Actuators for demanding chassis applications –

Clever mechanical design relieves electric motors

Manfred Kraus

Introduction

The trend towards the dry chassis and need-orientated initiation of actuators ("avoiding of parasitic elements") to reduce fuel consumption is leading to electro-mechanical actuators.

The increasing advance in the micro-electronics sector and the combination/integration of sensor systems, electro-mechanical actuator systems and software are opening up entirely new possibilities for increasing the active safety of vehicles and for further utilisation of potential function within the chassis.

The electro-mechanical chassis or even the mechatronic chassis also includes, alongside braking and steering systems, adaptive damper systems in the vertical direction plus actuators to activate the camber, toe-in and roll angles. In addition to the latter, there will be new areas of application in the chassis area for electro-mechanical actuators, e.g. as active mass dampers to decouple the subframe from the vehicle superstructure.

The performance limit still present today because of the 12 V on-board power supply will be resolved to an increasing extent when hybrid vehicles and higher performance on-board power supply systems with a rating of more than 12 V are available in the near future. However, this does not relieve us of the obligation to use the power made available by the combustion engine or the on-board power supply more effectively.

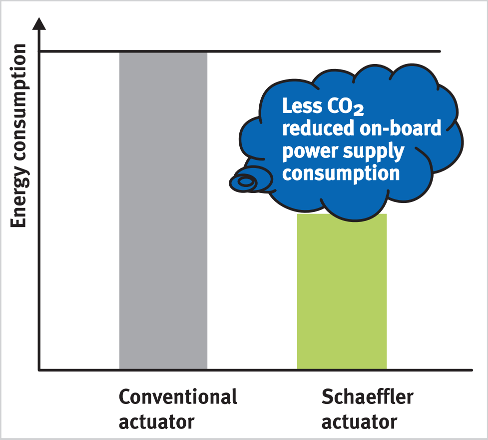


Figure 1 The target for the development of Schaeffler actuators

The Schaeffler Group has set itself the target – in addition to initiation of the actuators in accordance with need – of investigating further potential and developing actuators with a better energy balance sheet. The aim of the publication is to indicate how these systems/actuators could be developed further and used more effectively with regard to energy, for example via intelligent mechanical systems (see figure 1).

Framework of Conditions Within the Schaeffler Group

A high level of experience and competence is available within the Schaeffler Group not only in mechanical products but also in electrotechnical products and fabrication processes. In addition to the latter, an integrated development process ensures the practical and integrated combination of mechanical systems, electrical engineering, sensor systems and information technology. Bringing this experience together under one roof only produces advantages for the customer because the mechanical knowledge collected over many long years can thus be integrated in the software in the best possible way without losses and/or in the mechatronic system and because all the strengths can be brought into the system without loss at interfaces. The statements below show examples of these developments and clarify which areas of competence are required and how these need to be brought together in a targeted way so that a successful product is created.

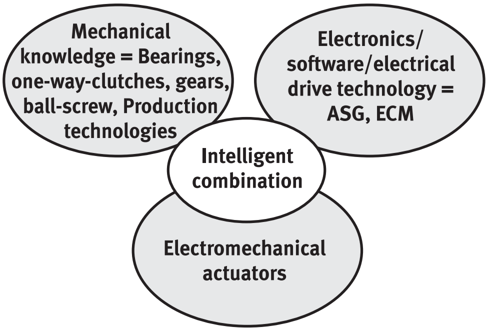


Figure 2 Framework of conditions for the development of mechatronic actuators

Roll Stabilisation

Features, Structure, Function

The passive stabiliser in the form of a torsion bar spring must solve the conflict which arises between the objectives of sufficient rigidity to reduce the sideways tilt (roll movement/angle) when travelling round bends and sufficient give when interference is caused on one side, e.g. when driving over a kerb on one side (to reduce the vertical movement of the body).

Nowadays hydraulic actuators are used as active actuators which twist a divided torsion bar when travelling round bends depending on the transverse acceleration and thus reduce the tilt by the body noticeably. When travelling straight ahead in the presence of interference on one side, the stabiliser must have an "open" effect which represents a gain in comfort in comparison with a passive stabiliser. Tilting by the body can also be prevented by hydraulically adjustable suspension struts on the individual wheels, which can eliminate the pitching movement when braking and accelerating in addition to the roll movement. Pneumatic systems are not suitable for this because of the high compressibility of the air.

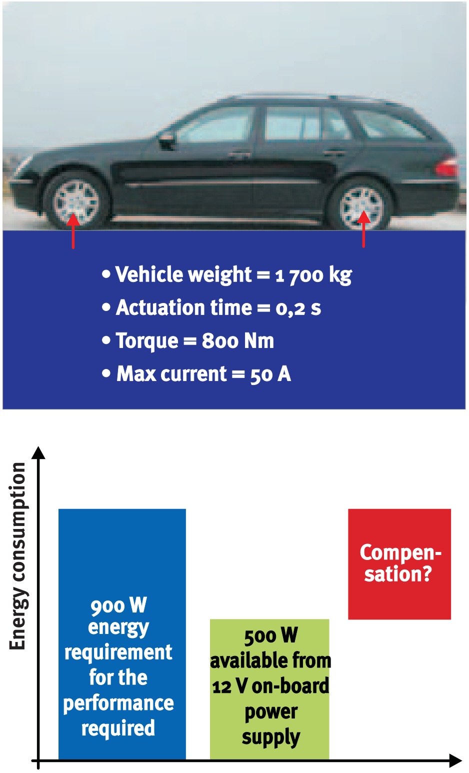


Figure 4 Requirements imposed on a roll stabilisation system for a mid-range vehicle

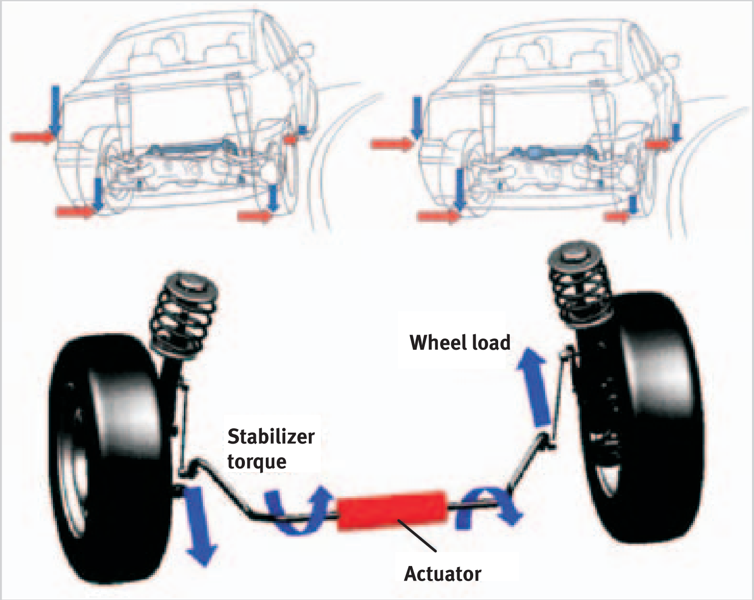


Figure 3 Mode of operation of roll stabilisation

The requirements imposed on a roll stabilisation system for a mid-range vehicle are summarised in figure 4.

The concept of only initiating the actuator in accordance with the requirement has led to an electric roll stabiliser consisting of an electric motor with ECU and a rotational gear with a high ratio (figure 5).

The Schaeffler Group has set itself the target of improving the energy balance sheet for the actuator and/

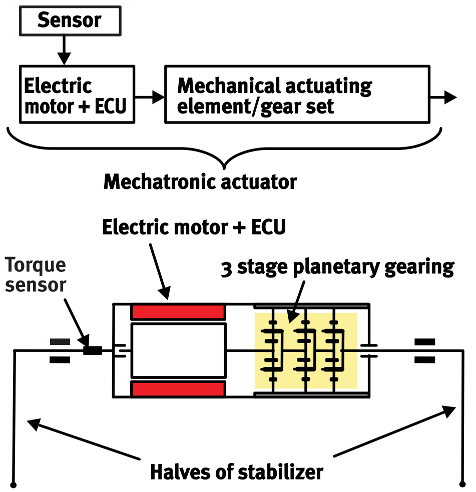


Figure 5 Structure of an actuator for roll stabilisation without compensation

or to extend the application limits "upwards", based on a 12 V on-board power supply. To do this, the electric drive is combined with a compensation module developed by the Schaeffler Group and therefore relieved of stress. Figure 6 is a schematic representation of this.

The left side of figure 6 shows a chassis with load-bearing springs and the torsion bar illustrated symbolically as a suspended beam with compression springs arranged on both sides. If a curved profile is attached to the centre of this beam on which a roller pretensioned by a spring can move, then the roller pretensioned by a compensation spring could move along this curved profile when the vehicle travels round a bend. This leads to a rotation of the suspended beam and the spring energy of the compensation spring is fed into the left spring of the stabiliser. In this way the stabiliser is pretensioned and the sideways tilt of the vehicle is reduced. When travelling straight ahead – if everything were free from friction – the energy from the left compression spring of the stabiliser is fed back into the compensation spring because this relieves itself of pressure when the vehicle is travelling straight ahead.

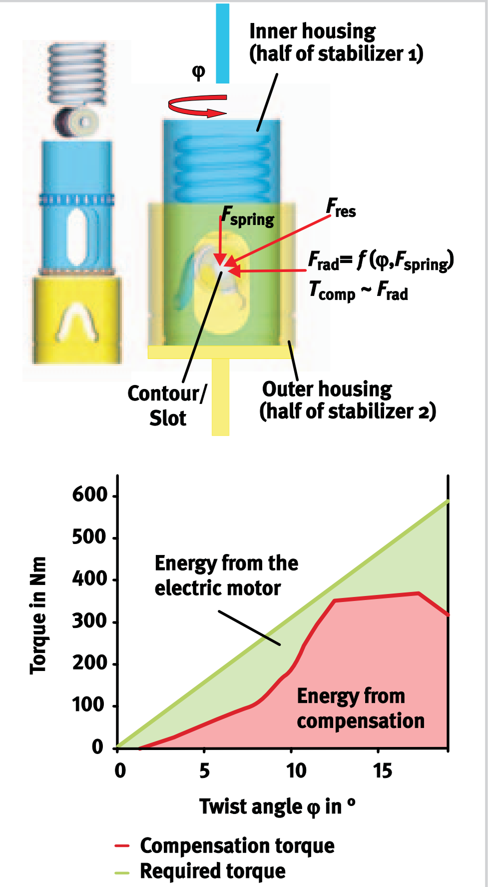


Figure 7 Structure of the compensation mechanism and saving via the compensation

The left side of figure 7 shows the individual parts of the compensation mechanism, consisting of the inner sleeve (blue), outer sleeve (yellow), the compensation spring and the roller. Now if the compensation module is integrated in the divided torsion bar (figure 7, centre), the roller is pretensioned by the compensation spring in the upper half of the housing (inner

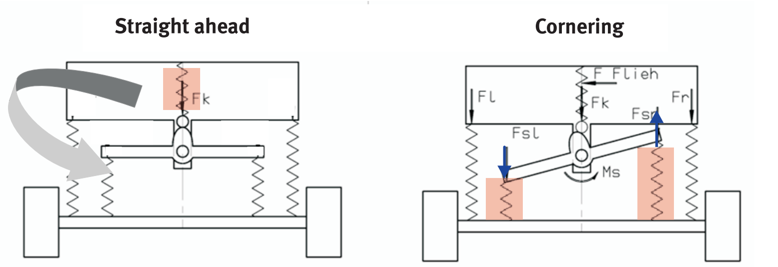


Figure 6 Principle of operation of the compensation

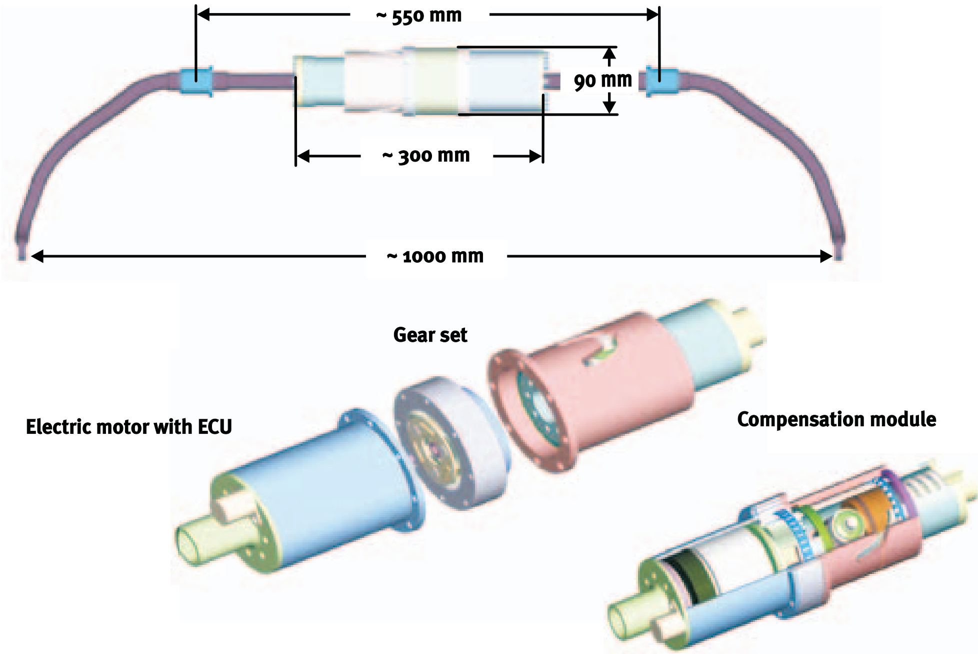


Figure 8 Structure and important main dimensions of the roll stabiliser

sleeve), which in turn is connected to the upper half of the stabiliser. The lower half of the housing (outer sleeve) which is connected to the lower half of the stabiliser with positive locking, forms a single unit with the V-shaped link. The inner sleeve is mounted in the outer sleeve so that it can rotate. Now if the compensation spring is relieved of pressure the roller rolls on the V-link and generates a rotational movement and a peripheral force – which multiplies with the lever arm (which is produced from the distance of the V-link to the centre line – induces a (bracing) moment in the actuator.

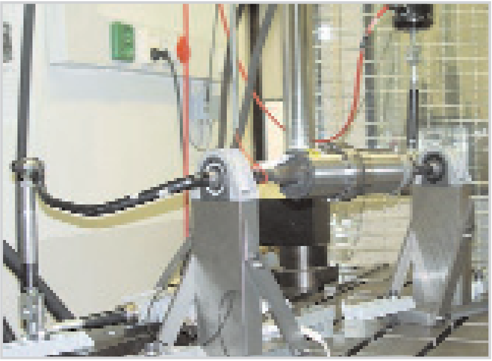


Figure 9 Roll stabiliser on the function test bench

On the right side of figure 7 the bracing moment of the stabiliser is entered over the angle of rotation (green line). The area created under it is the work which the actuator must apply. The work made available by the compensation spring is the part cross-hatched in blue. Therefore an electro-mechanical actuator switched in parallel must apply the work cross-hatched in red which leads to a significant improvement in the energy balance sheet for the actuator.

Figure 8 shows the structure of the electro-mechanical roll stabiliser from the Schaeffler Group. The actuator consists of the following main components:

- Electric motor with ECU
- Planetary gear set which is driven by the electric motor
- Compensation module, which is switched in parallel with the electric motor with the planetary gear set
- Halves of the stabiliser

Figure 9 shows the actuator on the test bench, which is used for determining its dynamic behaviour, durability and power consumption.

Roll Stabilisation – Results and Status of Development Work

In the development process, the foundations were created for simulating the behaviour of the actuator in the vehicle by integration of the simulation models of the actuator in an MKS-program. Furthermore, based on a single track model, a regulator was developed which initiates the actuator. After successful optimisation of various parameters in several iteration processes during the simulation it was possible to transfer the regulator and the initiation of the actuator to a rapid-controller-prototyping system and to prove their ability to function on the test bench. The fundamental mode of procedure in the development process was based on the "V-Model".

Examples are given below of some of the results of the development work from the simulation and the vehicle trial. Figure 10 shows the moment to be applied, the electrical consumption and the power consumed over time in the presence of square wave excitation. The lead time – i.e. the time in which the necessary bracing moment is built up – is 0.25s and is therefore 0.1s faster than with an actuator without compensation. In addition, the electrical and power consumption is approximately 50% lower during the process.

The electrical consumption determined in the simulation is confirmed by the vehicle test. In the vehicle test, it was possible to measure electrical power peaks for the battery current relevant to the load on the on-board power supply of a maximum of 15 A in the presence of square wave excitation (figure 11), thus proving the effectiveness of the

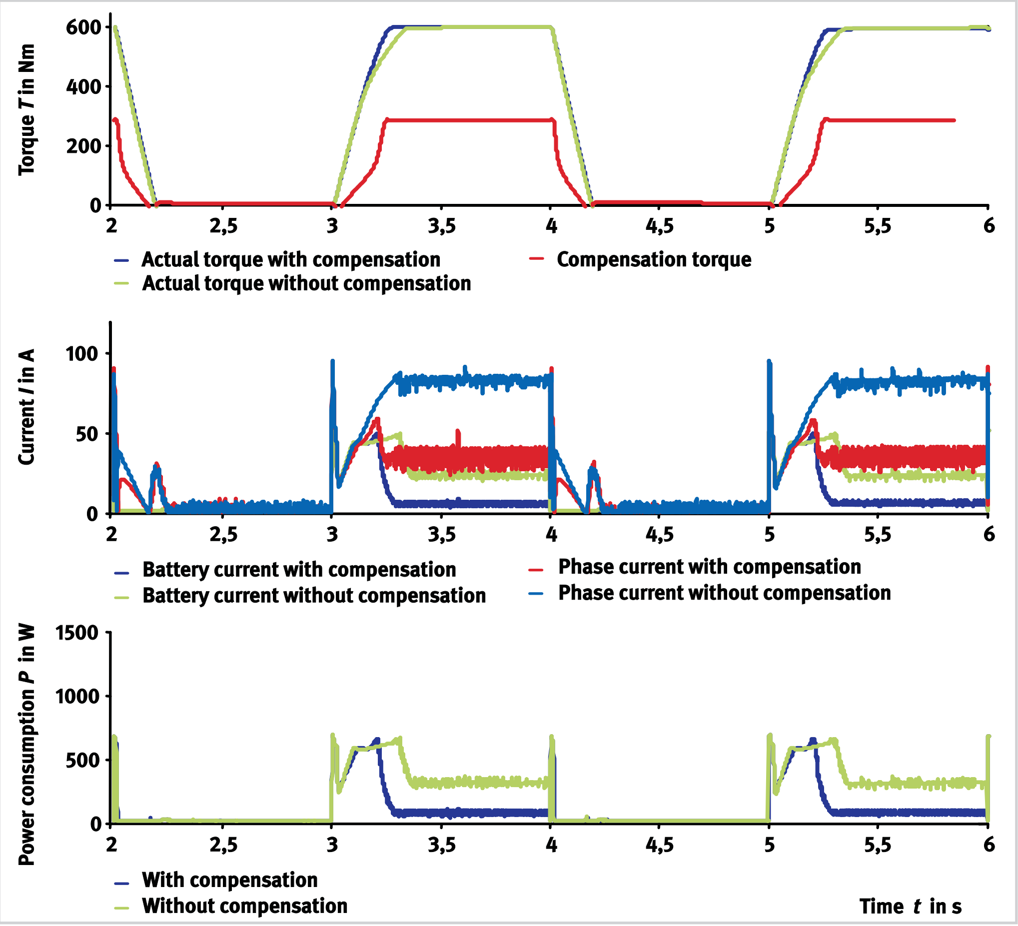


Figure 10 Simulation of the lead time, the electrical and power consumption over time

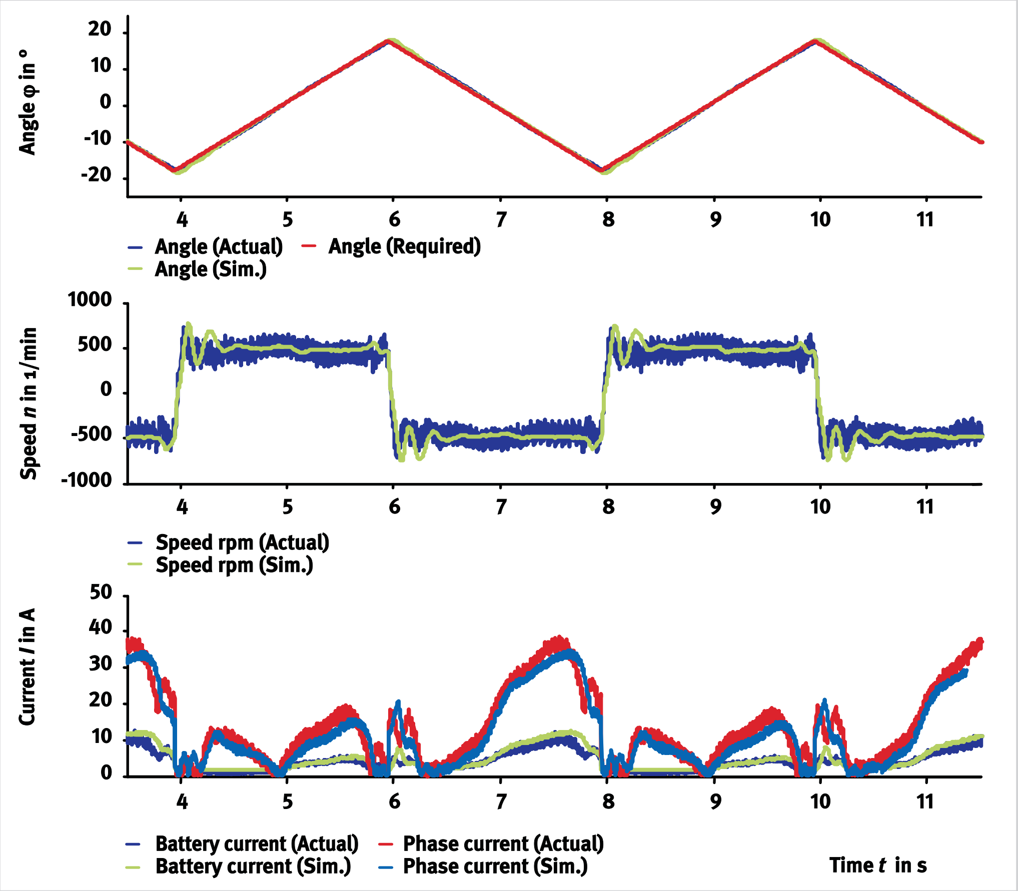


Figure 11 Comparison of measured electrical power consumption to simulation with the specified roll angle having a square wave pattern

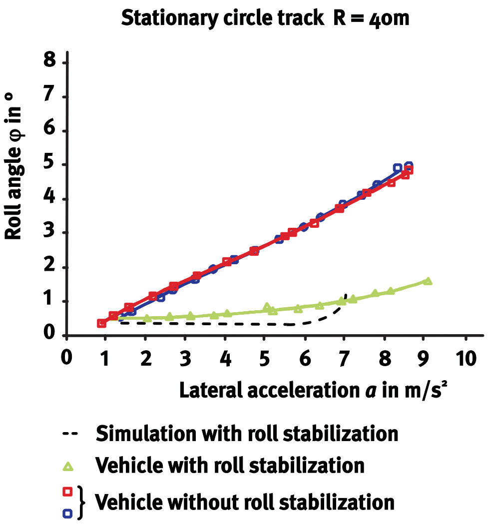


Figure 12 Results from the vehicle trial and simulation

compensation. Moreover, figure 11 shows a good correlation between the simulation and the electrical power pattern measured on the test bench.

Figure 12 shows an extract from the results of the vehicle test. A comparison is shown here of the roll angle over the transverse acceleration for a run on the circular track with a radius of R = 30 m. The comparison vehicles without roll stabilisation reveal a constant increase in the roll angle over the transverse acceleration. In contrast, the roll angle of the INA-vehicle remains almost constant and only permits roll when higher levels of transverse acceleration are reached to make the driver aware of the limit of adhesion by the tyres. The results of the simulation reveal a slight deviation from the vehicle test as in this case the compression of the tyres was only included in the model in a very much simplified form and a complex tyre model was not implemented.

Since the vehicle tests had a positive result, work is currently being undertaken on revising the design of the roll stabiliser. The aim here is to reduce the mass moments of inertia, decrease the space required and allow cost optimisations to flow into the design.

Mechatronic Linear Actuator

Electro-mechanical actuators are being used to an increasing extent everywhere where it is important to apply linear or rotational actuating movements without hydraulics for the reasons stated above. In this case, the basic configuration consists of the components shown in figure 5, electric motor with power electronics, sensor and gearing or mechanical actuating element. If the gearing is self-locking, no retaining forces/currents are required. However, as a consequence of the low efficiency, the power consumption during actuation is usually not insignificant. In contrast, an actuator optimised for efficiency has a lower power consumption and good dynamics, but in the presence of static loads, high retaining forces/currents are required to hold a position which has been reached. This is illustrated by the crane in figure 13 (left side).

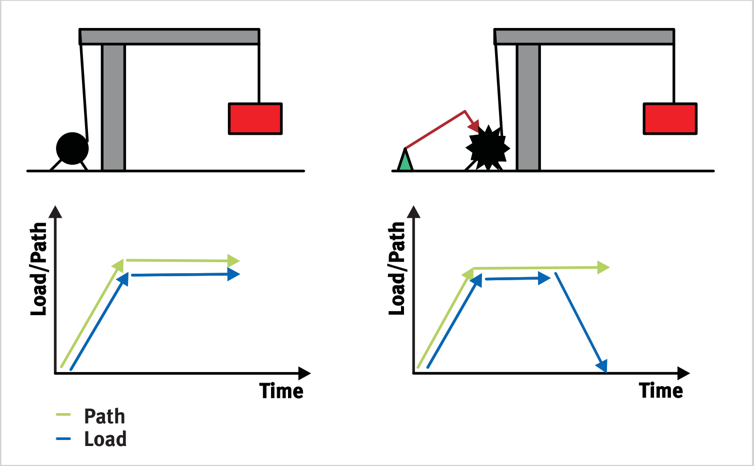


Figure 13 Actuator without and with locking mechanism

An energy improvement is achieved by combining the efficiency-optimised actuator with a locking mechanism, which "locks" the actuator under load in the position it has reached, as is shown on the right side of figure 13. This solves the problem of the conflict between the objectives, high efficiency and self-locking.

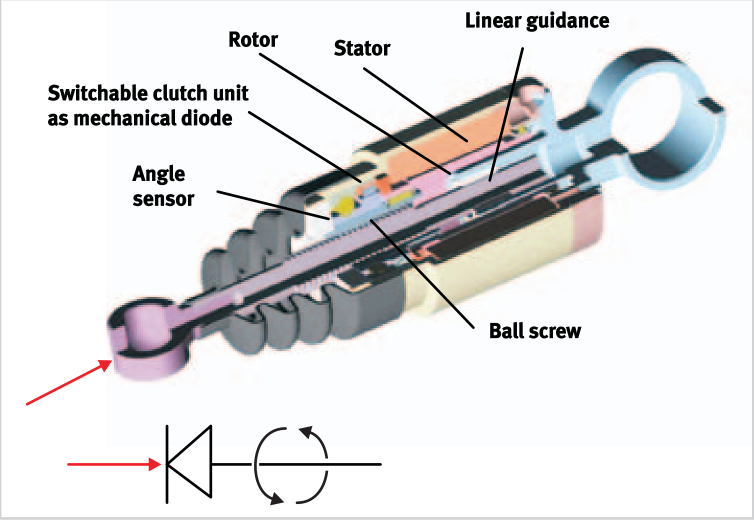


Figure 14 Structure of a linear actuator with switchable freewheel

Figure 14 shows the structure of an actuator of this type as a linear actuator. In addition to the electric motor and a ball-screw as the gearing, a freewheel which can be switched in either direction is integrated in the power flow of the actuator.

An analogy with an electrical diode is helpful in clarifying

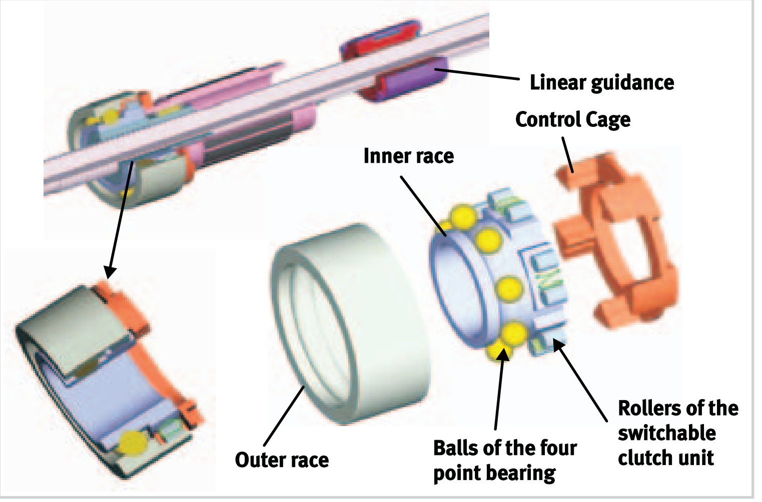


Figure 15 Illustration of the bi-directional freewheel

the function of the actuator whereby the comparison is only intended as an aid to understanding the concept as, strictly speaking, it is not accurate. As a simplification, you can say that all the energy which is brought into the actuator from the inside outwards – i.e. induced by the motor – reaches "the outside" where it is available for actuation. However, if external forces are acting on the actuator (illustrated symbolically by the red arrow), then the actuator is locked mechanically by the switchable freewheel, the motor is relieved of stress and is thus protected from high electrical power consumption.

If you separate the electric motor and the housing mentally from figure 14, then the mechanical components remain which are shown in figure 15.

if you follow the flow of power within the actuator, this produces the following cycle:

Electric motor receives current → rotor turns cage → rollers are released → nut turns → spindle is moved in a linear direction

The function of the switchable freewheel is shown in detail in figure 16. Figure 16 shows the freewheel when locked on the left side. An engaging moment on the inner race leads to the rollers locking, which are also designated the locking body. The lock is effective in both

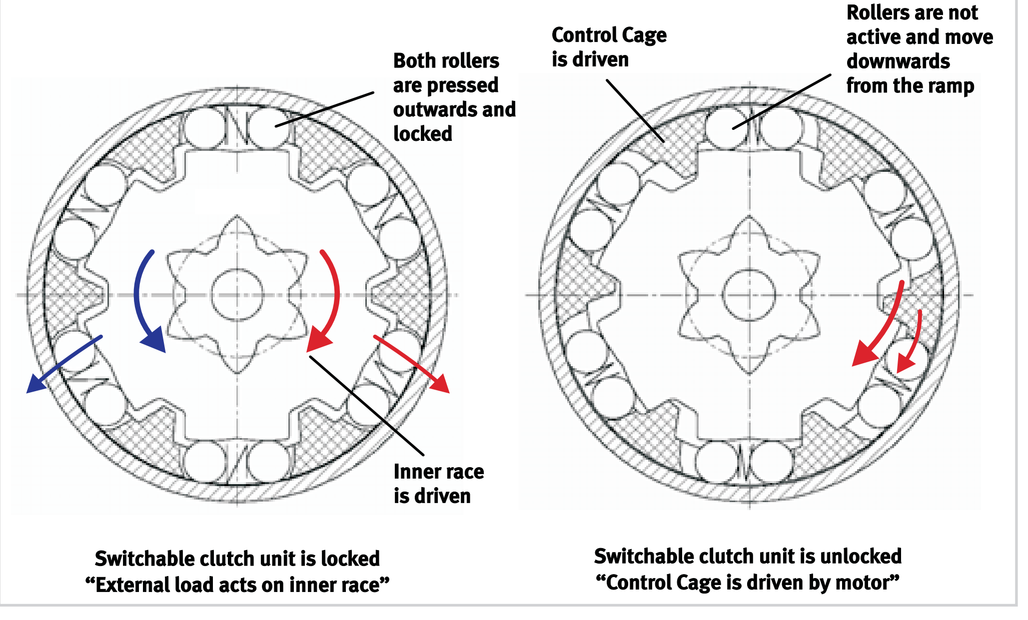


Figure 16 Mode of operation of the switchable freewheel

directions during this. On the right side of figure 16, the cage is driven by the motor and the free-wheel is unlocked The rollers are released by the cage. After releasing the rollers, the teeth of the cage engage in the grooves of the inner race and actuate/turn the downstream nut of the ball-screw, which leads to an actuating movement by the spindle.

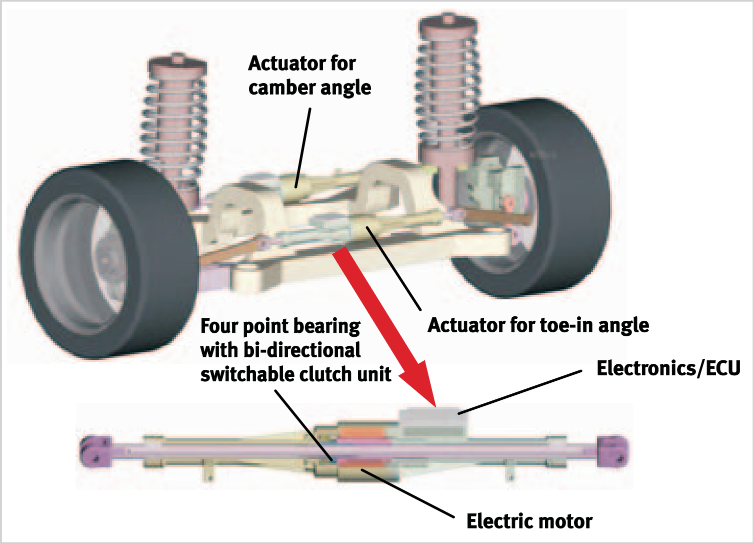


Figure 17 Actuator for the synchronous actuation of toe-in and camber angle on the rear axle

Requirements and Possible Applications

The actuator can be used to adjust camber and toe-in and for level control, amongst other things. In these systems the position under load must be held and/or locked. An electrical lock using an eddy current brake makes no sense either with regard to energy or on cost grounds. Important technical requirements are summarised in the table below:

Requirements for toe-in/camber actuation
• Angle: +/-3°
• Adjustment path = approx. 25 mm (dependent on the pivotal point)
• Actuation speed = 0.1 m/sec
• Actuation force up to approx. 7 kN, overload = 15 kN

The above-mentioned requirements refer to vehicles of the upper mid-range.

Figure 17 shows a rear axle with actuator for the synchronous actuation of camber and toe-in.

If the angles for camber and toe-in are to be adjusted individually for each wheel, this means that a total of 4 actuators are required for actuation (figure 18). Therefore it is possible for the toe-in and the camber to be adjusted as necessary and independently of each other. When travelling straight ahead, this permits driving with minimal toe-in, regardless of load, and enables the tyre tread to be positioned in contact with the road surface horizontally and when travelling round bends or taking avoiding action the necessary toe-in can be set at up to 3°.

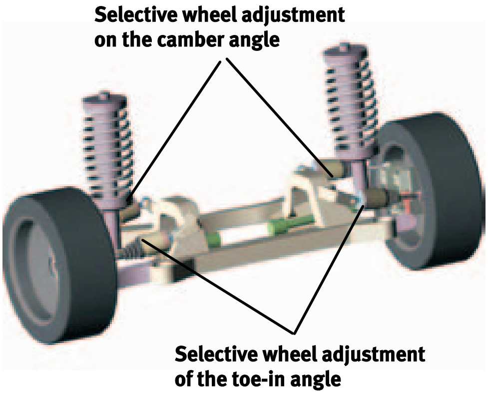


Figure 18 Actuator for the individual actuation of toe-in and camber angle on the rear axle

The most important features relevant to the end user are summarised in the table below.

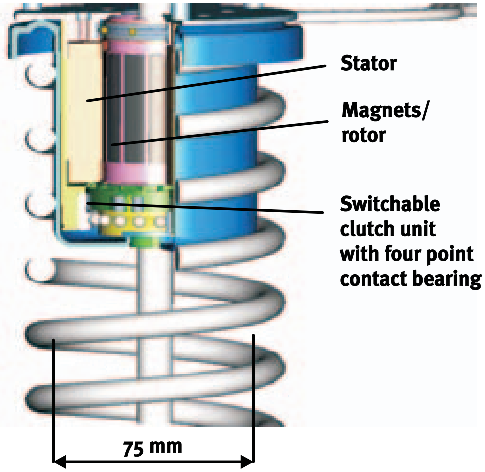
Features – toe-in actuation	Features – camber actuation
• Low tyre wear • Gain in safety/stability, especially when braking on bends in μ-split conditions • Optimised stability for trailer operation • Optimised response behaviour to steering commands • Reduction of the turning circle	• Higher transverse acceleration • Reduced tyre wear • Reduced brake path • Higher tyre load-bearing capacity

Electro-Mechanical Level Control via Base Point Adjustment of the Spring

In addition, the electro-mechanical linear actuator for adjusting the base point of the spring can be inserted advantageously in the suspension strut, thus producing the level control for the vehicle (figure 18). This enables load compensation to be achieved on the rear axle. If, in addition, an actuator of this type is installed in the suspension strut on both front wheels, general lifting/lowering of the vehicle is possible as is undertaken at present in sport utility vehicles using pneumatic springs.

The adjustment takes place quasi statically in a time of 10 to 15 seconds to keep the load for the on-board supply as low as possible. The method of construction selected enables the integration of the suspension strut with an inner diameter for the spring of 75 mm. The load data from figure 19 represent the figures for a mid-range vehicle.

As an alternative to the linear actuator, a so-called spring strip actuator can be integrated in the suspension strut. In this case, an inner rotor rotates within a spring strip (figure 20). The track rollers are roller-bearing mounted and enable



Load	7500 N
Stroke	60 mm
Time	10 s
Pitch	3 mm
Efficiency	85 %

Figure 19 Base point adjustment of the suspension strut with linear actuator

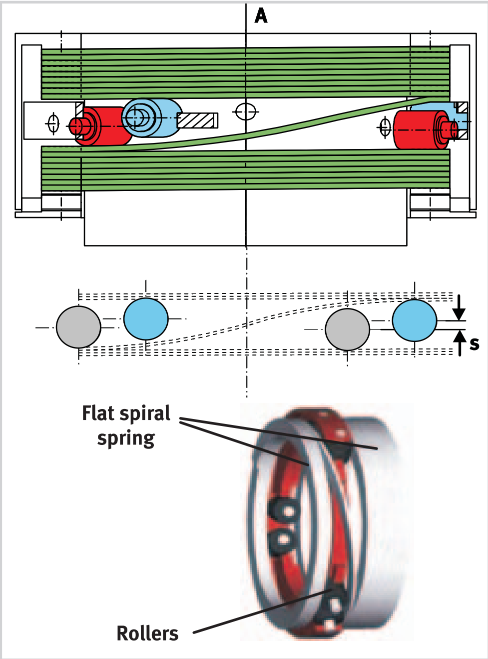


Figure 20 Schematic diagram of the spring strip actuator

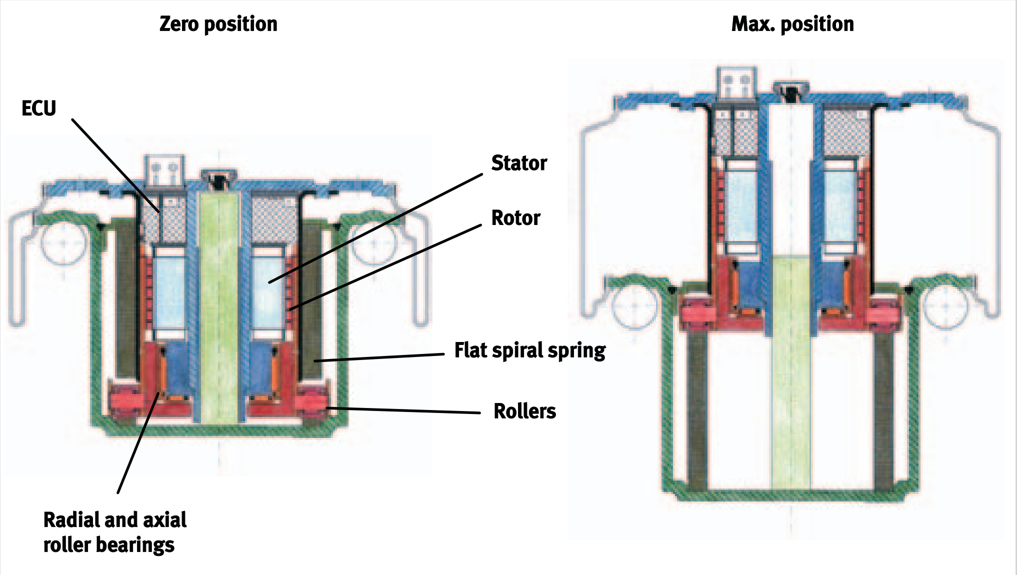


Figure 21 Spring strip actuator integrated in the suspension strut

the rolling movement of the inner race to be low in noise and friction within the spring strip. The rotation within the spring strip causes the inner race to generate an advancing movement which can be used to adjust the suspension strut.

In figure 21 the spring strip actuator is integrated into a suspension strut with an internal spring diameter of 75 mm. The arrangement also permits the integration of the ECU.

As a consequence of its design principle, the spring strip actuator has a pitch of 0.5 to 1.3 mm, which corresponds to the thickness of the sheet metal used in the spring strip. In addition to the latter, the actuator has an efficiency of 40 %, is self-locking and needs no locking mechanism. If a sufficiently long adjustment time is available (10 to 15 seconds), the loading on the on-board power supply is relatively low – despite the low efficiency – because the load is applied in a quasi static manner. The spring strip actuator competes with a screw drive, has a comparatively low pitch, but is considerably more efficient.

Conclusion

The electro-mechanical actuating mechanism is on the move and a response consisting of an electric motor, sensor and gearing is often not sufficient to offer the right or the competitive solution. The Schaeffler Group is therefore developing solutions which take the matter further and have an improved energy balance sheet. It is clear that the necessary knowledge and experience within the Group have been used in a targeted manner for this purpose and that solutions which go further with regard to technology and energy have been developed in comparison with the current state of the art. Implementation in mass-production will take place within the next 5 years.