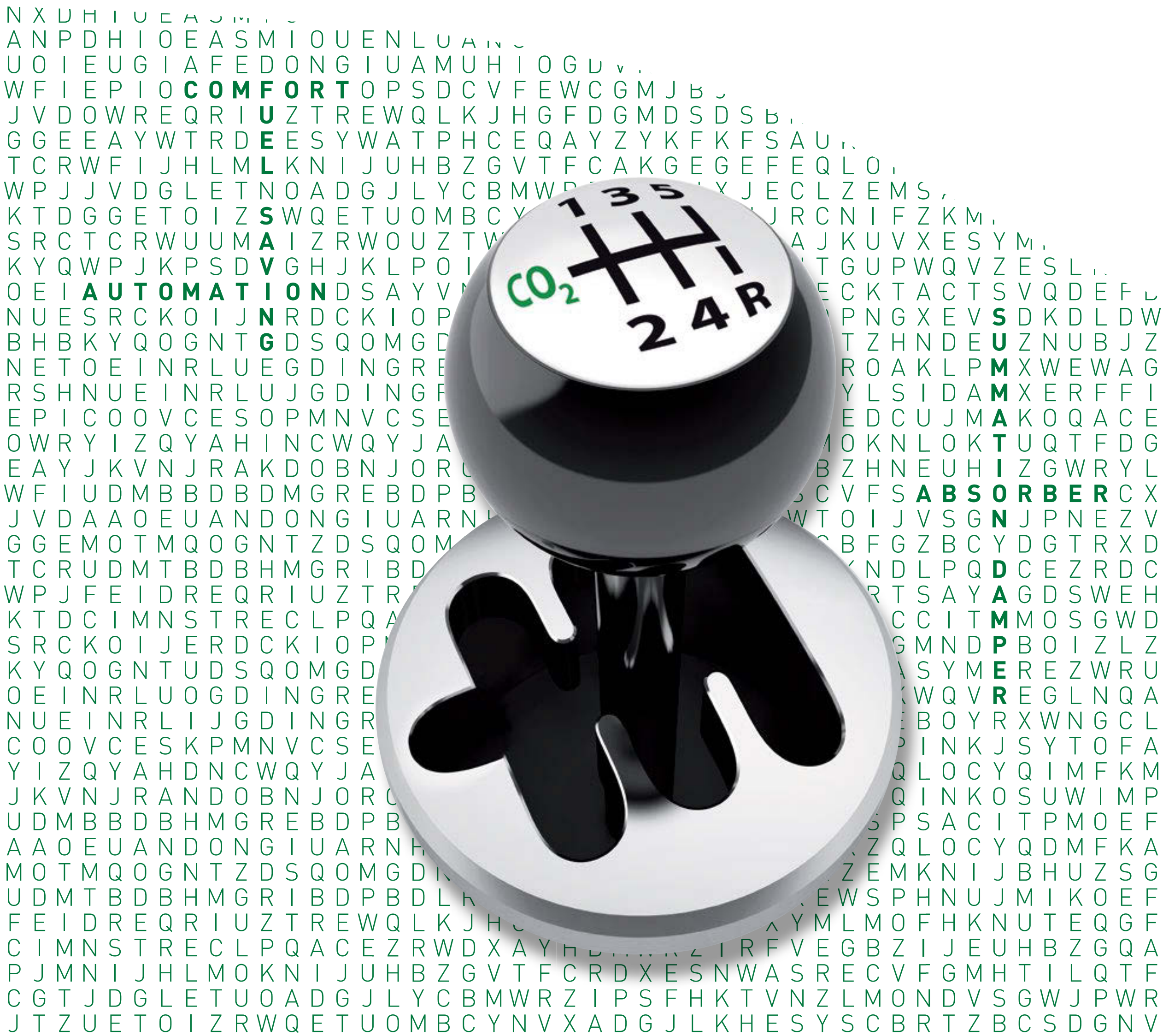
COMFORT
FUEL SAVING
AUTOMATION
SUMMATION
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The future of the manual transmission

Jürgen Kroll
Markus Hausner
Roland Seebacher

4

Introduction

The internal combustion engine will continue to be the dominating force behind individual mobility for some time to come. The biggest challenge in this context, however, revolves around lowering fuel consumption in line with ever more stringent legal requirements while at the same time maintaining driving comfort and pleasure. All aspects of the engine and transmission must be revisited with equal attention, whereby driving strategies that minimize consumption are key to achieving designated performance targets. To improve on these aspects, the transmission must be further automated and coupled with electrification measures. The conventional manual transmission is therefore coming under pressure and runs the risk of being „overrun“ by other designs at least in the developed markets. On the other hand, manual transmissions remain attractive for cost reasons and may continue to play a key role in the future if a way is found to develop systems that also enable „sailing“ and other efficient drive modes to be achieved in vehicles equipped with a standard transmission.

Adopting a partially automated setup for the manual transmission would also open the door to integrating comfort, convenience, and safety-oriented functions without additional cost. Fuel consumption could then be further reduced by opting for longer gear ratios, for example. Misuse, or abuse of the clutch, causing it to overheat, can be reliably prevented thanks to the partially automated setup.

The end result – "extreme" downspeeding – has disadvantages, however, especially when it comes to future engines, where few cylinders and/or feature cylinder deactivation will be widely used. In order to realize the comfort and convenience expected by end customers, ever better systems for isolating, or dampening, vibrations, must be developed. Although the centrifugal pendulum absorber (CPA) developed by LuK also offers good potential for the coming years, in the long term, even more capable systems will need to be integrated.

Initial situation – Manual transmissions under pressure

In addition to the effort expended to further reduce the consumption of the engine itself, equal focus must be placed on developing a transmission that optimizes the efficiency of the entire powertrain. The manual transmission is initially positioned quite well in this regard, since it offers a high level of operating efficiency. Additional, conventional improvement measures, such as reducing frictional loss and increasing the number of gears and gear ratio spread, are limited in their potential, however. The transmission can therefore only play a much more effective role if it enables the internal combustion engine to operate under conditions that allow it to burn as little fuel as possible. In terms of today's engines, this translates to low operating speeds or deactivation of the engine as soon as the driver's power requirement makes this possible. It goes without saying that a manual transmission does not offer the ideal setup for tapping this potential and is the reason why it is receiving more and is increasingly under pressure. Apart from visual shift point recommendations, it is not possible to implement any other, more sophisticated, fuel-saving shift strategies. In addition, hybrid and advanced start/stop functions require a specific, baseline level of automation.

Viewed from this perspective, automation is no longer only driven by the needs and wants of buyers looking for greater comfort and convenience, but is absolutely necessary

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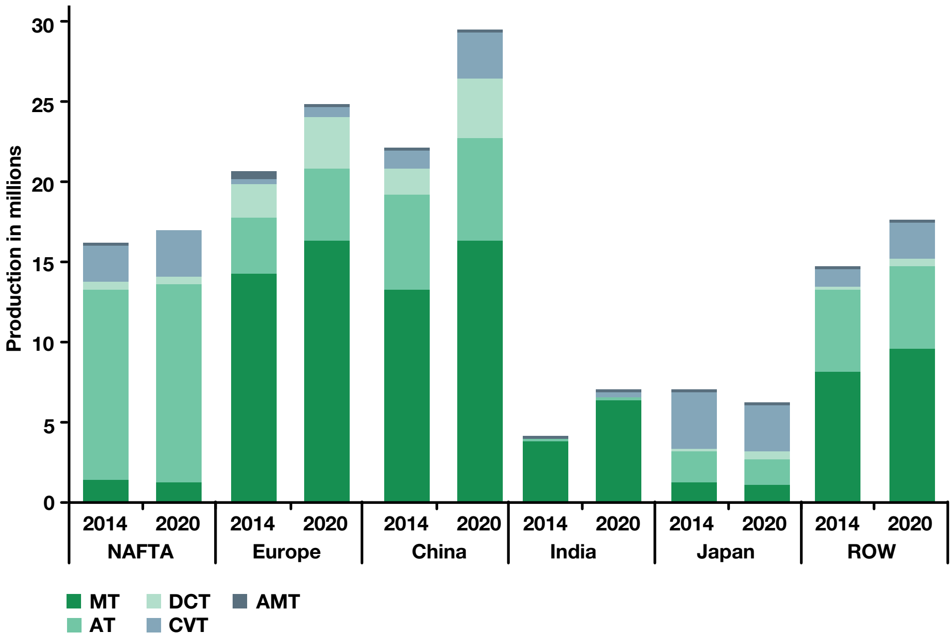


Figure 1 Global vehicle production based on transmission technologies (source: CSM, Aug. 2013)

in several vehicle categories in order to comply with tomorrow's CO_2 limits and avoid expensive penalty payments. Vehicles currently permitted to expel 135 g/km will only be allowed to produce in Europe 130 g/km in 2015, and in 2020, this limit will drop to 95 g/km.

Against this backdrop, the manual transmission isn't out of the game yet, as you might think, since current estimates point in the opposite direction. The manual transmission still enjoys the highest share of the market, especially in the entry vehicle segments in the BRIC nations and in Europe (Figure 1).

If this predominant market position is to be maintained in the future, the manual transmission will have to be upgraded. While emphasis needs to be placed on exploiting the potential available for reducing fuel consumption, aspects pertaining to convenience and comfort, such as launch or stop-and-go assist managing traffic jams, cannot be overlooked.

New opportunities for the manual transmission

Analyzing or assessing potential areas in which consumption can be reduced is best facilitated by conducting tests in line with the established driving cycles to pinpoint in which phases certain measures can offer beneficial results. The stop rate of 20 % in the New European Driving Cycle (NEDC), for instance, led to the widespread implementation ofstart/stop systems in Europe, which can reduce overall fuel consumption in the range of 5 %. The logical enhancement of this technology is to switch the engine off during normal driving, which in turn means that it has to be mechanically decoupled from the rest of the powertrain. This is what is known as "sailing" and theoretically is always a practical mode to be in when vehicle deceleration forces lie between those of driving

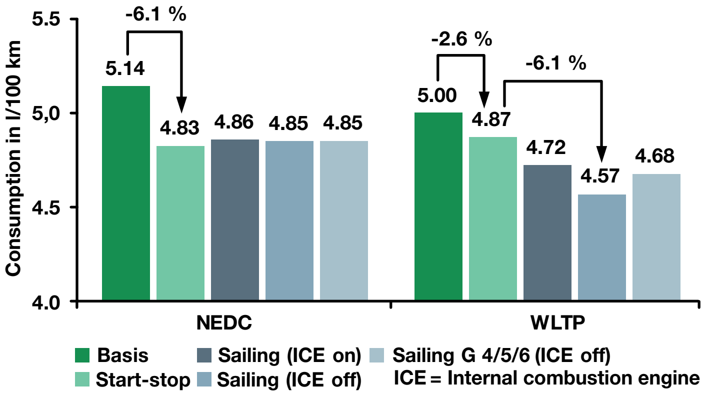


Figure 2 Consumption benefits of start/stop systems and sailing across different driving cycles

resistance and engine braking torque. Current NEDC do not incorporate these phases, which is why the sailing function does not bring about any concrete benefits when comparing posted fuel economy numbers. This will not be the case when the WTLP (Worldwide Harmonized Light Duty Test Procedure) takes effect, however. Internally conducted consumption simulations with a 2.0-liter diesel engine (Figure 2) show that a reduction in fuel consumption of more than 6 % is possible when a sailing strategy is incorporated. Even when sailing is only used in higher gears (4/5/6), it is possible to reduce consumption by approximately 4 %. This is counteracted by the decreased benefits of modern start/stop systems under WLTP conditions, however, which perform more than 50 % worse due to the lower stop rate.

The sailing function currently can only be combined with an automatic transmission and has already reached volume production for several models. The transmission itself does not need to be fully automated, however, and an automated clutch to disconnect the engine from the transmission theoretically could be sufficient enough. Unlike vehicles with an automatic transmission, their manually shifted counterparts are required to hold a certain gear in a defined speed range under cycled testing. If an engine is to also operate efficiently at low speeds, the gear ratios provided must be adapted accordingly. The potential here should not be underestimated, since a 10 % drop in engine speed reduces consumption by 7 % when traveling at a constant 70 km/h in fifth gear (example simulation with a 2.0-liter diesel engine); under NEDC and WLTP conditions, approximately 5.6 % and 2.5 % less fuel is consumed, respectively. Start-off performance would suffer somewhat, however, as comfort levels decrease and clutch wear increases. An automated clutch could provide the answer here, too, however, by resolving this inherent conflict. The higher operative requirements could be compensated for with automated or assisted

Figure 3 Motivation for clutch automation

launch procedures, for example, and additional safety and reassurance could be provided by incorporating a strategy that prevents excessive heat to the clutch.

Combining sailing with lower engine speeds can theoretically reduce consumption by 5 to 10 %, depending on the driving cycle. Integrating an automated clutch assembly would open up even more possibilities (Figure 3).The higher level of automation associated with this is perfect for setting the stage to transition to a hybridized manual transmission. Coupled with an additional electric drive, such as an electric 48-volt driven axle, it also would be possible to offer functions like electric launch and creeping in a special stop-and-go mode. Driving at constant speeds could likewise take place without the assistance of the internal combustion engine (electric sailing), and during braking, the effectiveness of an energy recovery system could be increased by the drag loss of the internal combustion engine. Internal calculations have shown that the total reduction in fuel consumption when all measures are combined can exceed 20 % under cycled testing conditions [1].

Increased comfort and convenience represent an additional aspect that complements the lower levels of consumption. In an automated stop-and-go mode, the driver could take his left foot off of the clutch pedal, making it much easier to drive in congested traffic while at the same time minimizing wear and tear on the clutch.

Figure 4 ECM at market launch (volume production) and in a concept vehicle

Automation of manual transmission – Old friends for the 21st Century

The electronic clutch management system (ECM, Figure 4) developed by LuK, which allows the driver to shift without having to engage the clutch, was launched in 1993 [2, 3]. What started out as a great idea did not win over end customers, however. Vehicles equipped with an ECM were well received by only a few people and are no longer on the market. One of the reasons why acceptance was so low presumably has to do with the fact that when a vehicle comes only with an accelerator and a brake pedal (i.e. no clutch pedal), it very much resembles a vehicle with

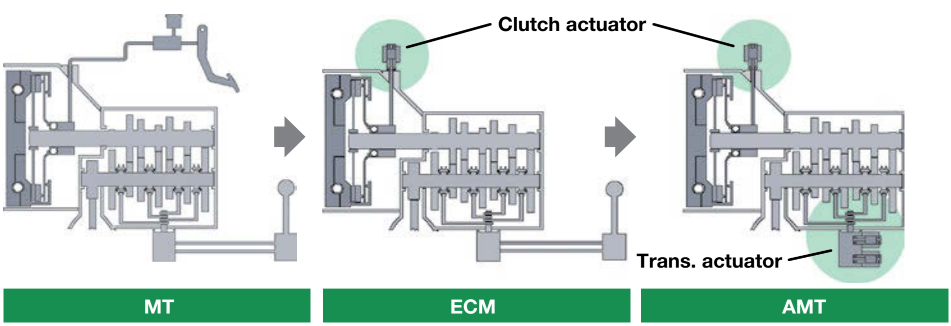


Figure 5 Automated manual transmission

a conventional automatic transmission, and the assumption is made that an ECM should behave in this manner, which it cannot due to its different design.

The automated manual transmission (AMT, Figure 5) also debuted in volume-produced vehicles around this time and competed directly with the ECM. Today, even this technology has not been able to win over customers and is currently offered on selected models only. This lack of acceptance can be attributed to the noticeable interruption in tractive power, which puts the AMT at an immediate disadvantage to the automatic transmission when it comes to comfort. The global market share for vehicles equipped with an AMT is under 1 %, making this type of transmission by far the one with the lowest unit quantities when viewed in the context of the other transmission technologies available.

It therefore almost goes without saying that previous attempts to automate the manual transmission have been less than fruitful, as the unit did not impress drivers enough in terms of enjoyment or comfort. Today, however, new opportunities have presented themselves. The ECM and the AMT both provide a solid basis to facilitate the aforementioned operative strategies for reducing consumption.

There are other ways to automate the manual transmission, however, without having to forego the clutch pedal.

Clutch by wire – Intelligent clutch

One well-known concept is the clutch-by-wire (CbW) design. For the driver, this transmission very much resembles a conventional manual transmission because three pedals are provided and there is no immediate sense of automation involved. Automation is, in fact, working "behind the scenes", since actuating the clutch pedal merely serves to communicate the driver's intention, which is detected by a position sensor. The clutch is actually operated by an actuator assembly. As the name "by wire" no doubt reveals, this system does not have a hydraulic or mechanical connection that links the clutch with the clutch pedal.

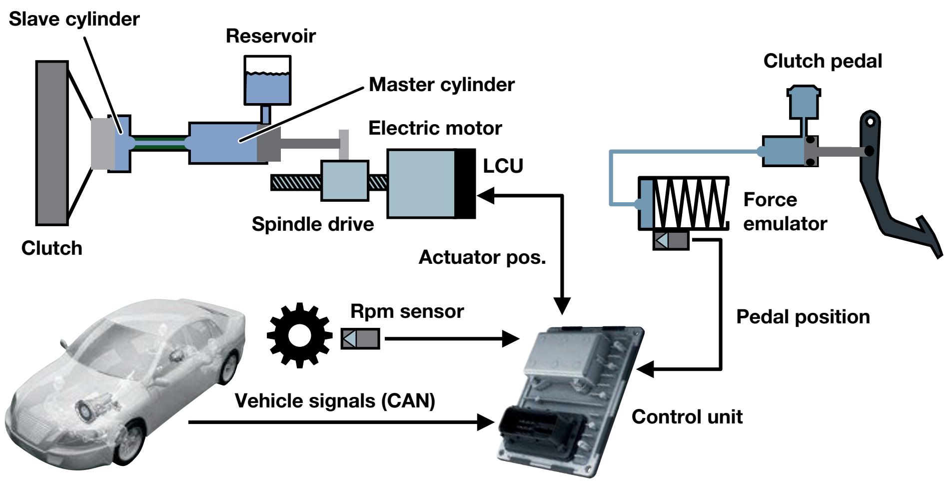


Figure 6 Design and components of the clutch-by-wire (CbW) system

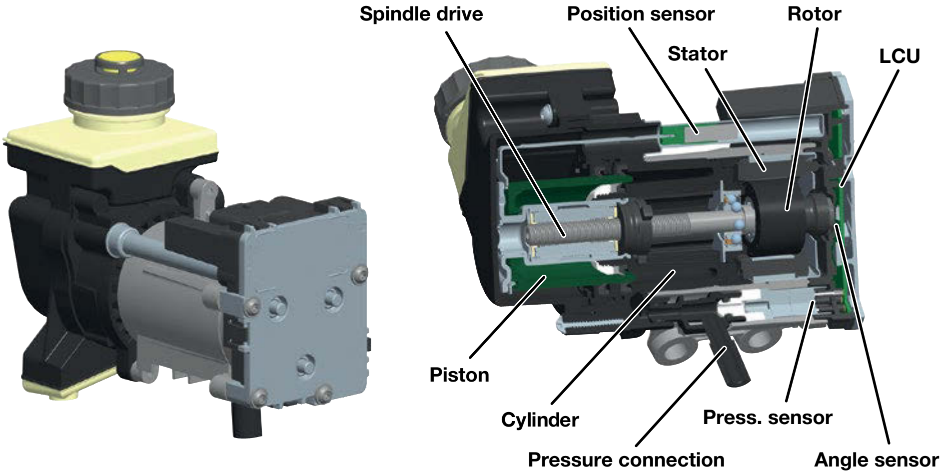


Figure 7 Hydrostatic clutch actuator – HCA

LuK has already presented the technology several times as a way to bring the manual transmission up to date, with design work focusing on improving comfort levels with regard to using the clutch, accelerating from a stop, and improving NVH behavior. The inherent problem with this approach, however, was that the functions offered did not lead to a favorable cost-benefit ratio. The concept was then no longer pursued from the original design perspective and has never entered volume production.

Figure 6 depicts the architecture of a clutch-by-wire system. The input data required by the clutch control unit comprises information about the vehicle (CAN) and the driver's intent (pedal position) as well as additional parameters such as transmission speed, which are provided by on-board sensors. Predefined strategies then determine the target clutch torque on this basis, and the system can correct driver inputs as required. For example, if the driver inadvertently misuses the clutch or does not coordinate it properly with the gas pedal which can cause the engine to stall, the system is clever enough to override the driver's commands.

In this arrangement, the physical release force of the clutch no longer acts on the pedal, which means that this must be emulated to provide for a realistic experience. Schaeffler has addressed this need by developing a new product that appeals from a cost and installation perspective. The result is a very compact force emulator that replaces the conventional hydraulic master cylinder while mirroring its dimensions (refer to [4] for details).

The hydraulic clutch actuator (HCA, Figure 7), also developed by Schaeffler, can likewise be fitted to actuate the clutch assembly and is described in detail in [5]. This actuator technology was designed specifically for hydraulically actuated clutches as found in automated transmissions and is now being used in volume production double clutch transmissions.

The inherent benefit of the HCA lies in its universal adaptability. Not only can it be accommodated without having to make major modifications to the vehicle; it can also actuate and control a CSC as well as a semi-hydraulic slave cylinder. The latter may not represent the best configuration, however. The internal axial stroke drives a hydrostatic system that, in turn, produces an axial stroke on the release lever of the clutch. It is therefore practical to actuate the

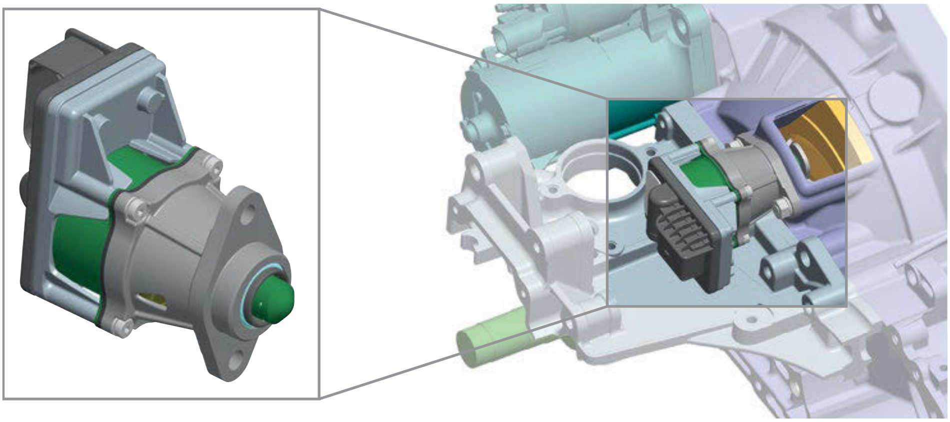


Figure 8 Electromechanical actuator for CbW – Compact and performance oriented

release lever directly instead of indirectly, by means of hydraulics. This has prompted Schaeffler to develop a compact, performance-oriented solution (Figure 8). The design objective is to replace the semi-hydraulic cylinder with an electromechanical actuator without having to make substantial modifications to the transmission, since this makes it possible to add an automated clutch to an existing transmission with minimal additional cost.

In an effort to enhance flexibility still further, Schaeffler has taken an additional step by developing a modular actuator system that allows the same base actuator to be used in all applications (Figure 9). This actuator houses all electronics, including the sensors, electric motor, and a special spindle drive for manual clutches (self-locking in the closing direction). Depending on the constraints of the application, the base actuator is mated to a mechanical or hydraulic module, which also serves as the connection point to the transmission. Development and system costs are minimized as a result, which is absolutely required if these systems are to be offered in conjunction with price-sensitive manual transmissions.

An additional description of this system and current developments in actuator technology as pursued by Schaeffler can be found in [6].

The design requirements for the actuator are comparably high with respect to the aforementioned possibilities for automating the manual transmission. The ECM and CbW in particular require a pronounced dynamic response to also enable fast gearshifts. If progress is made to considerably reduce these requirements, costs can be lowered further. With this in mind, Schaeffler has taken a new direction whereby the clutch is no longer operated by an actuator every time.

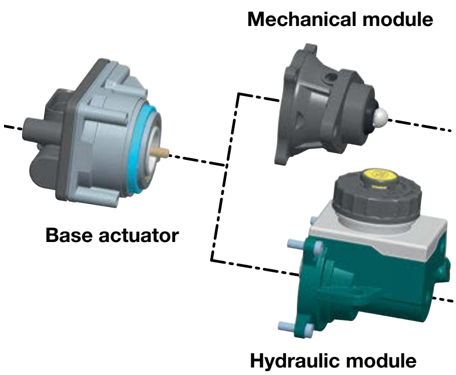


Figure 9 Modular actuator concept for maximum flexibility

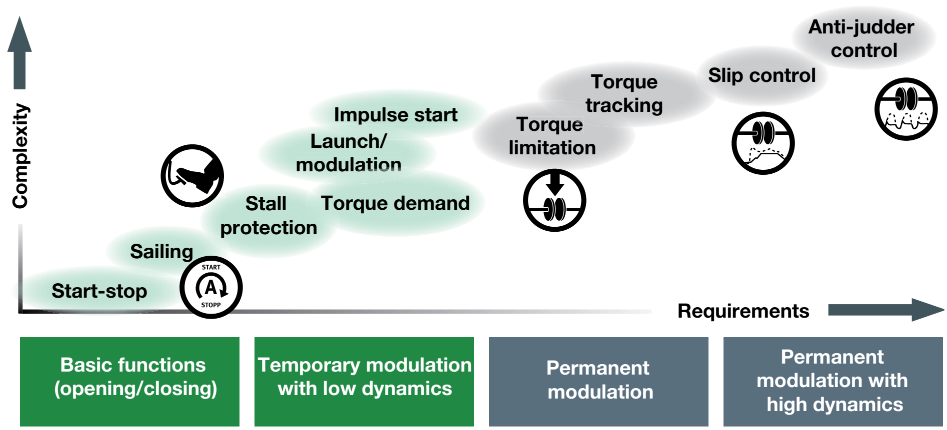


Figure 10 Actuator requirements versus functions

MT*plus* – Partially automated alternative

The underlying idea is to arrange an actuator in parallel with the release system to considerably reduce the actuator performance or capacity required. Consideration must also be given to the functions that can still be executed, however, and whether the remaining added value can justify an automated setup. Figure 10 provides a rough estimate or outline in this context by assessing several functions based on dynamic performance and application times as pertinent evaluation criteria. The highest requirements relate to functions for reducing vibrations. The requirements for accelerating from a stop and sailing are small by comparison as they do not require high dynamic response or ongoing clutch modulation.

According to this estimation, a smaller actuator would already offer sufficient potential for upgrading a manual transmission and make it possible to include the func-

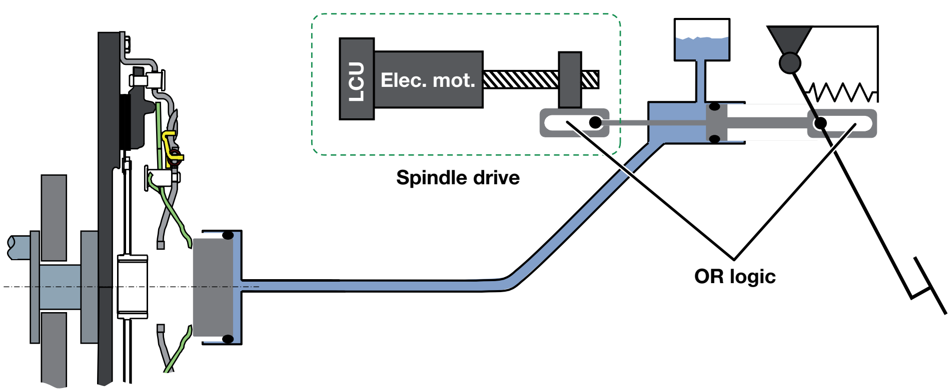


Figure 11 Basic concept of MTplus partial automation with OR logic

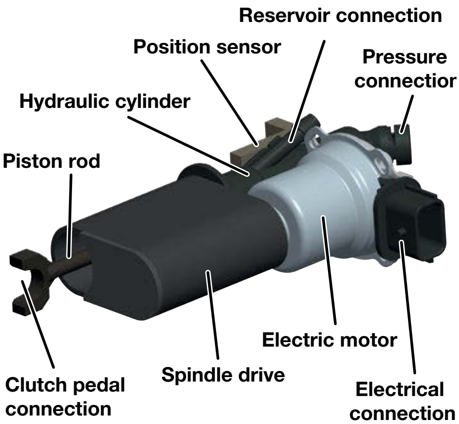


Figure 12 Example of an active master cylinder (OR logic)

tions mentioned above for reducing consumption.

The challenge is to find a suitable actuator concept that allows a clutch to be actuated conventionally and automatically. Steps must also be taken to ensure that the actuator does not interfere with foot-actuated operation and that the driver always has complete control over the vehicle.

Detailed concept studies were conducted to find solutions for this application scenario. The basic concept devised is shown in Figure 11 and has two defining characteristics: 1) At no time when the actuator is actuated does this translate into the clutch pedal being moved and 2) the release position of the clutch is well defined by OR logic. This, in turn, ensures that the driver's intent is highly prioritized at all times.

The sketch provided in Figure 11 characterizes an active master cylinder in principle, with a structural design shown in Figure 12. The electric motor with spindle drive is arranged next to the master cylinder. The connections linking the pedal and spindle drive to the piston rod allow only one force to be transmitted in the disengaging direction, which correlates with the OR logic.

An active master cylinder has noticeable drawbacks, however, including a greater risk of noise being transmitted by the electric motor to the interior, additional installation space required in the already cramped area surrounding the cylinder, and little to no universal adaptability. This type of actuator would have to be modified or redesigned in many cases for different application scenarios, which does not make it very attractive from a cost standpoint. The same holds true for the majority of installation arrangements near the slave cylinder, which likewise lead to moderate results.

Integrating the actuator in the hydraulic

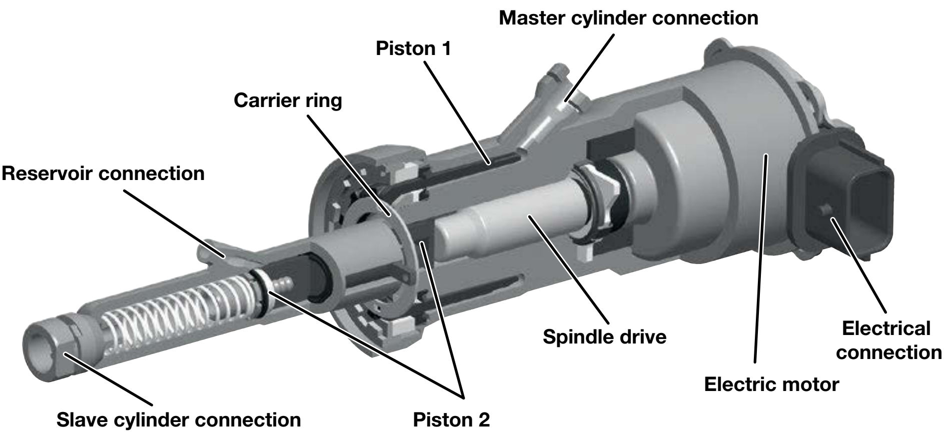


Figure 13 Actuator variant for MTplus with two intermediate pistons

pressure line, on the other hand, is much more favorable with respect to installation space and adaptability. In this setup, the actuator unit is positioned where it can be physically accommodated and is connected to the hydraulic line. A direct transfer fom the design shown in Figure 11 leads to an intermediate cylinder with two pistons which divide the hydraulic system (Figure 13). During automated actuation, piston 2 is driven directly by the actuator, while piston 1 remains stationary.

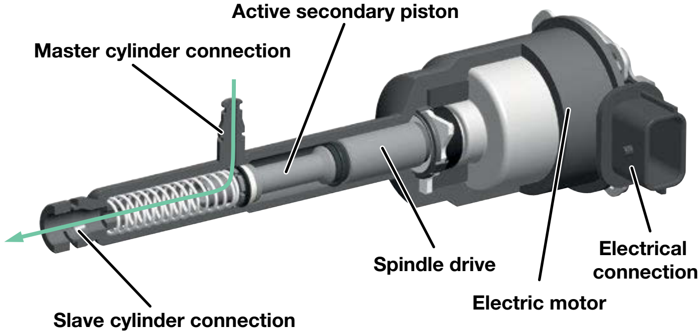


Figure 14 Alternative intermediate piston variant without additional loss encountered during foot-operated actuation

During manual, foot-operated actuation, piston 1 drives piston 2 by way of the carrier ring, which in turn leads to two drawbacks: 1) The seals produce additional friction and 2) the “sniffing” function required of the piston 2 cylinder further minimizes travel.

To counteract these drawbacks, design work is being carried out on an alternative variant that does not call for the release system to be permanently split into two separate parts (Figure 14). The result is a direct fluid path extending from the master to the slave cylinder (blue arrow) during foot-operated actuation, with minimal additional loss encountered. In automated mode, the active intermediate piston blocks the inlet access point of the master cylinder and assumes actuation of the clutch. Another problem area that needs to be addressed for this concept is ensuring a smooth transition when a driver override input is received. To this end, different valve and reservoir arrangements are currently being investigated (not shown in Figure 14).

System comparison – Limitless possibilities

The previous sections discuss a number of possibilities for automating the clutch used in a manual transmission. Figure 15 compares each of these variants side by side. The most consequent variant is the ECM, which does away with the clutch pedal and only senses driver inputs through the gear selector. The CbW offers similar possibilities at comparable cost. Although the driver must engage the clutch, all direct actuations of the clutch are executed by an actuator as is the case with the ECM.

The new MTplus concept was devised to offer a cost-effective alternative with a reduced functional scope by partially automating the clutch assembly. Unlike the ECM and CbW, the clutch is only automated when accelerating from a stop in gears 1, 2, and R; when the driver shifts to higher gears, the clutch is operated manually only. The design challenges specific to this concept are to provide for good operability while optimally coordinating actuator and foot-operated actuation inputs. Further analysis will be conducted in a trial test using a demonstrator. The following benefits

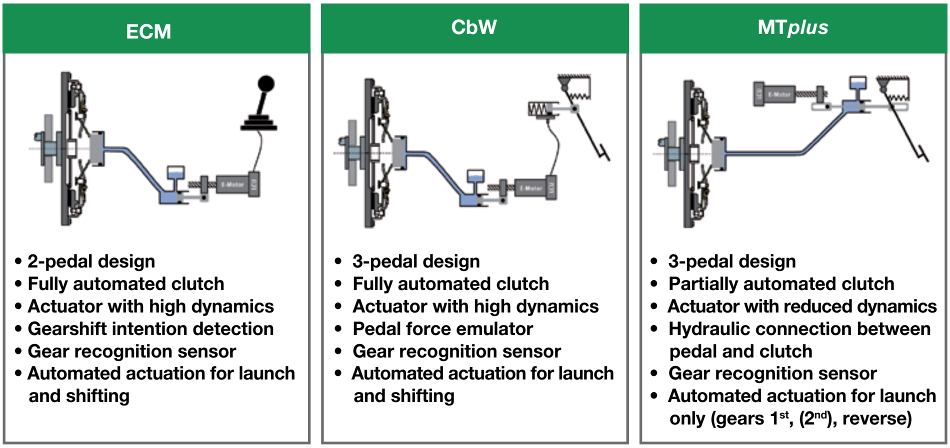


Figure 15 Variations of clutch automation for manual transmissions

are achieved in comparison to an ECM or CbW:

- Lower cost thanks to reduced actuator requirements (dynamic response and application times)
- Mechanical override capability (reduced functional safety requirements)
- No possibility of a breakdown should the actuator system fail

All three systems offer comprehensive functionality (Figure 16). This especially applies to the options available for reducing consumption, which are supported by each system. The sailing and other functions offered make the

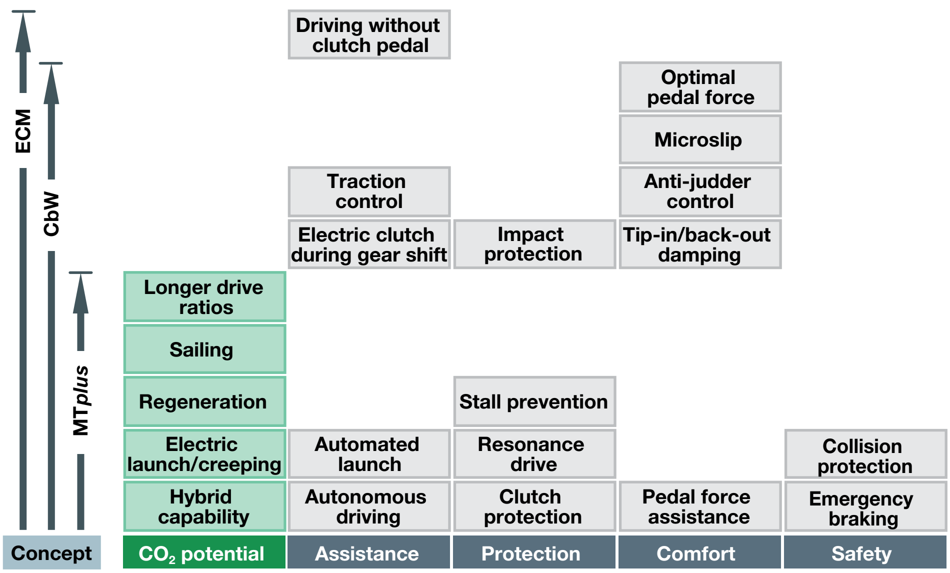


Figure 16 Functions afforded by clutch automation

manual transmission much more hybrid friendly from an overall design perspective. A wide variety of technical features and options also improves comfort and durability and can even be extended to include assistance systems.

Looking optimistically into the future

The trend toward greater levels of automation and electrification to reduce fleet consumption also requires solutions for the manual transmission. Schaeffler is dedicated to finding these solutions by promoting technical developments for automating the clutch. In the process, the effects on the overall powertrain cannot be overlooked. For example, further reducing consumption by adding longer gear ratios leads to increased engine excitations as a result of lower operating speeds, which in turn necessitate better operative characteristics of the torsion dampers.

Improving the efficiency of the powertrain and the challenges to be overcome

The previous section already discussed the importance of shifting the operating point of an engine to lower operating speeds (downspeeding) in order to significantly reduce fuel consumption. For example, when the mean operating speeds of a current 2.0-liter diesel engine are reduced by 10 %, it is possible to consume 5.6 % less fuel under NEDC testing conditions. This potential can only be tapped, however, if doing so does not lead to any drawbacks in driving dynamics or comfort. Thus, to ensure that these driving dynamics remain fairly consistent and comparable, the same output must be achieved when the engine operates at a speed that is 10 % lower, which is why maximum torque must also be increased by approximately 10 % (Figure 17).

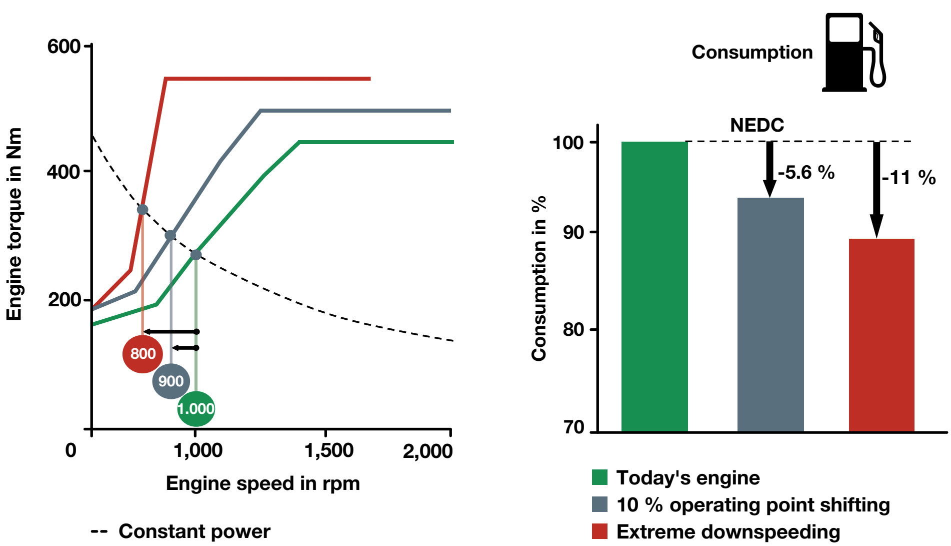


Figure 17 Operating point shifting and potential reduction in consumption with downspeeding

In addition, it is foreseeable that usable speeds will be expanded much further down in the rev range. Some engines in the future will even reach their peak torque at below 1,000 rpm! Compared to today's engines, this will allow these power units to theoretically reduce their consumption by 11 % under NEDC testing conditions.

Such engine developments ultimately lead to considerably higher vibrations from the powertrain. This initially becomes evident in the rotational irregularity that increases proportionately to an increase in torque or a drop in engine speed. Adding to this is the fact that as engine speed goes down, the excitation frequency becomes more closely aligned with the natural frequency of the rest of the powertrain.

Figure 18 summarizes the effects on the rotational irregularity in the powertrain. Relative to a current engine (green line), the oscillation range at the transmission input doubles for the same damper technology when engine speed is reduced by 10 % (blue line). This marks the starting point at which target comfort levels can no longer be attained. Some drivers would even intentionally avoid low engine speeds for this reason and thereby not profit from the lower fuel consumption otherwise possible.

Further downspeeding amplifies the situation disproportionately (red line). When maximum torque is available below 1,000 rpm, the comfort target at this speed is undershot by more than 600 %. In order to achieve an acceptable comfort level with these engines, performance-oriented damper systems must be fitted and are critical to ensuring that the consumption benefits afforded by downspeeding can, in fact, be realized.

Vibration isolation – State of the art

Some 20 years ago, the requirements placed on damper technology dramatically rose as a result of the direct-injected diesel engines then offered for passenger cars (Figure 19).

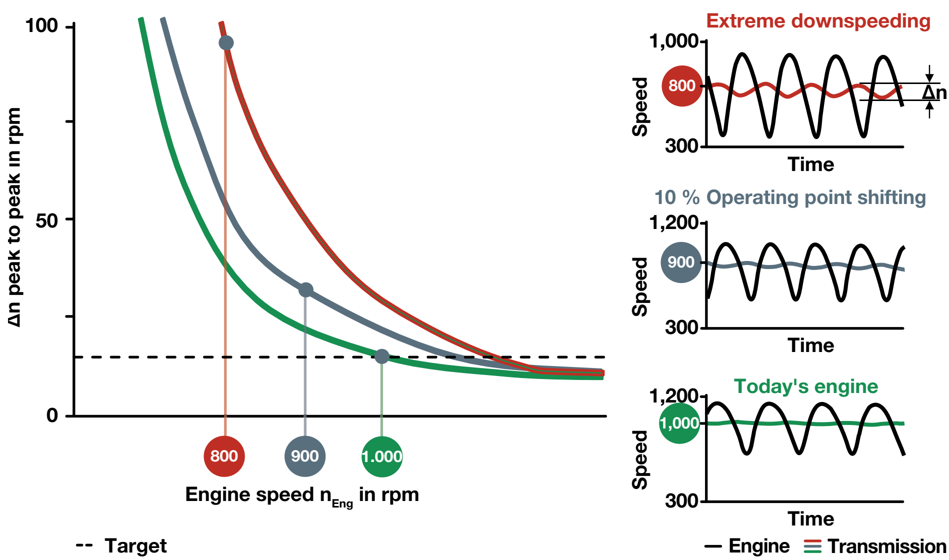


Figure 18 Rotational irregularity at the engine and transmission input for current and future engines

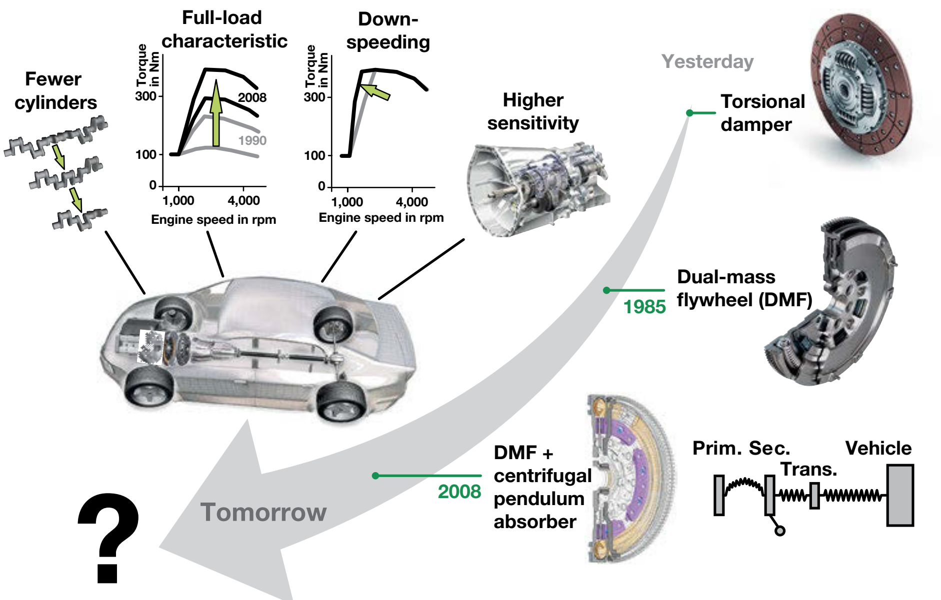


Figure 19 Dramatic increase in performance requirements for vibration-dampening systems

This shift in engine technology presented the developers of these systems with entirely new challenges. The resulting rotational irregularity could not be sufficiently counteracted using the available torsion-damped clutch disks. Although the principle of the low-pass filter was known, it was not regarded as being technically feasible until the dual-mass flywheel (DMS) was introduced in passenger-car applications. By leveraging its comprehensive knowledge of the operating principles of passive damping systems, LuK systematically started investigating the underlying correlations early on and was consequently able to offer a compatible solution that met the emerging challenges in good time. Many years of know-how in metalworking then finally led to a robust product.

In the years that have passed, specific torque outputs have more than doubled in comparison to the first turbocharged, direct-injection diesel engines. The resulting effect is that even today, some engines experience torsional vibrations that cannot be counteracted with a DMS alone. The answer to these increased requirements is the centrifugal pendulum absorber (CPA), which is a damper assembly that introduces additional mass external to the power flow. The dual-mass flywheel and centrifugal pendulum absorber have been continually refined and advanced and will meet the requirements associated with the upcoming evolutionary stages set for the current generation of engines [7].

The next engine generation, however, which is currently under development, will call for vibration isolation measures that are even more capable, which is why Schaeffler is not only investigating the possibilities and constraints of today's technology, but is also looking at alternative solutions.

Alternative solutions – Options and the operating principles that define them

Before implementation concepts are considered at product level, the operating principles that govern them must be thoroughly evaluated with respect to future requirements. It is in this context that the method that uses simple, linearized models to investigate the relative operating principles has proven successful. Not only the technical potential of the different approaches must be factored into the overall assessment, however, but also their cost-benefit ratio, whereby the objective must always be to find approaches that offer equal, uniform performance across an engine's entire operating speed range. Improvements made at very low engine speeds are not optimal if they compromise the progress already achieved in the mid and high-speed ranges. In addition, only those solutions that comply with the restrictions for installation space and weight and are just as robust as current systems when it comes to friction, wear, and manufacturing tolerances are promising candidates.

The following systems will be investigated to determine whether (and under which conditions) their physical potential is capable of isolating the torsional vibrations of a motor that utilizes an extreme downspeeding concept so that comfortable driving is possible from 800 rpm.

Spring-mass system – Principle of the dual-mass flywheel

The basic operating principle of this arrangement is that two masses connected to each other by a spring-damping system oscillate against one another. In terms of the operating range used today and the excitations that are encountered as a result, dampers demonstrate overcritical performance, and provide better isolation as frequency increases. When frequency drops, the resonance frequency is more closely aligned with these excitations and torsional vibrations become more prevalent.

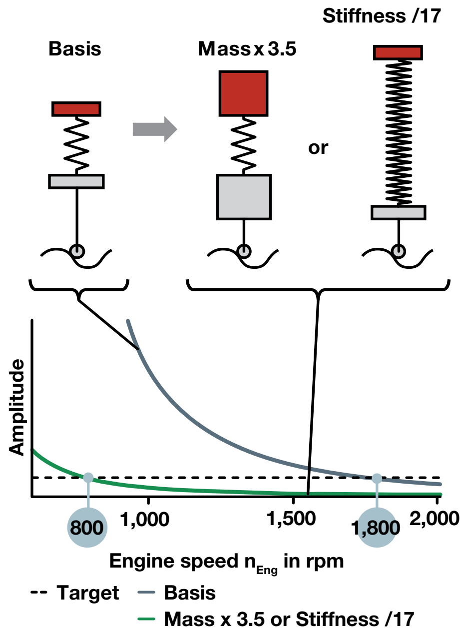


Figure 20 Isolation capacity and limitations of the spring-mass system

Theoretically, it is also possible to use a spring-mass system to reach the required target even in extreme downspeeding scenarios. This, however, would require the mass to be increased by a factor of 3.5 or the spring rate to be reduced by a factor of 17 compared to the base construction. Neither is realistic. Arguments not in favor of increasing mass are the increased installation space required, added weight, and worse driving dynamics. Reducing the spring rate by an extreme amount is also not possible as a result of the installation space problem and the compromised driving experience that would result.

Anti-resonance – Principle of interference

The following describes two concepts for generating anti-resonance: The spring-mass absorber and the summation damper. Although both concepts use a different operating principle, they produce similar results under the same conditions.

The spring-mass absorber

The spring-mass absorber is based on a second spring-mass system. When this system is excited at its resonance frequency, an opposing oscillation is generated that ideally completely cancels out the original excitation. With a conventional absorber connected via a spring, this effect occurs at exactly one frequency – the resonance frequency of the absorber. The drawback is an additional resonance point above the absorber resonance frequency.

A conventional absorber is therefore not a suitable means of reducing torsional vibrations in the powertrain. What is required is a absorber whose dampening frequency corresponds to the ignition frequency of the engine at all times. This property is fulfilled by the centrifugal pendulum absorber (Figure 22), which restoring force is dominated by the centrifugal force of the absorber mass. Since the centrifugal force changes quadrically in relation to the engine speed,

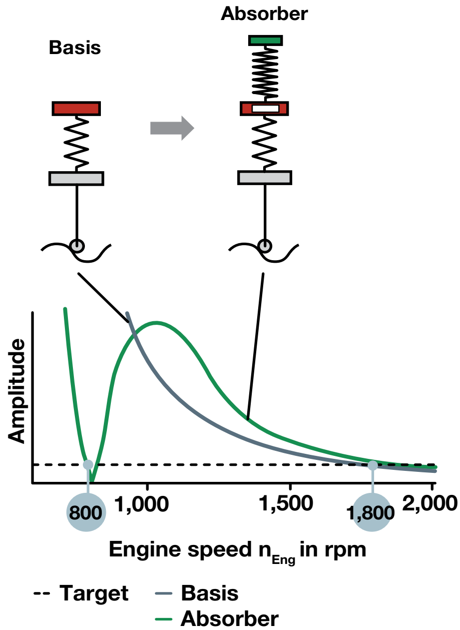


Figure 21 Principle and isolation effect of a conventional absorber

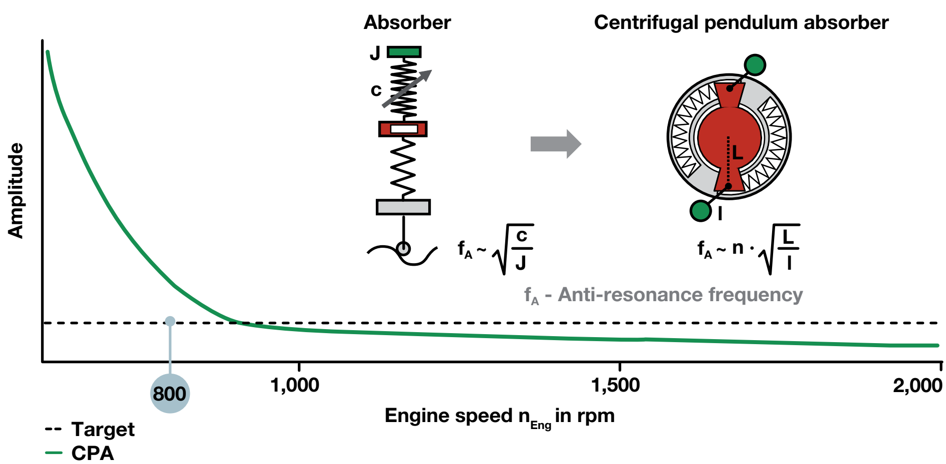


Figure 22 Centrifugal pendulum absorber (CPA) as a speed-dependent absorber

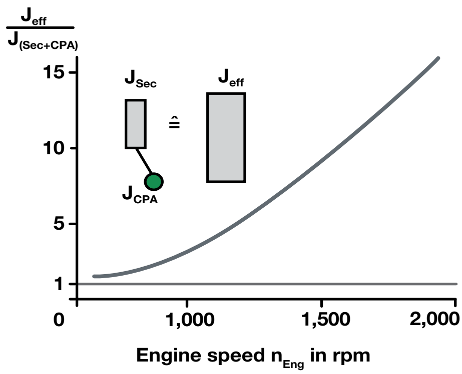


Figure 23 Equivalent effective mass inertia of a centrifugal pendulum absorber

the centrifugal pendulum absorber has a absorber frequency that is proportionate to this speed. This is the ideal property or attribute for reducing torsional vibrations in the powertrain, since a fixed excitation order can be dampened.

Figure 23 shows how effective the mass of a centrifugal pendulum absorber is. The graph depicts, in relation to the engine speed, by what factor the secondary mass would have to be increased for similar performance – e.g. by a factor of 3 at a speed of 1,000 rpm or a factor of 9 at 1,500 rpm.

With a CPA, a vibration isolation figure of 100 % could theoretically be achieved up on a defined frequency. In demonstrator vehicles, a decoupling performance rating of up to 99 % was already demonstrated in conjunction with a DMF. This, in turn, makes it easy to meet the requirements of today's engines and their upcoming evolution stages. Current systems are even capable of fulfilling the requirements of two-cylinder engines. The potential offered by the CPA is described in an additional article in this book [7].

When engine speed drops, the centrifugal pendulum absorber must absorb more energy. The ability of this pendulum to respond depends on the mass involved and the vibration angle, whereby the latter is intrinsic. The mass of the pendulum can also only be increased to a certain extent due to the installation space available.

Whether the CPA can produce a vibration isolation that is also compatible with the excitations of the next generation of engines is not entirely clear at present. Recent improvements made to the system support this working hypothesis, however.

Nevertheless, Schaeffler also continues to search for alternative approaches. Using mass intelligently is the key to implementing future solutions.

The summation damper

Another way of dampening vibrations with anti-resonance is to add two vibration paths together. Figure 24 charts this principle. Vibrations are transferred via a spring-mass system along the one path and directly to a lever on the other. The pivot point of the lever (summation unit) is void of force and motion from a dynamic vibration perspective.

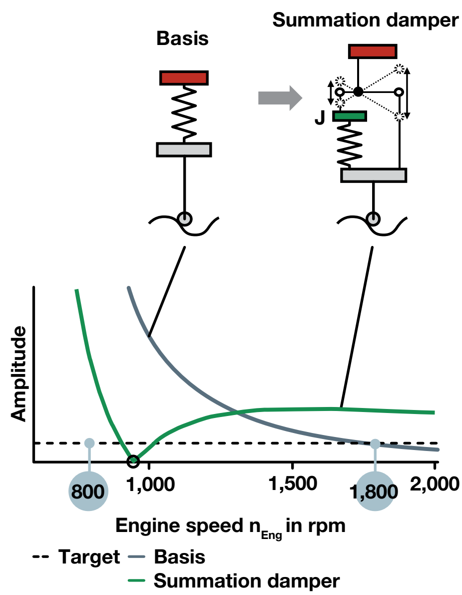
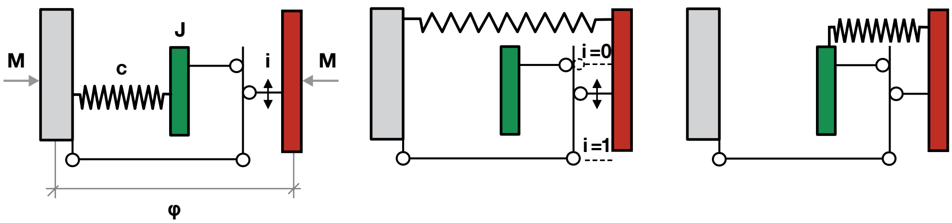


Figure 24 Principle and isolation effect of a summation damper



$$f_A = \frac{1}{2\pi}\sqrt{\frac{c_0\,(i-1)^2}{J \cdot i}} \qquad c_0 = \frac{\Delta M}{\Delta \varphi}$$

f_A = Anti-resonance frequency **c_0 = Effective stiffness**

Figure 25 Variations in spring arrangement for the summation damper

As in the case with a conventional absorber, a summation damper can also decouple 100 % of vibrations but only for a single frequency. The summation damper therefore has an advantage over the absorber in that no additional natural frequency is generated. Unwanted vibrations above and below the anti-resonance frequency remain present, however.

The frequency to be isolated, or targeted, can theoretically be selected as required. When coordinating the system, the summation damper provides one additional parameter not available with the conventional absorber – the lever ratio in addition to the spring rate and the rotary mass (J). Another benefit is that the system can also be configured so that a dampening effect is achieved on the primary side (engine side).

Further arrangements are possible in addition to the summation damper characterized in Figure 24. For example, the spring can be positioned at any point required (Figure 25). Comprehensive testing has revealed that the same basic laws and principles apply irrespective of the positional arrangement of the spring. The anti-resonance frequency can even be calculated for all concepts using a single formula. Assuming that the lever ratio, spring capacity, and mass J do not change, not only is the same anti-resonance frequency yielded for all of the concepts, but also an identical transfer response.

When the transfer response for design concepts with different anti-resonance points is considered, the typical properties of a summation damper become apparent. Anti-resonance frequencies can theoretically be shifted to any low engine speed. Doing this, however, not only reduces the absorbtion width, but also the isolating properties above the anti-resonance frequency (Figure 26). This, in turn, means that a summation damper configured for very low anti-resonance responds sensitively to fluctuating parameters. A satisfactory solution can only be achieved if at least one of the three relevant parameters is variable with respect to engine speed.

In a direct comparison, the summation damper has a slightly higher theoretical potential for dampening vibrations than the conventional damper (Figure 27). Having said this, the advent of the centrifugal pendulum absorber has already provided a solution for realizing a variable-speed damper and is currently being used in volume production applications. Variable-speed summation dampers, on the other hand, have yet to be integrated.

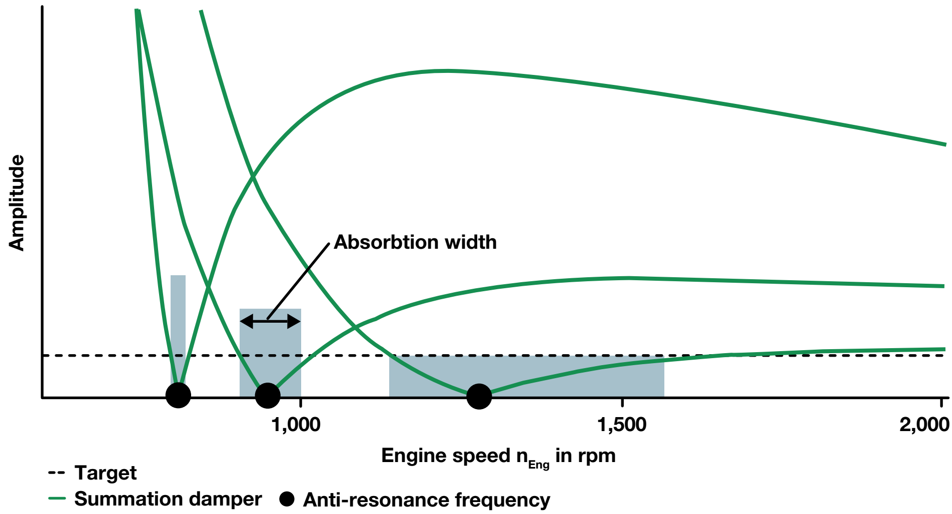


Figure 26 Influence of the anti-resonance frequency on the absorbtion width

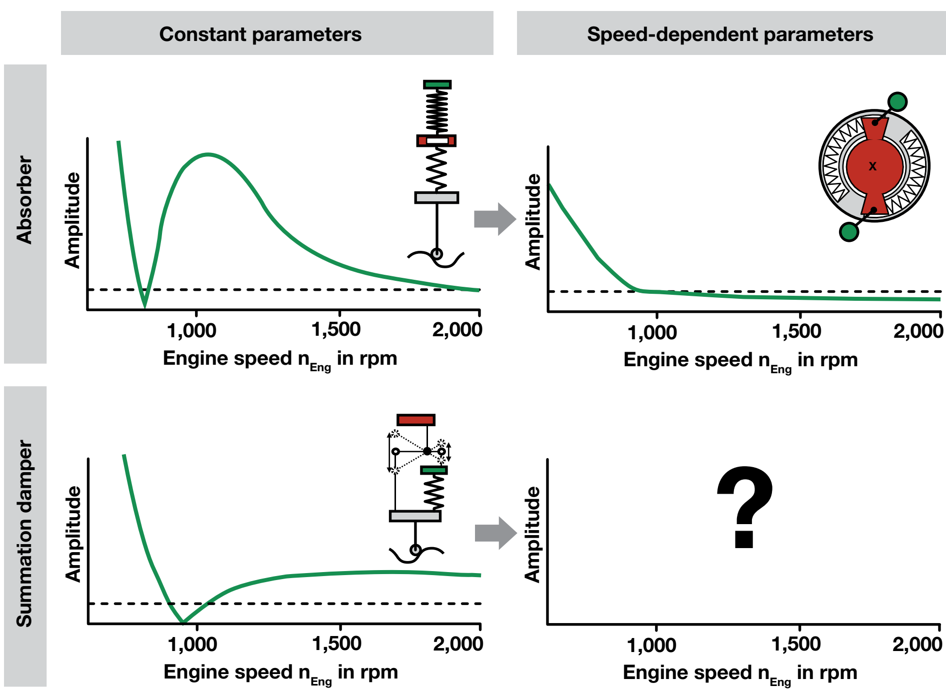


Figure 27 Evolution of the absorber and summation damper

Summary

In the race to achieve global CO_2 targets, automatic transmissions have clearly taken an early lead as they allow engineers to develop fuel-saving strategies by decoupling the engine from the transmission. The manual transmission also offers certain benefits, however, including reliability, durability, and a low price, the latter of which continues to appeal to buyers of small vehicles in particular. The logical next step of advancing the technology of the proven manual transmission must therefore focus on automating the clutch so that the driving strategies explored here can also be implemented in vehicles with manual transmissions. In addition to offering technical solutions that have already been developed (ECM, CbW), Schaeffler is working on systems that, when scaled down in scope, largely maintain the price advantage that a manual transmission has over its automatic counterpart.

Automated clutches are not only capable of decoupling the engine from the rest of the powertrain, but also actively support and facilitate many other comfort and protective functions. Automating acceleration from a stop, for example, can prevent the clutch from being overloaded or misused, which in turn allows the powertrain to be configured differently so that longer gear ratios can be implemented to further reduce fuel consumption.

The operating point of the internal combustion engine then shifts to lower speeds and specific torque is increased. Both measures lead to more pronounced rotational irregularity, however. The resulting higher design requirements for mechanisms that isolate frequencies will nevertheless be reliably met by current technology as it is incorporated into today's engines and those targeted for the next evolution stage. The problem revolves around the next generation of engines, which will require even more capable systems. Although the technology offered by the dual-mass flywheel in conjunction with a centrifugal pendulum absorber is a prime candidate, the summation damper is also worth considering if a way can be found to extend its high potential at low operating speeds to mid-range and higher speeds. Schaeffler continues to investigate both concepts with a great deal of interest. The key to developing a more responsive summation damper lies in the ability to vary one relevant parameter with respect to engine speed. A solution that is robust, affordable, and can be deployed on a large scale has not yet crystallized, however.

Literature

[1] Gutzmer, P.: Individuality and Variety. 10th Schaeffler Symposium, 2014

[2] Kremmling, B.; Fischer, R.: The Automated Clutch. 5th LuK Symposium, 1994

[3] Fischer, R.; Berger, R.: Automation of Manual Transmissions. 6th LuK Symposium, 1998

[4] Welter, R.; Herrmann, T.; Honselmann, S.; Keller, J.: Clutch Release Systems for the Future. 10th Schaeffler Symposium, 2014

[5] Müller, M.; Kneissler, M.; Gramann, M.; Esly, N.; Daikeler, R.; Agner, I.:Components for Double Clutch Transmissions. 9th Schaeffler Symposium, 2010

[6] Müller, B.; Rathke, G.; Grethel, M.; Man, L.: Transmission Actuators. 10th Schaeffler Symposium, 2014

[7] Kooy, A.; The Evolution of the Centrifugal Pendulum Absorber. 10th Schaeffler Symposium, 2014

[8] Fidlin, A.; Seebacher, R.: DMF Simulation Techniques. 8th LuK Symposium, 2006

[9] Kroll, J.; Kooy, A.; Seebacher, R.: Torsional Vibration Damping for Future Engines. 9th Schaeffler Symposium, 2010

[10] Reik, W.; Fidlin, A.; Seebacher, R.: Gute Schwingungen – böse Schwingungen. VDI-Fachtagung Schwingungen in Antrieben, 2009