**Introduction:** The European legislation on the reduction of CO₂ emissions from passenger cars and light commercial vehicles represents major challenges to automobile manufacturers. By the end of 2020, the average CO₂ emissions of a manufacturer’s new vehicle fleet must be reduced to 95 gCO₂/km [3]. If these targets are not met, financial penalties amounting to billions of euros will be imposed on the manufacturers.

Consequently, car companies try to meet the above-mentioned CO₂ requirements by optimising the existing drivetrain components, among other things. In particular, disengaged wet-type multiple-disc clutches generate significant drag losses in automatic transmissions. In order to reduce these losses, the latter can, in some cases, be replaced by dog clutches, although these may cause a perceptible reduction in shifting comfort. To combine the advantages of a multiple-disc clutch in terms of shifting comfort with the low drag losses and high transmittable torques via form-fit of a dog clutch, an alternative shifting element, named TorqueLINE Cone Clutch, has been developed in a joint project between HOERBIGER Antriebstechnik Holding GmbH and the Gear Research Centre (FZG) of the Technical University of Munich. To reduce the original drag losses, a cone clutch has been chosen instead of the multiple-disc clutch. When implemented in automatic transmissions, the cone clutch is required for a smooth synchronisation of speed, whereas the dog clutch transmits the entire torque in the engaged condition. [2]

Preliminary investigations have already shown the potential of the new shifting element. In the lower differential speed range, the drag losses can be reduced by almost 90 % compared to a reference wet-type multiple-disc clutch, while at higher differential speeds, the savings potential is still above 50 % [2]. Hence, CO₂ emissions can be reduced by up to 2.5 gCO₂/km when using the TorqueLINE Cone Clutch [1].

**Task:** In the first part of the Master’s Thesis, the general shifting behaviour of the TorqueLINE Cone Clutch had to be investigated. The focus was on analysing the form-fit process of the dog clutch, as well as on determining the performance of different dog clutch geometries. In addition, the impacts of wear on the form-fit discs had to be investigated. For this purpose, a multibody model of the TorqueLINE Cone Clutch had to be developed. In order to be able to make any reliable statements, the validity of the simulation model had to be proven. Therefore, test-rig runs were performed and compared to the simulation results. In the second part of the Master’s Thesis, the gear change of a power-shifting nine-speed automatic transmission had to be redesigned for the TorqueLINE Cone Clutch. Furthermore, it was necessary to maximise the shifting comfort and to evaluate the gear change in terms of a number of criteria. For this reason, a multibody model of a nine-speed automatic transmission was developed, including all shifting elements, planetary gears and shafts. The previously created model of the TorqueLINE Cone Clutch was merged with the one of the automatic transmissions.

**Simulation models and results:** The parametric multibody model of the TorqueLINE Cone Clutch (see Fig. 1a) was created with the MBS SIMPACK software application.

![Multibody system of the TorqueLINE Cone Clutch](image1.png)

**Fig. 1:** a: Multibody system of the TorqueLINE Cone Clutch; b: Simulation vs. Test-rig; c-f: Results

To validate the model, more than 1,000 engagements were performed for defined operating points on the test-
rig. A variety of validation tests illustrate the high performance and reliability of the simulation model and confirm an outstanding match of simulation and experiment (see Fig. 1b). Generally, a reliable form-fit over a large operating range – spanning the parameters of shifting speed and differential speed – is required from the dog clutch. According to the simulation, the boundary between form-fit and tooth-rejection is described by a linear relation of shifting speed and differential speed (see Fig. 1c). Primarily, the performance of the two form-fit discs is determined by their angular backlash (see Fig. 1d). Changes in the backlash in even a small value range were found to have an extremely strong impact on the size of the operating region. From a critical backlash, however, the operating range cannot be extended significantly any more. Generally, the angular backlash should be kept small, for example, to prevent vibration and noise in the drivetrain. According to the simulation, a modified tooth surface shape does not lead to any sensible improvement in the shifting behaviour (see Fig. 1e). Hence, in this application, the reference tooth surface shape is to be preferred. With regard to wear, the simulation shows the largest possible operating range for ideal tooth edges. The TorqueLINE-control guarantees a constant shifting behaviour of worn form-fit discs over the entire transmission life and does not worsen the performance of the TorqueLINE Cone Clutch. However, excessive wear of the tooth edges may only occur after several deliberately performed abuse shifts, which are avoided by the transmission control. Potential impacts of excessive tooth wear are shown in Fig. 1f. Having successfully proved the validity of the simulation model and identified the operating regions of the dog clutch, an analysis was performed of the impact on the driving comfort. For this purpose, the multibody system developed for the nine-speed automatic transmission was used (see Fig. 2a). All the investigations were performed for a traction downshift under maximum engine torque, as this type of shifting is considered being the most critical for comfort. The analysis of the simulation results showed that the shifting comfort can be controlled by varying the decrease rate of the actuation force in the torque transfer phase of the outgoing shifting element (SE) (see Fig. 2b). By opening the outgoing shifting element more quickly, the shifting time can be reduced and the dynamic performance of the shifting can be increased. Nonetheless, the highly dynamic engagement of the TorqueLINE-system (see Fig. 2c) shows a torque signal that does not differ from a shift with a standard clutch. Indeed, the driver perceives a sporty feeling from the downshift. Investigations also show, that the shifting comfort and time are at the same high level as benchmark transmissions.

Fig. 2: a: Multibody system of the nine-speed automatic transmission; b: Actuation of the shifting elements; c-d: Results

Innovation: The findings of this Master’s Thesis support the application of positive-locking shifting elements in automatic transmissions and may possibly contribute to significantly reducing the CO₂ emissions of existing drivetrains. At the same time, the use of this innovative shifting element would drastically reduce the financial penalties imposed on automobile manufacturers for missing the CO₂ target of 95 gCO₂/km. The simulation models developed are powerful tools for research on form-fit systems that do not affect the shifting comfort and dynamic performance of automatic transmissions. The proved models’ validity allows the usually time-consuming and cost-intensive bench tests to be completely replaced. Moreover, it is possible to estimate the performance of the new shifting element in the phase of development. Besides this, the impacts of dynamic engagements of form-fit shifts on the driving comfort can be predicted. In addition, the TorqueLINE model can even determine the influences of geometric deviations and wear on the shifting behaviour.

References