Efficiency, cost and weight potential through reduced line pressure in DCTs with servo synchronizers

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1 Introduction

There are many ways to improve the efficiency of double clutch transmissions [3] (DCTs). Increasing the number of gears is a well known one. Clutch losses can be reduced e.g. by using dry clutches instead of wet clutches. The actuation system losses can be reduced by using electromechanical actuation or by new hydraulic powerpack solutions. Hybridization and powertrain management software algorithms, oil management and reduction of bearing friction and other dissipation losses in the mechanical part are a list of possible ways to improve the efficiency of a DCT. This paper will introduce a new approach using newly developed full servo synchronizers.
The key component for that approach is a self-energising synchronizer, which can reduce the actuation energy significantly. These systems use basically the same effect as self-energising brakes (e-brake) and self-energising clutches as used in all wheel drives.

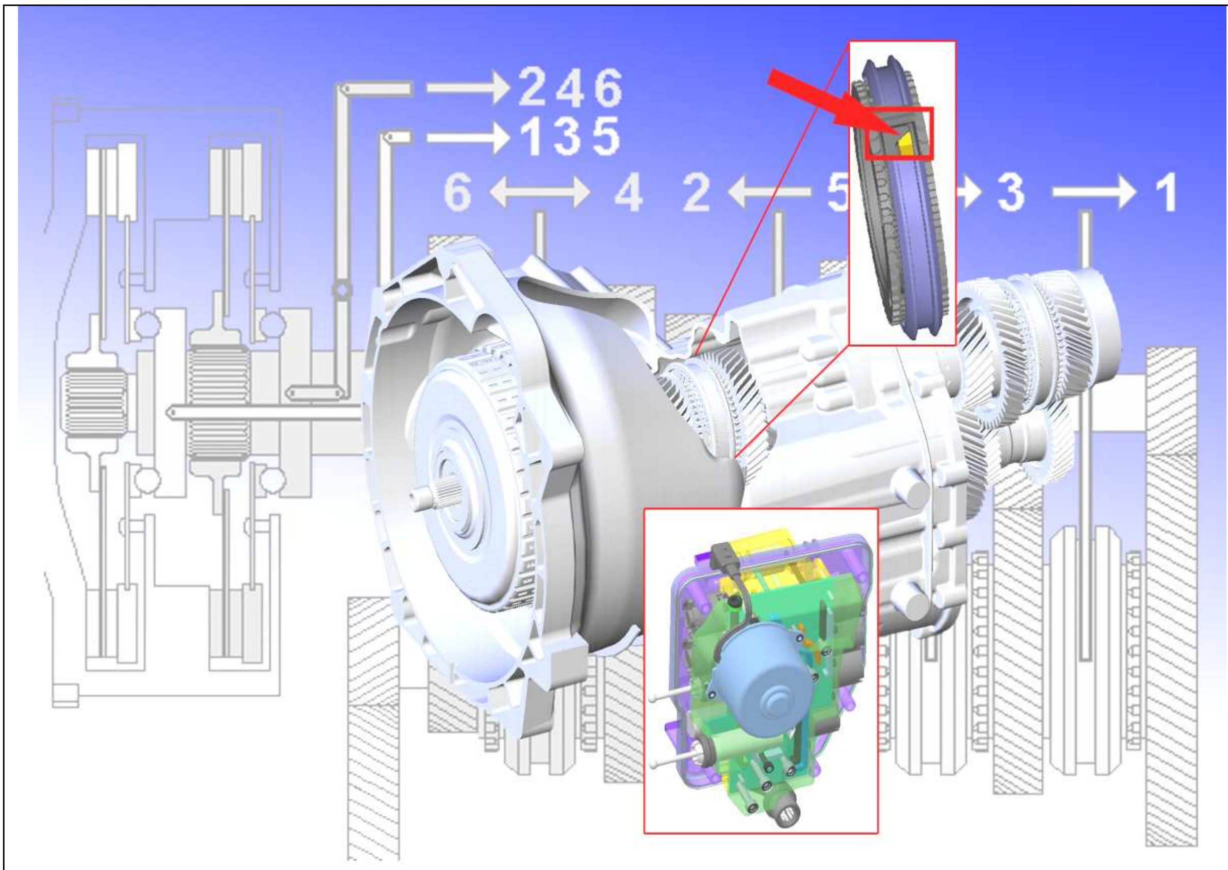

Fig. 1	DCT System

2 Approach

Synchronizers in DCTs have to synchronize gears in the open part of the double clutch transmission. This function is called “pre-selection” and has to be as fast and smooth as possible to ensure quick shifts and high comfort. The limiting factor is the torque generated by a synchronizer. Figure 2 shows the DCT system including the positions of synchronizers and the torque generated by a standard synchronizer depending on the actuation force.

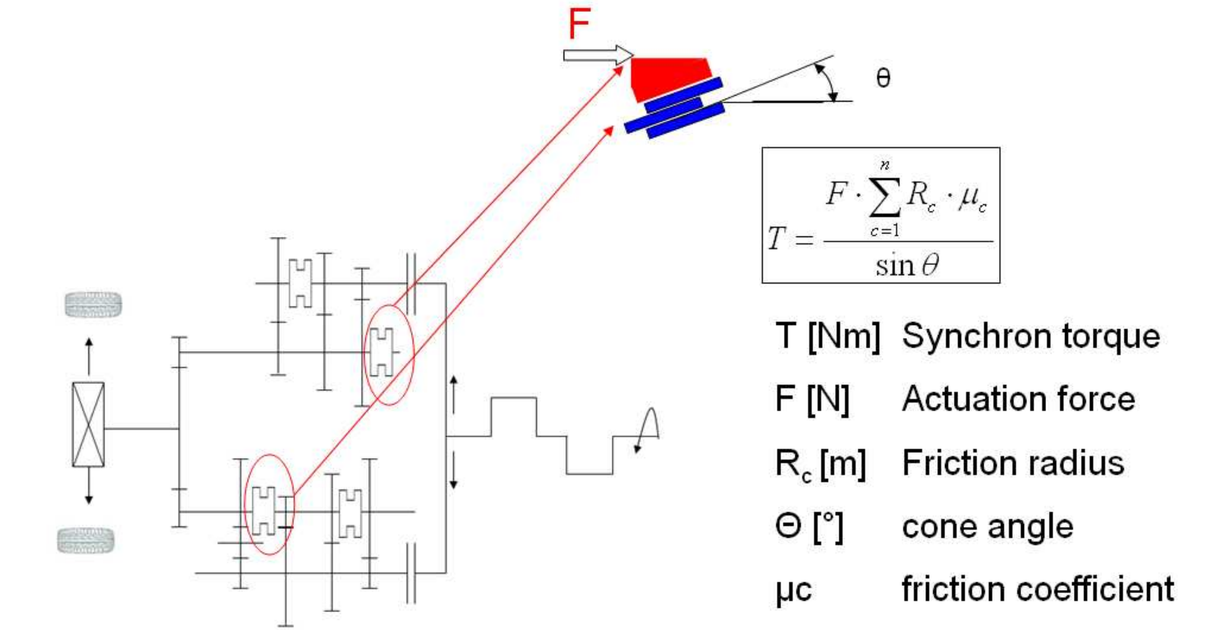

Fig. 2	Synchronizer torque in a DCT

The limiting factors for the generated torque are the diameter and other dimensions, the friction material and self lock safety and the number of friction cones (n). Figure 3 shows a simplified hydraulic system for DCT actuation. In the hydraulic system, the highest pressures are needed to shift the synchronizers and not to close the clutches.

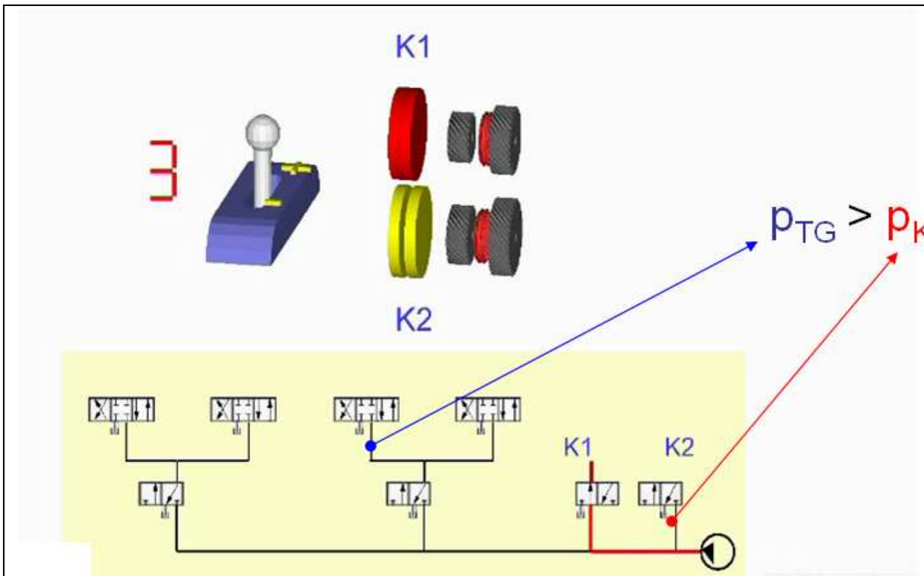

Fig. 3	Simplified hydraulics of a DCT

During a driving cycle (Figure 4), many synchronization processes have to be performed and due to that a lot of energy is lost because of the high actuation forces. This energy can be reduced by synchronizers with higher performance.

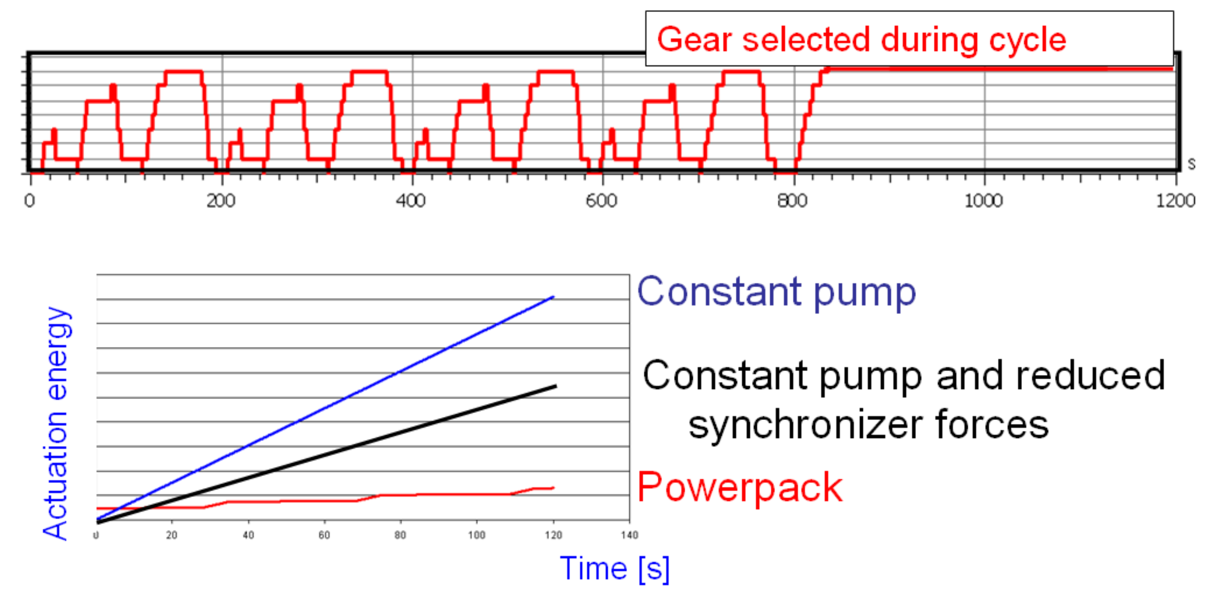

Fig. 4	Actuation energy during a driving cycle

3 Full servo synchronizers

Newly developed full servo synchronizers can reduce the shift forces and times significantly. There are many patents and designs of servo-synchronizers (Figure 5). All of them are using the friction torque via an active servo slope to get an additional force in the actuation direction. Mostly, this is done by special thrust pieces. Generally there is a difference between semi servo synchronizers [4], which are using only a part of the synchronizing torque, and full servo synchronizers, which are using the full torque and get more self-energising effect leading to better synchronizer capacity.

Several producers and suppliers have tried to develop servo synchronizers for serial production. The goal is to improve shift quality of manual transmissions (MTs) and to reduce the shifting energy in automated manual transmissions (AMTs) and DCTs. hofer powertrain has published the verification of function and durability of semi servo synchronizers in the past [4].

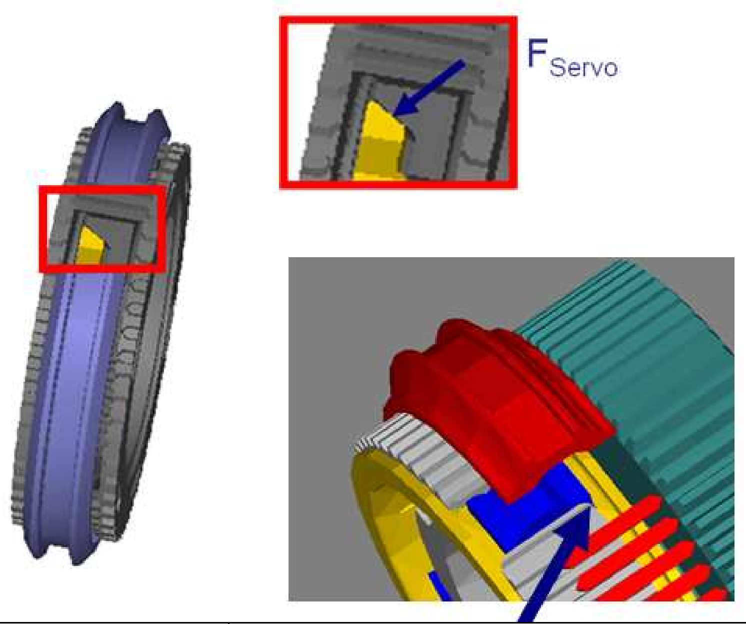

Fig. 5	Principles of full servo synchronizers

Now we have proven the even higher performance of full servo synchronizers with prototypes that have also passed durability tests. These Systems have way better performance than systems currently available on the market.

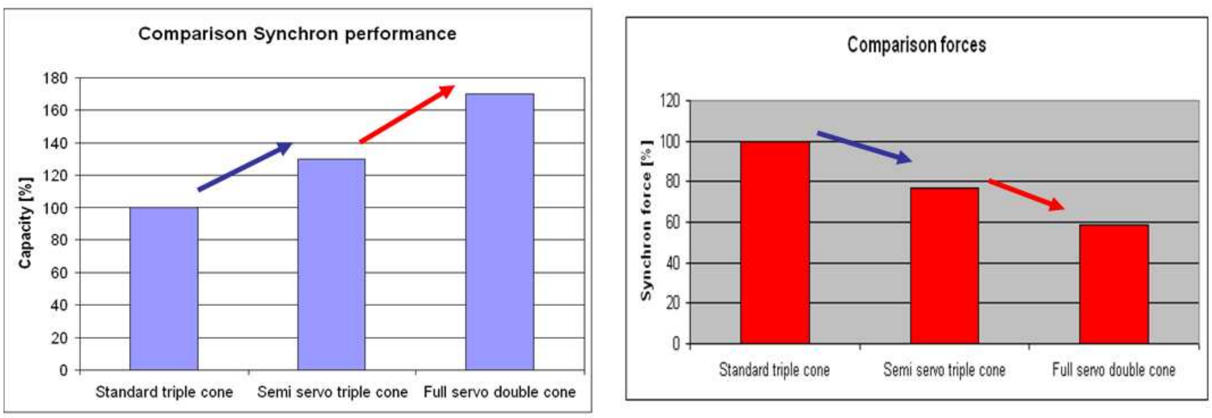

Fig. 6	Comparison of synchronizer systems

This break through has been achieved by using state of the art simulation methodologies in parallel to test bench tests. With this systematic, efficiency and shift quality can be projected in early concept stage which is accelerating the development process significantly.

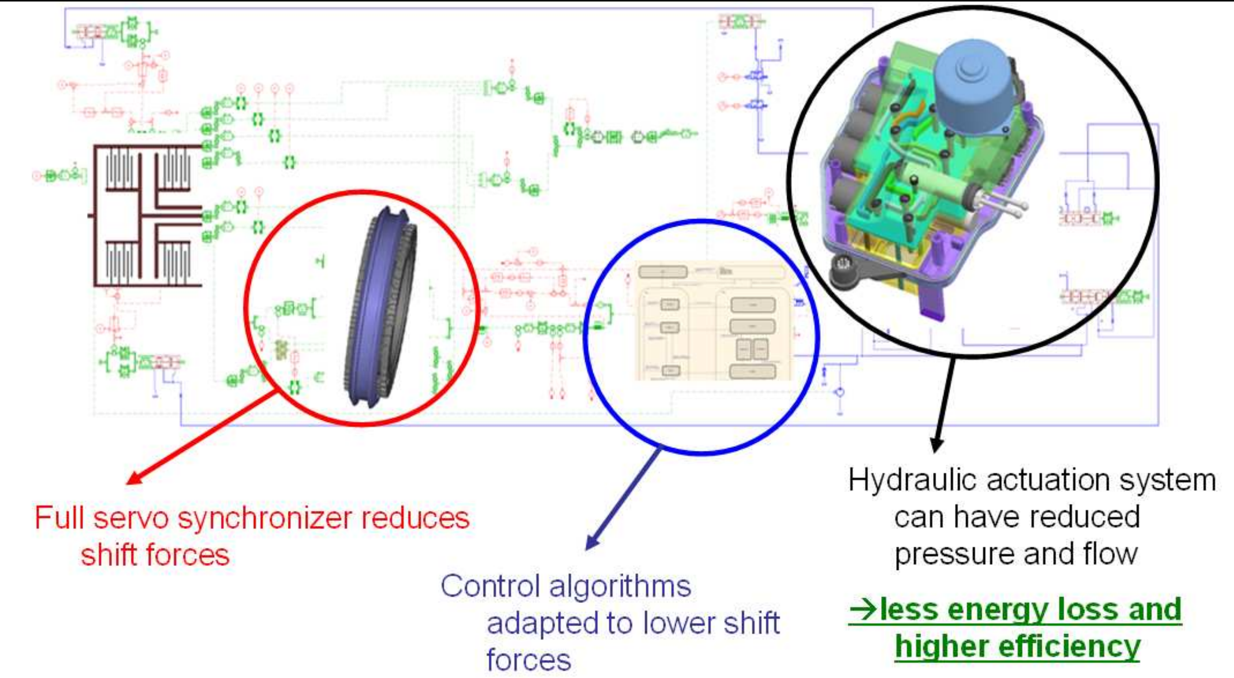

Fig. 6	Simulation model for Integration of full servo synchronizers in a DCT

To integrate servo synchronizers into a DCT, there are two necessary steps. To get the optimum out of the system, the first step is to identify the synchronizer positions ideal for servo synchronizers. The second step is the design of the servo synchronizer itself. To identify the best positions for servo synchronizers, the main criteria to consider are performance and costs.

For the design of the servo synchronizer itself, there are many criteria to consider. Friction material durability safety factors [1], synchronizer capacity, self lock safety [4] and unlock safety at low temperatures.

An important point is the choice of the friction material. There are design limits regarding specific pressure, relative speed, specific heat, specific performance and (for glued materials) shear stress to be considered. If only the shift forces are reduced to achieve the same shift performance, the same friction materials can be used without danger also for servo synchronizers. If the shift performance is increased and the loads on the synchronizer materials increased, the design limits have to be checked. Durability tests at MIBA Sinter Austria with shorter shift time using full servo synchronizers have proven full functionality during 100.000 shifts as can be seen in figure 7.

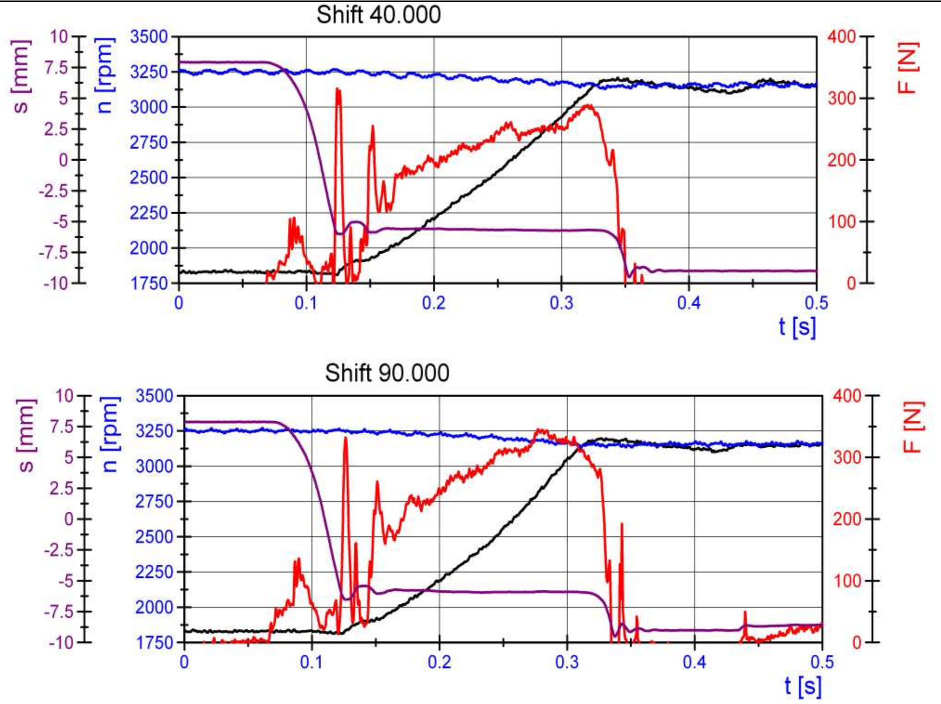

Fig. 7	Durability test with new full servo synchronizers (MIBA Sinter Austria)

4 Systematic

hofer powertrain uses system simulation tools starting from the specification since DCTs are very complex mechatronic systems. These simulation tools are fine tuned during the development process. The system simulation tools comprise the mechanical components of the transmission like clutches, synchronizers and gears, the driveline and an engine model, if needed hybrid components, side shafts, tyre-street contact, vehicle longitudinal dynamics model, the hydraulic control, the actuation system and the logic algorithms including e.g. shift strategies. These simulation models deliver quick answers in advance to verify functional features in a very early stage. hofer powertrain has fine tuned the modelling by constant calibration with measurements. So by using special macros, we can simulate transient dynamic phenomena during the shift process in detail. This enables us to optimize the geometry of a servo synchronizer without hardware.

The models are used in reduced complexity for virtual model-based software development. The hardware application in the vehicle is reduced significantly due to this virtual testing. That safes precious development time with hardware prototypes.

5 Advantages

The actuation losses of a DCT with constant supply pump can be very high and every reduction of the pressure level leads directly to an efficiency improvement. The maximum pressure level is defined by the necessary pressure for a shift and can be a multitude of the maximum pressure at the clutches. Of course, this reduction of pressure is only possible if the same or even better synchronizing times can be achieved (criterion double back shift). This can only be achieved by a higher synchronizer capacity. The limit of conventional standard synchronizers is a triple cone type. Four-cone-synchronizers have turned out to be no reasonable technical and economical solution. That means that only a completely new synchronizer technology can disclose further potential. hofer powertrain has now found a full servo synchronizer design, that can increase the synchronizer capacity by 70% while reducing the number of cones from three (triple cone) to two (double cone). This means a big reduction of actuation force (minimum 40% depending on detent forces, drag torque and shift speed). It also has a positive effect on the shift time (Figure 8).

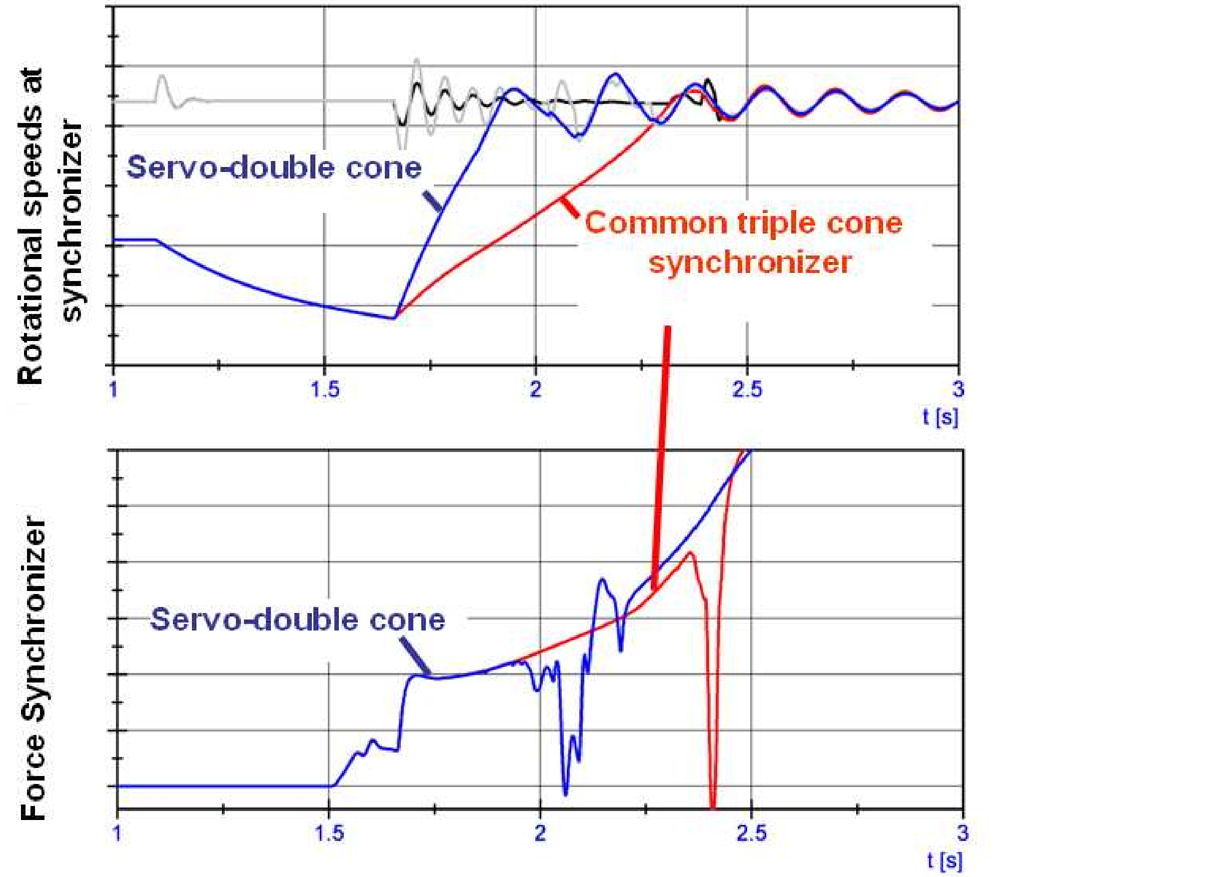

Fig. 8 Comparison between standard and full servo synchronizer in a DCT

The internal shifting system can be reduced in size and weight due to the lower forces and the leakage of the hydraulic system is reduced also. The system can also be used to get extremely quick shifts with the same pressure. This might be interesting in high performance applications. Certainly, when using the system for shortening of shift time, the durability of the friction materials has to be considered.

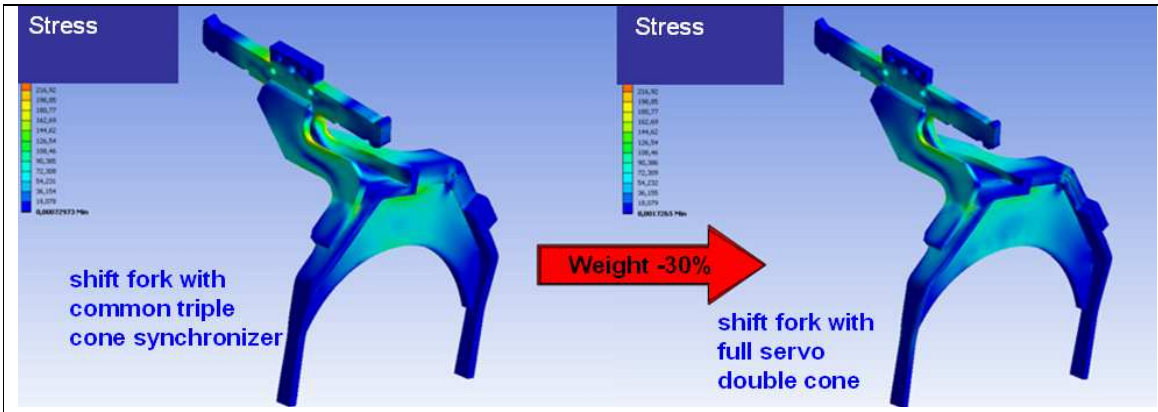

Fig. 9 Weight reduction with a full servo synchronizer in a DCT

The advantages of full-servo-synchronizers:

- Better shift times with reduced shift force
- Reduction of cones (e.g. double cone replaces triple cone) and thus drag torque reduction and cost advantage
- Reduced shift forces with same shift time thus
    - Lower hydraulic pressure and less leakage
    - Weight reduction of internal shift system and hydraulic components due to lower forces and pressure
    - Efficiency advantage due to less actuation energy
    - Less shift noise
- In systems with hydraulic powerpacks, the piston area can be reduced at same pressure level to reduce pump and accumulator size and/or actuation time
- Less current demand and smaller electric motors in DCTs with electromechanical actuation

Depending on the actuation system, there is a combination of these advantages for every transmission. This can be projected in advance with the help of simulation. Since the interfaces and space of the synchronizers are not any different to common synchronizers, the application in DCTs in serial production is possible by replacing the synchronizer and software adaption only.

6 Summary and outlook

New full servo synchronizers with double cone design have proven that the shift forces can be reduced by 40% compared to standard synchronizers with triple cone design. Prototypes have also passed durability tests. These systems have a big advantage regarding performance compared to available systems on the market. Nevertheless there is still potential in the area of synchronizers especially when we consider the increasing performance of electronics in the transmission. The mechanical blocking function of servo synchronizers could be replaced by electronics and software completely [2]. Self energising cone clutches [5] could lead to the same advantages in automatic transmissions (AT´s). This means an ongoing race between the different transmission concepts.

7 Literature

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