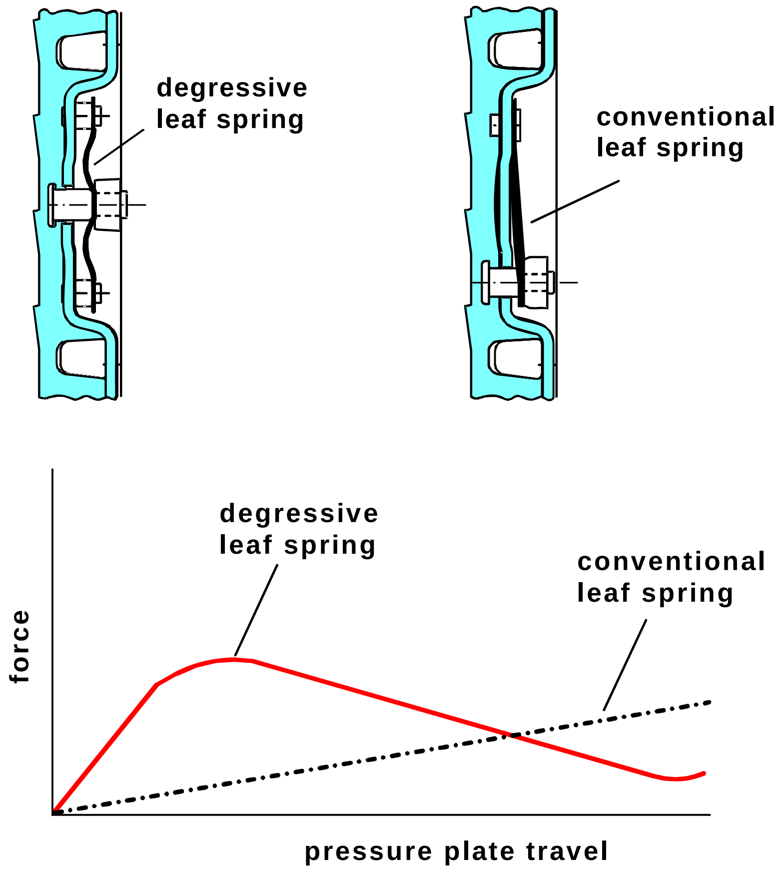

Figure 11: Leaf spring configuration with linear and degressive characteristic curve

The sensor force increase along the release travel is enhanced further, if the sensor diaphragm spring with increasing force characteristic extends radially further in at the diaphragm spring fingers instead of at the rotation point of the main diaphragm spring (Figure 12).

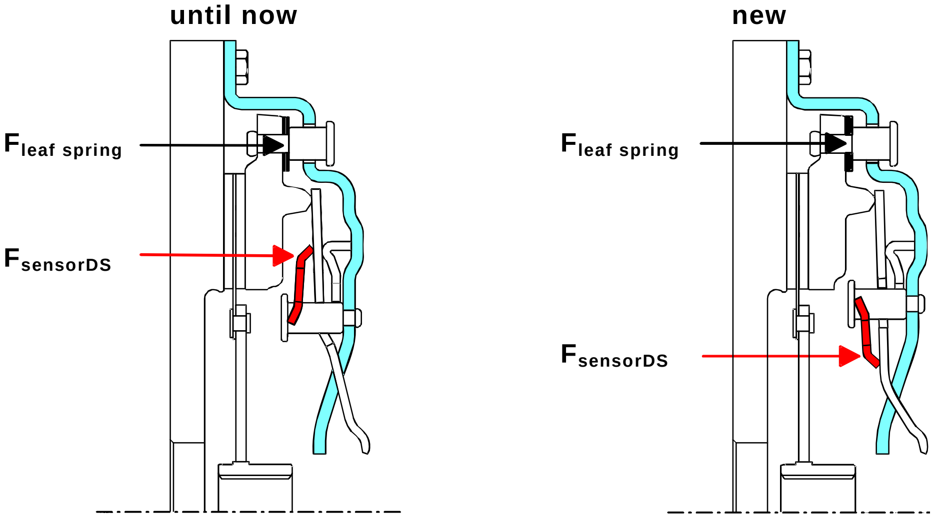

Figure 12: Sensor force increase via the sensor diaphragm spring

In comparison to the current SAC, an additional decrease in the actuation forces of 20-30% is possible. The drop in the actuation force characteristic curve (drop off) can be reduced by 50% by using leaf springs with a degressive characteristic curve and is thus comparable to conventional clutches.

The solutions presented thus far allow for a further reduction in the actuation forces, which is advantageous, for example, for high-torque engines or electric motor clutch actuation. There are a large number of applications (small vehicles), however, for which there is no need to reduce the actuation force when the clutch is new. Yet the SAC has the following advantages that are desirable even for these applications:

- constant actuation force over the service life
- higher wear reserve
- less axial installation in the diaphragm spring finger area

without significant cost increases in comparison to the conventional clutch.

For this reason, reducing costs in the further development of the SAC is a priority.

Reducing Costs

To implement wear adjustment in a clutch, a wear sensor and an adjustment mechanism are necessary. Hence, the SAC requires the following additional components or component modifications in comparison to a standard conventional clutch:

- Sensor diaphragm spring
- Adjuster ring
- Ramps in the clutch cover
- Coil springs to rotate the adjuster ring

In addition, assembly of the SAC is more costly in comparison to a conventional clutch.

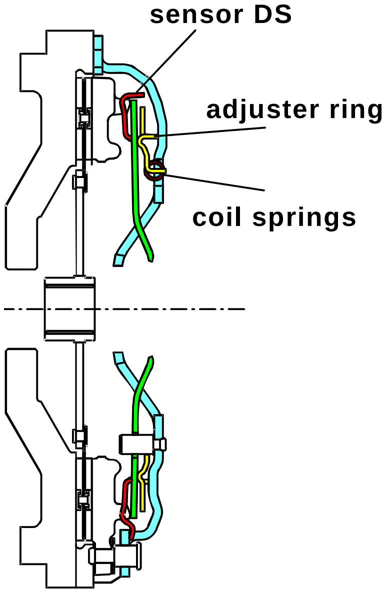

Figure 13: Additional components for the SAC

Efforts were made to reduce the number of additional parts and to combine multiple functions in the single components.

Two methods are described below:

Sensor Force From Leaf Springs

The total sensor force in the wear and overtravel adjustment points is determined essentially from the force of the sensor diaphragm spring and leaf springs in the SAC. Both spring forces are tuned such that the sum of both spring forces remains constant along the wear travel (e.g. 2.5 mm). Since the leaf spring force increases during facing wear, due to increased preload, the sensor diaphragm spring force must drop as the wear travel (preload path) increases. Therefore, the sensor diaphragm spring must have a degressive characteristic curve. The sensor diaphragm spring force can act on any point of the main diaphragm spring for the wear adjustment function, so the sensor diaphragm spring can also be replaced by leaf springs with a degressive spring characteristic (see Figure 14).

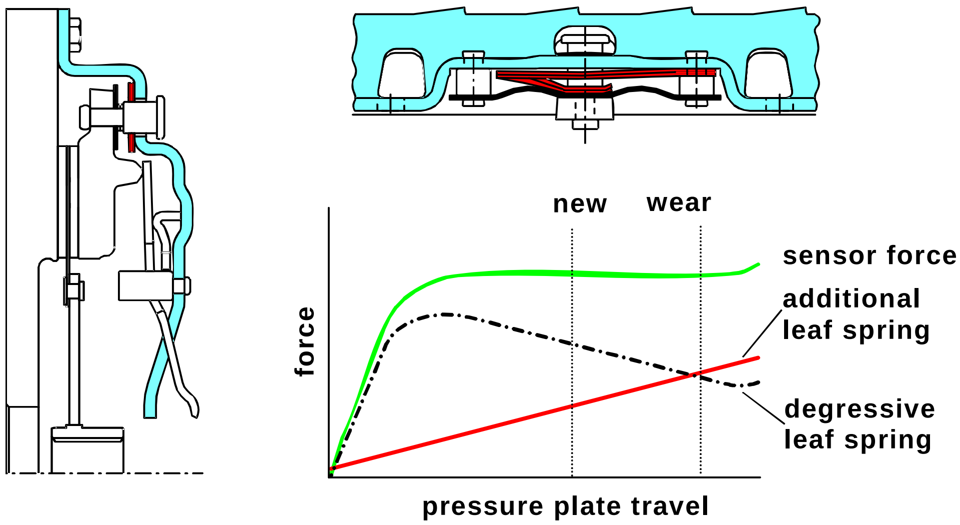

Figure 14: Sensor force from leaf springs

Since the sensor force in this design acts on the pressure plate, the diaphragm spring force is reduced. This must be maintained in the diaphragm spring design. In addition to the lower cost, this self-adjusting clutch is advantageous in that it requires less axial installation space because the sensor diaphragm spring is eliminated.

Sensor Force from the Main Diaphragm Spring

The necessary sensor diaphragm spring force can also be applied by individual, appropriately formed, diaphragm spring fingers. Thus the main diaphragm spring is supported against the cover with a defined force (sensor force) (Figure 15).

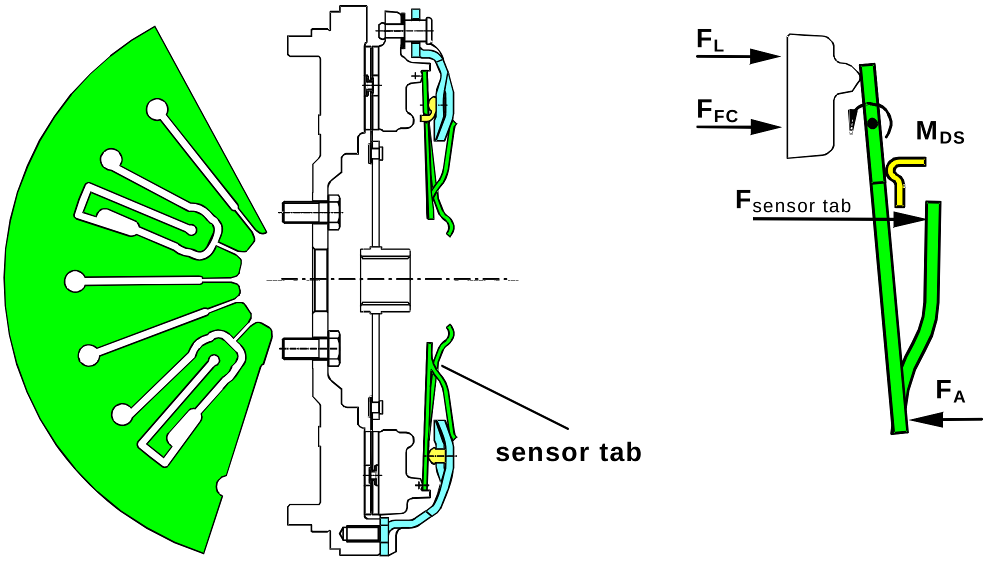

Figure 15: SAC with sensor force from the main diaphragm spring

During clutch wear, the increased actuation force again pushes the diaphragm spring away from the cover so that the wear can be compensated for between the diaphragm spring and the cover.

So that preload of the sensor tabs remains constant, the contact on the cover must be configured as a ramp and the diaphragm spring must rotate in relation to the cover during wear. The torque for the main diaphragm spring rotation results from the radial movement of the sensor tabs on the tangentially-sloped cover ramp, when the clutch is actuated.

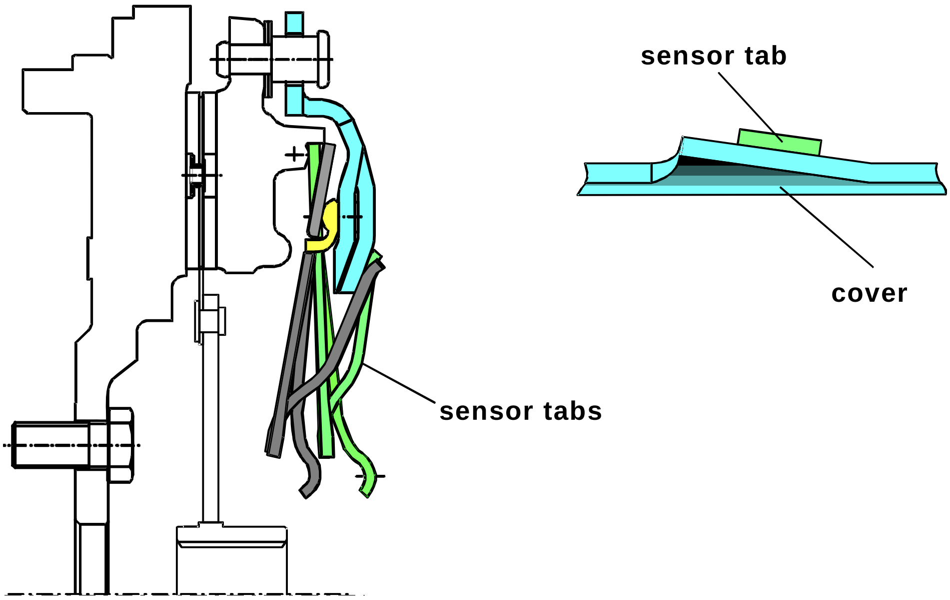

Figure 16 Sliding movement of the sensor tabs on the cover ramps

Since with this principle, the diaphragm spring rotates relative to the cover during wear, the coil springs, which generate a propulsive force on the adjuster ring in the SAC, can be eliminated. The adjuster ring must therefore be connected to the diaphragm spring so that the ring cannot rotate relative to the diaphragm spring.

In comparison to a conventional clutch, only a ramp ring is added in addition to the complicated diaphragm spring for the SAC II. However, the diaphragm spring retainer bolts and the pivot rings are eliminated.

Speed fluctuations in the drive train and particularly the irregularity of the engine, create varying torques on the diaphragm spring, which can lead to undesired adjustment in the SAC II. Hence, the SAC II is primarily unsuitable for any clutches in which the mass moment of inertia of the diaphragm spring must be kept at a low value.

Summary

The wear-adjusting clutch, SAC, has been implemented in the meantime in numerous high-torque engines with clutch sizes ∅ 200 - ∅ 300 mm. In addition to the description of the basic function, this presentation has served primarily to illustrate further development potential.

The development goals are to lower further the actuation force, i.e., optimize the actuation force curve, and to reduce the costs.

Options and advantages for the various developments are:

SAC with compensation spring

- More favorable actuation force characteristic

SAC with increasing sensor force

- Lower actuation force
- More favorable actuation force characteristic

SAC with sensor force from leaf springs

- Lower costs

SAC with sensor force from main diaphragm spring SAC II

- Lower costs

The SAC still has great potential for further development and with its additional advantages will be utilised in the future, in the lower vehicle class.

Literature

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